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MTADS UNEXPLODED ORDNANCE OPERATIONS AT THE BADLANDS BOMBING RANGE AIR FORCE RETAINED AREA

PINE RIDGE RESERVATION, SD
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Naval Research Laboratory, Washington, DC

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13. ABSTRACT *(Maximum 200 words)*

Approximately 2,500 acres of the Badlands Bombing Range on the Oglala Sioux Reservation has not been returned to Tribal control. This area, referred to as the Impact Area (IA) or the Air Force Retained Area, was used as a ground artillery training range for about 15 years during the 1960s. There have been several UXO clearances, including a comprehensive Mag and Flag clearance of the entire IA in 1997 conducted by active duty EOD detachments. The 1997 Mag and Flag clearance discovered and removed one 105-mm and three 155-mm projectiles. During the fall of 1999 the *MTADS* was deployed to the IA. 130 acres near the center of the IA were surveyed using the magnetometer array and the EM array was used to resurvey approximately 25 acres near the center of the magnetometer survey. Survey data were separately analyzed using different techniques to evaluate discrimination algorithms. All targets considered to be potential projectiles were dug, including 362 targets from the magnetometry survey and 109 targets from the EM survey. Fifteen HE-filled and fuzed dud projectiles were recovered and destroyed in-place, including ten 155-mm and five 8-in projectiles. The performance of the *MTADS* system using differing data analysis approaches is evaluated and contrasted with the Mag and Flag clearance.

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1.0 INTRODUCTION

Through funding provided by the Environmental Security Technology Certification Program (ESTCP), the U.S. Naval Research Laboratory has developed and fielded the Multi-sensor Towed Array Detection System (*MTADS*). The performance of the *MTADS* system has been evaluated and documented in several demonstrations.[1-3] Following demonstrations at prepared ranges, *MTADS* has conducted demonstrations and geophysical site characterizations at several live sites. These activities include surveys on Native American lands,[4-6] an ordnance survey at the former Ft. Pierce Naval Amphibious Base[7] and at the former Buckley Air Base.[8]

In July of 1997, NRL surveyed over 150 acres, identifying and analyzing over 1400 targets at the Badlands Bombing Range on the Pine Ridge Reservation in South Dakota.[4] Over 400 of these targets were selectively dug; 71 bombs, 50 rocket bodies and warheads were remediated and 220 items of ordnance related scrap were recovered.

The focus of this demonstration was a section of the BBR (~2500 acres) that has not been turned back to Tribal control. This area, which has recently been referred to as the Air Force Retained Area, was previously called the Impact Area (IA). The IA was used between 1965 and 1973 by the South Dakota National Guard for ground-to-ground ordnance and artillery practice. Firing points for the ground artillery and observation bunker locations have been identified. Working from aerial photographs, likely impact craters have been identified near the center of the site. There have been five separate organized ordnance clearance activities on the BBR[9-12] which include the area in IA, two of these were specifically focused on IA. Car bodies, which served as targets have been removed from the site along with reports of removal of a few thousand pounds of OE scrap, frag and metallic clutter.

As the Air Force prepares to return the IA to Tribal control, several activities have taken place. In 1997, US Air Force EOD technicians conducted a walk over investigation using mine detectors. They performed a surface and subsurface (to 1.5 feet) clearance of ordnance and OE scrap (larger than 3 inches).[13-15] A Preliminary Assessment/Site Inspection, PA/SI, of the IA was submitted.[16] This resulted in a final report, issued in 1999.[17] These activities were conducted to evaluate the area as a potential CERCLA site and was also designed to meet the requirements of the federal Range Rule, and the guidelines of the USACE TERC number DACW45-94-D-001. The results of the study have been used to rank the site according to the Hazardous Ranking System and to evaluate whether the site requires addressing under CERCLA. As the *MTADS* represents the current state-of-the-art in detection technology for UXO site characterization, and because it recently was successfully used to find and characterize bombing targets on the Tribal lands on Cuny Table,[4] NRL has been invited to return to the BBR to conduct a demonstration and UXO site evaluation on the IA. There were several organizations that were supporting or sponsoring our activities as described in this document. The Command at Ellsworth AFB invited us to evaluate the technology on the IA; the test plan and our activities on site were monitored by Mr. Del Petersen of the Civil Engineering Services Division at Ellsworth. The Army Corps of Engineers, Omaha Regional Office had responsibility for recent environmental assessment activities on the IA in association with the PA/SI. Mr Len Havel, of the Army Corps of Engineers/Omaha (CENWO-PM-H) provided support for the *MTADS* demonstration. The ESTCP, who sponsored the development of the *MTADS*, is also

sponsoring the evaluation of the technology on several Native Lands sites with ordnance concerns. Both ESTCP and SERDP are sponsoring follow-on programs at NRL to improve the *MTADS* technology to allow discrimination between intact ordnance and OE scrap.[18,19] ESTCP, through the Native Lands Program, sponsored this demonstration on the IA.

2.0 TECHNOLOGY DESCRIPTION

The Environmental Security Technology Certification Program (ESTCP) provided funds to NRL for the development and demonstration of a multi-sensor vehicular towed array system. The *MTADS* incorporates both cesium (Cs) vapor, full-field magnetometers and active, time-domain EM sensors. The sensors are mounted as linear arrays on low-signature platforms that are towed over survey sites by an all-terrain vehicle. The position-over-ground is plotted using state-of-the-art Real-Time Kinematic (RTK, or on-the-fly) technology that also provides vehicle guidance during the survey. Using mature sensor technologies, NRL has focused on the development and integration of a Data Analysis System (DAS) to locate, identify and categorize all military ordnance at its maximum probable self-burial depths. On typical sites, the DAS provides one day turn-around target analyses to allow concurrent remediation operations.

The *MTADS* technology has been described in detail previously.[1-4] Briefly, the 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, is a custom-built off-road vehicle, specifically modified to have an extremely low magnetic self-signature. Details of the vehicle construction and performance are described in the Vehicle Owners/Shop Manuals.

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. The time-dependence of the Earth's background field is measured by a ninth sensor deployed as a reference at a static site during survey operations. The magnetometers were specially selected for sensitivity, sensor noise, heading error, dead zones, and inter-sensor compatibility.

The EM sensors are deployed as an overlapping horizontal array of three pulsed induction sensors (a variant of the Geonics EM-61 instrument). Metallic objects absorb the transmitted energy, inducing eddy currents that re-radiate electromagnetic energy. This signal is time sampled by six detection coils that are collocated with and above the three transmission coils.

The sensor positions on the surface of the Earth (latitude, longitude, and height above ellipsoid) are determined using 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. 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

setup tool and provides real-time guidance displays and information for the operator.

Perimeter surveys or point landmarks are used to define the survey bounds. The DAQ develops a survey track grid that is presented to the vehicle operator *via* a touch screen display located beside the steering wheel. The survey course-over-ground (COG) is plotted in real time on the display, as are presentations of the course heading error and distance-off-track information. This allows the operator to respond to both visual cues on the ground and to the survey guidance display in the vehicle. Following a survey, the operator can return to survey any missed areas before leaving the field.

Survey data in the DAQ computer is downloaded onto a ZIP disk for transfer to the DAS computer. The DAS software was developed specifically for this program as a stand-alone suite of programs written using IDL development tools, and graphical user interfaces (GUI's) working in a UNIX-based workstation environment. The DAS is written in multiple levels for both sophisticated and novice users. An extensive range of expert options are available to facilitate the cleanup of navigation data, sensor nulling and leveling, noise filtering, and other electronic data preprocessing options.

The Geonics EM-61 sensors have been extensively modified. These modifications include changing the time position and time width of the sampling window monitoring the return signal. The power of the transmitted pulse has been increased, as has the pulse repetition rate. The amplifier gain of the detectors has been increased and the time constant applied to the signal has been significantly reduced. The overall detection sensitivity has been increased by a factor of 4 -8, depending upon the composition, size, and

Figure 1. The *MTADS* Tow Vehicle surveying with the magnetometer array.

Figure 2. The *MTADS* survey system deployed with the pulsed induction array.

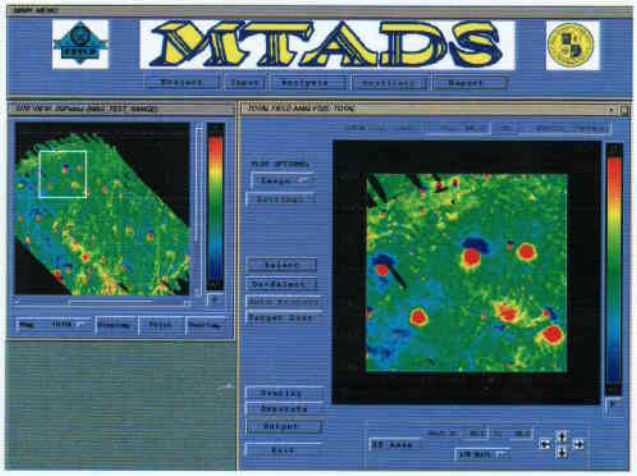

Figure 3. The *MTADS* data analysis system showing the site view and target analysis windows.

depth of the target. The combination of the EM and magnetometer arrays is now capable of detecting all US military ordnance to their maximum self burial depths.

The best ordnance detection performances at both JPG I and JPG II were based upon the use of Cs vapor full-field magnetometers or Geonics EM-61 sensors. These same commercial magnetometers and EM sensors have also turned in marginal results in the hands of other demonstrators at JPG. How these sensors are deployed in data collection, (and probably more importantly, how the data are processed and analyzed to recognize and characterize targets), is critical to achieving optimal results.

Over a period of 10 years, NRL has overseen the development of two previous generations of DAS software. The current *MTADS* DAS software is truly third generation. We have built upon the successes of the earlier programs, addressing shortcomings recognized in earlier DAS versions. Using the DAS we have demonstrated at JPG III and at the Badlands Bombing Range that significant discrimination can be made to sort between ordnance and clutter, particularly under favorable circumstances.

3.0 THE AIR FORCE RETAINED AREA

3.1. Site History

In 1942 the Department of War annexed 341,725 acres of the Pine Ridge Reservation for use as an aerial gunnery and bombing range. This site is located in the Southwest corner of South Dakota, with the largest part of the Bombing Range located in Shannon County. From 1942 until 1948 various sections of this range were used for bombing exercises and various air to ground operations. 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. In 1978, all remaining BBR lands were declared excess with the exception of 2,486 acres, (subsequently referred to as the Air Force Retained Area). Prior to 1978 this parcel was referred to as the Impact Area. In about 1965 the South Dakota National Guard placed up to 100 car bodies on the 2486 acre area and began using them for artillery targets during training exercises. The National Guard training exercises took place on the IA between 1966 and 1973. The Impact Area is shown in Figure 4 outlined in red. The north fence line is 3 miles south of Highway 40 at the Bouquet Table exit which is a section-line dirt road. A second fence line (outlined in green) defines the perimeter of the area referred to as the Buffer Zone. There are no surface features, nor available historical documentation, that provides a logical explanation for the shape of the area or the location of the boundaries.

3.1.1 Previous UXO Clearances. There have been 6 documented UXO clearance operations on the BBR[9-15] taking place between 1948 and 1997. These are discussed in more detail in Ref. 16. Only two have significant relevance to the present demonstration on the IA.

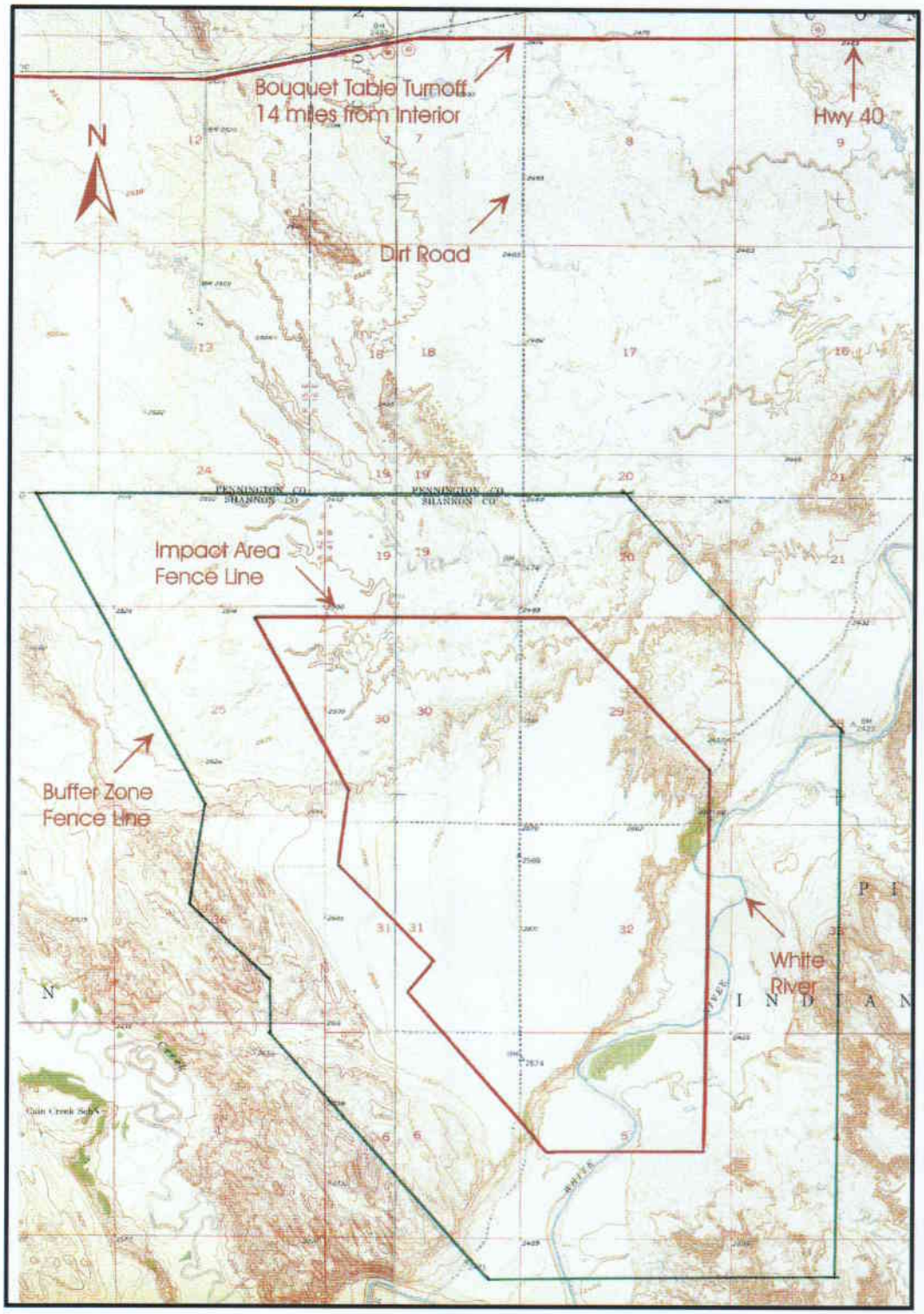

Figure 4. Portions of USGS 7.5 minute maps annotated to show the location of the Impact Area on Bouquet Table.

3.1.2 The 1975 Clearance. During the summer and fall of 1975 EOD personnel participated in a searchline walking clearance of 22,403 acres and a vehicular search of 19,222 acres. This clearance[11, 12] included a walking searchline survey of the entire IA and the buffer zone. With the exception of the IA, all lands were declared as cleared and certified for return to the Tribe. Reportedly, the IA apparently contained too much OE material to declare the area "cleared." The 1975 Certificate of Clearance describes the plowing of 1088 acres of the IA using ripper plows presumably to unearth buried ordnance. Aerial photographs clearly show that the plowing took place after 24 July 1976.[16] The Clearance Report documents recovery of the items listed below without specifying where they were recovered or which of them were associated with the IA.

- 5 - 155mm Howitzer projectiles
- 3 - 155 mm illumination projectiles
- 1 - 8 in Howitzer projectile
- 1 - 10 lb Spotting Charge
- 2 - 155 mm Illumination Candles
- 4 - Smoke Grenades
- 15 - 50 Cal Cartridges
- 46 - 100 lb Practice Bombs

3.1.3 The 1997 Clearance. Between June and October 1997 EOD personnel operating from Ellsworth AFB conducted a 1-foot clearance on 2,469 acres of the IA in accord with a Clearance Plan[13] approved by the Department of Defense Explosive Safety Board in March 1997.[14] In preparation for the clearance, the area was surveyed into 1,500 X 1,500 foot grids. Then a searchline ordnance clearance was conducted by using Vallon metal detectors; flagged targets were dug immediately behind the EOD surveyors. With the exception of 17.5 acres of very rugged terrain along the White River, the entire area was cleared. The Range Decontamination Report[15a] documents removal of 8,000 lbs of munitions fragments, 14,000 lbs of automobile parts and other target residue, and 2,000 lbs of wire fencing. The Clearance Plan called for removal of shrapnel pieces larger than 3 inches. Recovered live ordnance items that were blown in place are enumerated below.

- 3 - 20 mm aircraft gun ammunition
- 1 - 50 Caliber Projectile
- 1 - 105 mm High Explosive Howitzer Round
- 3 - 155 mm High Explosive Projectiles

The Certificate of Clearance issued by the EOD Flight of the 28th CES in June 1999, was submitted by HQ AFSC/SEWOP in November 1999 to and accepted by DDESB.[15b] The Document certified the land for unrestricted future use that did not require digging more than 12 inches deep.

