AD NO. _____
DTC PROJECT NO. 8-CO-160-UXO-021
REPORT NO. ATC-9694

STANDARDIZED

UXO TECHNOLOGY DEMONSTRATION SITE

BLIND GRID SCORING RECORD NO. 895

SITE LOCATION:
U.S. ARMY YUMA PROVING GROUND

DEMONSTRATOR:
G&G SCIENCE, INC.
873 23 ROAD
GRAND JUNCTION, CO 81505

TECHNOLOGY TYPE/PLATFORM:
ADVANCED ORDNANCE LOCATOR (AOL)
DUAL MODE/TOWED

PREPARED BY:
U.S. ARMY ABERDEEN TEST CENTER
ABERDEEN PROVING GROUND, MD 21005-5059

JUNE 2008

Prepared for:
U.S. ARMY ENVIRONMENTAL COMMAND
ABERDEEN PROVING GROUND, MD 21010-5401

U.S. ARMY DEVELOPMENTAL TEST COMMAND
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TEDT-AT-SLE

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2. I, the undersigned, am aware of the intelligence interest in open source publications and in the subject matter of the information I have reviewed for intelligence purposes. I certify that I have sufficient technical expertise in the subject matter of this scoring record and that, to the best of my knowledge, the net benefit of this public release outweighs the potential damage to the essential secrecy of all related ATC, DTC, ATEC, Army or other DOD programs of which I am aware.

Dennis Teefy		June 2008
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14. ABSTRACT

This scoring record documents the efforts of G & G Science, Inc. to detect and discriminate inert unexploded ordnance (UXO) utilizing the YPG Standardized UXO Technology Demonstration Site Blind Grid. This Scoring Record was coordinated by William Burch and the Standardized UXO Technology Demonstration Site Scoring Committee. Organizations on the committee include the U.S. Army Corps of Engineers, the Environmental Security Technology Certification Program, the Strategic Environmental Research and Development Program, the Institute for Defense Analysis, the U.S. Army Environmental Command, and the U.S. Army Aberdeen Test Center.

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SECTION 1. GENERAL INFORMATION

1.1 BACKGROUND

Technologies under development for the detection and discrimination of unexploded ordnance (UXO) require testing so that their performance can be characterized. To that end, Standardized Test Sites have been developed at U.S. Army Aberdeen Proving Ground (APG), Maryland, and U.S. Army Yuma Proving Ground (YPG), Arizona. These test sites provide a diversity of geology, climate, terrain, and weather as well as diversity in ordnance and clutter. Testing at these sites is independently administered and analyzed by the government for the purposes of characterizing technologies, tracking performance with system development, comparing performance of different systems, and comparing performance in different environments.

The Standardized UXO Technology Demonstration Site Program is a multiagency program spearheaded by the U.S. Army Environmental Command (USAEC). The U.S. Army Aberdeen Test Center (ATC) and the U.S. Army Corps of Engineers Engineer Research and Development Center (ERDC) provide programmatic support. The program is being funded and supported by the Environmental Security Technology Certification Program (ESTCP), the Strategic Environmental Research and Development Program (SERDP) and the Army Environmental Quality Technology Program (EQT).

1.2 SCORING OBJECTIVES

The objective in the Standardized UXO Technology Demonstration Site Program is to evaluate the detection and discrimination capabilities of a given technology under various field and soil conditions. Inert munitions and clutter items are positioned in various orientations and depths in the ground.

The evaluation objectives are as follows:

a. To determine detection and discrimination effectiveness under realistic scenarios that vary targets, geology, clutter, topography, and vegetation.

b. To determine cost, time, and manpower requirements to operate the technology.

c. To determine demonstrator's ability to analyze survey data in a timely manner and provide prioritized "Target Lists" with associated confidence levels.

d. To provide independent site management to enable the collection of high quality, ground-truth, geo-referenced data for post-demonstration analysis.

1.2.1 Scoring Methodology

a. The scoring of the demonstrator's performance is conducted in two stages. These two stages are termed the RESPONSE STAGE and DISCRIMINATION STAGE. For both stages, the probability of detection (P_d) and the false alarms are reported as receiver-operating

characteristic (ROC) curves. False alarms are divided into those anomalies that correspond to emplaced clutter items, measuring the probability of false positive (P_{fp}), and those that do not correspond to any known item, termed background alarms.

b. The RESPONSE STAGE scoring evaluates the ability of the system to detect emplaced targets without regard to ability to discriminate ordnance from other anomalies. For the blind grid RESPONSE STAGE, the demonstrator provides the scoring committee with a target response from each and every grid square along with a noise level below which target responses are deemed insufficient to warrant further investigation. This list is generated with minimal processing and, since a value is provided for every grid square, will include signals both above and below the system noise level.

c. The DISCRIMINATION STAGE evaluates the demonstrator's ability to correctly identify ordnance as such and to reject clutter. For the blind grid DISCRIMINATION STAGE, the demonstrator provides the scoring committee with the output of the algorithms applied in the discrimination-stage processing for each grid square. The values in this list are prioritized based on the demonstrator's determination that a grid square is likely to contain ordnance. Thus, higher output values are indicative of higher confidence that an ordnance item is present at the specified location. For digital signal processing, priority ranking is based on algorithm output. For other discrimination approaches, priority ranking is based on human (subjective) judgment. The demonstrator also specifies the threshold in the prioritized ranking that provides optimum performance, (i.e. that is expected to retain all detected ordnance and rejects the maximum amount of clutter).

d. The demonstrator is also scored on EFFICIENCY and REJECTION RATIO, which measures the effectiveness of the discrimination stage processing. The goal of discrimination is to retain the greatest number of ordnance detections from the anomaly list, while rejecting the maximum number of anomalies arising from non-ordnance items. EFFICIENCY measures the fraction of detected ordnance retained after discrimination, while the REJECTION RATIO measures the fraction of false alarms rejected. Both measures are defined relative to performance at the demonstrator-supplied level below which all responses are considered noise, i.e., the maximum ordnance detectable by the sensor and its accompanying false positive rate or background alarm rate.

e. All scoring factors are generated utilizing the Standardized UXO Probability and Plot Program, version 3.1.1.

1.2.2 Scoring Factors

Factors to be measured and evaluated as part of this demonstration include:

a. Response Stage ROC curves:

(1) Probability of Detection (P_d^{res}).

(2) Probability of False Positive (P_{fp}^{res}).

(3) Background Alarm Rate (BAR^{res}) or Probability of Background Alarm (P_{BA}^{res}).

b. Discrimination Stage ROC curves:

(1) Probability of Detection (P_d^{disc}).

(2) Probability of False Positive (P_{fp}^{disc}).

(3) Background Alarm Rate (BAR^{disc}) or Probability of Background Alarm (P_{BA}^{disc}).

c. Metrics:

(1) Efficiency (E).

(2) False Positive Rejection Rate (R_{fp}).

(3) Background Alarm Rejection Rate (R_{BA}).

d. Other:

(1) Probability of Detection by Size and Depth.

(2) Classification by type (i.e., 20-mm, 40-mm, 105-mm, etc.).

(3) Location accuracy.

(4) Equipment setup, calibration time and corresponding man-hour requirements.

(5) Survey time and corresponding man-hour requirements.

(6) Reacquisition/resurvey time and man-hour requirements (if any).

(7) Downtime due to system malfunctions and maintenance requirements.

1.3 STANDARD AND NONSTANDARD INERT ORDNANCE TARGETS

The standard and nonstandard ordnance items emplaced in the test areas are listed in Table 1. Standardized targets are members of a set of specific ordnance items that have identical properties to all other items in the set (caliber, configuration, size, weight, aspect ratio, material, filler, magnetic remanence, and nomenclature). Nonstandard targets are ordnance items having properties that differ from those in the set of standardized targets.

TABLE 1. INERT ORDNANCE TARGETS

Standard Type	Nonstandard (NS)
20-mm Projectile M55	20-mm Projectile M55
	20-mm Projectile M97
40-mm Grenades M385	40-mm Grenades M385
40-mm Projectile MKII Bodies	40-mm Projectile M813
BDU-28 Submunition	
BLU-26 Submunition	
M42 Submunition	
57-mm Projectile APC M86	
60-mm Mortar M49A3	60-mm Mortar (JPG)
	60-mm Mortar M49
2.75-inch Rocket M230	2.75-inch Rocket M230
	2.75-inch Rocket XM229
MK 118 ROCKEYE	
81-mm Mortar M374	81-mm Mortar (JPG)
	81-mm Mortar M374
105-mm HEAT Rounds M456	
105-mm Projectile M60	105-mm Projectile M60
155-mm Projectile M483A1	155-mm Projectile M483A
	500-lb Bomb
	M75 Submunition

JPG = Jefferson Proving Ground.
HEAT = high-explosive antitank.

SECTION 2. DEMONSTRATION

2.1 DEMONSTRATOR INFORMATION

2.1.1 System Description (provided by demonstrator)

Under development since 2003, the Advanced Ordnance Locator (AOL) system is a dual-mode (EM/Mag) system for UXO detection and characterization. The prototype AOL system was developed under contract to Naval Explosive Ordnance Disposal Technology Division (NAVEODTECHDIV) (Indian Head) by Blackhawk GeoServices (now Zapata Blackhawk) with Geometrics and G&G Sciences acting as subcontractor. In 2006, G&G Sciences received a follow-on contract to continue the development of AOL system. As a platform for electromagnetic interference (EMI) research, the AOL2 system is unique and innovative in several respects:

a. Multiple Transmitter Loops1. The AOL2 antenna platform includes 3 mutually orthogonal transmitter loops.

b. 3-Axis Sensor Array2. The AOL2 antenna platform includes a spatial array of 9 3-axis receiver antennas (27 independent measurements of the secondary magnetic field).

c. Electronically Switched TEM Transmitter Loop Driver. The AOL2 system is unique in its ability to drive its transmitter loop array. Under control of the data acquisition (DAQ) computer, the output of the transmitter can be directed to any single loop or automatically multiplexed between loops. There is also control of the fundamental waveform period, dutycycle, and pulse polarity. Typically, however, the loops are driven with a classical bipolar pulse type TEM waveform (i.e., alternating pulse polarity with a 50 percent duty-cycle. Depending on the survey mode (e.g., Static/Dynamic), the fundamental frequency of transmission can be varied from a low of $1.11 < f < 810$ Hz.

