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Advanced UXO Detection/Discrimination Technology Demonstration–U.S. Army Jefferson Proving Ground, Madison, Indiana

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Contents

List of Figures

List of Tables

Preface

The work documented in this report was performed during the period June to November 2000 as part of the Unexploded Ordnance (UXO) Technology Demonstration Program. This program was funded by the Department of Defense's Environmental Security Technology Certification Program (ESTCP) and directed by Dr. Jeffrey Marqusee. Funding for the analysis documented in this report was provided by the Installation Restoration Research Program, U.S. Army Corps of Engineers, directed by Dr. M. John Cullinane, Environmental Laboratory (EL), U.S. Army Engineer Research and Development Center (ERDC), Vicksburg, MS, site.

Mr. Hien Dinh, Naval Explosive Ordnance Disposal Technology Division, Indian Head, Maryland, had overall responsibility for the ESTCP project and was responsible for procuring and preparing the UXO test targets used for this study. Dr. Ernesto R. Cespedes, EL, ERDC, was responsible for planning and executing the field demonstrations and was the author of this report. He developed the metrics used to evaluate the performance of the demonstrators, participated in the field demonstration activities, and directed the analysis of the results. EL UXO team members who assisted with the data processing, analysis, and presentation of results include Ms. Diane Cargile, Mr. H.H. Bennett, Ms. Tere Demoss, and Mr. Ricky Goodson. Mr. George Robitaille, U.S. Army Environmental Center, was a co-principal investigator on the ESTCP project and was responsible for providing most of the clutter items used for this study and coordinating with regulators, including local, state, and Federal. The review and recommendations provided by Dr. Anne Andrews, Institute for Defense Analyses, are gratefully acknowledged.

This project was performed under the general supervision of Dr. David Tazik, Chief, Ecosystem Evaluation and Engineering Division, and Dr. Edwin A. Theriot, Acting Director, EL.

At the time of publication of this report, the Director of ERDC was Dr. James R. Houston, and the Commander and Executive Director was COL John W. Morris III, EN.

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1 Introduction

The Environmental Security Technology Certification Program (ESTCP) funded the Naval Explosive Ordnance Disposal Technology Division (NAVEODTECHDIV) (lead agency), the U.S. Army Engineer Research and Development Center (ERDC), and the U.S. Army Environmental Center (AEC) to design and conduct controlled technology demonstrations at the U.S. Army Jefferson Proving Ground (JPG) in Madison, Indiana. These technology demonstrations were conducted during the period June to November 2000 at three 1-hectare areas located near the test site used during the JPG Phase IV demonstrations (NAVEODTECHDIV 2000a)). The demonstrations were designed to assess the capabilities of state-of-the-art technologies to detect, discriminate, and identify unexploded ordnance (UXO) in areas containing natural (magnetic rocks/soils) and man-made (munitions fragments) clutter. This report documents the results of these demonstrations and is intended to aid the Government in selecting effective and efficient systems for UXO detection and discrimination in difficult magnetic clutter sites such as those encountered at Kaho'olawe, Hawaii.

Background Information

The Department of Defense (DOD) is currently involved in a number of UXO site remediation efforts where rapid transition of advanced technologies can save substantial sums of money, improve UXO detection efficiency, and significantly expedite the transfer of lands for reuse. One of the most prominent of these efforts is the ongoing UXO cleanup of the Kaho'olawe bombing ranges. The major difficulty with this site is that the significant magnetic anomalies from geologic sources and near-surface fragments make traditional magnetometer-based surveys impractical. Even surveys conducted with commercially available electromagnetic induction (EMI) instruments such as the Geonics EM-61 have performed ineffectively in these conditions. As of 1 March 2000, contractors at Kaho'olawe have detected 12,121 subsurface anomalies, and after digging, they have found that only 4 percent are UXO, 32 percent are false positives resulting from geologic variations, and 64 percent are the result of buried metal from both UXO and non-UXO-related materials (NAVEODTECHDIV 2000b). The focus of this project is to evaluate the top sensing technologies identified during previous JPG demonstrations, but under more realistic conditions, in order to quantify their detection, discrimination, cost, and production rates while operating at several areas within JPG that contain varying degrees of geologic magnetic noise. The purpose of this report is to aid managers of UXO cleanup projects, as well as regulators and other stakeholders, to make informed decisions concerning the capabilities, costs, and risks associated with applying these technologies to their site-specific UXO remediation projects. A list of points of contact from the regulatory and other communities who are aware of this demonstration project is provided in Appendix A. Following in-depth evaluation of performance at the JPG site, ESTCP plans to transition the most promising technologies to Kaho'olawe for additional demonstrations at controlled and live sites during FY01.

This project was designed to incorporate the lessons learned from previous UXO technology demonstrations and to extend the results of the JPG Phase IV Demonstrations that were completed during FY 97. The JPG Phase IV results indicated that advanced UXO sensing and processing technologies have the potential to significantly reduce the number of false alarms. Unfortunately, those demonstrations incorporated a number of artificial factors that limited the validity of the conclusions that could be determined from the results. Some of the artificialities included the use of nonrealistic clutter items, the fact that all of the clutter items were made available to the demonstrators for system training prior to the field tests, and the lack of wide area search requirements (i.e., target locations were provided to the demonstrators). In addition, JPG Phase IV demonstrations did not provide the operational performance data required to quantify the cost savings and risks associated with using these technologies in actual cleanup operations.

Official DOD Requirement Statement(s)

This project addresses the Tri-Service Environmental Quality Research, Development, Test, and Evaluation Strategic Plan, UXO requirements, and more specifically, the U.S. Army requirement A(1.6a), titled: UXO Screening, Detection, and Discrimination and described the FY99 Army Environmental Requirements and Technology Assessments (AERTA). This Army requirement has been ranked as the highest priority user need in the Environmental Cleanup Pillar. In addition, this project addresses the UXO detection and discrimination requirements and recommendations described in the Defense Science Board Task Force Final Report on UXO Clearance and Remediation published in 1998 and will provide data to support the development of more accurate estimates of the overall DOD UXO environmental remediation costs.

The advanced technologies demonstrated as part of this effort address all aspects of the requirements for land-based, man portable buried UXO detection and discrimination systems. The results of these demonstrations were used to quantify the capability of state-of-the-art systems to detect, locate, classify, and identify buried targets. The performance of the advanced systems was compared with the baseline comprised of traditional "mag and flag" surveys, and costs and production rates of each technology were documented.

This technology demonstration creates a framework for the evaluation of state-of-the art sensor technologies to detect, locate, and identify UXO. Baseline technology performance is established and technology capabilities and limitations are assessed. Results from this program will be widely distributed to aid in the selection and utilization of companies, systems, and sensors for UXO characterization and restoration efforts.

Objectives of the Demonstration

The overall technical objective of this demonstration project was to evaluate the detection and discrimination capabilities (including production rates and costs) of advanced UXO systems in difficult magnetic clutter environments such as those encountered at Kaho'olawe, Hawaii. Three test areas within JPG were prepared to present a limited range of conditions to the various demonstrators to identify scenarios where one technology may be better suited than the others.

The evaluation objectives for the demonstrations were as follows:

a. To evaluate the demonstrators' detection and discrimination capabilities by means of surveys of three 1-hectare areas within Jefferson Proving Ground under realistic target/ geologic clutter/ man-made clutter/ topography scenarios and while operating as efficiently as possible (minimizing time, manpower, and costs).

b. To evaluate the demonstrators' ability to analyze survey data onsite as efficiently as possible and provide prioritized "dig lists" with associated classification confidence levels. (These dig lists are available via the ftp server listed in Appendix B.)

c. To collect manpower, time, and cost data for all tasks required to produce their final products (prioritized dig sheets and georeferenced anomaly maps).

d. To compare the performance of the advanced systems with the baseline "mag and flag" technology.

e. To provide high quality, ground-truthed, georeferenced data for post-demonstration analysis, development of Receiver Operating Characteristic (ROC) curves, and for use by other Government, university, and industry researchers to develop improved models and analysis technologies.

Regulatory Issues

The primary regulatory issue affecting UXO detection and discrimination technologies is gaining confidence and approval from Federal, state, and local regulators, stakeholders, and users. In addition, acceptance of these innovative technologies from agencies such as the U.S. Army Corps of Engineers and the Naval Facilities and Engineering Command is needed to ensure that future Requests for Proposals (RFPs) for UXO cleanup projects will be written in a manner that will either sanction these technologies, or at least allow their inclusion in proposals for site work.

Previous Testing of the Technology

Versions of the technologies demonstrated under this effort have been previously tested as part of the Defense Advanced Research Projects Agency (DARPA) Clutter Experiment (FY97), the Jefferson Proving Ground Phases II through IV Demonstrations, and a number of ESTCP-funded field demonstration projects. However, this is the first set of controlled field experiments where the three technologies have been tested under realistic conditions that allow for side-by-side comparison of performance, production rates, and costs.

2 Technology Description

Description

The three advanced technologies demonstrated under this project include a) the Geophex Ltd. GEM-3, a multichannel frequency domain electromagnetic induction (EMI) sensor system operated by Geophex Ltd. personnel with processing support from AETC Corp., b) the Naval Research Laboratory (NRL) Man-Portable EM System (EMMS) Adjunct to the Multisensor Towed Array Detection System (MTADS) system, a single time-channel time domain EMI sensor operated by personnel from NRL with processing support from AETC Corp, and c) the Geonics Ltd. EM-63, a multi-channel time domain EMI sensor operated by personnel from NAEVA Geophysics. Each of the three sensors was integrated into a man-portable platform that included data acquisition/storage and differential Global Positioning System (GPS) receivers. These sensor systems are shown in Figures 1 through 3 conducting surveys at the JPG test areas. Descriptions of these three systems are included in the Technology Demonstration Plan (NAVEODTECHDIV 2000a).

In addition to the EMI surveys conducted by these three systems, magnetic surveys of the three areas were conducted by NRL with a combination of the MTADS vehicular-towed magnetometer array and the Man-Portable Magnetometer System (MMS) shown in Figures 4 and 5, and by EODT Technology, Inc. (a commercial UXO services firm under contract to the U.S. Army Corps of Engineers, Engineering and Support Center, Huntsville), using the Schonstedt handheld GA-52Cx magnetic gradiometer shown in Figure 6. The MTADS/MMS platforms collected georeferenced total magnetic field data over the three test areas. The purpose of the MTADS/MMS survey was to collect a more complete data set to support postdemonstration analysis and to identify/quantify any performance improvements resulting from adding magnetometer information to the EMI data. The Schonstedt GA-52 Cx is an analog magnetic gradiometer that provides only an audio signal to the operator when it senses a disturbance in the magnetic field (most likely caused by a buried ferrous object). The operator is then responsible for interpreting the strength and spatial extent of the audio signal to determine if it corresponds to an UXO-sized object; if so, he places a plastic pin flag at the estimated location of the object. EODT personnel were provided samples of emplaced ordnance and were instructed to disregard any buried object that they determined to be smaller than the smallest emplaced munition (20-mm projectiles). ERDC personnel then surveyed each flagged location to produce the georeferenced "mag and flag" maps included in this report. The purpose of the

Schonstedt survey was to establish a baseline for detection performance, cost, and production rate for comparison with the advanced EMI systems.

Strengths, Advantages, and Weaknesses

The following paragraphs represent a summary of the perceived, claimed, and documented capabilities of each of the three technology demonstrators, compared to currently fielded, standard UXO technologies (e.g., "mag and flag", digital magnetometer/gradiometer, and single-channel EMI systems such as the EM-61).

GEM-3

The strength of the GEM-3 system is claimed to lie in its ability to rapidly collect multiple channels of complex frequency domain EMI data over a wide range of audio frequencies (30 Hz to over 20 kHz). This allows for performing what Geophex Ltd., the developer of the system, calls Electromagnetic Induction Spectroscopy (EMIS) of buried objects (Won, Keiswetter, and Nobikova 1998). EMIS provides a method to discriminate UXO targets from natural and manmade clutter objects by means of their unique, complex (inphase and quadrature) frequency responses. The GEM-3 system was the top performer in the discrimination and identification tests conducted during JPG Phase IV. A concern and possible weakness of the GEM-3 is that, to accomplish a wide area detection and discrimination survey in a reasonable time, it must keep the number of frequencies to a relatively low number (seven in the case of these JPG tests) and must transmit them simultaneously rather than sequentially as was done during the static JPG IV tests. This simultaneous transmission of multiple frequencies may reduce the power dedicated to each frequency and this could affect the depth capability of the GEM-3 system. Another possible weakness of the GEM-3 system is that high-accuracy position information is required to perform the discrimination. In the previous JPG IV demonstrations, this high degree of position accuracy was obtained by means of templates placed over specified target locations allowing static point measurements to be made. That approach was not viable for the wide area search requirements of the current project and Geophex had to rely on Global Positioning System (GPS) position information, which results in significantly greater position errors and sparser data sets. Finally, it was observed that the GEM-3 system is still in development and the sensor design, platform, and analysis approaches have not been optimized or finalized. This problem surfaced during the JPG field demonstrations when it was realized that the UXO signatures library had been collected with a coil size that was different from the one used for the JPG field surveys.

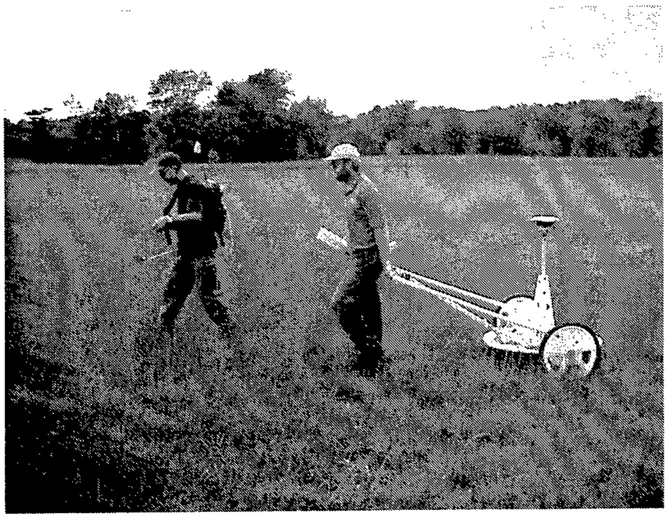


Figure 1. GEM-3 operated by Geophex Ltd.

Figure 4. MMS operated by NRL

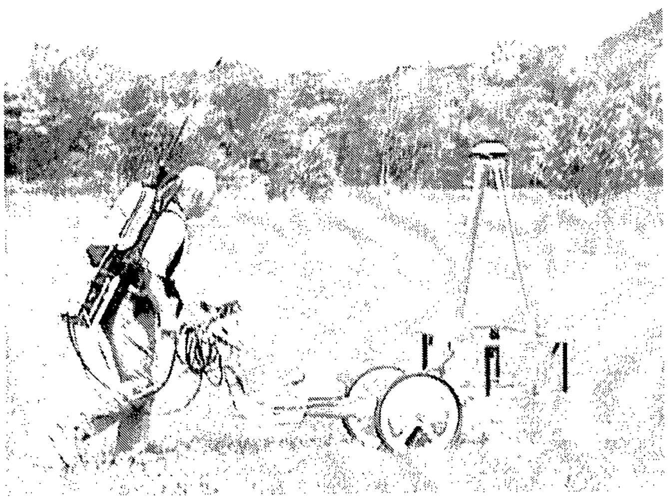


Figure 2. EMMS operated by NRL

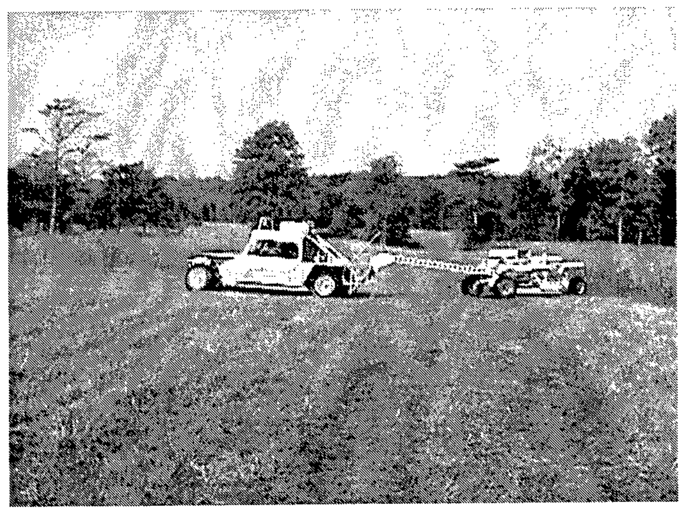


Figure 5. MTADS operated by NRL

Figure 3. EM-63 operated by NAEVA

Figure 6. GA-52Cx operated by EODT

EMMS

The EMMS is derived from the highly successful MTADS development effort and thus incorporates many of its sensing, navigation, and data analysis system (DAS) advances demonstrated and documented in a number of ESTCP-funded field demonstrations. The specifications and performance improvements incorporated into the version of the EMMS demonstrated at JPG are fully described in the ESTCP report titled "Man-Portable Adjuncts for the MTADS" (Naval Research Laboratory 2001). Based on a modified version of the commercially available EM-61, the most widely used EMI system for UXO detection applications, the EMMS sensor is expected to have good UXO detection capability to the maximum depths of the objects emplaced at JPG. Coupled with the very high accuracy of the MTADS-derived, digital inclinometer/GPS system, the EMMS is expected to produce high quality georeferenced EMI data. A potential limitation of the EMMS is the single channel of data available, which may limit the discrimination performance compared to what can ultimately be achieved by multichannel systems. However, the extent to which the additional data available in these other systems can be exploited to improve performance has not been established in field conditions and this demonstration provides an early opportunity to do some initial comparisons. In addition, the EMMS was used at this demonstration with a recently developed software classification algorithm that had not been extensively evaluated in realistic field tests.

EM-63

The strengths of the EM-63 are similar to those attributed to the GEM-3, since they are both capable of collecting multiple channels of information at each survey point. The EM-63 collects multiple channels of time domain data for each point surveyed, thereby enhancing the amount of information available to perform discrimination and identification of buried targets. Unlike other prototype and/or developmental systems, the EM-63 is a commercially available sensor (produced by Geonics Ltd. which also manufactures the EM-61) and has been ruggedized for field use. Another significant strength of the system demonstrated at JPG is the processing expertise of NAEVA personnel. During previous JPG demonstrations, NAEVA has consistently ranked among the top performers, even though they had employed sensor data that were equivalent to that of other less-successful demonstrators. Perceived weaknesses of the NAEVA EM-63 demonstration system include their limited experience with the EM-63, since it has only recently become available, and NAEVA has had very limited access to the sensor (via rental arrangements) prior to the JPG tests. In addition, the analysis techniques were still under development and had not been fully tested nor implemented in transportable computers at the time that NAEVA arrived at JPG for the required demonstrations. Finally, the commercial GPS system was integrated with the EM-63 only shortly before arriving at JPG and, as a result, NAEVA personnel had very limited experience operating the system.

Factors Influencing Cost and Performance

The factors evaluated as part of this project that influence the cost and performance of each of these systems include:

a. Equipment setup and calibration time and man-hour requirements.

b. Actual survey time and man-hour requirements for each of the three test areas.

c. Downtime resulting from system malfunctions and maintenance requirements.

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

e. Data processing/analysis time and man-hour requirements.

f. Detection performance and false alarm rates (as determined from prioritized dig lists with associated confidence levels).

g. Discrimination capability (ability to separate detected anomalies into UXO and non-UXO objects).

h. Identification capability (ability to classify UXO targets by class (e.g., mortar, projectile) and type (e.g., 152 mm).

i. Predicted target location accuracy (including depth estimates).

This demonstration at JPG was designed to collect the necessary information to evaluate each of these cost and performance factors. The Demonstration Workplan (NAVEODTECHDIV 2000a) includes a detailed description of the methods and metrics used to evaluate each of the factors.

3 Site/Facility Description

Background

The selection criteria for the three JPG demonstration areas are detailed in the Site Preparation Plan (NAVEODTECHDIV 2000b). The selection of the test areas was driven by the main demonstration objective, which was to evaluate the performance of advanced EMI technologies in the presence of magnetic noise from geologic sources and in different terrains. In addition, the three sites were seeded with varying concentrations of inert UXO and man-made clutter items.

Site/Facility Characteristics

The three 1-hectare areas within JPG were selected to provide the demonstrators with varying degrees of natural magnetic clutter and terrain difficulty. Area 1 was selected because it contains very high magnitude magnetic anomalies from geologic sources that cover a fairly large area as shown in Figure 7. The long magnetic anomaly (red area) appearing near the center of Area 1 represents variations from the background mean of +150 nT to –100 nT as measured by the MTADS system during previous JPG surveys. Area 1 has sparse tree/shrub coverage and its topography includes rolling terrain and ditches. Area 1 was seeded with the largest concentration of target and clutter items, and a substantial number of these were placed within the high magnetic background locations. Area 2, also shown in Figure 7, was chosen because it has a significant number of magnetic geologic anomalies (red area). In Area 2 the magnetic anomalies are more compact and lower in magnitude (+ 35 nT), thus providing a different clutter problem from that of Area 1. The topography in Area 2 also includes rolling terrain and a small ravine. Area 2 was seeded with a smaller number of target and clutter items than Area 1. Area 3 was chosen because it has very low amplitude magnetic anomalies from geologic sources and very flat terrain. This area has a variation from the mean background of only $\pm$6 nT. Area 3 was seeded with the fewest UXO target and clutter items. The Site Preparation Plan (Appendix C) includes topographic maps of these three areas prior to any target emplacement activities. The emplaced target locations are included in Appendix C, Site Preparation Plan, and are part of the ground truth, which will be released at the discretion of the ESTCP Program Office

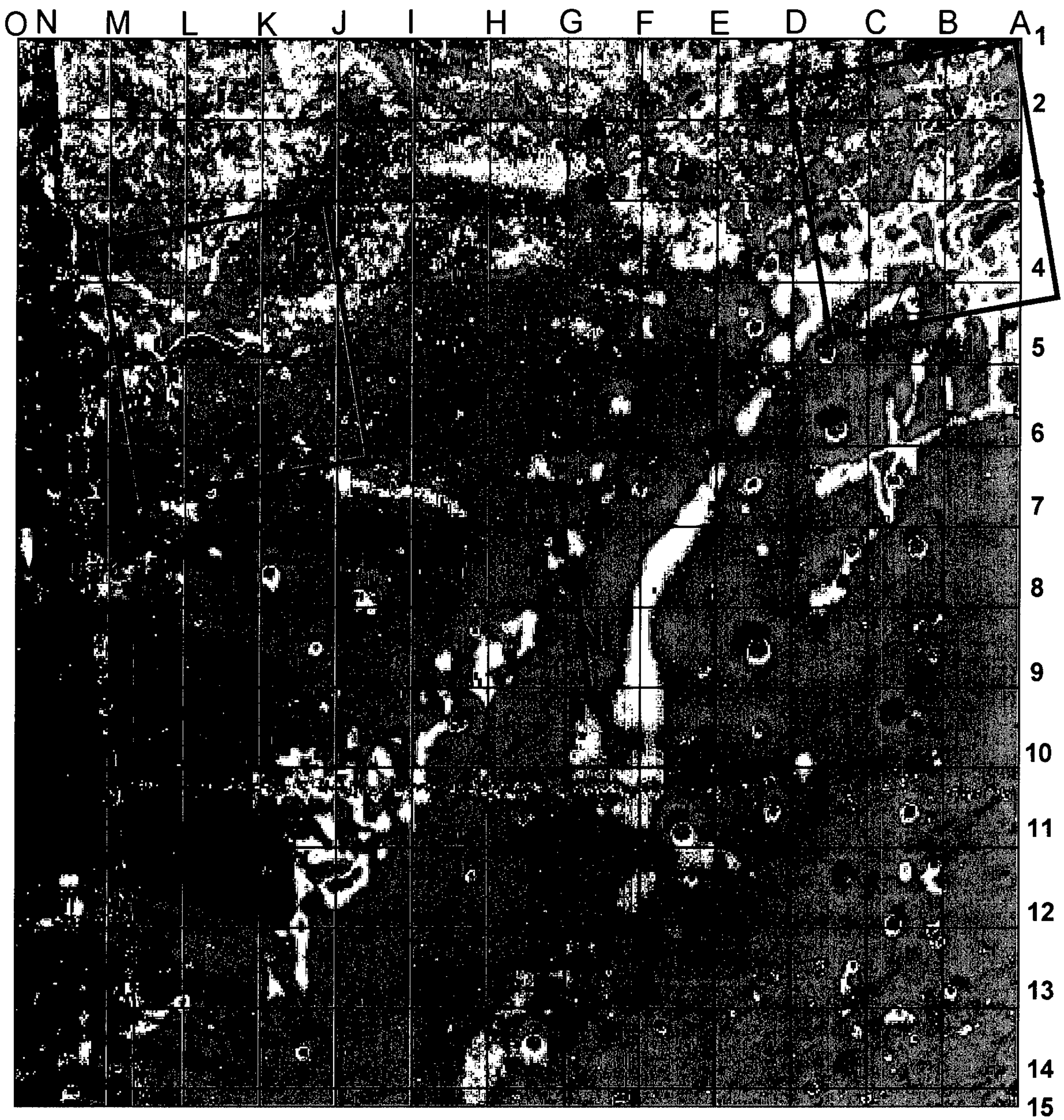


Figure 7. JPG site map showing magnetic anomalies in Areas 1 and 2. (Magnetic data collected by MTADS system (NRL) and provided by AETC)

4 Demonstration Approach

Performance Objectives

The rationale driving the design of this demonstration is based on the application of lessons learned from past JPG demonstrations to address a specific UXO Environmental Remediation goal – the cleanup of Kaho'olawe-type sites. As a result, this demonstration was planned to simultaneously evaluate the detection and discrimination capabilities of advanced UXO systems under realistic time and cost (manpower) considerations. Based on the results of the JPG Phase III and Phase IV demonstrations, we identified the need to couple production rates and costs to the detection and discrimination capabilities of the systems. As a result, this demonstration included survey and analysis time requirements, as well as man-hour requirements, in the evaluation factors. Based on concerns raised by JPG Phase IV demonstrators, no unrealistic (fabricated) clutter items were used; instead, actual munitions fragments and magnetic rocks from actual UXO remediation sites were employed. Also, based on previous JPG experience, all inert UXO targets that had not been previously fired/shot were demagnetized prior to emplacement to simulate the magnetic properties of ordnance that has been fired. The procedures used to demagnetize the UXO targets are described in the Site Preparation Plan and are summarized in the following text. In addition, extra precautions were taken to avoid surface disturbances (e.g., the "bathtub" effect) that could alert the demonstrators to the presence of a buried object. An angle drill/push rig was used to emplace most of the medium and large inert UXO items.

The scope of this demonstration was not intended to be a competition where the Government declares an overall winner. However, it was intended to collect sufficient information from this limited range of test scenarios to quantify the advantages and disadvantages of each of the three technologies so that they may be properly applied to specific UXO cleanup problems. The immediate goal of this effort is to collect the data needed to identify appropriate technologies to transition to Kaho'olawe-type environments where natural (magnetic rocks/soils) and man-made (munitions fragments) clutter have rendered cleanup operations using conventional technologies both expensive and ineffective. A longer-term objective of this demonstration is to provide high-quality, georeferenced data to support sensor development and improvements in UXO analysis technologies.

The goals of this demonstration are to:

a. Evaluate demonstrators operating in realistic target, geologic clutter, man-made clutter, and topography scenarios. Criteria for evaluation are:

(1) Detection, discrimination, and identification capabilities based on prioritized dig lists produced from onsite data analysis.

(2) Manpower, time, and costs required to produce onsite dig lists.

(3) Additional detection and discrimination capabilities based on offsite, post demonstration analyses.

b. Provide baseline data for comparison of advanced EMI technologies with traditional "mag and flag."

c. Archive high-quality, ground-truthed, georeferenced data for broader use in the UXO technology development community.