3.2 Site/Facility Characteristics

3.2.1 Climate and Weather. The Badlands Bombing Range (BBR) has a High Plains climate, which is semiarid and characterized by large daily and seasonal ranges of temperature. The

average annual precipitation is 16 inches. The months of May and June statistically have the highest rainfall. The prevailing winds in the summer are from the SE at 10 mph. The mean winter low temperature is between 10° and 20° F. Snowfall is typically the highest in March averaging 8 inches. On average 3 days each year the August temperature reaches 100 F. Typically there is sunshine during three-fourth of the daylight hours during July and August.

3.2.2 Topography. Shannon and Jackson Counties are located in the Great Plains physiographic province at the northern extremity of the High Plains. The Great Plains province is a broad highland area that slopes gradually eastward. The area surrounding the Badlands is located in the Missouri Plateau subprovince, which is a region of low relativity, undulating farm land and grass land. Approximately half of the BBR has Badlands topography, with the remainder consisting of sparse grasslands. The Badlands regions are nearly devoid of vegetation. In this terrain, erosion has cut the land into an intricate maze of narrow ravines and sharp crests. Intermittent streams dissect the area.

The 2500 acres of the IA is located on Bouquet Table. The majority of the IA is relatively flat to gently rolling grassland, Fig 4, intermittently grazed by cattle. The meandering White River, which crosses the southeast side of the IA, is accompanied by flat isolated terraces at elevations from 80 to 200 feet above the stream level. Erosion associated with the river and its flood plain has created a rugged topography within the IA that precluded clearance of about 17 acres in the 1997 EOD clearance. The rugged area lies south and east of the portions of the IA most likely associated with impacts from the identified howitzer firing range fans.

4.0 DEMONSTRATION APPROACH

4.1 Performance Objectives

This demonstration at the Badlands Bombing Range involved the survey of selected portions of the IA. Areas chosen for survey were intended to maximize the probability of finding ordnance associated with National Guard live fire exercises. Our specific demonstration objectives as specified in the approved Demonstration Work Plan[20] are enumerated below.

- Conduct an *MTADS* magnetometry survey of at least 100 acres within the IA;
- Conduct an *MTADS* EM survey of at least 20 acres selected from areas surveyed with the magnetometer array;
- Process all data on site, selecting an initial dig list of targets to guide targets to be prosecuted on the remainder of the surveyed area;
- Following collection of EM survey data, continue magnetometry surveys , within the survey schedule, to maximize the total survey area coverage;
- Prepared Dig lists to maximize both ordnance recoveries and collection of a useful "ground truth" data set for the EM surveys;
- Employ Native American Labor in support of both survey and target recovery operations;

- Prepare a report of the demonstration results for comment by ESTCP, Ellsworth AFB, USACE, US EPA (Region 8) and the South Dakota Department of the Environment and Natural Resources;
- Transmit survey graphical products to the BBR Program Office for GIS integration; and
- Track expenditures to allow separate cost analysis for our logistics, survey and analysis, target recovery, and scrap disposal operations.

Based upon information in references 11 and 12, on other information summarized in reference 16, on recommendations made by Ellsworth AFB personnel familiar with the site, and on our personal inspection of the site, we felt that the most likely impact areas were just to the southeast of the crossroads at the intersection of Sections 29, 30, 31, and 32. The plan then involved initial long transect surveys using the magnetometer array. Based upon results from the transect surveys, subsequent survey regions were to be set up to maximize the probable detection of intact ordnance. Ultimately, we conducted more than 130 acres of magnetometry surveys.

Initial data analysis concentrated upon selection of a set of targets for the two 3-man dig teams to begin remediating. Each dig team was manned by UXO technicians from EOTI, Inc. working with OST Tribal members who were recent graduates of the Texas A & M UXO school. All target recovery operations took place under the supervision of a senior UXO supervisor from EOTI who also served as the Site UXO safety officer. Dig teams were scheduled to began working one week after survey operations. The teams used hand tools or backhoes, in conjunction with hand-digging operations, to recover targets. OE scrap was collected and stockpiled for later certification and disposal (see Section 5.3.3). Recovered ordnance was blown in place after being photographed. All UXO operations took place according to USACE guidelines specified in DoD Directive Manual 4160.21-M-1, Chapter 2, Paragraph D and within the guidelines of the Health and Safety Plan and the UXO Safety Plan incorporated as appendices to the Test Plan.[17] Following soil sampling, as requested by Ellsworth AFB, all excavations were filled and returned to grade. All OE scrap was certified as explosives-free, loaded into 55 gallon barrels and accepted for disposal by a certified hazardous waste hauler.

An area within the magnetometry survey area was chosen for further surveying using the EM array. The area chosen for the EM survey was based upon the observed presence of significant ferrous target concentrations. The objective of the EM survey was to test new EM data analysis algorithms designed to allow differentiation between ordnance and OE scrap based upon target shape information.[18] Ultimately, an area of about 25 acres was surveyed with the EM array. EM surveys were halted because of a major failure in the EM data acquisition electronics that could not be repaired during the time on site. After this occurrence, the survey teams returned to conducting magnetometry surveys until the end of the survey period.

Beginning target digging one week after beginning surveying, allowed time for data analysis, selection of targets, preparation of dig lists, dig sheets and dig images, and way pointing of an initial set of targets for the two dig teams to begin remediating. Data analysis continued for 2 days after completion of surveying to prepare dig lists and way pointing of targets for the dig team

to complete. The dig teams worked for one week following completion of survey and analysis operations to allow completion of all planned digs, blowing in place of HE-filled ordnance, sampling of dirt from all detonation craters, returning all holes to grade, and sorting, certifying and packing of all OE scrap for disposal.

During the survey and analysis phase all target dig lists (Excel Spreadsheets) were sent by Email to an IDA representative before targets were way pointed or dug.[21] After the EM survey and target analysis, all targets designated for remediation based upon the EM analysis were reanalyzed in the magnetometry data and independent declarations were made for each target based upon the magnetometry data analysis. These separate analyses and dig spreadsheets were forwarded to IDA before way pointing and digging.

4.2 Physical Setup, Presurvey Operations

4.2.1 Demonstration Coordinating and Planning. Primary support for the *MTADS* demonstration on the IA was provided under the Native American Lands Programs of the ESTCP and the Army Corps of Engineers, Omaha Regional Office (CENWO-PM-H). Oversight of activities on the IA was provided by the Environmental Office (Civ 28 CES/CEVR) of Ellsworth AFB.[22] All operations associated with this demonstration were carried out as described in the Demonstration Test Plan.[17] This plan, in Draft form, was submitted for comment to the ESTCP Program Office, CENWO, Ellsworth AFB, EPA (Region 8), the South Dakota Department of Environment and Natural Resources and the Badlands Bombing Range Project Office of the Oglala Sioux Tribe. A meeting was held on 16 August 1999 at the Ellsworth AFB for review of the Demonstration Plan and for coordination of NRL activities on the IA. The Test Plan was considered final on 29 August 1999.

NRL was the program manager for all activities associated with the *MTADS* Demonstration on the IA. The NRL on-site project manager, J.R. McDonald, or his designated assistant, was responsible for coordinating operations at the IA and approving alterations or changes to the demonstration plan or schedule. All persons working on site were NRL employees, contractors working for NRL, or were employees or subcontractors of the prime contractors identified in Appendix A. As defined in the Site Safety Plan, there was always a Safety Officer on site who was the authority for decisions on safety-related issues. The Senior UXO Technician was the safety officer in charge of UXO digging operations. On each day that surveying or digging operations were conducted, tailgate site safety briefings were conducted before field work began. Separate safety briefings were conducted for UXO and the survey crews.

4.2.2 Logistics and Accommodations. It has been NRL's experience that the efficiency of the *MTADS* demonstrations is strongly dependent upon having an established base of operations, from which all activities are coordinated. These facilities serve as a focal point for all field activities, including the location for the *MTADS* Data Analysis System. They provide the base station for communications, a contact point for site visitors, and as the depot for equipment storage and repair. For this demonstration no essential support services were available on-site. Accordingly, NRL made provisions for all requisite supplies, materials, and facilities. The nearest source for rental

equipment is Rapid City, about 75 miles from the IA. Figure 5 shows some of the logistics support equipment that we set up about 200 meters west of the cross roads at the center of the IA. Two backhoes for UXO operations were leased and put on site to support UXO crews.

The interior of the trailer used by the Survey Team is shown in Figure 6. The survey and remediation teams were provided separate office facilities (8 by 40 ft trailers). The survey team trailer, on the right in Figure 5, housed the DAS, communications equipment, and office facilities for coordination briefings. The remediation team trailer, in the center, was used for the storage of field equipment and also housed an electronics repair station and tools and repair supplies. The 8 x 48 foot container, shown on the left, was used 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. Cellular phone communications were available at the office trailer. A 500 gallon diesel fuel tank was located on site for the generator and for backhoes. A 20 x 30 ft frame tent was placed on site to facilitate routine maintenance tasks during daily operations. Portable toilets were maintained for work crews of 15 people for the duration of the operation.

Figure 5. Support trailers set up to support the *MTADS* demonstration on the IA.

4.2.3 Survey Control In preparation for our 1997 *MTADS* demonstrations on Cuny Table, first-order survey points were established on the BBR. One of these points, OST 5, was established near the Impact Area. Using this first-order point, Ellsworth AFB upgraded several other survey points to support their 1997 range clearance. These control points are given in Table 1. While these control points are not strictly first-order in accuracy, they are believed to be accurate to 0.1m.[22] The point labeled North Bench Mark was used in support of all *MTADS* activities on the IA. Radio repeater units were used, as required, in order to conduct all operations from this single control point.

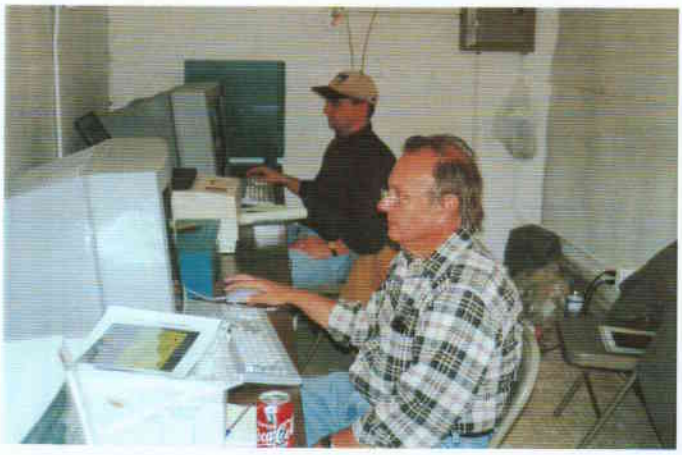

Figure 6. Interior view of Office Trailer located on site.

Table 1. Impact Area Survey Coordinates

Point	Latitude	Longitude	Northing (m)	Easting (m)	Height (m)
			NAD 83		
OST 5	43° 42' 05.2702"	-102° 18' 35.5186"	4842233.05	716761.31	804.460
North BM	43° 40' 19.1197"	-102° 14' 20.5113"	4839145.82	722578.26	762.530
East BM	43° 39' 21.2053"	-102° 13' 42.8268"	4837387.2	723481.89	764.260
USGS BM	43° 38' 53.7820"	-102° 14' 18.7564"	4836514.29	722705.23	765.940

4.3 Demonstration Schedule

The top level *MTADS* Badlands Bombing Range Demonstration Planning Schedule is given in Table 2.

4.3.1 Survey Setup An expanded image of the IA is shown in Figure 7. Locations of the survey control points established by Ellsworth AFB within the IA are shown. The primary impact area from the National Guard artillery training was believed to be in the northwest quarter of Section 32. Therefore, the magnetometry survey transects were set up to sample this region. The initial intent was to conduct a 100 X 1000 meter exploratory survey which is labeled N-S Transect, to be followed by survey of the NW-SE Transect as shown in Figure 7. The N-S transect centerline is 300 meters east of the northeast corner of Section 32 and extends 200 meters north of the east-west Section road. The diagonal transect centerline passes through and extends 200 meters northwest of the cross roads at the northwest corner of Section 32. Coordinates were established to place flags at the corners of the transects and every 100 meters along the centerlines These coordinates are given in Tables 3 and 4. It was our intent to extend the transect surveys based upon the analysis of the data taken in the transects. We completed the N-S transect and half of the diagonal transect using the magnetometer array.

It is standard practice to download data from the DAQ hourly. Data is inspected and preprocessed immediately to verify quality. Individual data files are added to the survey master files in preparation for target analysis. When target digging takes place concurrently with the surveying, two analysts are required on site. Data from the field is preprocessed as described above. Targets are analyzed and, based upon expectations, target selections are made for remediation. At the Impact Area we primarily expected to encounter projectiles, ground-fired 105- and 155-mm and 8-in rounds. Initial selections were made for target analysis with thresholds small enough to assure that 105-mm projectiles were not overlooked.

Based upon the targets selected for remediation, data analysts prepare dig lists, dig sheets, dig images. The dig lists are in the form of Excel spreadsheets which list target positions, depths, sizes, and orientations, and the analyst's comments. The location information in the spreadsheet is also used to program the GPS target reacquisition computer (TDC) for target way pointing. The dig images are provided to the way pointing team to aid in location and orientation when they flag the targets for digging. The images are also provided to the remediation teams, along with the dig

sheets. A dig sheet is provided for each target to be dug. It provides the information present in the dig list spreadsheet and provides a checklist to be filled out by the remediation team when the target is recovered. Space is provided to draw a sketch of the target, at the discretion of the remediator, and to record information as to photographs that are taken on the recovered target.

Table 2. Badlands Bombing Range Demonstration Planning Schedule

Date	Action
8/01/99	Complete Draft of Badlands Bombing Range Test Plan
8/16/99	NRL Site Visit
9/08/99	Logistics Support Equipment Placed on Site
9/10/99	*MTADS* equipment arrives at the IA
9/13/99	*MTADS* Survey and Data Analysis Teams Arrive on Site
9/13/99	New Control Point Verified to Support Surveys
9/13/99	Way Pointing Team Flags Transects
9/13/99	*MTADS* Transect Surveys Begin
9/14/99	*MTADS* Primary Survey Areas Established and Magnetometry Surveying Continues.
9/17/99	Preliminary Dig Lists & Dig Sheets Completed
9/18/99	First Targets are Way Pointed
9/20/99	EOTI Dig Teams Deploy on IA
9/21/99	Magnetometry Survey Completed, EM Surveys Begin
9/24/99	EM Surveys Complete
9/25/99	*MTADS* Packout and Depart
9/29/99	Excavation Completed
9/30/99	Disposal Procedures & Scrap Certification Completed
10/01/99	Rentals Returned, Dig Team Departs
10/04/99	Native American Team Removes All Flags and Cleans Site

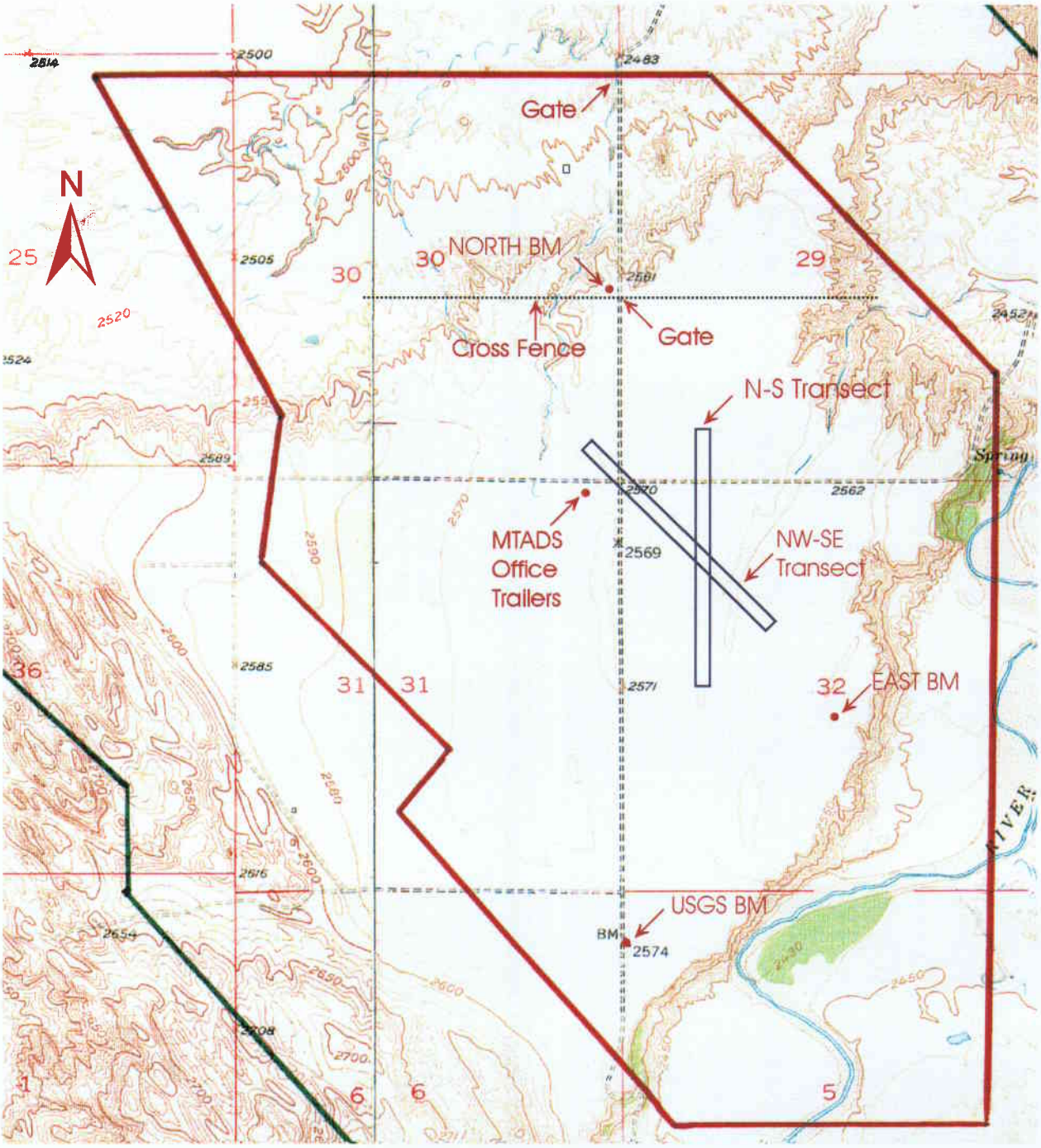

Figure 7. The perimeter of the Impact Area is shown in red overlaid on USGS 7.5 minute maps. Survey control points and transect surveys are indicated.