Figure 1. Demonstrator's system, AOL dual mode/towed.

2.1.2 Data Processing Description (provided by demonstrator)

AOL2 Data Process Description, Acquisition Modes. The AOL2 system is, by design, a very flexible system for acquisition of time domain electromagnetic (EM) (TEM) data. It is beyond the scope of this document to fully describe that flexibility. Simply stated, data are acquired in time blocks that consist of a fixed number of transmitter cycle Repeats. Both the period (T) and the repeat factor (N) are operator selectable and are varied in multiplicative factors of 3.3. It has two data acquisition modes:

a. Static-Mode Acquisition. In this mode, data sampled transients from each of the 27 receiver loops plus a channel to sense the transmitter loop current are rectified and stacked for a specified number of acquisition blocks. The resulting transients are (optionally) decimated into a set of logarithmically spaced time gates after which they are stored to a single binary data file. As its name implies, static-mode acquisition is used to obtain precise data while the antenna platform is parked at a single spatial data point.

b. Continuous-Mode Acquisition. As its name implies, continuous-mode data acquisition results in the data acquisition cycle being repeated until the operator intervenes to halt it. Each of the "Data Points" are appended to a single binary data file and thus the resulting data file may consists of tens or even hundreds of data points. This mode is used for dynamic surveying. Typically, a data file consists of all the points acquired along a single profile. Regardless of the acquisition mode, the TEM data thus acquired includes the most current Global Positioning System (GPS) position and the platform attitude angles (magnetic heading, pitch, and roll).

Depending on the block period (T) and the repeat factor (N), sampling rates of approximately 20 samples/sec can be achieved 4. As we have stated above, the data are stored as binary formatted files. However, our processing software includes the capability to export the data to a Geosoft Oasis Montaj data base for further QC and map compilation. The processing also includes the capability to export the data to text files and to Matlab™.

2.1.3 Data Submission Format

Data were submitted for scoring in accordance with data submission protocols outlined in the Standardized UXO Technology Demonstration Site Handbook. These submitted data are not included in this report in order to protect ground truth information.

2.1.4 Demonstrator Quality Assurance (QA) and Quality Control (QC) (provided by demonstrator)

QC. The AOL2 data acquisition system integrates data acquired from 3 (optionally 4) sensors into a sample data point. These systems are position; attitude; EM, and optional magnetic gradiometer. The data from each of the systems are integrated into a single data structure (i.e., a TEMDataPoint). We will perform system checks by returning to a calibration point to acquire data. Typically, the system check consists of a short profile (say 10m) that we survey repeatedly two or more times a day. The profile will be set up in an area of typical background response (i.e., no targets). The calibration survey will consist of a dynamic survey run over a calibration target (typically a shotput) centered along the profile. We start the calibration survey by acquiring a static point at the beginning of the calibration line. We then survey dynamically over the target in one direction and then repeat the survey in the opposite direction. Finally, we halt the antenna array directly over the target and acquire a static data point. The calibration survey lines, repeated in opposite directions, provide a check of survey timing latency between the acquisition of the GPS position and the acquisition of the EM data. Because of the way we integrate the GPS position directly with the data, we have not experienced position latencies typical of systems where survey positions and data are merged from independent data files based on a time stamp. However, this experiment provides proof-positive that there is no significant timing latency in the acquisition system. The amplitude of the dynamic survey peaks as they cross over the calibration target and also provides a crude measure of the EM drift. A better measure of the drift is provided by the static measurements of the background and the target response. As part of the static background measurement, we will also establish a precise method for putting the cart into a known and repeatable attitude so that we may check the reliability of our orientation system. It is notable that our data acquisition system constantly monitors the quality of our GPS positions and provides a visual warning to the operator when the GPS quality for any reason degrades below that of real-time kinematic (RTK). Furthermore, the acquisition software includes the ability to graphically display data from any point in any data file. This plotting capability allows us to check data at any time while in the field.

QA. We plan to conduct a series of surveys over both the calibration lanes and the blind test grid that exercise Static-Mode and Dynamic-Mode acquisition. Station locations will be acquired with an RTK GPS system with the base station located at one of the benchmark locations at the UXO site. As we alluded above, the acquisition software constantly monitors the quality of the GPS solution, and when that quality degrades so that the positions are not RTK quality, a visual warning appears on the DAQ monitor. RTK quality positions with accuracies on the order of centimeters are essential for the high resolution dynamic surveys we intend to conduct. For static surveys, RTK quality is not essential. However, it is important that the accuracy of positions be on the order of ±10 cm to assure that we identify each target with the correct target cell.

2.1.5 Additional Records

The following record(s) by this vendor can be accessed via the Internet as Microsoft Word documents at www.uxotestsites.org.

2.2 YPG SITE INFORMATION

2.2.1 Location

YPG is located adjacent to the Colorado River in the Sonoran Desert. The UXO Standardized Test Site is located south of Pole Line Road and east of the Countermine Testing and Training Range. The open field range, calibration grid, blind grid, mogul area, and desert extreme area comprise the 350- by 500-meter general test site area. The open field site is the largest of the test sites and measures approximately 200 by 350 meters. To the east of the open field range are the calibration and blind test grids that measure 30 by 40 meters and 40 by 40 meters, respectively. South of the open field is the 135- by 80-meter Mogul area consisting of a sequence of man-made depressions. The Desert Extreme area is located southeast of the open field site and has dimensions of 50 by 100 meters. The desert extreme area, covered with desert-type vegetation, is used to test the performance of different sensor platforms in a more severe desert conditions/environment.

2.2.2 Soil Type

Soil samples were collected at the YPG UXO Standardized Test Site by ERDC to characterize the shallow subsurface (< 3 m). Both surface grab samples and continuous soil borings were acquired. The soils were subjected to several laboratory analyses, including sieve/hydrometer, water content, magnetic susceptibility, dielectric permittivity, X-ray diffraction, and visual description.

Two soil complexes are present within the site: Riverbend-Carrizo and Cristobal-Gunsight. The Riverbend-Carrizo complex is composed of mixed stream alluvium, whereas the Cristobal-Gunsight complex is derived from fan alluvium. The Cristobal-Gunsight complex covers the majority of the site. Most of the soil samples were classified as either a sandy loam or loamy sand, with most samples containing gravel-size particles. All samples had a measured water content of less than 7 percent, except for two that contained 11-percent moisture. The majority of soil samples had water content between 1 to 2 percent. Samples containing more than 3 percent were generally deeper than 1 meter.

An X-ray diffraction analysis on four soil samples indicated a basic mineralogy of quartz, calcite, mica, feldspar, magnetite, and some clay. The presence of magnetite imparted a moderate magnetic susceptibility, with volume susceptibilities generally greater than 100 by 10-5 SI.

For more details concerning the soil properties at the YPG test site, go to www.uxotestsites.org on the Web to view the entire soils description report.

2.2.3 Test Areas

A description of the test site areas at YPG is included in Table 2.

TABLE 2. TEST SITE AREAS

Area	Description
Calibration grid	Contains the 15 standard ordnance items buried in six positions at various angles and depths to allow demonstrator equipment calibration.
Blind grid	Contains 400 grid cells in a 0.16-hectare (0.39-acre) site. The center of each grid cell contains ordnance, clutter, or nothing.

SECTION 3. FIELD DATA

3.1 DATE OF FIELD ACTIVITIES (23 through 27 and 30 April and 3 May 2007)

3.2 AREAS TESTED/NUMBER OF HOURS

Areas tested and total number of hours operated at each site are summarized in Table 3.

TABLE 3. AREAS TESTED AND NUMBER OF HOURS

Area	Number of Hours
Calibration lanes	53.68
Blind grid	20.52

3.3 TEST CONDITIONS

3.3.1 Weather Conditions

A YPG weather station located approximately 1 mile west of the test site was used to record average temperature and precipitation on a half-hour basis for each day of operation. The temperatures listed in Table 4 represent the average temperature during field operations from 0700 to 1700 hours while precipitation data represents a daily total amount of rainfall. Hourly weather logs used to generate this summary are provided in Appendix B.

TABLE 4. TEMPERATURE/PRECIPITATION DATA SUMMARY

Date, 2007	Average Temperature, ^{o}F	Total Daily Precipitation, in.
23 April	69.3	0.00
24 April	76.8	0.00
25 April	84.1	0.00
26 April	83.3	0.00
27 April	84.4	0.00
30 April	87.9	0.00
1 May	84.4	0.00
2 May	82.4	0.00
3 May	76.4	0.00

3.3.2 Field Conditions

G&G Science surveyed the blind grid April 24 through April 26 and 3 May 2007. The field was dry and the weather was warm throughout the survey.

3.3.3 Soil Moisture

Three soil probes were placed at various locations within the site to capture soil moisture data: calibration, mogul, open field, and wooded areas. Measurements were collected in percent moisture and were taken twice daily (morning and afternoon) from five different soil depths (1 to 6 in., 6 to 12 in., 12 to 24 in., 24 to 36 in., and 36 to 48 in.) from each probe. Soil moisture logs are included in Appendix C.

3.4 FIELD ACTIVITIES

3.4.1 Setup/Mobilization

These activities included initial mobilization and daily equipment preparation and break down. A two-person crew took 4 hours and 15 minutes to perform the initial setup and mobilization. There was 55 minutes of daily equipment preparation and end of the day equipment break down lasted 1 hour and 1 minute.

3.4.2 Calibration

G&G Science spent a total of 53 hours and 41 minutes in the calibration lanes, of which 34 hours and 57 minutes were spent collecting data.

3.4.3 Downtime Occasions

Occasions of downtime are grouped into five categories: equipment/data checks or equipment maintenance, equipment failure and repair, weather, demonstration site issues, or breaks/lunch. All downtime is included for the purposes of calculating labor costs (section 5) except for downtime due to demonstration site issues. Demonstration site issues, while noted in the daily log, are considered nonchargeable downtime for the purposes of calculating labor costs and are not discussed. Breaks and lunches are discussed in this section and billed to the total site survey area.

3.4.3.1 Equipment/data checks, maintenance. Equipment data checks and maintenance activities accounted for 31 minutes of site usage time. These activities included changing out batteries and performing routine data checks to ensure the data were being properly recorded/collected. G&G Science spent an additional 32 minutes for breaks and lunches.

