ESTCP
Cost and Performance Report

(UX-9526)

Multi-Sensor Towed Array Detection System (MTADS)

September 1999

ENVIRONMENTAL SECURITY
TECHNOLOGY CERTIFICATION PROGRAM

U.S. Department of Defense

Report Documentation Page	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE **SEP 1999**	2. REPORT TYPE	3. DATES COVERED **00-00-1999 to 00-00-1999**

4. TITLE AND SUBTITLE **Multi-Sensor Towed Array Detection System (MTADS)**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Environmental Security Technology Certification Program (ESTCP),4800 Mark Center Drive, Suite 17D08,Alexandria,VA,22350-3605**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S)
	11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**63**	

TABLE OF CONTENTS

This page was intentionally left blank.

LIST OF FIGURES

LIST OF FIGURES (continued)

LIST OF TABLES

Page

LIST OF ACRONYMS

BBR	Badlands Bombing Range
bgs	below ground surface
BIA	Bureau of Indian Affairs
CBD	Chesapeake Bay Detachment
CEHNC-OE	U.S. Army Corps of Engineers, Huntsville, Ordnance and Explosives
COG	Course-Over-Ground
CRT	Cathode Ray Tube
DAQ	Data Acquisition Computer
DARPA	Defense Advanced Research Projects Agency
DAS	Data Analysis System Computer
DENIX	Defense Environmental Network and Information Exchange
DTIC	Defense Technical Information Center
DWP	Demonstration Work Plan
EM	Electromagnetic
EOD	Explosives Ordnance Disposal
ESTCP	Environmental Security Technology Certification Program
GIS	Geographic Information System
GP	Ground Penetrating
GPS	Global Positioning System
GUI	Graphics User Interface
HAZWOPR	Hazardous Waste Operations
IDA	Institute for Defense Analyses
JPG	Jefferson Proving Ground
JUXOCO	Joint Unexploded Ordnance Coordination Office
MCAGCC	Marine Corps Air Ground Combat Center
MTADS	Multi-Sensor Towed Array Detection System
MTR	Magnetic Test Range
NEODTC	Naval Explosive Ordnance Disposal Technology Center
NRL	Naval Research Laboratory
OEW	Ordnance Explosives Wastes
OST	Oglala Sioux Tribe

LIST OF ACRONYMS (continued)

PC	personal computer
PRC	Personnel Readiness Center
QA	Quality Assurance
QC	Quality Control
R&D	Research and Development
RTK	Real Time Kinematic
SGI	Silicon Graphics, Inc.
SNR	signal to noise ratio
USGS	U.S. Geological Survey
UTM	Universal Transverse Mercator
UXO	Unexploded Ordnance

This page was intentionally left blank.

ACKNOWLEDGMENTS

The Multi-Sensor Towed Array Detection System (*MTADS*) development and initial demonstrations were supported by the Environmental Security Technology Certification Program (ESTCP) Program Office. The demonstration at the Badlands Bombing Range, and several subsequent demonstrations have been principally supported by Native American Lands funds administered by the ESTCP Program Office. In addition, *MTADS* demonstration projects at the Former Ft. Pierce Naval Amphibious Training Facility, the Former Buckley Air Base, and the Air Force Impact Area on the Pine Ridge Reservation have been carried out with joint support by the ESTCP Program Office and the Army Corps of Engineers (Huntsville, CEHNC-OE, and Omaha, CENWO-PM).

All *MTADS* activities have been managed by the Naval Research Laboratory. The principal investigator is Dr. J.R. McDonald. Dr. H.H. Nelson is the deputy principal investigator.

We wish to acknowledge the critically important contributions made by AETC, Inc. (Tom Bell, Bernard Puc, Bruce Barrow, and Nagi Khadr) in the development of the data analysis system and in support of the field demonstrations. We appreciate continual program administrative support by Richard Robertson (Hughes, Associates) and field support by Larry Koppe (GeoCenters, Inc).

Tom Altschuler's (formerly of IDA [Institute for Defense Analysis], currently at Defense Advanced Research Projects Agency [DARPA]) enthusiastic support in refining our thinking about unexploded ordnance (UXO) target attributes and how to intuitively exploit them have improved our ability to differentiate buried UXO from buried clutter in "on-the-fly" target decisions that must be made in the field.

Finally, we wish to express our grateful appreciation to Dr. Jeff Marqusee for his unflagging and continual commitment to developing and refining automated UXO detection and remediation technologies, and specifically for his belief in the *MTADS* concept. This commitment has led to demonstration and validation of a fully field-hardened prototype and to its transition to the commercial sector where is currently available to provide commercial UXO services.

This page was intentionally left blank.

1.0 TECHNOLOGY DESCRIPTION

1.1 BACKGROUND AND INTENDED USE

UXO is a serious and prevalent environmental problem currently facing DoD facility managers. Mitigation and remediation activities are often hindered by the fact that UXO is colocated with other environmental threats including ordnance explosives wastes (OEW), chemical wastes, and other toxic and hazardous materials. Not limited to active sites and test ranges, these problems also occur at DoD sites that are currently dormant, and in areas adjacent to military ranges that belong to the civilian sector or are under control of other government agencies. Traditional techniques for UXO detection, site characterization, and remediation are very slow, labor intensive, and inefficient. Typical detection and characterization technologies involve hand-held detectors operated by explosives ordnance disposal (EOD) or civilian technicians who must slowly walk across a survey area. Time consuming and sometimes dangerous, this process has been well documented as inefficient,[1] as well as marginally effective. Many ordnance items are disguised by the presence of extensive surface clutter and frag from ordnance operations. Large and deep ordnance targets are often not found, because either their footprints are too large to be "visualized" by the walking operator or their signatures are lost in magnetic disturbances associated with geophysical anomalies. Developing an image of a deep target, especially in a field of shallow targets, is most difficult for the hand-held surveyor. The *MTADS* technology is designed to address these issues.

The primary goals of the *MTADS* Dem/Val program are enumerated below:

- Field a vehicular-based system employing arrays of sensors for efficient surveying of ranges,
- The system should have the sensitivity to detect all buried UXO to its self-penetration depths,
- Precise position location and survey guidance using satellite-based Global Positioning System (GPS) navigation,
- Software routines are used to efficiently analyze, locate, and characterize buried UXO targets for remediation, and
- Create a permanent record in Global coordinates of the positions of all targets.

The intended use of this automated technology is for site characterization of DoD bombing and target ranges. The system must be capable of efficiently and rapidly surveying relatively large areas typical of ranges used during and since WW II that occupy hundreds to thousands of acres.

1.2 TECHNOLOGY DESCRIPTION

1.2.1 Field Hardware

The *MTADS* system hardware includes a low magnetic signature vehicle that is used to tow linear arrays of magnetic and electromagnetic (EM) sensors to conduct surveys of large-areas to detect buried UXO. The *MTADS* Tow Vehicle, manufactured by Chenowth Racing Vehicles,[2] is a custom-built off-road vehicle, specifically modified to have an extremely low magnetic self-signature. Most ferrous components have been removed from the body, drive train, and engine, and replaced by nonferrous alloys. The vehicle is powered by a modified Volkswagen aluminum engine.

Figure 1. The *MTADS* deployed with the magnetic sensor array

The *MTADS* magnetic sensors are Cs vapor full-field magnetometers (a variant of the Geometrics 822 sensor, designated as the Model 822ROV). An array of eight sensors is deployed either as a magnetometer array or as a four-unit gradiometer array measuring the vertical component of the Earth's total field. The Tow Vehicle and passive magnetometer platform are shown in Figure 1. The time-dependence of the Earth's background field is measured by a ninth sensor deployed at a static site during survey operations. The specially-selected magnetometers, which are airborne quality, were acceptance tested at the manufacturer's facility to verify sensitivity, sensor noise, heading error, dead zones, inter-sensor compatibility, and performance with the multi-sensor interface modules.

Figure 2. The *MTADS* deployed with the EM sensor array

The EM sensors are deployed as an array of three pulsed induction units (a variant of the Geonics EM-61 instrument), as shown in Figure 2. These sensors, configured as an overlapping horizontal array, transmit a tailored electromagnetic pulse into the Earth. Metallic objects efficiently absorb the energy, inducing eddy currents which re-radiate electromagnetic energy. This secondary signal is time sampled by six detection coils that are co-located with the three transmission coils.

The sensor positions on the surface of the Earth (latitude, longitude, and height above ellipsoid) are determined using satellite-based GPS navigation, employing the latest Real Time Kinematic (RTK) technology which provides a real-time position update (at 5 Hz) with an accuracy of about 5 cm. GPS satellite clock time is used to time-stamp both position and sensor data information for later correlation. In addition, an electronic compass, attitude sensors (pitch, roll and yaw), and tick wheel sensors provide navigation back-up and dead-reckoning capability. All navigation and sensor data are provided through electronic interfaces to the Data Acquisition Computer (DAQ) in the Tow Vehicle. The DAQ computer also functions as a survey set-up tool and provides real-time guidance displays and information for the driver. Perimeter surveys, or point landmarks, are used to define the survey bounds. The survey course-over-ground (COG) is plotted in real time on the display, as are presentations showing the data quality for the primary sensors and the GPS navigation fix quality. This allows the operator to respond to both visual cues on the ground and to the survey guidance display. Following a survey, the operator can return to survey any missed areas before leaving the field.

1.2.2 Data Analysis

Survey and navigation data recorded in the DAQ computer in the Tow Vehicle is down-loaded by tape or hard wire connection to a notebook computer for transfer to the Data Analysis System computer (DAS). The DAS software was developed specifically for this program as a stand alone suite of programs written using IDL development tools, and graphics user interfaces (GUI) working in a UNIX-based workstation environment. The DAS is written in multiple levels for both sophisticated and novice users. A novice user can perform a complete data analysis using menu-driven tools and the background default analysis settings, see Figure 3. An extensive range of expert options are also available to facilitate the cleanup of navigation data, sensor nulling and leveling, noise filtering, and other electronic data preprocessing options as desired.

The DAS uses resident independent physics-based algorithms to execute target analyses interactively using magnetometry, gradiometry, and EM data. Extensive training data sets (using inert ordnance) have been taken and used to refine the algorithms to improve target analysis. In addition to position, depth, and size solutions, magnetic analyses provide target orientation and effective caliber information and, using a “goodness of fit” analysis, provide guidance in distinguishing ordnance from nonordnance targets.

The DAS provides a range of graphical and numerical outputs to document the results of the target analysis process and to support remediation efforts. Visual images of selected parts of a survey in a variety of color and grey scale presentations can be created showing target data overlaid by landmark information and analysis results in bitmap (tif) or editable (eps) formats. Local, State Plane, or Global Coordinate system (UTM or Lat/Lon) presentations are selectable. The graphics are appropriate either for reports or to support target way pointing and remediation operations. Numerical target analysis results are prepared in tabular form in any combination of desired coordinate systems. These outputs are formatted to be incorporated into reports or imported into spreadsheets which can be electronically loaded into the GPS navigation equipment to reacquire the targets in the field for remediation.

1.3 SPECIFICATIONS

1.3.1 Performance

The overall system was designed to a set of performance requirements which were drafted separately for the magnetometry and EM systems. These top level system performance requirements are documented in Table 1. The overarching design goal was to be able to detect all buried ordnance to its maximum self penetration depth. The smallest ordnance considered to be relevant at the beginning of the program were 60 mm mortars. During the development and early demonstration phases of the program, requirements were imposed involving detection of smaller items including submunitions and antipersonnel rounds (40mm and 30mm). Finally, in range remediation operations, it has often become apparent that detection of 20mm antiaircraft rounds is a requirement. Although detection of this smaller ordnance was not a program requirement, careful use of the EM platform for surveys has demonstrated that these items can be confidently detected.

The subsystem and project descriptions are tabulated below. The EM sensor platform is shown in Figure 4, with the interior of the *MTADS* Tow vehicle shown in Figure 5.

- Field Support and Test Site Development

- Active Sensors
- Passive Sensors
- Navigation and Survey Guidance System
- Tow Vehicle
- Magnetometer Platform
- Active Sensor Platform
- Data Acquisition Electronics and Vehicle Electrical System
- Data Analysis System
- System Integration and Shakedown, and
- Documentation.

Information on the subsystem hardware, their development and selection may be reviewed in References 3-12.

Table 1. *MTADS* System Design and Performance Requirements

System Specification	Magnetometer Array	Gradiometer Array	EM Array
Continuous Survey Operation	8 hours/day 4 hours continuous	8 hours/day 4 hours continuous	4 hours continuous
Survey Coverage	10-25 acres/day Terrain Dependent	6-5 acres/day Terrain Dependent	1-2 acres/day Terrain Dependent
Sensor Sensitivity	0.5 nT	0.1nT/m	10 mV
Detection Level			
Small Targets 60mm-105mm	2-3 ft	1-2 ft	1-2 ft
Medium Targets 155mm-Mk 80	4-7 ft	2-5 ft	2-5 ft
Large Targets Mk 81 and larger	9-25 ft	5-15 ft	5-8 ft
Survey Speed	6 mph	6 mph	3 mph
Location Accuracy	±0.03m	±0.03m	±0.03m
Depth Accuracy	±0.5m	±0.5m	N.D.
Data Processing & Target Analysis	Equals Survey Time For 20 Targets/Acre	Equals Survey Time For 20 Targets/Acre	Equals Survey Time For 20 Targets/Acre
Missed Area Mapping	Available in real-time in Tow Vehicle	Available in real-time in Tow Vehicle	Available in real-time in Tow Vehicle

1.3.2 Personnel and Training Requirements

The tow vehicle with its support electronics is designed to allow for a single operator to define a survey area, set up the survey using the on-board computer and to survey the grid following visual cues on the ground and the cathode ray tube (CRT) display of the survey grid and the course-over-ground progress. In reality, even after several upgrades of the display system, drivers find it impractical to rely on the visual display to guide the survey without help from others on the ground. Part of the problem lies in the electronic and computational burden which leads an update of the vehicle position display which lags the real-time position by about a second. This situation has been mitigated by the ready availability of relative inexpensive labor (and a strong political impetus to use them) at all of our demonstration sites. Typically, we use 3-5 "flaggers" along the vehicle path to provide guidance and to help in reorienting the driver after turns. The flaggers are drawn from local indigenous labor pools and require minimal training.

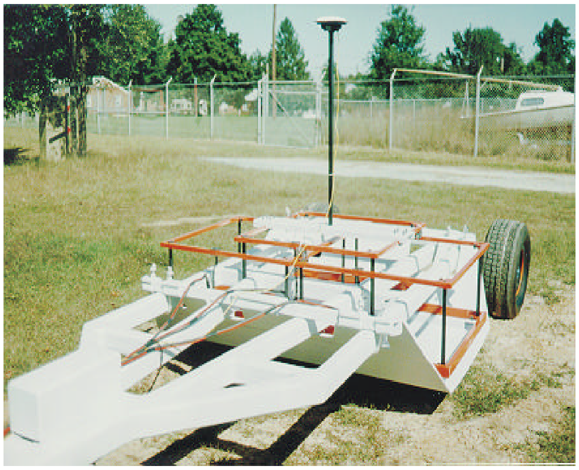

Figure 4. The overlapping EM array mounted on the active sensor platform

MTADS demonstration surveys have all been carried out with simultaneous or overlapping remediation operations. This requires the presence of experienced data analysts and data support people because of the required quick turn-around for target analysis and preparation of remediation support graphics and data tables for electronic loading onto the GPS equipment for target way pointing. The *MTADS* DAS is designed to allow operation by relatively inexperinced, but computer literate, personnel. When time allows, we have trained and successfully used inexperienced personnel to conduct target analyses on extended and highly cluttered ranges.