Table 3. Coordinates for the survey flags for the N-S Transect Survey

Flag Number	Northing (m)	Easting (m)	Latitude	Longitude
10-E	4838528.00	722980.00	43.666300889	-102.234308612
10-W	4838528.00	722880.00	43.666330880	-102.235547521
N10	4838528.00	722930.00	43.666315886	-102.234928066
N9	4838428.00	722930.00	43.665416532	-102.234969379
N8	4838328.00	722930.00	43.664517179	-102.235010691
N7	4838228.00	722930.00	43.663617825	-102.235052000
N6	4838128.00	722930.00	43.662718471	-102.235093308
N5	4838028.00	722930.00	43.661819116	-102.235134613
N4	4837928.00	722930.00	43.660919762	-102.235175917
N3	4837828.00	722930.00	43.660020407	-102.235217218
N2	4837728.00	722930.00	43.659121052	-102.235258518
N1	4837628.00	722930.00	43.658221697	-102.235299816
N0	4837528.00	722930.00	43.657322342	-102.235341112
0-E	4837528.00	722980.00	43.657307350	-102.234721751
0-W	4837528.00	722880.00	43.657337331	-102.235960474

Table 4. Coordinates for the survey flags for the NW-SE Transect Survey

Flag Number	Northing (m)	Easting (m)	Latitude	Longitude
10-NE	4838504.78	722523.93	43.666228729	-102.239968492
10-SW	4838434.07	722453.22	43.665613957	-102.240873678
E10	4838469.42	722488.58	43.665921298	-102.240421028
E9	4838398.71	722559.29	43.665264195	-102.239574161
E8	4838328.00	722630.00	43.664607086	-102.238727313
E7	4838257.29	722700.71	43.663949971	-102.237880484
E6	4838186.58	722771.42	43.663292850	-102.237033673
E5	4838115.87	722842.13	43.662635723	-102.236186881
E4	4838045.16	722912.84	43.661978591	-102.235340107
E3	4837974.45	722983.55	43.661321453	-102.234493351
E2	4837903.74	723054.26	43.660664309	-102.233646614
E1	4837833.03	723124.97	43.660007159	-102.232799895
E0	4837762.31	723195.69	43.659349910	-102.231953075
0-NE	4837797.67	723231.04	43.659657308	-102.231500550
0-SW	4837726.96	723160.33	43.659042603	-102.232405716

5.0. DEMONSTRATION RESULTS

5.1 Walkover and Surface Clean

As described above, there have been several UXO clearances conducted on the IA prior to the *MTADS* survey, including the1997 extensive sweep-line Mag and Flag clearance described in Section 3.3.3. Our observations during our preliminary site visit and inspection of the site revealed evidence of impact craters, but no significant presence of visible OE scrap. Therefore, a decision was made not to conduct another surface clearance prior to the *MTADS* surveys.

5.2 Survey Results

After unpacking, assembly, and checkout of the *MTADS* equipment (Table 3), survey operations began on 13 September with the magnetometry survey of the North-South Transect. At the end of the second day of surveying with the magnetometer array, the North-South and one-half of the Northwest-Southeast Transects had been completed. Visualization of the data revealed that a target bull's eye lay about 100 meters southeast of the crossroads. The magnetometer anomaly image map is shown in Figure 8. The locations of the Section Roads and the *MTADS* support trailers are shown in the image. Walking inspection of the area labeled as the Bull's Eye shows that the land is very disturbed, likely as a result of earlier digging. Small automobile parts and pieces are evident all around the area. The blue shadow to the southwest of the cross roads is the negative dipole of the magnetic anomaly signature created by the steel *MTADS* trailers. The group of clutter signals south and west of the E-9 transect flag is generated by reinforced concrete rubble from the remnants of a home that predated the Impact Area. The basement is still largely intact. Historical records indicated that a primary firing point was near a ranch about 5 miles southwest of the crossroads. We felt it likely that the scattering of targets between the N9 and N10 transect flags was overshoot of the bull's eye from that firing point. A clustering of targets near the intersection of the transects also drew our attention as requiring further investigation.

At this point we stopped the transect surveys and set up large rectangular survey blocks to fill in the areas around the bull's eye along the presumed primary line of fire. The area called the North Site was then surveyed. This area lies between the transects northeast of the bull's eye. The North Site survey block, shown in Figure 9, clearly fills in the overshoot pattern stretching northeast from the bull's eye. Two further areas, the West and East sites were then blocked out to complete the magnetometry survey.

The *MTADS* Survey log, presented in Table 5, documents the magnetometry and EM survey operations that took place during the Demonstration. On Friday 17 September survey operations switched from the magnetometer array to begin taking EM data. At that point preliminary analysis of magnetometry data from the North Site had been completed and an area of medium target density in the overshoot area was chosen for the EM survey work. An initial area of 200 X 300 meters (6 Ha = 14.8 acres) was chosen for survey. It was surveyed in an east-west pattern on 17 September. On 18 September survey of the area in a north-south pattern was begun. A catastrophic failure in the EM DAQ electronics occurred late on 18 September and was not

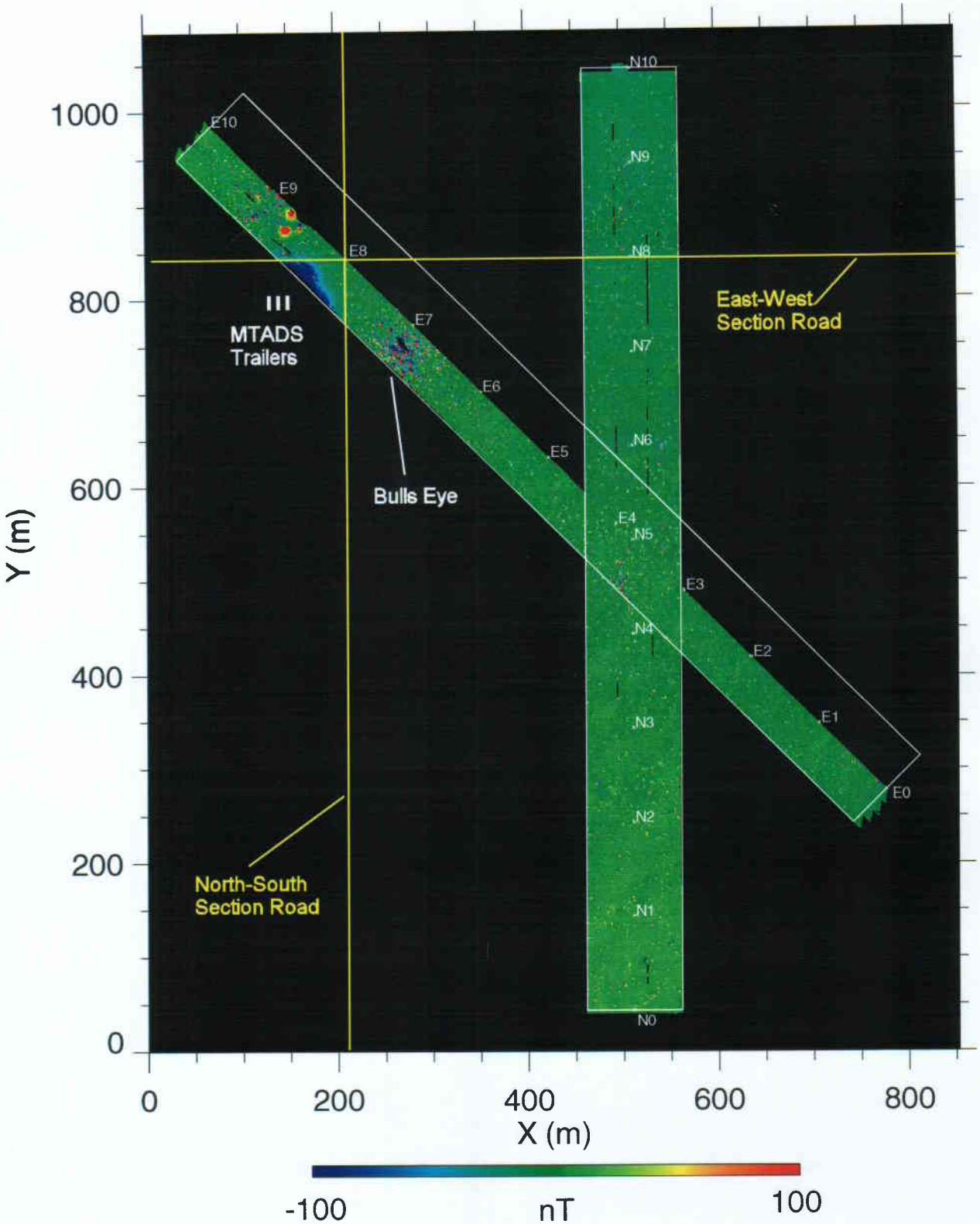

Figure 8. Magnetic Anomaly image of the North-South and the Northwest-Southeast Transects.

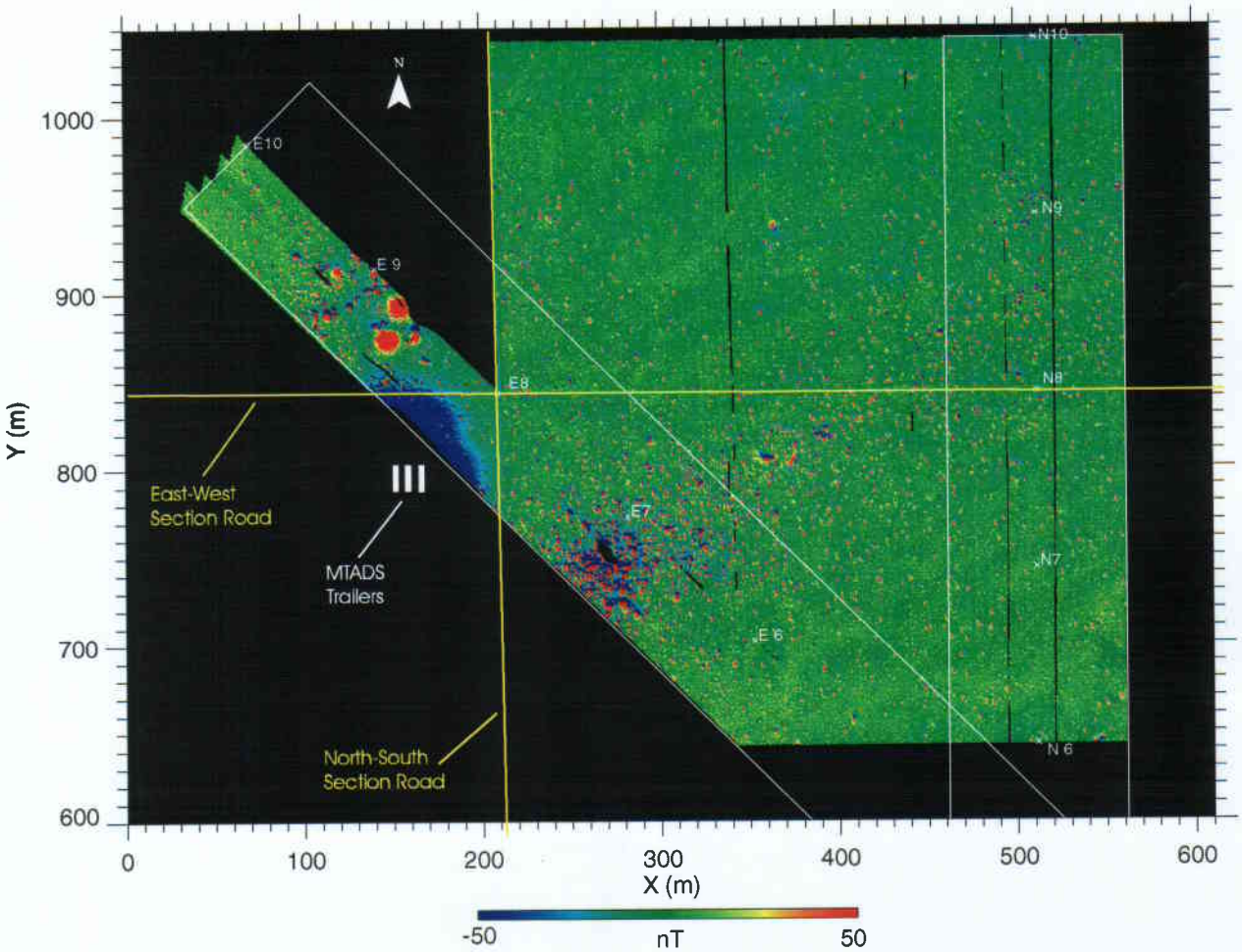

Figure 9. Magnetic anomaly image map of the North Site showing the bull's eye and the overshoot pattern.

recoverable in the field. On 20 September survey with the magnetometry array was resumed to complete the west survey block. All survey operations were suspended at the end of the day on 22 September to allow for orderly analysis of the data and preparations for completion of target digging operations. A total of 32.7 hours of magnetometry data were taken over a period of 7 working days. This corresponds to a production rate of 4.0 acres per hour while surveying. A total of 130 acres were surveyed with the magnetometer array. EM survey operations were limited to two days by equipment failure in the field which could not be recovered. A total of 10.15 hours of EM data were taken, 23.5 acres were surveyed with the EM array. This corresponds to a production rate of 2.3 acres per hour. The EM data are discussed in Section 5.6 of this report.

5.3 Target Analysis

An overview of the magnetometry survey is shown in Figure 10. For analysis purposes the survey was broken into 4 data sets. The area bounded in yellow, called Impact Area South (IA-S), was analyzed and dug first, as described below. The area bounded in blue is Impact Area West (IA-W). The final block that was surveyed is called Impact Area East (IA-E). It is bounded in red in Figure 10. The remaining area, bounded in white, is Impact Area North (IA-N).

Table 5. *MTADS* Data Log

Date	Survey/Area	File	Survey Start (GMT) / Duration (min)
Monday, 13 September	Magnetometer/N-S Transect	99256721DAQ	17:18:16 / 29.1
	Magnetometer/N-S Transect	99256742DAQ	17:49:19 / 56.8
	Magnetometer/N-S Transect	99256786DAQ	18:52:27/ 40.1
	Magnetometer/N-S Transect	99256821DAQ	19:43:24 / 40.1
	Magnetometer/N-S Transect	99256851DAQ	20:26:16 / 55.4
	Magnetometer/N-S Transect	99256890DAQ	21:22:16 / 55.4
Daily Total			276.1 min
Tuesday, 14 September	Magnetometer/N-S Transect	99257594DAQ	14:16:22 / 41.1
	Magnetometer/N-S Transect	99257632DAQ	15:11:14 / 53.2
	Magnetometer/N-S Transect	99257673DAQ	16:09:09 / 55.0
	Magnetometer/N-S Transect	99257721DAQ	17:18:24 / 14.9
	Magnetometer/NW-SE Transect	99257753DAQ	18:04:46 / 56.3
	Magnetometer/NW-SE Transect	99257793DAQ	19:03:14 / 55.1
	Magnetometer/NW-SE Transect	99257834DAQ	20:01:46 / 44.4
	Magnetometer/NW-SE Transect	99257867DAQ	20:49:34 / 51.0
	Magnetometer/NW-SE Transect	99257906DAQ	21:46:00 / 6.3
Daily Total			377.3 minutes
Wednesday, 14 September	Magnetometer, North Site	99258589DAQ	14:08:39 / 28.8
	Magnetometer, North Site	99258611DAQ	14:41:11 / 13.4
	Magnetometer, North Site	99258629DAQ	15:07:01 / 52.7
	Magnetometer, North Site	99258669DAQ	16:03:47 / 59.3
	Magnetometer, North Site	99258710DAQ	17:03:35 / 29.5
	Magnetometer, North Site	99258749DAQ	17:58:53 / 60.3
	Magnetometer, North Site	99258793DAQ	19:02:27 / 57.0
	Magnetometer, North Site	99258837DAQ	20:05:18 / 54.1
	Magnetometer, North Site	99258876DAQ	21:02:16 / 17.6
	Magnetometer, North Site	99258890DAQ	21:22:16 / 16.7
Daily Total			389.4 minutes