3.4.3.2 Equipment failure or repair. No time was needed to resolve equipment failures that occurred while surveying the blind grid.

3.4.3.3 Weather. No weather delays occurred during the survey.

3.4.4 Data Collection

G&G Science spent a total time of 20 hours and 31 minutes in the blind grid area, of which 17 hours and 32 minutes were spent collecting data.

3.4.5 Demobilization

The G&G Science survey crew went on to conduct a full demonstration of the site. Therefore, demobilization did not occur until 3 May 2007. On that day, it took the crew 1 hour and 35 minutes to break down and pack up their equipment.

3.5 PROCESSING TIME

G&G Science submitted the raw data from the demonstration activities on the last day of the demonstration, as required. The scoring submittal data was also provided 10 July 2007.

3.6 DEMONSTRATOR'S FIELD SURVEYING METHOD

G&G Science surveyed the blind grid in a linear fashion and in a south to northwest to east direction.

3.7 SUMMARY OF DAILY LOGS

Daily logs capture all field activities during this demonstration and are located in Appendix D. Activities pertinent to this specific demonstration are indicated in highlighted text.

SECTION 4. TECHNICAL PERFORMANCE RESULTS

4.1 ROC CURVES USING ALL ORDNANCE CATEGORIES

Figure 2, 4, and 6 shows the probability of detection for the response stage (P_d^{res}) and the discrimination stage (P_d^{disc}) versus their respective probability of false positive for the EM sensor(s), MAG sensor(s) and combined EM/MAG picks respectively. Figure 3, 5, and 7 shows both probabilities plotted against their respective probability of background alarm. Both figures use horizontal lines to illustrate the performance of the demonstrator at two demonstrator-specified points: at the system noise level for the response stage, representing the point below which targets are not considered detectable, and at the demonstrator's recommended threshold level for the discrimination stage, defining the subset of targets the demonstrator would recommend digging based on discrimination. Note that all points have been rounded to protect the ground truth.

The overall ground truth is composed of ferrous and non-ferrous anomalies. Because of the limitations of the magnetometer, the non-ferrous items cannot be detected. Therefore, the ROC curves presented in Figures 4 and 5 of this section are based on the subset of the ground truth that is solely made up of ferrous anomalies.

N/A

Figure 2. EM Sensor blind grid probability of detection for response and discrimination stages versus their respective probability of false positive over all ordnance categories combined.

N/A

Figure 3. EM Sensor blind grid probability of detection for response and discrimination stages versus their respective probability of background alarm over all ordnance categories combined.

N/A

Figure 4. MAG Sensor blind grid probability of detection for response and discrimination stages versus their respective probability of false positive over all ordnance categories combined.

N/A

Figure 5. MAG Sensor blind grid probability of detection for response and discrimination stages versus their respective probability of background alarm over all ordnance categories combined.

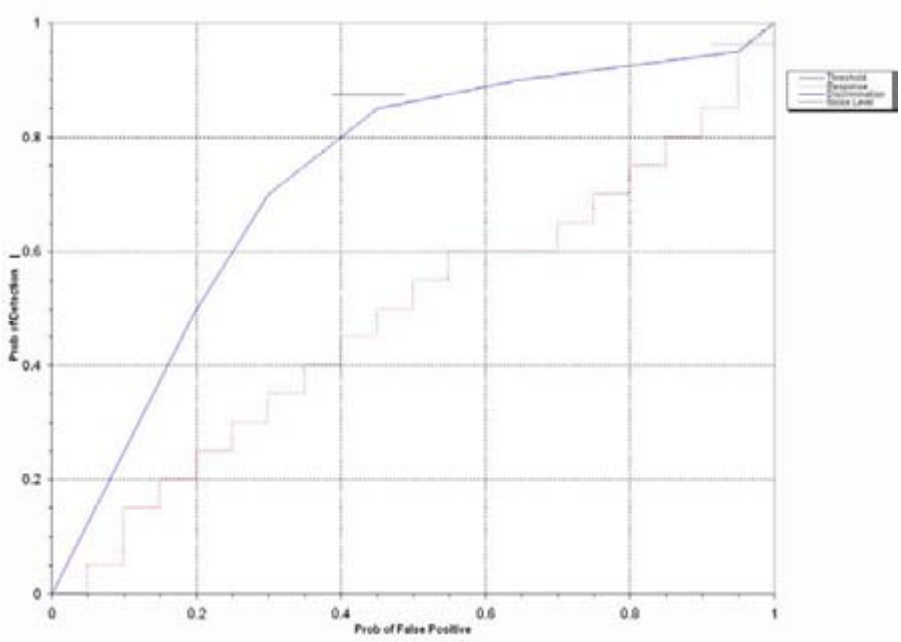

Figure 6. Combined Sensor blind grid probability of detection for response and discrimination stages versus their respective probability of false positive over all ordnance categories combined.

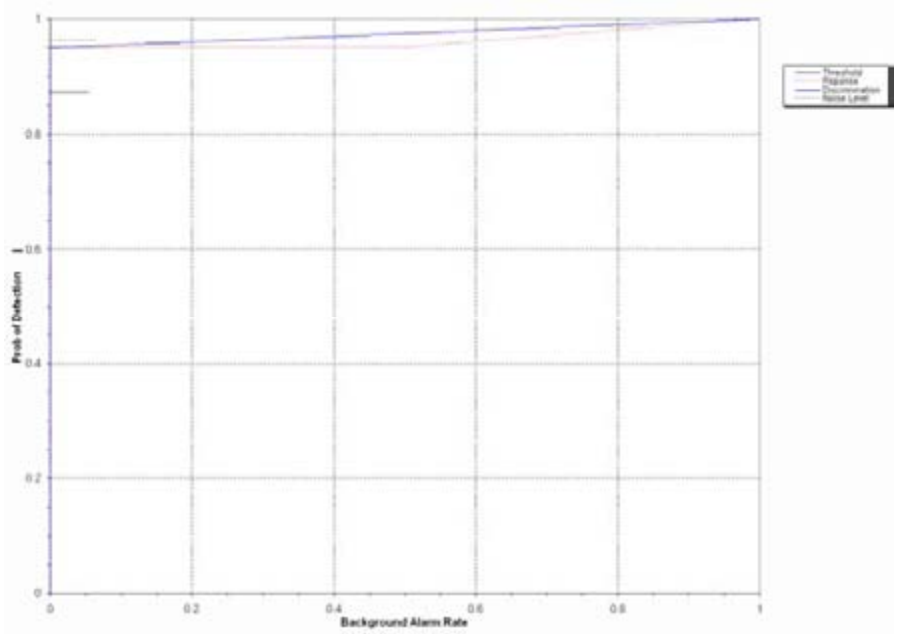

Figure 7. Combined Sensor blind grid probability of detection for response and discrimination stages versus their respective probability of background alarm over all ordnance categories combined.

4.2 ROC CURVES USING ORDNANCE LARGER THAN 20 MM

Figure 8, 10, and 12 shows the probability of detection for the response stage (P_d^{res}) and the discrimination stage (P_d^{disc}) versus their respective probability of false positive when only targets larger than 20 mm are scored for the EM sensor(s), MAG sensor(s) and Combined EM/MAG picks respectively. Figure 9, 11, and 13 shows both probabilities plotted against their respective probability of background alarm. Both figures use horizontal lines to illustrate the performance of the demonstrator at two demonstrator-specified points: at the system noise level for the response stage, representing the point below which targets are not considered detectable, and at the demonstrator's recommended threshold level for the discrimination stage, defining the subset of targets the demonstrator would recommend digging based on discrimination. Note that all points have been rounded to protect the ground truth.

The overall ground truth is composed of ferrous and non-ferrous anomalies. Because of the limitations of the magnetometer, the non-ferrous items cannot be detected. Therefore, the ROC curves presented in Figures 10 and 11 of this section are based on the subset of the ground truth that is solely made up of ferrous anomalies.

N/A

Figure 8. EM Sensor blind grid probability of detection for response and discrimination stages versus their respective probability of false positive for all ordnance larger than 20 mm.

N/A

Figure 9. EM Sensor blind grid probability of detection for response and discrimination stages versus their respective probabilities of background alarm for all ordnance larger than 20 mm.

N/A

Figure 10. MAG Sensor blind grid probability of detection for response and discrimination stages versus their respective probability of false positive for all ordnance larger than 20 mm.

N/A

Figure 11. MAG Sensor blind grid probability of detection for response and discrimination stages versus their respective probabilities of background alarm for all ordnance larger than 20 mm.

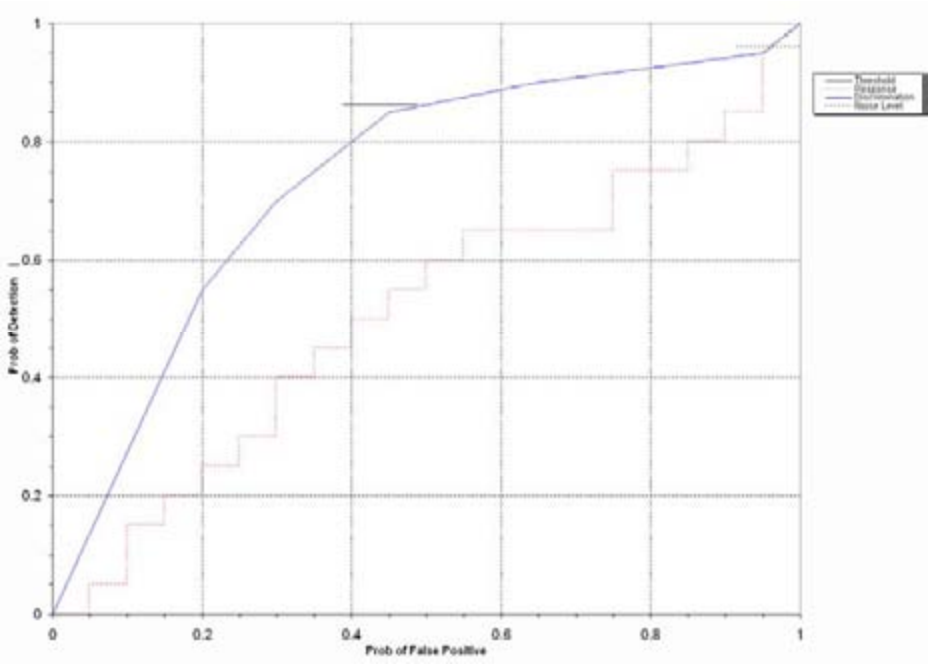

Figure 12. Combined Sensor blind grid probability of detection for response and discrimination stages versus their respective probability of false positive for all ordnance larger than 20 mm.

