DEMONSTRATION REPORT

Comparative Demonstration and Evaluation of
Classification Technologies:
Closed Castner Range
Fort Bliss, Texas

ESTCP Project MR-201229

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Arcadis-US, Inc.

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14. ABSTRACT
This is one of a series of the Environmental Security Technology Certification Program (ESTCP) live site demonstrations of classification technologies for Munitions Response (MR). This demonstration was designed to evaluate advanced classification methodology at the Former Camp Ellis Military Range (CEMR), which is a site known to contain evidence of 2.36-inch practice rockets, hand grenades, and rifle grenades.
During the live site demonstration, ARCADIS conducted dynamic surveys with the Geometrics MetalMapper and Naval Research Laboratory's TEMTADS advanced electromagnetic induction sensors and static, cued surveys to classify anomalies as either targets of interest (TOI) or non-TOI. Static data was analyzed using the Geosoft Oasis Montaj UX-Analyze Advanced module to classify anomalies.

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List of Acronyms

AGC	Advanced Geophysical Classification
Arcadis	Arcadis US, Inc.
bgs	below ground surface
BSI	Blind Seed Item
cm	centimeter
CR	Castner Range
DGM	Digital Geophysical Mapping
DGPS	Differential Global Positioning System
DoD	Department of Defense
EMI	Electromagnetic Induction
ESTCP	Environmental Security Technology Certification Program
GPS	Global Positioning System
hrs	hours
IDA	Institute for Defense Analyses
IMU	Inertial Measurement Unit
ISO	Industry Standard Object
m	meter
MD	Munitions Debris
MEC	Munitions and Explosives of Concern
MMRP	Military Munitions Response Program
MQO	Measurement Quality Objective
MR	Munitions Response
MRS	Munitions Response Site
ms	milliseconds
mV	milliVolts
NRL	Naval Research Laboratory
ROC	Receiver Operating Characteristics
RTK	Real-Time Kinematic
TEMTADS	Time-domain Electromagnetic Multi-sensor Towed Array Detection System 2x2

TOI	Target of Interest
UFP-QAPP	Uniform Federal Policy-Quality Assurance Project Plan
URS	URS Group, Inc.
US	United States
UXO	Unexploded Ordnance

1.0 INTRODUCTION

This is one of a series of the Environmental Security Technology Certification Program (ESTCP) live site demonstrations of classification technologies for Munitions Response (MR). In this demonstration, Arcadis United States (U.S.), Incorporate (Arcadis) performed advanced geophysical classification (AGC) of cued Time-domain Electromagnetic Multi-Sensor Towed Array Detection System 2x2 (TEMTADS) data that was collected by URS Group, Inc. (URS) at the Castner Range (CR) at Fort Bliss, Texas.

1.1 BACKGROUND

ESTCP contracted Arcadis to conduct AGC analysis of the TEMTADS data that was collected by URS at the Closed Castner Range as part of AGC live site demonstrations to transfer AGC technologies to Arcadis. Mr. Steve Stacy (Analyst 1) and Mr. Gabriel Hebert (Analyst 2) performed AGC analysis of the TEMTADS dataset separately. A list of points of contact are included in **Appendix A**.

1.2 OBJECTIVE OF THE DEMONSTRATION

Arcadis has previously demonstrated AGC approaches another ESTCP live site demonstration (Arcadis, 2013; Arcadis 2015a). The primary objectives of this demonstration were to determine the effectiveness of the technology in minimizing the number of anomalies that require intrusive investigation while still recovering all the targets of interest (TOI), which include munitions and explosives of concern (MEC) and industry standard objects (ISOs) used as blind seed items (BSIs).

The goals of the demonstration included:

- Demonstrate the cost and performance of the TEMTADS and AGC.
- Train Arcadis analysts on the application of AGC to a challenging site with varying background response.

1.3 REGULATORY DRIVERS

The Department of Defense's (DoD's) Military Munitions Response Program (MMRP) is charged with characterizing and, where necessary, remediating munitions response sites (MRSs). When an MRS is remediated, it is typically mapped with a geophysical system, (*i.e.*, either a magnetometer or electromagnetic induction [EMI] sensor), and the locations of all detectable signals are excavated. Many of these detections do not correspond to munitions, but rather to other harmless metallic objects or geology: field experience indicates that often in excess of 90% of objects excavated during the course of a MR are found to be nonhazardous items. Current geophysical technology, as it is traditionally implemented, does not provide a physics-based, quantitative, validated means to discriminate between hazardous munitions and nonhazardous scrap metal.

With no information to suggest the origin of the signals, all anomalies are currently treated as though they are intact munitions when they are dug. They are carefully excavated by unexploded ordnance (UXO) technicians using a process that often requires expensive safety measures, such as barriers or exclusion zones. Thus, most of the costs to remediate a munitions-impacted site are currently spent on excavating targets that pose no threat. If these items could be determined with high confidence to be nonhazardous, some of these expensive measures could be eliminated or the items could be left unexcavated entirely.

The MMRP is severely constrained by available resources. Remediation of the entire inventory using current practices is cost prohibitive within current and anticipated funding levels. With current planning, estimated MR completion dates on many sites are decades out. The Office of the Under Secretary of Defense for Acquisition (OSDA) observed in its 2003 report that significant cost savings could be realized if successful classification between munitions and other sources of anomalies could be implemented (OSDA, 2003). If these savings were realized, the limited resources of the MMRP could be used to accelerate the remediation of MRSs that are currently forecast to be untouched for decades.

2.0 TECHNOLOGY

This demonstration consisted of AGC analysis of cued TEMTADS data. Details of this technology and a brief description of the major components of the demonstration are provided below.

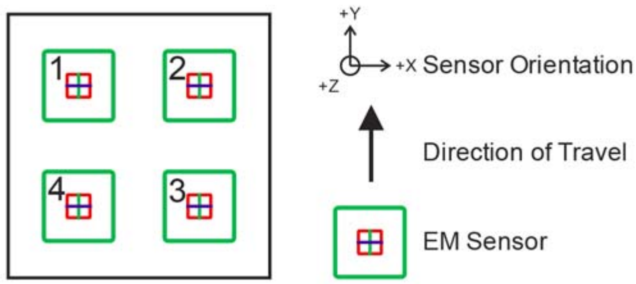
2.1 TECHNOLOGY DESCRIPTION

2.1.1 TEMTADS

The TEMTADS is a man portable, advanced EMI sensor array (see **Figure 2-1)** developed by the Naval Research Laboratory (NRL) and based on their larger, 5x5 TEMTADS array. The TEMTADS consists of four 35-centimeter (cm) transmit coils with four 8 cm tri-axial receiver cubes (see **Figure 2-2**). The TEMTADS was developed through ESTCP (Kingdon, 2012) and has been shown to reliably retain the performance of the original TEMTADS in a much smaller size, which enables the man portable version to access difficult terrain where mobility is limited (ESTCP, 2012a and 2012b; Kingdon, 2012). URS operated the TEMTADS system in static classification mode at CR in a litter mode (not pictured).

Figure 2-1: TEMTADS 2x2

Figure 2-2: TEMTADS Coil Geometry



2.2 TECHNOLOGY DEVELOPMENT

Technologies used during this demonstration include the above TEMTADS sensor with real time kinematic (RTK) differential global positioning system (DGPS), and the UX-Analyze Advanced module within Geosoft Oasis Montaj©. The TEMTADS and UX-Analyze Advanced were developed under ESTCP and further descriptions of their development can be found in the following reports:

- TEMTADS: Kingdon et. al, 2012;
- UX-Analyze Advanced: Keiswetter, 2009, and the following projects, which do not currently have technical reports that are available:
  - MR-201164: Demonstration of Physics-Inspired Classification Methodologies for MR
  - MR-201312: UXO Classification Demonstrations at Live Sites Using UX-Analyze

2.3 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

The major advantage of the TEMTADS and UX-Analyze Advanced module is that combined, they provide the ability to classify anomalies as being due to either TOI or non-TOI. This can lead to significant cost savings in MR cleanups. Conventional digital geophysical mapping (DGM) sensors (*e.g.*, EM61-MK2) have very limited ability to correctly classify TOI and non-TOI. Other advanced EMI sensors have also been successful in ESTCP funded classification demonstrations; however, they were not used during this live site demonstration.

3.0 PERFORMANCE OBJECTIVES

Performance objectives or measurement quality objectives (MQOs) were developed and document in the project's Uniform Federal Policy- Quality Assurance Project Plan (UFP-QAPP) to measure the quality of the data collected during the ESTCP live site demonstration. MQOs are outlined below.

3.1 STATIC DATA PERFORMANCE OBJECTIVES

The performance objectives for the cued TEMTADS data collection and interpretation are summarized in **Table 3-1** and the below sections.

Table 3-1: Cued TEMTADS Data Collection and Analysis Objectives

Performance Objective	Metric	Data Required	Success Criteria
Confirm all background measurements are valid	Sensor response	Background measurements	All decay amplitudes lower than project threshold and qualitatively agree with initial measurement
Confirm all measurements have an applicable background	Background measurements	Cued survey data	Time Separation between background measurement and anomaly measurement < 2 hours (hrs)
Valid Position Data (1): GPS	GPS status flag	Cued survey data	Confirm GPS status flag indicates RTK fix
Valid Position Data (2): Inertial Measurement Unit (IMU)	IMU Orientation data	Cued survey data	Orientation data valid data input string checksum passes
Confirm inversion model supports classification (1 of 3)	Fit Coherence	Cued survey data	Derived model response must fit the observed data with a fit coherence $\geq$ 0.8
Confirm inversion model supports classification (2 of 3)	Fit location	Cued survey data	Fit location estimate of item $\leq$ 0.4-meters (m) from center of sensor
Confirm inversion model supports classification (3 of 3)	Fit Location	Cued survey data	100% of blind seed item positions $\leq$ 0.25-m from predicted position (x, y, z)
Confirm derived features match	Fit Location	Prioritized classification dig list and dig results	100% of recovered (excluding can't analyze category) item

Performance Objective	Metric	Data Required	Success Criteria
ground truth (1 of 2)			positions ≤ 0.25-m from predicted position (x, y)
Confirm derived features match ground truth (2 of 2)	Classification results	Prioritized classification dig list and dig results	100% of recovered object size estimates (excluding can't analyze category) qualitatively match predicted size
Validation of TOI/non-TOI thresholds	Classification results	Prioritized classification dig list and dig results	100% of predicted non-TOI intrusively investigated are non-TOI

3.1.1 Objective: Confirm all background measurements are valid

The reliability of the production data required background measurements that were free of metallic objects that could adversely affect background corrections. Ongoing background measurements were required to minimize time-variable changes in background response.

3.1.1.1. Metric

The metric for this objective were the background measurement responses.

3.1.1.2. Data Requirements

The initial and ongoing cued background measurements were used to evaluate success of this objective.

3.1.1.3. Success Criteria

The objective was met if decay amplitudes qualitatively agreed with the initial background measurement.

3.1.2 Objective: Confirm all measurements have an applicable background

The reliability of the production data required background measurements be collected to record time-variable effects in background response to minimize their impact to the classification results.

3.1.2.1. Metric

The metric for this objective were the background measurement responses.

3.1.2.2. Data Requirements

Background measurements were nominally collected every 2-hrs.

3.1.2.3. Success Criteria

The objective was met if the time separation between background measurement and anomaly measurement is less than 2-hrs.

3.1.3 Objective: Valid Position Data – GPS

Data acquisition software was monitored to ensure that all data streams (*e.g.*, GPS, IMU) were valid and being recorded. The objective was to have valid position data from the GPS.

3.1.3.1. Metric

The GPS status flag and GPS quality metric were used to evaluate performance.

3.1.3.2. Data Requirements

The GPS position of the cued survey data was used to evaluate success of this objective.

3.1.3.3. Success Criteria

Successful completion required that the GPS status flag indicated RTK fix.

3.1.4 Objective: Valid Position Data – IMU

Data acquisition software was monitored to ensure that all data streams (*e.g.*, GPS, IMU) were valid and being recorded. The objective was to have valid position data from the IMU.

3.1.4.1. Metric

The IMU status was used to evaluate success of this objective.

3.1.4.2. Data Requirements

The cued TEMTADS data was used to evaluate performance under this objective.

3.1.4.3. Success Criteria

Successful completion required a valid orientation on the data.

3.1.5 Objective: Confirm Inversion Model Supports Classification (1 of 3)

The reliability of the classification results depends on collecting data that had a relatively high fit coherence to indicate the data can be modeled.

3.1.5.1. Metric

The metric for this objective was the fit coherence.

3.1.5.2. Data Requirements

The modeled and detected cued survey data was used to evaluate success of this objective.

3.1.5.3. Success Criteria

Successful completion required that the derived model response must fit the observed data with a fit coherence of greater than or equal to 0.8.

3.1.6 Objective: Confirm Inversion Model Supports Classification (2 of 3)

The reliability of the classification results depended on collecting data where the sensor is above the subsurface metallic object.

3.1.6.1. Metric

The metrics for this objective were the sensor array and fit location.

3.1.6.2. Data Requirements

The cued survey data and classification fit locations were used to evaluate success of this objective.

3.1.6.3. Success Criteria

The objective was met if the fit location estimate of the subsurface item was less than or equal to 0.4-m from center of sensor.

3.1.7 Objective: Confirm derived features match ground truth (1 of 2)

The reliability of the classification results depended on reliably being able to classify targets at their respective location.

3.1.7.1. Metric

The metrics for this objective were the fit location and the known BSI location.

3.1.7.2. Data Requirements

The cued survey data were used to evaluate success of this objective.

3.1.7.3. Success Criteria

The objective was met if 100% of predicted seed positions was less than or equal to 0.25 m from known position (x, y, z).

3.1.8 Objective: Confirm derived features match ground truth (2 of 2)

The reliability of the classification results depended on reliably being able to classify the size of targets.

3.1.8.1. Metric

The metric for this objective were the classification and results.

3.1.8.2. Data Requirements

The prioritized classification dig list and dig results were used to evaluate success of this objective.

3.1.8.3. Success Criteria

The objective was met if 100% of recovered object size estimates (excluding can't analyze category) qualitatively matched predicted size.

3.1.9 Objective: Validation of TOI/non-TOI thresholds

The data reliability depended on the classification approach to correctly identify TOI and non-TOI.

3.1.9.1. Metric

The metric for this objective was the classification results.

3.1.9.2. Data Requirements

The prioritized classification dig list and dig results were used to evaluate success of this objective.

3.1.9.3. Success Criteria

The objective was met if 100% of predicted non-TOI intrusively investigated are non-TOI.

4.0 SITE DESCRIPTION

See the ESTCP Programmatic Office's demonstration plan for details on the Closed Castner Range Conceptual Site Model.

5.0 TEST DESIGN

The objective of this demonstration was to demonstrate a methodology for the use of AGC in the MR process. The three key components of this methodology are collection of high-quality geophysical data and principled selection of anomalous regions in those data, analysis of the selected anomalies using physics-based models to extract target parameters such as size, shape, and material properties, and the use of those parameters to construct a ranked anomaly list. Each of these components were handled separately in this program. URS was responsible for collection and quality of the TEMTADS data. Arcadis was responsible for evaluating this data and developing ranked anomaly lists.

Each Arcadis analyst submitted a ranked anomaly list for the TEMTADS data set. All anomalies were categorized and placed on the dig list in the following order:

- *Category -1:* Anomalies for which training labels had been requested. These anomalies were placed at the top of the dig list.
- *Category 0:* Anomalies for which Arcadis was not able to extract reliable parameters.
- *Category 1:* Anomalies that had a high likelihood of being a TOI based on the analyst's classification method.
- *Category 2:* Anomalies for which the analysts were unsure whether the anomalies were TOI or non-TOI. Category 2 anomalies, as well as those listed above, were placed above the analyst's stop dig threshold.
- *Category 3:* Anomalies that had a high likelihood of being clutter items and/or a low likelihood of being TOI. These anomalies were placed below the dig threshold.

These inputs were scored by the Institute for Defense Analyses (IDA) with emphasis on the number of items that were correctly labeled nonhazardous (*i.e.*, non-TOI) while correctly labeling all TOI.

The primary objective of the demonstration was to assess how well the two Arcadis analysts could order our ranked anomaly lists and specify the threshold separating high confidence clutter from all other items.

5.1 CONCEPTUAL EXPERIMENTAL DESIGN

Arcadis performed the following tasks to achieve this overall objective:

- Data Analysis
    - Pre-Processing and QC (See **Section 6.1**)
    - Parameter estimation (See **Section 6.3**)

- Classification and classifier training (See **Section 6.4**)
- Classification (See **Section 6.5**)

- Data Products (See **Section 6.6**)
  - Ranked anomaly list

5.2 SITE PREPARATION

See the ESTCP Programmatic Office's report for details on the site preparation activities.

5.3 SYSTEM SPECIFICATION

5.3.1 TEMTADS MP 2x2

URS collected static TEMTADS data at 1,492 of the detected anomalies. Arcadis' two data analysts imported these files into Geosoft Oasis Montaj© for processing using the UX-Analyze Advanced module and performed QC, background corrections, and AGC for each of the anomalies.

See the ESTCP Programmatic Office's report for details on the data acquisition parameters that were used to collect cued TEMTADS data.

5.4 CALIBRATION ACTIVITIES

See the ESTCP Programmatic Office's report for details on site calibration activities.

5.5 DATA COLLECTION

See the ESTCP Programmatic Office's report for details on the data collection efforts.

5.6 VALIDATION

See the ESTCP Program Office's report for details on the data validation efforts.

6.0 DATA ANALYSIS AND PRODUCTS

The two Arcadis data analysts processed, and analyzed the cued TEMTADS data by subtracting background measurements and performing AGC of the data.