Table 5. Continued

Date	Survey/Area	File	Survey Start (GMT) / Duration (min)
Thursday, 16 September	Magnetometer, West Site	99259597DAQ	14:19:50 / 31.7
	Magnetometer, West Site	99259629DAQ	15:06:17 / 57.6
	Magnetometer, West Site	99259671DAQ	16:06:18 / 13.4
	Magnetometer, West Site	99259689DAQ	15:32:31 / 63.8
	Magnetometer, West Site	99259735DAQ	17:39:23 / 60.2
	Magnetometer, West Site	99259804DAQ	19:18:59 / 61.2
	Magnetometer, West Site	99259850DAQ	20:24:47 / 100.6
Daily Total			388.5 minutes
Friday, 17 September	EM, North Site/NS	99260629DAQ	15:06:55 / 89.1
	EM, North Site/NS	99260695DAQ	16:41:10 / 107.8
	EM, North Site/NS	99260783DAQ	18:48:30 / 89.5
	EM, North Site/NS	99260850DAQ	20:24:31 / 52.8
	EM, North Site/NS	99260887DAQ	21:18:26 / 17.0
	EM, North Site/NS	99260910DAQ	21:51:47 / 57.4
Daily Total			413.6 minutes
Saturday, 18 September	EM, North Site/EW	99261587DAQ	14:06:02 / 36.7
	EM, North Site/EW	99261622DAQ	14:55:49 / 96.7
	EM, North Site/EW	99261692DAQ	16:36:44 / 110.3
	EM, North Site/EW	99261786DAQ	18:52:14 / 97.8
	EM, North Site/EW	99261857DAQ	20:35:07 / 71.0
	EM, North Site/EW	99261911DAQ	21:52:14 / 69.5
Daily Total			482 minutes

Table 5. Continued

Date	Survey/Area	File	Survey Start (GMT) / Duration (min)
Monday 20 September	Magnetometry/West Site	99263698DAQ	16:46:26 / 64.5
	Magnetometry/West Site	99263747DAQ	17:55:54 / 61.1
	Magnetometry/West Site	99263805DAQ	19:20:10 / 55.2
	Magnetometry/West Site	99263847DAQ	20:20:10 / 50.7
	Magnetometry/West Site	99263888DAQ	21:20:07 / 41.1
Daily Total			272.6 minutes
Tuesday, 21 September	Magnetometry/East Site	99264590DAQ	14:10:53 / 68.1
	Magnetometry/East Site	99264639DAQ	15:20:19 / 63.0
	Magnetometry/East Site	99264687DAQ	16:29:38 / 53.9
	Magnetometry/East Site	99264740DAQ	17:45:53 / 58.2
	Magnetometry/East Site	99264781DAQ	18:45:07 / 61.0
	Magnetometry/East Site	99264831DAQ	19:56:39 / 58.0
	Magnetometry/East Site	99264872DAQ	20:56:37 / 60.1
Daily Total			354.2 minutes
Wednesday, 22 September	Magnetometry/East Site	99265588DAQ	14:07:54 / 18.4
	Magnetometry/East Site	99265611DAQ	14:40:45 / 61.4
	Magnetometry/East Site	99265656DAQ	15:45:09 / 61.1
	Magnetometry/East Site	99265745DAQ	16:55:05 / 57.0
	Magnetometry/East Site	99265704DAQ	17:53:49 / 67.7
	Magnetometry/East Site	99265799DAQ	19:11:37 / 129.7
	Magnetometry/East Site	99265890DAQ	21:22:39 / 30.1
Daily Total			290.0 minutes

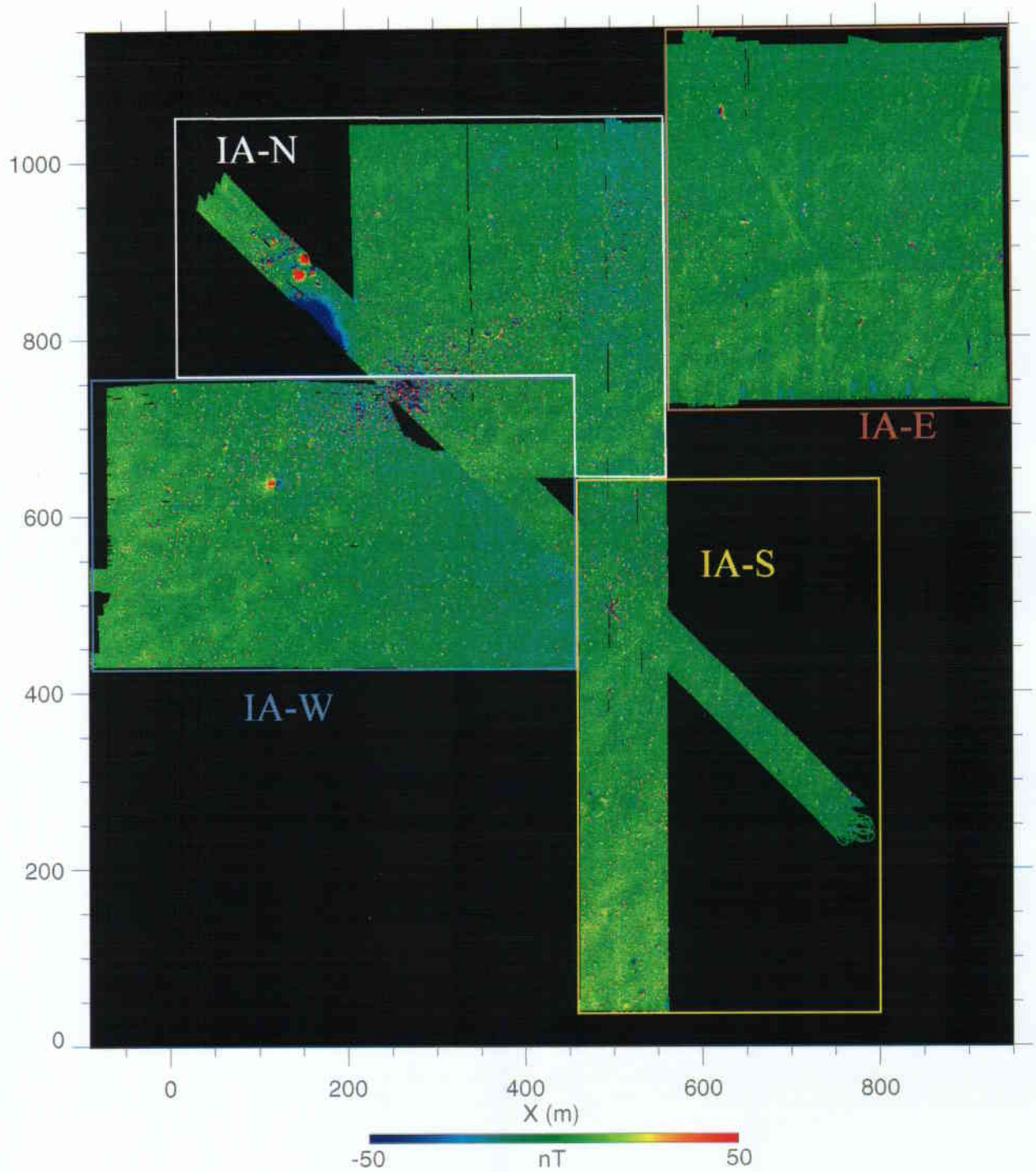

Figure 10. Magnetic anomaly image map of the areas surveyed on the Impact Area. The South Site is bounded in yellow, the West Site in blue, the East Site in red, and the North Site in white.

The dig teams were scheduled to deploy on 20 September, and to begin digging targets following orientation, training of the Tribal members of the team, and safety briefings. This required that target analysis, preparation of dig lists, dig images, and programming of the GPS field equipment be completed to allow way pointing and flagging of targets. Target analysis began with data in the South Site, the area bounded in yellow in Figure 10, from the original transect surveys. The analyst selected 88 targets for fitting. After review, a final dig list was prepared with 67 targets. Targets were selected primarily with predicted sizes of 90-mm and above, although a few smaller targets were also selected for digging.

Dig images and dig sheets were prepared and the targets were loaded into the Trimble TDC for target reacquisition and flagging. The way pointing operation is shown underway in Figure 11. During target reacquisition, Dr. Nelson is shown locating a target using directions from the TDC. Mr. Robertson marks the position with a pin flag inscribed with the target identification number. Depending upon the target densities, typically 30-50 targets can be reacquired and flagged in an hour. The dig team, Figure 12, is also provided with the dig image and a dig sheet for each target. An example of a dig image is shown in Figure 13. The dig sheet contains information identifying the target location and predicting its size, depth and orientation, and noting other features observed by the data analyst, such as the presence of other nearby targets.

Figure 11. Target reacquisition and way pointing is usually done as a 2-man operation.

Figure 12. The dig team uses a combination of hand tools and a backhoe to uncover each flagged target. All OE scrap and other ferrous materials are removed from the hole to a central stockpile point.

5.4 Target Remediation

There was sufficient room to deploy both dig teams on the sections of the transects in IA-S, while allowing them to maintain the required exclusion zones based upon the size of the predicted largest ordnance expected on site. The dig list for IA-S is shown in Table 6. The dig lists from all sections are included in Appendix B. The dig list spreadsheets also include field comments and observations for each recovered target; this information was extracted from the dig sheets which were filled out by the remediation teams.

Table 6. Target Analysis and Dig Team Comments from Impact Area South.

DATA ANALYSIS									DIG NOTES		
ID	Local X (m)	Local Y (m)	Depth (m)	Size (m)	Incl. (deg)	Azim. (deg)	Fit	Analyst Comments	Field Comments	Depth (m)	Photo ID
IAS-1	469.82	54.08	0.73	0.10	83	278	0.886	good dipole	4" X 1" FRAG	0.6	1,2
IAS-3	488.86	51.36	1.02	0.11	84	175	0.788	likely is 2 targs, NE-SW	6 PIECES FRAG, VARIOUS SIZES	1	3.4
IAS-9	509.95	76.93	0.95	0.11	61	60	0.716	tracks poorly registered	FRAG, 2 PIECES. LARGEST 3" X 1"	1	7,8
IAS-11	490.18	129.44	0.54	0.08	49	29	0.857	likely is multiple targets	FLAG MISSING		
IAS-14	530.63	59.71	0.95	0.20	53	0	0.968	Dig This, small clutter 1 m SE	PROJECTILE, 155 MM, M107 W/FUZE, PD, M51, E-W ORIENTATION	1	5,6
IAS-15	535.00	72.88	0.93	0.11	81	8	0.789	likely group of targs	6 PIECES OF FRAG, VARIOUS SIZES & DEPTHS	0.77	
IAS-18	556.01	103.70	0.80	0.12	25	44	0.747	group of clutter	PIECES OF FRAG, VARIOUS SIZES & DEPTHS	0.6	13,14
IAS-19	548.59	113.60	0.51	0.29	2	287	0.692	large inverted target, clutter all about	2 PIECES FRAG, LARGEST 4" X 1"	0.46	
IAS-20	537.10	114.79	0.93	0.11	72	326	0.822	poor fit	FRAG, SEVERAL PIECES	0.46	21,22
IAS-21	522.75	95.92	0.30	0.22	68	274	0.974	Dig This, clutter 1m SE	PROJECTILE, 8", M10S W/FUZE, MT FUZE, N-S ORIENTATION; PROJ. IS FUZED MT, FIRED. NO POSITIVE ID ON THE FUZE, BUT TIME RINGS ARE VISIBLE	0.31	18,19, 20
IAS-23	526.81	161.52	0.65	0.10	49	17	0.734	not clean target	FRAG, SEVERAL PIECES, ALL FOUND IN SAME AREA	0.66	23,24
IAS-24	534.06	183.85	1.22	0.13	83	25	0.714	clutter pile	FRAG FROM 155	1.08	
IAS-25	507.05	187.09	0.73	0.10	80	124	0.891	ragged edges	FRAG, 18 PIECES	0.72	
IAS-26	506.76	211.00	0.44	0.09	50	44	0.881	clutter all around	27 PCS FRAG 12"X2" = 1/2"X1/2"	0.41	
IAS-28	539.57	227.64	0.77	0.12	31	31	0.861	maybe multiple targs	29 PCS FRAG, ALL SIZES	0.61	
IAS-29	497.51	224.43	0.48	0.09	49	46	0.808	clutter all around	35 PCS FRAG, 1/2"X1/2" TO 16" X 4"	0.46	

DATA ANALYSIS									DIG NOTES		
ID	Local X (m)	Local Y (m)	Depth (m)	Size (m)	Incl. (deg)	Azim. (deg)	Fit	Analyst Comments	Field Comments	Depth (m)	Photo ID
IAS-30	471.24	284.28	0.81	0.12	36	332	0.758	large target 2 m NE	37 PCS FRAG, 1/2" WIDE TO 4", 1/2 LONG TO 14" LONG	0.72	
IAS-31	515.40	255.03	1.03	0.12	82	161	0.710	nasty signature	FRAG, 2" X 1/2"	1.23	
IAS-32	528.79	276.14	0.44	0.09	14	331	0.866	good target, but smallish	SIX FRAG ITEMS, 1/2" X 1" TO 4" X 18"	0.46	
IAS-33	535.36	297.44	0.67	0.10	48	37	0.840	poor fit	5 PCS FRAG, 1/2" X 3/4" TO 2" X 14"	0.61	
IAS-34	542.45	347.29	0.85	0.11	63	249	0.870	clutter all around	9 PCS FRAG 1/2" X 1" TO 3" X 7"	0.46 - 0.61	
IAS-35	504.10	350.55	0.63	0.10	82	231	0.910	partial signal	FRAG, 4 PCS 1" X2" - 1" X 4"	0.15 - 0.31	
IAS-37	532.90	382.38	1.00	0.13	85	91	0.847	clutter everywhere	8 PCS FRAG 1/2" X1/2" TO 6"X2"	0.92	
IAS-38	547.11	395.31	0.75	0.11	-2	319	0.896	clutter above	FRAG, 1.5" X 5"	0.72	
IAS-39	513.43	435.61	0.59	0.12	49	45	0.902	clutter on S edge	SEVERAL PIECES OF FRAG	0.31	
IAS-40	463.13	451.06	0.74	0.09	86	186	0.877	smallish for 105	SEVERAL PIECES OF FRAG	0.61	
IAS-41	499.87	461.85	0.88	0.13	53	354	0.938	dig this	FRAG, SEVERAL PIECES	0.72	
IAS-42	522.68	514.75	0.64	0.10	37	37	0.872	possible 105	FRAG, SEVERAL PIECES	0.61	
IAS-43	498.50	514.26	0.45	0.12	41	318	0.900	clutter all around	SEVERAL PIECES OF FRAG, 3" X 1" PIECE OF ROTATING BAND FROM 105 MM PROJECTILE	0.46	
IAS-44	472.78	518.51	0.50	0.10	36	29	0.940	possible 105	SEVERAL PIECES OF FRAG, LARGEST WAS 6" X 1"	0.31	
IAS-45	475.00	513.84	0.79	0.13	30	30	0.796	possible UXO, clutter all around	SEVERAL PIECES OF FRAG, LARGEST IS 12" X 1.5"	0.61	
IAS-46	481.89	520.05	0.66	0.10	47	16	0.829	possible UXO	SEVERAL PIECES OF FRAG, LARGEST WAS 6" X 1"	0.61	
IAS-47	475.53	551.17	0.46	0.09	87	90	0.875	possible multiple targets	21 PIECES FRAG	0.47	
IAS-48	555.76	540.44	0.68	0.11	36	7	0.870	Possible 105	FRAG, SEVERAL PIECES. SOME CHROME PIECES BELIEVED TO BE CAR PARTS	0.61	

DATA ANALYSIS									DIG NOTES		
ID	Local X (m)	Local Y (m)	Depth (m)	Size (m)	Incl. (deg)	Azim. (deg)	Fit	Analyst Comments	Field Comments	Depth (m)	Photo ID
IAS-49	547.44	546.02	0.27	0.11	9	22	0.917	Possible 105, very shallow	SEVERAL PIECES OF FRAG AND CAR PARTS	0.31	
IAS-50	530.62	519.07	0.64	0.09	47	30	0.767	smallish for a 105 mm	SEVERAL PIECES OF FRAG, VARIOUS SIZES	0.61	
IAS-51	506.46	533.92	0.59	0.14	13	27	0.823	between 105 and 155, very shallow	9 PCS FRAG	0.61	
IAS-53	463.34	527.50	0.47	0.10	42	46	0.904	good target	23 PCS FRAG	0.31	
IAS-54	469.92	531.21	0.59	0.09	82	359	0.853	small target	FRAG. SEVERAL PIECES FROM 155 MM	0.61	
IAS-55	465.70	541.60	0.34	0.10	33	1	0.917	small target at 1 foot	18 PCS FRAG FROM 105 MM SHELL	0.31	
IAS-56	461.48	536.59	0.67	0.10	56	336	0.891	small targt at 2 ft	MECHANICAL TIME PROJECTILE FUZE (FIRED) 15 PCS FRAG	0.61	
IAS-57	457.59	537.68	0.39	0.10	73	26	0.910	small target at 15 in.	30 PCS FRAG FROM 105 MM SHELL	0.31	
IAS-58	438.11	564.96	0.48	0.12	43	52	0.918	possible 105 at 1.5 ft	25 PCS FRAG FROM 105 & 155 MM SHELLS	0.46	
IAS-59	465.79	551.84	0.72	0.11	89	296	0.739	possible 105 at 2 ft.	11 PIECES FRAG, 1 M51 FUZE PROJECTILE	0.61	
IAS-62	506.49	558.24	1.12	0.14	79	295	0.685	between 105/155, clutter all around	20 PCS FRAG	1.13	
IAS-63	546.77	558.25	0.77	0.12	74	85	0.892	possible 105, 2nd targ. 1m NNW	FRAG, SEVERAL PIECES	0.61	
IAS-64	551.96	570.42	0.84	0.10	67	200	0.712	possible 105, clutter N&W	FRAG, SEVERAL PIECES	0.77	
IAS-65	554.55	595.58	0.66	0.09	87	200	0.809	small target at 2 ft.	5 PCS FRAG; 1 M51 FUZE PD (FIRED) PROJECTILE	0.61	
IAS-66	529.12	573.46	0.74	0.11	71	72	0.835	possible 105, clutter on W edge	17 PCS FRAG	0.72	
IAS-67	449.07	584.37	0.81	0.11	68	33	0.840	possible 105 at 2 ft.	14 PIECES FRAG	0.61	
IAS-68	450.17	599.78	0.74	0.11	84	312	0.815	possible 105, 2nd target 1m NNE	11 PIECES FRAG	0.77	