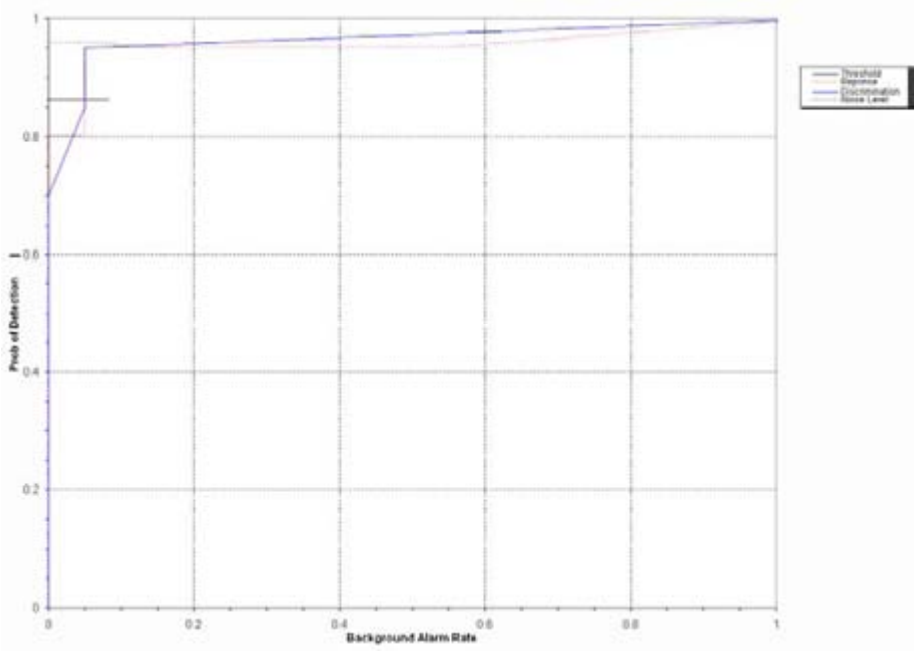

Figure 13. Combined Sensor blind grid probability of detection for response and discrimination stages versus their respective probabilities of background alarm for all ordnance larger than 20 mm.

4.3 PERFORMANCE SUMMARIES

Results for the blind grid test broken out by sensor type, size, depth and nonstandard ordnance are presented in Table 5a, b, and c (for cost results, see section 5). Results by size and depth include both standard and nonstandard ordnance. The results by size show how well the demonstrator did at detecting/discriminating ordnance of a certain caliber range. Size definitions are provided in Appendix A. The results are relative to the number of ordnance items emplaced. Depth is measured from the geometric center of anomalies.

The RESPONSE STAGE results are derived from the list of anomalies above the demonstrator-provided noise level. The results for the DISCRIMINATION STAGE are derived from the demonstrator's recommended threshold for optimizing UXO field cleanup by minimizing false digs and maximizing ordnance recovery. The lower 90-percent confidence limit on probability of detection and P_{fp} was calculated assuming that the number of detections and false positives are binomially distributed random variables. All results in Table 5 have been rounded to protect the ground truth. However, lower confidence limits were calculated using actual results.

The overall ground truth is composed of ferrous and non-ferrous anomalies. Because of the limitations of the magnetometer, the non-ferrous items cannot be detected. Therefore, the summary presented in Table 5b is split exhibiting results based on the subset of the ground truth that is solely the ferrous anomalies and the full ground truth for comparison purposes.

All other tables presented in this section are based on scoring against the ferrous only ground truth. The response stage noise level and recommended discrimination stage threshold values are provided by the demonstrator.

TABLE 5a. SUMMARY OF BLIND GRID RESULTS FOR THE AOL DUAL MODE/TOWED (EM SENSOR)

Metric	Overall	Standard	Nonstandard	By Size			By Depth, m		
				Small	Medium	Large	< 0.3	0.3 to <1	>= 1
RESPONSE STAGE									
P_d	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
P_d Low 90% Conf	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
P_d Upper 90% Conf	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
P_{fp}	N/A	-	-	-	-	-	N/A	N/A	N/A
P_{fp} Low 90% Conf	N/A	-	-	-	-	-	N/A	N/A	-
P_d Upper 90% Conf	N/A	-	-	-	-	-	N/A	N/A	-
P_{ba}	N/A	-	-	-	-	-	-	-	-
DISCRIMINATION STAGE									
P_d	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
P_d Low 90% Conf	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
P_d Upper 90% Conf	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
P_{fp}	N/A	-	-	-	-	-	N/A	N/A	N/A
P_{fp} Low 90% Conf	N/A	-	-	-	-	-	N/A	N/A	-
P_d Upper 90% Conf	N/A	-	-	-	-	-	N/A	N/A	-
P_{ba}	N/A	-	-	-	-	-	-	-	-

Response Stage Noise Level: N/A.
Recommended Discrimination Stage Threshold: N/A.

TABLE 5b. SUMMARY OF BLIND GRID RESULTS FOR THE AOL DUAL MODE/TOWED (MAG SENSOR)

Ferrous only Ground Truth									
Metric	Overall	Standard	Nonstandard	By Size			By Depth, m		
				Small	Medium	Large	< 0.3	0.3 to <1	>= 1
RESPONSE STAGE									
P_d	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
P_d Low 90% Conf	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
P_d Upper 90% Conf	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
P_{fp}	N/A	-	-	-	-	-	N/A	N/A	N/A
P_{fp} Low 90% Conf	N/A	-	-	-	-	-	N/A	N/A	-
P_d Upper 90% Conf	N/A	-	-	-	-	-	N/A	N/A	-
P_{ba}	N/A	-	-	-	-	-	-	-	-
DISCRIMINATION STAGE									
P_d	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
P_d Low 90% Conf	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
P_d Upper 90% Conf	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
P_{fp}	N/A	-	-	-	-	-	N/A	N/A	N/A
P_{fp} Low 90% Conf	N/A	-	-	-	-	-	N/A	N/A	-
P_d Upper 90% Conf	N/A	-	-	-	-	-	N/A	N/A	-
P_{ba}	N/A	-	-	-	-	-	-	-	-
Full Ground truth									
Metric	Overall	Standard	Nonstandard	By Size			By Depth, m		
				Small	Medium	Large	< 0.3	0.3 to <1	>= 1
RESPONSE STAGE									
P_d	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
P_d Low 90% Conf	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
P_d Upper 90% Conf	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
P_{fp}	N/A	-	-	-	-	-	N/A	N/A	N/A
P_{fp} Low 90% Conf	N/A	-	-	-	-	-	N/A	N/A	-
P_d Upper 90% Conf	N/A	-	-	-	-	-	N/A	N/A	-
P_{ba}	N/A	-	-	-	-	-	-	-	-
DISCRIMINATION STAGE									
P_d	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
P_d Low 90% Conf	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
P_d Upper 90% Conf	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
P_{fp}	N/A	-	-	-	-	-	N/A	N/A	N/A
P_{fp} Low 90% Conf	N/A	-	-	-	-	-	N/A	N/A	-
P_d Upper 90% Conf	N/A	-	-	-	-	-	N/A	N/A	-
P_{ba}	N/A	-	-	-	-	-	-	-	-

Response Stage Noise Level: N/A.
Recommended Discrimination Stage Threshold: N/A.

TABLE 5c. SUMMARY OF BLIND GRID RESULTS FOR THE AOL DUAL MODE/TOWED (COMBINED EM/MAG RESULTS)

Metric	Overall	Standard	Nonstandard	By Size			By Depth, m		
				Small	Medium	Large	< 0.3	0.3 to <1	>= 1
RESPONSE STAGE									
P_d	0.95	0.95	0.95	1.00	0.95	0.95	1.00	0.95	0.70
P_d Low 90% Conf	0.92	0.90	0.87	0.91	0.84	0.75	0.95	0.87	0.40
P_d Upper 90% Conf	0.99	0.99	1.00	1.00	1.00	0.99	1.00	1.00	0.92
P_{fp}	0.95	-	-	-	-	-	0.95	0.95	0.00
P_{fp} Low 90% Conf	0.93	-	-	-	-	-	0.92	0.88	0.00
P_{fp} Upper 90% Conf	0.98	-	-	-	-	-	0.99	1.00	0.00
P_{ba}	0.00	-	-	-	-	-	-	-	-
DISCRIMINATION STAGE									
P_d	0.85	0.85	0.90	0.95	0.75	0.85	1.00	0.80	0.55
P_d Low 90% Conf	0.81	0.78	0.78	0.88	0.59	0.66	0.91	0.65	0.28
P_d Upper 90% Conf	0.92	0.92	0.96	0.99	0.86	0.96	1.00	0.88	0.83
P_{fp}	0.45	-	-	-	-	-	0.35	0.65	0.00
P_{fp} Low 90% Conf	0.38	-	-	-	-	-	0.30	0.50	0.00
P_{fp} Upper 90% Conf	0.50	-	-	-	-	-	0.44	0.75	0.00
P_{ba}	0.00	-	-	-	-	-	-	-	-

Response Stage Noise Level: 0.82.
Recommended Discrimination Stage Threshold: 2.50.

Note: The recommended discrimination stage threshold values are provided by the demonstrator.

4.4 EFFICIENCY, REJECTION RATES, AND TYPE CLASSIFICATION (All results based on combined EM/MAG data set)

Efficiency and rejection rates are calculated to quantify the discrimination ability at specific points of interest on the ROC curve: (1) at the point where no decrease in P_d is suffered (i.e., the efficiency is by definition equal to one) and (2) at the operator-selected threshold. These values are reported in Table 6.

TABLE 6. EFFICIENCY AND REJECTION RATES

	Efficiency (E)	False Positive Rejection Rate	Background Alarm Rejection Rate
At Operating Point	0.91	0.55	0.67
With No Loss of P_d	1.00	0.00	0.00

At the demonstrator's recommended setting, the ordnance items that were detected and correctly discriminated were further scored on whether their correct type could be identified (table 7). Correct type examples include 20-mm projectile, 105-mm HEAT Projectile, and 2.75-inch Rocket. A list of the standard type declaration required for each ordnance item was provided to demonstrators prior to testing. For example, the standard type for the three example items are 20mmP, 105H, and 2.75in, respectively.