Figure 5. Layout of the *MTADS* Tow Vehicle showing the data acquisition and survey guidance electronics

1.3.3 Health and Safety Training

When working on live ranges or former bombing or gunnery targets, we routinely conduct a walkover and surface clean prior to conducting vehiclar surveys. These costs are discussed in a later section, but typically cost about $250 per acre. The surface walkovers are carried out by subcontracting to UXO-certified specialists. The typical team consists of one UXO-certified supervisor and 5 laborers. Depending on the circumstances, the laborers either have hazardous waste operations (HAZWOPR) certification or are trained on site by the UXO supervisor. A course grid is usually laid out to guide the walkover. The recovered ordnance scrap and metallic clutter is sorted after the walkover and certified for disposal by the UXO specialist. Ordnance items that cannot be removed, must be blown-in-place by the UXO specialist or by military EOD teams responsible for the site. Carrying out the walkover provides invaluable information for the *MTADS* survey and analysis crews also. Invariably, the material recovered from the surface provides a complete inventory of the ordnance used on a range and provides information used in building a survey strategy and in guiding target analysis.

1.3.4 Ease of Operation

First-order survey points are always established prior to conducting *MTADS* surveys. While these points could be established by the *MTADS* crew, it is more efficient and economical to contract with a local surveyor to bring the points in before the *MTADS* arrives on site. This allows for advance survey planning, establishing the base station positions, and the required positions for the radio repeater units, etc.

1.4 TECHNOLOGY LIMITATIONS

Historically, UXO clearance has relied on "mag and flag" (hand survey) operations in preparation for remediation. Such approaches are notoriously inefficient; many sources believe that much more than 50% of buried ordnance remains undetected and unremediated using this approach.[1] Furthermore, "mag and flag" produces an uncertifiable survey product, lacking any ability to perform quality control (QC) and quality assurance (QA) evaluations. Such operations leave no permanent record of actions taken for historical archives, and thus provide no documentable support or evidence in case of litigation. *MTADS* was specifically designed to address these shortcomings. By establishing first-order survey control and using GPS navigation for all survey operations, subsequent analysis products including all graphics, and target description information is created in global coordinates. This provides a permanent record of all activities and targeting information that will allow reacquisition at any future date. This approach is very amenable to QA/QC evaluations. The *MTADS* graphical imagery and target tables can be created using any local grid, state plane projections or in global Universal Transverse Mercator (UTM) or Lat/Lon coordinates. The output is also compatible with incorporation into Geographic Information System (GIS) databases or routinely-used computer spreadsheets.

A significant limitation of the *MTADS* is associated with the GPS navigation system. GPS navigation is limited to areas with good sky view, precluding operation in heavily wooded areas and limiting operations in urban areas with tall buildings. The *MTADS* has dead reckoning capability using the tick wheels and the attitude sensors to augment the GPS. Our dead-reckoning capability is intended to provide fill-in for loss of satellite navigation for up to 20 seconds (with degraded accuracy). Recent improvements in GPS technology provides for more graceful degradation of signal quality allowing continued surveying with better than 0.5 m accuracy under circumstances that would have stopped operations previously. Additionally, new equipment reinitializes very quickly (seconds) after reacquisition of additional satellite signals allowing continuing operations.

1.5 MOBILIZATION AND OPERATIONAL REQUIREMENTS

The *MTADS* has mobilized to 6 ESTCP-sponsored surveys[17-22] and 3 extended surveys sponsored by other DoD agencies.[23-25] Three of the surveys were against prepared ordnance sites (Jefferson Proving Ground [JPG]III, Twentynine Palms, and JPGIV), five were at (or associated with) current or former military ranges (Badlands Bombing Range, The Laguna Pueblo, The Walker River Reservation, Ft. Pierce Naval Amphibious Training Range and the Former Buckley Air Base) and one was on an extensive landfill (The Portsmouth Naval Shipyard). At 5 of these surveys remediation operations were carried out either simultaneously with, or shortly after, completion of the survey operations.

All *MTADS* equipment is designed to be transported to field sites to support survey and remediation operations. All electronic and office equipment has foam-padded containers that can be shipped or transported by truck. All field equipment is designed to transport by tractor trailer. We pack and transport an extensive list of spare equipment and components for field repair or replacement. Small electronics repair and mechanical repair support stations are modularly packed and resupplied before each deployment. We have dedicated cellular telephones and 10 two-way radios to support field operations. Modular battery charging stations are packed to support all radios, electronics, and navigation equipment.

We mobilize to survey sites using a rented tractor-trailer. This is economical and is typically left on site throughout the survey for storage. All *MTADS* equipment can be transported in a 50 ft trailer. At some sites electrical power, water, and office facilities are available to support our operations. More typically, they are not. In these cases all necessary logistic support requirements are leased or rented and delivered to the site before the *MTADS* arrives. Table 2 shows typical logistics support requirements along with lease or rental costs. These costs are typical and do not vary significantly from site to site.

This page was intentionally left blank.

2.0 DEMONSTRATIONS

During the original *MTADS* Program we conducted 4 demonstrations.[17-20] Each demonstration was carried out under an approved Demonstration Plan and the results of each demonstration was documented in a Demonstration Report. The details of these operations are provided in the documents. The Demonstration Plans and Demonstration Reports are available through the ESTCP Program Office. Additionally, the Demonstration Reports are archived publications available from the authors or from the Defense Technical Information Center (DTIC).

2.1 THE TECHEVAL DEMONSTRATION

The Chesapeake Bay Detachment (CBD) Magnetic Test Range

Concurrent with the construction of the *MTADS*, a Magnetic Test Range was developed at Naval Research Laboratory (NRL)/CBD. Because open space and magnetically clean areas were very limited, the test facility was set up to make individual measurements of ordnance and other items in specific orientations and at specific depths in the specially constructed covered pit and well set up for this purpose. Figure 6 shows the installation of a 4 foot diameter, 7 meter long fiberglass casing, which allows for the placement of large ordnance items. For smaller ordnance items, a 1-meter deep test pit, shown in Figure 7 was also installed. A large variety of inert ordnance was acquired ranging from 20 mm projectiles to Mk 82 ground penetrating (GP) bombs. Special jigs were constructed to suspend the items at known positions, depths and orientations in either of the test fixtures for test measurements. During the course of development several hundred ordnance target signatures were collected with each sensor array. This information aided in the development of the system, allowed us to evaluate performance during the requirements evaluations and subsequently were collected and provided to Joint Unexploded Ordnance Coordination Office (JUXOCO) and are available on the Defense Environmental Network and Information Exchange (DENIX)[13] web site for others to use in development.

Figure 6. Fiberglass liner of the test well being lowered into place at CBD

Figure 7. The CBD test pit used for shallow tests of smaller ordnance items

2.1.1 The Ordnance Signature Database

A primary objective of the shakedown phase of the development was the creation of an ordnance signature library for both the magnetometer and EM arrays to evaluate their performance and create a database for improved target analysis algorithm development. To accumulate these data sets, we constructed two

Table 2. Typical Logistics Costs for a 2-Week Survey Assuming No Surface Clearance or Remediation

	$K	**$K**
Presurvey Expenses		
Initial Site Visit	3.0	
Establish Navigation Control Points	6.0	
Draft Demonstration Plan & Health and Safety Work Plan	20.0	
Presurvey Subtotal		29.0
Equipment Transport		
Truck Rental	3.5	
Fuel/Permits/Tolls	0.7	
Driver	1.5	
Subtotal for Equipment Transport		5.7
On-site Logistics		
Office Trailer	2.5	
Electrical Hookup	0.9	
Portable Toilets	0.5	
Power Generator/Fuel	2.5	
Tent for Equipment Repair	1.0	
Subtotal for on-site logistics		7.4
Total Logistics Support		42.1

Table 3. Magnetic Signature Collection Test Matrix

Ordnance Item	Depths (m)	E-W Survey Width (m)	Mag Spacing (cm)	Azimuth	Inclination
20 mm projectile	surface	1.75	25	0°, 90E	0°
30 mm projectile	surface	1.75	25	0°, 90E	0°
M42 grenade	surface, 0.15	1.75	25	0°, 90E	0°
M46 submunition	surface, 0.15	1.75	25	0°, 90E	0°
60 mm mortar	0.25, 0.5	5.75	25	45E steps	45E steps
81 mm mortar	0.5, 0.75, 1.0	5.75	25	45E steps	45E steps
105 mm projectile	0.5, 0.75, 1.0	9.75	25	45E steps	45E steps
5" rocket	1.0, 1.5	9.75	25	45E steps	45E steps
250 lb bomb	2.0, 3.5	13.75	25	90E steps	90E steps
Mk 82, 500 lb bomb	2.0, 3.5, 5.5	13.75	25	90E steps	90E steps

test pits in which a range of ordnance items could be placed and evaluated at selected depths and orientations, Figures 6 and 7. Table 3 shows a part of the ordnance signature database intended for evaluation by both systems. Over 160 ordnance test signatures have been measured.

2.1.2 *MTADS* Performance With the Ordnance Database

Magnetic Signatures

The *MTADS* fit algorithm displayed good dipole fits in all cases tested. For well-measured, strong signal to noise ratio (SNR) cases (peak >20 nT), the "goodness of fit" parameter ranged from 0.969 to 0.996 with an average value of 0.988. These magnetic anomaly signatures are well described by a magnetic dipole signal. Subtraction of the modeled dipole signal from the measured data left no coherent residual signal indicative of higher order magnetic moments in the magnetic signature.

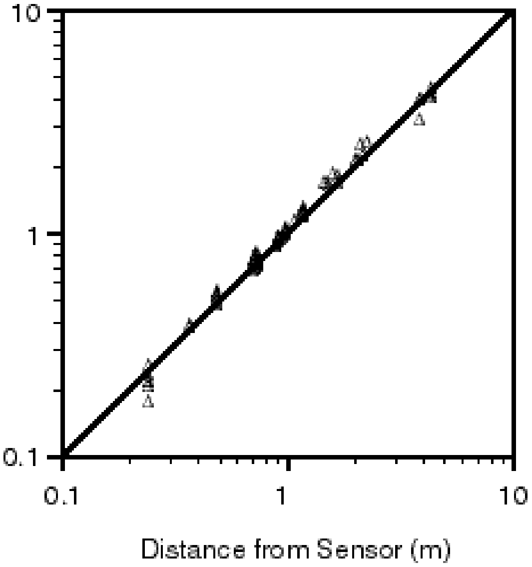

Figure 8. *MTADS* DAS estimate of test ordnance distance below the magnetometer array vs. the actual distance

The standard deviation in the (Δx, Δy) location errors was 0.05 m for the high SNR objects. This is on the order of the accuracy of the GPS system by itself. For the lower SNR (10 to 20 nT peak anomalies) objects, location errors were 0.10 m. The shallow ordnance had larger location errors in x (0.08 m) than in y (0.04 m). All of the data were collected with the vehicle driving in the y direction; so, the sensor sampling was effectively 0.25 m in the x direction (array spacing) and 0.06 m in the y direction. The deep ordnance had the largest standard deviation in the location errors, on the order of 0.40 m. The spatial extent of these signatures extended well outside of the survey area and this presumably contributed to the location error. For the entire magnetometer data set, the average offset of the fitted position was 15 cm.

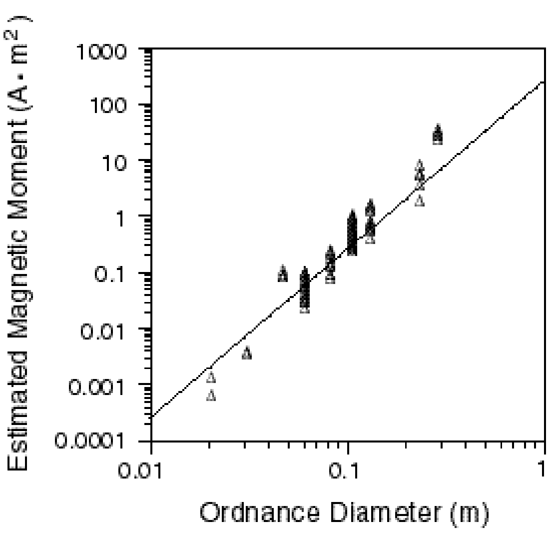

Figure 9. DAS estimated dipole moment strength vs. actual ordnance diameter

The estimate of the dipole's vertical distance beneath the sensors is plotted against the actual distance (the sensor array was 0.25 m above the ground) of the ordnance in Figure 8. The dipole fitting algorithm gives accurate depth estimates. The standard deviation in the relative depth errors (Dz/z) is 0.06. The largest relative depth errors are about 0.18 and occur for both the shallow and deep targets.

The strength of the estimated dipole moment is plotted versus ordnance diameter in Figure 9. The line shows the predicted dipole moment based on equating the volume of the ordnance to the volume of a sphere and calculating the induced dipole moment for this equivalent sphere. The *MTADS* fitting algorithm estimates size based on this equivalent sphere model. The estimated dipole moments show significant variation for a given object. For instance, as the 105 mm projectile at 0.5 m depth is varied through 11 orientations, its estimated moment varies from 0.254 to 1.02 Amps-m^2. Table 4 presents the variation in estimated moments for the 60-mm mortar, the 81-mm mortar, the 105-mm projectile, and the 5-in rocket over various orientations and depths. The result this has on the effective size calculated is shown for each. For the 105 mm projectile, the calculated effective size ranges from 100 mm to 163 mm. Using this effective size estimate, it is not possible to uniquely resolve ordnance items of similar sizes.

Table 4. Estimated Moments and Effective Sizes of Ordnance from the *MTADS* DAS

Ordnance	Average Moment (Amps-m^2)	Moment Range (Amps-m^2)	Average Size (mm)	Size Range (mm)
60-mm	0.0583	0.0235 - 0.104	60	45 - 74
81-mm	0.158	0.0767-0.259	84	67 - 101
105-mm	0.610	0.254-1.10	132	100 - 163
5-in (127-mm)	0.957	0.415-1.63	153	118 - 186

The EM Signatures

As in the case of the magnetic signatures, all EM signatures collected in this demonstration were well fit by the *MTADS* DAS. The offset distances were similar to, and in some cases smaller than, those found in the case of the magnetic signatures. This is true even though the antenna size is 1 m^2 and the along track sampling rate is ~2.5 smaller for the EM platform. The average miss distance for the entire set was 11 cm. This EM data set does not include many of the bigger, deeper items that increased the average distance for the magnetometer test set.

The EM sensor array has the sensitivity to detect a range of small and intermediate ordnance at depths below the detection limit of the magnetometer array. However, while the EM fit algorithm based on the sphere model was found to be effective for spherical objects, it was not as effective at predicting the signal shape or amplitude of elongated ordnance. At any depth, the measured ordnance signal was found to vary significantly from the sphere model as a function of the ordnance orientation relative to the direction of travel of the EM array. For elongated objects the vertical orientation has a signal that is narrower than the sphere model and larger in amplitude. The along-track orientation has a signal that is different in shape[26,27] and amplitude. The cross track orientation has a signal similar in width to the sphere model. These observations formed the basis for future algorithm development to exploit this shape information to discriminate intact ordnance from more randomly shaped scrap items.