Once the static data was pre-processed, Arcadis employed physics-based models to extract target parameters and then applied a library matching classification algorithm contained in the Oasis Montaj advanced UX-Analyze Advanced module to produce a ranked anomaly list.

6.1 PREPROCESSING

URS performed data pre-processing. See the ESTCP Programmatic Office's report for further details on pre-processing.

6.2 TARGET SELECTION FOR DETECTION

See the ESTCP Program Office's report for details on target selection for detection.

6.3 PARAMETER ESTIMATES

Arcadis analyzed a total of 1,492 cued TEMTADS. Each anomaly was analyzed using the single and multi-object solver algorithms in the UX-Analyze Advanced module within Geosoft Oasis Montaj©. Both intrinsic (size, shape, materials properties) and extrinsic (location, depth, orientation) parameters were estimated in these analyses and a list of the relevant target parameters from each analysis compiled.

The static data was processed using UX-Analyze Advanced module to extract the three principal axis polarizability curves for each target. Arcadis then matched the polarizability curves for each target to a library of polarizability curves to classify the target as either TOI or non-TOI.

6.4 CLASSIFIER

Arcadis' classifier involved matching the measured polarizabilities to a library that contained TOI from previous sites. The size and shape of polarizabilities (or βs) were matched to the known library items for the following four scenarios:

- 3 component target classification
    - Size – β_1
    - Shape 1 – β_2/β_1
    - Shape 1 – β_3/β_1
- 2 component target classification (1)
    - Size – β_1
    - Shape 1 – β_2/β_1

- 2 component target classification (2)
  - Size – β_1
  - Shape 1 – β_3/β_1
- 1 component target classification
  - Size – β_1

Based on this initial classification, both data analysts requested training data from the program office to verify the library matching model that was being proposed. The two data analysts requested the following training data:

- Analyst 1:
  - Request 1: 43 anomalies
  - Request 2: 7 anomalies
- Analyst 2:
  - Request 1: 25 anomalies
  - Request 2: 4 anomalies

Analyst 1 requested training data to determine whether small munitions (e.g., fuzes, 20-mm projectiles, and 37-mm projectiles) were present on the site and for anomalies that had relatively low confidence metrics (*e.g.*, 0.7 – 0.85) for munitions suspected to be present at the site to aid in determining the appropriate location of the dig threshold. Of the requested training data, only 2 targets were TOIs. The remaining anomalies selected confirmed that fuzes and 20-mm projectiles weren't anticipated TOI at the site.

Analyst 2 requested calibration data to assist in identifying an appropriate dig/no-dig threshold and to determine whether small munitions were present on the site. Two separate analyst calibration dig lists were submitted. Within these lists, two items were confirmed as TOI. These items were both 37-mm projectiles, and were confirmed as high confidence matches in the initial classifier. The remaining targets were primarily frag and small arms items. The information from the calibration digs were used to refine the classification library on the basis that items smaller than 37-mm projectiles were not likely to be present at the site.

6.5 CLASSIFICATION

6.5.1 Initial Classification

Analysts 1 and 2 each produced a ranked anomaly list for the TEMTADS library matching approach. The library matching approach for both sensors included matching to both suspected TOI at the site, which included small ISOs, 37-mm projectiles, and larger munitions. The final classification used a combined confidence metric that averaged the confidence metric for the best fitting TOI (or clutter item in the library) for the 3-, 2-, and 1- component matches. The best fitting TOI (or clutter item) for the 3-component match was then assigned as the TOI Type. Each analyst then classified each anomaly as one of the following categories:

- Analyst 1
  - *Category -1:* anomalies for which training labels had been requested. These anomalies were placed at the top of the dig list.
  - *Category 0:* Anomalies for which Arcadis was not able to extract reliable parameters.
  - *Category 1:* Anomalies that had a combined metric match to TOI greater than 0.925. These anomalies were believed to have a high likelihood of being TOI.
  - *Category 2:* These anomalies were anomalies for which Analyst 1 was unsure whether the anomaly was TOI or non-TOI and were classified as follows:
    - Targets that met all criteria in Table 1 in the Analyst 1 Anomaly Decision Memo **(**See **Appendix B**) with decision statistics between 0.825 and 0.925, and
    - Non-weak targets that had decision statistics above 0.75.
  - *Category 3:* Anomalies that had a combined metric match to TOI that didn't meet any of the above criteria. These anomalies had a high likelihood of being clutter items and/or a low likelihood of being TOI. These anomalies were placed below the dig threshold.
- Analyst 2
  - *Category -1:* anomalies for which training labels had been requested. These anomalies were placed at the top of the dig list.
  - *Category 0:* Anomalies for which Arcadis was not able to extract reliable parameters.
  - *Category 1:* Anomalies that had a combined metric match to TOI greater than 0.925. These anomalies were believed to have a high likelihood of being TOI.
  - *Category 2:* Anomalies that had a combined metric match to TOI between 0.78 and 0.925. Arcadis was unsure whether these anomalies were TOI or non-TOI.
  - *Category 3:* Anomalies that had a combined metric match to TOI less than 0.78. These anomalies had a high likelihood of being clutter items and/or a low likelihood of being TOI. These anomalies were placed below the dig threshold.

Table 6-1 shows an example of how both Arcadis data analysist ordered their ranked anomaly list. Category -1, 0, 1, 2 anomalies were placed above the dig threshold in descending order, while Category 3 anomalies were placed below the dig threshold. The first items on each ranked anomaly list were those targets for which ground truth labels were requested (training data). Following this, anomalies for which reliable parameters could not be extracted and therefore had to be dug were listed. Next were the items that Arcadis was the most confident are "highly likely" to be TOI. The items were ranked in descending confidence that the item is TOI. Any items that the analyst could analyze, but were not able to classify (*i.e.*, Category 2 anomalies) were placed next on the anomaly list. Finally, all Category 3 items that the analyst was confident were not TOI were ranked in descending order of their confidence metric. The Category 3 anomalies were ordered in descending order based on their confidence metric.

Table 6-1: Example Ranked Anomaly List

Target ID	Category	Dig Decision (1=Dig; 0=Do Not Dig)	Type (mm)	Confidence Metric	Comment
CR-24	-1	1	127	1	Training Data
…	…	…	…	…	Training Data
CR-339	-1	1	127	0.65	Training Data
CR-17	0	1	127	9999	Can't Analyze
…	…	…	…	…	…
CR-862	0	1	127	9999	Can't Analyze
CR-841	1	1	25	1	High Confidence Match to TOI
…	…	…	…	…	…
CR-562	1	1	25	0.85	High Confidence Match to TOI
CR-625	2	1	60	0.85	Cannot Decide
…	…	…	…	…	…
CR-167	2	1	60	0.8	Cannot Decide
CR-710	3	0	0	1	High Confidence Match to Clutter Items
…	…	…	…	…	…
CR-1006	3	0	0	0.8	High Confidence Match to Clutter Items
CR-631	3	0	0	0.79	Low Confidence Match to TOI and Clutter Items
CR-978	3	0	0	0	Low Confidence Match to TOI and Clutter Items

Note:
mm – millimeter

In addition, Arcadis provided an assignment to the 'Type' column, indicating the specific type of munition caliber (*i.e.*, 75 mm). The final, ranked anomaly lists are provided in **Appendix B**.

6.5.2 Feedback Based on QC Seed Performance

The initial ranked anomaly lists were submitted to the ESTCP program office to confirm that all QC seeds had been classified correctly. QC seed items were not marked to be dug on the initial dig list; therefore, the ESTCP Program Office provided the location and identity of the misclassified QC seeds as additional on-site training data. Arcadis used this additional information to modify our classification procedures to ensure that the revised methods correctly classified the seeds missed originally. A second stage list was then submitted accompanied by a Failure Analysis memo outlining the causes of the misclassification, the revisions made in classification procedures, and a demonstration that the revised procedures successfully classified the missed seeds. **Appendix B** contains the QC Seed Failure Memos for the TEMTADS dig lists for both Analyst 1 and 2. Upon acceptance of the memos by the ESTCP Program Office, the analysts submitted Final Ranked Dig Lists (see **Appendix B**) to the Program Office and IDA scored the second stage list.

6.6 DATA PRODUCTS

6.6.1 Ranked Anomaly Lists and Results

As discussed above, each Arcadis Analyst submitted a ranked anomaly list for the cued TEMTADS data (see **Appendix B**). Upon submittal of the final ranked dig lists, IDA constructed Receiver Operating Characteristic (ROC) curves for each anomaly list. **Figure 6-1** and **Figure 6-2** show the ROC curves for Analyst 1 and Analyst 2, respectively.

Figure 6-1: Analyst 1 ROC Curve

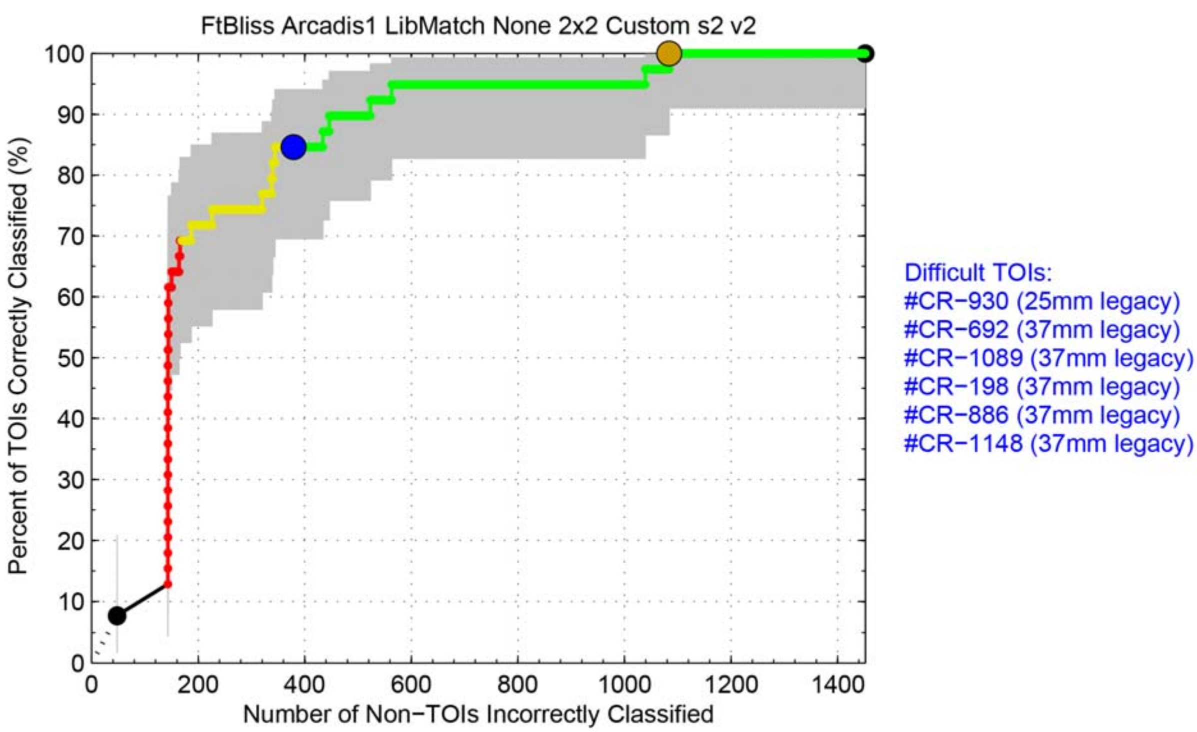
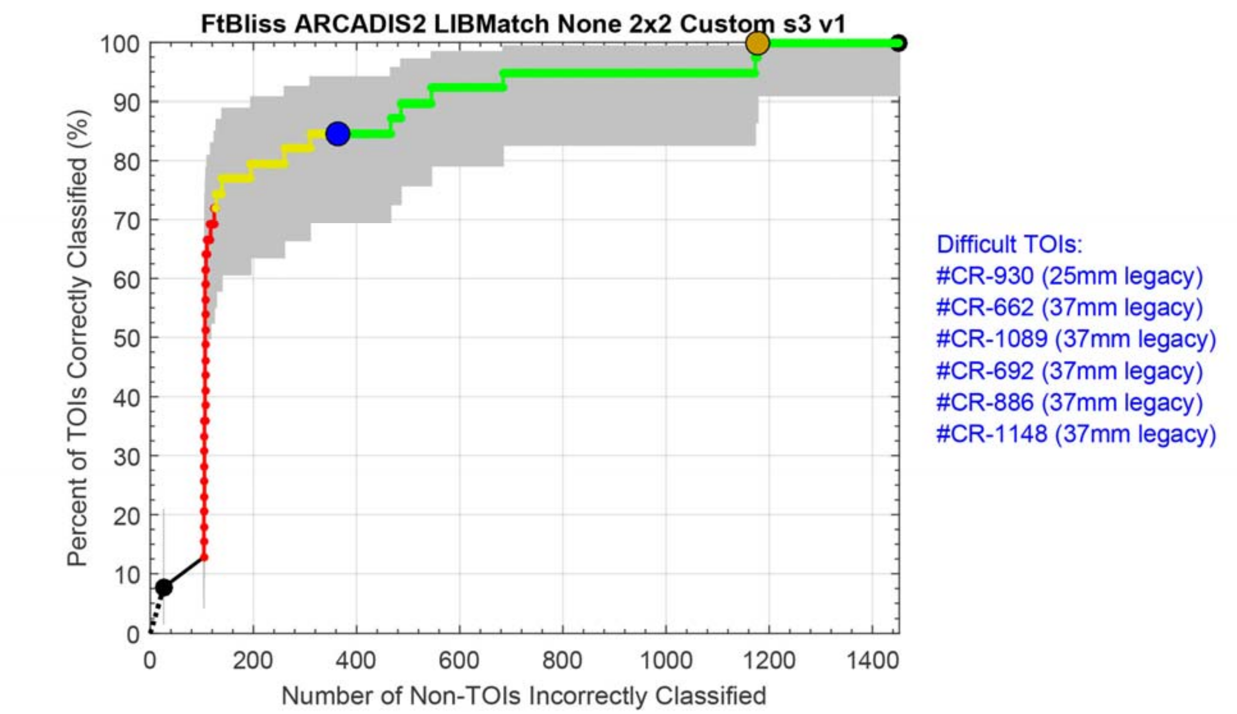


Figure 6-2: Analyst 2 ROC Curve



The key regions to interpret the ROC curves are:

- The black dashed line corresponds to the targets that were dug for training data.
- The solid black line corresponds to the targets that were categorized as "can't extract reliable parameters" that were treated as potential TOI because no meaningful classification could be done. At least one TOI was identified in this part of the curve for each of the three ROC curves.
- Targets in red, yellow, green, correspond to Category 1, 2, and 3 targets, respectively.
- The blue dot corresponds to the dividing point between TOI and not-TOI.
- The orange dot corresponds to the point at which ARCADIS detected all TOI.

As discussed in **Section 3.0**, the primary performance metric was the point at which the ROC curve reaches 100% identification of TOI. The number of clutter items correctly identified at this point is a measure of the savings possible for each method. As seen in **Figures 6-1** and **6-2**, both Arcadis analysts had 6 difficult to detect targets that were incorrectly classified as non-TOI. **Section 7.0** contains an assessment as to why these were incorrectly classified as non-TOI.

6.6.2 Intrusive Investigation Results

See the ESTCP Program Office report for intrusive investigation results.

7.0 PERFORMANCE ASSESSMENT

Performance objectives were established in the demonstration plan to evaluate the quality of data collected as part of this demonstration. These performance objectives were first discussed in **Section 3.0** of this report. This section documents the results and evaluates the data quality and whether the performance metrics were met. **Table 7-1** shows the performance results for each of the performance objectives for both analysts, while the following sub-sections describe the performance relative to the MQOs. Where the results of the two analysts vary, additional sub-sections have been included to document the results of both analysts.