TABLE 7. CORRECT TYPE CLASSIFICATION OF TARGETS CORRECTLY DISCRIMINATED AS UXO

Size	Percentage Correct
Small	17.5
Medium	0.0
Large	0.0
Overall	10.3

4.5 LOCATION ACCURACY

The mean location error and standard deviations appear in Table 8. These calculations are based on average missed depth for ordnance correctly identified in the discrimination stage. Depths are measured from the closest point of the ordnance to the surface. For the blind grid, only depth errors are calculated because (X, Y) positions are known to be the centers of each grid square.

TABLE 8. MEAN LOCATION ERROR AND STANDARD DEVIATION (M)

Depth	-0.07	0.22

SECTION 5. ON-SITE LABOR COSTS

A standardized estimate for labor costs associated with this effort was calculated as follows: the first person at the test site was designated "supervisor," the second person was designated "data analyst," and the third and following personnel were considered "field support." Standardized hourly labor rates were charged by title: supervisor at $95.00/hour, data analyst at $57.00/hour, and field support at $28.50/hour.

Government representatives monitored on-site activity. All on-site activities were grouped into one of ten categories: initial setup/mobilization, daily setup/stop, calibration, data collection, downtime due to break/lunch, downtime due to equipment failure, downtime due to equipment/data checks or maintenance, downtime due to weather, downtime due to demonstration site issue, or demobilization. See Appendix D for the daily activity log. See section 3.4 for a summary of field activities.

The standardized cost estimate associated with the labor needed to perform the field activities is presented in Table 9. Note that calibration time includes time spent in the calibration lanes as well as field calibrations. "Site survey time" includes daily setup/stop time, collecting data, breaks/lunch, downtime due to equipment/data checks or maintenance, downtime due to failure, and downtime due to weather.

TABLE 9. ON-SITE LABOR COSTS

	No. of People	Hourly Wage	Hours	Cost
Initial setup				
Supervisor	1	$95.00	4.25	$403.75
Data Analyst	1	57.00	4.25	242.25
Field Support	0	28.50	0.00	0.00
Subtotal				**$646.00**
Calibration				
Supervisor	1	$95.00	53.68	$5,099.60
Data Analyst	1	57.00	53.68	3,059.76
Field Support	0	28.50	0.00	0.00
Subtotal				**$8,159.36**
Site survey				
Supervisor	1	$95.00	20.52	$1,949.40
Data Analyst	1	57.00	20.52	1,169.64
Field Support	0	28.50	0.00	0.00
Subtotal				**$3,119.04**

See notes at end of table.

TABLE 9 (CONT'D)

	No. of People	Hourly Wage	Hours	Cost
Demobilization				
Supervisor	1	$95.00	1.58	$150.10
Data Analyst	1	57.00	1.58	90.06
Field Support	0	28.50	0.00	0.00
Subtotal				**$240.16**
Total				**$12,164.56**

Notes: Calibration time includes time spent in the calibration lanes as well as calibration before each data run.

Site survey time includes daily setup/stop time, data collection, breaks/lunch, and downtime due to system maintenance, failure, and weather.

SECTION 6. COMPARISON OF RESULTS TO DATE

No comparisons to date.

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SECTION 7. APPENDIXES

APPENDIX A. TERMS AND DEFINITIONS

GENERAL DEFINITIONS

Anomaly: Location of a system response deemed to warrant further investigation by the demonstrator for consideration as an emplaced ordnance item.

Detection: An anomaly location that is within R_{halo} of an emplaced ordnance item.

Munitions and Explosives Of Concern (MEC): Specific categories of military munitions that may pose unique explosive safety risks, including UXO as defined in 10 USC 101(e)(5), DMM as defined in 10 USC 2710(e)(2) and/or munitions constituents (e.g. TNT, RDX) as defined in 10 USC 2710(e)(3) that are present in high enough concentrations to pose an explosive hazard.

Emplaced Ordnance: An ordnance item buried by the government at a specified location in the test site.

Emplaced Clutter: A clutter item (i.e., non-ordnance item) buried by the government at a specified location in the test site.

R_{halo}: A pre-determined radius about the periphery of an emplaced item (clutter or ordnance) within which a location identified by the demonstrator as being of interest is considered to be a response from that item. If multiple declarations lie within R_{halo} of any item (clutter or ordnance), the declaration with the highest signal output within the R_{halo} will be utilized. For the purpose of this program, a circular halo 0.5 meters in radius will be placed around the center of the object for all clutter and ordnance items less than 0.6 meters in length. When ordnance items are longer than 0.6 meters, the halo becomes an ellipse where the minor axis remains 1 meter and the major axis is equal to the length of the ordnance plus 1 meter.

Small Ordnance: Caliber of ordnance less than or equal to 40 mm (includes 20-mm projectile, 40-mm projectile, submunitions BLU-26, BLU-63, and M42).

Medium Ordnance: Caliber of ordnance greater than 40 mm and less than or equal to 81 mm (includes 57-mm projectile, 60-mm mortar, 2.75 in. Rocket, MK118 Rockeye, 81-mm mortar).

Large Ordnance: Caliber of ordnance greater than 81 mm (includes 105-mm HEAT, 105-mm projectile, 155-mm projectile, 500-pound bomb).

Shallow: Items buried less than 0.3 meter below ground surface.

Medium: Items buried greater than or equal to 0.3 meter and less than 1 meter below ground surface.

Deep: Items buried greater than or equal to 1 meter below ground surface.

Response Stage Noise Level: The level that represents the point below which anomalies are not considered detectable. Demonstrators are required to provide the recommended noise level for the blind grid test area.

Discrimination Stage Threshold: The demonstrator selected threshold level that they believe provides optimum performance of the system by retaining all detectable ordnance and rejecting the maximum amount of clutter. This level defines the subset of anomalies the demonstrator would recommend digging based on discrimination.

Binomially Distributed Random Variable: A random variable of the type which has only two possible outcomes, say success and failure, is repeated for n independent trials with the probability p of success and the probability 1-p of failure being the same for each trial. The number of successes x observed in the n trials is an estimate of p and is considered to be a binomially distributed random variable.

RESPONSE AND DISCRIMINATION STAGE DATA

The scoring of the demonstrator's performance is conducted in two stages. These two stages are termed the RESPONSE STAGE and DISCRIMINATION STAGE. For both stages, the probability of detection (P_d) and the false alarms are reported as receiver operating characteristic (ROC) curves. False alarms are divided into those anomalies that correspond to emplaced clutter items, measuring the probability of false positive (P_{fp}) and those that do not correspond to any known item, termed background alarms.

The RESPONSE STAGE scoring evaluates the ability of the system to detect emplaced targets without regard to ability to discriminate ordnance from other anomalies. For the RESPONSE STAGE, the demonstrator provides the scoring committee with the location and signal strength of all anomalies that the demonstrator has deemed sufficient to warrant further investigation and/or processing as potential emplaced ordnance items. This list is generated with minimal processing (e.g., this list will include all signals above the system noise threshold). As such, it represents the most inclusive list of anomalies.

The DISCRIMINATION STAGE evaluates the demonstrator's ability to correctly identify ordnance as such, and to reject clutter. For the same locations as in the RESPONSE STAGE anomaly list, the DISCRIMINATION STAGE list contains the output of the algorithms applied in the discrimination-stage processing. This list is prioritized based on the demonstrator's determination that an anomaly location is likely to contain ordnance. Thus, higher output values are indicative of higher confidence that an ordnance item is present at the specified location. For electronic signal processing, priority ranking is based on algorithm output. For other systems, priority ranking is based on human judgment. The demonstrator also selects the threshold that the demonstrator believes will provide "optimum" system performance, (i.e., that retains all the detected ordnance and rejects the maximum amount of clutter).

Note: The two lists provided by the demonstrator contain identical numbers of potential target locations. They differ only in the priority ranking of the declarations.

RESPONSE STAGE DEFINITIONS

Response Stage Probability of Detection (P_d^{res}): P_d^{res} = (No. of response-stage detections)/ (No. of emplaced ordnance in the test site).

Response Stage False Positive (fp^{res}): An anomaly location that is within R_{halo} of an emplaced clutter item.

Response Stage Probability of False Positive (P_{fp}^{res}): P_{fp}^{res} = (No. of response-stage false positives)/(No. of emplaced clutter items).

Response Stage Background Alarm (ba^{res}): An anomaly in a blind grid cell that contains neither emplaced ordnance nor an emplaced clutter item. An anomaly location in the open field or scenarios that is outside R_{halo} of any emplaced ordnance or emplaced clutter item.

Response Stage Probability of Background Alarm (P_{ba}^{res}): Blind Grid only: P_{ba}^{res} = (No. of response-stage background alarms)/(No. of empty grid locations).

Response Stage Background Alarm Rate (BAR^{res}): Open Field only: BAR^{res} = (No. of response-stage background alarms)/(arbitrary constant).

Note that the quantities P_d^{res}, P_{fp}^{res}, P_{ba}^{res}, and BAR^{res} are functions of t^{res}, the threshold applied to the response-stage signal strength. These quantities can therefore be written as $P_d^{res}(t^{res})$, $P_{fp}^{res}(t^{res})$, $P_{ba}^{res}(t^{res})$, and $BAR^{res}(t^{res})$.

DISCRIMINATION STAGE DEFINITIONS

Discrimination: The application of a signal processing algorithm or human judgment to response-stage data that discriminates ordnance from clutter. Discrimination should identify anomalies that the demonstrator has high confidence correspond to ordnance, as well as those that the demonstrator has high confidence correspond to non-ordnance or background returns. The former should be ranked with highest priority and the latter with lowest.

Discrimination Stage Probability of Detection (P_d^{disc}): P_d^{disc} = (No. of discrimination-stage detections)/(No. of emplaced ordnance in the test site).

Discrimination Stage False Positive (fp^{disc}): An anomaly location that is within R_{halo} of an emplaced clutter item.

Discrimination Stage Probability of False Positive (P_{fp}^{disc}): P_{fp}^{disc} = (No. of discrimination stage false positives)/(No. of emplaced clutter items).