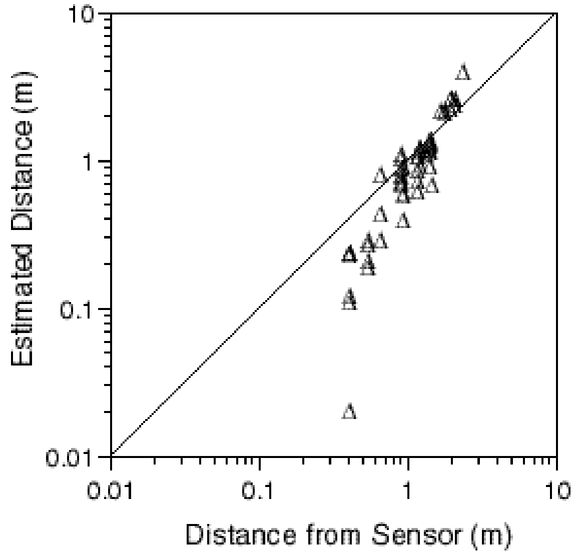

Figure 10. DAS estimate of the distance below the EM sensors vs the actual ordnance distance

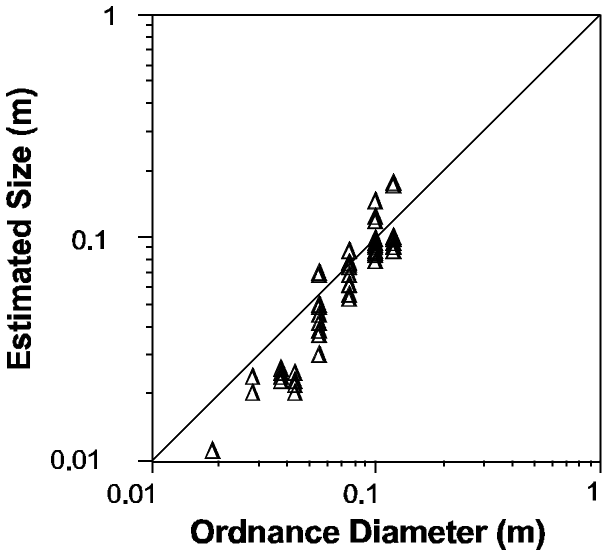

Figure 11. DAS estimate of ordnance size from measured EM signatures vs actual ordnance diameter

2.2 DEMONSTRATION AT THE MAGNETIC TEST RANGE AT THE MCAGCC

2.2.1 Background

The Magnetic Test Range at the Marine Corps Air Ground Combat Center (MCAGCC) in Twentynine Palms, CA, was established by NRL and the Naval Explosive Ordnance Disposal Technology Center (NEODTC) in the late 1980's to serve as a test and evaluation site for prototype magnetometer and GPR-based survey systems. In August of 1992, this site was used to evaluate the performance of two gradiometer systems: the Forster Model 4.021 (military designation MK-26) and the Schonstedt Model GA-72CV. Data collection for this evaluation was executed by four Marine groups from the MCAGCC EOD team at Twentynine Palms. Results of these studies have previously been reported.[1] The overall detection rate for UXO was 25-35% by the EOD teams using either detector.

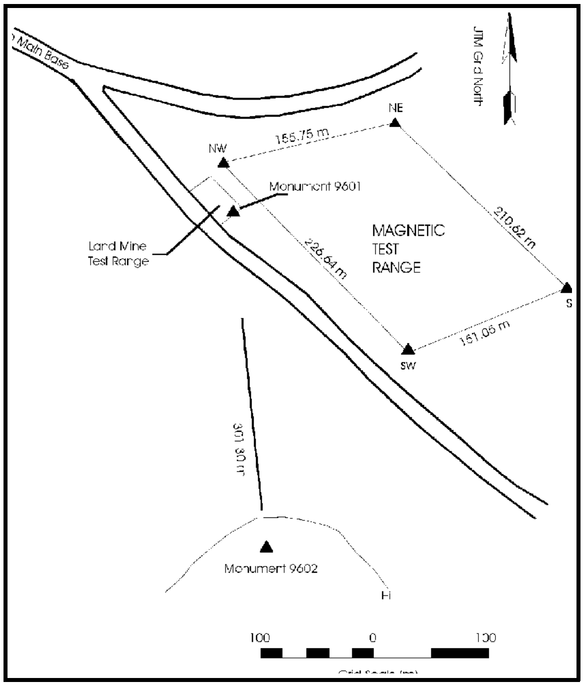

Figure 12. Schematic layout of the Magnetic Test Range showing the control points

The Magnetic Test Range (MTR), outlined in Figure 12, encompasses approximately 8 acres. The field is located in a desert environment typical of the live-fire ranges located in the western half of the United States. Soils are fairly conductive and have a significant magnetic background. There are currently 70 inert ordnance items permanently emplaced at depths ranging from 0.5 to 17 feet. The ordnance items span the range from 60 mm mortars to a Mk-84 2000-lb bomb.

In most cases, the larger the item, the deeper it is buried, consistent with projected self-penetration depths. In some instances, multiple targets are buried with small separations and some large targets are buried fairly shallow, as they are often found on live ranges. Table 5 lists the permanent ordnance at the MTR and the submunitions that we temporarily emplaced, including 20 and 30-mm rounds, 40-mm antitank rounds, and M-46 grenades. These items, particularly the latter two, are of specific concern on the active ranges at MCAGCC.

2.2.2 Performance Objectives

The performance objectives for the demonstration at Twentynine Palms were twofold. The first objective was a continued evaluation of the *MTADS* in a realistic field environment measuring system performance against system requirements and performance specifications. Undertaking an extended operation requiring shipping all equipment several thousand miles with an extended set up at a remote site also demonstrated the readiness of the *MTADS* system for transition as field hardware and allowed us to evaluate the system under rugged conditions and to determine the appropriateness of our choice of support components and system spares.

Table 5. Ordnance at the Magnetic Test Range

Permanent Ordnance	Number of Items	Range of Depths (m)
60 mm mortar	10	0.15-0.46
81 mm mortar	7	0.46-0.76
105 mm projectile	10	0.46-1.10
155 mm projectile	10	0.61-1.22
8" projectile	10	1.83-2.74
Mk 81 bomb	10	1.43-3.11
Mk 82 bomb	10	1.22-4.42
M 117 bomb	1	3.96
Mk 83 bomb	1	5.09
Mk 84 bomb	1	4.88
Submunitions		
20 mm	1	flush
30 mm	5	flush
M 42	1	flush
M 46	5	flush

The second demonstration objective focused on evaluation of system performance for locating and characterizing buried ordnance. Target analysis of the three surveys was independently carried out by the Institute for Defense Analyses (IDA) personnel who were not involved in the development of the system. Prior to analysis, the types of ordnance at the site were known to them, but the ordnance location truth tables were not. The IDA personnel had only a short learning period with the software and users manuals (that were still in rudimentary form) in preparation for this task. Their interaction with us in this demonstration provided very useful information helping us to prepare the DAS as a transition product appropriate for the end user.

2.2.3 Registration Targets

As an integral part of the *MTADS* evaluation procedures were established to facilitate the determination of the overall performance of the combined DAQ, DAS, and navigational hardware and software. Prior to beginning surveys, a number of reference points were established within the site. The registration targets include 30 12-inch long sections of 3/8-inch diameter steel rebar. The sections of rebar were vertically driven into the ground until flush with the surface. The rebar targets were driven about 5 meters apart along the north and south edges of the field, as shown in Figure 13. The submunitions were placed about 5 meters apart along the perimeter beginning at the NW and NE posts. The precise positions of the rebar registration targets and the submunitions were determined using the land marking tools associated with the DAQ and the Tow Vehicle. Independent landmark data files were created to record these positions. Based upon prior experience, we expected these way pointed positions to be accurate to 3 to 5 cm.

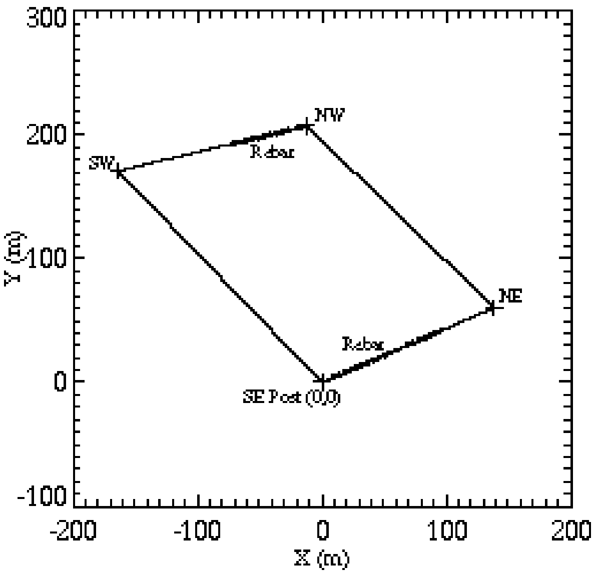

Figure 13. Schematic of the MTR showing the corner posts and the two lines of rebar registration targets

2.2.4 MTADS Surveys

Surveys of the range were carried out by NRL personnel employing magnetometer, gradiometer, and the EM pulsed induction arrays. The magnetometer survey was conduced with the array 0.25 m above the surface; sampling at 50 Hz. Data collection was completed in 2 hours and 40 minutes of survey time. The gradiometer survey was also collected at 50 Hz with a horizontal sensor separation of 0.5 m.

The lower sensors were 0.4 m above the surface and the vertical sensor separation was 0.55m. Data collection took 3 hours and 10 minutes. The EM survey data was taken at 10 Hz with the lower sensors 25 cm above the surface. Data collection took 5 hours and 30 minutes.

Survey rates with the magnetometer array are 2.5-3.0 acres per hour and with the EM array are 1.25-2.0 acres per hour. These production rates are highly dependent on terrain and the length of the survey lanes. For instance, at this site about 30% of the time is spent in turn-arounds.

The Registration Targets

The rebar targets were analyzed for positions using the *MTADS* DAS. In the magnetometry survey the average difference between the analyzed positions and the way pointed positions was 6 cm. This value is very close to the 5 cm accuracy expected from our way pointing accuracy alone. The average discrepancy in the analyzed positions of the rebar targets in the EM survey was about 11 cm.

IDA UXO Target Analyses

The survey data were independently analyzed by NRL and the IDA. The *MTADS* DAS was installed on a Silicon Graphics, Inc. (SGI) platform at IDA, and a data tape was used to transfer the processed data files for the magnetometer, gradiometer, and EM surveys. The operation of the analysis software routines was demonstrated and a draft of the DAS operator's manual was provided. IDA devised their own approach to target analyses. EM analyses were carried out as described in the DAS operator's manual. The analyzed magnetometry and gradiometry targets were categorized at 7 different levels relating to probability of the target being ordnance. The higher the value assigned to a target the lower its probability of being ordnance.

Analysis of the EM survey was carried out as described in the DAS Operator's Manual and a Target Table was generated. 252 targets were analyzed; all were declared as ordnance. Their calculated ferrous sizes ranged from 40 mm to 390 mm. Six targets were fit to a depth of 0 m, while the deepest target was calculated to have a depth of 4.09 m. The NRL utility was used to evaluate the fits based upon information in the *MTADS* Target Table. There were four target pairs that were buried with small horizontal separations. The IDA analysis detected these target pairs, but declared them as single targets.

All ordnance smaller than the 8-in projectiles were detected, as were eight of the ten 8-in projectiles. With the exception of the closely paired targets and target C-l, all targets were correctly located to within 0.5 m. Overall, 61 of the 70 ordnance targets were located. With the exception of the Mk 84 and the paired targets, all targets were located within a 1.0 meter critical radius. With two exceptions (targets C-2 and C-7) all the undetected targets were buried deeper than 3 meters.

Summaries of the IDA magnetometry and gradiometry analyses are presented in Tables 6 and 7. In the magnetometer survey a total of 656 targets were analyzed. Including all levels of probability, 57 of the 70 UXO targets (81%) were identified. This declaration rate corresponds to a false alarm rate of 190 per hectare. In the less noisy gradiometer survey, a total of 302 targets were analyzed. 54 UXO items were correctly identified with a corresponding false alarm rate of 80 per hectare.

Table 6. Summary of the IDA Magnetometry Survey Analysis

Probability Score	Total Declared Targets	Ordnance Correctly Located Within Critical Radius			False Alarms/Hectare At the Stated Critical Radius		
		0.5 m	1.0 m	2.0 m	0.5 m	1.0 m	2.0 m
0	91	29	40	42	19.7	16.2	15.6
0-1	138	30	46	48	34.4	29.3	28.7
0-2	179	31	48	50	47.1	41.7	41.1
0-3	202	31	48	50	54.5	49.0	48.4
0-4	214	31	48	50	58.3	52.9	52.2
0-5	221	31	48	50	60.5	55.1	54.5
0-6	656	33	52	57	198.4	192.4	190.8

Table 7. Summary of the IDA Gradiometer Survey Analysis

Probability Score	Total Declared Targets	Ordnance Correctly Located Within Critical Radius			False Alarms/Hectare At the Stated Critical Radius		
		0.5 m	1.0 m	2.0 m	0.5 m	1.0 m	2.0 m
0	111	36	42	47	23.9	22.0	20.4
0-1	140	37	43	48	32.8	30.9	29.3
0-2	148	37	43	48	35.4	33.4	31.8
0-3	156	39	46	51	37.3	35.0	33.4
0-4	164	40	47	52	39.5	37.3	35.7
0-5	170	40	47	52	41.4	39.2	37.6
0-6	302	41	49	54	83.1	80.6	79.0

The NRL UXO Target Analysis

The EM survey analysis was carried out according to the DAS operator's manual. Targets with fit sizes of 20-mm and below were declared as non-ordnance. These exclusions were based upon experience working with the baseline target sets from the NRL CBD TECHEVAL. These studies were not available to the IDA personnel when they undertook their target analyses. A total of 183 targets were declared, 63 were correctly located (within 2 m) ordnance targets. This correlates to a false alarm ratio of 2.0 or 38 false alarms per hectare. The EM results are summarized in Table 8. The results are very similar to the IDA EM analysis. All ordnance 155 mm and smaller were correctly identified, as were eight of the ten 8-inch projectiles. All small targets (with the exception of the paired targets) were located within the 0.5 m critical radius. Of the bombs that were not found by the EM array, all were buried at depths of greater than 3.0 meters.

Table 8. Summary of NRL Target Analyses for the MTR Surveys

Survey	Targets Fit	Declared "Not Ordnance"	Declared Ordnance	Valid Targets Within Critical Radius			False Alarms (2 m Critical Radius)	
				0.5 m	1.0 m	2.0 m	Ratio	Per Hectare
Magnetometer	257	74	183	48	57	63	1.9	38
Gradiometer	248	47	201	38	52	57	2.5	46
EM	227	44	183	54	60	63	1.9	38
Fused Analysis	427	164	263	51	60	66	3.0	64

In the magnetometry analysis, all likely targets were boxed for analysis. Targets were chosen for analysis based upon the assumption that 60-mm mortars were the smallest ordnance on the site. Many anomalies that were obviously too small to be 60-mm mortars were excluded. All targets with a fit size of 30-mm and smaller were declared as non-ordnance. Targets with a fit size of 50-mm or larger were declared as ordnance unless their visual image showed them as clusters of smaller items. Of the targets with fit sizes of 40-mm, some were declared as ordnance, some were not. Factors considered included dipole orientation, calculated depth, goodness of fit, and whether the target was located within a clutter region. In the magnetometry analysis, 74 of the analyzed targets were declared as "not ordnance." Of the 183 declared ordnance targets, 63 were valid ordnance targets, correctly located within the 2 m critical radius. The 10% missed targets included 60-mm mortars, 105-mm and 8-inch projectiles and 250- and 1000-lb bombs. All items missed in this analysis were also missed in the IDA magnetometry target analysis (probability levels of 0-2). The NRL false alarm ratio was 1.9 or 38 false alarms per hectare.

In the gradiometer survey analysis, 47 targets were declared as "not ordnance" and 201 targets were declared as ordnance. Fifty-seven of these were valid targets, located within the 2 meter critical radius. This correlates with an 81% probability of correctly locating ordnance and a false alarm ratio of 2.5 or 46 false alarms per hectare. The ordnance items missed include 60- and 81-mm mortars, 105-, 155-mm and 8-inch projectiles and 250-, 500-, and 1000-lb bombs. The ordnance items that were missed were mostly missed because the signals were too weak to visualize or the signal-to-noise ratio was too small to allow a successful fit.

2.2.5 UXO Identification

The MTR is located in extremely magnetic soils. The geological magnetic anomalies result both from magnetic rocks (with typical ordnance sizes) to sweeping magnetic background signals with spatial scales on the order of meters. Many of the ordnance items were buried at this range at the maximum depths that they are ever likely to be found. Several items were buried very close together and some items were buried above other UXO. Given the difficulty of this range, the detection efficiency was very high, approaching 95%.