Table 7-1: Cued TEMTADS Data Collection and Analysis Objectives

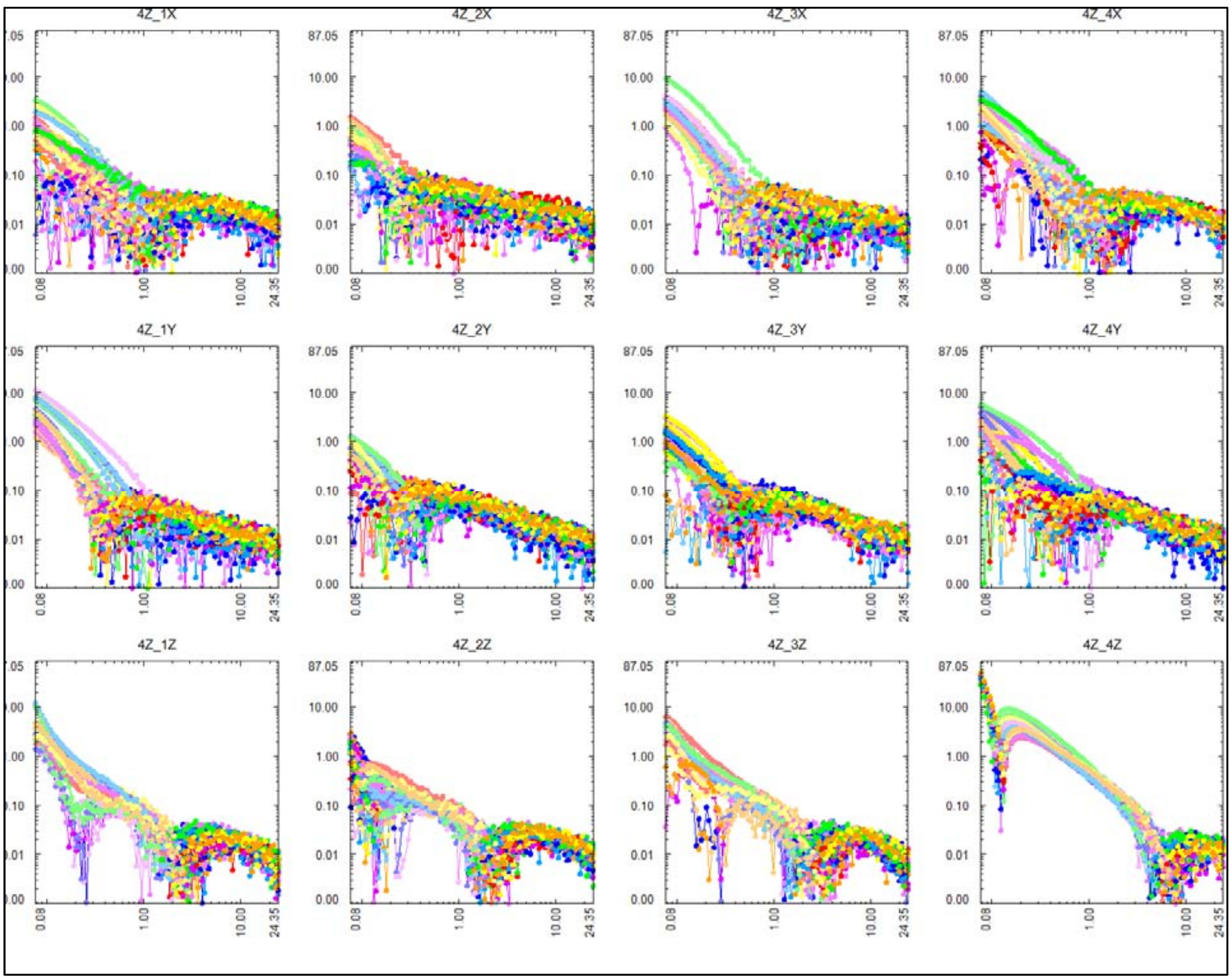
Performance Objective	Metric	Data Required	Success Criteria	Analyst 1 Results	Analyst 2 Results
Confirm all background measurements are valid	Sensor response	Background measurements	All decay amplitudes lower than project threshold and qualitatively agree with initial measurement	MQO Achieved, 61% of backgrounds rejected	MQO Achieved, 64% of backgrounds rejected
Confirm all measurements have an applicable background	Background measurements	Cued survey data	Time Separation between background measurement and anomaly measurement < 2-hrs	MQO not achieved, 84.3% < 2-hrs after removing bad backgrounds	MQO not achieved, 80.6% < 2-hrs after removing bad backgrounds
Valid Position Data (1): Global Positioning System (GPS)	GPS status flag	Cued survey data	Confirm GPS status flag indicates RTK fix	MQO achieved, 100%	MQO achieved, 100%
Valid Position Data (2): IMU	IMU Orientation data	Cued survey data	Orientation data valid data input string checksum passes	MQO achieved, 100%	MQO achieved, 100%
Confirm inversion model supports classification (1 of 3)	Fit Coherence	Cued survey data	Derived model response must fit the observed data with a fit coherence ≥ 0.8	MQO not achieved 98% of targets	MQO not achieved 98% of targets
Confirm inversion	Fit location	Cued survey data	Fit location estimate of item ≤	MQO achieved	MQO Achieved

Performance Objective	Metric	Data Required	Success Criteria	Analyst 1 Results	Analyst 2 Results
model supports classification (2 of 3)			0.4m from center of sensor		
Confirm inversion model supports classification (3 of 3)	Fit Location	Cued survey data	100% of blind seed item positions ≤ 0.25 m from predicted position (x, y, z)	MQO not achieved, 71.4% < 0.25-m	MQO not achieved, 75% < 0.25-m
Confirm derived features match ground truth (1 of 2)	Fit Location	Prioritized classification dig list and dig results	100% of recovered (excluding can't analyze category) item positions ≤ 0.25 m from predicted position (x, y)	MQO not achieved, 80% ≤ 0.25-m	MQO not achieved, 66% ≤0.25-m
Confirm derived features match ground truth (2 of 2)	Classification results	Prioritized classification dig list and dig results	100% of recovered object size estimates (excluding can't analyze category) qualitatively match predicted size	MQO not achieved	MQO not achieved
Validation of TOI/non-TOI thresholds	Classification results	Prioritized classification dig list and dig results	100% of predicted non-TOI intrusively investigated are non-TOI	MQO not achieved, 83% of TOI correctly classified	MQO not achieved, 83% of TOI correctly classified

7.1 OBJECTIVE: CONFIRM ALL BACKGROUND MEASUREMENTS ARE VALID

Throughout the cued data collection process, URS collected ongoing background measurements approximately every 2 hours to minimize the time-variable changes in the background response. To maintain production, the background location selected for a given background measurement were based on proximity to the location of cued data acquisition. This resulted in a total 180 background readings collected at 15 different background locations (3 located within the IVS area, 6 located within grid areas, and 6 located outside of grid areas) over the course of cued data acquisition. The reliability of advanced EMI sensor cued data collection and processing is foundationally dependent on acquiring background measurements that are free of metallic objects that could adversely affect the background subtraction process. However, over the course of cued data collection, the data collection contractor did not pay enough attention to this detail, resulting in background locations where metal objects were located less than 5 feet away from some and less than 1 foot in others. **Figure 7-1** shows an example of the variation in background response at background location 2 for transmit coil 4. Ideally, there would be very little variation, particularly in the early time gates (e.g., before 1 millisecond[ms]). However, it is apparent from the figure that there are large responses (e.g., 10 milliVolt [mV]/amp in the 4Z_3x response) that indicate there are metallic objects near the sensor. These metallic objects should have been removed from the area prior to use this particular background location.

Figure 7-1: Example of Background Variability at Background Location 2



Because of the metallic objects near background locations, 7 of the 15 total background locations were deemed to be compromised after an initial visual inspection of the decay amplitudes. The remaining background readings from the 8 acceptable background locations were further inspected, and all quantitative and qualitative outliers were removed from the list of available background readings. Analyst 1 determined that only 69 of the 160 background measurements

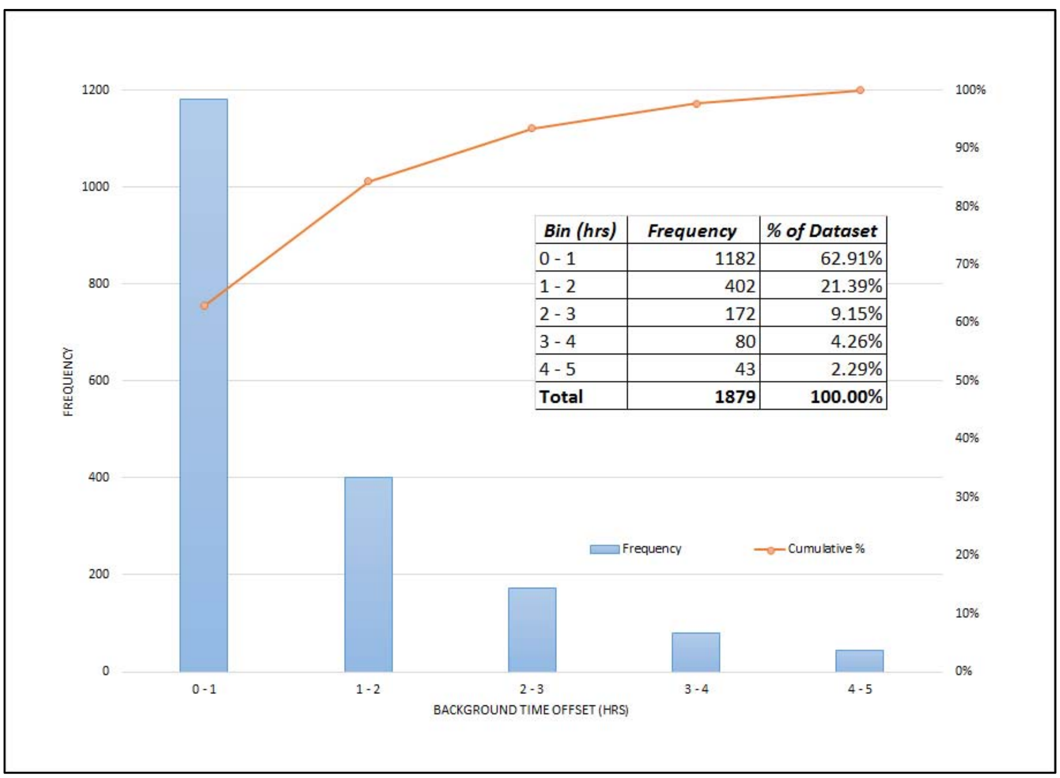
(38.33%) were acceptable to level the cued data. Analyst 2 used the same evaluation process as Analyst 1, but determined that only 64 of the 180 background measurements (35.6%) were acceptable to level the cued data.

7.2 OBJECTIVE: CONFIRM ALL MEASUREMENTS HAVE AN APPLICABLE BACKGROUND

7.2.1 Analyst 1

The Final QAPP and SOP MEC-AC-12 specify that the time separation between background measurements should be less than 2 hours to minimize the time-variable changes in the background response. However, as stated in **Section 7.1**, after the background QC process was completed, Analyst 1 determined that only 69 out of the total 180 background measurements (38.33%) were acceptable for background subtraction. **Figure 7-2** shows a summary of the time between background readings that Analyst 1 determined were acceptable and for all the cued data. Only 84.3% of the 1879 cued measurements (including re-shots) had an acceptable background reading collected within the 2-hour window. This resulted in the use of background readings far outside of the typical 2-hour window (up to 5 hours) to complete the cued data analysis.

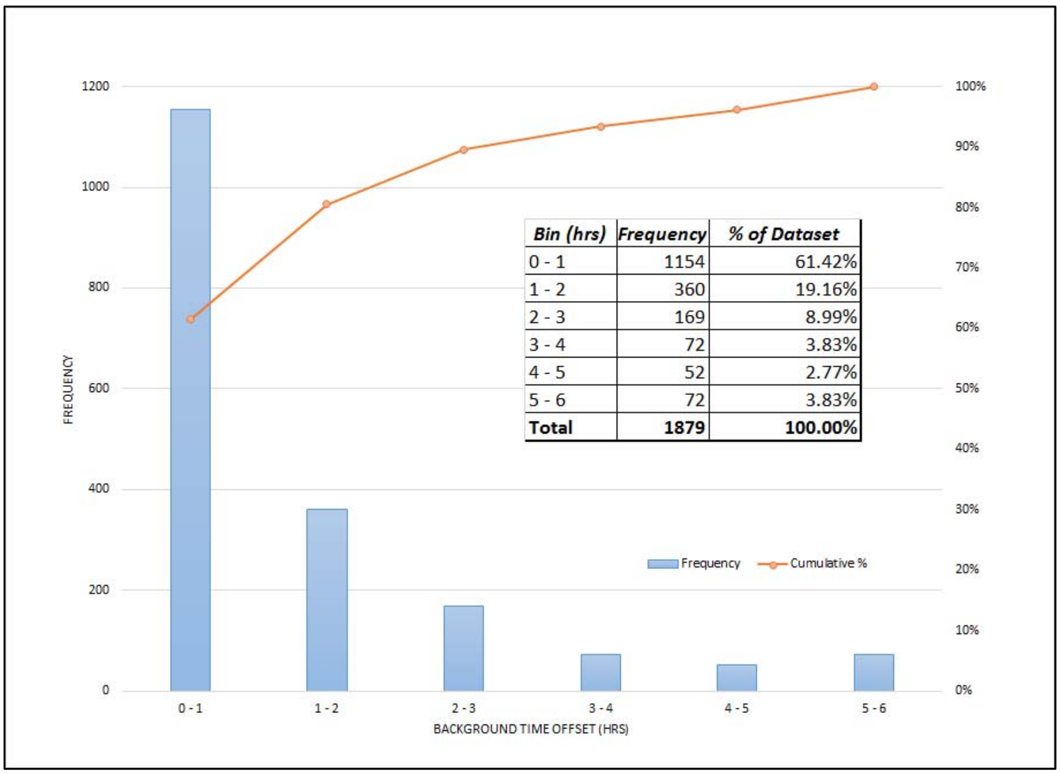
Figure 7-2: Analyst 1 Background Reading Time Window Distribution



7.2.2 Analyst 2

The Final QAPP and SOP MEC-AC-12 specify that the time separation between background measurements should be less than 2 hours to minimize the time-variable changes in the background response. However, as stated in **Section 7.1.2**, after background QC process was completed, only 64 out of the total 180 background measurements (36%) were deemed acceptable for background subtraction. **Figure 7-3** shows a summary of the time between background readings that Analyst 2 determined were acceptable and for all the cued data. Only 80.6% of the 1,879 cued measurements (including re-shots) had an acceptable background reading collected within the 2-hour window. This resulted in the use of background readings far outside of the typical 2-hour window (up to 6 hours) to complete the cued data analysis.

Figure 7-3: Analyst 2 Background Reading Time Window Distribution



Bin (hrs)	Frequency	% of Dataset
0 - 1	1154	61.42%
1 - 2	360	19.16%
2 - 3	169	8.99%
3 - 4	72	3.83%
4 - 5	52	2.77%
5 - 6	72	3.83%
Total	**1879**	**100.00%**

7.3 OBJECTIVE: VALID POSITION DATA (1) – GPS

The RTK fix quality flag was used to evaluate whether each cued measurement had a valid RTK GPS location recorded with it. All cued data had an RTK fix quality of 4, indicating that valid positioning was recorded for each measurement. All data passes this performance metric for both analysts.

7.4 OBJECTIVE: VALID POSITION DATA (2) – IMU

During data acquisition, the field software was monitored to ensure that all data streams (*e.g.*, GPS, IMU) were valid and being recorded. The objective was to record a valid data stream from the IMU for each cued measurement. The IMU data stream recorded in each cued measurement were evaluated by checking the raw data import for a valid value in each of the UXA_pitch, UXA_yaw, and UXA_roll database channels. This performance metric was met for both analysts, as valid pitch, roll, and yaw data streams were recorded for each cued measurement.

7.5 OBJECTIVE: CONFIRM INVERSION MODEL SUPPORTS CLASSIFICATION (1 OF 3) – FIT COHERENCE

The reliability of the classification process depended on collecting high quality data to support the modeling process. This objective evaluated how well the modeled results of the inversion process correlated to the observed data. A fit coherence metric (UXA_Fit_Coh) is calculated for each model during data inversion, and is used as a basis for determining how well the model matches the observed data.

Each cued measurement was assessed by evaluating the coherencies derived for single source and multi-source fits. The highest fit coherency value from either solver was used as the basis for evaluation. Modeled results with a neither a single source or multi-source fit coherence greater than 0.8 were placed in the 'cannot analyze' category.

This objective requires that the model derived during the inversion process match the observed data to within a correlation of 0.8. This metric, provided by UX Analyze as the 'fit coherence' (UXA_Fit_Coh) is an output of the dipole analysis inversion routine.

For both Arcadis analysts, 98% of the inversion results resulted in fit coherences greater than 0.8. The fit coherences were likely decreased due to the large time distance between cued measurements and acceptable background data, as well as to the overall quality of the background measurements.

7.6 OBJECTIVE: CONFIRM INVERSION MODEL SUPPORTS CLASSIFICATION (2 OF 3) – FIT LOCATION

The reliability of the classification results also depended on collecting data where the sensor is above the subsurface metallic object. The metric for this objective was met if the center of the instrument was positioned within 40-cm of the actual anomaly location for 100% of the cued anomalies. Single and multi-source fit locations were evaluated for each cued measurement location to assess this metric. Based on the fit results, 100% of the cued measurements evaluated during this demonstration had a fit location within 40-cm of the recorded location of the TEMTADS 2x2 array center for both analysts.

7.7 OBJECTIVE: CONFIRM INVERSION MODEL SUPPORTS CLASSIFICATION (3 OF 3) – FIT LOCATION

7.7.1 Analyst 1

The reliability of the classification results also depended on reliably being able to classify targets at their respective location. The metric for this objective was met if 100% of the modelled seed locations were less than or equal to 0.25-m from their known position (x, y, z).

For Analyst 1, 20 of the 28 total seed items (71.4%) met this criterion. For Analyst 2, 21 of the 28 total seed items (75%) met this criterion. Thus, both analysts did not meet this MQO. This failure was likely due to a combination of inconsistent background readings (taken greater than 2 hours apart) and the abundance of signal interference from the presence of immediately adjacent shallow clutter/munitions debris (frag and fuse components). **Figure 7-4** and **Figure 7-5** present a summary of offsets between the fit locations of the inverted data and the seed item locations for analysts 1 and 2, respectively.