Physical Setup and Operation

Descriptions of the inert UXO targets and the clutter items used for this demonstration are included in the Site Preparation Plan (Appendix C). Photographs, descriptions, dimensions, and emplacement information of each target and clutter item are available as part of the ground-truthed information in CD form from the ESTCP program office. Briefly, the UXO targets ranged from 20-mm projectiles buried near the surface to 155-mm projectiles buried up to 1.2 m below the surface. Clutter items emplaced ranged from small (less than 0.5-kg) to large (up to 5-kg) munitions fragments and included large magnetic rocks and man-made clutter such as horseshoes and metal banding. A 2-m by 2-m area around each planned target location was surveyed with a G-858 magnetometer to detect and remove any metallic objects prior to emplacing an inert UXO target. The results of these surveys are available from the data server listed in Appendix B.

Degaussing of the small UXO items was performed using an AudioLab magnetic tape degausser, Model TD-5, and the magnetic signatures were measured with a Geometrics Model G-822L portable magnetometer. Prior to degaussing, the magnetic state of the item was determined by aligning it with the nose pointing North at a set distance from the magnetometer. The item was then rotated 180 deg so that the tail was facing the magnetometer and at the same preset distance. The difference between the two readings was recorded and the item placed on the degausser to lower the difference to 2nT or 20-percent of the original difference reading with the degausser. The time of degaussing and the power setting used were varied as needed to obtain the desired reduction in the difference measurements. The larger items, such as 5-in. projectiles and 155-mm projectiles, were degaussed using the fixed facilities at NAVEODTECHDIV. The magnetization of each large UXO item was checked in the three orthogonal orientations using the same magnetometer and procedures as before, and the item was then degaussed in the three directions until all three difference readings matched the tolerances listed previously.

Samples of each of the UXO targets emplaced were made available to each demonstrator prior to arriving on site for signature collection and system training, and additional samples were also available at the demonstration site for calibration purposes. Unlike the previous JPG tests, the clutter items were not made available to the demonstrators for signature collection and system training. A 2 m-long by 0.75 m-wide by 0.75 m-deep trench in the calibration area (NAVEODTECHDIV 2000a) located near test area 2 was made available to demonstrators for system calibration and checkout purposes.

Three resurveyed, first-order control points located within the original JPG 40 acre site were made available for demonstrators to set up GPS base stations. The primary reference monument is located near the southwest corner of Test Area 3 and was used as the reference point for all site preparation and demonstration activities. This marker was brought up to first-order accuracy during the site preparation activities, and updated coordinates were provided to the demonstrators prior to the scheduled demonstrations. Two other monuments were also resurveyed to first-order accuracy and made available to the demonstrators. One was designated Monument #1 (see NAVEODTECHDIV 2000a) and is located within test Area 2 near its south boundary. The other is designated Monument #3 and is located approximately 40 m southwest of Test Area 1.

The Government installed a meteorological station near the three 1-hectare areas to continuously record weather conditions beginning 1 month prior to the demonstrations and continuing through the end of the testing periods. These data were automatically recorded at 15-min intervals and transmitted to ERDC for archiving. It includes wind speed, wind direction, solar insolation, rainfall, temperature, humidity, and soil moisture. The archived data are available from ERDC upon request. It should be noted that other than short delays (under 2-hr duration) resulting from rain, there were no significant weather events during the scheduled field work that affected the demonstrations. There were, however, several severe weather events recorded during nonsurvey periods that resulted in partial flooding of some of the test areas and forced the demonstrators to modify their planned survey order to allow time for the areas to drain. Some small portions of the test grids remained under standing water for long periods of time, and demonstrators had to survey in conditions characterized by 10 to 20 cm of standing water and soft soil.

The four corners of each test area were surveyed by the Government and marked with a metallic marker (rebar) driven flush with the ground for use by the demonstrators as fiducial markers to check/correct their position information. Plastic pin flags were placed at 5-m increments along the perimeter of each of the test areas to assist in maintaining proper lane spacing.

The demonstration test areas were mowed as part of the site preparation activities during June 2000. Prior to starting surveys, the first demonstrator (Geophex) inspected the test areas and determined that additional mowing was not required for their survey activities. The site was mowed for a second time prior to arrival of the second demonstrator (NRL). No additional mowing was conducted until the completion of the “mag and flag” surveys during November 2000.

Sampling Procedures

The Demonstration Work Plan describes the procedures required for each of the demonstrations. Demonstrators were responsible for developing their specific survey plans (including lane spacing, sampling rate, number of channels recorded, calibration methods, etc.) and these procedures, together with their analysis techniques, are described in Appendix C.

Each of the demonstrators was allotted one 10-day period (Monday through Wednesday of the following week) during 14 August 2000 through 20 September 2000 to complete their surveys and submit the required onsite dig sheets. Each workday could extend to a maximum of 10 hr onsite.

Analytical Procedures

The evaluation factors, metrics, products, and procedures related to this demonstration are described in the Demonstration Workplan and include the following information:

a. Equipment setup, calibration time, and man-hour requirements.

b. Actual survey time and man-hour requirements for each of the three test areas.

c. Downtime because of system malfunctions and maintenance requirements.

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

e. Actual data processing/analysis time and man-hour requirements (all to be performed onsite).

f. Prioritized dig lists with associated confidence levels.

g. Discrimination capability (ability to separate detected anomalies into UXO and non-UXO objects).

h. Identification capability (ability to classify UXO targets by class (e.g., mortar, projectile) and type (e.g., 152 mm).

i. Predicted target location accuracy (including depth estimates).

j. Georeferenced anomaly maps.

k. Probabilities of Detection (Pd).

l. False Alarm Rates (FAR).

The method for determining and documenting the first three items involved the Government onsite representatives tracking and recording the number of personnel and time spent performing each of the tasks. Adequate rest and lunch/dinner breaks were provided and these times were not included in the performance metrics calculations. If, during the analysis of the data, the demonstrator determined that he needed to resurvey any part of the test areas or any previously detected anomalies, all setup, calibration, survey, downtime, and reacquisition times and man-hour requirements were recorded individually (as in items a through c), but were compiled separately as reacquisition/resurvey time (item d).

To evaluate item e, the Government required that all data processing and analysis tasks required to produce items f through j be conducted in the JPG office trailer, and no data be taken offsite until these items are submitted to the onsite Government representative. Demonstrators were responsible for providing all computer hardware, software, and support equipment needed to produce the required analysis products.

Development and evaluation of (previously listed) items f through j are as follows:

a. Each demonstrator was required to combine the EM sensor data with the GPS position information to develop two-dimensional (2-D) anomaly maps of each 1-hectare area. These anomaly maps, together with the corresponding digital geophysical sensor data, were then analyzed to identify all detected anomalies that could potentially be a buried UXO target for each of the three areas. These anomalies were then tabulated into one preliminary dig sheet for each test area. The objective of this phase was to include as many anomalies in these lists as required to ensure as high a Pd as possible for the full range of UXO targets considered.

b. Each anomaly in each list was then further analyzed to develop the final prioritized dig sheets as illustrated in Table 1. The demonstrators were asked to refine the location (x, y) and estimate the burial depth (z) of each object, to attempt to separate (discriminate) UXO from clutter items, to identify UXO by class and type (if possible), and to rank the list in the following descending order: UXO – high confidence, UXO – medium confidence, UXO – low confidence, Clutter – low confidence, Clutter – medium confidence, and Clutter – high confidence. In addition, the list was required to include predicted ordnance class and size (e.g., mortar/81 mm) for all anomalies declared as UXO with high and medium confidence levels, and, if possible, UXO orientation (Azimuth and Inclination).

Table 1
Sample Dig Sheet

Sample Dig List DIG LIST: 1 Demonstrator: EMMS Test Area: 1 Including 20 mm ?: NO

Ranking	Northing meters	Easting meters	Depth meters	Type ordnance/ clutter	Confidence	Size/Weight	Azimuth degrees	Inclination degrees	Class	Type
001	4309738.557	641594.2038	0.9144	ordnance	high	Large	180	20	projectile	152 mm
.										
.										
.										
.										
.										
050	4309689.964	641519.4151	0.89042	ordnance	low	small	-	-	projectile	unknown
.										
.										
165	4309700.031	641516.8877	0.82296	clutter	high	medium	-	-	frag	-

c. Each demonstrator was then required to specify a threshold (row) on each prioritized list where he would recommend that all objects at or above that threshold be excavated and those below be left in place. The goal of this step is to evaluate the demonstrators' ability to discriminate UXO targets from clutter. To add realism to this discrimination decision process, demonstrators were instructed beforehand that the following cost factors would be applied: 1) For every clutter item selected for "digging," a $200 cost penalty was assigned (the average cost of excavating items at actual UXO remediation sites). 2) To reflect the unacceptable risk of leaving UXO in the ground, a very high penalty was assigned if any detected anomaly that corresponded to a UXO target was erroneously declared as clutter and placed in the "no dig" portion of the list. As a result, if one or more UXO items were placed in the "no dig" portion of the list, it would be assumed that the grid (i.e., the entire 1-hectare area) has failed the Quality Assurance and/or regulatory acceptance and a cost penalty equal to the cost of a resurvey would be assigned. One or more missed targets (anomalies too weak to be included in the lists developed in the description of equipment setup, calibration time, and man-hour requirements discussed previously) in each area were also assigned a cost factor equal to the cost of a resurvey, but it should be noted that they reflect a deficiency in the sensor rather than in the analysis and decision making process. Missed targets are also reflected in the less than 100-percent maximum Pd achieved by each system and are documented in this report to aid regulators and managers in assessing residual risks associated with the various sensing technologies.

Items k and l were calculated from the prioritized dig lists as follows: Maximum achievable Pds for each area were calculated as the number of items in the entire list that correspond to emplaced UXO targets (even though they may have been misclassified as clutter) divided by the actual number of UXO targets emplaced in that site. Note that in order to be declared a correct detection, the declared object location must be within a 1-m radius of the actual emplaced target location. The operating (single-point) Pd was determined by calculating the number of actual UXO targets that are included in the list at or above the threshold described in the previous paragraph. Similarly, the operating (single-point) FAR was calculated as the number of clutter items that are above the dig threshold. An ROC-like curve was developed by the Government by varying the dig threshold until the maximum Pd was reached and computing Pd and FAR at each increment. Performance comparisons between systems include using the ROC-like curves to determine FAR at the Pd required for Kaho'olawe Tier II clearance (Pd = 85-percent) and also using the single point performance (Pd and FAR) of the mag and flag surveys as a baseline.

After each demonstrator had submitted the dig sheets described above, the timing for the analysis tasks was stopped and he was to be given the opportunity to reanalyze the data to develop prioritized dig sheets that take into account only targets larger than 20-mm projectiles (20-mm projectiles were assumed to be clutter for this portion of the evaluation). These dig sheets were to be submitted to the Government representative prior to leaving the JPG site. However, because of a late start and ensuing hardware problems that required additional delays for collection of additional calibration, the first onsite demonstrator (Geophex Ltd.)

was unable to complete all of the required data analysis in the allotted time. They requested, and ESTCP approved, a deviation from the Workplan requirement that all processing be conducted onsite. As a result, only the initial sets of dig sheets (EM only including all targets) were required to be submitted prior to departing the site. In addition, the last demonstrator (NAEVA) did not deploy their computer workstations to the JPG site, and subsequently requested and received approval from the ESTCP office to perform the processing offsite. As a result, the integrity of the onsite analysis costs was compromised and affected the overall cost evaluation included in Section 6 of this report. NAEVA transmitted the field survey data offsite for processing and was able to submit a set of dig sheets prior to departing the site so that a comparison of the detection and discrimination performance is still viable.

After all onsite analysis products had been submitted, the demonstrators were provided with magnetometer data collected by MTADS. Demonstrators were then requested to reanalyze their data offsite using this additional information to develop final prioritized dig sheets for each test area.

5 Performance Assessment

Performance Data

In accordance with the Demonstration Test Plan, each of the demonstrators was responsible for determining the best method of employing his system in order to: (a) ensure full coverage of each test area, (b) collect high-quality sensor data to support detection and discrimination requirements, (c) achieve high production rates, and (d) minimize man-hour requirements and costs. All demonstrators were able to complete the field surveys within the allotted time periods (NAVEODTECHDIV 2000a). Figures 8 through 16 show the georeferenced anomaly maps produced by each of the systems used during these demonstrations. The Geophex maps depict the 930-Hz quadrature-phase data in parts-per-million referenced to the primary field strength and color-coded as shown in the corresponding color scale. The EMMS maps depict the single-channel EMI sensor data in millivolts and color-coded as indicated in the corresponding false color scale. The NAEVA maps depict the EM-63 time gate number 10 readings in millivolts, color-coded as indicated in the corresponding scale. In view of the fact that each demonstrator included different data (and in some cases only a small subset of the sensor data acquired) in these anomaly maps, direct comparison and evaluation of the quality and utility of each of these maps is inappropriate. The only overall conclusions that may be derived from these maps is that all three systems demonstrated the capability to suppress the high magnetic background from geologic sources and that all demonstrated the capability to provide high-quality (well-localized, high signal-to-background target signatures) georeferenced data.

The results of the "mag and flag" surveys conducted by EODT (a commercial UXO firm under contract to the Corps of Engineers, Huntsville Engineering Center) were used as a baseline for documenting performance and cost improvements from the application of advanced EMI technologies. The locations flagged by EODT were surveyed by Government personnel using Kinematic Differential GPS (KDGPS) equipment, and the results are presented in Figures 17 and 18.