2.3 DEMONSTRATION AT THE JPGIII

2.3.1 Background

The Jefferson Proving Ground (JPG) was opened in preparation for World War II, to provide live fire testing of ammunition and served in this capacity for over 50 years. The base was officially deactivated before the beginning of the JPGIII Demonstrations; a small Army contingent remains to oversee the transfer of land and facilities to the civilian sector. A small fraction of the former base is now being used as farm land. The remainder must be remediated or certified for appropriate use before significant new uses can be undertaken. The Indiana Air National Guard continues to use the northern ranges for live fire exercises, but no other military operations are conducted at the installation.

Recognizing the needs associated with the development and application of advanced technologies for cost-effective, accurate and reliable UXO characterization and cleanup, Congress provided funding in fiscal years 1993-1995 for the development and demonstration of emerging technologies for the detection, identification, and cleanup of sites contaminated by UXO. The Army Environmental Command (AEC), in conjunction with the NEODTC, prepared two sites at JPG seeded with ordnance placed at known positions and buried at known depths and orientations as a test facility to evaluate emerging technologies for site characterization and remediation. During the summers of 1994, 1995 ane 1996 three rounds of demonstrations were conducted by commercial vendors and service providers on these specially prepared sites. These have become known as JPGI,[27, 28] JPGII,[29] and JPGIII.[30] A variety of ground and airborne systems using several sensor technologies have been demonstrated with widely ranging levels of success.

The JPGIII Demonstration was conducted on the 40 acre North Site, which measures 1,320 feet along each edge. The site[30] is divided into 100-foot-by 100-foot grid cells, with the northeast corner of each area as the point of origin (grid cell A-1). Subsequent grid cells along the northern boundary progress westward alphabetically, and the grid cells along the eastern boundary progress southward numerically. Three permanent benchmarks (surveyor's monuments) were established at the site as reference points for maps, and for surveying emplaced targets. The monuments were positioned to be within the demonstrator's field of view while operating on the site. The site layout for the JPGIII Demonstration for commercial systems was separated into four different "scenarios". The information below is summarized from the JPGIII Demonstration Work Plan[31] The narratives describe the presumed "Scenarios" for creation of the UXO Demonstration Plots shown as quadrants in Figure 14.

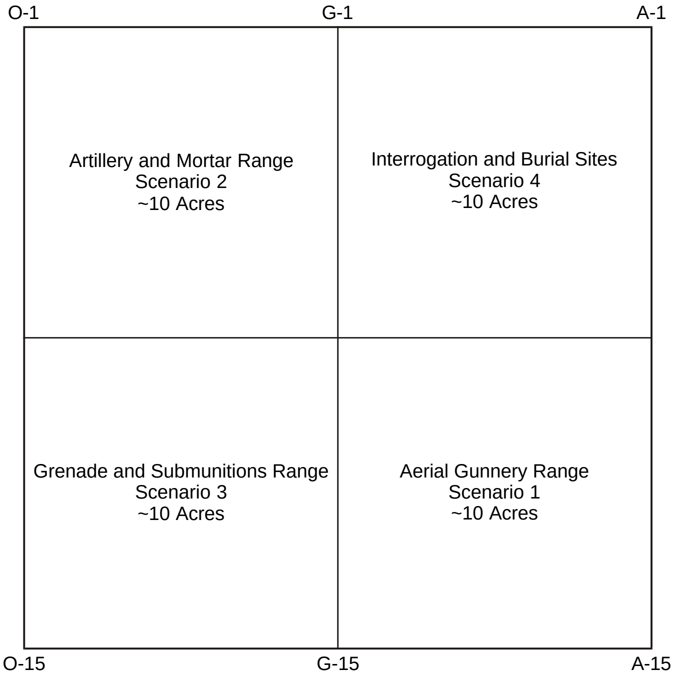

Figure 14. Layout plan for the "North Site," JPGIII ground ordnance surveys

Scenario 1 Aerial Gunnery Range

An aerial gunnery range simulates aerial delivery of ordnance from both helicopter and fixed wing aircraft. Ordnance typically ranges from 2.75-inch rockets to 2,000-pound bombs typically found at depths ranging from near surface to 3 meters below ground surface (bgs).

Scenario 2 Artillery and Mortar Range

A typical artillery and mortar range contains assorted types of conventional ground ordnance fired at fixed hardened targets, usually from a position outside of the range. Ordnance typically ranges from 60-millimeter mortars to 8-inch projectiles present at depths ranging from near surface to 1.2 meters bgs.

Scenario 3 Grenades and Submunitions Range

The grenades and submunitions range is a portion of a conventional impact area set aside for sensitive-fuzed submunitions fired by aircraft and field artillery. The area has been surface swept, and no surface contamination is known to be present. This impact area was historically used for conventional weapons testing, and may contain other munitions at depths greater than 0.5 meters bgs. However, the purpose of the Phase III demonstrations is to detect submunitions and grenades at depths of 0.5 meters or less bgs.

Scenario 4 Interrogation and Burial Area

The interrogation area represents a conventional impact area. The targets used in this impact area are aerial weapon systems ranging from 2.75-inch rockets to 2,000-pound bombs, as well as conventional ground weapons ranging from 60-mm mortars to 8-inch projectiles. Burn or burial sites may be present in this impact area, as well as fragments from exploded munitions and other ordnance components, such as mortar fins and empty illumination rounds. This area has been surface swept and should be clear of surface contamination. Ordnance has been emplaced at depths ranging from near surface to 2 meters bgs.

The JPG Demonstration Work Plan[31] (DWP) presents and describes these Scenarios and their layouts for JPGIII. Appendix C-3 of the DWP presents the inert munitions list for ordnance used at JPGI and JPGII. Appendix C-5 of the DWP presents a list of “Estimated Maximum Ordnance Penetration Depths” for two soil types which is attributed to a study by the Naval Explosive Ordnance Technology Center in 1990. This information is incorporated into Table 9.

Table 9. List of Ordnance and Submunitions Expected at JPGIII with Maximum and Typical Penetration Depths

Ordnance Diameter (mm)	Ordnance Type	Maximum* Penetration in Sand (m)	Maximum* Penetration in Clay (m)
20	Artillery Shell	0.3	1.0
30	Artillery Shell		
40	Grenade/		
60	Mortar	0.3	1.0
70	2.75" Rocket	0.8	2.5
81	Mortar	1.0	2.1
90	Projectile	2.3	4.3
105	Projectile	1.8	3.8
107	4.2" Mortar	1.3	2.8
152	Projectile	2.5	4.9
155	Projectile	2.8	5.4
175	Projectile	3.9	7.8
203	8" Projectile	3.9	7.8
233			
273	500-lb	9.2	11.5
310	1000-lb	10.8	17.1
	2000-lb		

* Information provided by reference in Reference 13.

2.3.2 Performance Objectives

The *MTADS* performance objectives were simple; survey all accessible areas of Scenarios 1, 2, and 3 as efficiently as possible using both the magnetometer and EM arrays. Analyze all targets using both data sets, declare all targets identified as UXO and list all targets declared as "not UXO." Report the results to the Army Environmental Center for analysis and comparison with results from other demonstrators. The overarching objective was to demonstrate the capabilities of the *MTADS* relative to the best commercially-available technologies.

No slots were available to NRL for demonstration during the normal rotation involving the other demonstrators. It was planned to take *MTADS* to JPGIII in the fall of 1996 following completion of activities by the commercial demonstrators. NRL was unable to gain access to the site until January of 1997.

2.3.3 *MTADS* Surveys at JPGIII

The *MTADS* arrived at JPG on Monday, January 13, 1997. The first day was devoted to off-loading the system from the transport truck, ferrying the system to the survey area, preparing the storage building provided for occupation by *MTADS* by supplying generator power for lights and heat, and setting up the data analysis system in the office trailer provided by Personnel Readiness Center (PRC). On Tuesday, January 14, the system was assembled, checked out, and test data taken over the prove-out site. The actual demonstration surveys were carried out during the period January 15-22. The survey dates and times for the individual scenarios are shown in Table 10. No performance-limiting problems were encountered during the survey. In spite of the weather, less than three hours of down time for the equipment were experienced during the survey period. Some inefficiencies were encountered due to the exposure limits which we imposed on our field support personnel during the coldest periods (with wind chills below -20F). The tall forest adjacent to parts of the survey areas limited survey times at the edges to periods with favorable satellite positions which we predicted each morning using GPS planning software.

Table 10. Dates and Times *MTADS* Surveys of Individual Scenarios

Scenario	Survey	Survey	Survey Time	Survey Time
Aerial Gunnery	15-16 Jan	22 Jan	5.3	5.8
Artillery & Mortar	16 Jan	17-18 Jan	5.4	7.8
Grenades & Submunitions	21 Jan	18, 20 Jan	5.9	7.8

The denser wooded areas and tree/fence lines with stacked up debris precluded *MTADS* survey of some of the grid cells. The surveyed and unsurveyed grid cells are clearly defined in Table 11. As was true of all JPGIII demonstrators, performance was evaluated only on those grid cells which we reported as surveyed.

Table 11. Quadrants Surveyed and Not Surveyed by MTADS

Scenario	Quadrants Surveyed[*]	Quadrants Not Surveyed[*]
1 - Aerial Gunnery	A8 through A12 B8 through B14 C8 through C14 D8 through D14 E8 through E14 F8 through F14	A13, A14
2 - Artillery and Mortar	G2 through G7 H2 through H7 I1 through I7 J1 through J7 K1 through K7 L1 through L7 M1 and M2 N1 and N2	G1 H1 M3 through M7 N3 through N7
3 - Submunitions and Grenades	G8 through G14 H8 through H14 I8 through I14 J8 through J14 K8 through K10 & K12 through K14 L8 and L9	K11 L10 through L14 M8 through M14 N8 through N14

[*] Quadrant A1 is the cell bounded by stakes A1, A2, B1 and B2, etc.

2.3.4 Survey Results

Figures 15 and 16 show the anomaly image maps for the total-field magnetometer and EM surveys of the Aerial Gunnery Scenario. These data are typical of the remainder of the sites. Most targets were easily detectible, primarily because of their relatively shallow burial depths. Missed areas resulting from tree lines were filled in by surveying locally in a north-south direction.

After returning from the JPG site, all survey data were analyzed using the *MTADS* DAS. Targets were sorted by size and depth and categorized as ordnance or non-ordnance based on the design characteristics of each of the three scenarios and other information described above. The results were reported to the Army Environmental Center using the spreadsheets provided for this purpose. A summary of the reported results is shown in Table 12.