Figure 7-4: Analyst 1 Predicted Seed Location Distribution

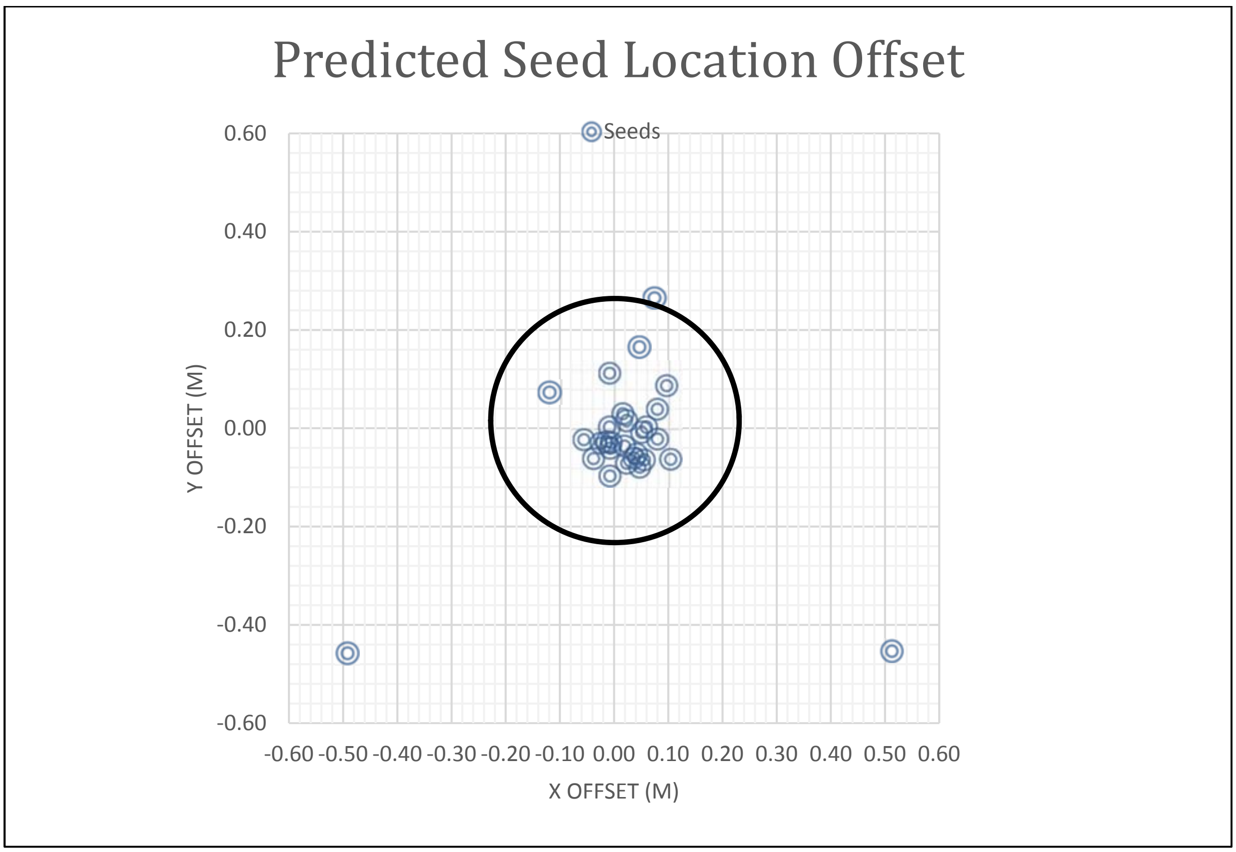
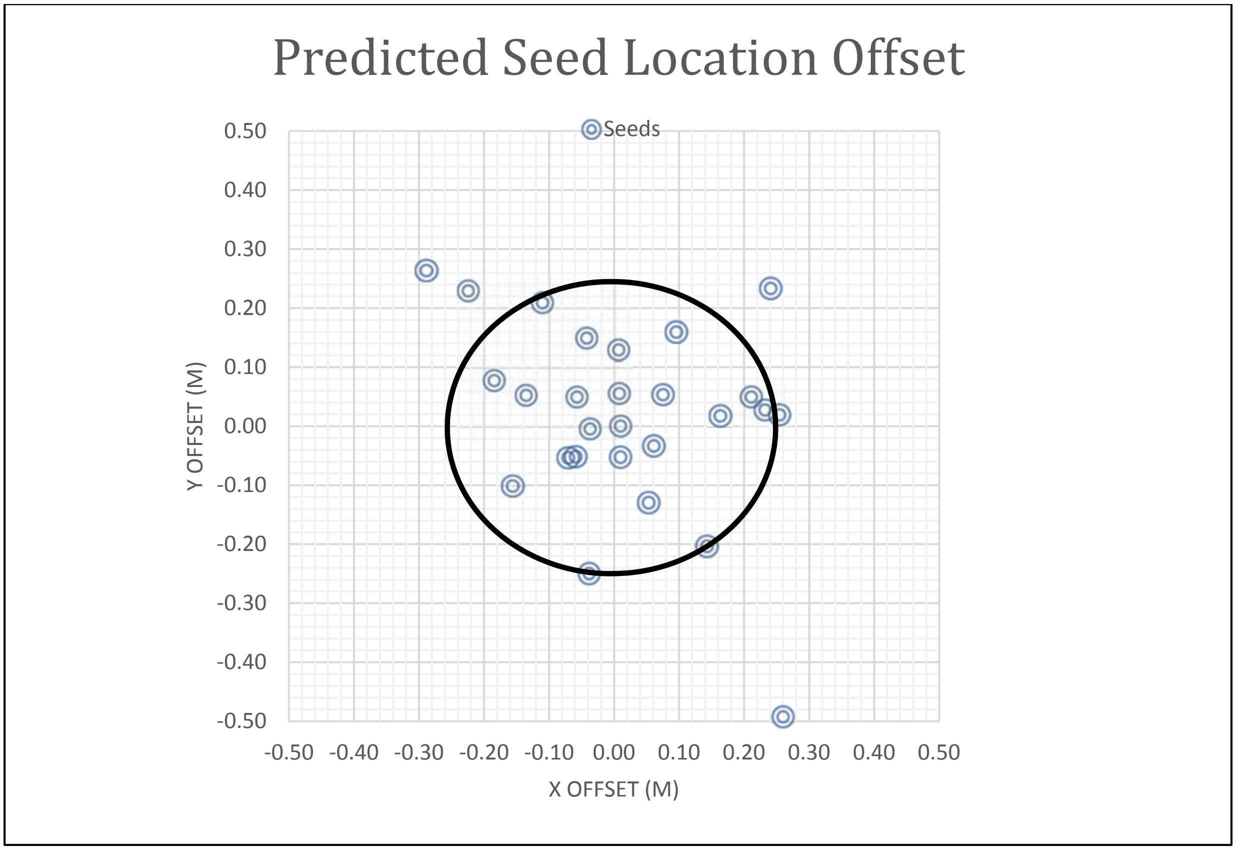


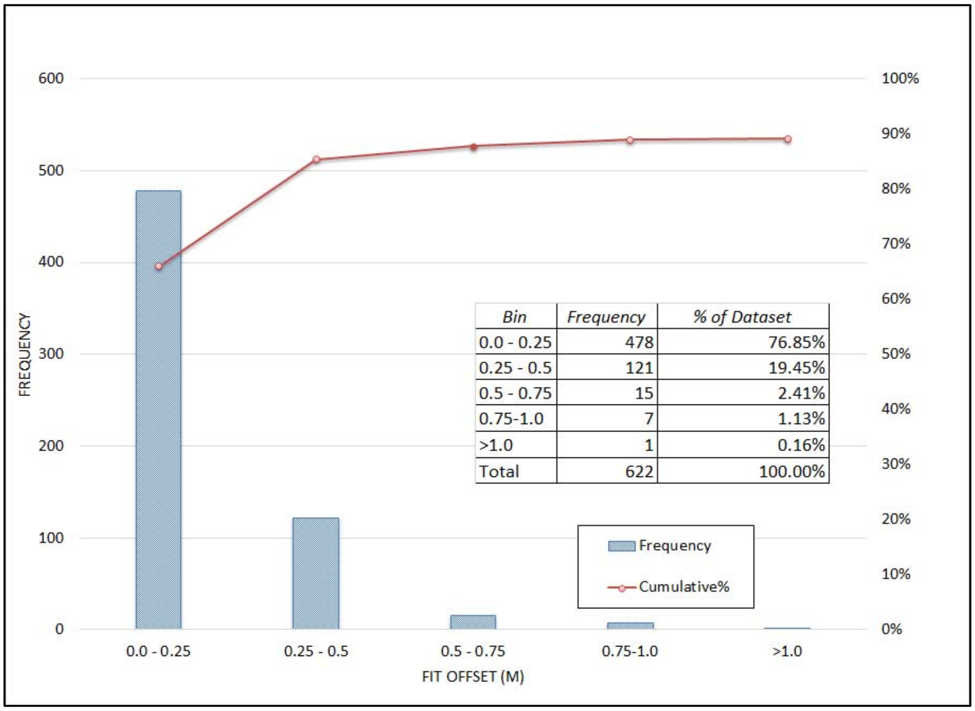
Figure 7-5: Analyst 2 Predicted Seed Location Distribution



7.8 OBJECTIVE: CONFIRM DERIVED FEATURES MATCH GROUND TRUTH (1 OF 2)

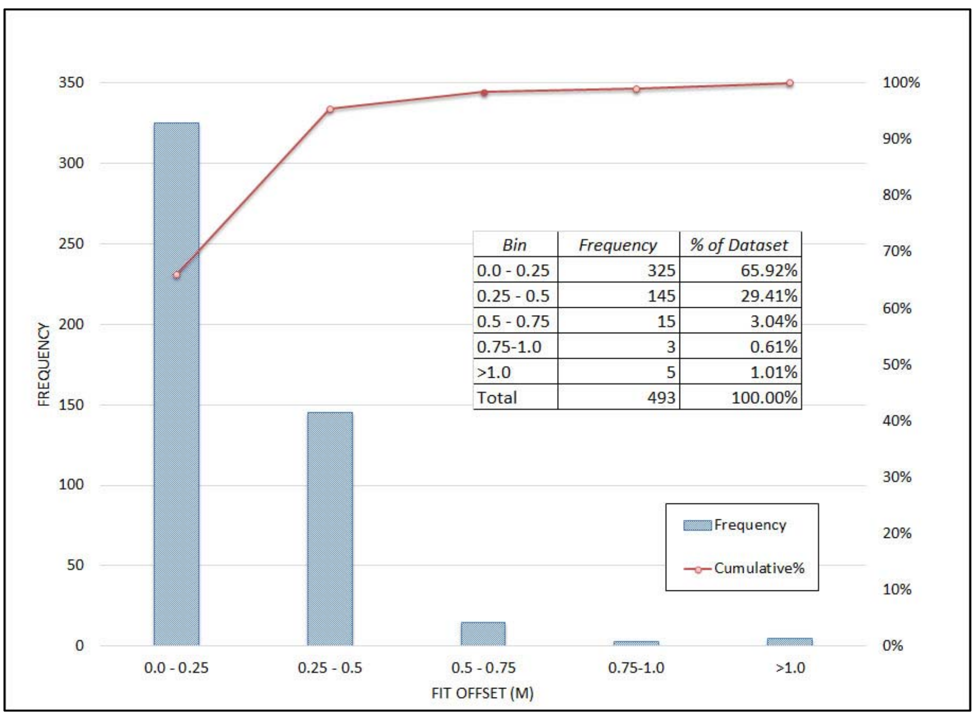
The reliability of the classification results depended on reliably being able to classify targets at their respective location. The performance objective was met if 100% of the predicted target locations of all items recovered from target locations in the training set (-1), likely TOI (1), and can't decide (2) class of the final dig list were less than or equal to 0.25 m from known position (x, y, z). **Figure 7-6** and **Figure 7-7** show summaries of the offsets between the fit locations of the inverted data and the locations of the recovered items within dig classes -1, 1, and 2 for analysts 1 and 2, respectively. They respectively show that 80% and 66% of the modeled target locations for Analysts 1 and 2 met this criterion, thus neither analyst achieved this MQO. This failure was likely largely due to the abundance of shallow clutter and munitions debris recovered within the dig proximity of the primary target of concern and possibly due to the extended period between background readings after removing bad background readings.

Figure 7-6: Analyst 1 Target Location Offset Distribution



Bin	Frequency	% of Dataset
0.0 - 0.25	478	76.85%
0.25 - 0.5	121	19.45%
0.5 - 0.75	15	2.41%
0.75-1.0	7	1.13%
>1.0	1	0.16%
Total	622	100.00%

Figure 7-7: Analyst 2 Target Location Offset Distribution



Bin	Frequency	% of Dataset
0.0 - 0.25	325	65.92%
0.25 - 0.5	145	29.41%
0.5 - 0.75	15	3.04%
0.75-1.0	3	0.61%
>1.0	5	1.01%
Total	493	100.00%

7.9 OBJECTIVE: CONFIRM DERIVED FEATURES MATCH GROUND TRUTH (2 OF 2)

The reliability of the classification results depended on reliably being able to classify the size of targets. The objective was met if 100% of recovered object size estimates (excluding can't analyze category) qualitatively match predicted size. The performance metric was met if 100% of the recovered object size estimates qualitatively matched the predicted sizes. To assess this, the predicted sizes of the targets in Class 1 (likely TOI) and 2 (can't decide) on the final submitted dig list were compared to the dig results in the training data for the site provided by ESTCP. The size bands approximated on the dig list were based on object diameter and ranged from 0 to 50-mm (size band 1), between 50 mm and 100 mm (size band 2), and greater than 100 mm (size band 3).

7.9.1 Analyst 1

Of the 465 targets Analyst 1 classified as class 1 and 2 targets on the final dig list, 298 targets were interpreted as size band 1, 164 targets were interpreted as size band 2, and 3 targets were interpreted as size band 3. From a qualitative perspective, all the items recovered from target locations predicted to contain objects in size band 1 were consistent with smaller diameter objects: munition fragments, small arms, fuse components, 37-mm rounds, and small ISO seeds. In contrast, the items recovered from target locations predicted to contain objects with diameters in size band 2 constraints were not consistent with medium diameter objects, also consisting of munition fragments, small arms, fuse components, and several small ISO seeds. However, the 3 targets selected to be in size band 3 did consist of large munitions debris. Analyst 1 didn't meet this MQO based on the relatively small items found in size band 2.

7.9.2 Analyst 2

Of the 483 targets Analyst 2 classified as class 1 and 2 targets on the final dig list, 327 were interpreted as size band 1, 155 were interpreted as size band 2, and 1 was interpreted as size band 3. From a qualitative perspective, all the items recovered from target locations predicted to contain objects in size band 1 were consistent with smaller diameter objects: munition fragments, small arms, fuse components, 37-mm rounds, and small ISO seeds. In contrast, the items recovered from target locations predicted to contain objects with diameters in size band 2 constraints were not consistent with medium diameter objects, also consisting of munition fragments, small arms, fuse components, and several small ISO seeds; as well as 0.50 caliber projectile. However, the only target selected to be in size band 3 did consist of a 105mm projectile. Analyst 2 didn't meet this MQO based on the relatively small items found in size band 2.

7.10 OBJECTIVE: VALIDATION OF TOI/NON-TOI THRESHOLDS

The data reliability depends on the classification approach to correctly identify TOI and non-TOI. The objective was met if 100% of predicted non-TOI intrusively investigated were non-TOI.

Analysts 1 and 2 prepared ranked anomaly lists for the cued TEMTADS dataset and IDA personnel used their scoring algorithms to assess the results. The objective was met if all the TOI were correctly labeled as TOI on the ranked anomaly list. **Figure 6-1** and **Figure 6-2** show the ROC curves for Analysts 1 and 2, while **Table 7-2** presents a summary of the results. As seen in the ROC curves, Analysts 1 and 2 both incorrectly classified 6 TOI as non-TOI. The following sub-sections present assessments for why each of the TOI were misclassified.

Table 7-2: Prioritized Dig List Statistics for Analysts 1 and 2

Analyst	TOI Identified		Training Targets		Cannot Analyze		List Length		Totals	
	Qty.	%	Qty.	%	Qty.	%	Qty.	%	Total TOI	Total Targets
Analyst 1	34	82.9%	81	5.4%	105	7.0%	651	43.7%	41	1491
Analyst 2	34	82.9%	42	2.8%	100	6.7%	629	42.2%		

7.10.1 Analyst 1

Figure 6-1 shows the ROC curve for Analyst 1. As seen on this figure, Analyst 1 incorrectly classified six TOI as non-TOI, which are listed below:

- CR-930: 25mm projectile
- CR-692: 37-mm projectile
- CR-1089: 37-mm projectile
- CR-198: 37-mm projectile
- CR-886: 37-mm projectile
- CR-1148: 37-mm projectile.

Initial Category 1 and 2 target selection thresholds were determined based on standard advanced classification processing recommendations made by Geosoft (0.925 to 0.825). However, given the elevated levels of background geologic noise, as well as the reduced number of acceptable background measurements and the failure to correctly classify a QC seed as TOI, the following decision statistics were used to classify targets as Category 1 through 3 targets in the final dig list:

- *Category 1:* Anomalies that had a combined metric match to TOI greater than 0.925. These anomalies were believed to have a high likelihood of being TOI.
- *Category 2:* These anomalies were anomalies for which Analyst 1 was unsure whether the anomaly was TOI or non-TOI and were classified as follows:
  - o Targets that met all criteria in Table 1 in the Analyst 1 Anomaly Decision Memo (See **Appendix B**) with decision statistics between 0.825 and 0.925, and

  - Non-weak targets that had decision statistics above 0.75.
- *Category 3:* Anomalies that had a combined metric match to TOI that didn't meet any of the above criteria. These anomalies had a high likelihood of being clutter items and/or a low likelihood of being TOI. These anomalies were placed below the dig threshold.

Can't Analyze anomalies were determined based on one or more of the following criteria:

- There were no polarizabilities because the inversion did not finish;
- The fit depth was unreasonable (*e.g.,* greater than 2-m below ground surface [bgs])
- There were negative polarizabilities;
- There was a poor fit coherence (*e.g.,* less than 0.8); and
- Reliable polarizabilities couldn't be extracted (*e.g.,* array center to fit location greater than 0.4-m).