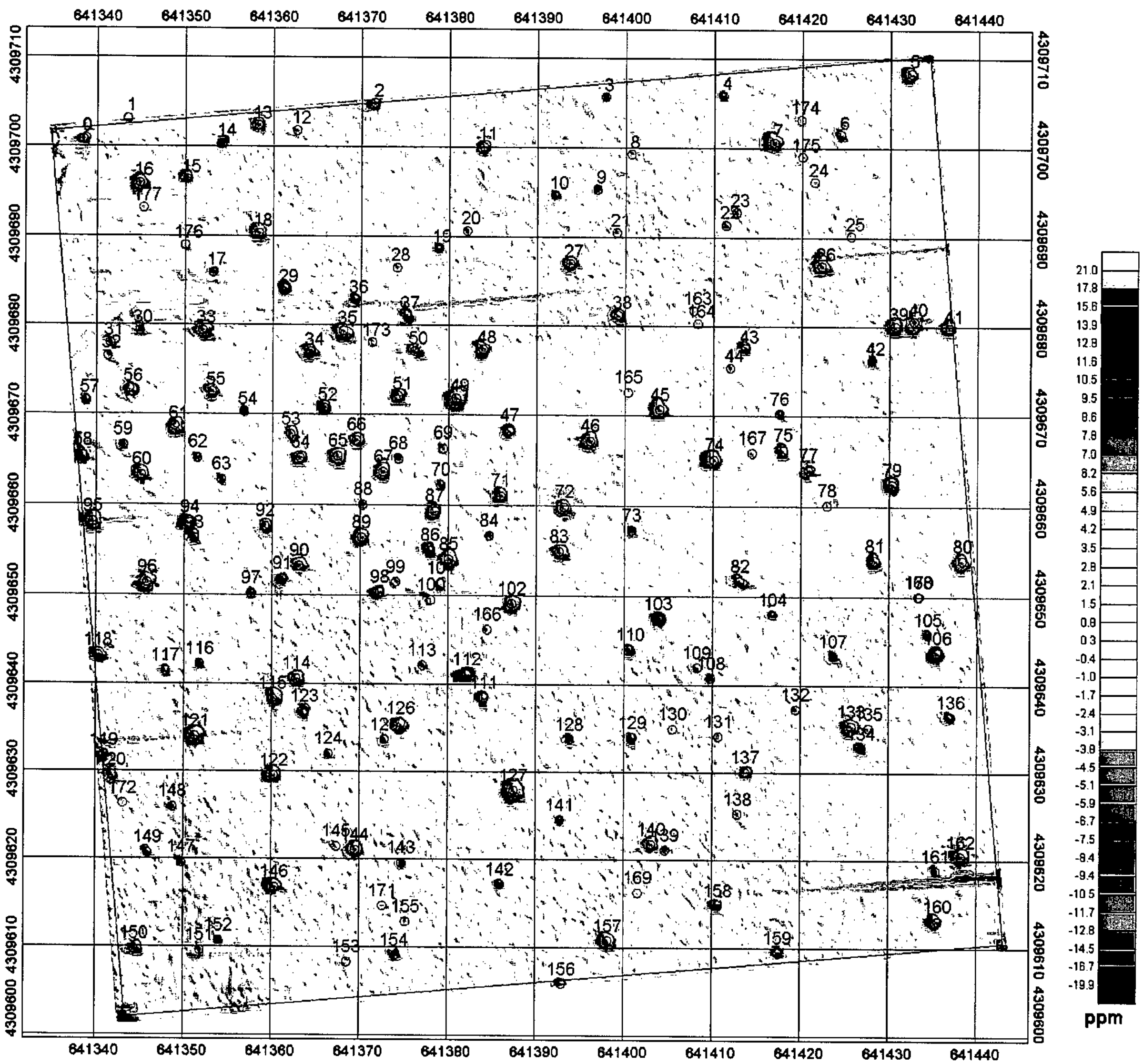


Figure 8. Geophex Ltd. GEM-3 survey results of Area 1

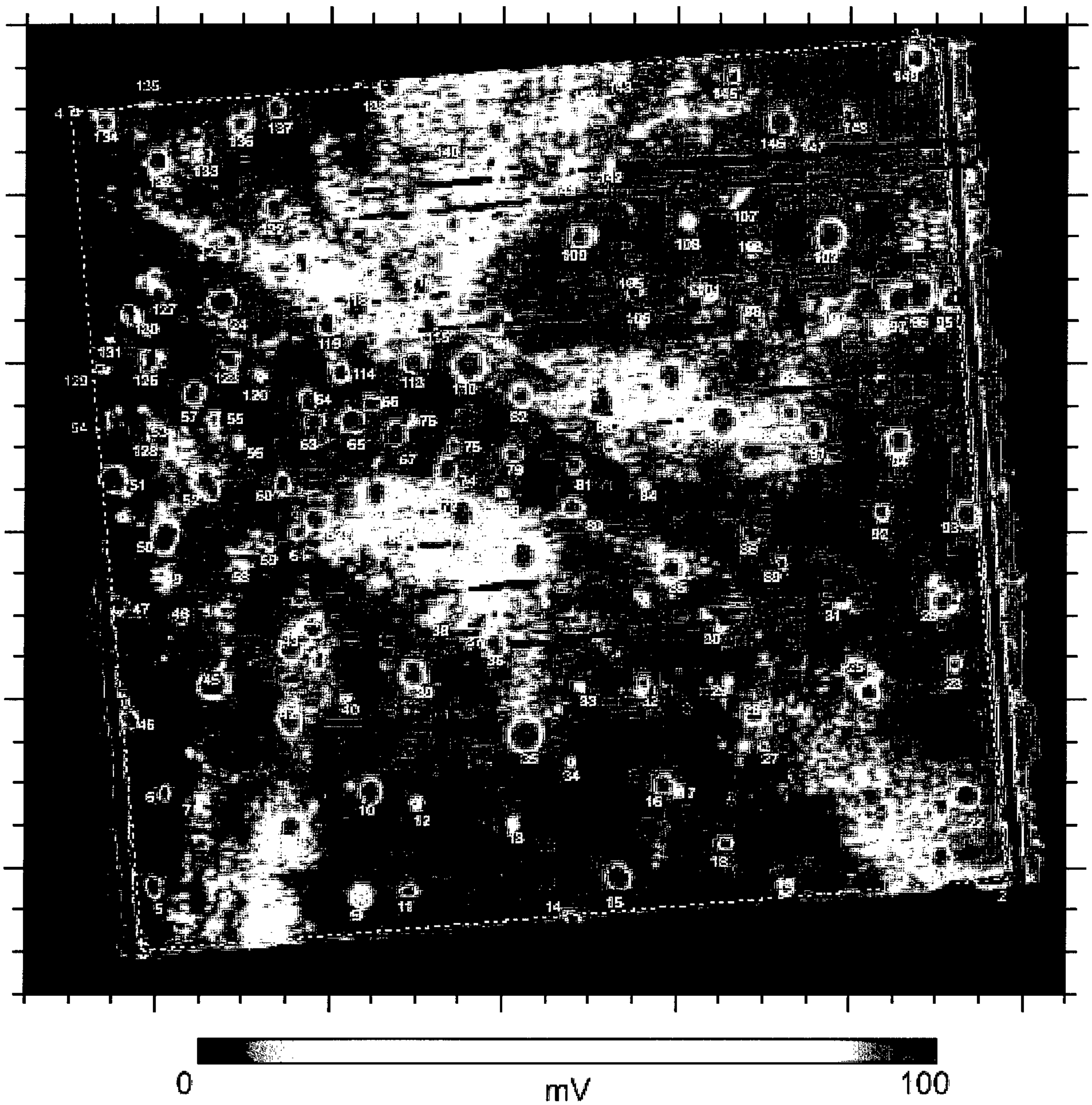


Figure 9. NRL EMMS survey results of Area 1

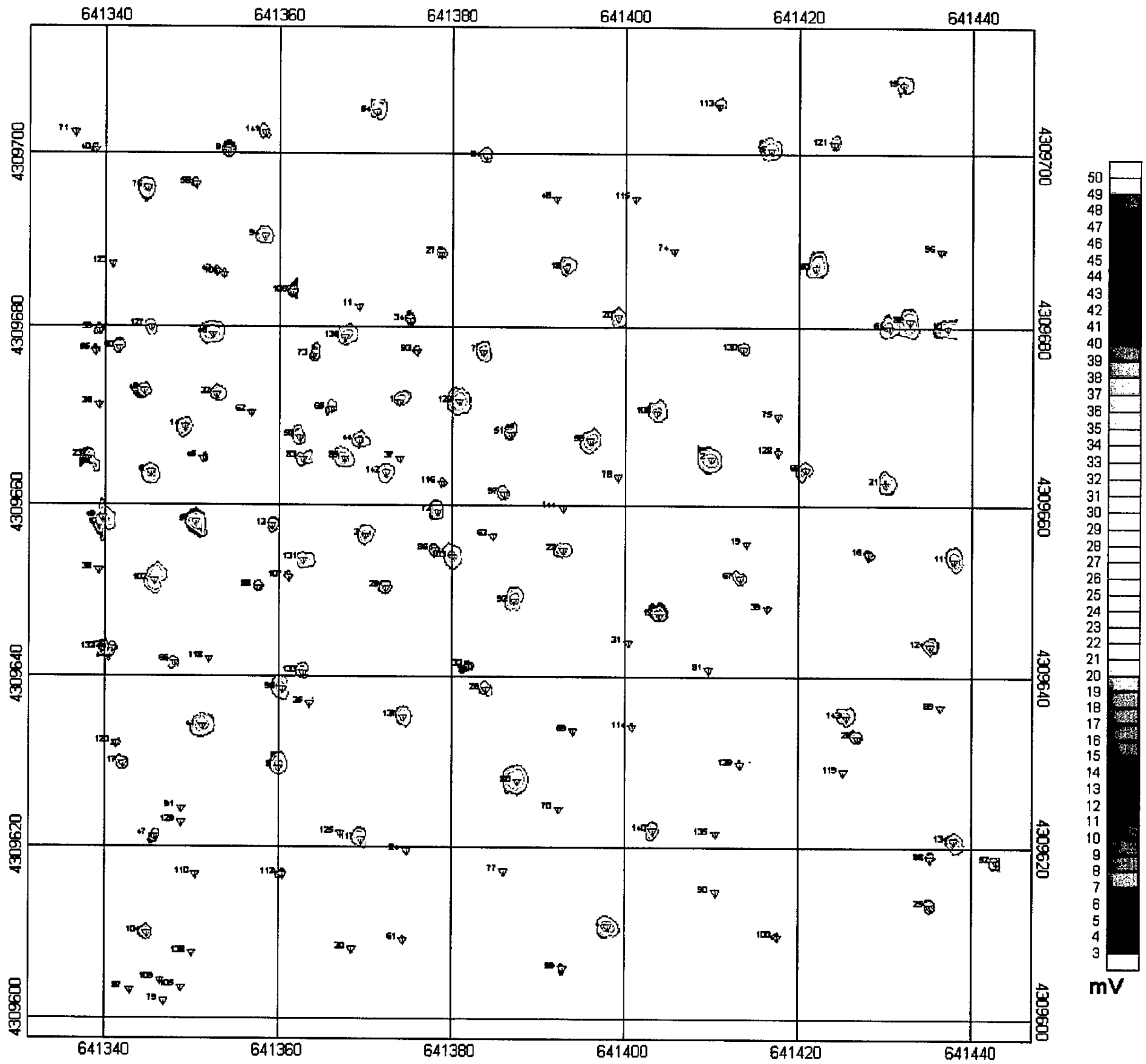


Figure 10. NAEVA EM-63 survey results of Area 1

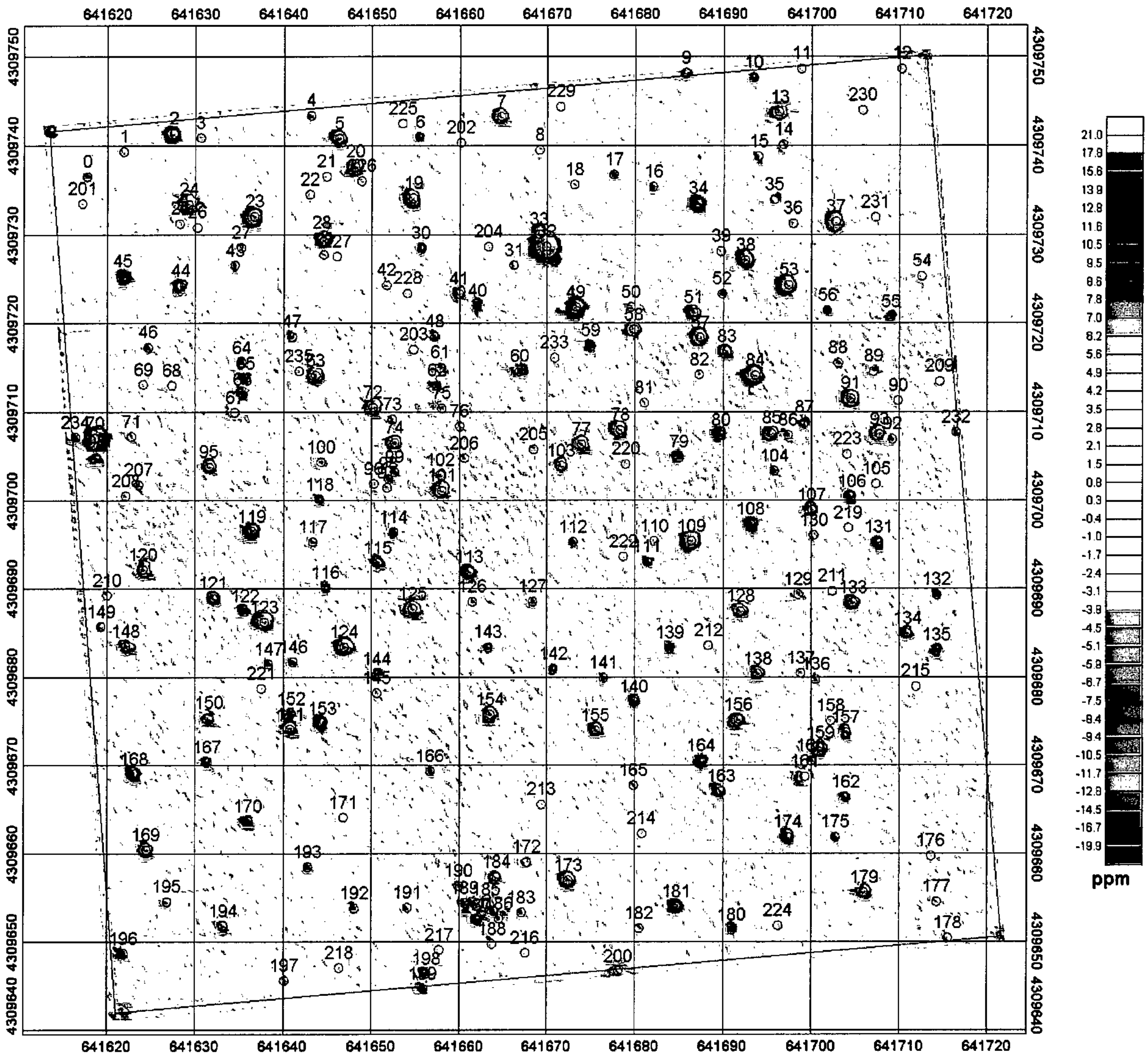


Figure 11. Geophex Ltd. GEM-3 survey of Area 2

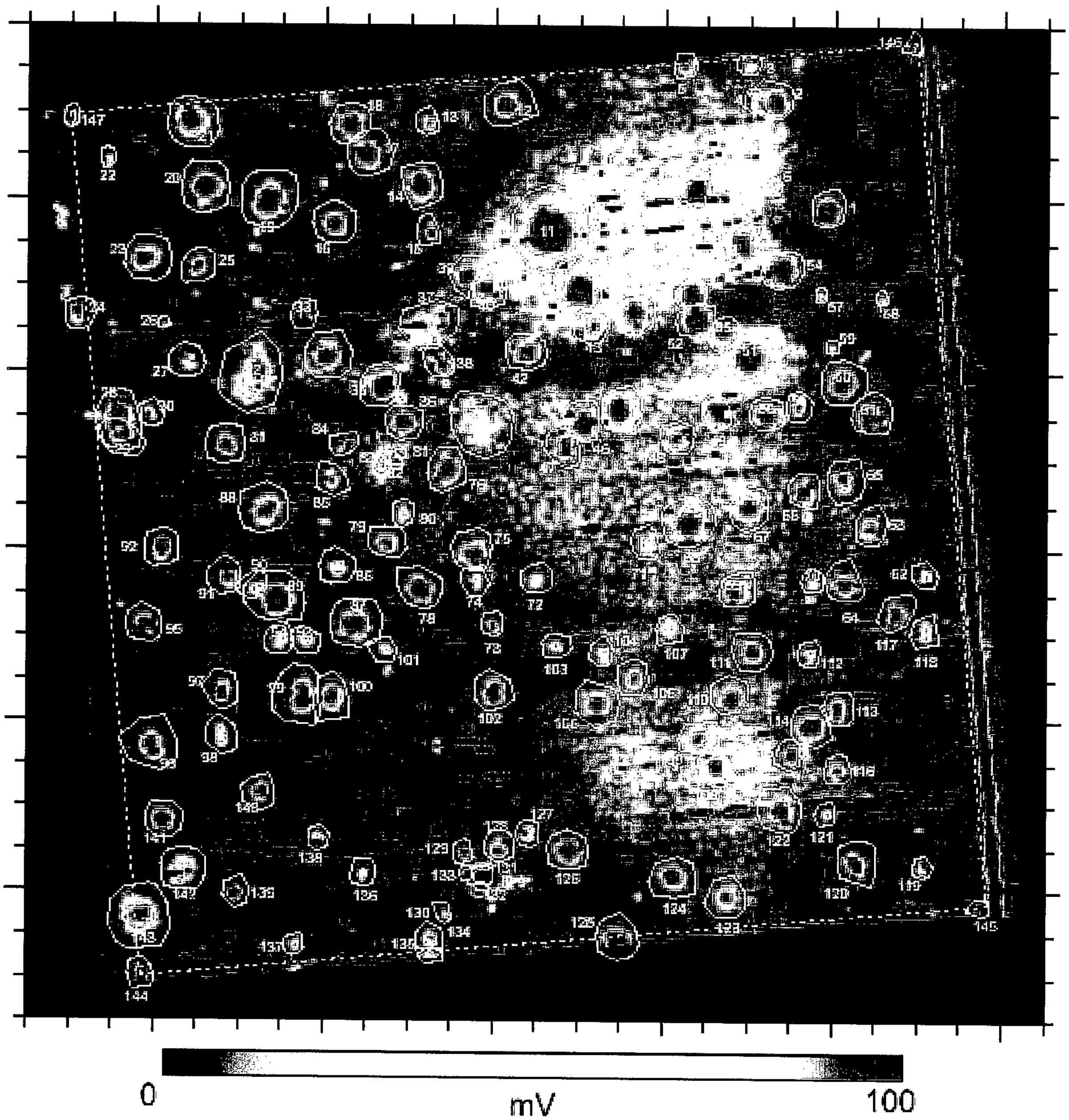


Figure 12. NRL EMMS survey of Area 2

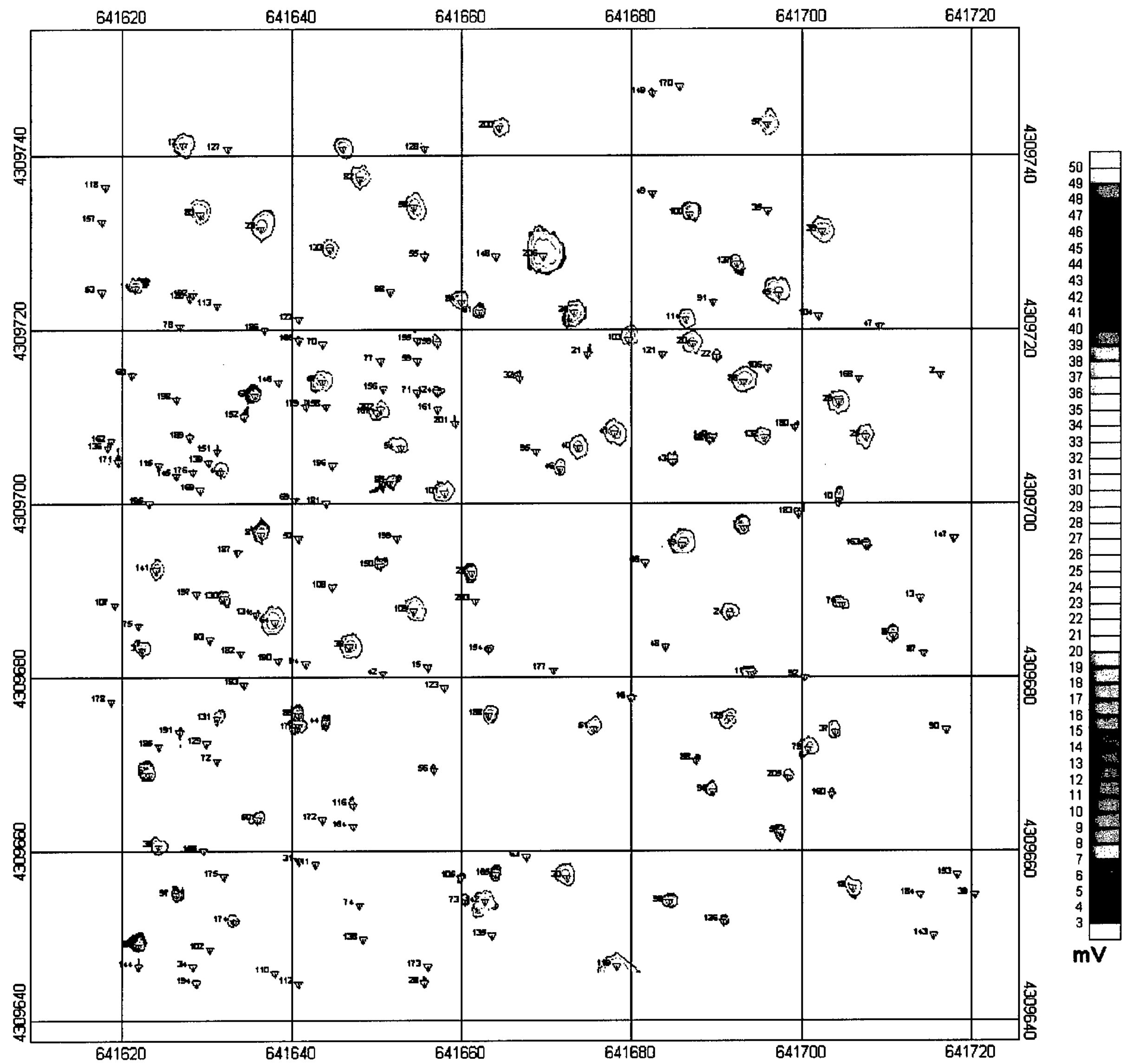


Figure 13. NAEVA EM-63 survey of Area 2

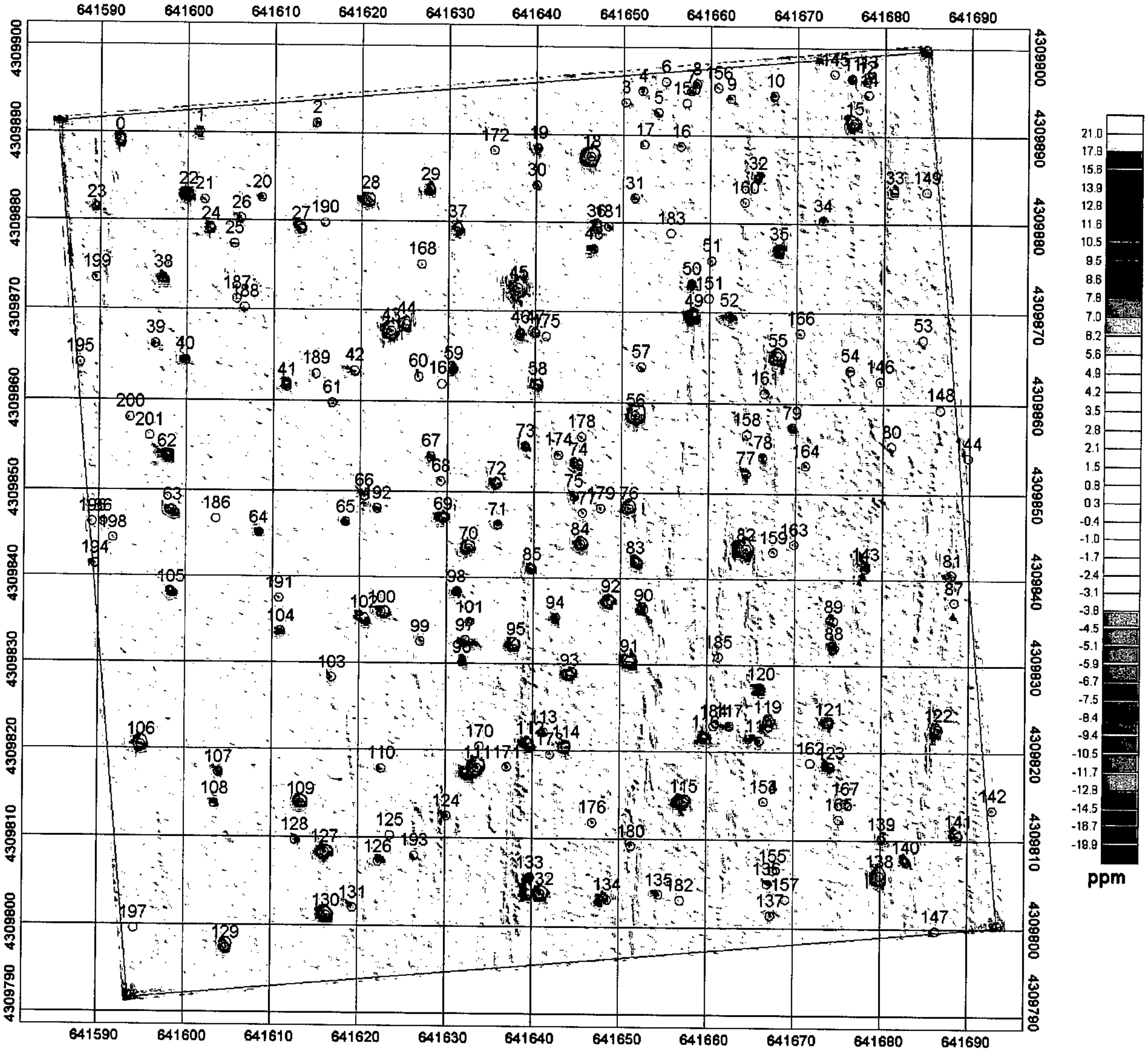


Figure 14. Geophex Ltd. GEM-3 survey of Area 3

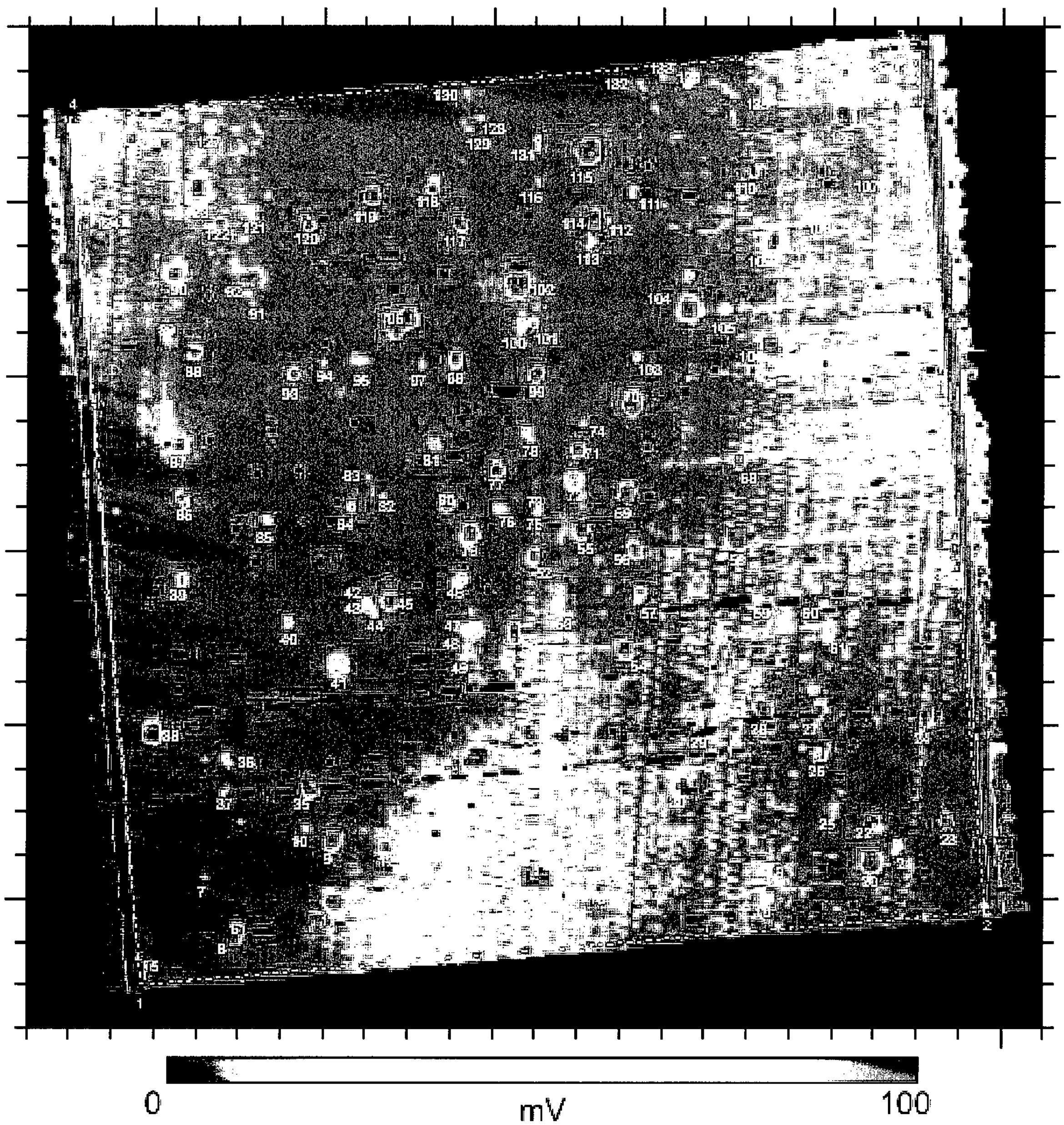


Figure 15. NRL EMMS survey of Area 3

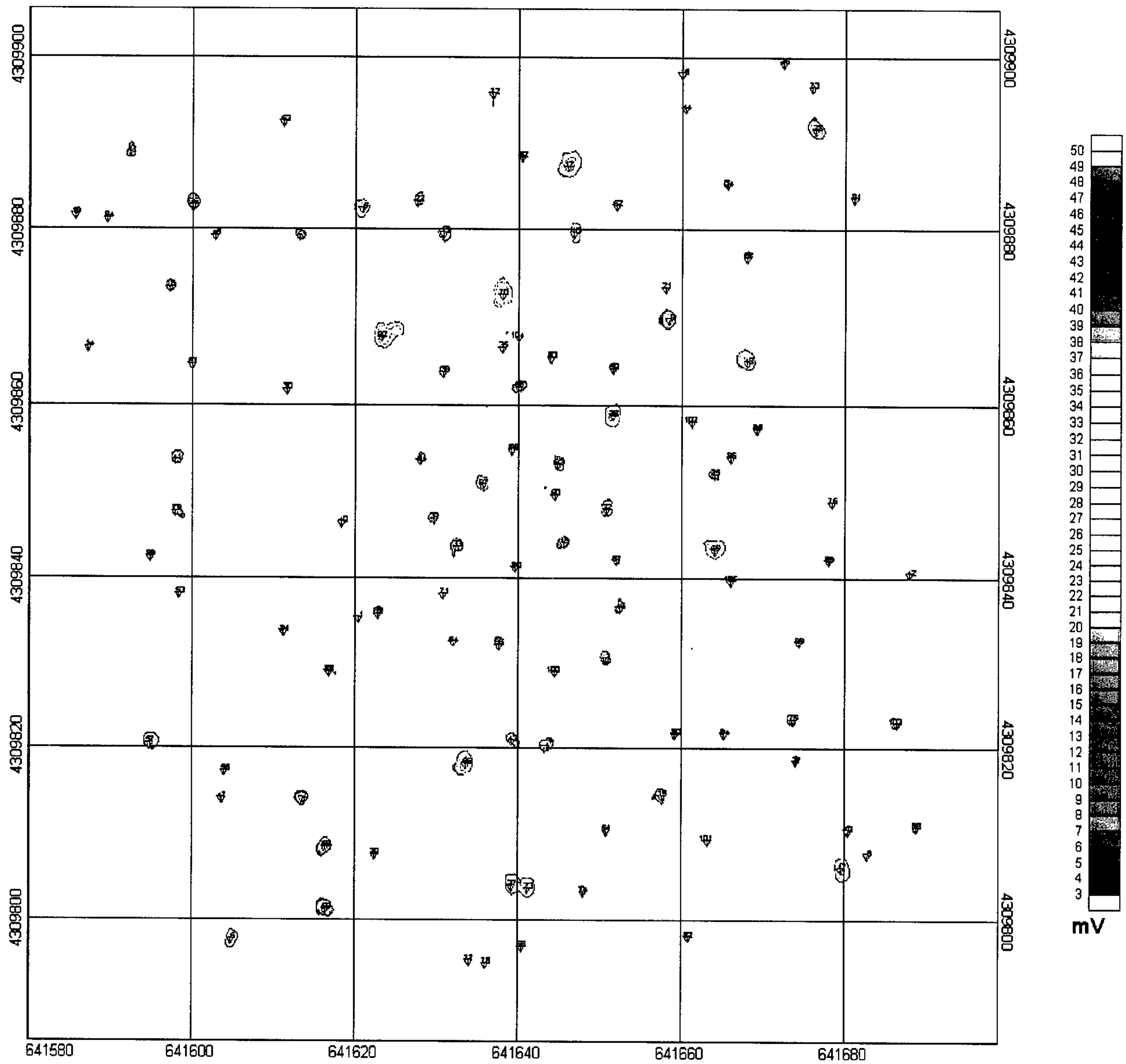


Figure 16. NAEVA EM-63 survey of Area 3

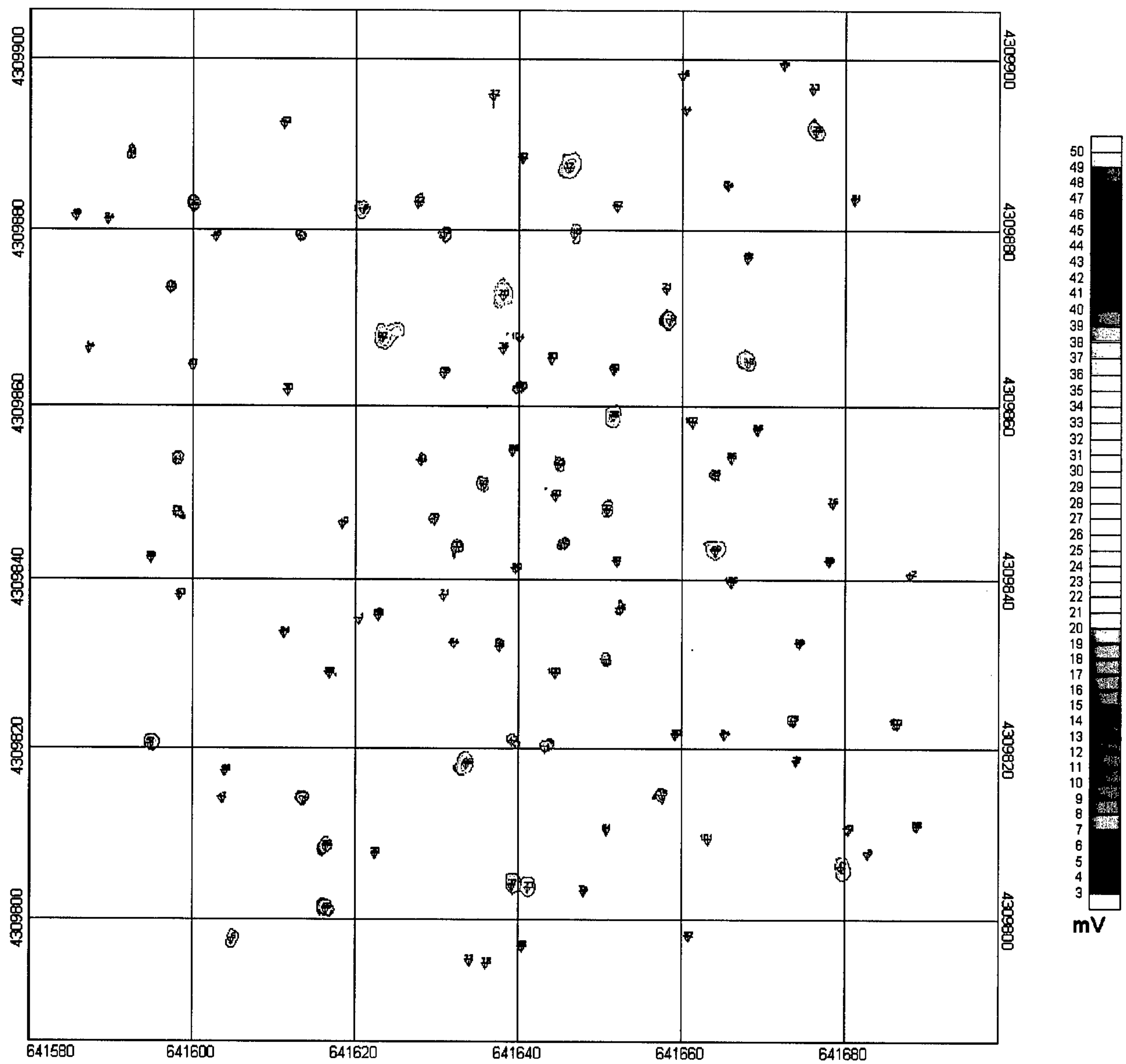


Figure 16. NAEVA EM-63 survey of Area 3

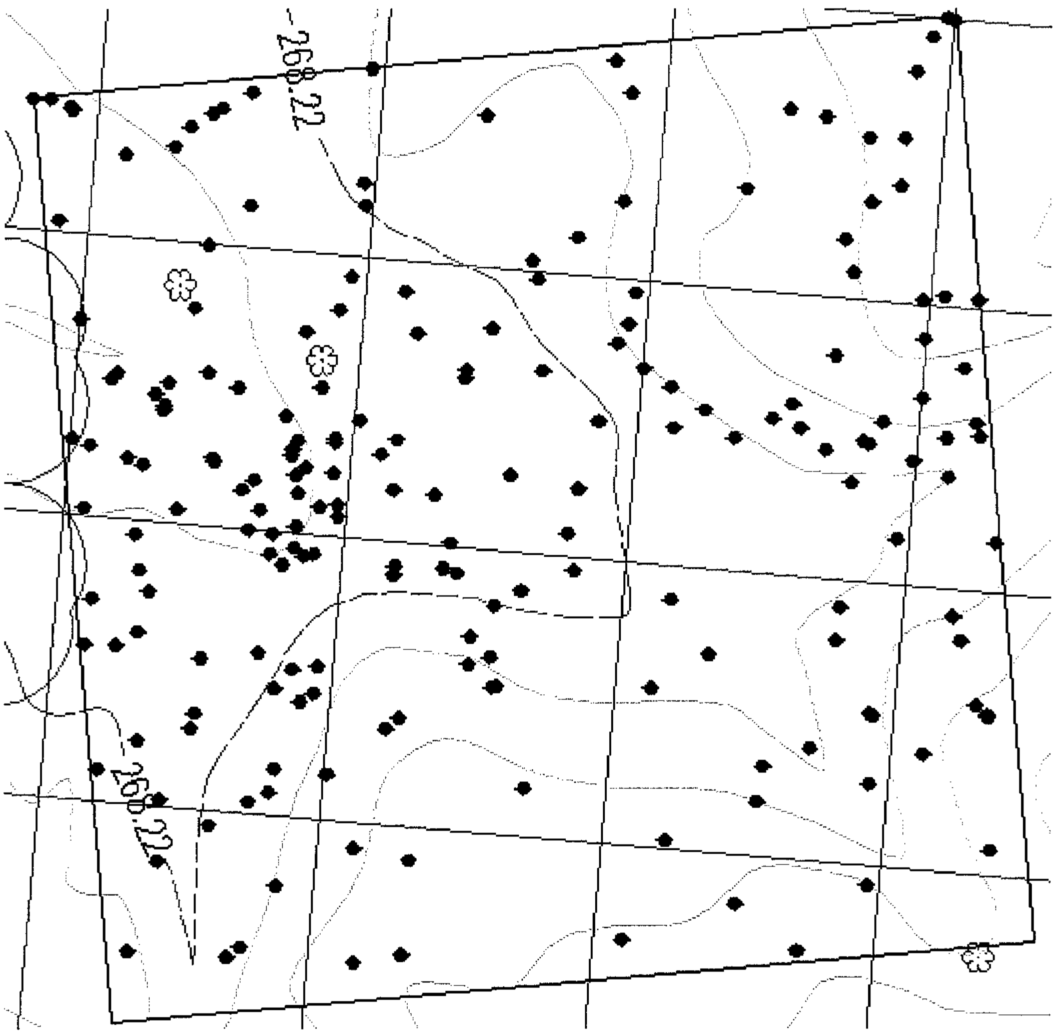
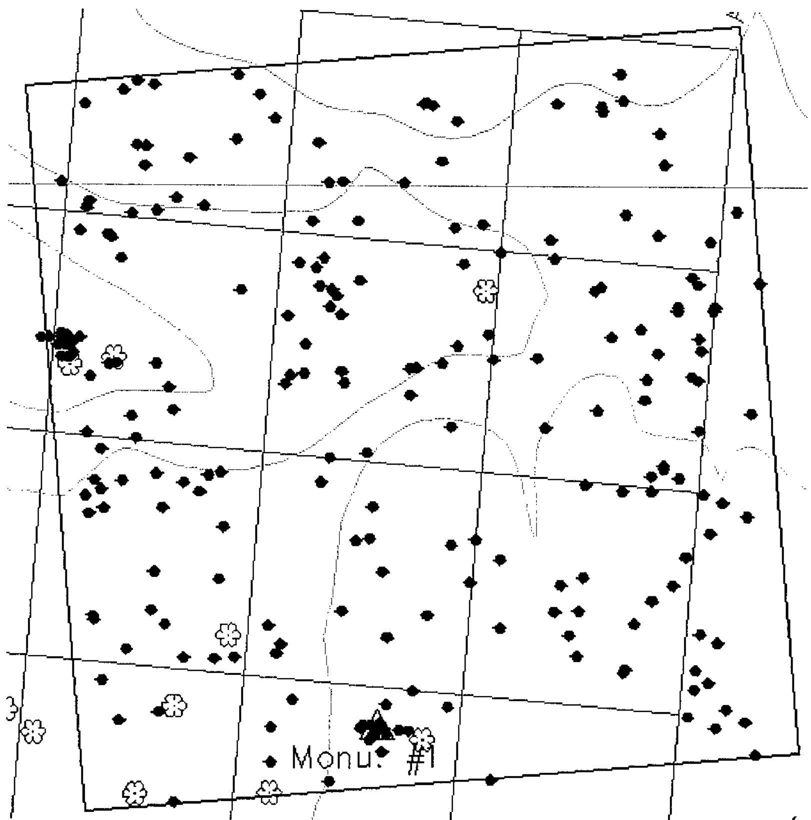