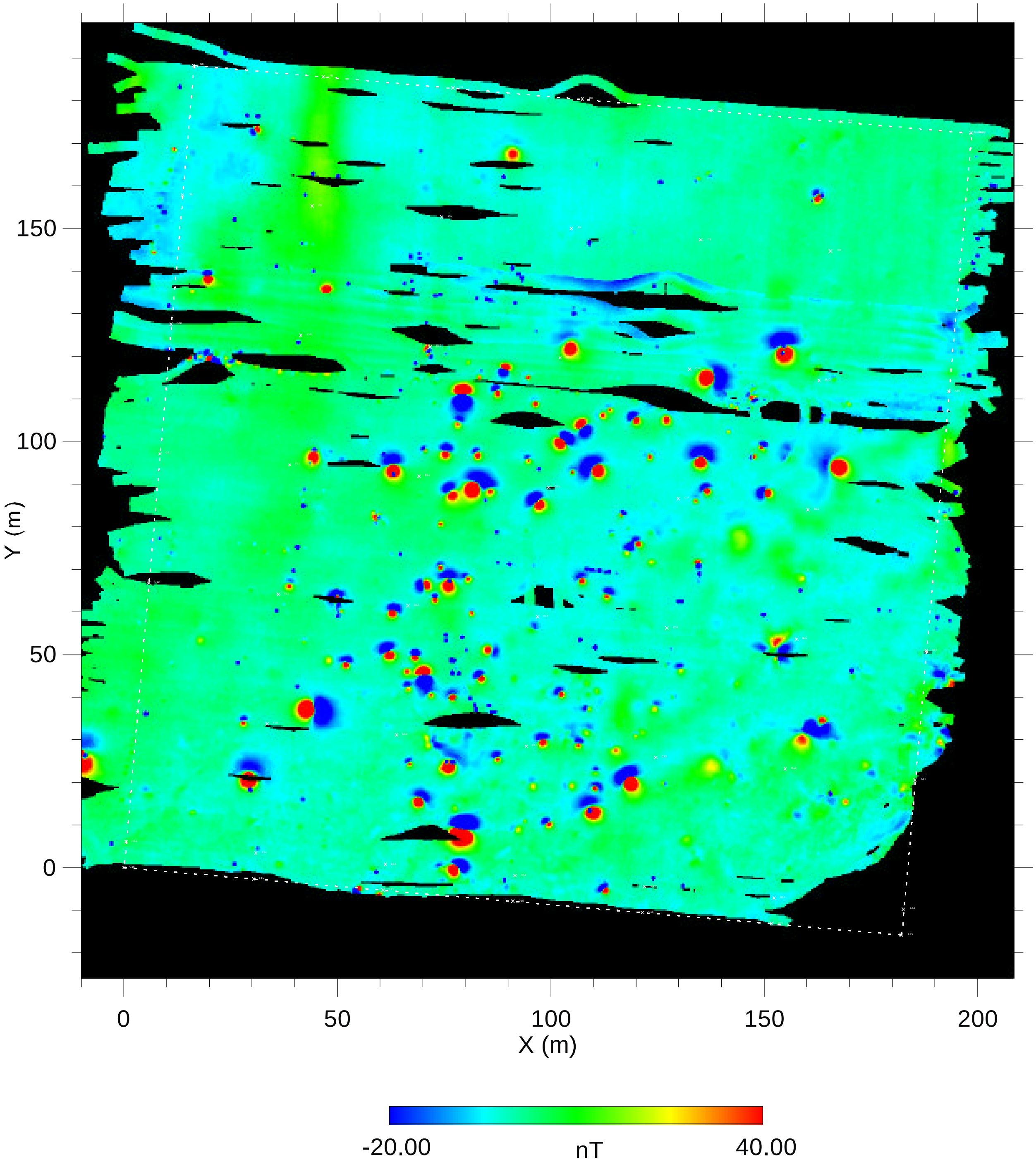

Figure 15. Magnetic anomaly image map of the Aerial Gunnery Scenario at JPGIII

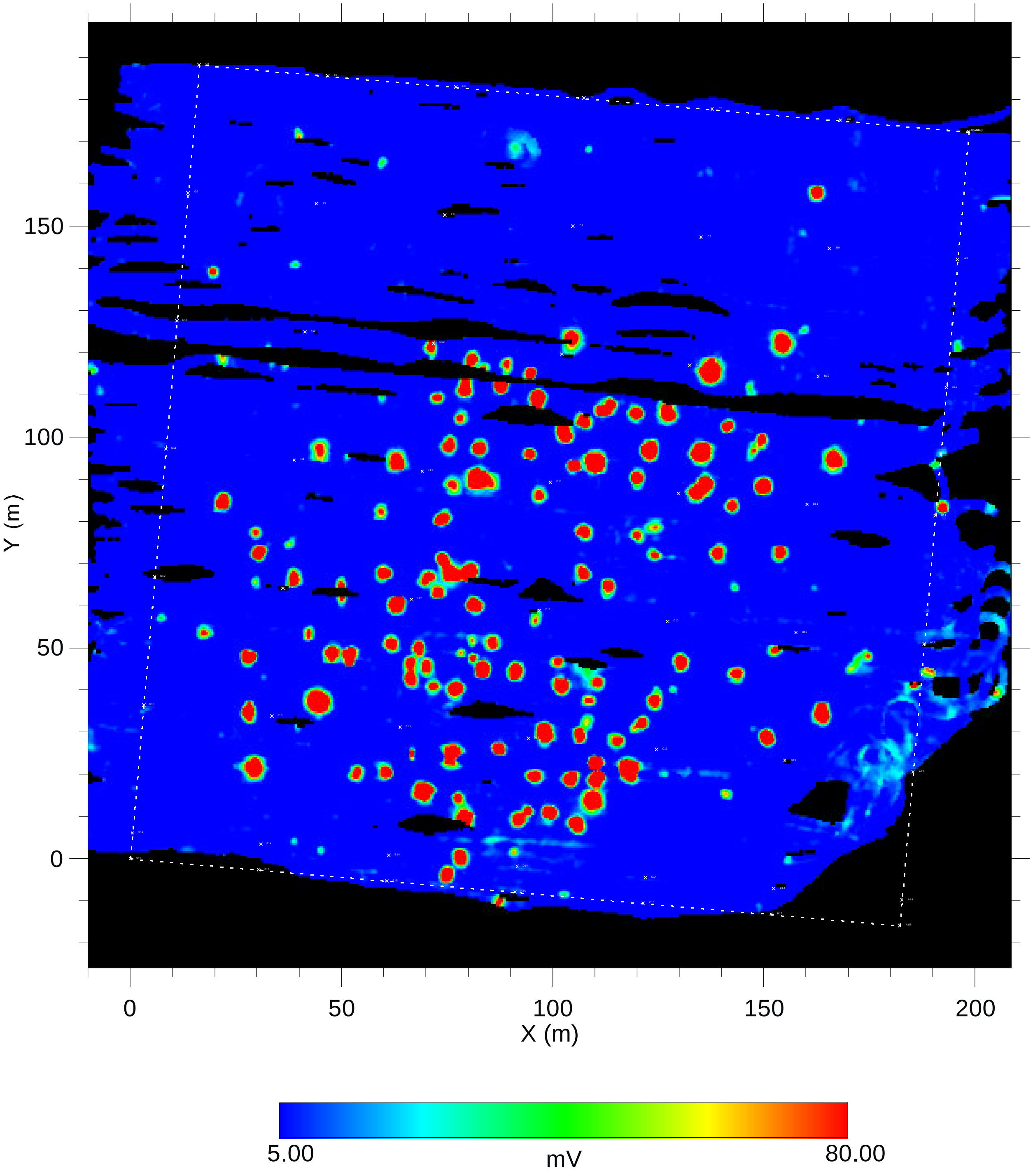

Figure 16. EM anomaly image map of the Aerial Gunnery Scenario at JPGIII

Table 12. Targets Reported to AEC by NRL for Each of the JPGIII Scenarios

Scenario	Declared Ordnance Targets	Declared Non-Ordnance Targets
Aerial Gunnery	186	81
Artillery & Mortar	218	44
Grenades & Submunitions	213	7 Unknown & Bombs

IDA Analysis of Results

The IDA was tasked to perform an independent analysis of the NRL results at the JPGIII demonstration. They worked with NRL-provided spreadsheets for each scenario that listed mag and EM detections for that scenario along with NRL's declarations and the JPG ground truth as provided to them by NEODTC. The results of the IDA analysis are contained in an IDA report.[32] Table 1 in reference 32 summarizes the IDA analysis and is reproduced here in Table 13.

Table 13. Summary of the IDA Analysis of *MTADS* Detections with a 1.0 m Critical Radius at JPGIII*

Scenario	Number of Baseline Ordnance	Number of Ordnance Declarations	Number of Correct Ordnance Declarations	P_D
Aerial Gunnery	47	185	45	0.96
Artillery and Mortars	73	216	70	0.96
Submunitions and Grenades	86	222	80	0.93

* Based on Table 1 of Reference 14.

IDA adopted the logical definition for false alarms as the number of ordnance declarations minus number of ordnance detections. This approach results in a false alarm rate about one third lower than the NEODTC analysis. These results are summarized in Table 14.

Table 14. Summary of the IDA Analysis of *MTADS* False Alarm Rates at JPGIII*

Scenario	Area Surveyed (hectare)	Number of False Alarms	False Alarm Rate (#/hectare)
Aerial Gunnery	3.34	140	41.9
Artillery and Mortars	3.94	146	37.6
Submunitions and Grenades	2.97	135	45.4

* Based on Table 2 of Reference 15

MTADS Performance Summary

An obvious conclusion from the data in Tables 10-14 is that the *MTADS* is an efficient and effective detection system for buried UXO. Each of the three scenarios were surveyed with both of the two sensor suites in less than a day each of survey time. The probability of detection for ordnance ranged from 93 to 96% using a 1m critical detection radius. The overall ordnance detection efficiency for all three scenarios with a 2-meter critical radius is 97.5%. The 2-meter critical radius is used for making all the plots in Ref 30. The detection probability for "nonordnance" was also impressively high except for the Submunitions and Grenades Scenario where the definition of the scenario led us to not declare several of the anomalies detected.

Figure 17 shows a recasting of Figure 6.2.1-1 from Ref 30. Data is included only for actual performers at JPGIII. The NRL results are a 97.5% ordnance detection efficiency (2-meter critical radius) and an overall false alarm rate of 41 per hectare.

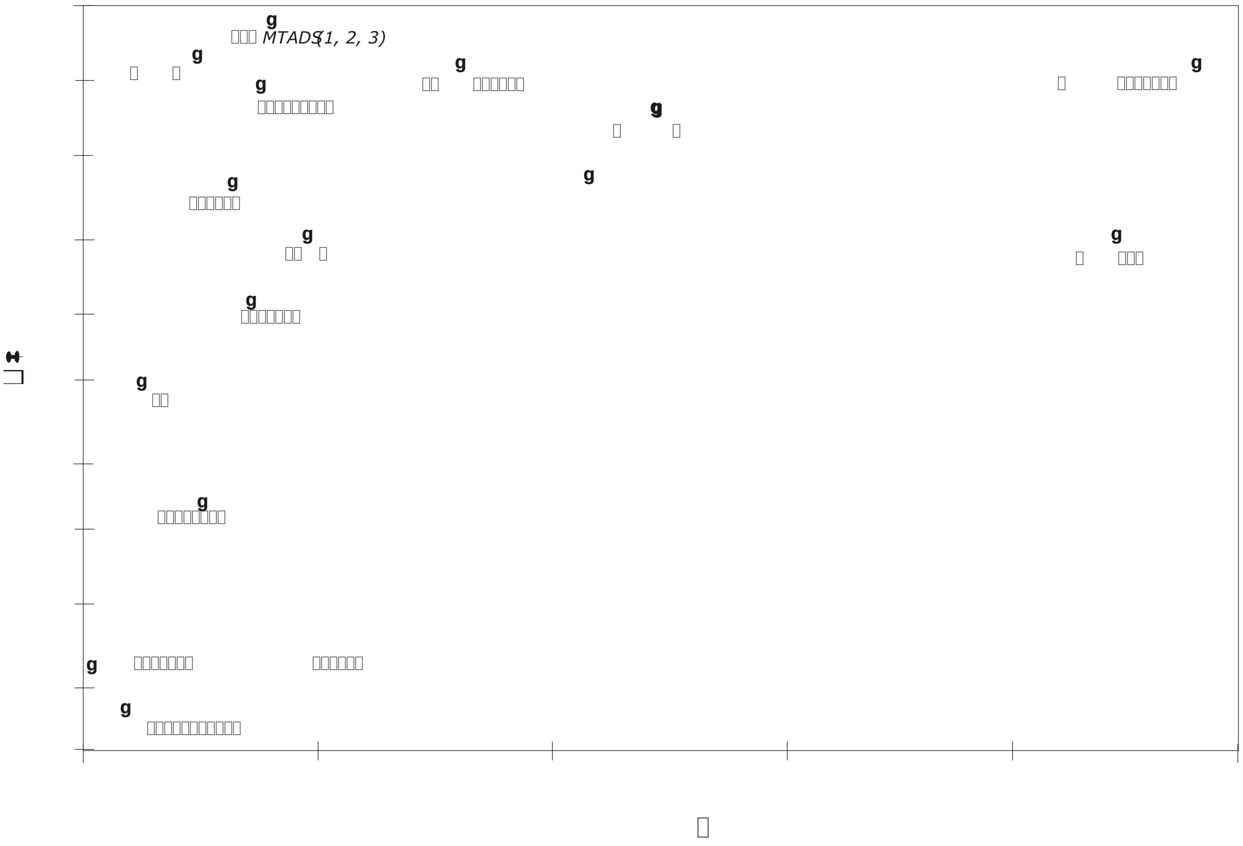

Figure 17. Plot of probability of detection for ordnance items in Scenarios 1-3 as a function of the reported false alarm rate per hectare. The actual Scenarios surveyed by individual performers are given in parentheses following the company names. This figure is adapted from Ref. 30.

2.4 THE BADLANDS BOMBING RANGE

2.4.1 Background

In 1942 the Department of War annexed 341,725 acres of the Pine Ridge Reservation for use as an aerial gunnery and bombing range. The Reservation is located in the Southwest corner of South Dakota, with the largest part of the Bombing Range located in Shannon County. The Badlands Bombing Range (BBR) was a live fire range for over 30 years, and most recently was used as a training range for the Air National Guard. Since 1960, portions of the land have been returned to the Oglala Sioux Tribe (OST) in a step-wise fashion. In 1968, Congress enacted Public Law 90-468 returning 202,357 acres to the OST, and setting aside 136,882 acres of formerly held Tribal lands to form the Badlands National Monument, to be managed by the National Park Service. The U.S. Air Force still retains 2,486 acres of land on Bouquet Table within the Reservation boundaries.

2.4.2 Objectives for the Badlands Bombing Range Survey

Conducted in conjunction with personnel from the U.S. Army Corps of Engineers, Huntsville (CEHNC-OE), a primary objective of this demonstration was to conduct an extended survey of sites within the boundaries of the BBR to evaluate the performance of the *MTADS* on a former ordnance training range. A survey of this type would be expected to encounter both intact ordnance and a range of ordnance scrap and clutter. Therefore, following target analysis, EOD contractors and personnel from CEHNC were scheduled to selectively remediate targets to evaluate both the detection and discrimination capabilities of *MTADS*. An initial set of targets (a training data set) was selected that included a range of target types and sizes; all targets in this set were dug and evaluated. This information was a guide for selection of targets for the remainder of the demonstration.

HAZWOPR trained and certified tribal members of the OST, were incorporated into the demonstration surveys. All survey results were shared with the Badlands Bombing Range Project Office to aid in the accomplishment of their restoration goals. NRL established several GPS-based first order survey points and integrated of all survey data into the OST Arc Info/Arc View GIS databases to allow correlation with digitized aerial photographic information available from the U.S. Geological Survey (USGS) and other commercial sources.

The participation of personnel from CEHNC-OE allowed the Army Corps to assess the suitability of the *MTADS* technology for buried ordnance site characterization of formerly used DoD ranges. *MTADS* survey products were prepared in formats suitable for integration into the Intergraph GIS data base resident in Huntsville and appropriate for reanalysis using their “Knowledge-Base” data processing system. Cost analyses were developed to document the operational costs to deploy the *MTADS* for the demonstrations at Twentynine Palms, at JPG and at the BBR site.

The recovered targets were extensively documented, both to evaluate *MTADS* performance, and to establish a magnetometry and pulsed induction sensor signature database for both ordnance and clutter targets typical of this site. All remediated targets were reacquired by GPS to precisely determine position; they were photographed, and target sketches, descriptions and orientations recorded on an extensive dig sheet report. Data sets acquired on the training area at the BBR were archived for future use by ourselves and others and are available on the JUXOCO Web site.[13]

2.4.3 The Primary and Secondary Survey Targets

BBR I is a highly visible circular target composed of a 500-foot diameter circular earthberm, with a cross-hair berm inside the circle. A 1991 aerial (1 meter resolution) photograph of this target is shown in Figure 18. A more recent color photograph is shown in Figure 19. The east-west fence bisects the bull's eye. The northern side is rented to a local rancher by the National Park for grazing. The southern side of the fence is Tribal land currently rented as farmland and under cultivation. During the *MTADS* surveys this area was partially covered by winter wheat (almost ready for harvest) and partially planted in millet which was about 10 inches tall. Cultivation of the southern side of the target has significantly reduced the height of the berm, however, it is still easily detectible.

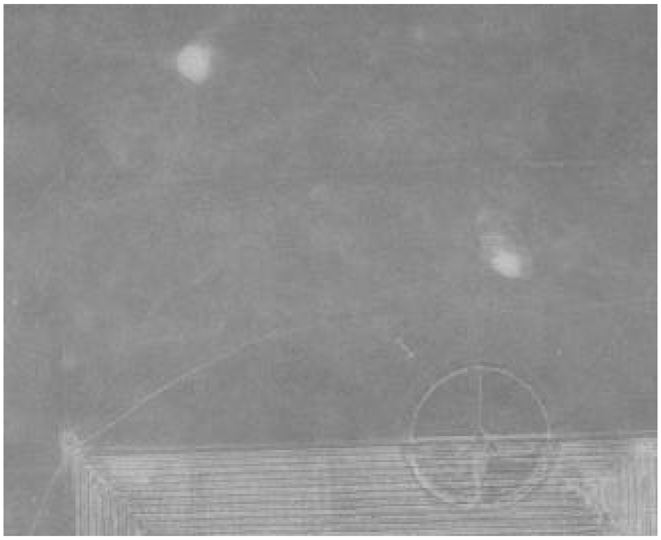

Figure 18. Aerial photograph of a portion of Cuny Table that displays Bombing Target, BBR I.

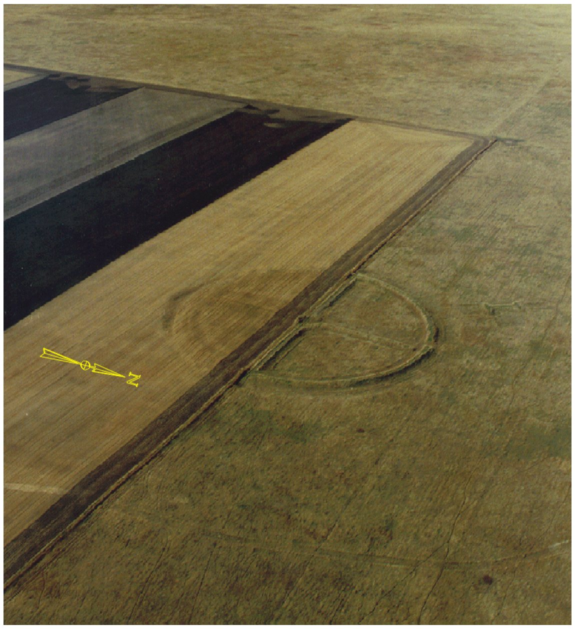

Figure 19. Recent aerial photograph of BBR I showing the division between crop land and grassland.

OST members from the BBR project office claimed that they could point out to us the position of the second target referred to above. The area they associate with this target is pasture land (in the National Park). Figure 20 shows a 1 meter resolution digitized aerial photograph of the approximate area under consideration. The current fences between Parkland and Tribal land under cultivation are superimposed as white lines. The white X denotes the center of the area pointed out to us by Tribal members. There are no detectible surface features similar to those at BBR I. There is ordnance related scrap widely scattered on the surface. The scrap is mostly tail fins from bombs and is similar to the surface scrap on BBR I.

The photographic and map records in the Bureau of Indian Affairs (BIA) office in Pine Ridge were again searched for information relevant to this target. A poor quality reproduction of a map was obtained that probably dates from the 1950's which shows the bull's eye, BBR I, which is labeled "Bomb Target" on the map. There are two additional faint circles. The closest to BBR I is approximately 6335 ft east and 1585 ft south of BBR I from caliper measurements on the map. The second faint target is 0.5 mi due east. These circles are labeled "Gunnery Targets" on the BIA map. If the western circle is the target identified by the OST members it would lie approximately at the circle shown on Figure 20. Rather than being in the Parkland, these measurements would locate the target on what is currently Tribal land. The circle shown on Figure 20 is currently located in a millet field about 200 ft south of and about 200 ft west of the fences shown as white lines on Figure 20.