In Analyst 1's final dig list, the six targets in question had a decision statistic range of 0.53 through 0.76, and as such, were classified as Category 3 targets and not recommended to be dug. **Table 7-3** shows the initial decision statistic and the best 3-component match for each of the missed TOI. The best fits included 3 rifle grenades, 2 37-mm projectiles, and 1 40-mm projectile. A visual inspection of the six recovered items shows that except for the item encountered at target CR-0930 (a 25-mm projectile), all the remaining targets consisted of large remnants of 37-mm projectiles, and as such, were classified as 37-mm munitions debris (MD) in the field. However, it was later determined by the site team that these items were close enough to a complete 37-mm projectile to be considered TOI for the purposes of AGC.

Table 7-3: Analyst 1 Decision Statistic Comparison

Target ID	Initial AGC Results		Revised AGC	
	Decision Statistic	Best Match	Decision Statistic	Best Match
CR-930	0.6119	37-mm	0.6925	20-mm projectile
CR-692	0.6568	Steel rifle grenade	0.8861	20-mm projectile
CR-1089	0.5275	37-mm	0.9139	20-mm projectile
CR-198	0.6775	Steel rifle grenade	0.8899	20-mm projectile
CR-886	0.7508	Steel rifle grenade	0.9356	20-mm projectile
CR-1148	0.7618	40-mm	0.8271	20-mm projectile

While 20-mm projectiles were initially included in the field verification and validate library versions of the TOI library, they were removed from the TOI library for the final classification to reduce the number of false matches to clutter objects after confirming with the ESTCP Program Office that 20-mm projectiles were not TOI at CR. After failing to identify the 6 missed TOI, the six targets in question were re-processed with 20-mm projectiles included in the TOI library.

Table 7-3 shows the revised AGC results for the 6 misclassified targets, which were assigned a decision statistic between 0.69 through 0.94, which all fall above the stop dig threshold except for target CR-930. Analyst 1 would have needed to include 20-mm projectiles in the TOI library and reduce the stop-dig threshold to 0.69 to correctly classify all the TOI. Reducing the stop-dig threshold to 0.69 would have significantly increased the number of non-TOI targets that required intrusive investigation to ensure all TOI were recovered. See **Figure 7-8** through **Figure 7-13** for the revised library match for each of the missed TOI.

7.10.2 Analyst 2

Figure 6-2 shows the ROC curve for Analyst 2. As seen on this figure, Analyst 2 incorrectly classified six TOI, which are listed below:

- CR-930: 25mm projectile
- CR-662: 37-mm projectile
- CR-1089: 37-mm projectile
- CR-692: 37-mm projectile
- CR-886: 37-mm projectile
- CR-1148: 37-mm projectile.

Initial Category 1 and 2 target selection thresholds were determined based on standard advanced classification processing recommendations made by Geosoft (0.925 to 0.75). However, given the elevated levels of background geologic noise, as well as the reduced number of acceptable background measurements, the following decision statistics were used to classify targets as Category 1 through 3 targets in the final dig list:

- Category 1 targets are those with decision statistics greater than 0.925.
- Category 2 targets are those with decision statistics between 0.925 and 0.71.
- Category 3 targets are those with decision statistics below 0.71.

Can't Analyze anomalies were determined based on one or more of the following criteria:

- There were no polarizabilities because the inversion did not finish;
- The fit depth was unreasonable (e.g., greater than 2-m bgs)
- There were negative polarizabilities;
- There was a poor fit coherence (e.g., less than 0.8); and
- Reliable polarizabilities couldn't be extracted (e.g., array center to fit location greater than 0.4-m).

In Analyst 2's final dig list, the six targets in question had a decision statistic range of 0.42 through 0.69, and as such, were classified as Category 3 targets and not recommended to be dug, although