DATA ANALYSIS									DIG NOTES		
ID	Local X (m)	Local Y (m)	Depth (m)	Size (m)	Incl. (deg)	Azim. (deg)	Fit	Analyst Comments	Field Comments	Depth (m)	Photo ID
IAS-69	426.19	591.37	0.53	0.10	49	34	0.927	small target at 1.5 ft.	4 PCS FRAG	0.31	
IAS-71	394.11	594.95	0.66	0.10	36	26	0.875	possible 105, clutter to SSE	FRAG, 21 PCS 4" X 11"	0.61	
IAS-73	495.83	613.16	0.77	0.11	68	190	0.738	possible 105 at 2 ft, clutter N&W	15 PCS FRAG	0.77	
IAS-74	507.97	617.64	0.49	0.11	62	58	0.931	possible 105, dig this	19 PCS FRAG	0.46	
IAS-75	514.48	608.53	0.47	0.09	58	48	0.865	small target at 1.5 FT.	17 PCS FRAG	0.46	
IAS-76	548.01	614.22	0.94	0.11	85	82	0.709	possible 105, deep, poor fit	8 PCS FRAG	0.92	
IAS-77	540.10	624.66	0.64	0.16	29	25	0.984	possible 155, shallow, dig this	155 MM BASE EJECTION TYPE, SW-NE ORIENTATION	0.61	
IAS-78	526.00	621.68	0.34	0.12	21	10	0.927	possible 105, clutter on 4 sides	7 PCS FRAG	0.31	
IAS-79	483.92	630.03	0.48	0.09	65	326	0.881	small target	FRAG, 4 PCS 1/2" X 1/2" - 2" X 12"	0.46	
IAS-80	397.33	639.26	1.07	0.13	34	37	0.843	between 105/155 at 1 meter	NO DIG SHEET		
IAS-82	590.22	416.30	0.92	0.12	59	42	0.850	possible 105 at 1m, dig this	NO DIG SHEET		
IAS-83	615.36	400.79	0.68	0.09	80	103	0.910	small target at 2 ft	NO DIG SHEET		
IAS-85	658.76	332.86	0.67	0.12	54	33	0.923	possible 105 in SE transect, dig this	NO DIG SHEET		
IAS-86	762.38	290.28	0.87	0.12	88	234	0.922	possible 105, in SE transect, dig this	NO DIG SHEET		
IAS-87	743.97	305.32	0.79	0.11	74	307	0.892	possible 105 in SE transect, dig this	NO DIG SHEET		
IAS-88	708.67	312.11	0.80	0.12	32	51	0.860	possible 105 in SE transect, dig this	NO DIG SHEET		

The digging and UXO demolition operations were managed by a senior UXO supervisor. Two dig teams worked on site, beginning on 20 September. Each team was supported by a UXO Technician from the OST and either one or two UXO-certified employees from EOTI. Each team had a four-wheel-drive back hoe for preliminary excavation of targets, as required. All targets required significant work with hand tools to expose the fuzing on ordnance items, or to recover all ferrous materials from each flagged position. All OE scrap was removed from each target site and the holes were cleared using a hand-held detector before refilling and tamping with the backhoe.

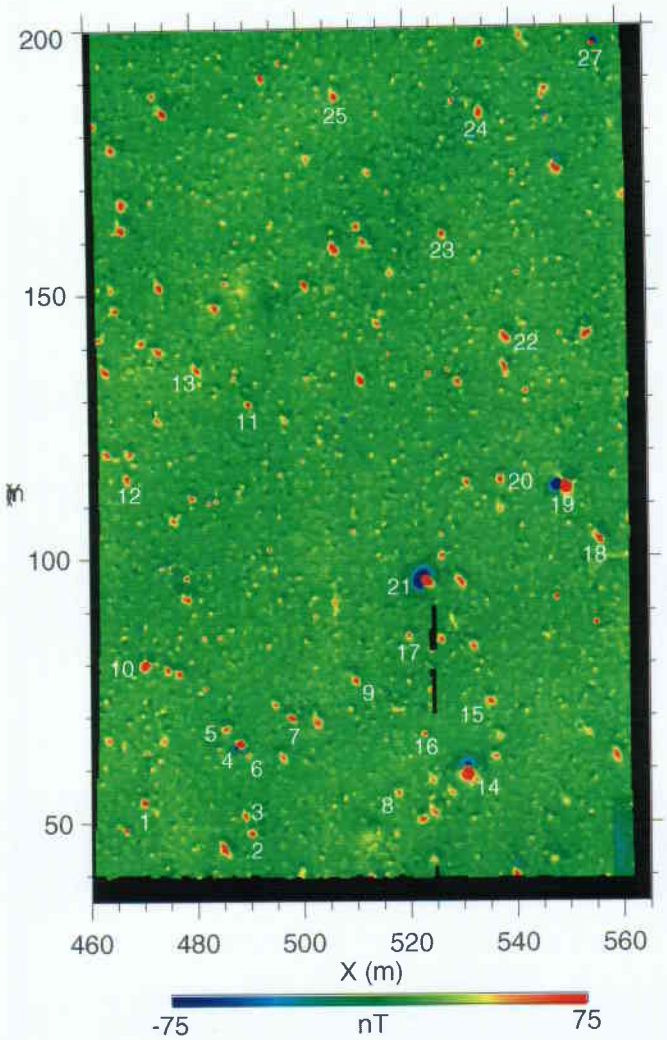

Figure 13. Example of a dig image used by the way pointing team to reacquire and flag targets and by the remediation team in preparation for digging. In this image target 14 is a 155-mm projectile and target 21 is an 8-inch projectile.

During the first two days of digging, 3 projectiles (highlighted in Table 7) were recovered from the part of the North-South Transect in the IA-S dig area. The signatures of two of these targets are shown in the dig image on the right. Although none of the targets in IA-S were 105-mm projectiles, a significant amount of recovered shrapnel and OE scrap was identified as originating from 105-mm projectiles. It was also apparent that the larger projectiles which impacted before they detonated often left a pattern of buried shrapnel that fit the expected anomaly signature and size of a 105-mm projectile in the baseline *MTADS* magnetometry analysis. It was a necessary consequence of this observation, that if we wished to recover all 105-mm projectiles from the survey areas that many targets resulting from shrapnel clusters from larger target detonations would have to be dug.

Targets in IA-W were dug next. Of the 158 targets dug, three 155-mm and one 8-inch projectile were recovered. The dig lists, including the comments from the dig team, are included as a Table in Appendix B. IA-N included the area around the bull's eye and the area surveyed by the EM array. The entire area, with the exception of a small area centered on the bull's eye was analyzed based upon the magnetometry data. The area in the EM survey was analyzed using the ESTCP *MTADS* fusion data analysis approach.[18] Based upon this analysis,109 fusion targets were chosen for remediation. These targets are discussed in Section 5.6. Outside of this area, within IA-

N, 118 targets were chosen for digging. From these digs, two 155-mm projectiles were recovered.

IA-E was dug last after completing the fusion target digs. At this point time was running short for the dig teams. The targets in IA-E were reviewed and edited to select all targets that might be 155-mm or 8-in projectiles and only the smaller targets were chosen that had the highest probability of being 105-mm projectiles. On the 28 acres of IA-E, 19 targets were designated for digging. Of these, 3 were 155-mm projectiles and 3 were 8-in projectiles.

Although a significant amount of OE scrap was recovered that was generated by detonation of 105-mm projectiles, no intact 105-mm projectiles were recovered. We conclude that the dud rate of the 105-mm ordnance must have been very low. A total of five 8-in and ten 155-mm shells were recovered. All were HE-filled duds. All were fuzed either with mechanical-time or powder-train-time fuzes. Because of the sensitivity of these fuzes, all recovered ordnance was blown in place. Figure 14 shows the distribution of the recovered projectiles within the survey area. The arrows denoting the locations of the projectiles are pointing in the direction that recovered ordnance was pointing. The recovered dud projectiles are almost randomly distributed over the survey area. They point in all directions, indicating that they were fired from many different locations. Ordnance was buried relatively shallow, about 2 feet to the projectile centers. It is likely that many would have eventually surfaced due to frost heave. Figure 15 shows an 8-inch projectile as it was uncovered. Note that the base of the shell was covered only by about 2 inches of soil, the average projectile was covered by about 1 foot of soil.

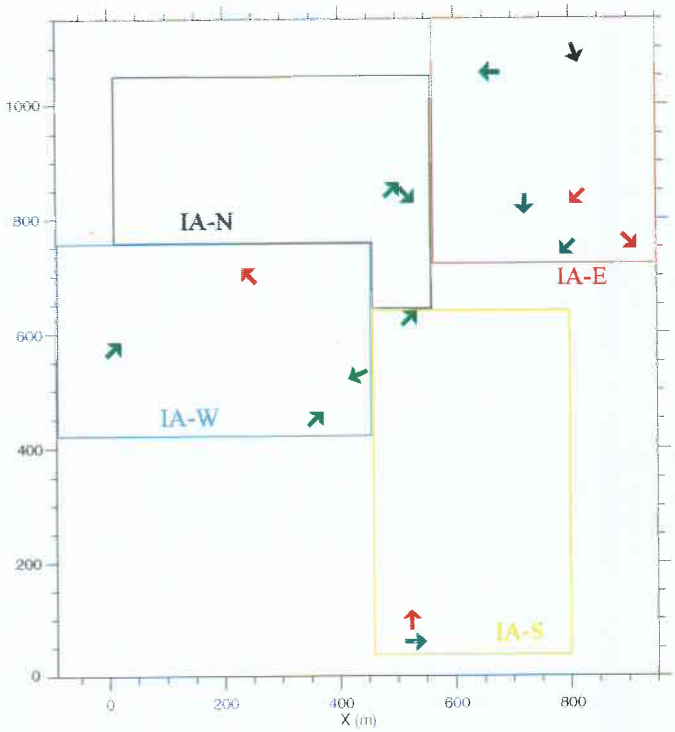

Figure 14. Distribution of projectile duds on the Impact Area Survey. 155-mm projectiles are noted in green, 8-in shells in red.

Figure 15. Target 21 on IA-S is an 8-inch projectile with a mechanical-time fuze.

To clear the dud projectiles from the Impact Area will require that the UXO surveys be extended in all directions until the OE scrap indicative of detonations is no longer present in the survey areas. The digs in IA-E shows that relatively few targets would have to be dug to recover 155-mm and 8-in shells. Many more targets will have to be dug to assure that no 105-mm shells are left in the field.

5.5 Ordnance and OE Scrap Disposal

As described above, all intact ordnance recovered were HE-filled 155-mm and 8-inch projectiles. All were mechanical-time or powder-train-time fuzed duds. Standard operating procedure calls for detonating all these items in place. Because the Impact Area is relatively secure, ordnance demolition was postponed until digging was complete. All uncovered live ordnance was red-flagged for later disposal. One of the 8-inch projectiles was discovered only about 150 feet from the *MTADS* DAS trailer. This distance is much too small to safely blow in place, even with soil tamping. The rental company was brought on site after all survey activities were ended to move the *MTADS* trailers a safe distance away from the recovered 8-inch projectile.

Ordnance was challenged using detonations from 2.5-in shaped-charges. UXO technicians from the OST, under supervision of a senior UXO supervisor from EOTI placed the jet perforators (Halliburton) on several ordnance items which were simultaneously blown in place using Nonel Shock Tube detonation techniques to minimize the probability of grass fires. Steve Wilson, an OST UXO technician, is shown preparing a demolition charge in Figure 16. In Figure 17 a group of 3 demolition explosions are shown at the south end of the North-South transect in the IA-S. All ordnance detonated high order verifying that all 15 ordnance items were HE-filled duds.

Figure 16. A shaped-charge challenge on a projectile is being tamped in place using soil to minimize scattering of shrapnel during detonation.

Figure 17. Three projectiles are detonated in a single shot in IA-S.

Following all the detonations a group of people from the OST, Ellsworth AFB, CES Division, and Rust Environment & Infrastructure, Inc., collected soil samples, Figure 18, from several points within each crater and from the ground surface down wind from each crater.[23] Using EPA 8330 protocols the samples were bottled, stored under refrigeration in the dark and submitted for explosives residue analysis. Additionally, the samples were analyzed for metals,

including barium, cadmium, chromium, copper, lead, magnesium, and nickel. These were sampled, stored and analyzed according to EPA Protocol 6010, Figure 19.

The results of the environmental sampling study are reported in a separate document prepared by Rust Environmental for the Army Corps of Engineers, Rapid City.[23] Within the limits of detection, all analyses for explosives residues were negative, both within the craters and in the downwind surface samples. The concentrations of the metals cited above were all above the limits of detection, but within expected native soil concentrations based upon prior soil sampling and analysis studies at the Impact Area. It is a specific conclusion of the Rust report that there were no energetic materials chemical residues nor metal residues that could be associated with the presence or detonation of these projectiles.

The blow-in-place demolition of these ordnance duds is a relatively clean process. Clearly, iron shrapnel is a significant residue of the detonations. However, the shrapnel residue from these detonations does not add measurably to the extensive contamination of the entire survey area from the myriads of detonations during the period the area was an active range. The detonation process leads to near complete consumption of the energetic materials composing the HE fill. The products of the detonation are high temperature gases (NO, NO_2, N_2O, N_2, CO, CO_2, H_2O, and other chemical species at trace levels) that are expelled into and dissipate in the air. At the macroscopic level, the combustion processes taking place during detonations of explosives formulations are well understood.[24]

Figure 18. Soil samples were collected from several points within each detonation crater.

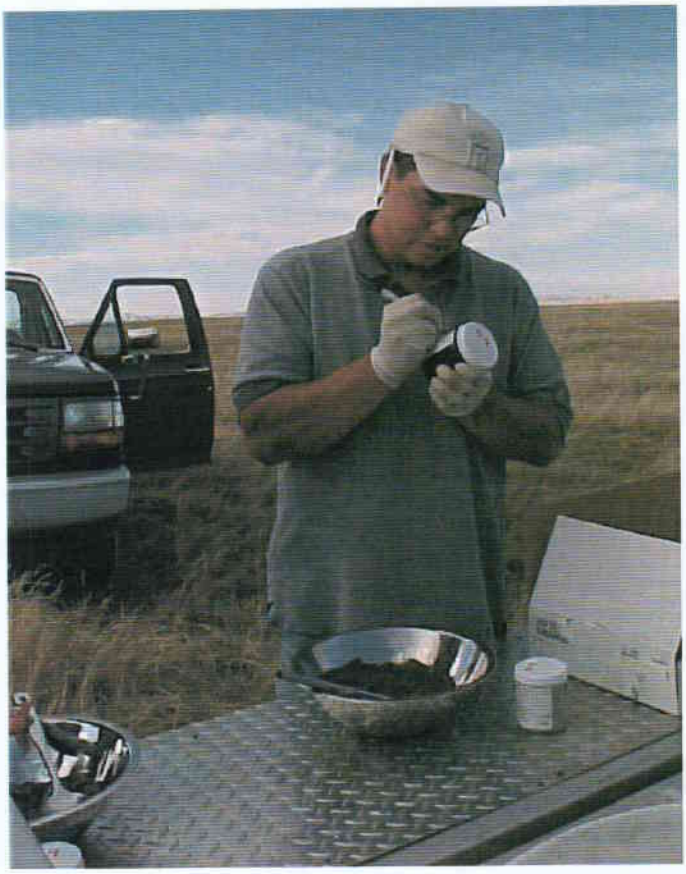

Figure 19. Joe Amiotte, from the BBR Project Office labeled soil samples for explosives residue analysis.

Following collection of the soil samples, the backhoes were used to fill all craters. Soil was tamped into place and the craters were returned to the natural grade. All ordnance-related scrap and all other metal residue was collected at a central stockpile point. All residue was inspected for explosives residue, packed in 55 gallon drums, and certified for disposal. The barrels were removed from the site by a certified hazardous waste hauler.

5.6 The EM Survey and Fusion Analysis

As described earlier, an area 200 X 300 meters, northeast of the bull's eye, was designated within IA-N for the EM survey. This encompasses the area north of the East-West Section Road and East of X = 300 meters (local coordinates) shown in Figure 9. The area was initially surveyed in an East/West direction and then the survey of the same area in a North/South direction was undertaken. This area is a region of intermediate target density, many targets are present, but they are sparse enough that their signatures do not significantly overlap in the magnetometry survey. The North/South EM survey was not completed because of electronics failure in the Data Acquisition System in the Tow Vehicle. The specific circuit board that self destructed was one of the few that was not spared when we built the system. It could have been replaced on emergency order from the factory within 3 days, however, there was insufficient time remaining in the survey period to recover. Therefore, IA-E was surveyed using the magnetometer array in the remaining available time. The EM surveys are shown in Figures 20 and 21.