Discrimination Stage Background Alarm (ba^{disc}): An anomaly in a blind grid cell that contains neither emplaced ordnance nor an emplaced clutter item. An anomaly location in the open field or scenarios that is outside R_{halo} of any emplaced ordnance or emplaced clutter item.

Discrimination Stage Probability of Background Alarm (P_{ba}^{disc}): P_{ba}^{disc} = (No. of discrimination-stage background alarms)/(No. of empty grid locations).

Discrimination Stage Background Alarm Rate (BAR^{disc}): BAR^{disc} = (No. of discrimination-stage background alarms)/(arbitrary constant).

Note that the quantities P_d^{disc}, P_{fp}^{disc}, P_{ba}^{disc}, and BAR^{disc} are functions of t^{disc}, the threshold applied to the discrimination-stage signal strength. These quantities can therefore be written as $P_d^{disc}(t^{disc})$, $P_{fp}^{disc}(t^{disc})$, $P_{ba}^{disc}(t^{disc})$, and $BAR^{disc}(t^{disc})$.

RECEIVER-OPERATING CHARACERISTIC (ROC) CURVES

ROC curves at both the response and discrimination stages can be constructed based on the above definitions. The ROC curves plot the relationship between P_d versus P_{fp} and P_d versus BAR or P_{ba} as the threshold applied to the signal strength is varied from its minimum (t_{min}) to its maximum (t_{max}) value.[1] Figure A-1 shows how P_d versus P_{fp} and P_d versus BAR are combined into ROC curves. Note that the "res" and "disc" superscripts have been suppressed from all the variables for clarity.

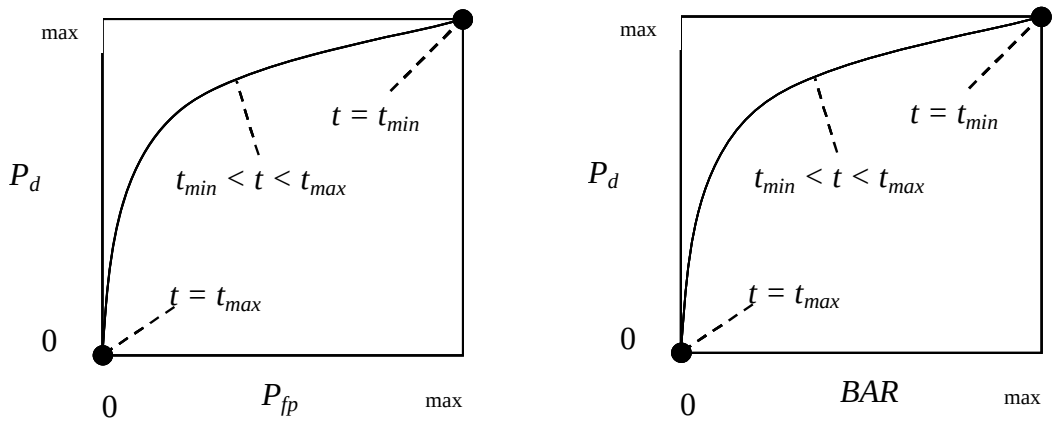

Figure A-1. ROC curves for open field testing. Each curve applies to both the response and discrimination stages.

[1]Strictly speaking, ROC curves plot the P_d versus P_{ba} over a pre-determined and fixed number of detection opportunities (some of the opportunities are located over ordnance and others are located over clutter or blank spots). In an open field scenario, each system suppresses its signal strength reports until some bare-minimum signal response is received by the system. Consequently, the open field ROC curves do not have information from low signal-output locations, and, furthermore, different contractors report their signals over a different set of locations on the ground. These ROC curves are thus not true to the strict definition of ROC curves as defined in textbooks on detection theory. Note, however, that the ROC curves obtained in the blind grid test sites are true ROC curves.

METRICS TO CHARACTERIZE THE DISCRIMINATION STAGE

The demonstrator is also scored on efficiency and rejection ratio, which measure the effectiveness of the discrimination stage processing. The goal of discrimination is to retain the greatest number of ordnance detections from the anomaly list, while rejecting the maximum number of anomalies arising from non-ordnance items. The efficiency measures the amount of detected ordnance retained by the discrimination, while the rejection ratio measures the fraction of false alarms rejected. Both measures are defined relative to the entire response list, i.e., the maximum ordnance detectable by the sensor and its accompanying false positive rate or background alarm rate.

Efficiency (E): $E = P_d^{disc}(t^{disc})/P_d^{res}(t_{min}^{res})$; Measures (at a threshold of interest), the degree to which the maximum theoretical detection performance of the sensor system (as determined by the response stage t_{min}) is preserved after application of discrimination techniques. Efficiency is a number between 0 and 1. An efficiency of 1 implies that all of the ordnance initially detected in the response stage was retained at the specified threshold in the discrimination stage, t^{disc}.

False Positive Rejection Rate (R_{fp}): $R_{fp} = 1 - [P_{fp}^{disc}(t^{disc})/P_{fp}^{res}(t_{min}^{res})]$; Measures (at a threshold of interest), the degree to which the sensor system's false positive performance is improved over the maximum false positive performance (as determined by the response stage tmin). The rejection rate is a number between 0 and 1. A rejection rate of 1 implies that all emplaced clutter initially detected in the response stage were correctly rejected at the specified threshold in the discrimination stage.

Background Alarm Rejection Rate (R_{ba}):

Blind Grid: $R_{ba} = 1 - [P_{ba}^{disc}(t^{disc})/P_{ba}^{res}(t_{min}^{res})]$.
Open Field: $R_{ba} = 1 - [BAR^{disc}(t^{disc})/BAR^{res}(t_{min}^{res})])$.

Measures the degree to which the discrimination stage correctly rejects background alarms initially detected in the response stage. The rejection rate is a number between 0 and 1. A rejection rate of 1 implies that all background alarms initially detected in the response stage were rejected at the specified threshold in the discrimination stage.

CHI-SQUARE COMPARISON EXPLANATION:

The Chi-square test for differences in probabilities (or 2 x 2 contingency table) is used to analyze two samples drawn from two different populations to see if both populations have the same or different proportions of elements in a certain category. More specifically, two random samples are drawn, one from each population, to test the null hypothesis that the probability of event A (some specified event) is the same for both populations (ref 3).

A 2 x 2 contingency table is used in the Standardized UXO Technology Demonstration Site Program to determine if there is reason to believe that the proportion of ordnance correctly detected/discriminated by demonstrator X's system is significantly degraded by the more challenging terrain feature introduced. The test statistic of the 2 x 2 contingency table is the

Chi-square distribution with one degree of freedom. Since an association between the more challenging terrain feature and relatively degraded performance is sought, a one-sided test is performed. A significance level of 0.05 is chosen which sets a critical decision limit of 2.71 from the Chi-square distribution with one degree of freedom. It is a critical decision limit because if the test statistic calculated from the data exceeds this value, the two proportions tested will be considered significantly different. If the test statistic calculated from the data is less than this value, the two proportions tested will be considered not significantly different.

An exception must be applied when either a 0 or 100 percent success rate occurs in the sample data. The Chi-square test cannot be used in these instances. Instead, Fischer's test is used and the critical decision limit for one-sided tests is the chosen significance level, which in this case is 0.05. With Fischer's test, if the test statistic is less than the critical value, the proportions are considered to be significantly different.

Standardized UXO Technology Demonstration Site examples, where blind grid results are compared to those from the open field and open field results are compared to those from one of the scenarios, follow. It should be noted that a significant result does not prove a cause and effect relationship exists between the two populations of interest; however, it does serve as a tool to indicate that one data set has experienced a degradation in system performance at a large enough level than can be accounted for merely by chance or random variation. Note also that a result that is not significant indicates that there is not enough evidence to declare that anything more than chance or random variation within the same population is at work between the two data sets being compared.

Demonstrator X achieves the following overall results after surveying each of the three progressively more difficult areas using the same system (results indicate the number of ordnance detected divided by the number of ordnance emplaced):

	Blind grid	Open field	Moguls
P_d^{res}	100/100 = 1.0	8/10 = .80	20/33 = .61
P_d^{disc}	80/100 = 0.80	6/10 = .60	8/33 = .24

P_d^{res}: BLIND GRID versus OPEN FIELD. Using the example data above to compare probabilities of detection in the response stage, all 100 ordnance out of 100 emplaced ordnance items were detected in the blind grid while 8 ordnance out of 10 emplaced were detected in the open field. Fischer's test must be used since a 100 percent success rate occurs in the data. Fischer's test uses the four input values to calculate a test statistic of 0.0075 that is compared against the critical value of 0.05. Since the test statistic is less than the critical value, the smaller response stage detection rate (0.80) is considered to be significantly less at the 0.05 level of significance. While a significant result does not prove a cause and effect relationship exists between the change in survey area and degradation in performance, it does indicate that the detection ability of demonstrator X's system seems to have been degraded in the open field relative to results from the blind grid using the same system.

P_d^{disc}: BLIND GRID versus OPEN FIELD. Using the example data above to compare probabilities of detection in the discrimination stage, 80 out of 100 emplaced ordnance items were correctly discriminated as ordnance in blind grid testing while 6 ordnance out of 10 emplaced were correctly discriminated as such in open field-testing. Those four values are used to calculate a test statistic of 1.12. Since the test statistic is less than the critical value of 2.71, the two discrimination stage detection rates are considered to be not significantly different at the 0.05 level of significance.

P_d^{res}: OPEN FIELD versus MOGULS. Using the example data above to compare probabilities of detection in the response stage, 8 out of 10 and 20 out of 33 are used to calculate a test statistic of 0.56. Since the test statistic is less than the critical value of 2.71, the two response stage detection rates are considered to be not significantly different at the 0.05 level of significance.

P_d^{disc}: OPEN FIELD versus MOGULS. Using the example data above to compare probabilities of detection in the discrimination stage, 6 out of 10 and 8 out of 33 are used to calculate a test statistic of 2.98. Since the test statistic is greater than the critical value of 2.71, the smaller discrimination stage detection rate is considered to be significantly less at the 0.05 level of significance. While a significant result does not prove a cause and effect relationship exists between the change in survey area and degradation in performance, it does indicate that the ability of demonstrator X to correctly discriminate seems to have been degraded by the mogul terrain relative to results from the flat open field using the same system.