Figure 7-8: Analyst 1 Revised Library Match for Target CR-930

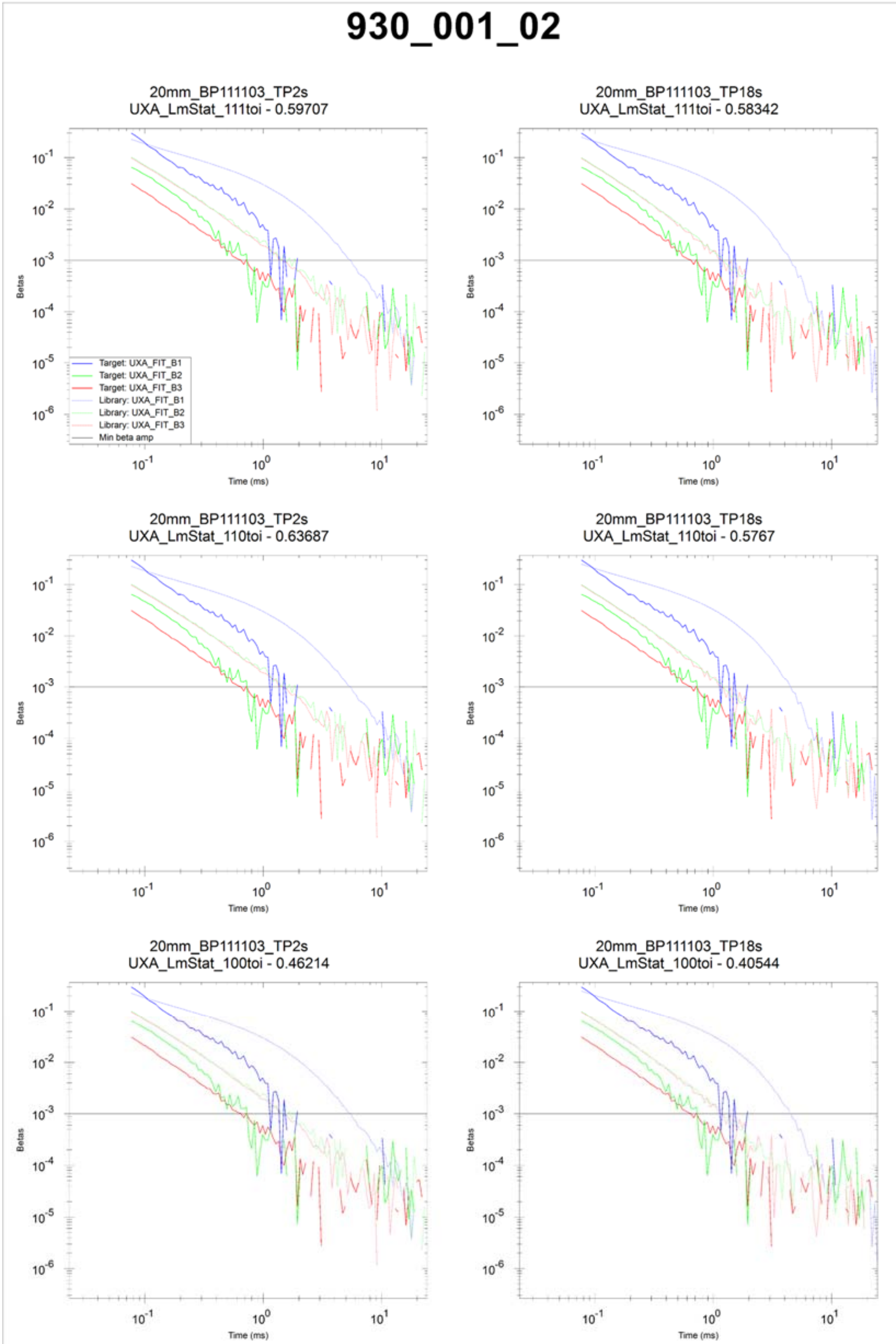


Figure 7-9: Analyst 1 Revised Library Match for Target CR-692

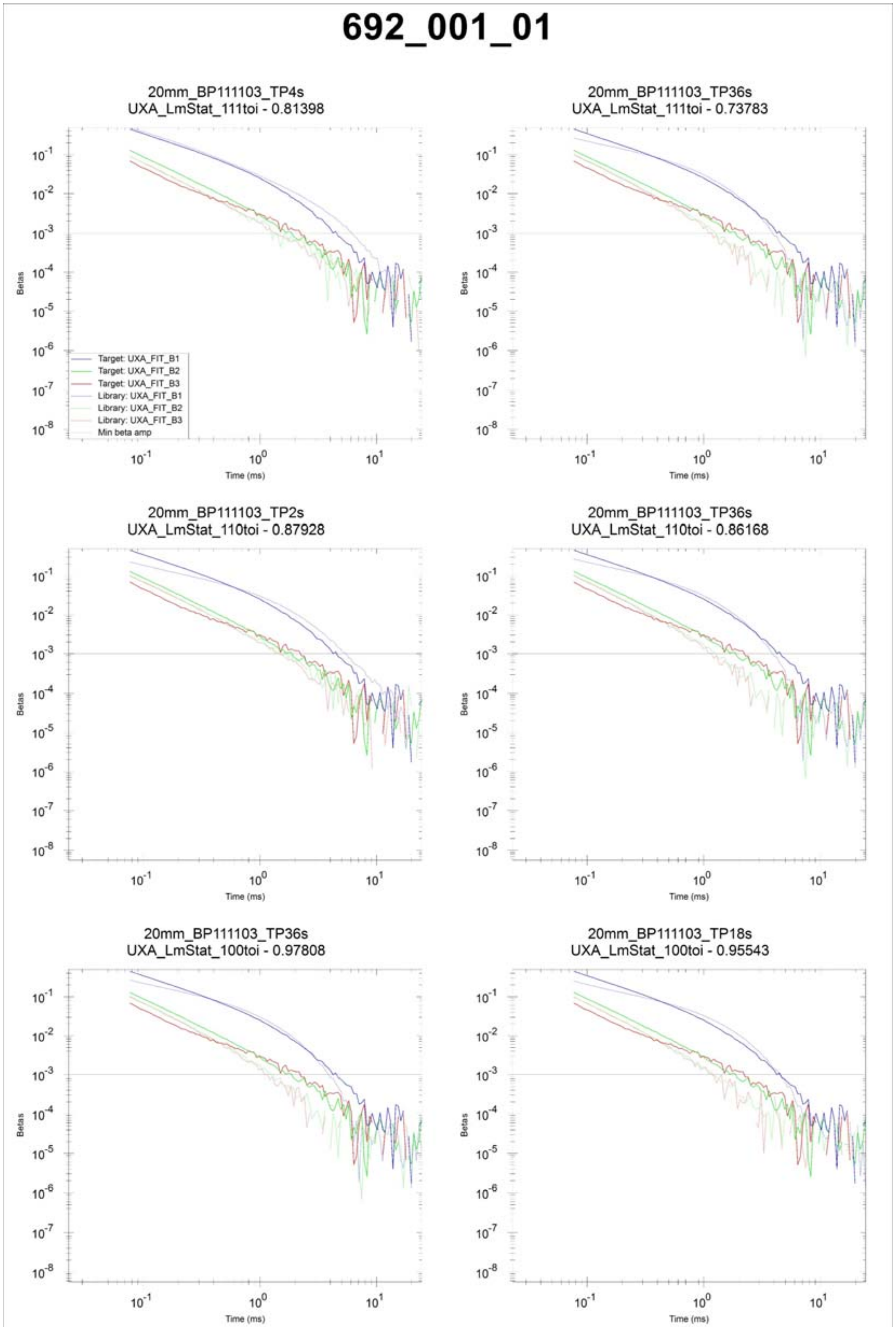


Figure 7-10: Analyst 1 Revised Library Match for Target CR-1089

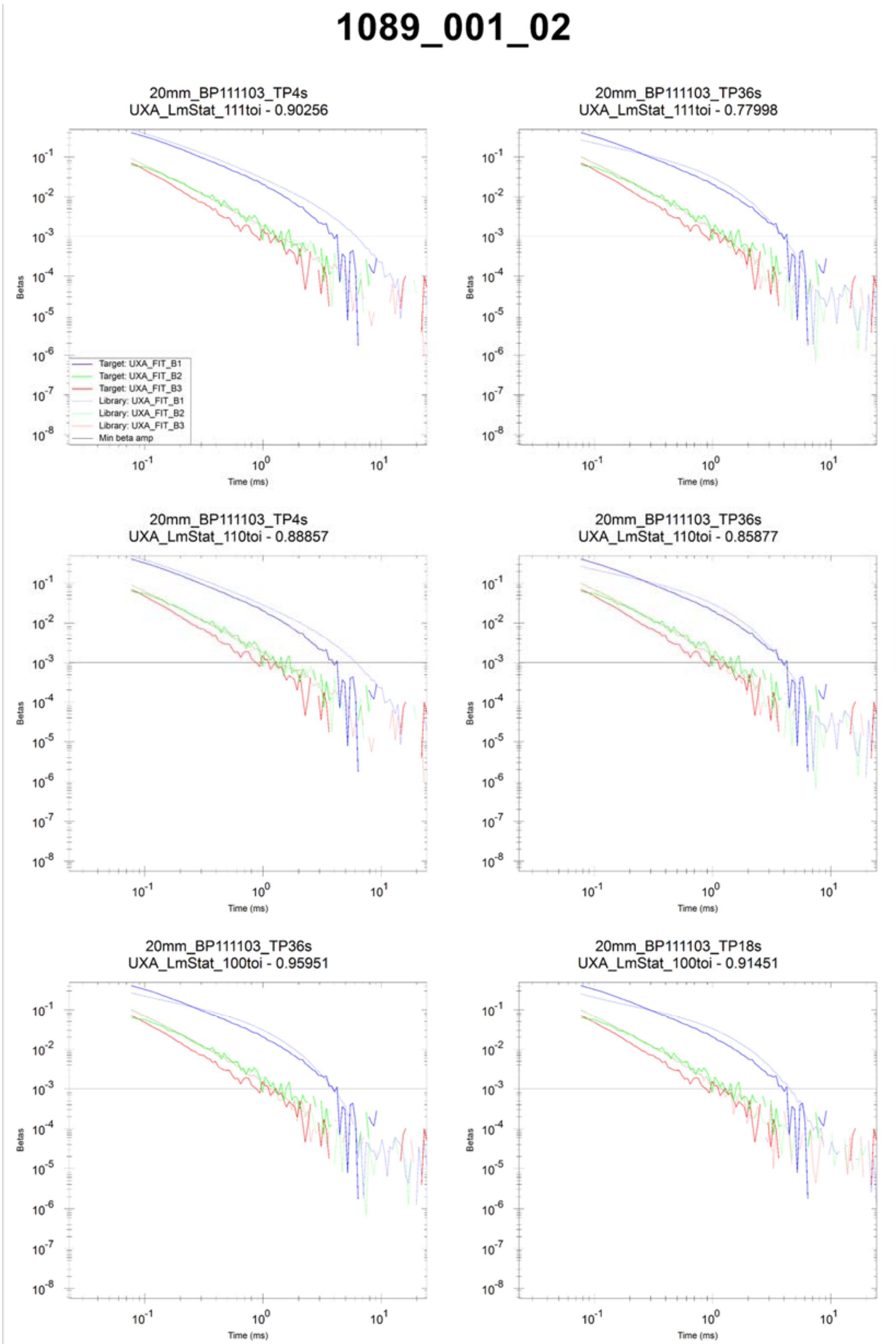


Figure 7-11: Analyst 1 Revised Library Match for Target CR-198

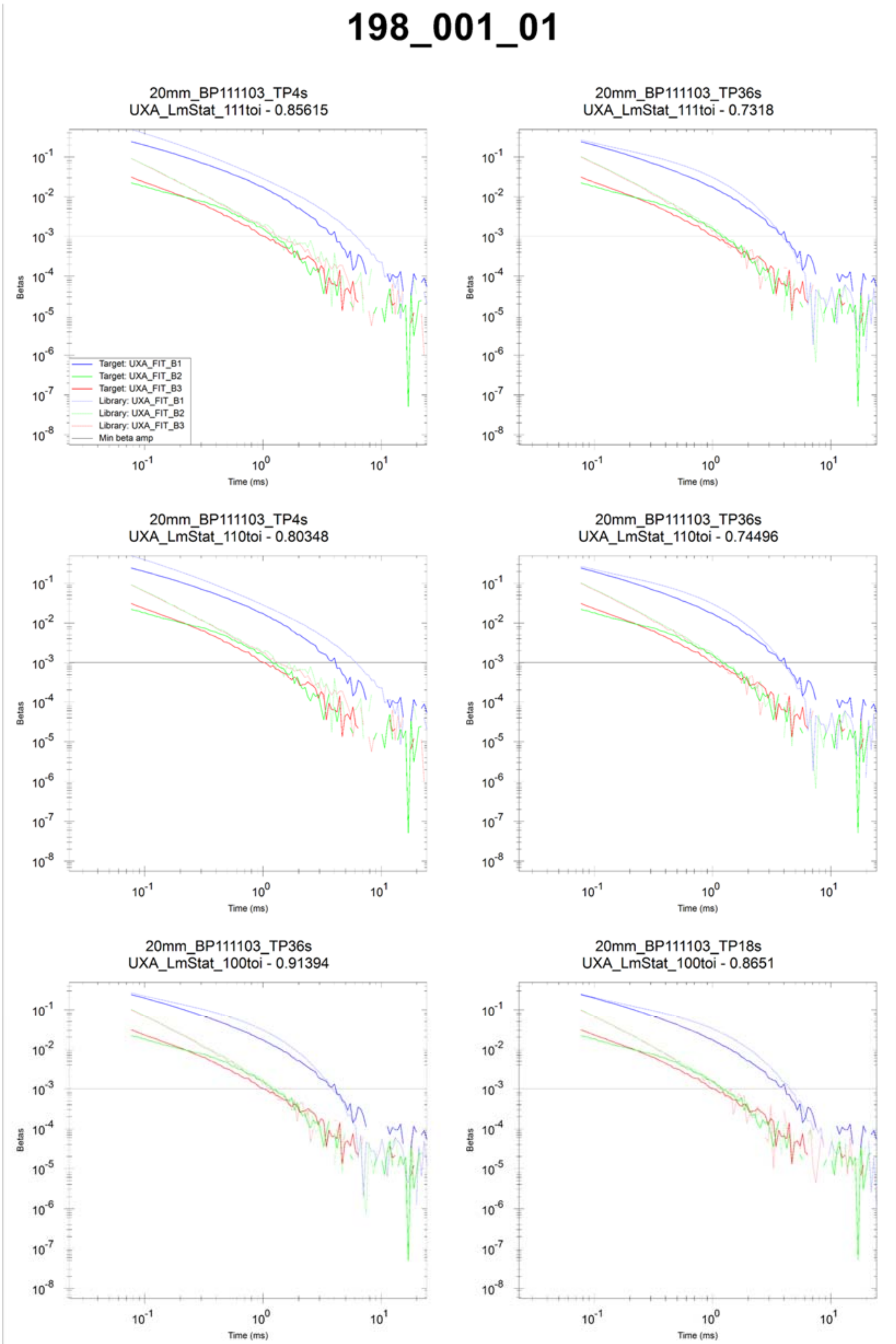


Figure 7-12: Analyst 1 Revised Library Match for Target CR-886

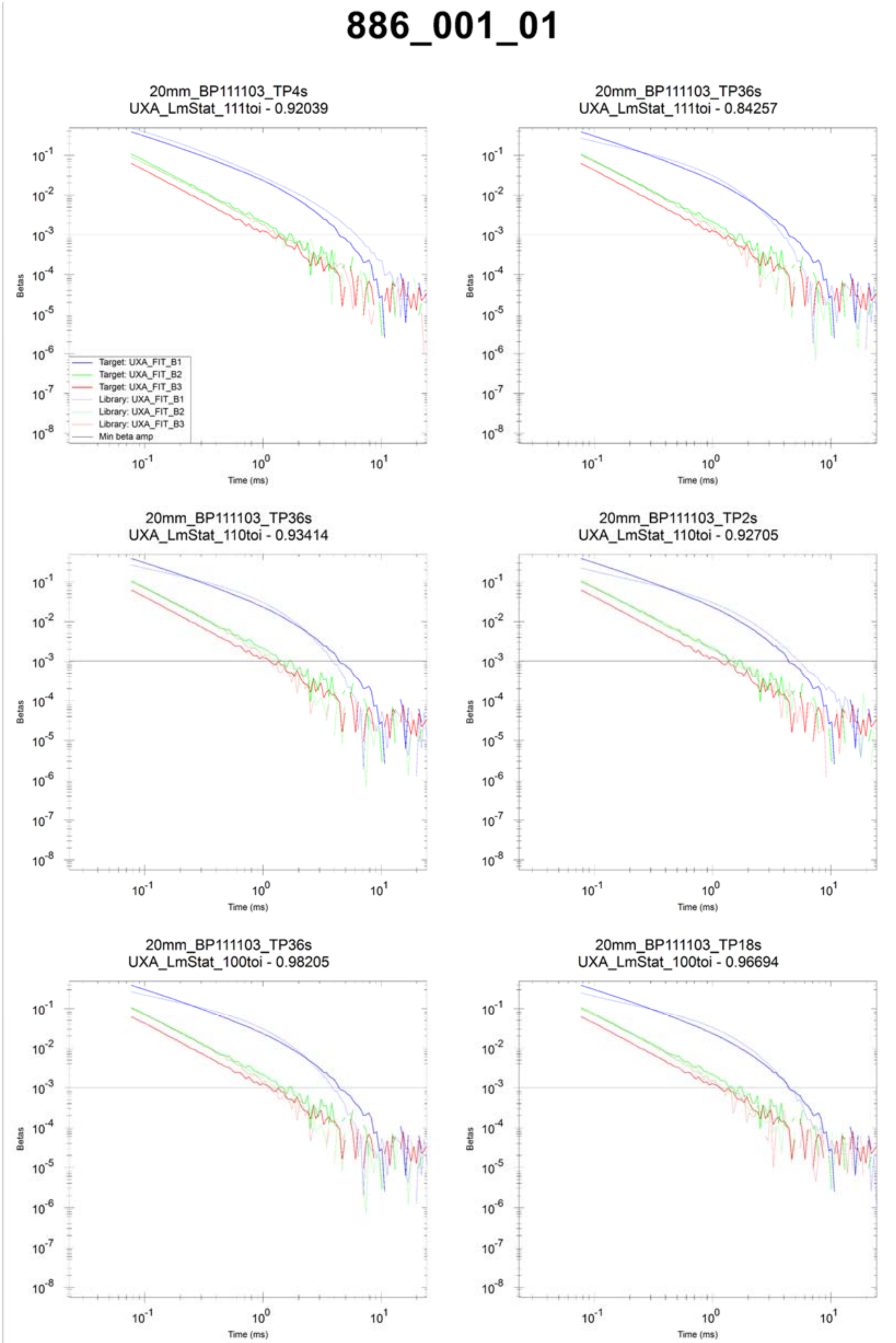
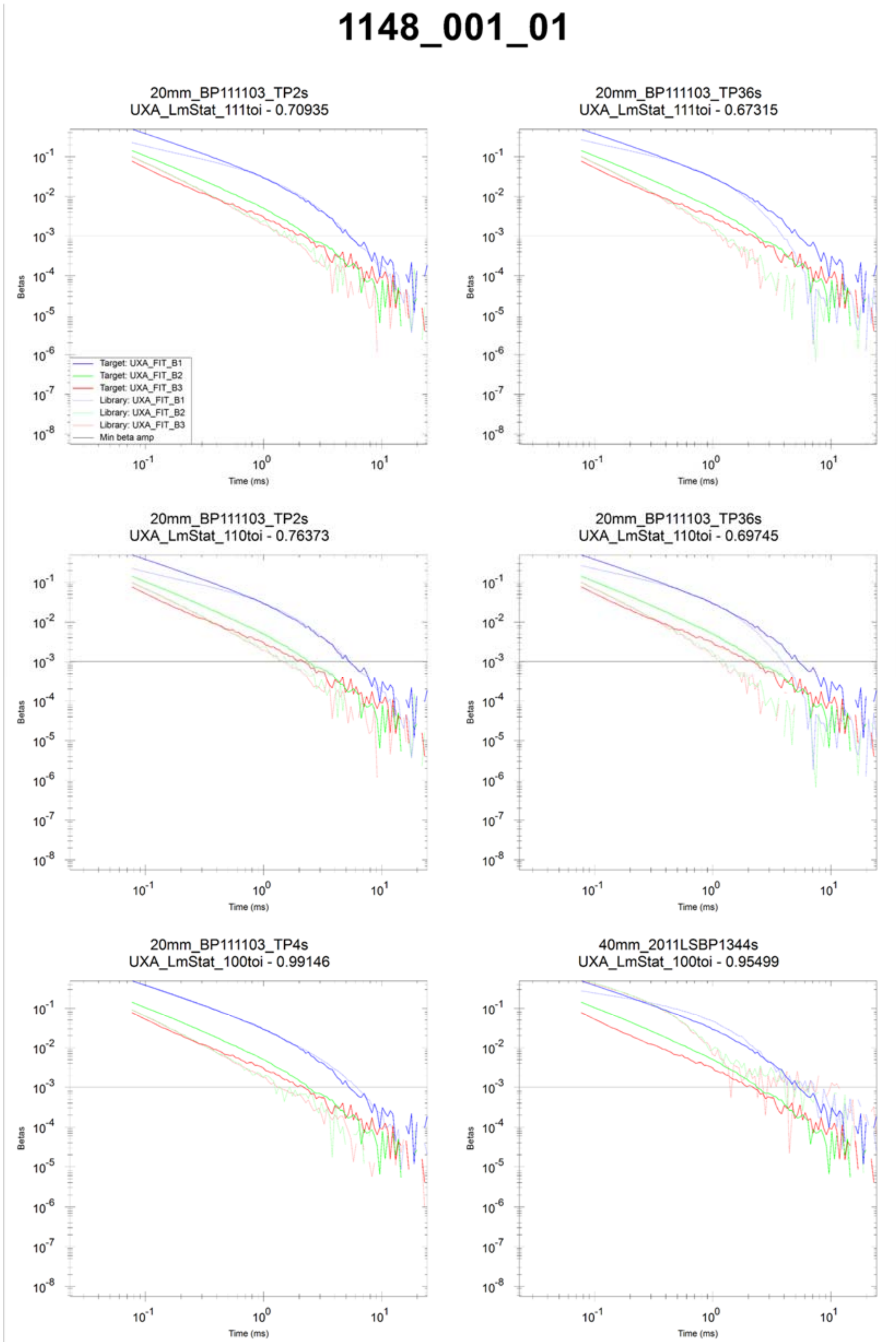


Figure 7-13: Analyst 1 Revised Library Match for Target CR-1148



it should be noted four of the six targets matched best to a 37-mm projectile (the remaining two matched to a steel rifle grenade). A visual inspection of the six recovered items shows that except for the item encountered at target CR-0930 (a 25-mm projectile), all the remaining targets consisted of large remnants of 37-mm projectiles, and as such, were classified as 37-mm MD in the field. However, it was later determined by the site team that these items were close enough to a complete 37-mm projectiles to be considered TOI. Additionally, while 20-mm projectiles were initially included in the field check and validate library versions of the TOI library, after confirming with ESTCP that no 20-mm projectiles were used on the site, they were not included in the final version of the TOI library used to classify and rank the targets prior to submitting the final dig list, to reduce false matches to fragmented clutter. When the six targets in question were re-processed with 20-mm projectile included in the final TOI library, these targets were assigned a revised UXA decision statistic range of 0.72 through 0.94, which now fall within the boundary of Category 1 and 2 targets (decision statistic greater than 0.71), and were all classified as 20-mm projectiles (see the polarization plots below presented as **Figure 7-14** through **Figure 7-19**.

In summary, Analyst 2 incorrectly classified the 6 TOI because they all consisted of incomplete rounds, and that 20-mm projectiles were not included in the final TOI library. Although none of the items recovered were 20-mm projectiles, the 20-mm projectile was their best match.

Table 7-4: Analyst 2 Decision Statistic Comparison

Target ID	Initial AGC Results		Revised AGC	
	Decision Statistic	Best Match	Decision Statistic	Best Match
CR-930	0.6463	37-mm projectile	0.7222	20-mm projectile
CR-662	0.6528	Steel Rifle Grenade	0.8705	20-mm projectile
CR-1089	0.4176	37 mm projectile	0.9119	20-mm projectile
CR-692	0.5568	37-mm projectile	0.8365	20-mm projectile
CR-886	0.6899	Steel Rifle Grenade	0.9360	20-mm projectile
CR-1148	0.7113	37-mm projectile	0.8609	20-mm projectile