Figure 17. EODT "mag and flag" survey of Area 1 (Black symbols include flagged locations)



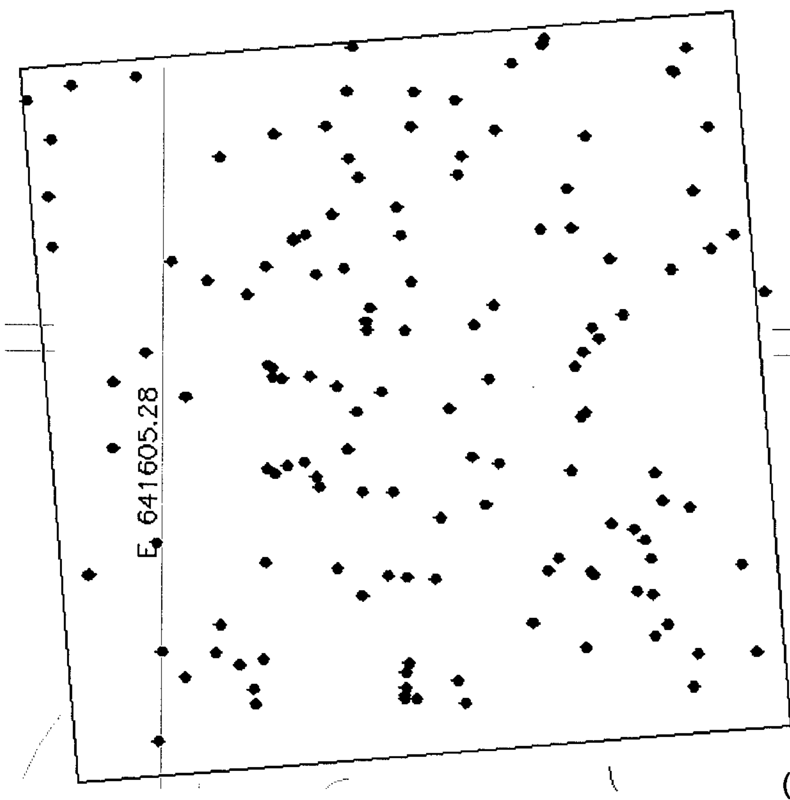


Figure 18. EODT "mag and flag" surveys at (a) Area 2 and (b) Area 3

Data Assessment

The demonstrators' analyses of the field survey data were performed in three stages. The data were initially analyzed prior to leaving the JPG test site, in order to produce three prioritized dig lists (one for each test area) that contained all anomalies investigated. The data were also analyzed offsite to produce three additional prioritized dig lists that included only those targets estimated to be larger than a 20-mm projectile (i.e., the smallest object of interest corresponded to a 57-mm projectile). Lastly, after submission of the second set of dig lists, the demonstrators were provided with the MTADS mag data and each was requested to submit two additional sets of prioritized dig lists (with and without 20 mm) that included combined mag and EMI analysis results. These dig lists are available via the ftp server listed in Appendix B. It should be noted that the demonstrators, as well as other researchers (e.g., U-Hunter, AETC, Duke University), conducted additional analyses of these datasets. Results from these analyses are not included in this report but will be evaluated and documented in subsequent reports.

A number of postdemonstration adjustments to the ground truth were necessary in order to accurately account for anomalies resulting from metallic objects that were neither detected nor emplaced during the site preparation for this demonstration. After initial evaluation of the submitted dig lists, it became apparent that all demonstrators declared targets at locations where no items had been emplaced and where the magnetic anomalies (from geologic sources) were not significant. A decision was made to excavate those locations within the three test areas where two or more demonstrators had declared UXO targets. The digging revealed that in Area 3 (the site north of the former 40-acre site during prior JPG demonstrations) all of the declarations corresponded to farm-related ferrous objects such as portions of horseshoes, plow points, and harness hardware, and did not include any items from previous JPG demonstrations. As a result, it was decided to include all of declarations not corresponding to emplaced items in Area 3 as false alarms due to non-UXO ferrous objects.

On the other hand, in Areas 1 and 2 (which are inside of the 40-acre site), the limited digging revealed a number of inert UXO left from previous JPG demonstrations including inert projectiles, mortars, flares, and fabricated clutter items. Even though the JPG IV ground truth had been used to clear these areas, it became obvious that items emplaced during earlier demonstrations had remained. As a result, the Government examined the JPG I – III ground truth and identified items that matched the locations of anomalies declared by any one of the demonstrators as UXO targets. These objects were then removed from the evaluation of results. All other UXO target declarations that did not correspond to items that were emplaced as part of this ESTCP project, and which were not included in the ground truth from the prior JPG demonstrations, were evaluated as false alarms. The option of limiting the evaluation to only the objects emplaced for this demonstration was considered and rejected because it would defeat the primary objective of the test, which was to evaluate system performance in high natural magnetic background environments.

Assessment of detection performance

One of the critical evaluation factors for this demonstration is the detection performance of the advanced systems. The metrics used to quantify the detection performance consist of the pseudo ROC curves, the single-point Pd/FAR, and the maximum achievable Pd. The methods used to estimate these metrics from the prioritized dig lists are described in detail in Chapter 4. Briefly, the pseudo ROC curve, which graphically represents the target detection percentage vs the number of false alarms (or false alarm rate in number of false alarms per hectare), is calculated by sequentially moving from the top of the prioritized dig list (i.e., the highest confidence UXO target declaration) and determining if each object on the list (whether classified as target or clutter) corresponds to an emplaced target location (a detection) or not (a false alarm). The single-point Pd/FAR performance is based on the point on the ROC curve that corresponds to the contractor-specified dig point on the prioritized dig list, and the maximum achievable Pd is based on the highest point on the ROC curve. These performance metrics are presented in the following graphs. The single-point Pd/FAR rate is shown as a colored triangle on the ROC curve, and the green diamond corresponds to the single-point Pd/FAR performance point of the "mag and flag" survey.

There are several points to keep in mind when interpreting these pseudo ROC curves: (a) the abscissa in the pseudo ROC curves is not Pfa but rather total number of false alarms or, equivalently, FAR (number of false alarms per hectare). As a result, the absolute slope of the curve has no intrinsic meaning, but is nevertheless useful for comparing relative performance between different systems. (b) These curves combine detection and discrimination of ordnance from nonordnance. Thus, the initial pseudo ROC curve's slope represents the anomalies that the demonstrator has declared as UXO with the highest confidence; a flat slope in this area would indicate very poor discrimination capability. (c) Similarly, the final slope of the pseudo curve represents anomalies that the demonstrator has declared as clutter with high confidence; a positive slope in this area indicates that there are UXO targets which the demonstrator would leave unexcavated.

Figure 19 shows the detection performance of the three demonstrators based on the results of the onsite analysis that included all potential targets. The red traces show the performance results of the Geophex Ltd. GEM-3 system. The relatively flat slopes of these ROC curves indicate that the analysis performed on the GEM-3 data were not effective in discriminating UXO targets from clutter. The Pd performance of the GEM-3 was superior to that of the standard "mag and flag" in the more difficult magnetic clutter environments of Areas 1 and 2 but did not demonstrate enhanced capability it in the low-noise environment of Area 3. In Areas 1 and 2, the single point GEM-3 Pd/FAR performance failed to meet the 85-percent specified to meet the Kaho'olawe Tier II requirements. The GEM-3 achieved 100-percent detection at all three sites but only at the expense of a significant number of false alarms.

In Figure 19, the blue traces show the performance results for the NRL EMMS. The steep early slope of the ROC curves indicates significant discrimination capability. The EMMS outperformed the "mag and flag" system at all three test areas, and the single-point performance points met the Kaho'olawe

Tier II requirements. Based on the maximum of the ROC curves, the EMMS did not achieve 100-percent detection at any of the three sites.

In Figure 19, the yellow traces show the corresponding performance results for the NAEVA EM-63 system. Again, the steep initial slopes of the ROC curves indicate significant discrimination capability. The Pd performance of the NAEVA system was significantly better than "mag and flag" across all sites. NAEVA's ROC-based performance was very similar across Areas 1 and 3 and considerably lower for Area 2. The single-point performance points meet the Kaho'olawe requirements. The EM-63 system did not achieve 100-percent detection at any of the three sites.

The naturally occurring geologic magnetic noise and the emplaced magnetic rocks presented no problems to the three EMI systems. All false alarms included in the submitted dig lists are attributable to metallic clutter, and analyses of the georeferenced maps show no discernible anomaly over any of the emplaced magnetic rocks. Overall, NRL and NAEVA demonstrated similar discrimination and false alarm rate performance and both were significantly higher than the demonstrated performance of Geophex Ltd. NRL's ROC performance for Area 2 was slightly better than NAEVA's, while NAEVA's was very slightly better for Area 1. Overall, Geophex was the only system that demonstrated 100-percent Pd at any of the three sites.

Figure 20 shows the detection performance of the three demonstrators based on the results of the offsite analyses that excluded objects that were estimated to be the size of 20 mm projectiles or smaller. The objective of this analysis was to determine the system performance based on the more commonly encountered, midsized (57 mm and larger) UXO targets. It should be noted that no comparisons with "mag and flag" results are included in these figures because analog magnetometers lack the capability to record the sensor data for reanalysis.

In Figure 20, the red traces indicate that the ROC-based performance of the GEM-3 system improved considerably from the onsite results shown previously in Figure 19. The offsite ROC curves have significantly steeper slopes (for all three areas) indicating much improved false alarm reduction capability. The operating Pd/FAR points, however, are much lower than in the previous set and, as a result, the GEM-3 operating Pd was below 80 percent and failed to meet Tier II requirements for all three areas. The GEM-3 achieved a max Pd of 100 percent only on Area 1 and achieved only 81-percent max Pd in Area 3. The significant decrease in operating and max Pds from the earlier results (where 100-percent max Pd was achieved at all three areas) is difficult to explain. The objects dropped from the earlier dig lists as a result of this analysis consisted of a 105-mm projectile in Area 2 and a 60-mm mortar and a 76-mm projectile in Area 3 with an 81-mm mortar.

In Figure 20, the blue traces show the corresponding performance for the NRL EMMS system. Again, comparison of these results with those provided onsite indicates significant improvement in ROC curve-based performance. In addition, the EMMS operating Pd/FAR points improved substantially, particularly in Area 1 where 100-percent Pd was obtained with only 55 false alarms.

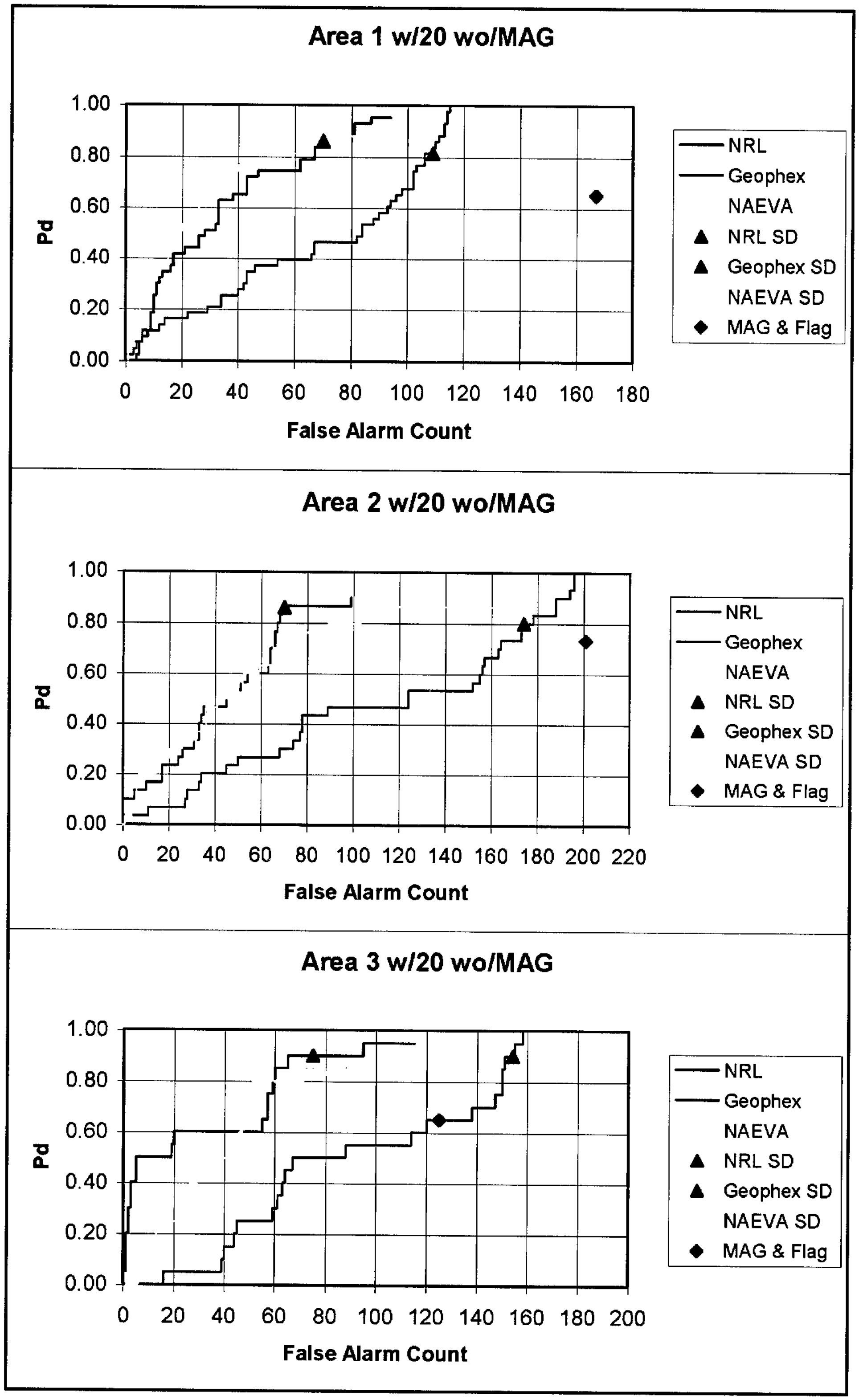


Figure 19. Detection performance of GEM-3, EMMS, EM-63 system (onsite results)

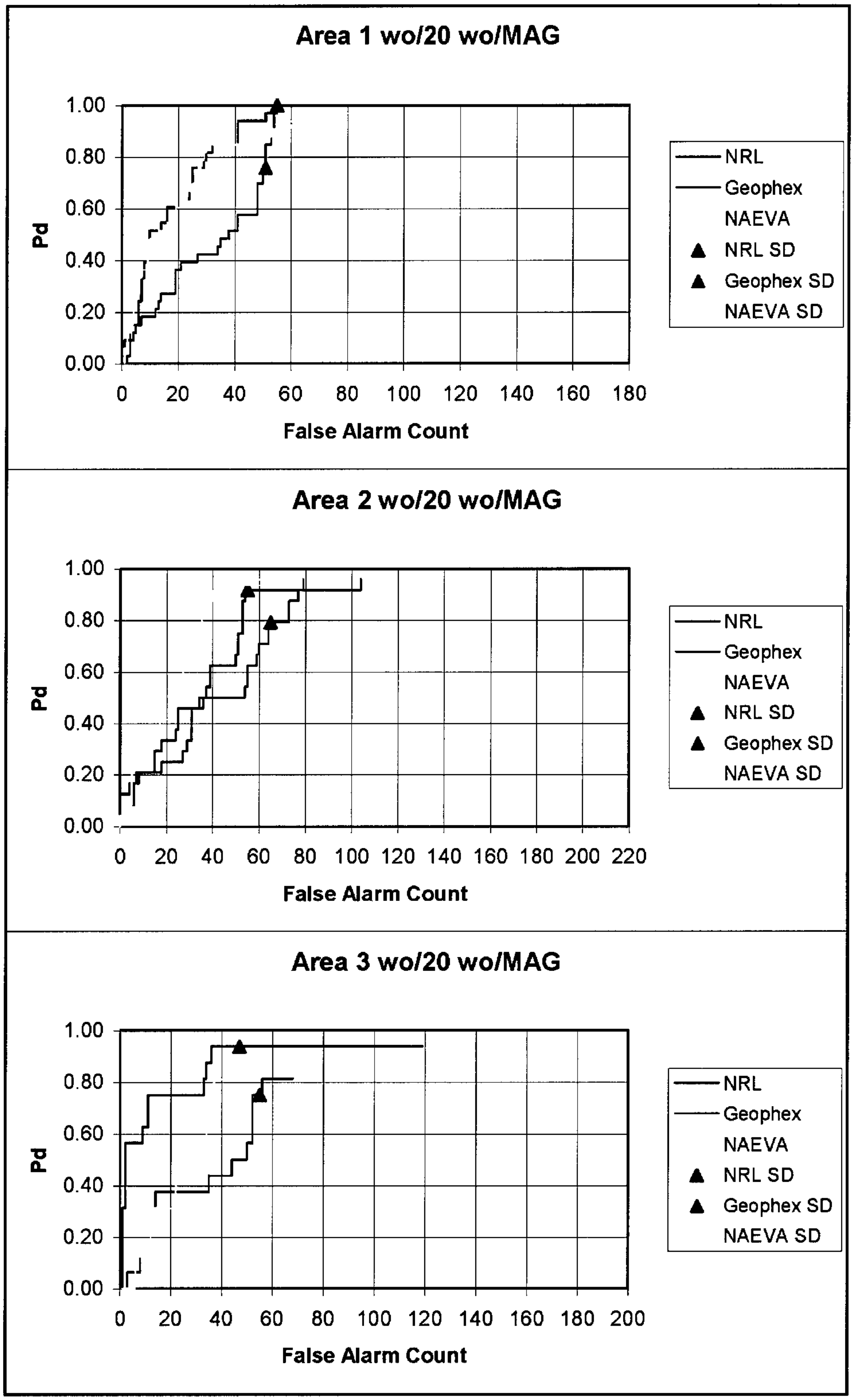


Figure 20. Detection performance of GEM-3, EMMS, EM-63 system (w/o 20-mm targets)

Maximum Pd also increased slightly in the other two areas and exceeded the Tier II requirements.

In Figure 20, the yellow traces show the corresponding performance for the NAEVA EM-63 system. Again, a comparison with earlier results shows improvement in all factors. By far the greatest improvement is seen in Area 2 where the operating Pd increased from 85 to 92 percent, and the corresponding false alarms were reduced from 128 to 56. Max Pd increased significantly in Areas 1 and 2, slightly in Area 3, and exceeded Tier II requirements, but again, NAEVA failed to reach the 100-percent max Pd in all areas.

Overall, NRL and NAEVA demonstrated similar ROC-based performance, which was again significantly better than that demonstrated by Geophex. In addition, both NRL and NAEVA significantly improved their dig point selection, since nearly everything beyond this point is nonordnance. NRL demonstrated slightly higher performance in Areas 1 and 3, while NAEVA was slightly higher in Area 2. It can be concluded that excluding the small targets resulted in significant performance improvements for the EMMS and EM-63 systems.

Figure 21 shows the performance of the three demonstrators when the MTADS mag data were added to the analysis, and all targets were considered. The red trace shows that the overall GEM-3 performance improved very slightly from the EMI-only analysis presented in Figure 19. The mag-assisted ROC curve performance is slightly higher, but the false alarm rates at the operating Pd/FAR are still high. The operating Pd did increase sufficiently to meet Tier II requirements for all three sites. The maximum Pd, however, was lowered by 10 percent in Area 2 and 5-percent in Area 3.

In Figure 21, the blue traces show that overall EMMS Pd detection performance actually decreased with the addition of the mag data. Comparison of these results with those in Figure 19 shows that, for all three areas, the ROC curve performance is lowered when the mag data are included in the analysis. In addition, the operating Pd/FARs are significantly lower because of both a decrease in Pd and an increase in the false alarms, and the operating Pd/FARs fail to meet Tier II requirements in all three areas. The maximum Pd is also slightly lower in all three areas.

In Figure 21, the yellow traces show that overall EM-63 performance improved slightly over the results presented in Figure 19. The ROC curve performance improved slightly for Areas 1 and 3 and significantly for Area 2. False alarms for Area 2 were reduced by nearly a factor of 2 but only slightly reduced for the other areas. The operating Pd, however, is lower than those obtained without the mag data and failed to meet Tier II requirements for all three areas. The maximum obtainable Pd was lower in all cases.

Comparison of the results across the three demonstrators indicates that any enhancements resulting from the addition of mag data are generally minor, and in many cases, the addition of mag data actually degraded system performance. NAEVA demonstrated the largest performance improvement (Area 2) over the EMI-only analysis and has the overall best ROC curve performance. NRL was slightly worse than NAEVA in Areas 1 and 2, and significantly worse in Area 3.

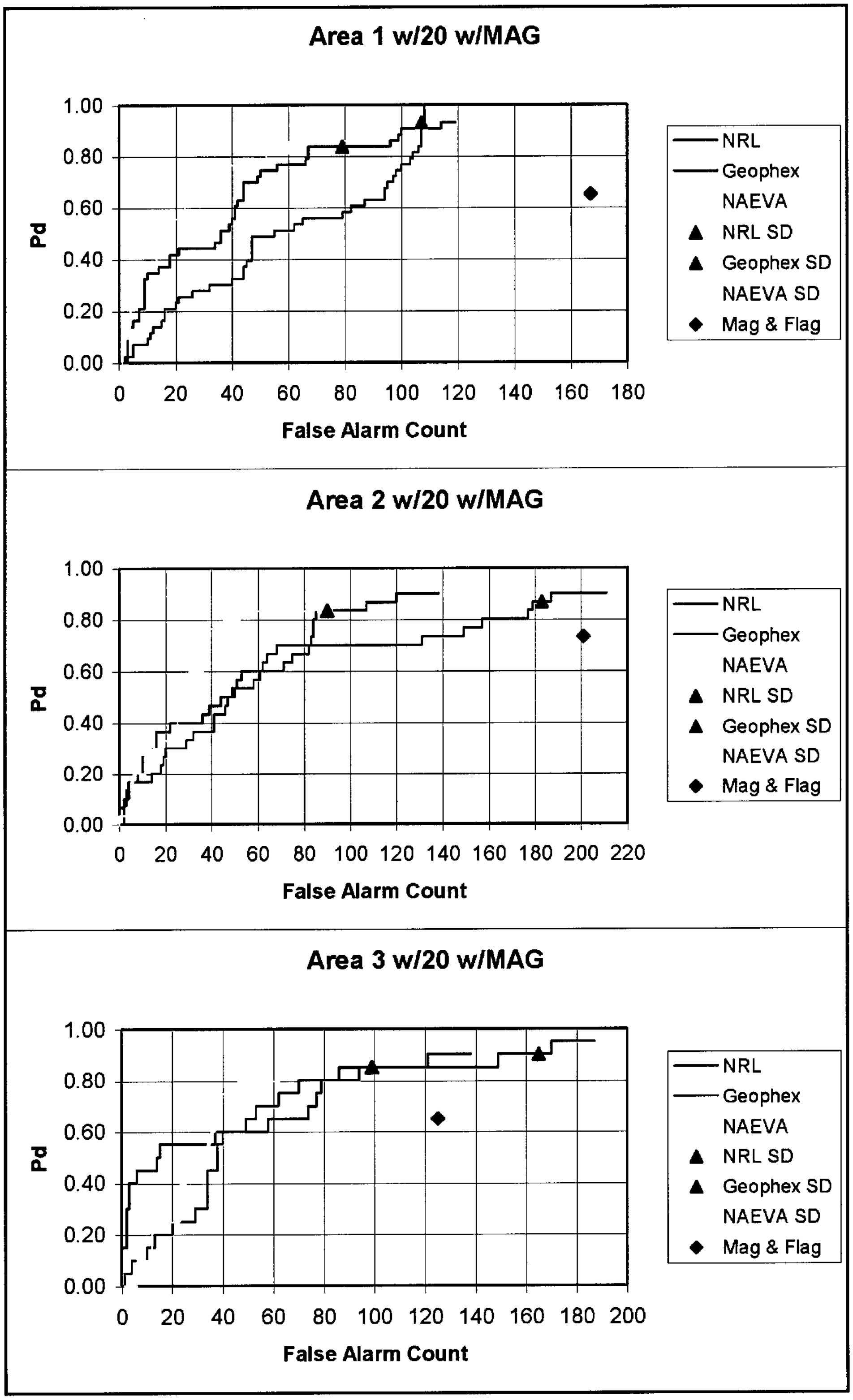


Figure 21. Detection performance of GEM-3, EMMS, EM-63 system (MAG w/20-mm results)

The GEM-3 ROC curve performance improved slightly but is still well below that of the other two demonstrators. The largest impact observed was on the operating Pd point, which improved for the GEM-3 while decreasing for the other two demonstrators. As a result, the GEM-3 was the only system meeting Tier II requirements. There appears to be no trend or reasonable explanation for the widely varying effects resulting from the addition of mag data in the analysis. For example, it would be expected that mag data would significantly enhance the EMI results, especially in Area 3 where the geologic magnetic noise is minimal, but the data do not support this hypothesis.

Figure 22 shows the detection performance of the three systems against 57-mm and larger targets after demonstrators were allowed to integrate magnetometer data into their analysis of the EMI data. The purpose of this analysis is to quantify performance improvements in midsized UXO detection from magnetometer data under varying clutter conditions.

In Figure 22, the red traces show that the overall GEM-3 results with the mag data included are radically different from the EMI-only analysis presented in Figure 20. There seems to very little correlation between the mag-enhanced and the EMI-only ROC curves, and these results are more closely correlated with the original onsite analysis that included the 20-mm projectile targets. It appears that the significant change seen in Figure 21 was because of a decision (or threshold) that resulted in the elimination of a large number of anomalies from the dig lists and that this decision was reversed in the course of the subsequent mag-EMI analysis. Comparison of the ROC curves in these two figures shows that the mag-EMI analysis includes almost twice as many objects as the EMI–only analysis. The initial slopes of the two sets of curves are very similar, but the mag-EMI set levels off and continues to much higher false alarm counts. The operating Pds in Figure 22, while significantly higher, occur at much higher false alarm counts. The mag-EMI operating Pds exceed the Tier II requirements for all three Areas, whereas all of the Pds from the EMI-only data failed to meet them. The maximum Pds are also considerably higher than for the EMI-only case and reach 100-percent for all three areas.