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APPENDIX B. DAILY WEATHER LOGS

23 April 2007		
Time	**Average Temperature, °F**	**Precipitation, in.**
0700	56.8	N/A
0800	60.7	
0900	63.8	
1000	66.3	
1100	68.4	
1200	70.2	
1300	72.2	
1400	73.4	
1500	75.6	
1600	76.9	
1700	77.7	
24 April 2007		
0700	59.0	N/A
0800	63.2	
0900	67.3	
1000	72.5	
1100	76.4	
1200	80.3	
1300	83.0	
1400	84.6	
1500	85.3	
1600	86.4	
1700	87.3	
25 April 2007		
0700	62.5	N/A
0800	72.0	
0900	76.2	
1000	80.3	
1100	85.7	
1200	89.2	
1300	90.7	
1400	91.2	
1500	92.1	
1600	92.5	
1700	92.5	

26 April 2007		
Time	**Average Temperature, ^{o}F**	**Precipitation, in.**
0700	63.9	0.00
0800	71.4	
0900	78.5	
1000	81.0	
1100	83.4	
1200	86.5	
1300	88.7	
1400	89.9	
1500	90.4	
1600	90.9	
1700	91.4	
27 April 2007		
0700	63.7	0.00
0800	73.5	
0900	76.8	
1000	80.5	
1100	84.3	
1200	86.5	
1300	89.1	
1400	91.5	
1500	93.0	
1600	94.4	
1700	95.1	
28 April 2007		
0700	69.5	0.00
0800	77.1	
0900	79.1	
1000	83.1	
1100	87.5	
1200	91.3	
1300	93.9	
1400	95.7	
1500	98.0	
1600	99.3	
1700	100.5	

29 April 2007		
Time	**Average Temperature, ^{o}F**	**Precipitation, in.**
0700	71.6	0.00
0800	78.8	
0900	82.0	
1000	85.7	
1100	88.6	
1200	91.0	
1300	92.7	
1400	94.6	
1500	95.5	
1600	96.4	
1700	96.8	

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APPENDIX C. SOIL MOISTURE

Date: 23 April 2007
Times: NA and 1400

Probe Location	Layer, in.	A.M. Reading, %	P.M. Reading, %
Calibration area	0 to 6	N/A	1.8
	6 to 12		2.2
	12 to 24		3.7
	24 to 36		3.8
	36 to 48		4.2
Mogul area	0 to 6		1.8
	6 to 12		3.8
	12 to 24		3.8
	24 to 36		4.6
	36 to 48		5.7
Desert extreme area	0 to 6		9.7
	6 to 12		3.8
	12 to 24		3.2
	24 to 36		4.0
	36 to 48		4.0

Date: 24 April 2007
Times: 0700 and 1400

Probe Location	Layer, in.	A.M. Reading, %	P.M. Reading, %
Calibration area	0 to 6	1.9	1.7
	6 to 12	2.2	2.1
	12 to 24	3.7	3.7
	24 to 36	3.7	3.7
	36 to 48	4.2	4.3
Mogul area	0 to 6	1.7	1.7
	6 to 12	3.8	6.7
	12 to 24	3.8	3.8
	24 to 36	4.5	4.5
	36 to 48	5.3	5.2
Desert extreme area	0 to 6	9.8	12.6
	6 to 12	3.8	3.8
	12 to 24	3.2	3.1
	24 to 36	4.0	4.0
	36 to 48	4.0	4.1

Date: 25 April 2007 **Times:** 0700 and 1400			
Probe Location	**Layer, in.**	**A.M. Reading, %**	**P.M. Reading, %**
Calibration area	0 to 6	1.8	1.8
	6 to 12	2.1	2.2
	12 to 24	3.7	3.7
	24 to 36	3.8	3.7
	36 to 48	4.2	4.2
Mogul area	0 to 6	1.7	1.8
	6 to 12	3.8	5.1
	12 to 24	3.8	3.8
	24 to 36	4.5	4.5
	36 to 48	5.4	5.6
Desert extreme area	0 to 6	6.8	9.6
	6 to 12	3.8	3.8
	12 to 24	3.2	3.2
	24 to 36	4.0	4.1
	36 to 48	4.0	4.1
Date: 26 April 2007 **Times:** 0700 and 1400			
Probe Location	**Layer, in.**	**A.M. Reading, %**	**P.M. Reading, %**
Calibration area	0 to 6	1.8	1.6
	6 to 12	2.2	2.0
	12 to 24	3.6	3.7
	24 to 36	3.7	3.7
	36 to 48	4.2	4.2
Mogul area	0 to 6	1.7	1.7
	6 to 12	3.8	6.4
	12 to 24	3.8	3.8
	24 to 36	4.5	4.5
	36 to 48	5.4	5.2
Desert extreme area	0 to 6	9.6	9.2
	6 to 12	3.8	3.8
	12 to 24	3.2	3.1
	24 to 36	4.0	4.0
	36 to 48	4.1	4.0

Date: 27 April 2007			
Times: 0700 and 1400			
Probe Location	**Layer, in.**	**A.M. Reading, %**	**P.M. Reading, %**
Calibration area	0 to 6	1.9	1.8
	6 to 12	2.1	2.3
	12 to 24	3.7	3.8
	24 to 36	3.7	3.7
	36 to 48	4.2	4.2
Mogul area	0 to 6	1.6	1.5
	6 to 12	3.8	3.8
	12 to 24	3.8	3.8
	24 to 36	4.5	4.6
	36 to 48	5.4	5.6
Desert extreme area	0 to 6	6.7	6.7
	6 to 12	3.8	3.8
	12 to 24	3.3	3.2
	24 to 36	4.0	4.0
	36 to 48	4.1	4.0

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Date	No. of People	Area Tested	Status Start Time	Status Stop Time	Duration min.	Operational Status - Comments		Track Method	Pattern	Field Conditions	
04/23/07	2	CALIBRATION LANES	710	1125	255	INITIAL SETUP	Setting up test equipment and initial calibration	NA	NA	Sunny	Cool
04/23/07	2	CALIBRATION LANES	1125	1217	0	COLLECTING DATA	Collecting data, Row A, West - East	GPS	Linear	Sunny	Windy
04/23/07	2	CALIBRATION LANES	1217	1229	12	DOWNTIME DUE TO EQUIPMENT MAINTENANCE/CHECK	Checking equipment	NA	NA	Sunny	Windy
04/23/07	2	CALIBRATION LANES	1229	1330	61	COLLECTING DATA	Collecting data, Row A, West - East	GPS	Linear	Sunny	Windy
04/23/07	2	CALIBRATION LANES	1339	1534	115	COLLECTING DATA	Collecting data, South - North - West - East	GPS	Linear	Sunny	Windy
04/23/07	2	CALIBRATION LANES	1534	1610	36	DAILY START, STOP	Breakdown end of day	NA	NA	Sunny	Windy
04/24/07	2	CALIBRATION LANES	640	748	68	DAILY START, STOP	Setup of equipment and calibration	NA	NA	Sunny	Cool
04/24/07	2	CALIBRATION LANES	748	840	52	COLLECTING DATA	Collecting data, South - North - West - East	GPS	Linear	Sunny	Cool
04/24/07	2	CALIBRATION LANES	840	855	15	DOWNTIME DUE TO EQUIPMENT MAINTENANCE/CHECK	Replaced battery in transmitter	NA	NA	Sunny	Cool
04/24/07	2	CALIBRATION LANES	855	1123	148	COLLECTING DATA	Collecting data, South - North - West - East	GPS	Linear	Sunny	Cool
04/24/07	2	CALIBRATION LANES	1123	1218	55	DOWNTIME DUE TO EQUIPMENT MAINTENANCE/CHECK	Downloading and verifying data	NA	NA	Sunny	Cool
04/24/07	2	BLIND TEST GRID	1218	1519	181	COLLECTING DATA	Collecting data, South - North - West - East	GPS	Linear	Sunny	Warm
04/24/07	2	BLIND TEST GRID	1519	1531	12	DOWNTIME DUE TO EQUIPMENT MAINTENANCE/CHECK	Replacing batteries	NA	NA	Sunny	Warm
04/24/07	2	BLIND TEST GRID	1531	1542	11	COLLECTING DATA	Collecting data, South - North - West - East	GPS	Linear	Sunny	Warm
04/24/07	2	BLIND TEST GRID	1542	1610	28	DAILY START, STOP	Breakdown end of day	NA	NA	Sunny	Warm
04/25/07	2	BLIND TEST GRID	638	705	27	DAILY START, STOP	Setup of equipment and calibration	NA	NA	Sunny	Cool
04/25/07	2	BLIND TEST GRID	705	1045	220	COLLECTING DATA	Collecting data, South - North - West - East	GPS	Linear	Sunny	Cool
04/25/07	2	BLIND TEST GRID	1045	1104	19	BREAK/LUNCH	Break	NA	NA	Sunny	Cool

Note: Activities pertinent to this specific demonstration are indicated in highlighted text.