Figure 7-14: Analyst 2 Revised Library Match for CR-930

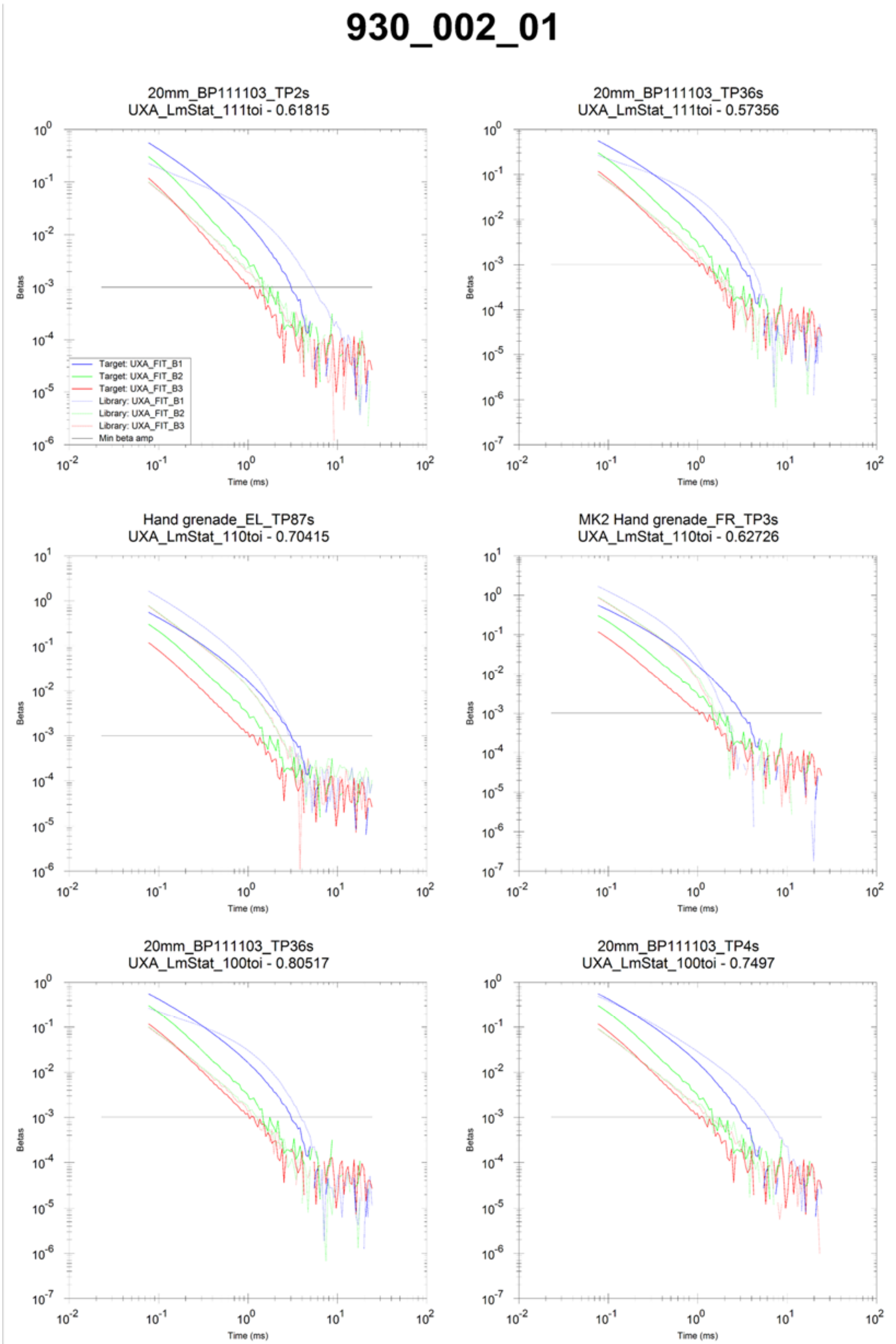


Figure 7-15: Analyst 2 Revised Library Match for CR-662

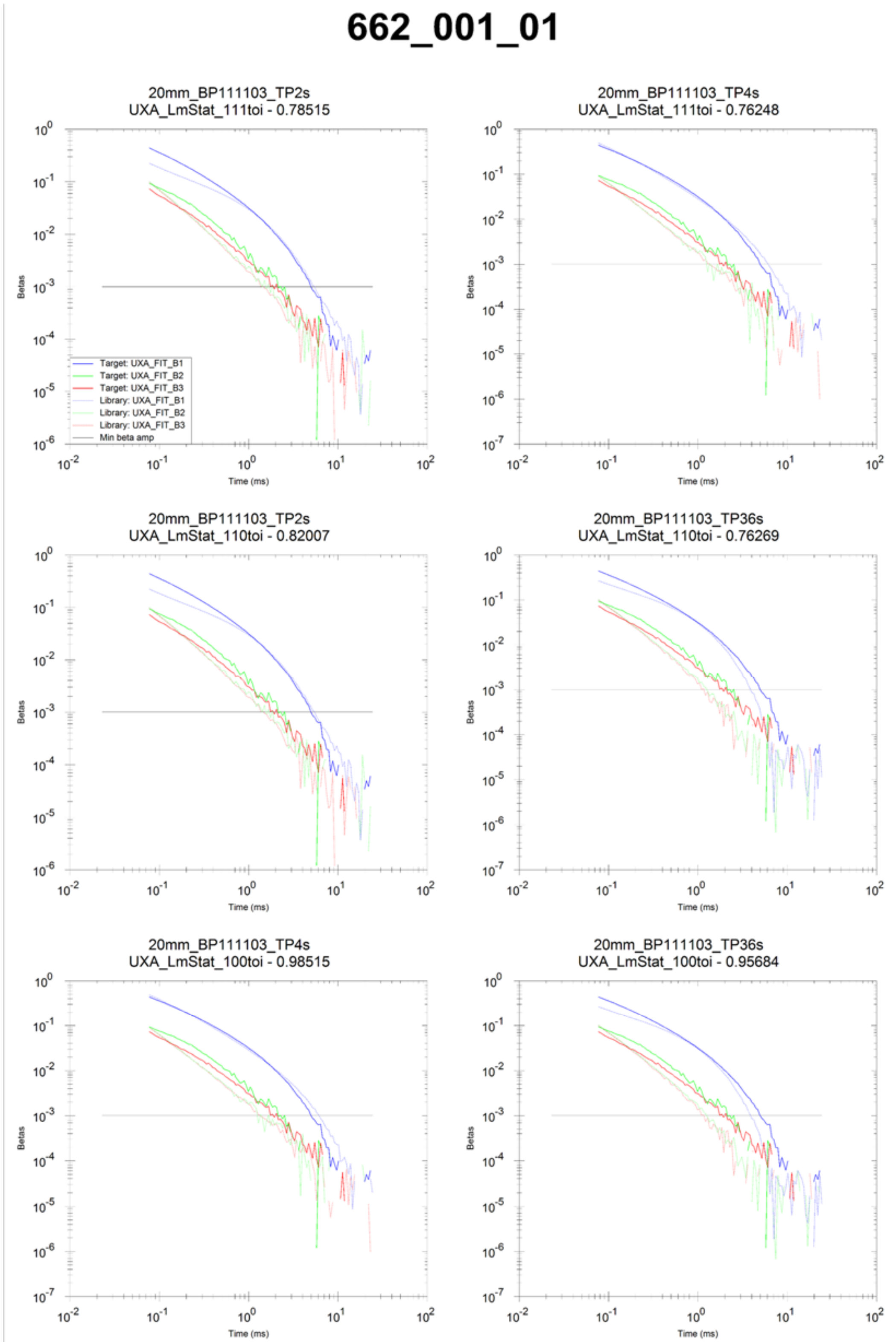


Figure 7-16: Analyst 2 Revised Library Match for CR-1089

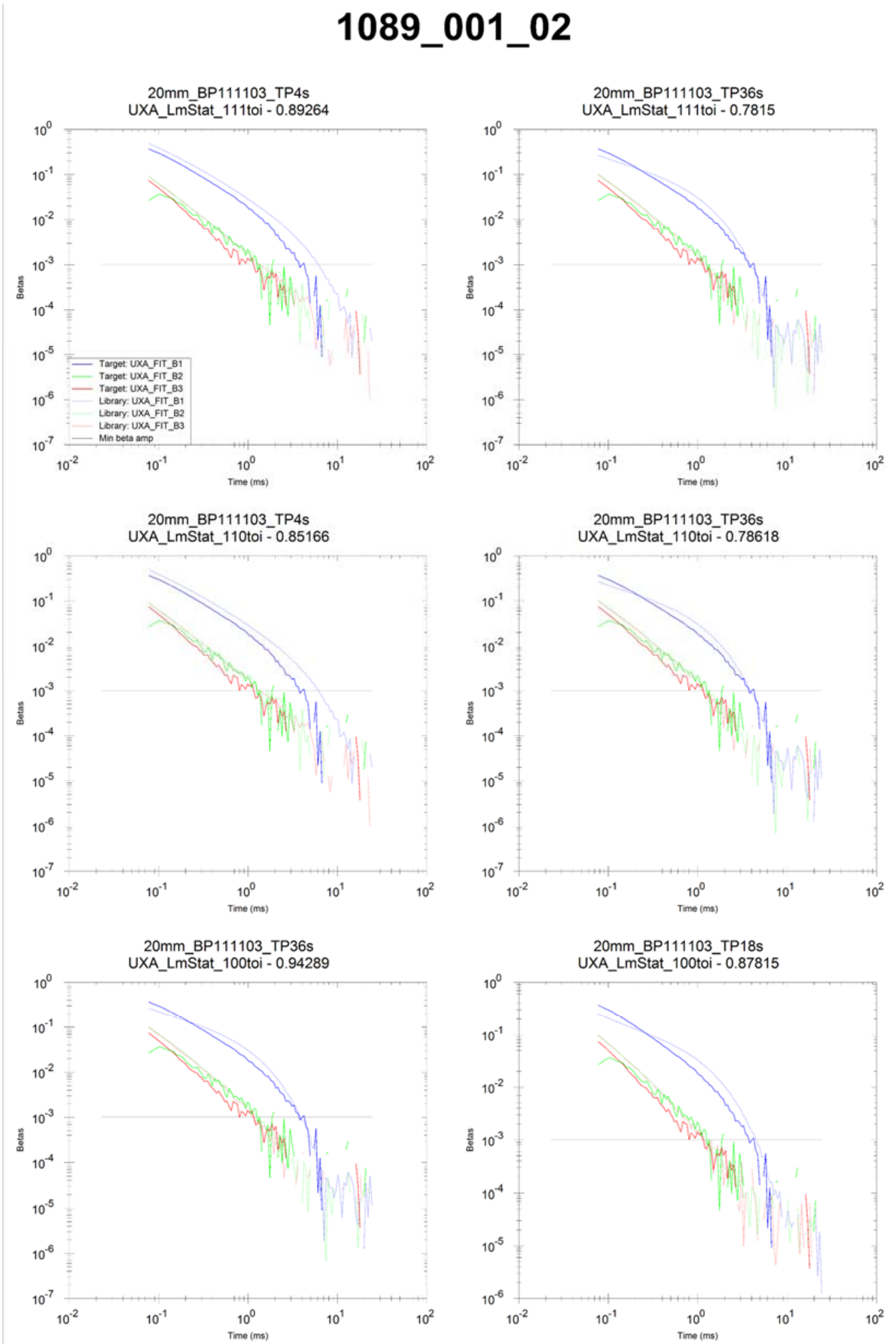


Figure 7-17: Analyst 2 Revised Library Match for CR-692

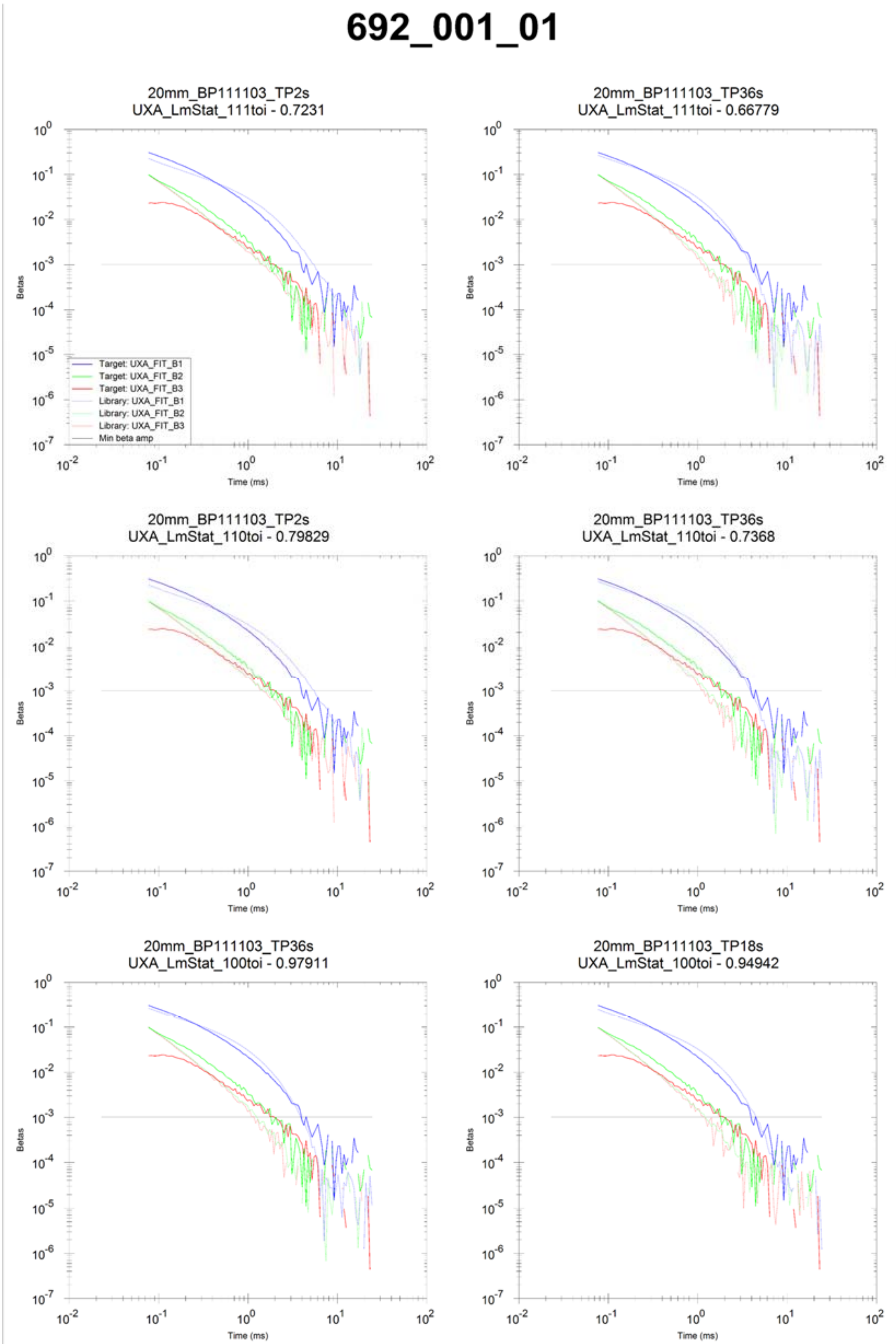


Figure 7-18: Analyst 2 Revised Library Match for CR-886

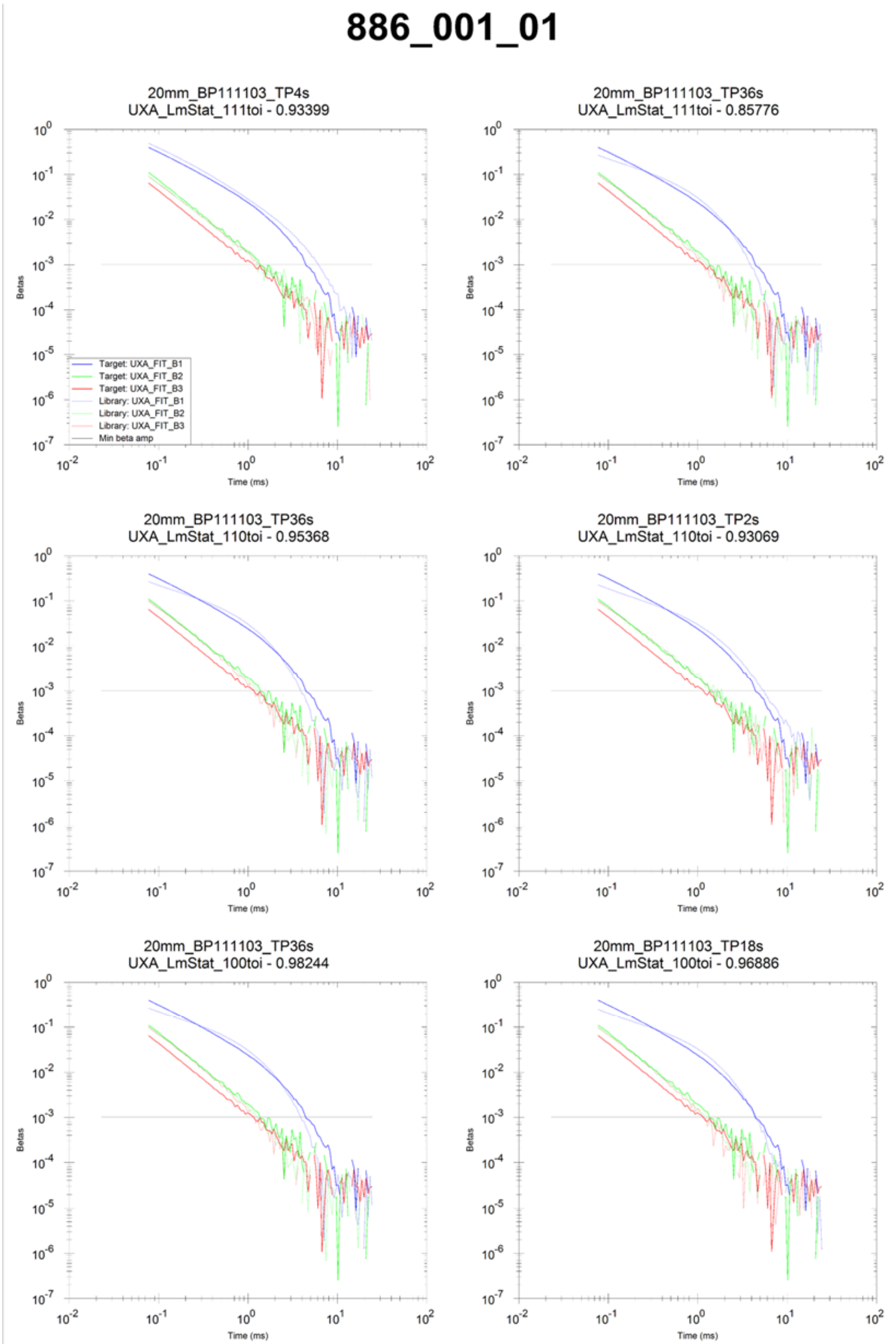
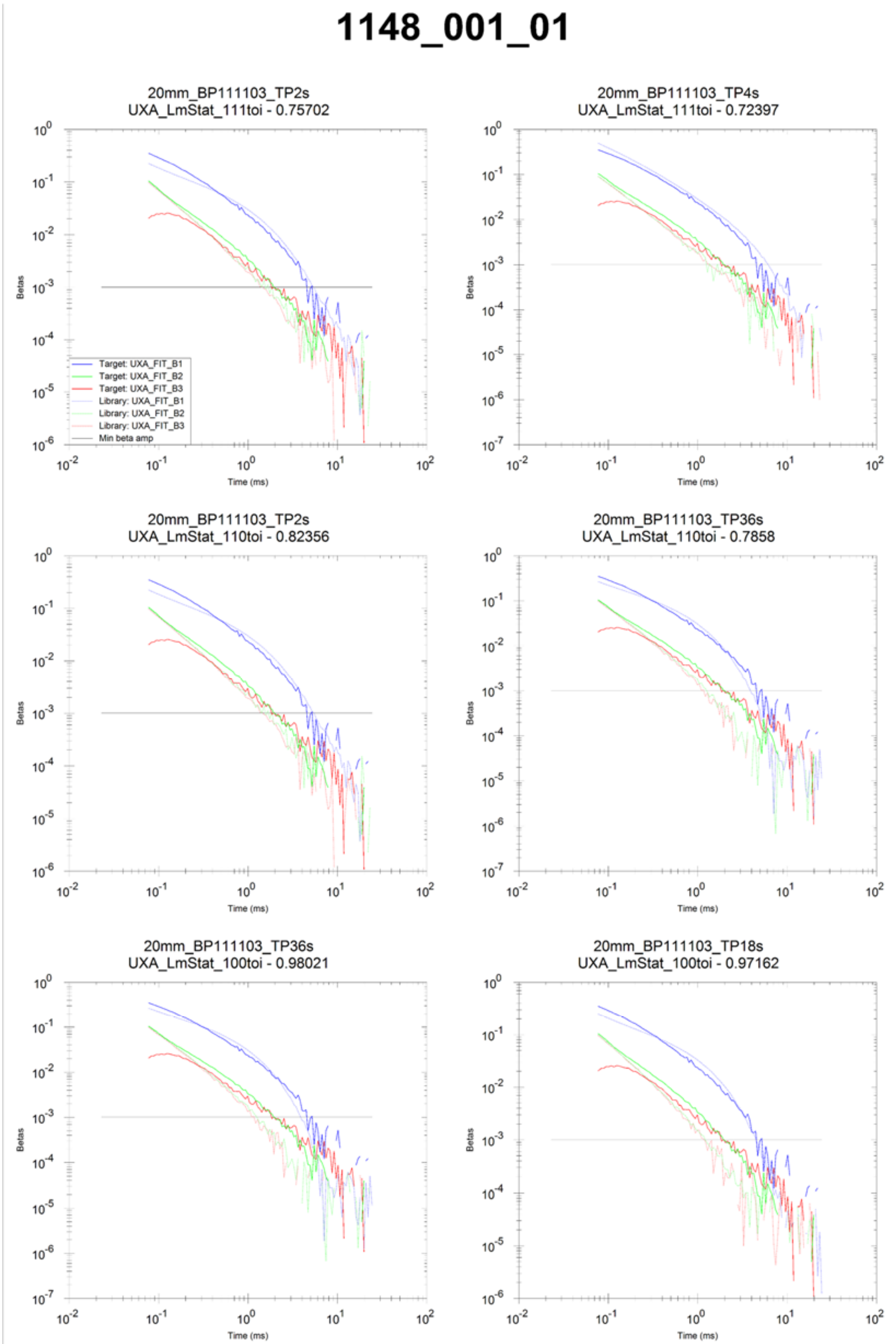


Figure 7-19: Analyst 2 Revised Library Match for CR-1148



8.0 COST ASSESSMENT

This section provides cost information to aid in helping professional involved in MR project to reasonably estimate costs for implementation at a given site. This section is broken down into sub-sections that discuss the cost model, cost drivers, and cost benefit of the various technologies employed at CR at Fort Bliss.

8.1 COST MODEL

Arcadis tracked costs throughout the ESTCP live site demonstration at CR and developed a simple cost model to aid professionals in the field to understand costing implications. The cost model reflects all cost elements that were required to plan, analyze the TEMTADS data, and report on the results. It does not include field activities that were conducted by another contractor. **Table 8-1** presents the cost elements for planning, analyzing the TEMTADS data, and reporting Arcadis' results for the CR live site demonstration. Field tasks were not part of this demonstration; therefore, field costs are not included on **Table 8-1**.

Table 8-1: Details of the Costs Tracked by Arcadis

Cost Element	Data Tracked During Demonstration	Estimated Costs
Project Planning	• Develop project-specific plans: o Demonstration Plan (doesn't include accident prevention plan, explosives siting plan or other plans. • General pre-planning activities	**$6,000**
TEMTADS Data Analysis Costs	For 1,491 anomalies: • Data Processing and QC • Target parameter extraction • Advanced anomaly classification	**Total Cost (1491 anomalies)** • **Analyst 1:** $11,454 (83 hours) • **Analyst 2:** $9,817 (106 hours) **Cost per Anomaly:** • **Analyst 1:** $7.68 • **Analyst 2:** $6.58
Validation Digging	• Target reacquisition • Intrusive investigation • Intrusive results reporting • Post-dig anomaly QC	**Total Cost (1,491 anomalies):** $248,512 **Cost per Anomaly:** $166.4 (estimate from Camp Ellis demonstration)
Final Report	• Develop project-specific final report	**$20,000 (estimated)**

8.2 COST DRIVERS

In general, the intrusive investigation costs are the largest cost drivers on MR projects. Additional cost drivers include the following.