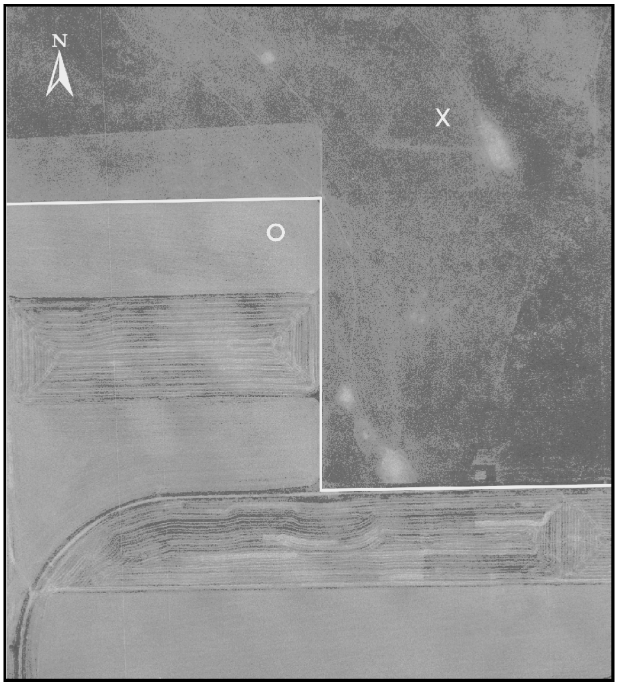

Figure 20. Aerial photograph of a portion of Cuny Table proposed to contain a bombing or gunnery target. See text for explanation of the symbols

2.4.4 Logistics

Transportation and Field Support

An NRL support contractor was responsible for transporting all *MTADS* hardware between Washington, DC and the field activities. They provided *MTADS* vehicle drivers and mechanical maintenance of all field hardware. The representative served as the site safety officer and was responsible for conducting all daily safety briefings. Additionally, the driver who is EOD certified, supervised all field activities of survey support crews and made ordnance and safety-related decisions about situations encountered in the field.

Logistics Support

Figure 21. Base Camp for the survey showing the 3 support trailers, the backhoes, and the power generator

For the effort at the BBR, there were no facilities of any type available to support our operation. The nearest source for rental equipment was Rapid City, about 75 miles from the Cuny Table Sites. Trailers, Figure 21, were rented for a field office and to house computer operations, for a field workshop and and storage for *MTADS* and EOD field hardware, and for overnight garaging of the *MTADS* vehicle and sensor platforms. An electrical generator and fuel storage was put in place to support the requirements of all three trailers and for overnight charging of the vehicle batteries. Backhoes suitable for EOD operations were leased and put on site to support EOD crews. Portable toilets were maintained for work crews of 15 people for the five weeks of the operation. All rented equipment was removed from the site and the site cleaned at the end of operations.

As remediation activities were to be conducted concurrently with survey operations, we established separate facilities to support the activities. Three cargo containers converted into lighted, air-conditioned

Figure 22. View of the interior of the survey headquarters trailer which supported all data analysis operations

office trailers were placed on site. The interior of the trailer used by the Survey Team is shown in Figure 22. The survey and remediation teams were provided separate office facilities (8 by 40 ft trailers). The survey team trailer housed the DAS, communications equipment, and modest office facilities for coordination briefings. The remediation team trailer was used for the storage of field equipment and also housed an electronics repair station and tools and repair supplies. An additional 8 x 48 foot container was used as to garage the *MTADS* vehicle and sensor platforms. Power to the trailers was provided by a 65 KW diesel field generator which was also used to recharge the vehicle, radios and GPS batteries overnight. Communications among on-site personnel was provided by hand-held VHF radios, with a base station located in the command trailer. Radios were provided to all field and office teams so that communications could be maintained. In addition, a 20 x 30 foot tent canopy was located adjacent to the garage trailer, permitting the survey team to service and repair the *MTADS* Tow Vehicle and sensor platforms. Fuel for the generator and backhoes was provided by a 500 gallon fuel tank . Cellular phone communications were available at the site. CEHNC established an explosives magazine trailer about 1 mile north of the Base Camp inside the Parkland fence.

2.4.5 Ordnance Remediation

CEHNC-OE Support

An objective of this project was to document the performance of *MTADS* in field activities demonstrating its readiness to conduct UXO site characterizations at DoD ranges and its transition potential as an automated survey support tool appropriate for commercial use by Army Corps of Engineers contractors at ordnance remediation sites. CEHNC-OE-CX agreed to support our activity through their Centers of Excellence Office and to provide a three person EOD field crew (from Army Corps staff) for a period of four weeks to conduct target recoveries and evaluations during the remediation process following our way pointing of targets. The EOD field crew also had the responsibility for providing explosives and blowing-in-place all dangerous recovered ordnance items.

Commercial EOD Support

To augment the remediation efforts of the CEHNC-OE crew we acquired, by subcontract, the support of a commercial EOD services firm. Their responsibilities included providing a dig crew to prosecute flagged targets. Additionally, they had responsibility for way pointing the targets scheduled for remediation by both their and the CEHNC crews. Way pointing is carried out using the Trimble TDC programed by the target analysts and dig images and dig sheets to precisely locate the specified targets in the field and planting a flag with the unique target number at the site. Following the disclosure of each target by the EOD team, the contractor was responsible for reacquiring the target using the Trimble TDC GPS equipment. The way pointing and reacquiring of targets was assisted by Native Americans with HAZWOPR certification.

2.4.6 *MTADS* Surveys

BBR I

The Survey Plan selected the northern side of BBR 1 as the starting point for the survey. This area, within the National Park, is grassland currently grazed by both horses and cattle. Except for a couple of low lying areas, the surface is firm and well drained, allowing surveying during light rain or after even heavy rains. The south side of the bull's eye was under cultivation in winter wheat and millet. The wheat was within 1 week of harvest when we began operations. It was our intention to allow harvest to be completed before entering this area. This was not feasible as intermittent rains prevented the harvest which was still not complete 5 weeks later when we left the site.

We intended to continue surveying towards the north until targets became sparse or until we were required to begin EM surveying in preparation for the Dig Teams who were scheduled to begin one week after the surveying. Data preprocessing and target analysis began immediately and continued in parallel with the field survey. Field data was usually downloaded every hour and were typically visualized within 2 hours. When the survey had extended 300 meters north of the bull's eye, targets became more sparse. However, there were still significant large targets at the eastern, western, and northern edges of the survey. Figure 23 shows a magnetic anomaly map for the 300 X 500 m survey conducted north of the bull's eye. After surveying15 hectares, the magnetometer array was traded for the EMarray. Analysis of the magnetometry data from the north side of BBR I resulted in identification of 485 targets. About 30% of these targets, based upon calculated size and depth, were likely candidates to be buried bombs.

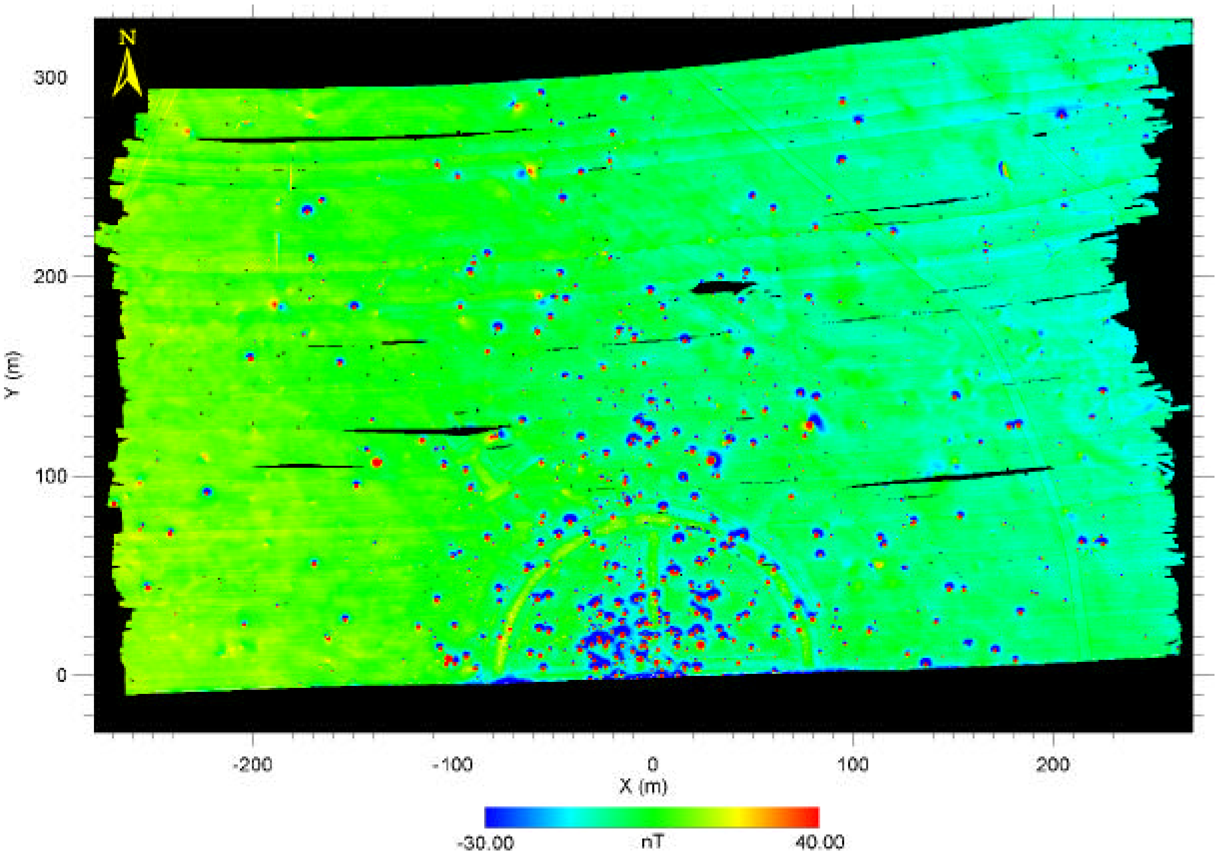

Figure 23. Magnetic anomaly image of the north side of target BBR I

The survey plan called for selecting a survey area containing 50 or more targets, in a mix of target sizes, and digging all targets in the set. The results of this remediation was inteneded provide information about the types of ordnance (and non-ordnance) present at the site. Prosecuting the smaller targets would determine whether small ordnance (such as 20 mm projectiles) were present. The magnetometry survey on BBR I north of Y = 150 meters in local coordinates had 82 analyzed targets. This area was selected for the training data set.

EM surveying began at the northern edge of the area surveyed with the magnetometers. Surveying proceeded southward to Y = 150 m covering the area to be used for the "training data set." Surveying with the EM array was suspended at the Y = 150 m level and all EM targets were analyzed. The EM analysis was carried out working jointly with the magnetometry target analysis screens using the techniques developed analyzing the Twentynine Palms and the JPGIII data. This joint analysis added 7 more targets to the dig list that did not appear on the magnetometry target list. This resulted in a combined list of 89 targets. Forty-five to fifty-five of these targets were considered as likely bomb candidates.

In the Twentynine Palms and JPG data analyses we used the EM target analyses to exclude certain magnetometer target picks based upon improbable EM signatures. This worked very well, particularly at JPG, in declaring numerous magnetometer signals as false alarms because the EM signatures were too small to be ordnance. In the BBR training data set we did not exclude any analyzed magnetic targets because digging them up could potentially provide valuable information to form the basis of future discrimination algorithms. Therefore, all 89 targets were dug. This resulted in the recovery of 40 M 38 practice bombs, 4 rocket bodies (2.25 inch SCAR) or rocket warheads (2.75 inch), 33 pieces of ordnance scrap (mostly tail fins) and 12 dry holes (false alarms). The targets classified as dry holes did not have detectible EM signatures.

BBR II

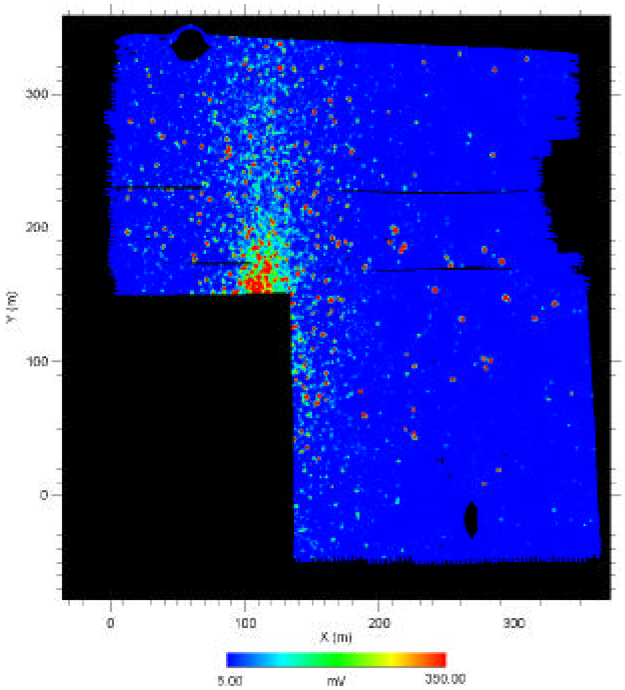

Figure 25. EM anomaly image for Target 2 at the Badlands Bombing Range

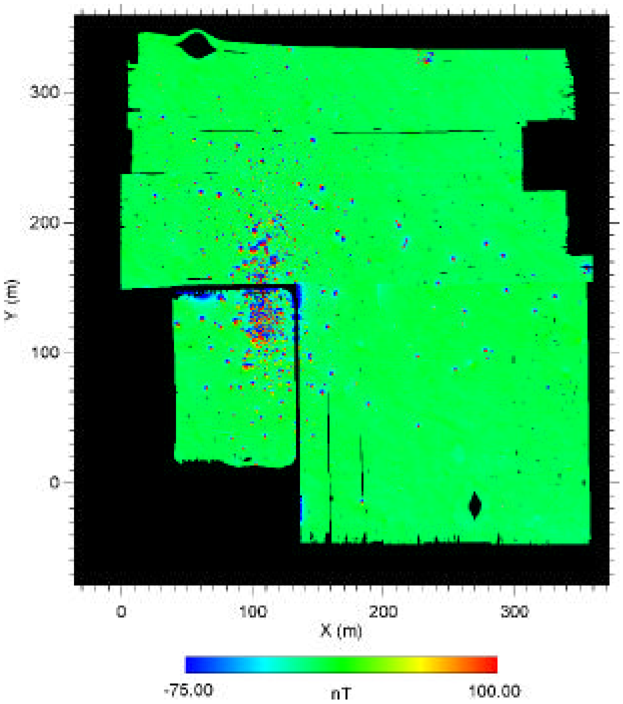

Figure 24. Magnetic anomaly image for Target 2 at the Badlands Bombing Range

Surveying on this site began at the time that target way pointing and remediation got underway on BBR I. We began magnetometry surveying BBR 2 in the grassland. This area, although east of BBR I by more than a mile, is in the same pasture as the north side of BBR I. Because there were no visual clues to locate a target center for this site we began driving long east-west lines starting about 100 meters east of the fence corner shown in Figure 20. The eastern limit of these lines was limited by a low lying wet area that became a pond further to the the north. After about 20 survey lanes were driven, data was preprocessed and visualized. Clustered targets were apparent with a highest density about 30 meters to the west of the fence corner. The western limit of the survey lanes was extended slightly and magnetometer surveying was continued toward the north until a block 350 m X 200 m was completed. A small area on the northeast corner and a larger area on the eastern edge were missed because of standing water. After completing this area, north-south survey lines, again in the pasture land, were driven to form a survey block extending almost 400 meters north to south and 350 meters east to west. At a later time, during a period of dry weather, the magnetometer array was moved onto the tribal land to survey a small block (about 80 X 130 m, or about 1 hectare) in the millet field to complete survey of the area that we suspected would contain the target center. The magnetic anomaly image of this complete survey is shown in Figure 24. The ill-defined center of the target cluster lies about 35 m south and east of the fence corner.