In Figure 22, the blue traces show that the overall EMMS performance improved very slightly from the EMI-only analysis presented in Figure 20. The ROC curve performance for all three areas is only slightly better than the EMI-only performance. The operating Pd performance is worse for the mag-EMI case since, for all three areas, the operating Pds are slightly lower and they occur at higher false alarm counts. Though lower, operating Pds still meet/exceed Tier II requirements in all three areas. The maximum achievable Pd is slightly lower for Areas 1 and 3 and unchanged in Area 2. Overall, EMMS performance was not improved by incorporating the mag data.

In Figure 22, the yellow traces show that the overall EM-63 performance is almost identical to the EMI-only analysis presented in Figure 20. Comparison of the two sets of results reveals that the only change is the addition of a few false alarms to the high end of each of the mag-EMI ROC curves. As a result, the ROC curve performance, operating Pds, and maximum achievable Pds remain unchanged. Overall, the EM-63 performance was not significantly improved by the addition of the mag data.

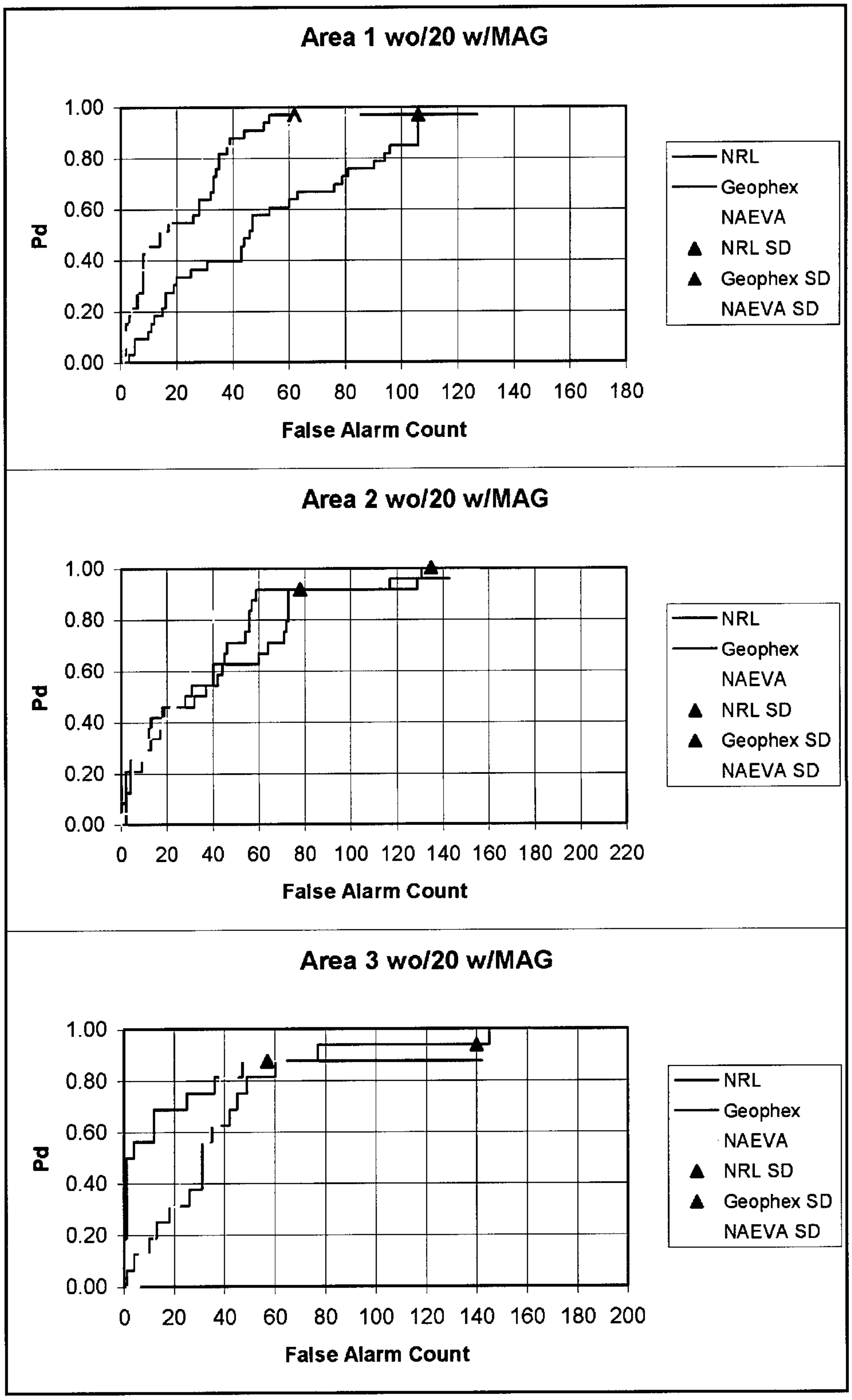


Figure 22. Detection performance of GEM-3, EMMS, EM-63 system (MAG w/o 20-mm results)

In general, the addition of mag data had very little effect on the early part of the ROC curve (i.e. discrimination ability). The effect on the operating Pds was minor for NRL an NAEVA, and quite significant for Geophex, but at greatly increased corresponding false alarm rates. The primary impact on the NAEVA and NRL results was an increase in the number of anomalies included in the dig lists, most of which are correctly classified as clutter. Comparison of this set of results across the three demonstrators provides very limited information that can support conclusions regarding systems' capabilities or to arrive at meaningful conclusions regarding the utility of multisensor data. In addition, the results are so inconsistent, that they will not support the objective of quantifying EMI performance improvements due to the addition of mag data.

Assessment of discrimination and identification performance

The discrimination and identification capabilities of UXO systems greatly affect the cost and residual risks associated with any UXO cleanup operation. The assessment of these capabilities for the three advanced systems demonstrated at JPG is included in this section, and results are summarized in the following figures and tables.

The discrimination and identification performance of each demonstrator is based on the UXO vs clutter and the UXO type declarations included in each of the required prioritized dig lists. The results presented in this section have been adjusted to account for UXO-related items that remained in Areas 1 and 2 from previous JPG demonstrations. Figures 23 through 34 include classification matrices that detail and summarize the detection/discrimination performance of each demonstrator. Each classification matrix includes the following entries:

a. The entry below the demonstrator's name and test area indicates the type of analysis used to obtain the results. There are four types: Onsite with 20-mm projectile targets included, Offsite without 20-mm projectile targets (EMI data only), MAG with 20-mm targets included (includes mag and EMI data), and MAG without 20-mm targets (includes mag and EMI data).

b. The classes across the top of the matrix are the actual (ground-truthed) target classes of the items emplaced. The projectiles are grouped into three classes. The small projectile class contains the 20-mm projectile. The medium projectile class contains the 57-, 76-, and the 105-mm projectiles. The large projectile class contains the 5-in., the 152-mm, and the 155-mm projectiles. A clutter class is listed as a separate entry and corresponds to a false alarm if classified as a UXO target and to a correct discrimination when classified as non-UXO by the demonstrator.

c. The classification column on the left side of the matrix lists the demonstrator's declaration for each detected UXO item. Again, the projectiles are grouped into three classes as previously described in the target classes.

d. The classification matrices for dig sheets that exclude the 20-mm projectiles do not have a small projectile class for the contractor classification or for the target classification. Any target declaration by the demonstrators that corresponds to a 20-mm projectile was included as a false alarm (i.e., considered as a clutter item).

e. The totals in the right hand column of the matrix correspond to the total number of items declared by the contractor as a particular class.

f. The "% Classified" row indicates the percentage of detected targets, for a given target class, that were correctly classified.

g. The "% Classified by Class" indicates the percentage of detected targets, for the given classes of projectile, mortar, and rocket, that were correctly classified.

h. The "% of Total Detected Targets Classified as Nonordnance Low/Med Confidence" is the percentage of detected ordnance that the contractor incorrectly classified as nonordnance with low or medium confidence.

i. The "% of Total Detected Targets Classified as Nonordnance High Confidence" is the percentage of detected ordnance that the contractor incorrectly classified as nonordnance with high confidence. This classification error carried the highest cost penalty (equivalent to the cost of a complete resurvey of the area).

Note that if a detected target was declared as belonging to more than one class, only the first class in the dig list has been included the classification matrix. For example, NRL generally declared multiple classes for their detections and their dig list always started with a projectile; therefore, no classifications for mortars were entered into these classification matrices.

The onsite analysis results presented in Figure 23 indicate that overall, the GEM-3 demonstrated poor capability to discriminate ordnance items from clutter across all target types and at all three areas. A total of 17 ordnance items were declared as nonordnance with high confidence, which in an actual UXO cleanup would have resulted in leaving live ordnance in the ground.

The results presented in Figure 24 indicate that the EMMS was fairly effective in correctly discriminating ordnance from nonordnance items, but still incorrectly declared a total of seven ordnance items (including five 20-mm projectiles) as nonordnance with high confidence. Identification performance was poor across all target types.

The results presented in Figure 25 show that the NAEVA EM-63 system demonstrated the highest discrimination performance based on the onsite dig lists. Only two items were classified as nonordnance with high confidence (none in Area 1). Identification performance was poor across all target types.

The offsite results using EMI only and excluding the 20-mm projectiles are presented in Figure 26 and show that, while the number of false alarms were significantly reduced, the discrimination and identification performance of the GEM-3 remained extremely poor. For example, out of a total number of 16 items in Area 1 that were declared as nonordnance with high confidence, 8 items were

Geophex Area 1	Classification Matrix									
On Site with 20 mm	Target Classification									
	Projectile Small	Projectile Medium	Projectile Large	Mortar	Mortar	Mortar	Rocket			
Contractor Classification	20 mm	57 mm thru 105 mm	5 in thru 155 mm	60 mm	81 mm	4.2 in	2.75 in	Clutter		Total
Projectile Small 20mm	4							32		36
Projectile Medium 57 mm thru 105 mm		1		1	1		2	6		11
Projectile Large 5 in thru 155 mm			1					3		4
Mortar 60 mm		2		2				21		25
Mortar 81 mm			1		2			4		7
Mortar 4.2 in			1			1		1		3
Rocket 2.75 in		1								1
Non-ordnance Low/Med	6	4	1	1	1		2	42		57
Non-ordnance High		2	3	1	1	1		14		22
Total	10	10	7	5	5	2	4	123	166	166
% Classified	40.00%	10.00%	14.29%	40.00%	40.00%	50.00%	0.00%			
% Classified by Class			% of Total Detected			% of Total Detected				
Projectile	22.22%		Targets Classified as			Targets Classified as				
Mortar	41.67%		Non-ordnance Low/Med			Non-ordnance High				
Rocket	0.00%		Confidence	34.88%		Confidence		18.60%		

Geophex Area 2	Classification Matrix									
On Site with 20 mm	Target Classification									
	Projectile Small	Projectile Medium	Projectile Large	Mortar	Mortar	Mortar	Rocket			
Contractor Classification	20 mm	57 mm thru 105 mm	5 in thru 155 mm	60 mm	81 mm	4.2 in	2.75 in	Clutter		Total
Projectile Small 20mm	2							58		60
Projectile Medium 57 mm thru 105 mm			1	1			2	9		13
Projectile Large 5 in thru 155 mm			2					5		7
Mortar 60 mm								18		18
Mortar 81 mm					4			4		8
Mortar 4.2 in			1			1				2
Rocket 2.75 in								4		4
Non-ordnance Low/Med	3	3		3				75		84
Non-ordnance High	1	2	1	1	2			23		30
Total	6	5	5	5	6	1	2	196	226	226
% Classified	33.33%	0.00%	40.00%	0.00%	66.67%	100.00%	0.00%			
% Classified by Class			% of Total Detected			% of Total Detected				
Projectile	25.00%		Targets Classified as			Targets Classified as				
Mortar	41.67%		Non-ordnance Low/Med			Non-ordnance High				
Rocket	0.00%		Confidence	30.00%		Confidence		23.33%		

Geophex Area 3	Classification Matrix									
On Site with 20 mm	Target Classification									
	Projectile Small	Projectile Medium	Projectile Large	Mortar	Mortar	Mortar	Rocket			
Contractor Classification	20 mm	57 mm thru 105 mm	5 in thru 155 mm	60 mm	81 mm	4.2 in	2.75 in	Clutter		Total
Projectile Small 20mm	3	1						62		66
Projectile Medium 57 mm thru 105 mm				1				7		8
Projectile Large 5 in thru 155 mm								1		1
Mortar 60 mm		1		2				17		20
Mortar 81 mm		1			1			2		4
Mortar 4.2 in										0
Rocket 2.75 in					1			1		2
Non-ordnance Low/Med	1	1	2	2			1	64		71
Non-ordnance High					2			28		30
Total	4	4	2	5	4	0	1	182	202	202
% Classified	75.00%	0.00%	0.00%	40.00%	25.00%	0.00%	0.00%			
% Classified by Class			% of Total Detected			% of Total Detected				
Projectile	30.00%		Targets Classified as			Targets Classified as				
Mortar	33.33%		Non-ordnance Low/Med			Non-ordnance High				
Rocket	0.00%		Confidence	35.00%		Confidence		10.00%		

Figure 23. Classification matrix for GEM-3 (onsite results)

Classification Matrix

NRL Area 1
On Site with 20 mm

Target Classification

Contractor Classification	Projectile Small 20 mm	Projectile Medium 57 mm thru 105 mm	Projectile Large 5 in thru 155 mm	Mortar 60 mm	Mortar 81 mm	Mortar 4.2 in	Rocket 2.75 in	Clutter		Total
Projectile Small 20mm	3							18		21
Projectile Medium 57 mm thru 105 mm		5	2	3	3	2	1	14		30
Projectile Large 5 in thru 155 mm			3					1		4
Mortar 60 mm										0
Mortar 81 mm										0
Mortar 4.2 in										0
Rocket 2.75 in		1	2				2	3		8
Non-ordnance Low/Med	1	4		2	2		1	34		44
Non-ordnance High	4							24		28
Total	8	10	7	5	5	2	4	94	135	135
% Classified	37.50%	50.00%	42.86%	0.00%	0.00%	0.00%	50.00%			

% Classified by Class	
Projectile	44.00%
Mortar	0.00%
Rocket	50.00%

% of Total Detected Targets Classified as Non-ordnance Low/Med Confidence 24.39%

% of Total Detected Targets Classified as Non-ordnance High Confidence 9.76%

Classification Matrix

NRL Area 2
On Site with 20 mm

Target Classification

Contractor Classification	Projectile Small 20 mm	Projectile Medium 57 mm thru 105 mm	Projectile Large 5 in thru 155 mm	Mortar 60 mm	Mortar 81 mm	Mortar 4.2 in	Rocket 2.75 in	Clutter		Total
Projectile Small 20mm	3							16		19
Projectile Medium 57 mm thru 105 mm		1	1	3	3			18		26
Projectile Large 5 in thru 155 mm			2					1		3
Mortar 60 mm										0
Mortar 81 mm										0
Mortar 4.2 in										0
Rocket 2.75 in							1	5		6
Mk84		0								0
Non-ordnance Low/Med	1	3	1	2	2	1	1	28		39
Non-ordnance High	0		1		1			30		32
Total	4	4	5	5	6	1	2	98	125	125
% Classified	75.00%	25.00%	40.00%	0.00%	0.00%	0.00%	50.00%			

% Classified by Class	
Projectile	46.15%
Mortar	0.00%
Rocket	50.00%

% of Total Detected Targets Classified as Non-ordnance Low/Med Confidence 40.74%

% of Total Detected Targets Classified as Non-ordnance High Confidence 7.41%

Classification Matrix

NRL Area 3
On Site with 20 mm

Target Classification

Contractor Classification	Projectile Small 20 mm	Projectile Medium 57 mm thru 105 mm	Projectile Large 5 in thru 155 mm	Mortar 60 mm	Mortar 81 mm	Mortar 4.2 in	Rocket 2.75 in	Clutter		Total
Projectile Small 20mm								23		23
Projectile Medium 57 mm thru 105 mm		4	1	3	2			15		25
Projectile Large 5 in thru 155 mm								2		2
Mortar 60 mm										0
Mortar 81 mm										0
Mortar 4.2 in										0
Rocket 2.75 in					1		1	1		3
Mk84										0
Non-ordnance Low/Med	3		1	1	1			34		40
Non-ordnance High	1							40		41
Total	4	4	2	4	4	0	1	115	134	134
% Classified	0.00%	100.00%	0.00%	0.00%	0.00%	0.00%	100.00%			

% Classified by Class	
Projectile	40.00%
Mortar	0.00%
Rocket	100.00%

% of Total Detected Targets Classified as Non-ordnance Low/Med Confidence 31.58%

% of Total Detected Targets Classified as Non-ordnance High Confidence 5.26%

Figure 24. Classification matrix for EMMS (onsite results)

NAEVA Area 1 On Site with 20 mm	Classification Matrix									
	Target Classification									
	Projectile Small	Projectile Medium	Projectile Large	Mortar	Mortar	Mortar	Rocket			
Contractor Classification	20 mm	57 mm thru 105 mm	5 in thru 155 mm	60 mm	81 mm	4.2 in	2.75 in	Clutter		Total
Projectile Small 20mm	2	0						18		20
Projectile Medium 57 mm thru 105 mm	2	3			1			7		13
Projectile Large 5 in thru 155 mm	1	1	3	1				6		12
Mortar 60 mm		3			2			7		12
Mortar 81 mm			1	2	2			9		14
Mortar 4.2 in	1	1				2	1	4		9
Rocket 2.75 in			2	1			2	5		10
Non-ordnance Low/Med		1		1			1	20		23
Non-ordnance High			1					19		20
Total	6	9	7	5	5	2	4	95	133	133
% Classified	33.33%	33.33%	42.86%	0.00%	40.00%	100.00%	50.00%			

% Classified by Class	
Projectile	36.36%
Mortar	33.33%
Rocket	50.00%

% of Total Detected Targets Classified as Non-ordnance Low/Med Confidence 7.89%

% of Total Detected Targets Classified as Non-ordnance High Confidence 2.63%

NAEVA Area 2 On Site with 20 mm	Classification Matrix									
	Target Classification									
	Projectile Small	Projectile Medium	Projectile Large	Mortar	Mortar	Mortar	Rocket			
Contractor Classification	20 mm	57 mm thru 105 mm	5 in thru 155 mm	60 mm	81 mm	4.2 in	2.75 in	Clutter		Total
Projectile Small 20mm	2			1			1	17		21
Projectile Medium 57 mm thru 105 mm		1	1		1			15		18
Projectile Large 5 in thru 155 mm			4	1	2			14		21
Mortar 60 mm		1		1	1			10		13
Mortar 81 mm				1	2			16		19
Mortar 4.2 in						1		6		7
Rocket 2.75 in		1					1	3		5
Non-ordnance Low/Med	1	1		1				47		50
Non-ordnance High	1	0						38		39
Total	4	4	5	5	6	1	2	166	193	193
% Classified	50.00%	25.00%	80.00%	20.00%	33.33%	100.00%	50.00%			

% Classified by Class	
Projectile	53.85%
Mortar	33.33%
Rocket	50.00%

% of Total Detected Targets Classified as Non-ordnance Low/Med Confidence 11.11%

% of Total Detected Targets Classified as Non-ordnance High Confidence 3.70%

NAEVA Area 3 On Site with 20 mm	Classification Matrix									
	Target Classification									
	Projectile Small	Projectile Medium	Projectile Large	Mortar	Mortar	Mortar	Rocket			
Contractor Classification	20 mm	57 mm thru 105 mm	5 in thru 155 mm	60 mm	81 mm	4.2 in	2.75 in	Clutter		Total
Projectile Small 20mm	1	1						12		14
Projectile Medium 57 mm thru 105 mm	1	1			1			12		15
Projectile Large 5 in thru 155 mm			1	2				12		15
Mortar 60 mm		1						7		8
Mortar 81 mm		1		2	3			8		14
Mortar 4.2 in								2		2
Rocket 2.75 in							1	7		8
Non-ordnance Low/Med			1					18		19
Non-ordnance High								10		10
Total	2	4	2	4	4		1	88	105	105
% Classified	50.00%	25.00%	50.00%	0.00%	75.00%	0.00%	100.00%			

% Classified by Class	
Projectile	37.50%
Mortar	37.50%
Rocket	100.00%

% of Total Detected Targets Classified as Non-ordnance Low/Med Confidence 5.88%

% of Total Detected Targets Classified as Non-ordnance High Confidence 0.00%

Figure 25. Classification matrix for EM-63 (onsite results)

Geophex Area 1	Classification Matrix								
Off Site without 20 mm	Target Classification								
	Projectile Medium	Projectile Large	Mortar	Mortar	Mortar	Rocket			
Contractor Classification	57 mm thru 105 mm	5 in thru 155 mm	60 mm	81 mm	4.2 in	2.75 in	Clutter		Total
Projectile Medium 57 mm thru 105 mm	1		1	1		2	6		11
Projectile Large 5 in thru 155 mm		1					3		4
Mortar 60 mm	2		2				21		25
Mortar 81 mm		1		2			4		7
Mortar 4.2 in		1			1		1		3
Rocket 2.75 in	1						0		1
Non-ordnance Low/Med	4	1	1	1	0	2	16		25
Non-ordnance High	2	3	1	1	1	0	8		16
Total	10	7	5	5	2	4	59	92	92
% Classified	10.00%	14.29%	40.00%	40.00%	50.00%	0.00%			

% Classified by Class		% of Total Detected Targets Classified as Non-ordnance Low/Med Confidence		% of Total Detected Targets Classified as Non-ordnance High Confidence
Projectile	11.76%			
Mortar	41.67%			
Rocket	0.00%	27.27%		24.24%

Geophex Area 2	Classification Matrix								
Off Site without 20 mm	Target Classification								
	Projectile Medium	Projectile Large	Mortar	Mortar	Mortar	Rocket			
Contractor Classification	57 mm thru 105 mm	5 in thru 155 mm	60 mm	81 mm	4.2 in	2.75 in	Clutter		Total
Projectile Medium 57 mm thru 105 mm		1	1			2	9		13
Projectile Large 5 in thru 155 mm		2					5		7
Mortar 60 mm							18		18
Mortar 81 mm				4			4		8
Mortar 4.2 in		1			1		0		2
Rocket 2.75 in							4		4
Non-ordnance Low/Med	3	1	3				25		32
Non-ordnance High	1		1	2			14		18
Total	4	5	5	6	1	2	79	102	102
% Classified	0.00%	40.00%	0.00%	66.67%	100.00%	0.00%			

% Classified by Class		% of Total Detected Targets Classified as Non-ordnance Low/Med Confidence		% of Total Detected Targets Classified as Non-ordnance High Confidence
Projectile	22.22%			
Mortar	41.67%			
Rocket	0.00%	30.43%		17.39%

Geophex Area 3	Classification Matrix								
Off Site without 20 mm	Target Classification								
	Projectile Medium	Projectile Large	Mortar	Mortar	Mortar	Rocket			
Contractor Classification	57 mm thru 105 mm	5 in thru 155 mm	60 mm	81 mm	4.2 in	2.75 in	Clutter		Total
Projectile Medium 57 mm thru 105 mm							8		8
Projectile Large 5 in thru 155 mm							1		1
Mortar 60 mm	1		2				17		20
Mortar 81 mm	1			1			2		4
Mortar 4.2 in									0
Rocket 2.75 in				1			1		2
Non-ordnance Low/Med	1	2	2			1	26		32
Non-ordnance High				1			13		14
Total	3	2	4	3		1	68	81	81
% Classified	0.00%	0.00%	50.00%	33.33%	0.00%	0.00%			

% Classified by Class		% of Total Detected Targets Classified as Non-ordnance Low/Med Confidence		% of Total Detected Targets Classified as Non-ordnance High Confidence
Projectile	0.00%			
Mortar	42.86%			
Rocket	0.00%	46.15%		7.69%

Figure 26. Classification matrix for GEM-3 (EMI only w/o 20 mm)

actually emplaced ordnance items. A total of 13 such items were incorrectly classified over the three test areas. With the possible exception of the 4.2-in. mortars (which were too few from which to draw valid conclusions), there was no identification capability demonstrated.

The offsite discrimination performance of the EMMS, which is summarized in Figure 27, showed significant improvement from the onsite results. A major reason for this improvement is due to the fact that 5 of the 7 UXO items erroneously classified as high confidence clutter in the onsite results were in fact 20 mm ordnance items. Since the offsite analysis was intended to ignore 20 mm sized target, the majority of the incorrectly classified items were easily eliminated. As a result, only one item (in Area 2) was incorrectly classified as nonordnance with high confidence. There was no demonstrated identification capability.

The offsite results for NAEVA are presented in Figure 28, and indicate significant discrimination capability. Only one ordnance item (in Area 1) was misclassified as nonordnance with high confidence. There was no demonstrated identification capability.

The next set of six figures summarizes the offsite analysis conducted after release of the MTADS magnetometry data. In general, the additional information from the mag data did not improve the identification capabilities of the three systems.

Comparison of the discrimination performance across the three systems shows that NAEVA demonstrated the best capability to reliably discriminate ordnance from clutter. NRL demonstrated considerably lower discrimination capability, and Geophex Ltd. demonstrated very poor discrimination capability. None of the systems could be considered to have demonstrated capability to identify ordnance items either by type or by class.

Summary of detection, discrimination, and identification performance

In order to facilitate the comparison of detection, discrimination, and identification performance across the three demonstrators, as well as with the "mag and flag" results, where appropriate, the dig list information is summarized again in Tables 2 through 5. It should be noted that in these tables, unlike the previous classification matrices, the dig list declarations were interpreted to accept the correct one of the first two choices listed. For example, if the dig list specified 57-mm projectile/60-mm mortar for an actual mortar target, credit was given in the mortar class.