Date	No. of People	Area Tested	Status Start Time	Status Stop Time	Duration min.	Operational Status - Comments		Track Method	Pattern	Field Conditions	
04/25/07	2	BLIND TEST GRID	1104	1218	74	COLLECTING DATA	Collecting data, South - North - West - East	GPS	Linear	Sunny	Cool
04/25/07	2	BLIND TEST GRID	1218	1237	19	DOWNTIME DUE TO EQUIPMENT MAINTENANCE/CHECK	Replacing batteries	NA	NA	Sunny	Warm
04/25/07	2	BLIND TEST GRID	1237	1402	85	COLLECTING DATA	Collecting data, South - North - West - East	GPS	Linear	Sunny	Warm
04/25/07	2	BLIND TEST GRID	1402	1415	13	BREAK/LUNCH	Break	NA	NA	Sunny	Warm
04/25/07	2	BLIND TEST GRID	1415	1520	65	COLLECTING DATA	Collecting data, South - North - West - East	GPS	Linear	Sunny	Warm
04/25/07	2	BLIND TEST GRID	1520	1553	33	DAILY START, STOP	Breakdown end of day	NA	NA	Sunny	Warm
04/26/07	2	BLIND TEST GRID	635	703	28	DAILY START, STOP	Setup of equipment and calibration	NA	NA	Sunny	Cool
04/26/07	2	BLIND TEST GRID	703	929	146	COLLECTING DATA	Collecting data, South - North - West - East	GPS	Linear	Sunny	Cool
04/26/07	2	CALIBRATION LANES	929	938	9	DOWNTIME DUE TO EQUIPMENT MAINTENANCE/CHECK	Replacing batteries	NA	NA	Sunny	Cool
04/26/07	2	CALIBRATION LANES	938	1048	70	COLLECTING DATA	Collecting data, South - North - West - East	GPS	Linear	Sunny	Cool
04/26/07	2	CALIBRATION LANES	1048	1056	8	DOWNTIME DUE TO EQUIPMENT MAINTENANCE/CHECK	Replacing batteries	NA	NA	Sunny	Cool
04/26/07	2	CALIBRATION LANES	1056	1215	79	COLLECTING DATA	Collecting data, South - North - West - East	GPS	Linear	Sunny	Cool
04/26/07	2	CALIBRATION LANES	1215	1239	24	BREAK/LUNCH	Break, verifying data	NA	NA	Sunny	Warm
04/26/07	2	CALIBRATION LANES	1239	1420	101	COLLECTING DATA	Collecting data, South - North - West - East	GPS	Linear	Sunny	Warm
04/26/07	2	CALIBRATION LANES	1420	1448	28	DOWNTIME DUE TO EQUIPMENT MAINTENANCE/CHECK	Downloading and verifying data	NA	NA	Sunny	Warm
04/26/07	2	CALIBRATION LANES	1448	1540	52	COLLECTING DATA	Collecting data, South - North - West - East	GPS	Linear	Sunny	Warm
04/26/07	2	CALIBRATION LANES	1540	1610	30	DAILY START, STOP	Breakdown end of day	NA	NA	Sunny	Warm
04/27/07	2	CALIBRATION LANES	640	825	105	DAILY START, STOP	Setup of equipment and calibration	NA	NA	Sunny	Cool
04/27/07	2	CALIBRATION LANES	825	910	45	COLLECTING DATA	Collecting data, South - North - West - East	GPS	Linear	Sunny	Cool

Note: Activities pertinent to this specific demonstration are indicated in highlighted text.

Date	No. of People	Area Tested	Status Start Time	Status Stop Time	Duration min.	Operational Status - Comments		Track Method	Pattern	Field Conditions	
04/27/07	2	CALIBRATION LANES	910	943	33	DOWNTIME DUE TO EQUIPMENT MAINTENANCE/CHECK	Verifying data	NA	NA	Sunny	Cool
04/27/07	2	CALIBRATION LANES	943	1030	47	COLLECTING DATA	Collecting data, South - North - West - East	GPS	Linear	Sunny	Cool
04/27/07	2	CALIBRATION LANES	1030	1255	145	DOWNTIME DUE TO EQUIPMENT MAINTENANCE/CHECK	Problems with data processor, comp continuing to freeze	NA	NA	Sunny	Warm
04/27/07	2	CALIBRATION LANES	1255	1425	90	COLLECTING DATA	Collecting data, South - North - West - East	GPS	Linear	Sunny	Warm
04/27/07	2	CALIBRATION LANES	1425	1438	13	DOWNTIME DUE TO EQUIPMENT MAINTENANCE/CHECK	Replacing batteries	NA	NA	Sunny	Warm
04/27/07	2	CALIBRATION LANES	1438	1540	62	COLLECTING DATA	Collecting data, South - North - West - East	GPS	Linear	Sunny	Warm
04/27/07	2	CALIBRATION LANES	1540	1608	28	DAILY START, STOP	Breakdown end of day	NA	NA	Sunny	Warm
04/30/07	2	CALIBRATION LANES	638	750	48	DAILY START, STOP	Setup of equipment and calibration	NA	NA	Sunny	Cool
04/30/07	2	CALIBRATION LANES	750	1022	152	COLLECTING DATA	Collecting data, South - North - West - East	GPS	Linear	Sunny	Cool
04/30/07	2	CALIBRATION LANES	1022	1034	12	BREAK/LUNCH	Break, replacing batteries	NA	NA	Sunny	Warm
04/30/07	2	CALIBRATION LANES	1034	1204	90	COLLECTING DATA	Collecting data, South - North - West - East	GPS	Linear	Sunny	Warm
04/30/07	2	CALIBRATION LANES	1204	1305	61	DOWNTIME DUE TO EQUIPMENT FAILURE	Problems with GPS, unable to acquire satellites	NA	NA	Sunny	Warm
04/30/07	2	CALIBRATION LANES	1305	1548	163	COLLECTING DATA	Collecting data, South - North - West - East	GPS	Linear	Sunny	Warm
04/30/07	2	CALIBRATION LANES	1548	1615	27	DAILY START, STOP	Breakdown end of day	NA	NA	Sunny	Warm
05/01/07	2	CALIBRATION LANES	640	735	55	DAILY START, STOP	Setup of equipment and calibration	NA	NA	Cloudy	Cool
05/01/07	2	CALIBRATION LANES	735	816	41	COLLECTING DATA	Collecting data, South - North - West - East	GPS	Linear	Cloudy	Cool
05/01/07	2	CALIBRATION LANES	816	835	19	DOWNTIME DUE TO EQUIPMENT MAINTENANCE/CHECK	Replace batteries	NA	NA	Cloudy	Cool

Note: Activities pertinent to this specific demonstration are indicated in highlighted text.

Date	No. of People	Area Tested	Status Start Time	Status Stop Time	Duration min.	Operational Status - Comments		Track Method	Pattern	Field Conditions	
05/01/07	2	CALIBRATION LANES	835	1040	125	COLLECTING DATA	Collecting data, South - North - West - East	GPS	Linear	Cloudy	Cool
05/01/07	2	CALIBRATION LANES	1040	1059	19	DOWNTIME DUE TO EQUIPMENT FAILURE	Replace batteries	NA	NA	Cloudy	Cool
05/01/07	2	CALIBRATION LANES	1059	1210	71	COLLECTING DATA	Collecting data, South - North - West - East	GPS	Linear	Cloudy	Cool
05/01/07	2	CALIBRATION LANES	1210	1228	18	BREAK/LUNCH	Lunch	NA	NA	Sunny	Warm
05/01/07	2	CALIBRATION LANES	1228	1409	101	COLLECTING DATA	Collecting data, South - North - West - East	GPS	Linear	Sunny	Warm
05/01/07	2	CALIBRATION LANES	1409	1417	8	DOWNTIME DUE TO EQUIPMENT FAILURE	Replacing batteries	NA	NA	Sunny	Warm
05/01/07	2	CALIBRATION LANES	1417	1456	39	COLLECTING DATA	Collecting data, South - North - West - East	GPS	Linear	Sunny	Warm
05/01/07	2	CALIBRATION LANES	1456	1528	32	DAILY START, STOP	Breakdown end of day	NA	NA	Sunny	Warm
05/02/07	2	CALIBRATION LANES	638	714	36	DAILY START, STOP	Setup of equipment and calibration	NA	NA	Sunny	Cool
05/02/07	2	CALIBRATION LANES	714	850	96	COLLECTING DATA	Collecting data, South - North - West - East	GPS	Linear	Sunny	Cool
05/02/07	2	CALIBRATION LANES	850	907	17	DOWNTIME DUE TO EQUIPMENT MAINTENANCE/CHECK	Replacing batteries	NA	NA	Sunny	Cool
05/02/07	2	CALIBRATION LANES	907	1144	157	COLLECTING DATA	Collecting data, South - North - West - East	GPS	G	Sunny	Cool
05/02/07	2	CALIBRATION LANES	1144	1312	88	DOWNTIME DUE TO EQUIPMENT MAINTENANCE/CHECK	Verifying data	NA	NA	Sunny	Cool
05/02/07	2	CALIBRATION LANES	1312	1440	88	COLLECTING DATA	Collecting data, South - North - West - East	GPS	Linear	Sunny	Warm
05/02/07	2	CALIBRATION LANES	1440	1525	45	DAILY START, STOP	Breakdown end of day	NA	NA	Sunny	Warm
05/03/07	2	CALIBRATION LANES	655	725	30	DAILY START, STOP	Setup of equipment and calibration	NA	NA	Sunny	Cool
05/03/07	2	BLIND TEST GRID	725	1155	270	COLLECTING DATA	Collecting data, South - North - West - East	GPS	Linear	Sunny	Cool
05/03/07	2	BLIND TEST GRID	1155	1330	95	DEMOBILIZATION	Breakdown end of test	NA	NA	Sunny	Cool

Note: Activities pertinent to this specific demonstration are indicated in highlighted text.

APPENDIX E. REFERENCES

1. Standardized UXO Technology Demonstration Site Handbook, DTC Project No. 8-CO-160-000-473, Report No. ATC-8349, March 2002.

2. Aberdeen Proving Ground Soil Survey Report, October 1998.

3. Data Summary, UXO Standardized Test Site: APG Soils Description, May 2002.

4. Yuma Proving Ground Soil Survey Report, May 2003.

5. Practical Nonparametric Statistics, W.J. Conover, John Wiley & Sons, 1980, pages 144 through 151.

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APPENDIX F. ABBREVIATIONS

AOL	=	Advanced Ordnance Locator
APG	=	U.S. Army Aberdeen Proving Ground
ATC	=	U.S. Army Aberdeen Test Center
DAQ	=	data acquisition
DMM	=	discarded military munitions
EM	=	electromagnetic
EMI	=	electromagnetic interference
ERDC	=	U.S. Army Corps of Engineers Engineer Research and Development Center
EST	=	Eastern Standard Time
ESTCP	=	Environmental Security Technology Certification Program
EQT	=	Army Environmental Quality Technology Program
GPS	=	Global Positioning System
HEAT	=	high-explosive antitank
JPG	=	Jefferson Proving Ground
MAG	=	Magnetometer
MEC	=	munitions and weapons of concern
NAVEODTECHDIV	=	Naval Explosive Ordnance Disposal Technology Division
NS	=	nonstandard
POC	=	point of contact
QA	=	quality assurance
QC	=	quality control
ROC	=	receiver-operating characteristic
RTK	=	real-time kinematic
RTS	=	robotic total station
SERDP	=	Strategic Environmental Research and Development Program
TNT	=	trinitrotulene
USAEC	=	U.S. Army Environmental Command
UXO	=	unexploded ordnance
YPG	=	U.S. Army Yuma Proving Ground

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