The EM array was used to survey the area within the Parkland that had been surveyed using the magnetometers. The EM anomaly image resulting from this survey is shown in Figure 25. To avoid further damage to the millet, the EM array was not taken into the cultivated area. The target density near the center of the cluster is so high that effective single target analysis cannot be carried out. The variety of target signatures within the millet field are very similar to those in the Parkland.

2.4.7 *MTADS* Performance Results

A complete target analysis was carried out using the magnetometry data for both the north and south side surveys on BBR I. In the BBR I magnetometer survey 704 anomalies were analyzed and declared as targets. EM surveys were carried out only on the north side of the bull's eye and were concentrated on the area north of Y = 150 m (in local coordinates) because this was the area used for the training set data. A total of 171 EM targets were picked; 51 of these did not have counterparts in the magnetometry analysis. On all of BBR I we remediated a total of 146 targets. Figure 26 shows that the analyzed target sizes from BBR 1 fall into a bimodal distribution. The smaller targets tend toward an analyzed size of 40 ± 20 mm while the larger size grouping analyzes as 160 ± 40 mm. Figure 27 similarly shows a bimodal distribution in analyzed target depths. The smaller targets lie between 0 and about 25 cm while the larger targets tend to be buried between 35 cm and 1.2 m. The smaller shallower targets were almost entirely ordnance scrap, primarily tail fins from M 38's. The deeper, larger targets were dominated by ordnance, primarily M 38s, but also included several SCARs, 2.75-in warheads, and four 250-lb bombs.

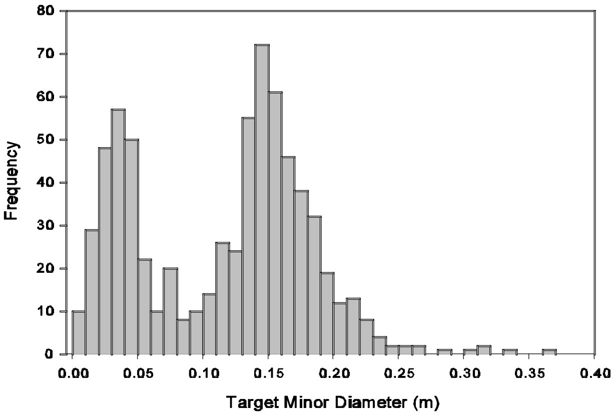

Figure 26. Analyzed distribution for targets on BBR I

For logistic reasons much of the digging took place on BBR 2. This was necessary because, for safety reasons, we had to maintain a minimum separation between each of the dig teams, and a minimum separation of the dig teams from the survey team. We attempted to remediate in areas that had both EM and magnetometry data analyzed. We also chose not to survey with the EM array on any of the crop lands to minimize destruction to the crops. While the dig teams were prosecuting the BBR I training data set targets, the magnetometer and EM surveys and data analysis got well ahead on BBR 2. Therefore, the dig teams concentrated much of their efforts on the second site. This was also influenced by the fact that there was a greater variety of targets on the second site.

A total of 255 targets were dug on BBR 2. Although there is currently no discernable bull's eye at this site, the center of the area that must have been the original target is heavily saturated with both large targets (mostly M 38 practice bombs) and rocket bodies and copious OEW scrap. The whole 350 X 380 meter surveyed area has a general scattering of M 38 practice bombs. More probably lie outside the survey area. Although this area was used as a bombing target, it was more heavily used as an aerial gunnery target for 2.25 inch SCAR and 2.75 inch rockets. The full range of analyzed target sizes were sampled in our remediation, however, we concentrated on smaller targets with the intention of sampling smaller ordnance. M 38s were the only bombs found at this range, 17 were recovered. Twenty-eight SCAR rocket bodies were recovered. Some were intact, but most were bent, crumpled, or showed evidence of low order detonations presumably from residual propellant which was burning at impact. The 2.75 inch rockets have aluminum bodies, venturies and tail fins, so only the iron warheads were recovered intact. Eleven intact 2.75 inch rocket warheads were recovered. The remainder of the dug targets were mostly ordnance scrap.

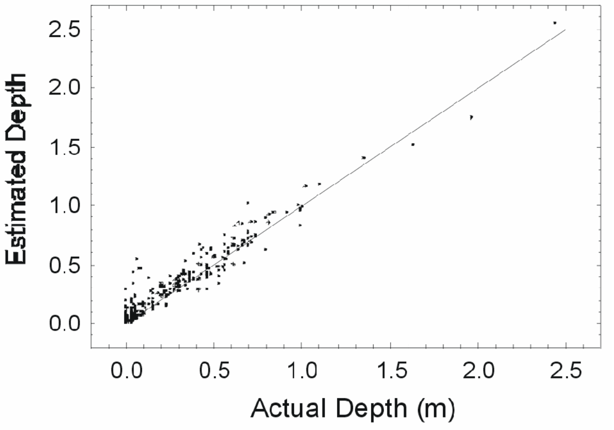

Figure 29. Comparison of the predicted and measured depths of the remediated targets

This demonstration provided an excellent demonstration of the position and depth locating abilities of the *MTADS*. The target way pointing and target reacquisition accuracies, based upon the current GPS protocols, each have an uncertainty of about 5 cm. Figure 28 shows a histogram of the *MTADS* target locating ability for all targets dug on both of the sites. The average target location error was 12 cm, 90% of all targets were located within 22 cm, and 95% of all targets were located within 29 cm. The few outlying points likely do not represent location errors, but identification of the wrong targets by the remediation team or location of small surface targets that were moved by the *MTADS* during survey or by the remediation team while prosecuting nearby targets. The ability of *MTADS* to precisely locate the positions of targets has been conclusively demonstrated. This is true for small targets on the surface of for deeper targets including many deformed M 38s and the 250 lb bombs at more than two meters. In most cases the location error of the target is smaller than the dimensions of the target.

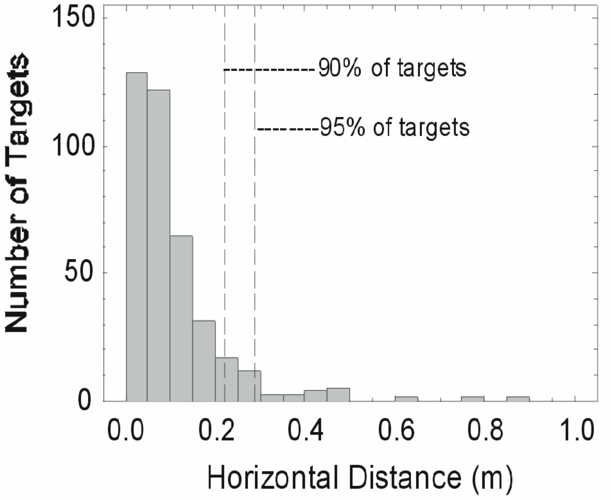

Figure 28. Histogram plot of the horizontal miss distance between the predicted and dug target positions

Figure 29 shows a plot of predicted vs reported target depth for all remediated targets. There is a very high correlation between the predicted and measured depths. For most targets significantly below the surface the error in the depth prediction is a small fraction of the observed depth. In general, the magnetometer-based depth predictions are of high precision and provide excellent information for the Remediation Team to plan and execute target recoveries.

2.4.8 Badlands Demonstration Costs

Table 15 summarizes the costs associated with the complete operation. Several items contributed to the expense of the operation that would not be typical of other similar efforts. The 3 hour daily round trip commute cut down on the time on site for work and added significantly to (overtime) costs for the remediation crews who required payment for commuting time.

The time required of the way pointing crew to reacquire target positions after they were uncovered and the lost time of the remediation crews waiting for this process added significantly to the individual target remediation costs. Remediation costs in a more routine operation would likely be 35-50% lower.

This page was intentionally left blank.

3.0 COMPARISON OF *MTADS* AND "MAG AND FLAG" SURVEY COSTS

To date, the *MTADS* has been a development system, and therefore, an objective analysis and comparison of operational and deployment costs relative to other survey methods (i.e. "Mag and Flag" operations) is not straight forward. We undertook an economic evaluation of the replacement costs for the *MTADS* hardware and software (as presently configured) to form the basis for a future life cycle cost analysis.

The replacement cost analysis is based upon producing an exact copy of the *MTADS* field equipment and DAS hardware and support equipment. We assumed the same vendors and suppliers as originally used and acquisition costs for the same spares and ancillary support equipment that currently support *MTADS*. Based upon these assumptions, the one-of-a-kind replacement cost is about $740,000.

There are several unrealistic assumptions in this estimate. The original computer hardware is no longer available and has been superseded by new models. Current analysis shows that our original reliance on high-end workstations can now be replaced by desktop personal computers (PCs) with no loss of operating capability, thus reducing both hardware and software licensing costs. The field hardware manufacturing costs are based upon quotes from the original research and development (R&D) firms that developed the equipment, rather than hardware fabricators who could presumable work from our detailed engineering drawings. It is likely that a savings of $150K to $200K could be realized on the major components by competitive use of commercial manufacturers and fabricators.

Based upon our experience in supporting and using the *MTADS* at the demonstrations described in this document, we propose to amortize $400K of the *MTADS* costs based upon a schedule of 4000 hours of surveys. This is a conservative estimate based on breakage, maintenance, and replacement costs for the past two years.

In our past experience with *MTADS* at field operations we have always had one senior scientist/supervisor on site supporting the operation. In addition, we have provided extensive logistics support such as tents for maintenance work, offices with bench spaces for repairs and onsite office spaces for computers and DAS support equipment. It is our experience that these support elements have a positive impact on our survey efficiency and on the quality of the data collected and the on-site analysis product. For this reason, we have built in the same support and logistics costs for the comparative study. A commercial firm in a cost competitive environment might forgo some of these logistics support costs.

The comparative study assumes various sized operations ranging from 15 acres up to a 3000 acre survey. Since comparisons are being made with a hypothetical commercial mag and flag operation, we also assume that only the *MTADS* magnetometer array will be used and that the survey sites are not terrain limited. We assume that the hypothetical sites contain an average of 20 targets per acre and factor this into an assumed production rate of 1.5 acres per day for a mag and flag operator and an *MTADS* survey and analysis capability of 10 acres per day (20 is more typical). Since only one *MTADS* exists, we assume a survey rate of 10 acres per day and provide travel costs to cycle *MTADS* personnel on a 30 day rotation. The *MTADS* surveys have a senior UXO technician on site in the field at all times and assume HAZWOPR-certified field support staff. Except for the smallest surveys we also assume that two dedicated people support the data analysis and site supervisory functions.

Table 15. Summary of Costs for the Badlands Bombing Range Demonstration

SURVEY TASK	COST CATEGORY	COST ($K) SUBTOTAL	TOTAL TASK COST ($K)
Site Assessment			3,000
Base Station Survey			4,500
Site Survey			
	Contractor, Labor, Travel, ODCs	89,608	
	NRL, Labor, Travel, ODCs	38,000	
	OST, Tribal Labor	10,098	
	MTADS Transportation	5,874	
	Survey Cost		143,580
Remediation/Disposal			
	CEHNC-OE	107,000	
	UXO Contractor	62,096	
	Disposal Total		169,096
Logistics			
	Maps, generator, trailers, toilets, radios, tent, fuel, labor, and misc.	25,000	
	Property Damage	2,000	
	Logistics Total		27,000
GIS Development		6120	
Survey Report	NRL		24,000
GRAND TOTAL			**377,296**

For the Mag and Flag operations, we assume that the number of personnel are put on site that can complete the survey in a two week period of performance. This minimizes the travel and logistics costs. The labor mix of UXO technicians to UXO supervisors and the site supervisor support and logistics support are typical of those that we have had quoted to support operations and also factor in information about labor rates and labor mixes typically quoted for operations similar to these.

Tables 16 and 17 are summaries of the assumptions made in making the cost comparisons for surveys ranging from 15 acres to 3000 acres, located at a distance of 2000 miles from the *MTADS* base of operations in Chesapeake Beach, MD. In the case of mag and flag operations, the personnel doing the survey are assumed to have similar travel requirements. No logistics costs are assumed for the mag and flag surveys except for the largest surveys which have associated logistics support personnel. Similar hotel and per diem costs are assumed for each arm of the study.

Table 16. Survey Cost Assumptions for Hypothetical *MTADS* Magnetometer Surveys

LABOR	BURDENED LABOR RATE ($/HR)	15 ACRES 2 DAYS	50 ACRES 7 DAYS	150 ACRES 15 DAYS	500 ACRES 50 DAYS	1000 ACRES 100 DAYS	3000 ACRES 300 DAYS
SUPERVISOR	$95	1 ($1,520)	1 ($3,800)	1 ($11,400)	1 ($38,000)	1 ($ 76,000)	1 ($228,000)
DATA ANALYST	$57	0 ($0)	0 ($0)	0 ($0)	0 ($0)	1 ($ 38,000)	1 ($136,800)
UXO SUPERVISOR	$57	0 ($0)	0 ($0)	1 ($6,840)	1 ($22,800)	1 ($45,600)	1 ($136,800)
HAZWOPR TRAINED STAFF	$22.80	0 ($0)	0 ($0)	2 ($5,472)	2 ($18,240)	2 ($36,480)	2 ($109,440)
LOGISTICS/ FIELD SUPPORT	$28.50	3 ($1,368)	3 ($3,420)	4 ($13,680)	4 ($45,600)	4 ($91,200)	4 ($273,600)
TOTAL LABOR COST :		**$2,888**	**$7,220**	**$37,392**	**$124,640**	**$287,280**	**$501,600**
TRAVEL @ $1000/PERSON		$4,000	$4,000	$8,000	$16,000	$27,000	$90,000
HOTEL @ $60/DAY		$480	$1,200	$7,200	$24,000	$54,000	$162,000
PER DIEM @ $75 /DAY		$600	$1,500	$9,000	$30,000	$67,500	$202,500
LOGISTICS SUPPORT		$10,000	$20,000	$20,000	$30,000	$35,000	$60,000
AMORTIZATION CHARGE @ $100/ACRE		$1,500	$5,000	$15,000	$50,000	$100,000	$300,000
TOTAL SURVEY COST:		**$19,468**	**$38,920**	**$96,592**	**$274,640**	**$570,780**	**$1,316,100**

Table 17. Survey Cost Assumptions for Hypothetical "Mag and Flag" Surveys

LABOR	BURDENED LABOR RATE ($/HR)	15 ACRES 5 DAYS	50 ACRES 7 DAYS	150 ACRES 10 DAYS	500 ACRES 17 DAYS	1000 ACRES 17 DAYS	3000 ACRES 17 DAYS
SITE SUPERVISOR	$64	1 ($2,650)	1 ($3,584)	1 ($5,120)	1 ($8,704)	1 ($8,704)	1 ($8,704)
DATA ANALYST	$57	0 ($0)	0 ($0)	0 ($0)	0 ($0)	0 ($0)	0 ($0)
UXO SUPERVISOR	$57	0 ($0)	0 ($0)	2 ($6,144)	4 ($20,890)	8 ($41,779)	25 ($130,560)
UXO SPECIALISTS	$28.80	1 ($1,152)	4 ($6,451)	8 ($18,432)	16 ($62,669)	32 ($125,338)	100 ($391,680)
LOGISTICS/ FIELD SUPPORT	$28.50	0 ($0)	0 ($0)	0 ($0)	0 ($0)	1 ($3,264)	2 ($6,528)
TOTAL LABOR COST :		**$3,712**	**$10,035**	**$29,696**	**$92,262**	**$179,085**	**$537,472**
TRAVEL @ $1000/PERSON		$2,000	$5,000	$11,000	$21,000	$41,000	$128,000
HOTEL @ $60/DAY		$600	$2,100	$6,600	$21,420	$41,820	$130,560
PER DIEM @ $75 /DAY		$750	$2,625	$8,250	$26,775	$52,275	$163,200
LOGISTICS SUPPORT		$500	$1,500	$2,000	$3,000	$6,000	$20,000
AMORTIZATION CHARGE @ $100/ACRE		$0	$0	$0	$0	$0	$0
TOTAL SURVEY COST:		**$7,562**	**$21,260**	**$57,546**	**$164,457**	**$320,180**	**$979,232**

Figure 30 shows a graphical comparison of the relative costs for the hypothetical surveys. We assumed no remediation of targets. The *MTADS* survey has been carried through target analysis providing target maps and target tables with depth and size information for all targets and target positions in global, state plane or local coordinates. The mag and flag surveyor is presumed to flag each target when it is detected. No permanent record is provided. Laying out a grid and surveying each target or measuring the coordinates of the flagged targets suitable for GIS integration would add an additional 30-50% to the cost of the mag and flag survey.