Performance of demonstrators against overlapping targets

Each demonstration area included three UXO targets that had clutter items in close proximity so that their magnetic and EMI signatures would overlap. The purpose of these closely spaced targets was to evaluate the spatial resolution of

NRL Area 1	Classification Matrix								
Off Site without 20 mm	**Target Classification**								
	Projectile Medium	Projectile Large	Mortar	Mortar	Mortar	Rocket			
Contractor Classification	57 mm thru 105 mm	5 in thru 155 mm	60 mm	81 mm	4.2 in	2.75 in	Clutter		Total
Projectile Medium 57 mm thru 105 mm	5	2	3	4	2	1	21		38
Projectile Large 5 in thru 155 mm		3					1		4
Mortar 60 mm									0
Mortar 81 mm									0
Mortar 4.2 in									0
Rocket 2.75 in	1	2				2	3		8
Non-ordnance Low/Med	4		2	1		1	30		38
Non-ordnance High							46		46
Total	10	7	5	5	2	4	101	134	134
% Classified	50.00%	42.86%	0.00%	0.00%	0.00%	50.00%			
% Classified by Class		% of Total Detected			% of Total Detected				
Projectile	47.06%	Targets Classified as			Targets Classified as				
Mortar	0.00%	Non-ordnance Low/Med			Non-ordnance High				
Rocket	50.00%	Confidence	24.24%		Confidence		0.00%		

NRL Area 2	Classification Matrix								
Off Site without 20 mm	**Target Classification**								
	Projectile Medium	Projectile Large	Mortar	Mortar	Mortar	Rocket			
Contractor Classification	57 mm thru 105 mm	5 in thru 155 mm	60 mm	81 mm	4.2 in	2.75 in	Clutter		Total
Projectile Medium 57 mm thru 105 mm	1	1	3	3			19		27
Projectile Large 5 in thru 155 mm		2					2		4
Mortar 60 mm									0
Mortar 81 mm									0
Mortar 4.2 in									0
Rocket 2.75 in						1	6		7
Mk84							1		1
Unknown ordnance							2		2
Non-ordnance Low/Med	3	1	2	3	1	1	25		36
Non-ordnance High		1					49		50
Total	4	5	5	6	1	2	104	127	127
% Classified	25.00%	40.00%	0.00%	0.00%	0.00%	50.00%			
% Classified by Class		% of Total Detected			% of Total Detected				
Projectile	33.33%	Targets Classified as			Targets Classified as				
Mortar	0.00%	Non-ordnance Low/Med			Non-ordnance High				
Rocket	50.00%	Confidence	47.83%		Confidence		4.35%		

NRL Area 3	Classification Matrix								
Off Site without 20 mm	**Target Classification**								
	Projectile Medium	Projectile Large	Mortar	Mortar	Mortar	Rocket			
Contractor Classification	57 mm thru 105 mm	5 in thru 155 mm	60 mm	81 mm	4.2 in	2.75 in	Clutter		Total
Projectile Medium 57 mm thru 105 mm	4	1	3	2			20		30
Projectile Large 5 in thru 155 mm							2		2
Mortar 60 mm									0
Mortar 81 mm									0
Mortar 4.2 in									0
Rocket 2.75 in				1		1	1		3
Non-ordnance Low/Med		1	1	1			24		27
Non-ordnance High							72		72
Total	4	2	4	4		1	119	134	134
% Classified	100.00%	0.00%	0.00%	0.00%	0.00%	100.00%			
% Classified by Class		% of Total Detected			% of Total Detected				
Projectile	66.67%	Targets Classified as			Targets Classified as				
Mortar	0.00%	Non-ordnance Low/Med			Non-ordnance High				
Rocket	100.00%	Confidence	20.00%		Confidence		0.00%		

Figure 27. Classification matrix for EMMS (EMI only w/o 20 mm)

NAEVA Area 1

Off Site without 20 mm

Classification Matrix

	Target Classification								
	Projectile Medium	Projectile Large	Mortar	Mortar	Mortar	Rocket			
Contractor Classification	57 mm thru 105 mm	5 in thru 155 mm	60 mm	81 mm	4.2 in	2.75 in	Clutter		Total
Projectile Medium 57 mm thru 105 mm	3			1			7		11
Projectile Large 5 in thru 155 mm	1	3	1				6		11
Mortar 60 mm	3			2			8		13
Mortar 81 mm		1	2	2			8		13
Mortar 4.2 in	1				2	1	6		10
Rocket 2.75 in		2	1			2	9		14
Non-ordnance Low/Med	1		1			1	18		21
Non-ordnance High		1					18		19
Total	9	7	5	5	2	4	80	112	112
% Classified	33.33%	42.86%	0.00%	40.00%	100.00%	50.00%			

% Classified by Class		% of Total Detected Targets Classified as Non-ordnance Low/Med Confidence		% of Total Detected Targets Classified as Non-ordnance High Confidence
Projectile	37.50%			
Mortar	33.33%			
Rocket	50.00%	9.38%		3.13%

NAEVA Area 2

Off Site without 20 mm

Classification Matrix

	Target Classification								
	Projectile Medium	Projectile Large	Mortar	Mortar	Mortar	Rocket			
Contractor Classification	57 mm thru 105 mm	5 in thru 155 mm	60 mm	81 mm	4.2 in	2.75 in	Clutter		Total
Projectile Medium 57 mm thru 105 mm	1	1		1			6		9
Projectile Large 5 in thru 155 mm		4	1	2			9		16
Mortar 60 mm	1		2	1			7		11
Mortar 81 mm			1	2			8		11
Mortar 4.2 in					1		6		7
Rocket 2.75 in	1					2	3		6
Non-ordnance Low/Med	1		1				18		20
Non-ordnance High	0						17		17
Total	4	5	5	6	1	2	74	97	97
% Classified	25.00%	80.00%	40.00%	33.33%	100.00%	100.00%			

% Classified by Class		% of Total Detected Targets Classified as Non-ordnance Low/Med Confidence		% of Total Detected Targets Classified as Non-ordnance High Confidence
Projectile	55.56%			
Mortar	41.67%			
Rocket	100.00%	8.70%		0.00%

NAEVA Area 3

Off Site without 20 mm

Classification Matrix

	Target Classification								
	Projectile Medium	Projectile Large	Mortar	Mortar	Mortar	Rocket			
Contractor Classification	57 mm thru 105 mm	5 in thru 155 mm	60 mm	81 mm	4.2 in	2.75 in	Clutter		Total
Projectile Medium 57 mm thru 105 mm	1			1			6		8
Projectile Large 5 in thru 155 mm		1	2				9		12
Mortar 60 mm	1						7		8
Mortar 81 mm	1		2	3			8		14
Mortar 4.2 in							3		3
Rocket 2.75 in						1	7		8
Non-ordnance Low/Med		1					9		10
Non-ordnance High							7		7
Total	3	2	4	4		1	56	70	70
% Classified	33.33%	50.00%	0.00%	75.00%	0.00%	100.00%			

% Classified by Class		% of Total Detected Targets Classified as Non-ordnance Low/Med Confidence		% of Total Detected Targets Classified as Non-ordnance High Confidence
Projectile	40.00%			
Mortar	37.50%			
Rocket	100.00%	7.14%		0.00%

Figure 28. Classification matrix for EM-63 (EMI only w/o 20 mm)

Geophex Area 1	Classification Matrix									
MAG with 20 mm	Target Classification									
	Projectile Small	Projectile Medium	Projectile Large	Mortar	Mortar	Mortar	Rocket			
Contractor Classification	20 mm	57 mm thru 105 mm	5 in thru 155 mm	60 mm	81 mm	4.2 in	2.75 in	Clutter		Total
Projectile Small 20mm								3		3
Projectile Medium 57 mm thru 105 mm	1	2					2	10		15
Projectile Large 5 in thru 155 mm			3	1				6		10
Mortar 60 mm	1	2		2	1			34		40
Mortar 81 mm			1		4	1		8		14
Mortar 4.2 in			1					2		3
Rocket 2.75 in			1			1		3		5
Unknown ordnance								7		7
Non-ordnance Low/Med	6	6	1	1			2	34		50
Non-ordnance High	2			1				23		26
Total	10	10	7	5	5	2	4	130	173	173
% Classified	0.00%	20.00%	42.86%	40.00%	80.00%	0.00%	0.00%			
% Classified by Class			% of Total Detected			% of Total Detected				
Projectile	18.52%		Targets Classified as			Targets Classified as				
Mortar	50.00%		Non-ordnance Low/Med			Non-ordnance High				
Rocket	0.00%		Confidence	37.21%		Confidence		6.98%		

Geophex Area 2	Classification Matrix									
MAG with 20 mm	Target Classification									
	Projectile Small	Projectile Medium	Projectile Large	Mortar	Mortar	Mortar	Rocket			
Contractor Classification	20 mm	57 mm thru 105 mm	5 in thru 155 mm	60 mm	81 mm	4.2 in	2.75 in	Clutter		Total
Projectile Small 20mm	1							40		41
Projectile Medium 57 mm thru 105 mm		1	1	1	1		1	9		14
Projectile Large 5 in thru 155 mm		1	1				1	9		12
Mortar 60 mm		2		1				32		35
Mortar 81 mm				1	3			12		16
Mortar 4.2 in						1		0		1
Rocket 2.75 in		1	2		1			9		13
Unknown ordnance								3		3
Non-ordnance Low/Med	3							71		74
Non-ordnance High	1		1	1				26		29
Total	5	5	5	4	5	1	2	211	238	238
% Classified	20.00%	20.00%	20.00%	25.00%	60.00%	100.00%	0.00%			
% Classified by Class			% of Total Detected			% of Total Detected				
Projectile	20.00%		Targets Classified as			Targets Classified as				
Mortar	50.00%		Non-ordnance Low/Med			Non-ordnance High				
Rocket	0.00%		Confidence	11.11%		Confidence		11.11%		

Geophex Area 3	Classification Matrix									
MAG with 20 mm	Target Classification									
	Projectile Small	Projectile Medium	Projectile Large	Mortar	Mortar	Mortar	Rocket			
Contractor Classification	20 mm	57 mm thru 105 mm	5 in thru 155 mm	60 mm	81 mm	4.2 in	2.75 in	Clutter		Total
Projectile Small 20mm								21		21
Projectile Medium 57 mm thru 105 mm	1	1					1	14		17
Projectile Large 5 in thru 155 mm		2	1					4		7
Mortar 60 mm	1	1		3				39		44
Mortar 81 mm	1			1	2			6		10
Mortar 4.2 in				0	0			3		3
Rocket 2.75 in				1	1			4		6
Unknown ordnance								26		26
Non-ordnance Low/Med	1							48		49
Non-ordnance High					1			22		23
Total	4	4	1	5	4	0	1	187	206	206
% Classified	0.00%	25.00%	100.00%	60.00%	50.00%	0.00%	0.00%			
% Classified by Class			% of Total Detected			% of Total Detected				
Projectile	22.22%		Targets Classified as			Targets Classified as				
Mortar	55.56%		Non-ordnance Low/Med			Non-ordnance High				
Rocket	0.00%		Confidence	5.26%		Confidence		5.26%		

Figure 29. Classification matrix for GEM-3 (MAG w/20-mm results)

NRL Area 1
MAG with 20 mm

Classification Matrix

Target Classification

Contractor Classification	Projectile Small 20 mm	Projectile Medium 57 mm thru 105 mm	Projectile Large 5 in thru 155 mm	Mortar 60 mm	Mortar 81 mm	Mortar 4.2 in	Rocket 2.75 in	Clutter		Total
Projectile Small 20mm	2							12		14
Projectile Medium 57 mm thru 105 mm		4	1	3	3	1	2	24		38
Projectile Large 5 in thru 155 mm		1	6				1	6		14
Mortar 60 mm										0
Mortar 81 mm								1		1
Mortar 4.2 in		1						2		3
Rocket 2.75 in		2		1	1	1		3		8
Unknown ordnance	1							1		2
Non-ordnance Low/Med	1	2		1			1	30		35
Non-ordnance High	4							40		44
Total	8	10	7	5	4	2	4	119	159	159
% Classified	25.00%	40.00%	85.71%	0.00%	0.00%	0.00%	0.00%			

% Classified by Class	
Projectile	48.00%
Mortar	0.00%
Rocket	0.00%

% of Total Detected Targets Classified as Non-ordnance Low/Med Confidence: 12.50%

% of Total Detected Targets Classified as Non-ordnance High Confidence: 10.00%

NRL Area 2
MAG with 20 mm

Classification Matrix

Target Classification

Contractor Classification	Projectile Small 20 mm	Projectile Medium 57 mm thru 105 mm	Projectile Large 5 in thru 155 mm	Mortar 60 mm	Mortar 81 mm	Mortar 4.2 in	Rocket 2.75 in	Clutter		Total
Projectile Small 20mm	2							11		13
Projectile Medium 57 mm thru 105 mm		1	2	2	2		1	30		38
Projectile Large 5 in thru 155 mm			1					4		5
Mortar 60 mm										0
Mortar 81 mm					1					1
Mortar 4.2 in										0
Rocket 2.75 in				1						1
Mk84		0						2		2
Non-ordnance Low/Med	1	3	2	2	3	1		43		55
Non-ordnance High	1						1	48		50
Total	4	4	5	5	6	1	2	138	165	165
% Classified	50.00%	25.00%	20.00%	0.00%	16.67%	0.00%	0.00%			

% Classified by Class	
Projectile	30.77%
Mortar	8.33%
Rocket	0.00%

% of Total Detected Targets Classified as Non-ordnance Low/Med Confidence: 44.44%

% of Total Detected Targets Classified as Non-ordnance High Confidence: 7.41%

NRL Area 3
MAG with 20 mm

Classification Matrix

Target Classification

Contractor Classification	Projectile Small 20 mm	Projectile Medium 57 mm thru 105 mm	Projectile Large 5 in thru 155 mm	Mortar 60 mm	Mortar 81 mm	Mortar 4.2 in	Rocket 2.75 in	Clutter		Total
Projectile Small 20mm								21		21
Projectile Medium 57 mm thru 105 mm		2		3	3			22		30
Projectile Large 5 in thru 155 mm			1	0				2		3
Mortar 60 mm										0
Mortar 81 mm										0
Mortar 4.2 in								2		2
Rocket 2.75 in		2					1	1		4
Non-ordnance Low/Med	3			1	1			51		56
Non-ordnance High	1							39		40
Total	4	4	1	4	4	0	1	138	156	156
% Classified	0.00%	50.00%	100.00%	0.00%	0.00%	0.00%	100.00%			

% Classified by Class	
Projectile	33.33%
Mortar	0.00%
Rocket	100.00%

% of Total Detected Targets Classified as Non-ordnance Low/Med Confidence: 27.78%

% of Total Detected Targets Classified as Non-ordnance High Confidence: 5.56%

Figure 30. Classification matrix for EMMS (MAG w/20-mm results)

NAEVA Area 1
MAG with 20 mm

Classification Matrix

	Target Classification									
Contractor Classification	Projectile Small 20 mm	Projectile Medium 57 mm thru 105 mm	Projectile Large 5 in thru 155 mm	Mortar 60 mm	Mortar 81 mm	Mortar 4.2 in	Rocket 2.75 in	Clutter		Total
Projectile Small 20mm	2							11		13
Projectile Medium 57 mm thru 105 mm	1	3			2			5		11
Projectile Large 5 in thru 155 mm	1	1	3	1				5		11
Mortar 60 mm		3			2			5		10
Mortar 81 mm			1	1	2			9		13
Mortar 4.2 in	1	1				2	1	4		9
Rocket 2.75 in			2	1			2	5		10
Non-ordnance Low/Med		1		1			1	16		19
Non-ordnance High			1					20		21
Total	5	9	7	4	6	2	4	80	117	117
% Classified	40.00%	33.33%	42.86%	0.00%	33.33%	100.00%	50.00%			

% Classified by Class	
Projectile	38.10%
Mortar	33.33%
Rocket	50.00%

% of Total Detected Targets Classified as Non-ordnance Low/Med Confidence: 8.11%

% of Total Detected Targets Classified as Non-ordnance High Confidence: 2.70%

NAEVA Area 2
MAG with 20 mm

Classification Matrix

	Target Classification									
Contractor Classification	Projectile Small 20 mm	Projectile Medium 57 mm thru 105 mm	Projectile Large 5 in thru 155 mm	Mortar 60 mm	Mortar 81 mm	Mortar 4.2 in	Rocket 2.75 in	Clutter		Total
Projectile Small 20mm	2			1			1	4		8
Projectile Medium 57 mm thru 105 mm		1	1		1			8		11
Projectile Large 5 in thru 155 mm			4	1	2			10		17
Mortar 60 mm		1		1	1			7		10
Mortar 81 mm				1	2			9		12
Mortar 4.2 in						1		4		5
Rocket 2.75 in		1					1	2		4
Non-ordnance Low/Med		1		1				23		25
Non-ordnance High								25		25
Total	2	4	5	5	6	1	2	92	117	117
% Classified	100.00%	25.00%	80.00%	20.00%	33.33%	100.00%	50.00%			

% Classified by Class	
Projectile	63.64%
Mortar	33.33%
Rocket	50.00%

% of Total Detected Targets Classified as Non-ordnance Low/Med Confidence: 8.00%

% of Total Detected Targets Classified as Non-ordnance High Confidence: 0.00%

NAEVA Area 3
MAG with 20 mm

Classification Matrix

	Target Classification									
Contractor Classification	Projectile Small 20 mm	Projectile Medium 57 mm thru 105 mm	Projectile Large 5 in thru 155 mm	Mortar 60 mm	Mortar 81 mm	Mortar 4.2 in	Rocket 2.75 in	Clutter		Total
Projectile Small 20mm	1	1						5		7
Projectile Medium 57 mm thru 105 mm		1			1			6		8
Projectile Large 5 in thru 155 mm			1	2				9		12
Mortar 60 mm		1						6		7
Mortar 81 mm		1		2	3			8		14
Mortar 4.2 in								2		2
Rocket 2.75 in							1	6		7
Non-ordnance Low/Med			1					7		8
Non-ordnance High								13		13
Total	1	4	2	4	4		1	62	78	78
% Classified	100.00%	25.00%	50.00%	0.00%	75.00%	0.00%	100.00%			

% Classified by Class	
Projectile	42.86%
Mortar	37.50%
Rocket	100.00%

% of Total Detected Targets Classified as Non-ordnance Low/Med Confidence: 6.25%

% of Total Detected Targets Classified as Non-ordnance High Confidence: 0.00%

Figure 31. Classification matrix for EM-63 (MAG w/20-mm results)

Geophex Area 1	Classification Matrix								
MAG without 20 mm	Target Classification								
	Projectile Medium	Projectile Large	Mortar	Mortar	Mortar	Rocket			
Contractor Classification	57 mm thru 105 mm	5 in thru 155 mm	60 mm	81 mm	4.2 in	2.75 in	Clutter		Total
Projectile Medium 57 mm thru 105 mm	2					2	10		14
Projectile Large 5 in thru 155 mm		3	1				6		10
Mortar 60 mm	2		2	1			35		40
Mortar 81 mm		1		4	1		8		14
Mortar 4.2 in		2			1				3
Rocket 2.75 in							5		5
Unknown ordnance							7		7
Non-ordnance Low/Med	6	1	1			2	35		45
Non-ordnance High			1				24		25
Total	10	7	5	5	2	4	130	163	163
% Classified	20.00%	42.86%	40.00%	80.00%	50.00%	0.00%			

% Classified by Class		% of Total Detected Targets Classified as Non-ordnance Low/Med Confidence		% of Total Detected Targets Classified as Non-ordnance High Confidence	
Projectile	29.41%		30.30%		3.03%
Mortar	58.33%				
Rocket	0.00%				

Geophex Area 2	Classification Matrix								
MAG without 20 mm	Target Classification								
	Projectile Medium	Projectile Large	Mortar	Mortar	Mortar	Rocket			
Contractor Classification	57 mm thru 105 mm	5 in thru 155 mm	60 mm	81 mm	4.2 in	2.75 in	Clutter		Total
Projectile Medium 57 mm thru 105 mm	1	1	1	1		1	9		14
Projectile Large 5 in thru 155 mm	1	1				1	9		12
Mortar 60 mm	2		2				32		36
Mortar 81 mm			1	4			11		16
Mortar 4.2 in					1				1
Rocket 2.75 in	1	2		1			9		13
Unknown ordnance							3		3
Non-ordnance Low/Med		1	1				62		64
Non-ordnance High							21		21
Total	5	5	5	6	1	2	156	180	180
% Classified	20.00%	20.00%	40.00%	66.67%	100.00%	0.00%			

% Classified by Class		% of Total Detected Targets Classified as Non-ordnance Low/Med Confidence		% of Total Detected Targets Classified as Non-ordnance High Confidence	
Projectile	20.00%		8.33%		0.00%
Mortar	58.33%				
Rocket	0.00%				

Geophex Area 3	Classification Matrix								
MAG without 20 mm	Target Classification								
	Projectile Medium	Projectile Large	Mortar	Mortar	Mortar	Rocket			
Contractor Classification	57 mm thru 105 mm	5 in thru 155 mm	60 mm	81 mm	4.2 in	2.75 in	Clutter		Total
Projectile Medium 57 mm thru 105 mm	1	1				1	14		17
Projectile Large 5 in thru 155 mm	2	1					4		7
Mortar 60 mm	1		3				40		44
Mortar 81 mm			1	2			7		10
Mortar 4.2 in							3		3
Rocket 2.75 in			1	1			4		6
Unknown ordnance							26		26
Non-ordnance Low/Med							42		42
Non-ordnance High				1			22		23
Total	4	2	5	4		1	162	178	178
% Classified	25.00%	50.00%	60.00%	50.00%	0.00%	0.00%			

% Classified by Class		% of Total Detected Targets Classified as Non-ordnance Low/Med Confidence		% of Total Detected Targets Classified as Non-ordnance High Confidence	
Projectile	33.33%		0.00%		6.25%
Mortar	55.56%				
Rocket	0.00%				

Figure 32. Classification matrix for GEM-3 (MAG w/o 20-mm results)

NRL Area 1	Classification Matrix								
MAG without 20 mm	Target Classification								
	Projectile Medium	Projectile Large	Mortar	Mortar	Mortar	Rocket			
Contractor Classification	57 mm thru 105 mm	5 in thru 155 mm	60 mm	81 mm	4.2 in	2.75 in	Clutter		Total
Projectile Medium 57 mm thru 105 mm	3	1	3	3	1	2	26		39
Projectile Large 5 in thru 155 mm	2	6				1	6		15
Mortar 60 mm							0		0
Mortar 81 mm							1		1
Mortar 4.2 in	1						2		3
Rocket 2.75 in	2		1	1	1		3		8
Non-ordnance Low/Med	2		1			1	24		28
Non-ordnance High							65		65
Total	10	7	5	4	2	4	127	159	159
% Classified	30.00%	85.71%	0.00%	0.00%	0.00%	0.00%			

% Classified by Class		% of Total Detected Targets Classified as Non-ordnance Low/Med Confidence		% of Total Detected Targets Classified as Non-ordnance High Confidence	
Projectile	52.94%		12.50%		0.00%
Mortar	0.00%				
Rocket	0.00%				

NRL Area 2	Classification Matrix								
MAG without 20 mm	Target Classification								
	Projectile Medium	Projectile Large	Mortar	Mortar	Mortar	Rocket			
Contractor Classification	57 mm thru 105 mm	5 in thru 155 mm	60 mm	81 mm	4.2 in	2.75 in	Clutter		Total
Projectile Medium 57 mm thru 105 mm	1	2	2	2		1	34		42
Projectile Large 5 in thru 155 mm		1					4		5
Mortar 60 mm									0
Mortar 81 mm				1					1
Mortar 4.2 in									0
Rocket 2.75 in			1				1		2
Mk84							2		2
Non-ordnance Low/Med	3	2	2	3	1		37		48
Non-ordnance High						1	65		66
Total	4	5	5	6	1	2	143	166	166
% Classified	25.00%	20.00%	0.00%	16.67%	0.00%	0.00%			

% Classified by Class		% of Total Detected Targets Classified as Non-ordnance Low/Med Confidence		% of Total Detected Targets Classified as Non-ordnance High Confidence	
Projectile	22.22%		47.83%		4.35%
Mortar	8.33%				
Rocket	0.00%				

NRL Area 3	Classification Matrix								
MAG without 20 mm	Target Classification								
	Projectile Medium	Projectile Large	Mortar	Mortar	Mortar	Rocket			
Contractor Classification	57 mm thru 105 mm	5 in thru 155 mm	60 mm	81 mm	4.2 in	2.75 in	Clutter		Total
Projectile Medium 57 mm thru 105 mm	2		3	3			24		32
Projectile Large 5 in thru 155 mm		1	0				2		3
Mortar 60 mm									0
Mortar 81 mm									0
Mortar 4.2 in							2		2
Rocket 2.75 in	2					1	1		4
Non-ordnance Low/Med			1	1			28		30
Non-ordnance High							85		85
Total	4	1	4	4	0	1	142	156	156
% Classified	50.00%	100.00%	0.00%	0.00%	0.00%	100.00%			

% Classified by Class		% of Total Detected Targets Classified as Non-ordnance Low/Med Confidence		% of Total Detected Targets Classified as Non-ordnance High Confidence	
Projectile	60.00%		14.29%		0.00%
Mortar	0.00%				
Rocket	100.00%				

Figure 33. Classification matrix for EMMS (MAG w/o 20-mm results)

NAEVA Area 1 MAG without 20 mm	Classification Matrix Target Classification								
	Projectile Medium	Projectile Large	Mortar	Mortar	Mortar	Rocket			
Contractor Classification	57 mm thru 105 mm	5 in thru 155 mm	60 mm	81 mm	4.2 in	2.75 in	Clutter		Total
Projectile Medium 57 mm thru 105 mm	3			1			7		11
Projectile Large 5 in thru 155 mm	1	3	1				6		11
Mortar 60 mm	3			2			8		13
Mortar 81 mm		1	2	2			8		13
Mortar 4.2 in	1				2	1	6		10
Rocket 2.75 in		2	1			2	9		14
Non-ordnance Low/Med	1		1			1	18		21
Non-ordnance High		1					23		24
Total	9	7	5	5	2	4	85	117	117
% Classified	33.33%	42.86%	0.00%	40.00%	100.00%	50.00%			

% Classified by Class	
Projectile	37.50%
Mortar	33.33%
Rocket	50.00%

% of Total Detected Targets Classified as Non-ordnance Low/Med Confidence 9.38%

% of Total Detected Targets Classified as Non-ordnance High Confidence 3.13%

NAEVA Area 2 MAG without 20 mm	Classification Matrix Target Classification								
	Projectile Medium	Projectile Large	Mortar	Mortar	Mortar	Rocket			
Contractor Classification	57 mm thru 105 mm	5 in thru 155 mm	60 mm	81 mm	4.2 in	2.75 in	Clutter		Total
Projectile Medium 57 mm thru 105 mm	1	1		1			8		11
Projectile Large 5 in thru 155 mm		4	1	2			10		17
Mortar 60 mm	1		2	1			9		13
Mortar 81 mm			1	2			9		12
Mortar 4.2 in					1		6		7
Rocket 2.75 in	1					2	3		6
Non-ordnance Low/Med	1		1				20		22
Non-ordnance High							28		28
Total	4	5	5	6	1	2	93	116	116
% Classified	25.00%	80.00%	40.00%	33.33%	100.00%	100.00%			

% Classified by Class	
Projectile	55.56%
Mortar	41.67%
Rocket	100.00%

% of Total Detected Targets Classified as Non-ordnance Low/Med Confidence 8.70%

% of Total Detected Targets Classified as Non-ordnance High Confidence 0.00%

NAEVA Area 3 MAG without 20 mm	Classification Matrix Target Classification								
	Projectile Medium	Projectile Large	Mortar	Mortar	Mortar	Rocket			
Contractor Classification	57 mm thru 105 mm	5 in thru 155 mm	60 mm	81 mm	4.2 in	2.75 in	Clutter		Total
Projectile Medium 57 mm thru 105 mm	1			1			6		8
Projectile Large 5 in thru 155 mm		1	2				9		12
Mortar 60 mm	1						9		10
Mortar 81 mm	1		2	3			8		14
Mortar 4.2 in							3		3
Rocket 2.75 in						1	7		8
Non-ordnance Low/Med		1					9		10
Non-ordnance High							13		13
Total	3	2	4	4		1	64	78	78
% Classified	33.33%	50.00%	0.00%	75.00%	0.00%	100.00%			

% Classified by Class	
Projectile	40.00%
Mortar	37.50%
Rocket	100.00%

% of Total Detected Targets Classified as Non-ordnance Low/Med Confidence 7.14%

% of Total Detected Targets Classified as Non-ordnance High Confidence 0.00%

Figure 34. Classification matrix for EM-63 (MAG w/o 20-mm results)

Table 2
Demonstrators' Ability to Detect and Discriminate Targets by Class – Onsite Analysis Results

		Area 1			Area 2			Area 3			Total Score		
Demonstrator	Class	Actual	Found	Match	Actual	Found	Match	Actual	Found	Match	Actual	Found	Match
NRL	P	27	25	13	16	13	07	10	10	05	53	48	25
	M	12	12	08	12	12	06	09	08	05	33	32	19
	R	04	04	02	02	02	01	01	01	01	07	07	04
Geophex	P	27	27	06	16	16	05	10	10	04	53	53	15
	M	12	12	05	12	12	05	09	09	03	33	33	13
	R	04	04	0	02	02	0	01	01	0	07	07	0
NAEVA	P	27	22	12	16	13	08	10	08	05	53	43	25
	M	12	12	08	12	12	06	09	08	05	33	32	19
	R	04	04	02	02	02	01	01	01	01	07	07	04
EODT	P	27	19	-	16	08	-	10	04	-	53	31	-
	M	12	09	-	12	11	-	09	09	-	33	29	-
	R	04	03	-	02	02	-	01	0	-	07	05	-

Note: P - Projectile, M - Mortar, R – Rocket.