- **Static data collection:** TEMTADS data collection and data processing requires the reacquisition of target locations prior to cued data collection; therefore, it is generally more expensive to collect data than with the MetalMapper.

- **Intrusive investigation cost savings:** The cost savings associated with a reduced number of non-TOI can lead to a large cost savings since the intrusive investigation costs are the largest cost drivers. This demonstration was limited to data processing and analysis and therefore, Arcadis doesn't have the exact costs associated with TEMTADS data collection and intrusive investigation for this particular site. However, Arcadis assumes that performing AGC would have been more cost effective than intrusively investigating all targets at CR if the background data quality was sufficient for performing AGC and the Arcadis analysts correctly classified all targets.

8.3 COST BENEFIT

The primary driver for implementing advanced classification is to reduce the number of non-TOI targets that require intrusive investigation and thereby, decrease the overall costs of DoD's MMRP cost to complete. AGC has been shown to reduce the overall number of non-TOI digs by 60-90% at other sites. Arcadis successfully reduced the number of non-TOI digs by approximately 70% at Pole Mountain, while retaining all the TOI. However, both Arcadis analysts were unable to correctly classify all the TOI at CR; therefore, we were unsuccessful at significantly reducing the number of clutter digs while recovering all the TOI. This was a function of the poor background data quality, as well as the missed TOI (partial 37-mm projectiles and one 25-mm projectile) being most similar in size and shape to 20-mm projectiles and neither analyst including 20-mm projectiles in the TOI list.

9.0 IMPLEMENTATION ISSUES

Arcadis didn't collect the TEMTADS data at the CR MRS at Fort Bliss; therefore, we did not encounter implementation issues associated with data collection. However, based on our analysis of the background data collected by URS, it's apparent that there was significant background variation at individual background locations. This could have been due to there being metallic objects close to the background location and/or the TEMTADS not being placed back on the respective background locations in a consistent manner (e.g., could have been slightly off in location and/or orientation). Due to the background variation, each analyst found it challenging to determine the trade-off point between removing background data and keeping enough background measurements to level the data. Each analyst removed a significant number of background data prior to leveling cued data; however, each then needed to level cued data with background data points that were up to 6 hours from the cued data. More rigorous background QC procedures have been developed and demonstrated on other sites, such as Arcadis' Twentynine Palms Demonstration (Stacy, 2015). These procedures should continue to be used and updated as needed to ensure that high quality background data is collected.

In addition, the ESTCP program office informed Arcadis that 20-mm projectiles were not a TOI on the CR live site; therefore, both analysts removed 20-mm projectiles from the TOI library to minimize the number of small clutter that needed to be dug. No 20-mm projectiles were found, however, the TOI missed by both analysts included a 25-mm projectile and partial 37-mm projectiles that best fit to 20-mm projectiles. In future demonstrations or on production sites, the data analysts should request further information about whether partial projectiles that may not contain an explosive hazard are considered TOI and perform additional analyses to ensure that small non-hazardous MD items considered TOI are recovered.

10.0REFERENCES

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2. ESTCP. September 2012b. ESTCP Live Site Demonstrations Massachusetts Military Reservation Camp Edwards, MA, ESTCP MR -1165 Demonstration Data Report Central Impact Area TEMTADS MP 2x2 Cart Survey.

3. Keiswetter, Dean. February 2009. Description and Features of UX-Analyze, ESTCP Project MetalMapper-0210.

4. Kingdon, James B. et. al. April 2012. TEMTADS Adjust Sensor Systems Hand-Held EMI Sensor for Cued UXO Discrimination (ESTCP MR-200807) and Man-Portable EMI Array for UXO Detection and Discrimination (ESTCP MR-200909) Final Report.

5. OSDA, Technology and Logistics. 2003. *Report of the Defense Science Board Task Force on Unexploded Ordnance*, Washington, DC.

6. Stacy, Stephen. November 2015. ESTCP Live Site Demonstration Munitions Response Program Site UXO 01 at Marine Corps Air Ground Combat Center (MCAGCC) Twentynine Palms, California.

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Appendix A: Points of Contact

QAPP Recipients	Title	Organization	Telephone Number (optional)	E-mail Address or Mailing Address
Dr. Herb Nelson	Executive Director and MR Program Manager	ESTCP	571-372-6400	**ESTCP Program Office** 4800 Mark Center Drive, Suite 17D08, Alexandria, VA 22350-3605 Herbert.h.nelson10.civ@mail.mil
Ms. Kristen Lau	MR Technical Assistant	Noblis, Inc.	703-610-1622	**Noblis** 3150 Fairview Park Drive South Falls Church, VA 22042 Kristen.Lau@Noblis.org
Mr. Steve Stacy	Principal Investigator/Principal Geophysicist (Data Analyst 1)	Arcadis U.S., Inc.	703-465-4234	Arcadis U.S., Inc. 2101 L. St. NW, Suite 200 Washington, DC 20037 Steve.Stacy@arcadis.com
Mr. Gabriel Hebert	Project Geophysicist (Data Analyst 2)	Arcadis U.S., Inc.	317-236-2859	Arcadis U.S., Inc. 132 E. Washington Street, Suite 600 Indianapolis, IN 46204 Gabriel.Hebert@arcadis.com

Appendix B: Ranked Anomaly Lists and Anomaly Selection Memos

MEMO

ARCADIS Design & Consultancy for natural and built assets

SUBJECT: FORT BLISS ESTCP ANOMALY DECISION MEMO

TO
Dr. Herb Nelson

DATE
13 October, 2015

OUR REF

PROJECT NUMBER
04659010

FROM
Steve Stacy

DEPARTMENT
ARCADIS

COPIES TO
Not Applicable

This anomaly decision memo documents the procedures that Arcadis Analyst 1, Steve Stacy, used to develop a ranked anomaly list for the Advanced Geophysical Classification Live Site Demonstration on the Former Castner Range at Fort Bliss. Anomalies were classified using the procedures outlined in SOP MEC-AC-12 that was included as an appendix to the demonstration plan. Each target was analysed using the single source and multi-object solver algorithms in the UX-Analyze advanced module within Oasis montaj. Both intrinsic (size, shape, materials properties) and extrinsic (location, depth, orientation) parameters were estimated in these analyses and a list of the relevant target parameters from each analysis compiled.

ARCADIS Analyst 1 requested two sets of training data. The first training data request included 43 targets and the second training request included 7 targets. After the training data was requested, Arcadis Analyst 1 refined the TOI library and classified each target to produce a ranked target list.

Anomalies were classified into one of the following categories, and a dig/no-dig decision was made on each target:

- Category -1: Training Data
- Category 0: Can't Analyze
- Category 1: TOI (Highly likely to be MEC);
- Category 2: Unsure whether the TOI is TOI or non-TOI; and
- Category 3: Non-TOI (Highly unlikely to be MEC).

Table 1 presents the values that were used to prioritize and rank anomalies. The default values were used for all inputs, except that the minimum size value was changed to -5 to avoid potentially incorrectly classifying small TOI.

The decision statistic within UX-Analyze was used to classify targets as Category 1 through 3 as follows:

- Category 1 targets are those with decision statistics greater than 0.925.
- Category 2 targets were defined as follows:
    - Targets that met all criteria in Table 1 with decision statistics between 0.825 and 0.925,
    - Non-TOI weak targets that had decision statistics above 0.75, and
- Category 3 targets are those with decision statistics below 0.825.

Table 1: Advanced Geophysical Classification Prioritization and Ranking Inputs

Thresholds	Minimum	Maximum
Signal Amplitude	2	100
Fit Depth	NA	2
Decay	0	0.138
Size	-5	3.144
Diff – array position &Inverted Location	NA	0.4
Diff – array position & flag location	NA	0.75
Diff – Flag Location & inverted location	NA	0.6
Fit coherence	0.8	NA
Boundary of buffer and TOI	NA	0.925
Boundary of buffer and non-TOI	NA	0.825
Boundary of buffer and non-TOI weak targets	NA	0.75
High confidence match to clutter	NA	0.925

Can't Analyze anomalies were determined based on one or more of the following criteria:

- There are no polarizabilities because the inversion did not finish;
- The fit depth is unreasonable (e.g,. greater than 2 meter [m] below ground surface [bgs])
- There are negative polarizabilities;
- There is a poor fit coherence (e.g., less than 0.8); and
- Reliable polarizabilities couldn't be extracted (e.g., array center to fit location greater than 0.4m).

The attached ranked anomaly list is ordered from Category -1 through Category 3. The first items on the ranked anomaly list are the targets for which ground truth labels have been requested (training data). Following this, anomalies for which reliable parameters cannot be extracted and therefore must be dug are listed. Next are the items that Arcadis Analyst 1 is the most confident are "highly likely" to be TOI. The items were ranked according to decreasing confidence that the item is TOI (*i.e.*, decreasing decision statistic). Any items that Analyst 1 was able to analyze, but is not able to classify (*i.e.,* category 2 anomalies) are placed next on the anomaly list. Finally, all those items that Analyst 1 is confident are not TOI were classified as Category 3 anomalies and ranked by their decreasing decision statistic.

In addition to the ranking, Analyst 1 provided an assignment to the 'Type' column, indicating the relative size of the type of munition per ESTCP program office requirements.
The stop dig threshold is the boundary between Category 2 and 3 anomalies and was set at a decision statistic of 0.825 for targets that met all criteria and 0.75 for non-TOI weak targets. All anomalies with a Category -1, 0, 1, and 2 ranking were placed above the stop-dig threshold and all Category 3 anomalies were placed below the stop dig threshold.

Data was collected more than once for numerous anomaly locations. Because only one decision is required for each anomaly, Analyst 1 included only the ranking that corresponds to the most hazardous item (i.e., the item with the highest decision statistic).

If requested, Analyst 1 can provide the preliminary database of anomaly classifications to the ESTCP program office.

If you have any questions, please contact Mr. Stacy at 703-465-4234 or via e-mail at steve.stacy@arcadis.com.

Thank you,
Steve Stacy
Principal Geophysicist

Enc. FtBliss_ARCADIS1_LibMatch_None_2x2_None_s1_v1.csv

MEMO

ARCADIS Design & Consultancy for natural and built assets

SUBJECT: FORT BLISS ESTCP – MISSED QC SEED FAILURE FOR ANOMALY CR-0780

DATE
21 October, 2015

FROM
Gabriel Hebert

DEPARTMENT
ARCADIS

TO
Dr. Herb Nelson

OUR REF

PROJECT NUMBER
04659010

COPIES TO
Not Applicable

Introduction

This technical memorandum serves as a Failure Analysis for the TEMTADS 2x2 (TEM) dig list submitted by Arcadis Analyst 2 (Gabriel Hebert) to the Environmental Securities Technology Certification Program (ESTCP) for the Fort Bliss Site. Arcadis Analyst 2 initially submitted a dig list to ESTCP using the procedures outlined in SOP MEC-AC-12 that was included as an appendix to the demonstration plan. Each target was analysed using the single source and multi-object solver algorithms in the UX-Analyze advanced module within Oasis montaj. Both intrinsic (size, shape, materials properties) and extrinsic (location, depth, orientation) parameters were estimated in these analyses and a list of the relevant target parameters from each analysis compiled.

Prior to submitting the dig list, Arcadis Analyst 2 requested two sets of training data. The first training data request included 25 targets and the second training request included 3 targets. After the training data was requested, Arcadis Analyst 2 refined the TOI library and classified each target to produce a ranked target list. However, after the TEM dig list was submitted, Arcadis Analyst 2 was informed that a failure memo containing a root cause analysis and a revised dig list should be generated, due to a failure to correctly mark a seed item (CR-0780) for intrusive investigation. This memo documents the failure analysis and the changes made to the TEM dig list that is attached to this memo.

Failure Analysis

ESTCP informed Arcadis Analyst 2 that anomaly CR-0780 included one of the small industry standard object (ISO) quality control (QC) seeds buried at the site, and that it was incorrectly not marked for excavation. **Figure 1** shows the dig results for CR-0780. In addition to the seed item, a M48 series fuse component was also identified at the location of CR-0780 (see **Figure 1**).

For reference, in the original TEM dig list (FtBliss_ARCADIS2_LIBMatch_None_2x2_None_s1_v1.csv) the decision statistics within UX-Analyze was used to classify targets as Category 1 through 3 as follows:

- Category 1 targets are those with decision statistics greater than 0.925.
- Category 2 targets are those with decision statistics between 0.925 and 0.71.
- Category 3 targets are those with decision statistics below 0.71.

Can't Analyze anomalies were determined based on one or more of the following criteria:

- There are no polarizabilities because the inversion did not finish;
- The fit depth is unreasonable (e.g,. greater than 2 meter [m] below ground surface [bgs])

- There are negative polarizabilities;
- There is a poor fit coherence (e.g., less than 0.8); and
- Reliable polarizabilities couldn't be extracted (e.g., array center to fit location greater than 0.4m).

In the original TEM dig list, target CR-0780 was assigned a decision statistic of 0.63, and was as such, classified as a Category 3 target. Aside from the obvious reason for misidentifying the seed item present at target location CR-0780 (a significant piece of munitions debris located in immediate proximity to the seed item), upon further inspection, it was determined that target CR-0780 was initially corrected using a noisier than average background location. Additionally, during the root cause analysis and background inspection process, two additional "bad" background locations were identified. In total, 165 targets had been processed using the three background locations in question. As such, these 165 targets were re-processed with the three background locations removed from the list background readings. After this process, CR-0780 was assigned a revised decision statistic of 0.79, which now falls well within the boundary of Category 2 targets (decision statistic between 0.92 and 0.71). At this point, the re-processed targets (including CR-0780) were merged with original targets and then re-classified and ranked.

Conclusions

The failure to correctly classify anomaly CR-0780 as a TOI was due to improper processing due to a bad background location, and the adjacent presence of a significant piece of munitions debris, both of which led to a poor match to known TOI within the library.

If you have any questions, please contact Mr. Hebert at 317-694-3727 or via e-mail at gabriel.hebert@arcadis.com.

Thank you,
Gabriel Hebert
Project Geophysical Specialist

Figure 1: Anomaly CR-0780 Dig Results

ESTCP Classification Demonstration Ranked Anomaly List

Site	FtBliss
Analyst	Arcadis1
Method	LibMatch
Dynamic D	None
Cued Data	2x2
Training Se	Custom
Stage	2
Version	2

List all anomalies in both Training and Test Sets:
Include prefixes in Target ID column (for example: BE-138). Data in all other columns should be numerical (no text

Target ID:	Category:	Dig	TOI Size
CR-1246	-1	1	
CR-0046	-1	1	
CR-0069	-1	1	
CR-0110	-1	1	
CR-0140	-1	1	
CR-0218	-1	1	
CR-0242	-1	1	
CR-0244	-1	1	
CR-0444	-1	1	
CR-0453	-1	1	
CR-0459	-1	1	
CR-0474	-1	1	
CR-0520	-1	1	
CR-0546	-1	1	
CR-0560	-1	1	
CR-0589	-1	1	
CR-0613	-1	1	
CR-0639	-1	1	
CR-0657	-1	1	
CR-0686	-1	1	
CR-0757	-1	1	
CR-0780	-1	1	
CR-0811	-1	1	
CR-0901	-1	1	
CR-0904	-1	1	
CR-0915	-1	1	
CR-0923	-1	1	
CR-0970	-1	1	
CR-0977	-1	1	
CR-0993	-1	1	
CR-0995	-1	1	
CR-1011	-1	1	
CR-1059	-1	1	
CR-1120	-1	1	

CR-1160	-1	1
CR-1200	-1	1
CR-1212	-1	1
CR-1223	-1	1
CR-1254	-1	1
CR-1271	-1	1
CR-1284	-1	1
CR-1306	-1	1
CR-1323	-1	1
CR-1324	-1	1
CR-1347	-1	1
CR-1365	-1	1
CR-1396	-1	1
CR-1417	-1	1
CR-1418	-1	1
CR-1421	-1	1
CR-1492	-1	1
CR-0023	0	1
CR-0025	0	1
CR-0033	0	1
CR-0043	0	1
CR-0052	0	1
CR-0054	0	1
CR-0083	0	1
CR-0106	0	1
CR-0113	0	1
CR-0114	0	1
CR-0117	0	1
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CR-0162	0	1
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CR-0467	0	1

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CR-0729	0	1
CR-0733	0	1
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CR-0172	1	1	1
CR-0375	1	1	1
CR-0038	1	1	1
CR-1209	1	1	1
CR-0243	1	1	1
CR-0508	1	1	1
CR-1422	1	1	1
CR-0251	1	1	2
CR-0909	1	1	2
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CR-0446	1	1	1
CR-1198	1	1	2
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CR-0986	1	1	2
CR-0372	1	1	2
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CR-0581	1	1	1
CR-0584	1	1	2
CR-0460	1	1	1
CR-0561	1	1	1
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CR-1024	2	1	2
CR-0879	2	1	1
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CR-1336	2	1	1
CR-0539	2	1	2
CR-0913	2	1	1
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CR-0482	2	1	2
CR-1221	2	1	1
CR-1019	2	1	1
CR-1269	2	1	2
CR-0768	2	1	1
CR-1309	2	1	1
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CR-0748	2	1	2
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ESTCP Classification Demonstration Ranked Anomaly List

Site	FtBliss
Analyst	ARCADIS2
Method	LIBMatch
Dynamic D	None
Cued Data	2x2
Training Se	Custom
Stage	3
Version	1

List all anomalies in both Training and Test Sets:

Include prefixes in Target ID column (for example: BE-138). Data in all other columns should be numerical (no text

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