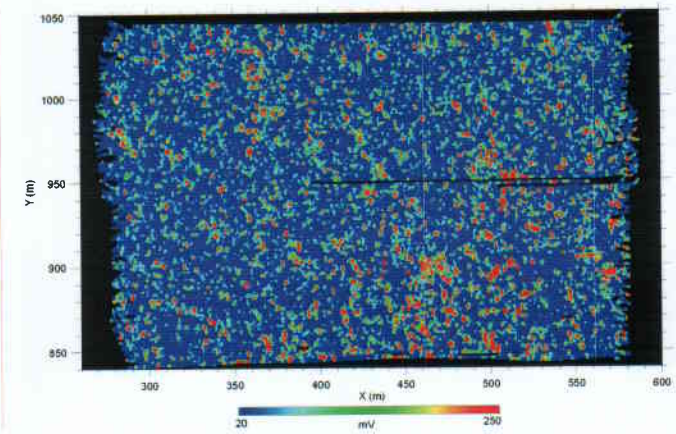

Figure 20. EM anomaly image of a portion of IA-N from the East/West survey.

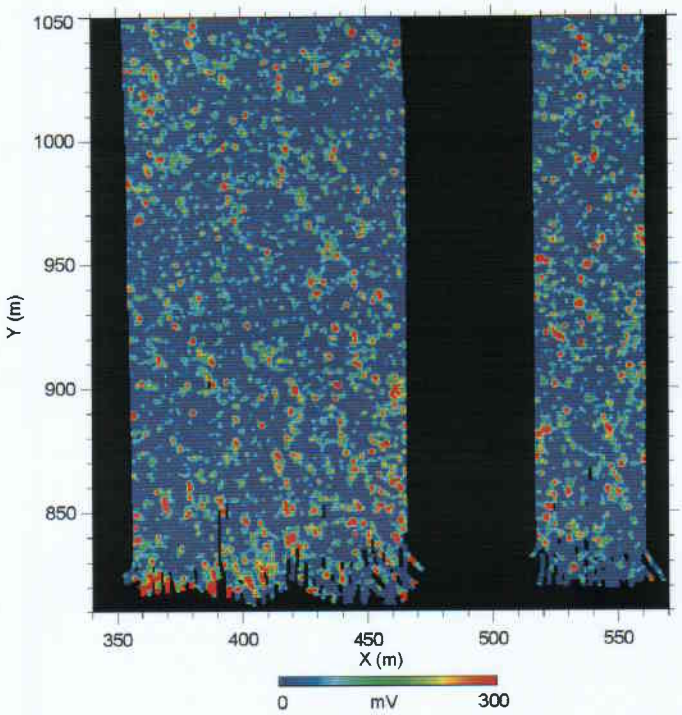

Figure 21. EM anomaly image of the section of IA-N surveyed in a North/South direction.

In the ESTCP program **(199812)**,[18] we developed a new target analysis routine using a data analysis approach that takes advantage of shape information in the EM target signatures. In this approach, the EM analysis fit exploits information about the relative shapes of the targets by approximating the dimensions along the

three primary coordinate axes of the item. An underlying premise of this analysis approach is that ordnance (with approximate cylindrical symmetry) is dominated by one long coordinate dimension and two smaller dimensions along the orthogonal axes. Conversely, an object with two large and one small dimension more closely resembles a flat plate (or a bomb tail fin). The shape information is much more apparent in the data when the long axis of the target lies along the survey path of the *MTADS* array. For this reason we surveyed in orthogonal directions with the EM array to take maximum advantage by illuminating the targets from two directions. The *MTADS* FUSION data analysis system undertakes an analysis in which a magnetometry and two EM data sets can be simultaneously analyzed in a single analysis step. An independent target analysis is provided from the magnetometry data (equivalent to the baseline *MTADS* analysis process) and separately, the EM analysis is carried out on the other two data sets. The result is the so-called 3-β analysis. This EM fitting routine converges to fitting parameters for x-y position, depth, the angles that describe the object's orientation, the 3 β values, and a goodness-of-fit value. The 3 βs formally are sensor response functions that correlate in a nonlinear manner with the three major orthogonal dimensions of the object.

5.6.1 Signatures from the *MTADS* Ordnance Library. Many measurements have been made in a test pit and on buried objects in our test field. The performance results have been reported in several publications.[25, 26] Figure 22, below shows the results of measurements made in the test pit on 105-, 155-mm and 8-in projectiles at a variety of depths and orientations. In this 2-dimensional presentation, the secondary β is the average of β_2 and β_3. Superimposed upon the standard plots for the pit data are ellipses that have been generated by application of noise from sources that we have found to be important in translating library data into field applications.[27] The sources of noise that we have accounted for include (1) those associated with the GPS navigation system, (2) the uncertainty in the sensor X-Y position due to the mapping and heading errors in correcting field measurements to absolute sensor position, (3) the uncertainty in the individual sensor height-above-ground measurement resulting from terrain roughness and (4) motion-induced noise in the individual sensor readings. In Figure 22, the first two noise sources we deem to be first-order independent of the particular field. The sensor height-above-ground measurement noise and the motion-induced sensor noise were evaluated specifically from the Impact Area data. The three concentric ellipses represent the 1-sigma (blue, 39.3%), 2-sigma (green, 86.5%), and 2.45-sigma (red, 95%) confidence level for each of the library data sets to capture field data and correctly classify it as a particular ordnance item. At the 2-sigma confidence level, on this basis, with the noise sources in the data at the Impact Area, we predict that we can confidently differentiate these three ordnance items from each other. At the 95% confidence level, the 155-mm and 8-in ellipsoids mildly overlap each other.

5.6.2 Field data from the Fusion Survey. In Figure 23 are shown the magnetometry and one of the EM analysis windows for a small portion of the joint analysis that was performed on this data. Target numbers from several representative fitted targets are shown from the fusion analysis. Targets were chosen only from the area that was covered by both of the orthogonal EM surveys and the magnetometry survey. In general, fusion targets were chosen that were not complicated by overlapping signatures from other nearby buried metallic objects. The fusion analysis was carried out without paying particular attention to the sizes of the objects being analyzed. Numerous targets were chosen that were significantly smaller than the analysis threshold that was used on the remainder of the site (assuming that 105-mm projectiles were the smallest ordnance of interest).

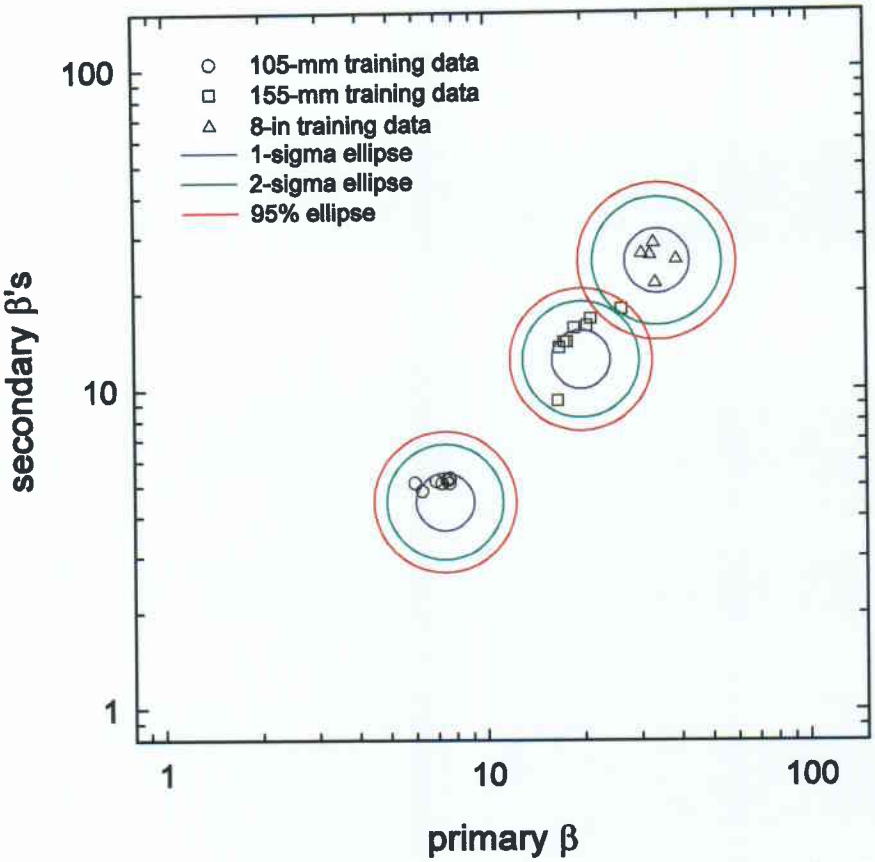

Figure 22. 3β Fusion analyses of 105-mm (lower left), 155-mm (center) and 8-inch (upper right) projectile signatures in the test pit at Blossom Point. The significance of the ellipses is explained in the text.

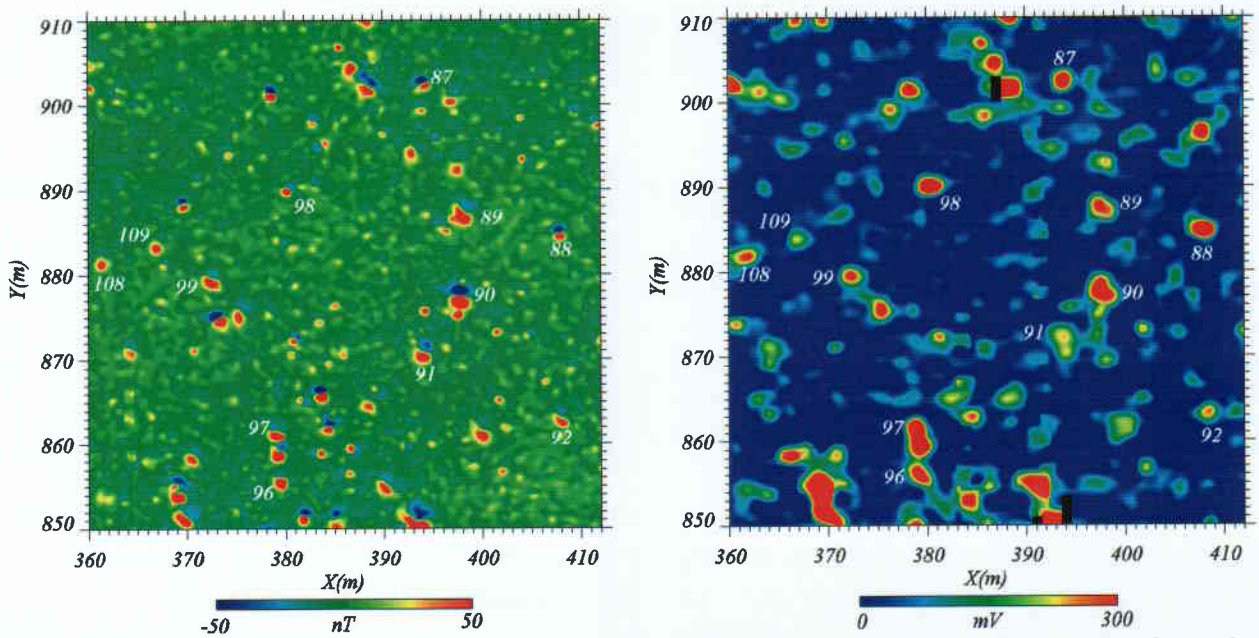

Figure 23. ***MTADS*** **Fusion Data Analysis from IA-N showing simultaneous target selections from the magnetometry and North/South EM surveys.**

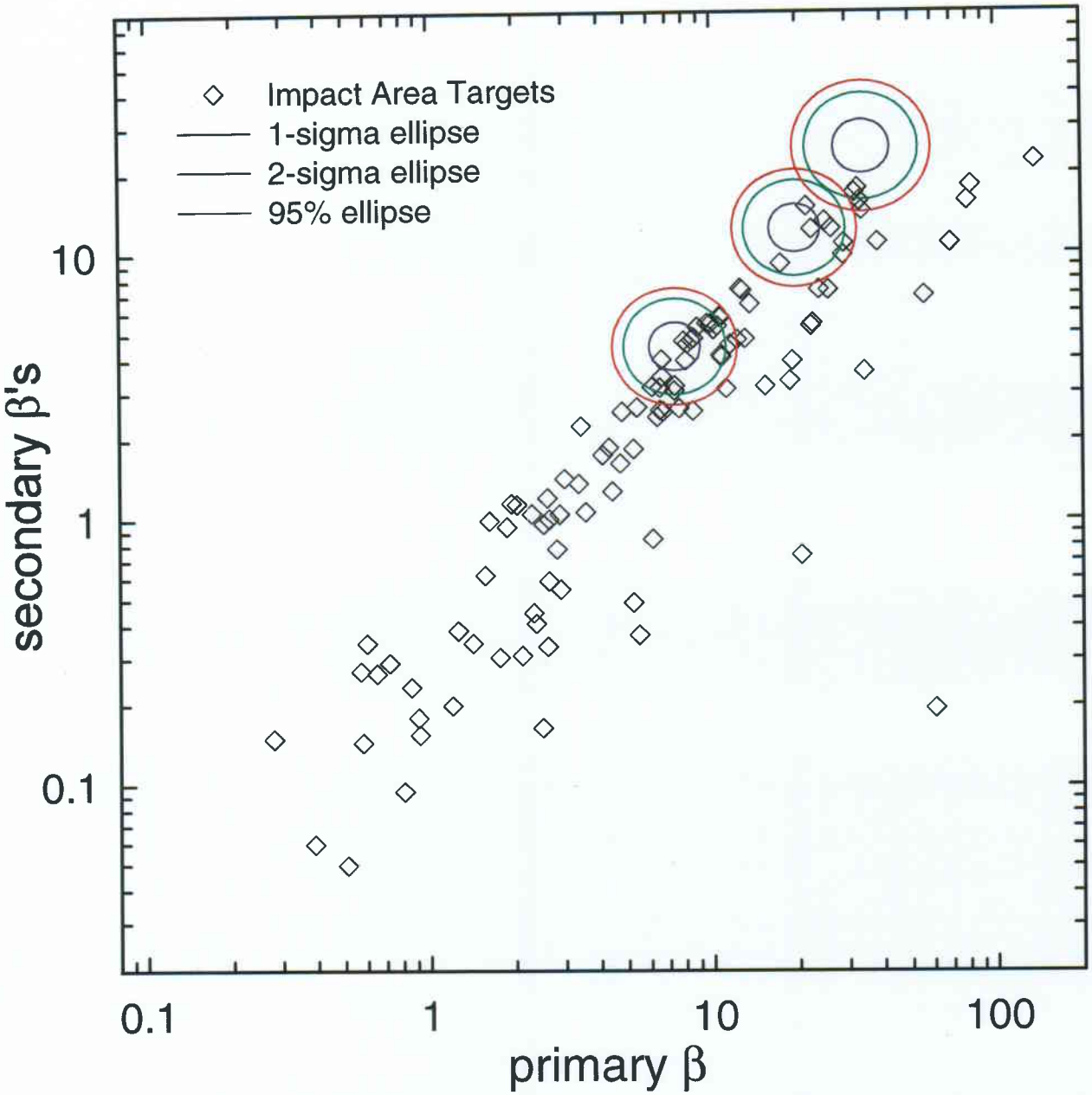

Figure 24. The 3β fusion analysis of the 109 selected targets from the fusion survey area. The lower target is a 105-mm projectile, the center target is a 155-mm and the upper target is an 8-in projectile.

The rationale of this approach was to specify and dig all fusion targets to demonstrate the ability of the system to discriminate objects on the basis of shape. In Figure 24 a 2-dimensional cut of the fusion analysis for the 109 selected targets is shown with the classification ellipses generated from the library data shown superimposed. Again, the secondary β is the average of β_2 and β_3. The 95% confidence ellipses in Figure 24 encompass 32 fusion targets and touch the symbols of an additional 8 targets. The situation is considerably different in 3-dimensions. The 3-dimensional 95% confidence ellipsoids capture only 9 targets, eight are classified as 105-mm projectiles, one as a155-mm projectile. The information presented in 5.6.1 and 5.6.2 above was developed during the

preparation of this report. No 3-β declarations were made classifying targets as ordnance or "not ordnance" prior to remediation of the fusion targets.

5.6.3 Comparison with the Magnetometry Analysis Following the selection and analysis of the 109 Fusion targets, the baseline *MTADS* DAS was used to independently analyze and, to the extent possible using only magnetometry data, categorize the anomalies chosen in the Fusion analysis. The magnetometry and Fusion analyses were independently carried out by different analysts and separately and independently reported to IDA before the targets were dug. Then all the fusion targets were dug. The results are summarized in **Table 7** and compared with the results reported by the UXO dig teams. To make the table more readable, information about target orientations has been deleted. The complete tables are on CD Rom in Appendix C. In the baseline magnetometry analysis the classification declarations, as they are included in Table 7, were made prior to remediation.

Unfortunately, with the exception of target FUS-107, there were no ordnance items among the Fusion targets. FUS-107 was the tail part of an 8-inch projectile which had been torn apart, but did not detonate. It contained high explosive formulation and was, by definition, ordnance. However, its shape more closely resembled OE scrap than an intact projectile.