Table 3
Demonstrators' Ability to Detect and Discriminate Targets by Class – 0ffsite (excluding 20 mm) Analysis Results

		Area 1			Area 2			Area 3			Total Score		
Demonstrator	Class	Actual	Found	Match	Actual	Found	Match	Actual	Found	Match	Actual	Found	Match
NRL	P	17	17	10	10	09	04	06	06	05	33	32	19
	M	12	12	09	12	12	06	09	08	05	33	32	18
	R	04	04	02	02	02	01	01	01	01	07	07	04
Geophex	P	17	17	02	10	09	03	06	05	0	33	31	05
	M	12	12	05	12	12	05	09	07	03	33	33	13
	R	04	04	0	02	02	0	01	01	0	07	07	0
NAEVA	P	17	16	07	10	09	06	06	05	02	33	30	15
	M	12	12	08	12	12	07	09	08	05	33	32	20
	R	04	04	02	02	02	02	01	01	01	07	07	05

Note: P – Projectile, M - Mortar, R – Rocket.

Table 4
Demonstrators' Ability to Detect and Discriminate Targets by Class – Joint Mag/Em (with 20 mm) Analysis Results

		Area 1			Area 2			Area 3			Total Score		
Demonstrator	Class	Actual	Found	Match	Actual	Found	Match	Actual	Found	Match	Actual	Found	Match
NRL	P	27	25	15	16	13	06	10	09	03	53	47	24
	M	12	11	07	12	12	05	09	08	06	33	31	18
	R	04	04	0	02	02	0	01	01	01	07	07	01
Geophex	P	27	27	06	16	15	05	10	09	05	53	51	15
	M	12	12	09	12	11	07	09	09	06	33	32	22
	R	04	04	0	02	02	0	01	01	0	07	07	0
NAEVA	P	27	21	11	16	12	08	10	07	03	53	40	22
	M	12	12	08	12	12	06	09	08	05	33	32	19
	R	04	04	02	02	02	01	01	01	01	07	07	04

Note: P - Projectile, M - Mortar, R – Rocket.

Table 5
Demonstrators' Ability to Detect and Discriminate Targets by Class – Joint Mag/Em (excluding 20 mm) Analysis Results

		Area 1			Area 2			Area 3			Total Score		
Demonstrator	Class	Actual	Found	Match	Actual	Found	Match	Actual	Found	Match	Actual	Found	Match
NRL	P	17	17	12	10	10	04	06	05	03	33	32	19
	M	12	11	07	12	12	05	09	08	06	33	31	18
	R	04	04	0	02	02	0	01	01	01	07	07	01
Geophex	P	17	17	05	10	10	04	06	06	05	33	32	13
	M	12	12	09	12	12	08	09	09	06	33	33	23
	R	04	04	0	02	02	0	01	01	0	07	07	0
NAEVA	P	17	16	07	10	09	06	06	05	02	33	30	15
	M	12	12	08	12	12	07	09	08	05	33	32	20
	R	04	04	02	02	02	02	01	01	01	07	07	05

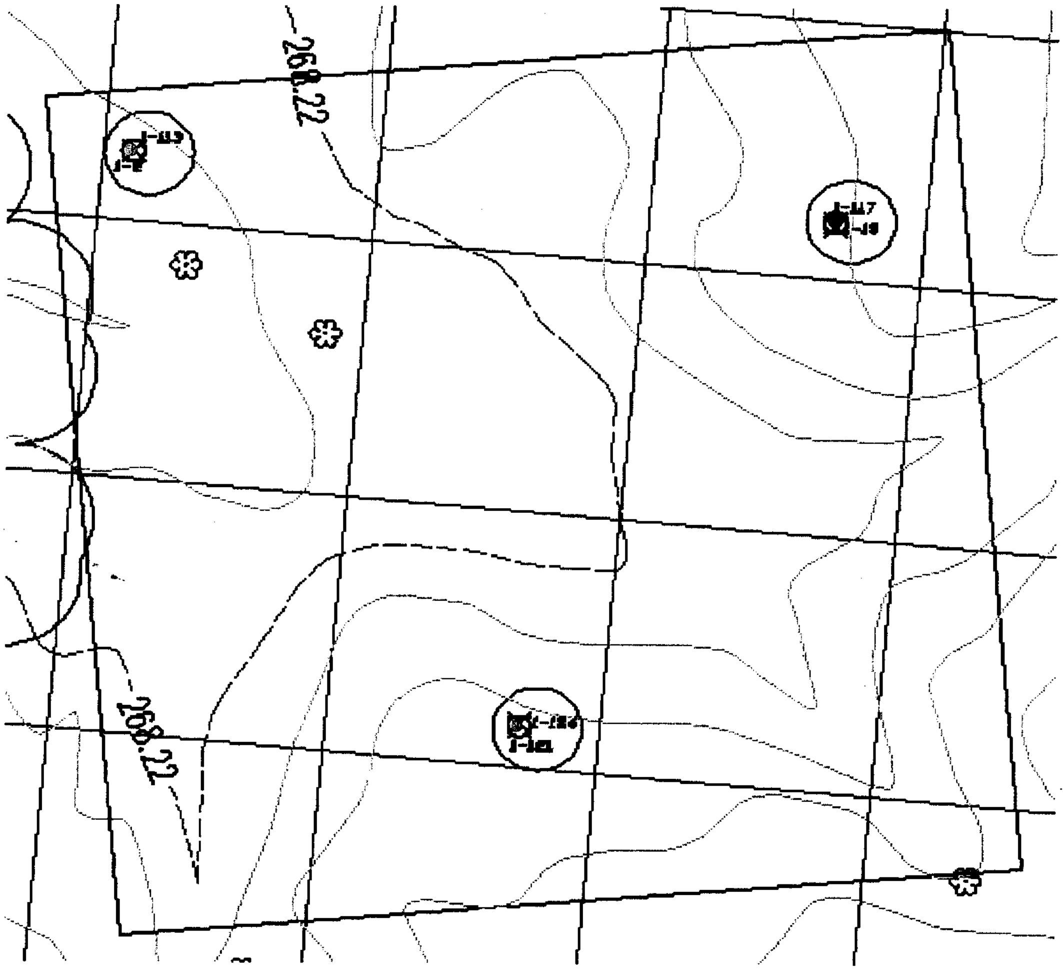
Note: P - Projectile, M - Mortar, R – Rocket

the EMI sensors and to determine the robustness of the various discrimination, classification, and identification techniques employed.

Figure 35 shows the abilities of the demonstrators against large UXO targets with overlapping clutter signatures. In all cases, the demonstrators reported only one target which indicates limited capability of resolving close targets when the signatures are fairly large. All three demonstrators were able to correctly locate target 1-113 which corresponds to a 105-mm projectile, and two (NRL and NAEVA) were able to correctly classify the target as a projectile. Geophex, on the other hand, incorrectly declared this target as clutter with high confidence. All three demonstrators incorrectly located target 1-117, a 152-mm projectile, at the location corresponding to the clutter item, but all three correctly discriminated the anomaly as a UXO target. Only NRL correctly classified the target as a projectile. Target 1-121 was a 155-mm projectile which was correctly located, discriminated, and classified as a projectile by both NRL and NAEVA. Geophex, on the other hand, declared the target at the clutter location and declared it as clutter with high confidence. NRL correctly identified this target as a 155-mm projectile.

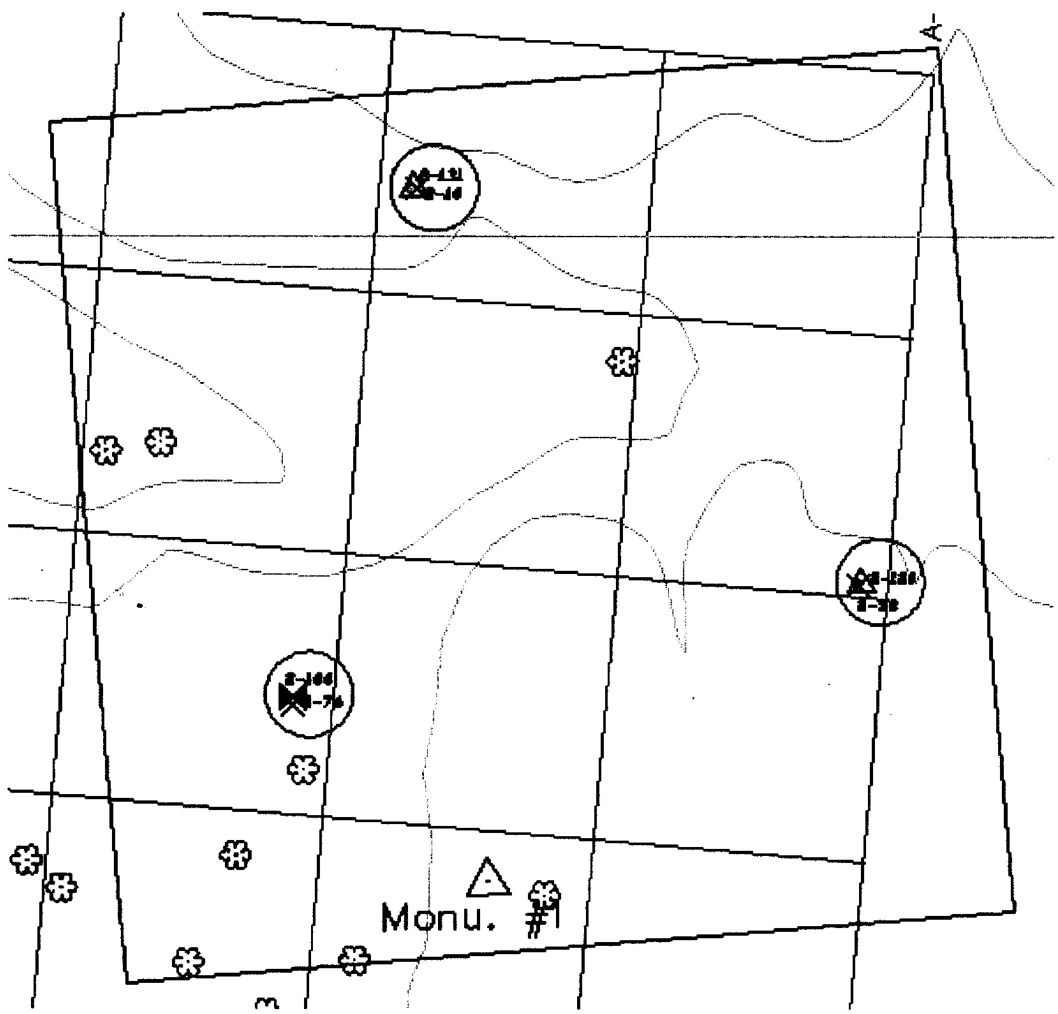
Figure 36 shows the capabilities of the demonstrators against smaller targets with overlapping clutter. Target 2-131 consisted of an 81-mm mortar which was located correctly by NRL and NAEVA, and correctly discriminated, classified and identified by all three systems. Target 2-120 consisted of a 60-mm mortar, was correctly located by all three systems and discriminated by NRL and NAEVA, and was classified as a mortar only by NRL. Target 2-166 consisted of a 2.75-in. rocket warhead and was the only target in this area that was resolved as two separate objects (by NAEVA and Geophex). Only NAEVA was able to discriminate it as a UXO target, and NRL and Geophex declared it as a clutter item (with medium and low confidence, respectively). None of the demonstrators were able to correctly classify this target as a rocket.

Figure 37 shows the capabilities against small mortar targets with overlapping clutter signatures. Target 3-68 consisted of a 60-mm mortar and was correctly located and resolved into two separate objects only by Geophex. Only



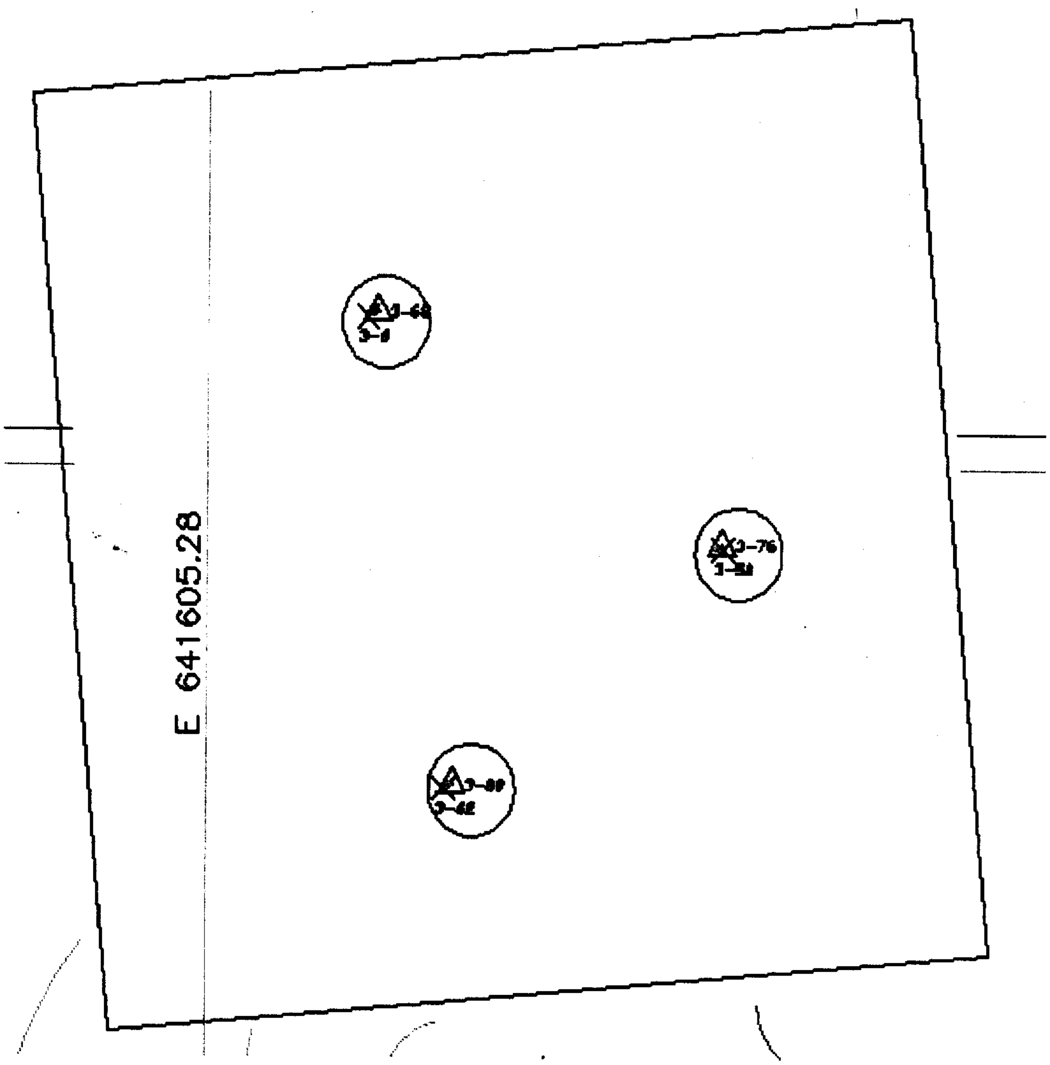
Groundtruth	Geophex		NRL		NAEVA	
Area 1	**Found**	**Declared**	**Found**	**Declared**	**Found**	**Declared**
2 – Clutter 113 - Projectile	113	C-H	113	P	113	P
18 – Clutter 117 - Projectile	18	M	18	P	18	M
184 - Clutter 121 - Projectile	184	C-H	121	P	121	P
Note: P-Projectile, M-Mortar, R-Rocket, C-L – Clutter Low, C-M – Clutter Medium, C-H – Clutter High						

Figure 35. Overlapping targets in Area 1



Groundtruth	Geophex		NRL		NAEVA	
Area 2	Found	Declared	Found	Declared	Found	Declared
16 – Clutter 131 - Mortar	16	M	131	M	131	M
88 – Clutter 120 - Mortar	120	C-L	120	M	120	P
76 – Clutter 166 - Rocket	76/166	C-L/P	166	C-M	76/166	P/P
Note: P-Projectile, M-Mortar, R-Rocket, C-L – Clutter Low, C-M – Clutter Medium, C-H – Clutter High						

Figure 36. Overlapping targets in Area 2



Groundtruth	Geophex		NRL		NAEVA	
Area 3	Found	Declared	Found	Declared	Found	Declared
6 - Clutter 68 - Mortar	6/68	R/P	6	C-H	6	C-L
50 - Clutter 76 - Mortar	76	R	50	C-M	76	M
62 - Clutter 80 - Rocket	80	C-H	80	M	80	M
Note: P-Projectile, M-Mortar, R-Rocket, C-L – Clutter Low, C-M – Clutter Medium, C-H – Clutter High						

Figure 37. Overlapping targets in Area 3

Geophex was able to discriminate this anomaly as a UXO but incorrectly classified it as a projectile. NRL and NAEVA declared this object as clutter with high confidence and low confidence, respectively. Target 3-76 also corresponded to a 60-mm mortar and was correctly and discriminated by Geophex and NAEVA. In addition, NAEVA was able to correctly identify the signature as that of a 60-mm mortar. NRL incorrectly declared this item as clutter with medium confidence. Target 3-80 consited of an 81-mm mortar and was correctly located by all three demonstrators. NAEVA and NRL discriminated the anomaly as UXO, and NAEVA correctly identified the target. Geophex incorrectly declared this item as clutter with high confidence.

Assessment of target location performance

The location (x,y) performance of each of the three demonstrators was evaluated by comparing each item in the onsite dig list with the ground truth, determining the closest item (within 1 m) to an emplaced UXO target location, and computing the error. In order to protect the ground truth information, the tables used to generate this evaluation will not be released until the ESTCP program office decides to release the ground truth. The ability to locate clutter items was not one of the evaluation criteria, but the raw data was available for such analysis if deemed useful.

The evaluation of the target locations reported by the demonstrators indicates that the GEM-3 achieved the highest location accuracy for all the targets detected (all three test areas). The average horizontal position error for the GEM-3 was 16.6 cm. The EMMS system demonstrated an average position error of 22.1 cm, and the NAEVA EM-63 system demonstrated an error of 26.8 cm. The large majority of the targets detected by the three demonstrators were well within the 0.5-m error radius required by Kaho'olawe cleanup criteria.

It should be noted that two UXO targets in Area 1 (items 1-124 and 1-126) produced the largest position errors (ranging from 1.1 to 1.56 m) for all demonstrators. We investigated the reason for these errors and concluded from the site preparation and previous JPG MTADS mag surveys that there were buried ferrous objects, outside of the 2- by 2-m areas cleared prior to target emplacement, that were large enough to affect the signatures of the emplaced targets. Review of ground-truth records from previous JPG demonstrations indicate that a large ferrous object had been placed in the vicinity of each of these locations.

The ability of the demonstrators to estimate the depth of the UXO targets is summarized in Table 6. These results indicate that, while the performance of each demonstrator varied significantly between each test area, the mean depth estimation errors were well within the 0.5-m allowable error. Overall, the NAEVA EM-63 system achieved the best depth estimation accuracy, followed by the NRL EMMS, with the Geophex GEM-3 demonstrating the largest maximum and mean depth estimation errors.

Table 6 UXO Target Depth Estimation Performance of the Demonstrators					
Area	**Demonstrator**	**Minimum Error, m**	**Maximum Error, m**	**Mean Error, m**	**Std. Dev**
1	NAEVA EM-63	0.00	0.63	0.19	0.14
	NRL EMMS	0.01	0.65	0.23	0.17
	GEOPHEX GEM-3	0.01	0.81	0.20	0.18
2	NAEVA EM-63	0.03	0.72	0.24	0.19
	NRL EMMS	0.00	0.86	0.27	0.24
	GEOPHEX GEM-3	0.04	0.93	0.30	0.23
3	NAEVA EM-63	0.01	0.76	0.16	0.21
	NRL EMMS	0.01	0.37	0.16	0.10
	GEOPHEX GEM-3	0.02	1.10	0.31	0.27

Assessment of production rate performance

As part of the demonstration criteria, the Government representatives at JPG recorded man-hour requirements to perform all onsite tasks, and this information is available from the ftp site. The evaluation factors related to production rate performance are described in the demonstration work plan and listed in the Chapter 4 of this report. Because of a variety of problems experienced in the field by some of the demonstrators (e.g., the need to collect a new target signature library onsite, the lack of capability to perform onsite analysis), direct comparison of all production rate factors is not possible. Since survey times are one of the more important production factors, and accurate information from all the demonstrators (including "mag and flag") is available, it has been decided to use this factor for production rate performance evaluation and comparison. A summary of the time and man-hours required to survey each site is presented in Table 7.

From the data summarized in this table, it can be concluded that the standard "mag and flag" approach achieved an average production rate of 1 hectare per 5.97 hr and required a three-person survey crew. The best performer among the advanced technology demonstrators was NRL EMMS, which achieved an average of 1 hectare per 6.56 hr, and required a field survey crew ranging from one to four persons. The GEM-3 system achieved an average production rate of 1 hectare per 8.95 hr and required a two-person survey crew. The NAEVA EM-63 required the most time, with an average of 13.34 hr per hectare with a two-person crew.

Technology Comparison

Overall, discrimination, classification, and identification performance of all three systems was lower than expected and significantly lower than those demonstrated at JPG Phase IV. Some obvious reasons for the decreased performance include the facts that, unlike at JPG IV, the demonstrators did not have prior access to the clutter items, the scenarios were more realistic and representative of

Table 7
Production and Man-hours

Demonstrator	Area	Survey Work	
GEOPHEX	1	Number of People	1-2
		Time on Site, hr, min	10:12
		Actual Man-hours	19:29
	2	Number of People	2
		Time on Site, hr, min	9:08
		Actual Man-hours	18:16
	3	Number of People	2
		Time on Site, hr, min	7:37
		Actual Man-hours	15:14
NRL	1	Number of People	1-4
		Time on Site, hr, min	5:49
		Actual Man-hours	19:13
	2	Number of People	3-4
		Time on Site, hr, min	7:55
		Actual Man-hours	25:20
	3	Number of People	3
		Time on Site, hr, min	5:56
		Actual Man-hours	17:50
NAEVA	1	Number of People	2
		Time on Site, hr, min	12:20
		Actual Man-hours	24:40
	2	Number of People	2
		Time on Site, hr, min	14:19
		Actual Man-hours	28:38
	3	Number of People	2
		Time on Site, hr, min	13:22
		Actual Man-hours	26:44
EODT	1	Number of People	3
		Time on Site, hr, min	7:00
		Actual Man-hours	14:00
	2	Number of People	3
		Time on Site, hr, min	6:10
		Actual Man-hours	12:20
	3	Number of People	3
		Time on Site, hr, min	4:45
		Actual Man-hours	9:30

actual live site surveys, and the systems were required to operate in a wide area search mode (rather than a point survey mode at JPG IV). This last factor significantly reduced the number of data samples (which resulted in decreased spatial data density and also reduced the ability to perform signal averaging to increase signal-to-noise ratios), may have also affected the available signal strength levels, and significantly reduced the position accuracy from that achieved during JPG IV.

The various advanced systems demonstrated varying degrees of maturity. The NRL EMMS demonstrated the highest degree of maturity and preparation, and conducted the field surveys and onsite analysis with no problems. In contrast, the GEM-3 and EM-63 systems demonstrated a lower level of readiness during the field evaluations. The Geophex team experienced a sensor failure shortly after starting the survey and was forced to use a spare GEM-3, which used a different coil size. This required the collection of an entirely new signature library and onsite modifications to the analysis software. The processing techniques used by the Geophex/AETC team were not fully developed/tested prior to the field demonstrations and the results reflect this lack of preparation. The NAEVA team arrived onsite without the capability to perform the analysis tasks and was unable to demonstrate onsite processing. The processing techniques used by the NAEVA team were also not fully developed/tested prior to the field demonstrations.

6 Cost Assessment

Field Cost Performance

Costs associated with each field task were computed by applying the cost factors described in the Demonstration Work Plan and are detailed in Table 8 and summarized in Table 9. It should be noted that the NAEVA cost breakdown does not include the major portion of the data analysis since it was conducted offsite and could not be tracked. The only analysis costs attributable to NAEVA were those required to download data to laptops. These laptops were then used to transmit these data to the workstations offsite for analysis and development of dig lists and georeferenced maps. As a result, Table 9 also includes a tabulation of the total field costs with and without data analysis in order to facilitate the comparison of costs across systems. It should also be noted that since the three demonstrated systems were man-portable, with similar support equipment and capital cost requirements, it was assumed that mobilization/demobilization and life-cycle costs would be equal and could be omitted from this cost performance evaluation.

Analysis of these tables show that the field costs of the three demonstrators were fairly close, with NRL demonstrating the lowest costs, followed by Geophex being slightly lower than NAEVA when analysis costs are neglected. The baseline "mag and flag" field work conducted by EODT was considerably lower than all three demonstrators, but it should be noted that EODT was not required (nor capable) of providing georeferenced sensor maps, prioritized dig lists, and target discrimination/classification. "Mag and flag" also failed to reach 80-percent Pd at any of the three test areas, had significantly higher false alarms at the high magnetic background areas, and would not have met the Kaho'olawe clearance requirements.