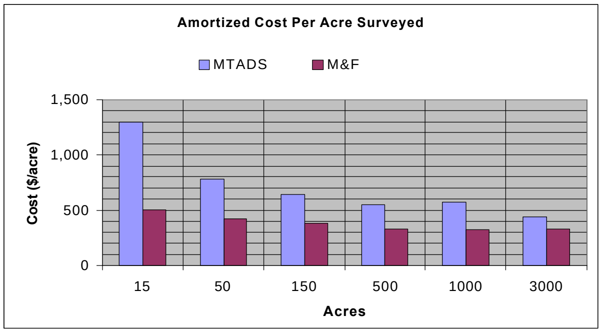

Figure 30. Cost comparison between *MTADS* and "Mag and Flag" surveys

These calculations do not address the ultimate goal of a particular survey, i.e., is the survey being conducted to assist in remediation activities, or simply to provide an indication of whether the site is contaminated and the extent of the ordnance contamination? Previous studies of the detection efficiencies of mag and flag operations have shown that (at least for sites where ordnance exists below 1 meter in depth), the majority of ordnance remains undetected.

Assuming that the survey is in support of a remediation activity, the cost per detected target is a useful comparison. Using documented[1] mag and flag detection efficiencies of 35%, Figure 31 provides this comparison. Regardless of the size of the survey, *MTADS* is more cost effective in flagging targets for remediation. It should also be noted that following the remediation based upon the mag and flag survey, 65% of the ordnance targets remain in the ground.

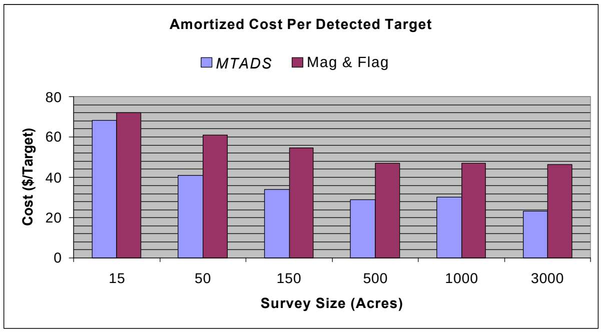

Figure 31. Comparison between *MTADS* and "Mag and Flag" surveys based upon target detection costs

These comparisons between *MTADS* and Mag and Flag surveys are based upon complex sets of assumptions. No real operation will compare identically with these assumed conditions. Moreover, the survey products are very different between the two approaches. The *MTADS* surveys provide a permanent record in global coordinates for all targets. The mag and flag survey provides a product that is only useful for immediate follow on remediation. These comparisons are most direct comparable if the surveys are being conducted only to define contaminated vs uncontaminated areas.

Figures 30 and 31 are perhaps misleading, as these comparisons do not take into account the ability of the *MTADS* to assist in the discrimination of targets from ordnance related scrap. Historical comparisons of Mag and Flag operations with those conducted with the *MTADS* have focused merely upon costs associated with surveys of a specified area, i.e. a "cost per acre" expense. In this respect, the costs associated with prosecuting detected targets has not been incorporated into discussions of potential cost savings. The development of the *MTADS* was predicated on establishing a rudimentary capability to discriminate between ordnance and ordnance-related scrap in field surveys. Completely ignoring the substantial technical shortcomings associated with Mag and Flag surveys (e.g. low detection efficiencies and no archival records), it is the ability of the *MTADS* to aid in target discrimination that represents the most substantial avenue for cost savings in a combined survey/remediation operation.

It is logical to assume that any target identified using a Mag and Flag survey must be investigated, due to the inability of such surveys to discriminate between ordnance and ordnance-related scrap. Training data sets taken with the *MTADS* (using models of all ordnance items presumed to be present at the location) allow for the elimination of a substantial number of detected anomalies, by virtue of clearly falling outside the parameters expected for intact ordnance. Data obtained by NRL during a *MTADS* survey at the Pueblo of Laguna in New Mexico clearly establish the ability of the *MTADS* to aid in the process of excluding selected anomalies, based upon the analytical capabilities of the Data Analysis System.

Table 18 shows the results of remediation of 1528 targets on Bombing Range N-9 at the Pueblo of Laguna which was a WWII high-speed bombing target. Following a surface walkover and clean, a *MTADS* magnetometer survey was conducted over 36 hectares on this target, as well as two Mag and Flag surveys on selected portions of the target. Using the *MTADS* data, specific areas for Mag and Flag surveys were selected, in which the target density and separation were conducive to reasonable analysis by commercial Mag and Flag methodologies. As the Mag and Flag survey provided no discrimination of targets, all flagged targets were dug. A total of over 1500 targets were remediated on Bombing Target N-9 on both Mag and Flag areas, and *MTADS*-surveyed areas.

Table 18. Results of Remediation of 1528 Targets at Bombing Range N-9 at the Pueblo of Laguna

Targets Remediated	Ordnance M 38	OEW	Non-Ordnance Scrap	No Target Recovered	Totals
***MTADS* Analyzed**	426	4	0	1	431
Mag & Flag Area 1	507	160	3	35	705
Mag & Flag Area 2	293	83	1	15	392

Using training data sets from previous *MTADS* operations, and data obtained on-site at the Pueblo of Laguna, the *MTADS* correctly identified over 98% of the total number of targets (classified as M 38) to be ordnance, with approximately 1% of targets classified as M 38 subsequently identified as OEW or dry holes. Correspondingly, of the 1,097 targets identified in the Mag & Flag survey, 297 were later identified as OEW, Non-Ordnance Scrap, or a dry hole. Therefore, on the basis of these results, over 25% of the total targets identified were non-ordnance. These figures support the conclusion that in instances where all Mag & Flag identified anomalies must be prosecuted, that employing the *MTADS* to declare the same number of targets as ordnance would result in a substantially higher percentage of any remediaton budget to be productively utilized in the identification and removal of actual ordnance, by perhaps as much as a factor of 25. Table 19 shows a theoretical scenario in which two surveys are conducted, one using the *MTADS*, and the other by commercial Mag & Flag is employed. In each case, a total of 1000 M 38 sized targets are identified and declared ordnance by each technique. Again, since Mag & Flag has no objective discrimination capabilities, it is assumed that <u>all</u> 1000 targets identified must be declared ordnance, thereby requiring that all 1000 detected targets be remediated. *MTADS* data would declare each item to be a M 38, and would require remediation.

Table 19. Theoretical Cost Comparison for *MTADS* vs. Mag & Flag Remediation Operations

For 1000 M 38 Sized Targets Detected and Classified as Ordnance @ $400/target ($400,000 Total Remediation Budget)			
	Targets Declared Ordnance	**Improperly Declared Targets**	**Non-Productive Costs Incurred**
***MTADS* Analyzed**	990	10	$ 4,000 **(1% of budget)**
Mag & Flag	750	250	$100,000 **(25% of budget)**

Inasmuch as Mag & Flag surveys are only capable of declaring anomaly/non-anomaly, a comparison of false alarm rates is not tenable. Moreover, the above discussion does not imply that the possible cost savings would be identical for all types of ordnance. However, the baseline data obtained to date indicate that the utilization of the *MTADS* to conduct surveys is substantially less expensive in terms of cost per target detected for surveys larger than 50 acres. In addition, for each item declared as ordnance and thereby requiring remediation, only 1% of the total remediation budget would be non-productive using *MTADS* data, versus 25% of Mag and Flag data. Accordingly, the *MTADS* clearly has achieved the objectives associated with establishing an ordnance detection capability that is substantially more accurate, efficient and cost effective in comparison to historical methodologies.

4.0 REFERENCES

1. "Handheld Gradiometer Survey Test at The Marine Corps Air Ground Combat Center, Twentynine Palms, CA," NAVEODTECHCEN TR, September 1992. This report describes hand-held magnetometry surveys of the MCAGCC Magnetic Test Range conducted by military EOD teams. The ordnance detection efficiency of the EOD teams at this site varied between 25% and 35%.

2. Chenowth Racing Products, Inc., El Cajon, CA.

3. "ESTCP *MTADS* Program Management Plan," J.R. McDonald and Richard Robertson, *MTADS*/6110-9511/Revision 10, 4 September 1996.

4. "Magnetic Sensor Field Tests and Evaluations for Towed-Array Systems, Ft. Devens, MA," J.R. McDonald and Richard Robertson, NRL/PU/6110--96-303, 2 April 1996.

5. "Multi-sensor Towed Array Detection System (*MTADS*). An Automated High-Efficiency Survey System for Characterization of Ordnance and Explosive Waste (OEW) Sites," J.R. McDonald and Richard Robertson, Proceedings of the UXO FORUM 1996, Williamsburg, VA, 26-28 March 1996, p. 53.

6. "Microwave and Differential GPS Navigation Systems; Field Performance Tests," J.R. McDonald, H. H. Nelson, and Richard Robertson, NRL/PU/6110--93-244, July 1993.

7. "Operator's Manual for the *MTADS* Tow Vehicle," Chenowth Racing Products, Inc., El Cajon, CA.

8. "Shop Maintenance, Service, and Repair Manual for the *MTADS* Tow Vehicle," Chenowth Racing Products, Inc., El Cajon, CA.

9. "Repair Parts Manual for the *MTADS* Tow Vehicle," Chenowth Racing Products, Inc., El Cajon, CA.

10. "The Combined Use of Magnetic and Electromagnetic Sensors for Detection and Characterization of UXO," Bruce Barrow, Nagi Khadr, Robert DiMarco, and Herbert H. Nelson, Proceedings of the Symposium on the Application of Geophysics to Engineering and Environmental Problems, The Environmental and Engineering Geophysical Society, Keystone, CO, 28 April - 2 May 1996, p. 469.

11. "Multi-sensor Towed Array Detection System (MTADS). An Automated High-Efficiency Survey System for Characterization of Ordnance and Explosive Waste (OEW) Sites," J.R. McDonald and Richard Robertson, Proceedings of the UXO FORUM 1996, Williamsburg, VA, 26-28 March 1996, p. 53.

12. “Processing and Analysis of UXO Signatures Measured with *MTADS*,” B. Barrow, R. DiMarco, N. Khadr, and H.H. Nelson, Proceedings of the UXO Forum 1997, Nashville, TN, 28-30 May 1997, p. 8.

13. http:/www.denix.osd.mil/

14. ESTCP Program 199811, “Man-Portable *MTADS* Detection System.”

15. SERDP Program CU1092, “Model-Based Data Fusion and Discrimination of UXO in Magnetometer and EM Surveys.”

16. ESTCP Program 199812, “Electromagnetic Induction and Magnetic Sensor Fusion for Enhanced UXO Target Classification.”

17. “*MTADS* TECHEVAL Demonstration, October 1996,” H.H. Nelson, J.R. McDonald and Richard Robertson, NRL/PU/6110–97-348

18. “Results of the *MTADS* Technology Demonstration #2 at the Magnetic Test Range at The Marine Corps Air Ground Combat Center (MCAGCC), Twentynine Palms, CA, December 1996,” J.R. McDonald, H.H. Nelson, Russell A. Jeffries and Richard Robertson, NRL/PU/6110-97-349

19. “Results of the *MTADS* Technology Demonstration #3, Jefferson Proving Ground, Madison, IN, January 1997,” J.R. McDonald, H.H. Nelson, Russell Jefferies and Richard Robertson, NRL/PU/6110–99-375

20. *“MTADS* Unexploded Ordnance Operations at the Badlands Bombing Range, Pine Ridge Reservation, Cuny Table, SD, July 1997,” J.R. McDonald, H.H. Nelson, J. Neece, R. Robertson and R.A. Jeffries, NRL/PU/6110–98-353

21. “*MTADS* Mapping and Ordnance Investigation at the Former Ft. Pierce Amphibious Base, Vero Beach, FL, March 1998,” J.R. McDonald, H.H. Nelson, R. Robertson, R.A. Jeffries and Karl Blankinship, NRL/PU/6110–98-372

22. “*MTADS* Live Site Survey, Bombing Target #2 at The Former Buckley Field, Arapahoe County, CO,” J.R. McDonald, H.H. Nelson and Richard Robertson, NRL/PU/6110–99-379

23. “*MTADS* Geophysical Survey at The Jamaica Island and Topeka Pier Landfills at Theh Portsmouth Naval Shipyard, Kittery, ME, October 1998,” J.R. McDonald, H.H. Nelson and Bernard Puc, NRL/PU/6110–99-381

24. “MTADS Live Site Survey, Bombing Targets N-9 and N-10 on the Laguna Pueblo, Albuquerque, NM, July 1998,” J.R. McDonald, H.H. Nelson and R.A. Jeffries, in preparation

25. "*MTADS* UXO Survey and Remediation on the Walker River Paiute Reservation, Schurz, NV, November 1998," J.R. McDonald, H.H. Nelson, and Richard Robertson, in preparation

26. "*MTADS* Demonstration at JPG IV, Jefferson Proving Ground, Madison, IN, October, 1998," H.H. Nelson, J.R. McDonald, H. Khadr and Richard Robertson.

27. "Unexploded Ordnance Advanced Technology Demonstration Program at Jefferson Proving Ground (Phase I)," U.S. Army Environmental Center, Report No SFIM-AEC-ET-CR-94120, December 1994.

28. "Evaluation of Individual Demonstrator Performance at the Unexploded Ordnance Advanced Technology Demonstration Program at Jefferson Proving Ground (Phase I)," U.S. Army Environmental Center, Report No. SFIM-AEC-ET-CR-95033, March 1995.

29. "Unexploded Ordnance Advanced Technology Demonstration Program at Jefferson Proving Ground (Phase II)," U.S. Army Environmental Center, Report No. SFIM-AEC-ET-CR-96170.

30. "UXO Technology Demonstration Program at Jefferson Proving Ground, Phase III," U.S. Army Environmental Center and the Na val Explosive Ordnance Disposal Technology Division, Report No. SFIM-AEC-ET-CR-97011, April 1997.

31. "Demonstration Work Plan for the Phase III UXO Detection, Identification, and Remediation Advanced Technology Demonstration, Jefferson Proving Ground, Madison, IN 22 August 1966."

32. "Evaluation of the Multi-sensor Towed Array Detection System (MTADS) Performance at Jefferson Proving Ground, January 14-24, 1997," Samuel L. Park and Marc Mander, IDA Draft Document D-2174, 9 October 1998.

This page was intentionally left blank.

APPENDIX A

Points of Contact

Project Investigators

Dr. Herbert Nelson
NRL
4555 Overlook Avenue, SW
Code 6110
Washington, DC 20375
Telephone: (202) 767-3686
Fax: (202) 404-8119
Email: herb.nelson@nrl.navy.mil

Dr. Jim McDonald
NRL
4555 Overlook Avenue, SW
Code 6110
Washington, DC 20375
Telephone: (202) 767-3340
Fax: (202) 404-8119
Email: j.mcdonald@nrl.navy.mil

ESTCP Program Office

901 North Stuart Street
Suite 303
Arlington, Virginia 22203

(703) 696-2117 (Phone)
(703) 696-2114 (Fax)

e-mail: estcp@estcp.org
www.estcp.org