In the columns on the left side of the table (Baseline Magnetometer Fit) the *MTADS* analyst's comments are those that would have been made had these targets been analyzed in IA-S, IA-W, or the remainder of IA-N. Target images which discernibly were composed of a group of items (clutter), complex-shaped objects, small pieces of trash on the surface, or items that were too small to be 105-mm projectiles were so labeled. This baseline magnetometry analysis declared 77 of the109 Fusion targets as not ordnance. The remaining 32 targets, highlighted in Table 7, would have been recommended for the dig list. Of these 32 targets, 22 were classified as probable 105-mm candidates. After digging the 32 designated targets only #76 (FUS-107) qualified as ordnance, as described above. The remainder were primarily clusters of shrapnel from exploded projectiles or automobile parts (scrap metal objects created by using automobiles as targets).

5.6.4 Value of the EM Survey Data and the 3-β Fusion Analysis. The 9 targets included in the 95% confidence level ellipsoids are highlighted in Table 7. Highlighted comments have been added to the 3-β comments column describing the ordnance fit and the 3-β confidence of the fit. This analysis and classification was made long after we left the Impact Area based upon re-analysis of target data in the test pit and analysis of noise levels in the data at the Impact Area. Other than on the L-Range at Blossom Point, we have not dug targets on a live range based solely on EM data, nor on the 3-β analysis approach. This test of our 3-β analysis, while completely defensible on a statistical basis, carries little information that would provide critical guidance remediating the remainder of the Impact Area (i.e. in rejecting scrap targets while correctly classifying projectiles). This is, of course, because there were no projectiles in the EM survey area.

The EM analysis presented in Table 7 is also skewed to some extent because a large fraction of the chosen targets were much too small to be projectiles. Additionally, targets with significant EM signatures were excluded from the Fusion analysis because their signatures were complex or contained contributions from multiple targets. Complex targets must also be addressed in a live site

Table 7. Comparison of the Baseline magnetometer analysis with the 3b fits on the EM Fusion targets.

Baseline Magnetometer Fit								3 β Fit									Field Observations	
Target ID	Mag Target ID	Mag Local X (m)	Mag Local Y (m)	Depth (m)	Size (m)	Fit	Mag Analyst Comment	Local X (m)	Local Y (m)	Depth (m)	β_1	β_2	β_3	χ^2	Fit	Fusion Analyst Comment	Depth (m)	Field Comments
FUS-1	1	535.06	1040.94	0.07	0.107	0.968	possible 105, almost on surface	535.16	1040.99	0.31	8.46	5.34	4.10	173292	0.964	105-mm, 2.45σ fit	Surface	CAR PART ON SURFACE, 18X12-in
FUS-2	3	533.74	1032.45	0.77	0.105	0.905	possible 105, nice target	533.98	1032.41	0.92	17.53	13.11	5.15	3609	0.928	SINGLE TRACK NS/EW	0.46	8" FRAG, 3 PCS, 6X1.25X3/4 2.5X1X1/2 2.5X1.5X3/4
FUS-3	172	462.19	1039.43	0.09	0.074	0.988	Too Small for UXO	462.28	1039.42	0.32	2.88	1.41	0.68	15799	0.964		-	FLAG MISSING
FUS-4	171	460.74	1029.65	0.81	0.111	0.911	Clutter Pile	460.69	1030.46	1.03	29.15	6.79	12.93	2430	0.906	SINGLE TRACK NS	0.77	FRAG, 6X1/2X3/4 in
FUS-5	170	460.89	1027.08	0.16	0.049	0.817	2 pieces of frag	460.74	1027.06	0.36	0.91	0.13	0.23	2226	0.880	SINGLE TRACK NS	0.15	FRAG, 4X2X1/2 in
FUS-6	175	386.59	1028.30	0.81	0.113	0.829	Clutter Pile	386.67	1028.33	1.04	29.28	18.84	2.98	3535	0.783		0.77	FRAG, 12X3X1/2, 6X4X1/4, 6X4X1/2 in
FUS-7	174	379.11	1031.65	0.18	0.043	0.892	frag, near surface	378.82	1032.12	0.46	1.57	0.29	0.95	2833	0.868	SINGLE TRACK NS	Surface	FRAG, 8X3X1/2 in
FUS-8	12	367.29	1022.59	0.40	0.119	0.733	possible 105 at 1 ft	367.18	1022.75	0.58	5.50	0.68	0.06	5048	0.644		0.31	1/8 in STEEL ROD 3 ft long, FRAG 4X2X1/4, 2X3X1/4 in
FUS-9	177	366.23	1006.71	0.04	0.036	0.755	frag, near surface	366.30	1006.87	0.35	1.42	0.46	0.23	3973	0.857	SINGLE TRACK NS	Surface	THIN METAL, FRAG 9X3X1/2 in
FUS-10	13	368.26	1017.98	0.60	0.088	0.913	possible105, clutter to SW	367.94	1018.08	0.84	10.46	7.57	3.09	1785	0.925	SINGLE TRACK NS/EW	0.61	FRAG, 24X2X1/2, 10X5X1/4 in
FUS-11	176	402.20	1010.47	0.06	0.051	0.738	frag, on surface	402.08	1010.37	0.37	2.65	1.44	0.56	8540	0.939	SINGLE TRACK NS	Surface	BRAKE PAD
FUS-12	173	415.46	1024.98	0.12	0.063	0.887	several pieces of frag	415.40	1025.00	0.42	2.61	0.19	0.48	4615	0.930	SINGLE TRACK NS	0.13	FRAG, 15X5X1 in
FUS-13	11	415.73	1021.90	0.95	0.125	0.858	likely is 2 targets lying E/W	415.51	1021.86	1.09	25.08	4.44	21.90	3468	0.749	NONDIPOLE	0.61	FRAG, 11X4X1/4, 6X2X1, 13X2X1 in
FUS-14	169	454.50	1008.77	0.16	0.041	0.844	frag, near surface	454.45	1008.87	0.29	0.65	0.21	0.32	2065	0.856		Surface	SCRAP, 4X4X1/4 in
FUS-15	125	552.45	1021.05	0.11	0.057	0.790	Too Small for UXO	552.39	1021.09	0.30	1.26	0.52	0.25	6582	0.913		Surface	CAR PART ON SURFACE, 16X4X1 in
FUS-16	5	556.29	1010.69	0.76	0.100	0.844	small target, poor fit	556.35	1009.98	1.23	38.59	7.97	14.02	3443	0.681	SINGLE TRACK NS - NOND	0.15	155 MM FRAG, 2X1X1 in
FUS-17	126	540.48	992.20	0.07	0.073	0.981	Too Small for UXO	540.55	992.14	0.34	2.82	1.12	0.43	20084	0.909	SINGLE TRACK NS / NEAR	Surface	CAR PARTS
FUS-18	4	542.64	1005.84	0.49	0.094	0.959	small target, clutter N&E	542.61	1006.04	0.70	8.62	6.04	3.55	5264	0.949	105-mm, 2σ fit	0.31	155 MM FRAG 5X1.25X1, 2X1X1/2, 1.5X1X3/4 in
FUS-19	35	534.50	991.58	0.61	0.103	0.957	good target at 1.5 ft	534.66	991.72	0.71	10.73	5.80	2.50	4946	0.908	SINGLE TRACK EW / NOND	0.46	155 MM FRAG 7X1.5X1/2, 3X1.25X1, 3X1.25X5/8, 3X1.5X3/4 in
FUS-20	168	443.59	997.98	0.07	0.048	0.970	frag, on surface	443.53	998.10	0.38	1.77	0.46	0.15	4422	0.860	SINGLE TRACK NS	Surface	155 MM FRAG 6X3X1/2 in
FUS-21	32	437.19	996.24	0.69	0.119	0.908	possible 105 at 2 ft	437.51	996.35	0.80	13.65	3.05	9.83	2788	0.937	SINGLE TRACK NS / NOND	0.61	FRAG 11X2X1/4, 5X4X1/4, 4X3X1/4, 12X4X1/4 in
FUS-22	31	417.66	996.51	0.71	0.118	0.902	possible 105, clutter to NW	417.65	996.75	0.98	33.35	23.56	7.73	6163	0.888		0.46	FRAG 3X4X1/2, 4X2X1, 2X3X1 in
FUS-23	179	367.40	992.39	0.87	0.121	0.729	Clutter Pile	367.76	992.71	0.87	26.45	5.49	19.25	7066	0.909	NONDIPOLE	0.77	FRAG 9X1X1/4, 5X2X1/4, 4X4X1/2 in
FUS-24	178	360.65	1006.64	0.79	0.101	0.874	multiple targets	361.01	1006.64	0.73	7.65	2.16	3.07	1847	0.931	NONDIPOLE	0.77	FRAG 11X3X1/2, 9X2X1/4, 2X3X1/2 in
FUS-25	180	379.24	991.89	0.10	0.054	0.814	frag, near surface	379.19	992.07	0.47	2.33	0.34	0.56	2078	0.941	SINGLE TRACK NS	Surface	FRAG 18X2X1/2 in
FUS-26	30	393.37	981.46	0.10	0.077	0.869	small target on surface	393.35	981.49	0.44	7.37	2.43	3.67	14001	0.972		Surface	CAR PART - FRAME, HEAVY METAL
FUS-27	181	394.88	976.98	0.08	0.046	0.901	frag, near surface	394.69	976.78	0.59	3.00	2.15	0.70	4256	0.808	SINGLE TRACK NS	Surface	THIN METAL
FUS-28	139	547.07	854.67	0.86	0.105	0.910	possible 105	546.91	855.08	0.80	8.57	3.80	1.32	2180	0.876		?	NO COMMENTS GIVEN
FUS-29	138	546.04	858.70	0.76	0.113	0.867	Clutter Pile	546.04	858.85	0.76	12.61	3.49	11.20	5786	0.881		0.46	155 MM FRAG 9X1.25X5/8, 3X2X3/4, 3X1.5X1/2 in
FUS-30	98	554.19	851.29	0.64	0.099	0.908	small for 105mm	554.07	851.28	0.69	6.72	1.50	3.59	4832	0.855		0.61	155 MM FRAG 6X1.5X1/2, 3X1.25X5/8, 3X1X3/4 in

Baseline Magnetometer Fit								3 β Fit									Field Observations	
Target ID	Mag Target ID	Mag Local X (m)	Mag Local Y (m)	Depth (m)	Size (m)	Fit	Mag Analyst Comment	Local X (m)	Local Y (m)	Depth (m)	β_1	β_2	β_3	χ^2	Fit	Fusion Analyst Comment	Depth (m)	Field Comments
FUS-31	219	547.20	868.16	0.66	0.100	0.873	possible 105, clutter all around	547.53	867.69	0.76	5.44	1.77	3.51	3026	0.886	single track EW	0.51	155 MM FRAG
FUS-32	136	554.68	908.62	0.69	0.099	0.870	Clutter Pile	554.69	908.78	0.73	9.61	2.74	8.16	3246	0.930		0.61	155 MM FRAG, 5X1X1/2, 3X3/4X1/2, 5X1.24X1/2, 3X1.75X3/4, 2.5X1.165X5/8 in
FUS-33	65	556.61	915.77	0.60	0.091	0.887	small target at 2 ft	556.71	916.04	0.69	4.73	0.62	2.63	2402	0.838		0.46	FRAG 6X2X1/2 in
FUS-34	135	553.80	919.89	0.59	0.082	0.815	Clutter Pile	553.52	920.51	1.00	22.65	6.54	4.39	3727	0.820		0.46	FRAG 2X1/2X1/2 in
FUS-35	137	542.47	906.95	0.07	0.051	0.936	Too Small for UXO	542.56	907.09	0.34	2.12	0.15	0.47	7836	0.905		0.15	FRAG, 5X1.5X3/4; SCRAP METAL 12X1/4X1 in
FUS-36	132	539.00	927.74	0.05	0.064	0.986	Too Small for UXO	538.98	927.81	0.33	1.88	0.85	1.03	9384	0.955		Surface	SHEET STEEL 8X5X1/8 in
FUS-37	222	558.61	937.15	0.01	0.050	0.000	too Small for UXO, trash on surface	558.55	937.31	0.24	0.60	0.48	0.21	8154	0.959	single track ns,EW	Surface	SCRAP, 8X6X1/8 in
FUS-38	131	541.59	956.60	0.21	0.113	0.686	likely multiple tgargets	541.54	956.66	0.29	6.15	1.40	0.29	64628	0.942	single track, EW	0.15	SCRAP 18X3.5X1/8; FRAG 4X1/2X3/4 in
FUS-39	130	544.40	960.36	0.88	0.125	0.761	Clutter Pile	543.88	959.73	1.13	33.91	23.46	5.43	6019	0.828	single track EW	0.77	CAR PARTS, FRAG 2X3/4X1/4 in
FUS-40	129	549.85	965.91	0.15	0.047	0.867	trash, near surface	550.15	965.86	0.41	1.00	0.00	0.01	1701	0.906	single track NS	0.15	FRAG, 1.5X1X1/4 in
FUS-41	128	538.68	971.48	0.17	0.046	0.879	trash, on surface	538.79	971.47	0.67	9.97	0.00	0.00	32414	0.946	single track, NS, EW	0.15	FRAG 12X4X1/4 in
FUS-42	127	524.45	982.91	0.71	0.092	0.905	Too Small for UXO	524.44	983.54	0.89	13.08	6.84	2.70	2400	0.857		0.61	FRAG 3X1X3/4 in
FUS-43	220	524.82	965.34	0.10	0.053	0.935	inverted, too small for UXO	524.86	965.39	0.31	0.92	0.10	0.21	9647	0.868		Surface	METAL PIPE 6X1.165 in
36		528.66	943.18	0.13	0.068	0.891	too small for 105	528.70	943.18	0.29	0.72	0.36	0.22	3277	0.948	single track, EW	0.15	CHROME 18X1X1/8 in
FUS-45	133	529.24	924.65	0.06	0.052	0.881	Too Small for UXO	529.24	924.65	0.19	0.57	0.19	0.35	24538	0.844	single track EW	Surface	FRAG 3X1X3/4 in, SCRAP METAL 6X6X1/8 in
FUS-46	67	524.92	901.01	0.57	0.096	0.935	possible 105, clutter on 4 sides	525.02	901.31	0.64	8.07	4.67	3.24	6820	0.940	105-mm, 2σ fit	0.46	FRAG 9X1X1/4 in
FUS-47	134	535.39	917.91	0.09	0.074	0.984	trash, on surface	535.45	918.01	0.33	2.53	1.47	0.45	41218	0.948	single EW	Surface	SCRAP METAL 12X6X1/8 in
FUS-48	141	463.42	846.39	0.52	0.094	0.807	Clutter Pile	463.21	846.51	0.45	8.20	2.59	6.55	65141	0.955	single track EW	0.46	FRAG 1X1X1 in, SCRAP METAL 12X12X1/8 in
FUS-49	221	463.17	859.28	0.64	0.126	0.866	likely 2 targets, touching E/W, dig	463.12	859.60	0.79	22.51	7.29	17.28	10565	0.936		0.61	FRAG LARGEST PIECE 6X1X1/2 in
FUS-50	142	455.57	852.34	0.05	0.064	0.831	trash, on surface	455.65	852.49	0.40	6.15	1.34	4.96	133616	0.932	single track EW,	Surface	FRAG 3X1X3/4 in
FUS-51	146	451.75	874.13	0.01	0.076	0.905	frag, on surface	451.80	874.12	0.23	2.04	0.93	1.35	31844	0.947		Surface	FRAG 8X8X1/8 in
FUS-52	147	452.23	878.00	0.48	0.101	0.843	Clutter Pile	452.35	878.05	0.73	7.40	5.04	1.32	4328	0.846	singel track, EW	0.46	FRAG, SEVERAL PIECES LARGEST 6X2X3/4 in
FUS-53	144	451.63	859.29	0.05	0.067	0.936	frag, on surface	451.80	859.29	0.34	2.38	0.26	0.56	9917	0.905	singel track, NS	-	FLAG MISSING
FUS-54	72	461.39	899.20	0.20	0.102	0.870	good target, very shallow	461.26	899.23	0.65	19.21	3.02	4.85	60599	0.810	single track ,NS	0.15	CAR PARTS 18X2.5X1.5 in, WIRE 12 in
FUS-55	153	456.28	888.29	0.48	0.072	0.834	Clutter Pile	456.38	888.61	0.58	2.90	0.14	0.96	2079	0.920	single track, EW, NS	0.46	FRAG 3X1X3/4 in
FUS-56	152	449.08	890.19	0.12	0.055	0.966	frag, near surface	449.06	890.03	0.37	0.81	0.01	0.18	2543	0.955	single track, NS	NG	?
FUS-57	154	451.68	896.18	0.20	0.063	0.702	frag	451.66	896.22	0.60	4.43	0.02	2.53	21114	0.901	single track, EW	Surface	THIN METAL
FUS-58	63	461.98	925.03	0.70	0.099	0.915	small target, not UXO	462.16	924.96	1.46	56.13	0.03	13.83	3784	0.851		0.61	FRAG, 11X2X1/4, 7X1.5X1/2, 13X1X1/4, 8X3X1/4, 15X2X1/4 in
FUS-59	62	452.43	935.08	0.53	0.088	0.932	good target	452.40	935.04	0.57	3.46	3.39	1.09	3288	0.936	single track, NS	0.46	8 IN projo Frag, 6X3X1, 6X2X1/4, 6X2X1, 11X4X1/2, 3X3X1 in
FUS-60	33	450.05	975.24	0.69	0.099	0.838	possible 105	450.13	975.62	0.86	9.88	2.88	7.99	1894	0.888	single track, NS	0.77	155 FRAG, 5X3X1/2, 3X2X1, 4X4X1 in
FUS-61	44	430.16	938.34	0.36	0.102	0.933	possible 105 at 1 ft	430.13	938.38	0.63	10.64	2.86	8.73	7043	0.936		NONE	NOTHING FOUND