Weighted Field Cost Performance

Table 10 summarizes the operational costs of the demonstrator systems after the cost penalties described in Chapter 4 were applied. These penalties consisted of \$200 for each false alarm (clutter item selected for digging by the demonstrator), and the cost of a complete resurvey for one or more UXO targets missed or erroneously classified as clutter with high confidence. This table highlights the fact that false alarms have (by a large margin) the greatest impact on the cost performance of each system. Table 10 indicates that all three demonstrators were

Table 8
Breakdown of Field Costs

Demonstrator	Area	Categories	Cost	Time (hrs, min)	Cost to Job
Geophex	1	Supervisor	$95.00	25:50	$2,454.16
		Data Analysis	$57.00	30:42	$1,749.90
		Logistic/Field Setup	$28.50	16:38	$474.05
		Logistic/Field Survey	$28.50	19:29	$555.27
		Logistic/Field Downtime	$28.50	0:46	$21.385
		Logistic/Field Resurvey	$28.50	0:00	$.00
		Rain Delay	$28.50	0:00	$.00
		Total			$5,255.23
	2	Supervisor	$95.00	27:48	$2,641.00
		Data Analysis	$57.00	15:35	$888.25
		Logistic/Field Setup	$28.50	25:34	$728.65
		Logistic/Field Survey	$28.50	18:16	$520.60
		Logistic/Field Downtime	$28.50	2:00	$57.00
		Logistic/Field Resurvey	$28.50	7:50	$223.25
		Rain Delay	$28.50	1:40	$0.00
		Other Calibration	$28.50	1:15	$35.63
		Total			$5,094.38
	3	Supervisor	$95.00	15:56	$1,513.66
		Data Analysis	$57.00	14:54	$849.30
		Logistic/Field Setup	$28.50	11:00	$313.50
		Logistic/Field Survey	$28.50	15:14	$434.15
		Logistic/Field Downtime	$28.50	0:00	$.00
		Logistic/Field Resurvey	$28.50	0:00	$.00
		Rain Delay	$28.50	0:00	$.00
		Total			$3,111.09
NRL	1	Supervisor	$95.00	13:56	$1,323.66
		Data Analysis	$57.00	12:05	$688.75
		Logistic/Field Setup	$28.50	6:58	$198.55
		Logistic/Field Survey	$28.50	24:28	$697.30
		Logistic/Field Resurvey	$28.50	5:09	$146.78
		Total			$3,055.04
	2	Supervisor	$95.00	18:32	$1,760.66
		Data Analysis	$57.00	26:16	$1,497.20
		Logistic/Field Setup	$28.50	11:22	$323.95
		Logistic/Field Survey	$28.50	25:20	$722.00
		Logistic/Field Resurvey	$28.50	0:00	$.00
		Total			$4,303.81
	3	Supervisor	$95.00	9:15	$878.75
		Data Analysis	$57.00	21:03	$1,200.35
		Logistic/Field Setup	$28.50	35:18	$1,006.05
		Logistic/Field Survey	$28.50	42:57	$1,224.08
		Logistic/Field Resurvey	$28.50	1:42	$48.45
		Total			$4,357.68

(Continued)

Table 8 (Concluded)

Demonstrator	Area	Categories	Cost	Time hrs, min	Cost to Job
NAEVA	1	Supervisor	$95.00	26:35	$2,525.41
		Data Analysis	$57.00	0:00	$.00
		Logistic/Field Setup	$28.50	19:12	$547.20
		Logistic/Field Survey	$28.50	24:40	$703.00
		Logistic/Field Resurvey	$28.50	6:44	$191.90
		Rain Delay	$28.50	0:00	$.00
		Total			$3,967.51
	2	Supervisor	$95.00	11:45	$1,116.25
		Data Analysis	$57.00	0:50	$47.50
		Logistic/Field Setup	$28.50	2:30	$71.25
		Logistic/Field Survey	$28.50	28:38	$816.05
		Logistic/Field Resurvey	$28.50	6:53	$196.17
		Rain Delay	$28.50	0:00	$.00
		Total			$2,247.22
	3	Supervisor	$95.00	33:01	$3,136.59
		Data Analysis	$57.00	1:10	$66.50
		Logistic/Field Setup	$28.50	16:06	$458.85
		Logistic/Field Survey	$28.50	26:44	$761.90
		Logistic/Field Resurvey	$28.50	9:06	$259.35
		Rain Delay	$28.50	1:30	$0.00
		Total			$4,683.19
EODT	1	Supervisor	$95.00	6:30	$ 617.50
		Data Analysis	$57.00	0:00	$.00
		Logistic/Field Setup	$28.50	1:30	$ 42.76
		Logistic/Field Survey	$28.50	10:30	$ 299.25
		Logistic/Field Downtime	$28.50	0:00	$.00
		Rain Delay	$28.50	0:00	$.00
		Total			$ 959.51
	2	Supervisor	$95.00	6:00	$ 570.00
		Data Analysis	$57.00	0:00	$.00
		Logistic/Field Setup	$28.50	0:30	$ 14.25
		Logistic/Field Survey	$28.50	11:30	$ 327.75
		Logistic/Field Downtime	$28.50	0:00	$.00
		Rain Delay	$28.50	0:00	$.00
		Total			$ 912.00
	3	Supervisor	$95.00	5:15	$ 498.75
		Data Analysis	$57.00	0:00	$.00
		Logistic/Field Setup	$28.50	1:30	$ 42.75
		Logistic/Field Survey	$28.50	9:00	$ 256.50
		Logistic/Field Downtime	$28.50	0:00	$.00
		Rain Delay	$28.50	0:00	$.00
		Total			$ 798.00

Table 9
Total Cost for All Test Areas

Demonstrator	Total Cost of Field Work	Total Cost of Field Work Excluding Data Analysis
NRL	$ 11,183.24	$ 7,854.44
GEOPHEX	13,507.27	9,972.32
NAEVA	10,940.68	10,783.93
EODT	2,669.51	2,669.51

Table 10
Demonstrator Costs Including Penalties for False Alarms and Leaving UXO Targets in Ground

Area Number		Demonstrator			
		NRL	Geophex	NAEVA	EODT
1	Cost of Survey	$ 3,055	$ 5,255	$ 3,968	$ 960
	Cost of Resurvey	$ 3,055	$ 5,255	$ 3,968	$ 960
	Cost of False Alarms	$14,200	$18,200	$15,000	$26,900
	Total Cost	$20,310	$28,710	$22,936	$28,820
2	Cost of Survey	$ 4,304	$ 5,094	$ 2,247	$ 912
	Cost of Resurvey	$ 4,304	$ 5,094	$ 2,247	$ 912
	Cost of False Alarms	$12,600	$32,800	$24,600	$34,000
	Total Cost	$21,208	$42,988	$29,094	$35,824
3	Cost of Survey	$ 4,358	$ 3,111	$ 4,683	$ 798
	Cost of Resurvey	$ 4,358	$ 3,111	$ 4,683	$ 798
	Cost of False Alarms	$13,000	$31,000	$15,800	$20,600
	Total Cost	$21,716	$37,222	$25,166	$22,196

were penalized with the cost of a resurvey at each of the three test areas because UXO had been left in the ground as a result of miss-classified or missed targets. NRL demonstrated significantly lower overall costs at all three areas, with NAEVA slightly lower than Geophex (once adjustments for lack of data analysis costs in the NAEVA tabulations). Comparison with the baseline "mag and flag" costs indicates that the best performing EMI technologies were considerably more cost effective. Even though the EMI systems costs include cost of analysis in both the survey and resurvey cost factors, they are consistently lower than EODTs. As expected, the EMI advantage is more significant in Areas 1 and 2, which have significant levels of magnetic noise from geologic sources.

7 Regulatory Issues—Compliance and Acceptance

Members of the regulatory community who are aware of these technology demonstrations are listed in Appendix A.

8 Technology/Transition Implementation

The next step for these technologies is to transition to demonstrations at prepared test sites on Kaho'olawe Island, which is located in the Hawaiian Islands chain. Kaho'olawe Island is rich in basalt, which results in a high magnetic background, making the detection of unexploded ordnance difficult. It is expected that the best performing technology will be rapidly transitioned to active cleanup operations at live sites throughout the island. The demonstrations will take place during the spring/summer of FY01. Currently, range clearance at Kaho'olawe is being conducted by Parson/UXB, who is the primary contractor for Naval Facilities Engineering Command (NAVFAC). Mr. Jim Putnam, (808) 474-0559, extension 224, is the project manager for NAVFAC.

The planned schedule for demonstrating and transitioning these advanced EMI technologies are as follows:

FY01 Milestones	Est. Completion
Complete Demonstration Plan	06/30/01
Award contracts to Technology Demonstration (1)	07/31/01
Complete prep of Kaho'olawe QA/QC sites with realistic target/clutter mix	08/31/01
Complete fieldwork for demonstration	10/31/01
Deliver georeferenced raw and processed data to ESTCP	12/31/01
Complete Draft Cost and Performance Report	01/31/02
Complete Draft Technical Report	02/28/02
Complete Final Report	04/30/02

9 Lessons Learned

The three advanced technology demonstrators were able to conduct area surveys under realistic field conditions and achieved high Pd (over 90 percent) in the presence of high magnetic background clutter. These Pd's were consistently higher than those achieved by the standard "mag and flag" surveys. Two of the three advanced systems (NAEVA and NRL) achieved higher Pd with much lower false alarm rates. All three of the advanced systems were able to meet or exceed the required Pd of 0.85 for Kaho'olawe cleanup, although not necessarily at the operating point selected. All of the advanced systems had lower numbers of false alarms at comparable Pd to "mag and flag".

None of the demonstrated EMI systems experienced false alarms from geologic sources and thus show excellent potential to transition to sites such as Kaho'olawe where over 30 percent of the false alarms are caused by high magnetic geology.

A significant conclusion resulting from the evaluation of the demonstration results is that the "pseudo ROC curves" developed under this effort provide a practical method for comparing detection performance within and across systems without artificially constraining the data analysis (e.g., requiring single threshold parameter).

The advanced systems demonstrated significantly improved ROC-based performance when the target list did not include the small 20-mm projectiles. Generally, substantial decreases in false alarms are accompanied by only small decreases in Pd. With the exception of one demonstrator (Geophex in Area 3), all of the advanced systems met the Kaho'olawe Tier 2 Pd requirement. NRL and NAEVA demonstrated ability to select an operating point beyond which there were very few ordnance items (almost exclusively clutter).

The demonstrated discrimination, classification, and identification performance of the three systems was lower than expected based on previous results obtained under less realistic test environments. When 20-mm projectiles are included in the target set, the best performer labeled 3 percent of the ordnance as clutter with high confidence. When 20-mm projectiles are excluded, both NRL and NAEVA were able to improve their discrimination performance so that only 1 percent of the ordnance was mislabeled as clutter with high confidence. None of the advanced systems demonstrated the capability to identify ordnance. It is recommended that the ground truth be made available to the three demonstrators prior to proceeding to the next demonstration phase in order to incorporate lessons learned from this effort. It is expected that self assessments using the ground truth will lead all three demonstrators to be more conservative in their anomaly picking and especially in their clutter/UXO declarations. In addition, comparison of this demonstration results with previous JPG IV data indicates that the discrimination and identification algorithms currently used are very dependent on a very high level of position accuracy. The large uncertainties in the GPS position information as well as the errors introduced by the sensors moving over rough terrain significantly degraded the systems' discrimination capabilities.

A significant and unexpected result of the demonstration was the fact that the re-analysis of the EMI data incorporating additional information from the NRL magnetometer data did not improve the EMI-only results. The mag/EMI results were so inconsistent that no strong conclusions can be drawn as to the utility of multisensor data. As a result, ESTCP plans to provide the mag and EMI survey data to a number of researchers involved in the development of UXO detection algorithms in order to fully evaluate any performance gains derived from the joint analysis of mag and EMI data.

The demonstration results show that the costs of survey and analysis were a factor of 4 to 5 higher for the advanced systems compared to standard "mag and flag". However, the overall costs, including the costs of excavating false alarms are higher for "mag and flag" than for any of the advanced systems.

One of the objectives of this demonstration was to identify scenarios where one EMI technology may be better suited than the others. The performance data acquired during these tests do not support strong conclusions regarding the relative merits of the three systems. As a result, all three systems will be included in the second phase demonstrations at Kaho'olawe during September through November 2001. It is expected that the significantly more difficult environment present at Kaho'olawe will highlight differences in performance between each of the systems.

A number of issues arose during the planning and execution of this demonstration project that had not been foreseen and which affected the data quality and results. Most important of these was the fact that a variety of contracting mechanisms were used to fund the demonstrators, and each of these contracts had inconsistent requirements. For example, NAEVA was funded directly from ESTCP under an existing contract, which had different requirements and timelines than our Demonstration Plan. As a result, NAEVA was not ready (or required by contract) to perform onsite analysis of the EM-63 data nor to reanalyze the data incorporating the MTADS/MMS magnetometer data. It is recommended that, in the future, demonstrations involving multiple Government and commercial demonstrators be funded under identical scopes of work, or be conducted with adherence to a common demonstration work plan.

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Appendix B Data Archiving and Demonstration Plan(s)

The raw data from each of the three demonstrators, including calibration data and descriptions are available via anonymous ftp from ftp://jpgdemo:estcpfy00@hawk.wes.army.mil. Also available via this ftp server are georeferenced maps of the surveyed areas and the dig lists submitted. A directory map of the archived data is as follows:

- **Geophex**
  - GEM3
    - AnomalyMaps
      - Area 1
      - Area 2
    - RawData
      - Area 1
      - Area 2
      - Area 3
- **NAEVA**
  - EM63
    - AnomalyMaps
      - Area 1
      - Area 2
    - RawData
      - Area 1
      - Area 2
      - Area 3
- **NRL**
  - MTADS
    - AnomalyMaps
      - Area 1
      - Area 2
    - RawData
      - Area 1
      - Area 2
  - MAG
    - RawData
      - Area 1
      - Area 2
      - Area 3

Appendix C Demonstrator's Data Collection and Analysis Plan(s)

Prior to arriving at the JPG site, the three demonstrators were required to submit a description of their proposed data collection and analysis plans. The plans, as approved by the ESTCP Program Office, are included in this appendix.

C.1 Geophex Ltd.

Advanced UXO Detection/Discrimination Technology Demonstration
U.S. Army Jefferson proving Ground, Madison, Indiana

Geophex / AETC Data Analysis Process
(Addendum)

Data Processing and Ranking

Our approach for identifying specific UXO types, as well as for discriminating between UXO and clutter, is to compare the sensor response to a library of UXO signatures. This requires a preprocessing step that fits the data to a dipole model, from which estimates of the target orientation and depth can be derived. Once this is done, the target can be effectively rotated into a principal axis coordinate system and the spectral response in this system can be compared to the library responses. Another way to state this is that the eigenvalues of the magnetic polarizability tensor that models the target are derived from the data. These eigenvalues are orientation invariant and can be used as intrinsic target signatures. The required computation to perform this preprocessing step is easily and rapidly carried out on a PC.

Declarations of UXO versus non-UXO will be determined based similarities of the derived eigenvalues and library signatures. Confidence rankings will be based upon the degree of fit. We also examine the amplitude, spatial pattern, and measured frequency response for sanity checks.

Anticipated Acquisition Parameters

GEM-3 data will be acquired using a line spacing of 0.5 m and a sample rate of around 10 Hz (dependent on number of frequencies selected). Anticipated tracking accuracy of our system is approximately 10 cm. Raw sensor output (GPS and GEM-3) is recorded in comma-separated ASCII files.

C.2 NRL

MTADS Survey Demonstration Plan

Jefferson Proving Ground, Madison, IN
27 August - 6 September 2000

The Survey Site

Three 1-hectare areas have been prepared at the JPG 16-hectare and the U.S. Army engineer Research and Development Center (ERDC), Vicksburg, MS, test sites, as described in the "Site Preparation Plan" (Ref. 1). The coordinates of the corners of the sites are given in Table C2.1 and the coordinates of four reference monuments are given in Table C2.2. These sites have been seeded with a variety of ordnance and OE scrap items as described in the Technology Demonstration Plan (Ref. 2).

The *MTADS* Demonstration Schedule

The primary goals of the demonstration are to:

- Conduct an EM survey of the three designated sites.
- Analyze the EM data to identify and locate the buried targets.
- Prepare dig images and dig lists of targets.
- Rank all analyzed targets with probabilities of their being OE scrap or intact ordnance items from the ordnance list in Ref. 1.

The *MTADS* EM Man-Portable adjunct will be used to conduct a survey of each site using the integrated GPS navigation system. The *MTADS* vehicular EM array will be available onsite as a backup should the Man-Portable system not be able to complete the survey.

Following completion of the EM survey, an *MTADS* vehicular survey of each site will be conducted using the magnetometer array. Magnetic anomaly images (similar to Figure 2, Ref. 1) will be prepared for each site and provided to the sponsor electronically and as hard copy.

If time permits, selected data will be taken using the *MTADS* Man-Portable Magnetometer System. These data will not be used specifically for this demonstration but will be used for comparative purposes in evaluation and reporting on the performance of the Man-Portable Instrument.

Hardware Description

We will deploy the Man-Portable EM system with the 0.5- χ 1.0-m coil mounted with the 1-m dimension cross-track. This system is now a standard (off-the-shelf) Geonics instrument. We will not cite all the operational characteristics of the instrument. As we will be using it, our data-sampling rate will be 10 Hz.

The system time gate (measured by ourselves) is 280-470 μsec following shutoff of the transmit pulse. The Trimble GPS navigation system provides position updates at 5 Hz. The horizontal positional accuracy (location of the GPS mobile antenna) is about 5 cm. An attitude sensor has been added to the EM Man-Portable survey system to provide pitch, roll, and yaw corrections to the sensor coil locations. We believe that the predicted horizontal location uncertainty for good signal-to-noise targets will be <30 cm for the EM Man-Portable system and <20 cm for the magnetometer Man-Portable system.

Data processing and data analysis will be accomplished using two PCs operating the *MTADS* Data Analysis System (DAS), as modified for this demonstration. Additionally, a third PC will be on site and used to create spreadsheets and Graphics Products that are unique to this demonstration.

Survey Setups

On each 1-hectare site, 1.5-m lanes will be established, oriented in the direction best suited for man-portable survey. Wooden stakes (1.5-m spacing) will be driven at the perimeter and strings will be pulled across the site to establish survey lanes. Survey lane spacing of 0.5 m will be used with the Man-Portable EM system. Vehicular surveys (if they are done with either the magnetometer or EM arrays) will be conducted with 1.75-m lane spacing. Survey priorities are as follows:

- All EM surveys will be completed.
- The vehicular *MTADS* survey will be conducted for all sites.
- Selected Man-Portable magnetometer survey data will be taken.

Target Analysis Approach

EM survey data will be analyzed using the 3-β *MTADS* DAS fitting routine. The DAS has been modified to allow the target analysis to be run on a single data set. Additionally, the DAS has been modified to also run the point-dipole EM fitting routine to generate a target caliber. Selected targets have been pre-surveyed and analyzed using the 3-β routine and information has been used to create probability functions based upon comparison to the three-dimensional ellipsoids generated from individual ordnance library data. Additionally, both magnetometry and EM libraries exist using vehicular survey data and traditional *MTADS* baseline fits for selected ordnance at a variety of depths and orientations. This graphical and numerical fitting data will be used to supplement the results and predictions of the 3-β analyses. Additional information is sometimes available from visual cues in the graphical presentations of the target data. In magnetometry data, these cues are used routinely to discriminate between single-object targets and clusters of smaller items. Magnetometry target data are routinely edited to remove spurious information and clutter objects, allowing refit of the data. This approach is much less useful with EM data. All this analysis information will be used to rank order the target list. We anticipate that initial assignments and ordering will be made based upon the 3-β fits. These will be refined using information as described above.

Quality Assurance Plan

NRL has prepared a Demonstration Test Plan for the use of the onsite personnel as we always do on any *MTADS* survey. This test plan contains operational routines and check lists that are followed to assure the fidelity of the data. This approach is simpler than typical of *MTADS* surveys because:

- The primary survey product employs only a single sensor (no reference sensor data are required and change-over between survey modes is not anticipated to be necessary to produce the primary survey products).
- No onsite target prove-out surveys must be conducted or analyzed. Target calibration measurements have been made separately before the demonstration.
- To assure the quality of the data, a preliminary short stationary data set is taken at the beginning of each day using a calibrated test object. These data are preprocessed and visualized before actual survey data collection begins.
- Survey data are downloaded hourly and immediately preprocessed and visualized to assure fidelity.
- Alterations have been made in the Man-Portable data collection device to allow sensor data streams to be visualized in real time in the field, and audio cues have been installed to alert the surveyor to the quality of the GPS fix being provided by the navigation system.
- At the end of each day. GPS data downloaded from the satellites are used to predict the navigation fix qualities as a function of time for the following day. Rest breaks and meal breaks can be planned around poor GPS periods. If surveys adjacent to tree lines are required, various GPS sky masks can be used to predict the best times for survey for a particular sky view.

MTADS Support Personnel

Name	Affiliation	Job Function
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Herb Nelson	NRL	Asst. PM, Field Hand, Data Analyst
Bernard Puc	AETC	Data Analyst
Larry Koppe	Geocenters	Field Hand
Local Laborer	Nova	Field Hand

References

1. "Site Preparation Plan, Advanced UXO Detection/Discrimination Technology Demonstration, US Army Jefferson Proving Ground, Madison, IN," 9 June 2000.

2. "Technology Demonstration Plan, Advanced UXO Detection/Discrimination Technology Demonstration, US Army Jefferson Proving Ground, Madison, IN," NAVEODTECHDIV, Research and Development Dept., 26 June 2000.

3. “Analysis of Magnetic and EMI Signatures from Impacted, Intact Ordnance and Exploded Fragments,” Bruce Barrow and Herbert H. Nelson, UXO Forum 2000, Anaheim, CA, 2-4 May 2000.

4. “Man-Portable Adjuncts for the MTADS,” J.R. McDonald, H.H. Nelson, Thomas H. Bell, and Bernard Puc, Naval Research Laboratory, Washington, DC, Draft, 22 December 2000.

Table C2.1
UTM Coordinates of JPG Site Corners

Site 1	**Northing**	**Easting**	**Elevation**
NE Corner	4309710.266	641434.444	270.508
SE Corner	4309610.653	641443.029	270.290
SW Corner	4309602.063	641343.410	269.219
NW Corner	4309701.673	641334.818	267.454
Site 2			
NE Corner	4309750.232	641713.068	273.705
SE Corner	4309650.606	641721.640	273.958
SW Corner	4309642.015	641621.998	273.261
NW Corner	4309741.643	641613.412	273.270
Site 3			
NE Corner	4309791.612	641593.714	272.661
SE Corner	4309891.174	641585.150	272.914
SW Corner	4309899.745	641684.758	272.866
NW Corner	4309800.142	641693.340	274.214

Table C2.2
UTM Coordinates of Reference Monuments

Reference Monuments:	**Northing**	**Easting**	**Elevation**
(WES-0)	4309790.274	641578.800	272.345
Monument 1	4309653.858	641662.717	273.853
Monument 2	4309425.242	641545.826	272.128
Monument 3	4309594.885	641309.431	272.128

C.3 NAEVA

Proposed Work Plan, Sept. 10 - 18, 2000

EM63 Ordnance Discrimination Demonstration, Jefferson Proving Ground, Ind.

NAEVA Geophysics, ESTCP Contract DACA72-00-C-0009

Introduction. This plan describes geophysical investigations proposed for NAEVA Geophysics' EM63 Demonstration (task three) at the Jefferson Proving Ground, Madison, Indiana. We plan to accomplish this work during the period September 10 through 19, 2000. We estimate 2 to 3 days to survey each of the 1-hectare seeded areas with closely spaced (0.5 m) traverse lines (8 days total), and one additional day for additional bench tests, or in case of instrument problems or weather delays.

NAEVA investigated the ordnance discrimination potential of the Geonics EM61-3D and Protem prototype multi-channel EM equipment at JPG4. The new Geonics EM63 instrument has been modified significantly since NAEVA's initial tests in October 1999, when it first became available. Measurements of the multi-channel response of a partial suite of JPG ordnance at all orientations in air (beneath the EM63 instrument on a test bench) were made during NAEVA's Blossom Point exercise in late May and early June 2000. Further tests on additional JPG ordnance items will be done during the week following Labor Day, before the JPG exercise. No unknown target can be identified or discriminated except by comparison with the measured response of an exactly equivalent item (the identical model, type, and/or construction). The technique works like 'fingerprints', in that each specific ordnance type has a distinct multi-channel response (at least for each 10-degree increment of orientation between vertical nose up and nose down), which must be in the discrimination database. The suite of sample ordnance items provided by NAVEODTD is still incomplete (there is no 3 inch projectile or 2.25 inch rocket, a 9" 60mm sample is badly split by a demo charge, which makes it non-representative of unexploded ordnance, and the 105 mm sample is an unusual 'beehive' or flychette type which is not representative of any 105 mm HE or armor piercing projectile).

1) Safety. There are no serious safety issues at the JPG test site, as no live ordnance is likely to be present on the surface (after surface clearance and several years of intensive geophysical activity) and the site is clear of serious surface hazards. NAEVA's field data acquisition team is experienced and OSHA safety trained, all normal safety procedures and precautions will be observed at all times.

2) Personnel. NAEVA's two-person data acquisition team (Alan Mazurowski and Todd Nash)is fully experienced with the EM63 and GPS equipment, and will exercise with the modified EM63 instrument for a week at NAEVA's test site before the Jefferson Proving Ground demonstration. The demonstration will be supervised in the field by Dr. G. Hunter Ware (geophysicist, principal investigator). Either Dr. William Tompkins (physicist) or Hunter A. Ware

(computer scientist) will also attend at least a part of the exercise, to assist with data post-processing and to verify data quality.

3) Test Site. The Jefferson Proving Ground site is familiar to NAEVA from previous JPG demonstrations, and is described in the May, 2000, Workplan distributed by Dr. Ernesto Cespedes. The coordinates of the three 1-hectare test sites were described in Cespedes E-mail of August 9, 2000.

4) Geophysical Investigation Methods. The test site will be investigated by traversing the EM63 instrument over closely spaced lines (approximately north-south and spaced approximately 0.5-m apart), traversing at slow speeds, so as to acquire adequate station densities. Extra calibration items (iron spheres) will be placed on the ground, probably just north of each test area, for amplitude calibrations (top and bottom coils).

5) Navigation. Accurately located (RTK differential GPS) locations will also be acquired, using GPS integration software developed during the Blossom Point exercise. Tapes or ropes will be placed on the ground, to assure an even and closely spaced distribution of traverse lines.

6) Instrument Calibration. The EM63 instrument will be zeroed (all 25 gates) in the air or over non-responsive soil periodically. The response to standard calibration objects (generally, 3.5-in. iron spheres) will be measured in each data file if possible.

7) Data Processing (Target Detection and Discrimination). EMFIT development software will be used for data post-processing and interpretation (detection, target location, and discrimination). Geonics DAT63 software may also be used for some purposes. The data will be leveled, de-spiked, and merged with GPS positions. A report detailing data editing and digital data format will be provided with the field data. Targets will be detected by thresholding (threshold to be determined by examination of local terrain noise). A prioritized target list will be developed, based upon chi-squared fit of bench test decay curves to target decay curves. No discrimination is possible for emplaced (target) items for which we do not have good representative bench test specimens. Ordnance items may generally be detected down to a depth of 10-x diameter, and discriminated to a depth of about 5-x diameter. Target objects in between (detectable, but not discriminatable) may be (a) guessed (randomly), (b) arbitrarily declared ordnance, (c) arbitrarily declared nonordnance, or (d) placed in a separate 'unknown' category. If you guess, you get half of the targets right! These remarks apply to time or frequency domain analysis.

We continue to make concerted efforts toward onsite data processing, but at this time, **we are still not able to generate a prioritized target list on site, using portable, onsite (laptop) computers**. This is because the development software routines will only run (or only run fast enough for large data sets), on our larger office computers. We expect that the final, compiled software will run onsite (for small data sets), but our business model continues to assume that data will be sent over the internet (by ourselves or our clients) to GPA's server computer for remote processing, as this will be faster and less expensive (services always available, no field and travel expenses for data processing). **We do plan to submit an initial prioritized target list before leaving JPG**. We will be happy to provide time spent on this remote processing. Additional prioritized target lists ((a) for other target suites (for example without 20 mm) and/or (b) prioritized by decay curve shape plus principal response moments) will require post-processing time in Charlottesville.

8) Quality Control. In addition to the zero and amplitude calibration procedures described above, principal traverse lines over target and calibration items will be surveyed in both directions in order to assure that the data are repeatable (and lag corrected). It is only by repeating lines in opposite directions in each data file that proper calibration and lag (latency) correction can be verified. We strive for +/- 2 mv or +/- 10% peak amplitude and +/- 2 cm repeatability, if possible. However, it must be recognized that the EM63 instrument is new, and its instrument noise levels over the range of time gates is not yet known.

9) Geophysical Data. All raw digital data files will be leveled, edited (fiducialed, if necessary), and converted to ASCII x-y-z1-z2-... format for further post-processing, archiving, and for presentation to ESTCP.

10) Performance Goals. We hope to acquire sufficient bench test data to permit characterization **(discrimination)** of all emplaced items (inert ordnance) for all inclinations. Detection depths and discrimination depths will be limited, as usual, by local terrain noise. We have not yet sampled this local noise (with an EM63), but we anticipate detection to approximately 10 times ordnance diameter, and discrimination to perhaps 5 times ordnance diameter (discrimination depth is always less than detection depth). All data will be repeatable (to instrument and survey noise levels), and there should be no so-called 'false positive' anomalies tat are not related to metal objects or magnetic rocks or soil.

G. Hunter Ware, Geophysicist

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14. ABSTRACT

The Environmental Security Technology Certification program (ESTCP) funded the Naval Explosive Ordnance Disposal Technology Division (NAVEODTECHDIV) (lead agency), the U.S. Army Engineer Research and Development Center (ERDC), and the U.S. Army Environmental Center (AEC) to design and conduct controlled technology demonstrations at the U.S. Army Jefferson Proving Ground (JPG) in Madison, Indiana. These technology demonstrations were conducted during the period June to November 2000 at three 1-hectare areas within JPG. The demonstrations were designed to assess the capabilities of state-of-the-art technologies to detect, discriminate, and identify unexploded ordnance (UXO) in areas containing natural (magnetic rocks/soils) and man-made (munitions fragments) clutter. In addition, cost and production rates for each of the systems were documented and compared with standard "mag and flag" operations. This report documents the metrics developed for evaluating field performance, summarizes the performance of each of the systems, and identifies areas where improvements are needed. The results of these demonstrations are intended to aid the Government in selecting effective and efficient UXO detection and discrimination systems for difficult magnetic clutter sites such as those encountered at Kaho'olawe, Hawaii.

15. SUBJECT TERMS
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