Baseline Magnetometer Fit								3 β Fit									Field Observations	
Target ID	Mag Target ID	Mag Local X (m)	Mag Local Y (m)	Depth (m)	Size (m)	Fit	Mag Analyst Comment	Local X (m)	Local Y (m)	Depth (m)	β_1	β_2	β_3	χ^2	Fit	Fusion Analyst Comment	Depth (m)	Field Comments
FUS-62	165	432.99	942.64	0.76	0.105	0.855	Clutter Pile	432.42	942.85	1.49	138.12	5.72	38.78	5064	0.892		0.46	FRAG 1X1X1/4, 2X1X1/4 in
FUS-63	166	438.89	953.45	0.50	0.088	0.855	Clutter Pile	438.55	953.54	0.76	10.15	2.36	7.99	3278	0.889		0.5	FRAG, 9X2X1/4, 9X2X1/4, 4X3X1/2 in
FUS-64	156	438.16	901.13	0.17	0.085	0.770	small for 105mm	438.13	901.25	0.34	6.66	3.19	4.77	32387	0.982	105-mm, 2σ fit	Surface	8 in projo frag, 24X10X1 in
FUS-65	157	435.00	906.30	0.06	0.066	0.983	frag, on surface	435.00	906.25	0.25	0.28	0.06	0.24	2355	0.954	single track, EW, NS	Surface	CAR GRILL
FUS-66	155	437.69	895.82	0.15	0.084	0.848	Too Small for UXO	437.56	895.90	0.34	2.64	0.14	1.04	5612	0.966	single track, NS	Surface	FENCE, METAL
FUS-67	151	439.07	886.28	0.53	0.088	0.854	Clutter Pile	439.21	886.04	0.84	10.70	7.39	4.06	3085	0.943	105-mm, 2.45σ fit	0.46	FRAG 9X1X1/4, 7X1/2X1/4; FIRED MTSQ FUSE
FUS-68	145	444.50	870.09	0.06	0.066	0.854	frag, on surface	444.51	870.11	0.55	5.28	2.79	0.90	9012	0.818	single track, NS, EW	Surface	CAR PART
FUS-69	143	446.84	852.36	0.08	0.056	0.968	frag, on surface	446.77	852.17	0.41	2.61	1.85	0.56	12312	0.875	single track, EW	-	FLAG MISSING
FUS-70	140	448.38	845.51	0.99	0.143	0.881	Clutter Pile	448.25	845.49	0.94	25.81	2.48	12.07	7569	0.842	single track, EW	-	FLAG MISSING
FUS-71	148	419.18	856.74	0.79	0.091	0.907	possible 105	419.44	857.14	1.70	60.41	0.07	0.32	3362	0.788		0.77	FRAG 4X2X1/2, 6X2X1/4, 1X1X1 in
FUS-72	150	430.02	862.18	0.07	0.043	0.933	frag, on surface	430.38	862.25	0.35	0.58	0.00	0.29	5227	0.869	single track, NS	-	FLAG MISSING
FUS-73	149	417.84	862.57	0.65	0.092	0.884	possible 105	417.77	862.69	1.43	34.32	6.84	0.34	5539	0.789	single track, EW	-	FLAG MISSING
FUS-74	158	417.75	879.83	0.69	0.093	0.920	frag pile	417.71	880.18	0.93	15.39	4.92	1.41	1621	0.886	single track, NS	0.61	FRAG 13X1X1/4, 11X1X1/2, 7X1X1/2 in
FUS-75	159	423.16	888.75	0.60	0.077	0.873	Clutter Pile	423.05	888.98	0.85	11.58	6.51	2.59	2217	0.879	single track, NS	0.61	FRAG 11X3X1/4, 5X3X1/4, 5X3X1/4, 1X1X1 in
FUS-76	160	419.12	889.73	0.64	0.087	0.885	Clutter Pile	419.47	890.17	1.05	31.97	27.22	6.43	4427	0.850	single track NS	0.61	FRAG 11X2X1/2, 9X1X1/2 in
FUS-77	161	422.67	913.63	0.68	0.092	0.938	2 targets touching N/S	423.17	913.63	1.07	11.22	5.90	0.31	3166	0.807	single track, NS	0.92	NOTHING FOUND
FUS-78	163	416.40	932.55	0.04	0.056	0.975	frag, on surface	416.28	932.51	0.34	0.86	0.00	0.47	3233	0.930		Surface	SCRAP METAL 8X6X1/4 in
FUS-79	164	413.55	935.85	0.10	0.043	0.941	frag, on surface	413.63	935.86	0.36	0.51	0.10	0.00	1410	0.922	single track, EW	Surface	FRAG 6X2X1/2 in
FUS-80	162	426.04	922.37	0.52	0.085	0.939	Clutter Pile	426.07	922.74	0.79	6.55	4.60	1.65	2362	0.818		0.46	FRAG 8X1X1/2, 6X1X1/4 in
FUS-81	183	410.29	954.88	0.06	0.065	0.943	frag, on surface	410.20	954.87	0.32	2.50	0.00	0.33	16908	0.887	single track, NS	Surface	METAL STRIP 18X1/8 in
FUS-82	167	426.95	965.06	0.10	0.057	0.954	frag, on surface	426.94	965.09	0.65	6.41	3.52	1.34	6357	0.846	single track, NS	0.01	FRAG 8X4X1 in; THIN METAL
FUS-83	45	424.46	974.62	0.53	0.087	0.866	weak fit, possible 105	424.28	974.98	0.97	22.34	4.14	6.54	2246	0.865		0.52	FRAG 11X2X1/4, 6X1X1/4, 1X1X1 in
FUS-84	184	391.09	960.65	0.63	0.088	0.937	small for a 105mm	391.33	960.67	1.31	20.51	1.25	0.22	5447	0.799		0.61	FRAG, 5X2X1/4, 4X1.5X1/4, 1/2X1/2X1/4, 7X2X1/5, 4X1X1/2 in
FUS-85	182	403.42	956.95	0.76	0.095	0.867	Clutter Pile	403.66	957.15	1.61	69.34	0.00	21.81	4356	0.740		0.77	105 projo frag, 12X2X1/4, 11X1.5X1/4, 6X4X1/4, 6X3X1/2, 12X3X1/4 in
FUS-86	189	402.14	925.36	0.10	0.081	0.949	small for a 105mm, on surface	402.17	925.39	0.39	5.25	0.89	0.09	6063	0.946		Surface	BARB WIRE 36", TRIM 12X1X1/8, in
FUS-87	195	394.10	902.65	0.09	0.065	0.931	frag clutter, near surface	393.93	902.53	0.47	3.56	0.47	1.66	8876	0.841		Surface	FRAG 8X2X1/2 in
FUS-88	197	407.77	884.88	0.09	0.064	0.931	Clutter Pile	407.76	884.90	0.34	1.95	1.27	1.03	12033	0.944		Surface	SHEET METAL 8X6X1/8 in
FUS-89	196	398.24	887.08	0.90	0.123	0.862	Clutter Pile	397.77	887.33	1.02	23.91	5.57	9.04	4661	0.790		0.77	FRAG, 11X3X1/2, 12X3X1/2, 16X2X1/2 in
FUS-90	85	397.72	877.44	0.55	0.131	0.924	good target, possible 105	397.77	877.90	1.26	82.11	26.11	9.68	7389	0.790		0.46	FRAG, HALF OF 8 in projo BASE PLATE
FUS-91	198	394.13	870.74	0.70	0.108	0.855	Clutter Pile	393.92	870.80	1.01	12.80	2.30	12.22	1244	0.867	single track, EW, NS	0.61	FRAG 9X3X1/2, 6X3X1, 8X2X1/2 in
FUS-92	199	408.18	862.76	0.76	0.095	0.731	multiple clutter targets	408.11	863.20	0.61	3.37	0.63	2.10	3557	0.829		0.77	FRAG 2X1X1/2, 8X2X1/2, 3X4X1/4 in
FUS-93	101	407.37	845.52	0.44	0.100	0.940	small target	407.28	845.57	0.51	4.32	0.71	3.03	10388	0.837		0.31	105 projo frag, 10X3X1/2 in
FUS-94	93	381.91	844.05	0.61	0.096	0.921	possible 105	381.79	844.35	0.51	2.30	1.54	0.56	3351	0.935	single track EW, NS	0.61	FRAG, 6X3X1/4, 6X1X1/4, 8X3X1/4 in
FUS-95	94	378.40	849.00	0.39	0.095	0.902	Clutter Pile	378.50	849.44	0.78	12.27	2.08	7.38	5318	0.865		0.31	FRAG 16X4X1/2, 8X2X1/4 in
FUS-96	97	379.63	855.56	0.50	0.082	0.918	Clutter Pile	379.22	856.02	0.90	18.81	2.07	4.55	3849	0.855		0.46	FRAG 2X2X1/4, 4X2X1/4 in

Baseline Magnetometer Fit								3 β Fit									Field Observations	
Target ID	Mag Target ID	Mag Local X (m)	Mag Local Y (m)	Depth (m)	Size (m)	Fit	Mag Analyst Comment	Local X (m)	Local Y (m)	Depth (m)	β_1	β_2	β_3	χ^2	Fit	Fusion Analyst Comment	Depth (m)	Field Comments
FUS-97	96	378.97	861.22	0.54	0.087	0.872	Clutter Pile	378.93	861.49	0.74	10.82	3.43	4.72	4582	0.921	105-mm, 2σ fit	0.46	FRAG 12X4X1/4, 6X2X1/4, 5X3X1/4 in
FUS-98	194	380.32	890.00	0.09	0.049	0.958	Clutter Pile	380.29	890.06	0.35	1.63	0.59	1.39	4771	0.935		0.09	FRAG, 8 in projo
FUS-99	193	372.55	879.54	0.65	0.098	0.836	Clutter Pile	372.36	879.78	1.70	79.64	0.06	31.27	5495	0.766		0.61	FRAG, 15X2X1/4, 13X1X1/4, 12X4X1/4 in
FUS-100	188	379.58	935.87	0.05	0.065	0.791	frag, on surface	379.74	935.87	0.41	1.20	0.09	0.31	4841	0.825		Surface	THIN METAL 3X2X1/16 in
FUS-101	46	383.17	936.33	0.57	0.094	0.890	small target at 1.5 ft	383.19	936.42	0.69	6.67	5.48	1.42	4581	0.841	single track, NS	0.46	FRAG 4X.75X1/4, 6X1.5X1/4, 12X6X1/4, 18X3X1/4, 4X1X1/2, 8X2X1/4, 6X1.5 1/4 in
FUS-102	187	373.92	949.39	0.67	0.090	0.873	small for 105mm	373.84	949.74	0.65	4.10	2.43	1.07	2242	0.885		0.61	FRAG, 6X1X1/4, 5X1X1/4, 2X1X1/8, 3X2X1/8, 1X1X1/4, 3X1X1/8 in
FUS-103	185	384.62	966.67	0.04	0.046	0.941	frag, on surface	384.60	966.64	0.29	0.39	0.12	0.00	1490	0.879	single track, NS	Surface	FRAG 5X1X1/2; METAL CAR PART
FUS-104	186	359.58	967.98	0.05	0.070	0.989	frag, on surface	359.52	967.90	0.36	8.88	6.74	3.80	57325	0.969	105-mm, 1σ fit	Surface	CAR PART, HEAVY STEEL
FUS-105	29	362.04	975.24	0.28	0.080	0.928	small target, good fit	362.03	975.29	0.54	4.81	3.01	2.08	9347	0.932		0.15	CAR PART, HEAVY STEEL
FUS-106	190	359.63	928.45	0.70	0.121	0.928	strongly inverted, clutter pile	359.31	928.37	0.73	7.96	6.68	2.71	3866	0.939	105-mm, 2.45σ fit	0.61	8 in projo frag, 2.5X1X1/2, 5X2X1/2, 4X3X3/4, 2X6X1, 5X3X1, 3X2X3/4
FUS-107	76	356.83	889.32	0.65	0.141	0.946	between 105 & 155	356.81	889.22	0.80	21.67	17.39	12.49	6717	0.974	155-mm, 2σ fit	0.61	TAIL SECTION OF 8 in projo, HE-filled, WITH COMP B EXPLOSIVE EXPOSED
FUS-108	191	361.11	881.21	0.75	0.086	0.638	multiple targets, not UXO	361.49	881.81	0.73	6.56	4.05	1.10	2870	0.817		0.74	FRAG, 9X3X1/4, 11X2X1/4, 4X2X1, 3X1X1/2 in
FUS-109	192	366.97	883.27	0.74	0.085	0.891	small for 105, dig this	366.90	883.68	1.55	32.80	21.47	13.53	3982	0.640			

remediation. Of the 32 targets recommended for digging from the magnetometry analysis, 25 were not among the 9 targets classified as projectiles in the 3-β analysis. Conversely, of the 9 targets classified as projectiles in the 3-β analysis, 4 were not classified as ordnance in the magnetometry dig list.

Most of the fusion targets were scrap metal pieces and/or collections of shrapnel. The EM survey data (using the 1-meter coil, or the array of three 1-meter coils) does not provide the spatial resolution to visualize collections of small objects. The 3–β Fusion EM Analysis, interestingly, does treat the groupings of shrapnel pieces in a way that allows them to be discriminated as "not projectiles." To a certain extent, this is the result of the size of the targets that were chosen for the Fusion analysis (i.e. both analyses excluded most targets on the basis of size, all βs are too small to be in the projectile class). In the cases where the magnetometry analysis designated a target for the dig list and the 3–β Fusion EM Analysis declared it as "not a projectile," the discrimination was based primarily on shape, not size. This is evidenced by 2 of the 3 βs falling within the 95% ellipsoid with the third falling outside.

Every live ordnance site on which we have worked is unique. Some have significant similarities, (i.e. the aerial bombing targets that have used only inert stores) others are highly heterogeneous with many different types of ordnance (and ordnance scrap) and varying levels of geological interference. On the Impact Area of the BBR, the EM survey data shows that the vast majority of clutter targets can be correctly classified as "not projectiles." However, we have not demonstrated that projectiles can be correctly classified while maintaining the successful classification of clutter as not ordnance. This can, of course, be accomplished only in a survey which contains both projectiles and clutter. The 3-β fusion analysis does, however, present a mathematically-sound, statistically-defensible rationale for distinguishing ordnance from clutter. On this site it was more successful in correctly classifying clutter than the more subjective (man-in-the-loop) decision making process used in the baseline *MTADS* magnetometry analysis.

The *MTADS* EM array potentially has the highest value when very small ordnance (20- and 30-mm) must be detected, when soil conditions are such that 60- and 81-mm mortars can penetrate to depths approaching one meter, and/or when highly volcanic soils are involved. In areas such as the Walker River Paiute Reservation adjacent to NAS Fallon, if all ordnance is required to be removed, the most economical approach would likely require the use of both magnetometer and EM array surveys.

5.7 Ordnance and Scrap Discrimination Based Only Upon Magnetometry Data. While the number of target digs in IA-S, IA-W and the remainder of IA-N was much higher than the number of actual recovered intact projectiles, the number of substantial magnetometer targets that the *MTADS* baseline DAS analyst was able to confidently recommend be left in the field was much more than 10 times higher than the number recommended for digging. The analyst's discrimination decisions were based upon:

- visual inspection of the gross target interpolated image (30 X 30 meter scale),
- rescaling of the 30 X 30 meter interpolated image (occasionally),

- fitting of possible dig target anomalies and visualization of the high-resolution pixel data and model fits,
- editing of complex signatures, if required, to remove clutter, and refitting edited data, and
- application of a minimum size threshold for target exclusion.

Consider the targets in Figure 23, which is typical of this site. Of the 50 targets with peak magnetometer signals well above 50 nT in this 0.75 acre area, only two (number 90 and number 109) were put onto the magnetometer dig list. The analyst confidently concluded that the remainder were "not ordnance." Based upon visual inspection of the interpolated image only 7 or 8 of the targets would have been chosen for analysis. These targets would have been boxed for initial fitting. If their fitted size exceeded the size threshold, the data in the boxed area would have been edited to remove second signatures or clutter objects and then the target would have been refitted. Only if (1) the refitted target exceeded the size threshold, (2) was apparently created by a single object, and (3) had a reasonable fit quality would it be a candidate for the dig list. This fitting, editing, and refitting process typically requires 1 to 3 minutes and is only be carried out on objects of borderline size with gross shapes and dipole signatures typical of an ordnance target. Two minutes spent excluding a target from the dig list is repaid several times over if it does not go onto a dig image, a dig list and into the TDC computer. Reacquiring and flagging the target, typically would require 2-5 minutes by the 2-man way pointing crew. Digging the target and clearing the hole would typically require 10-20 minutes by the 2 or 3-man dig crew (if the target was relatively shallow and if several shrapnel pieces had to be recovered and documented on the dig sheet). Larger, deeper targets, or deep false alarms due to magnetic soils or hot rocks require much more time to resolve.

6.0 COST ASSESSMENT

6.1 Cost Performance

Survey, remediation, and reporting costs are detailed in **Table 8**. Mobilization/logistics travel costs include transportation costs to and from the site and vehicle rental costs during the mobilization. Labor costs in this category include preparation of equipment for transport and labor to arrange logistics requirements. Miscellaneous costs include rental and repair costs for broken equipment. Survey and analysis costs include all labor costs for on-site survey, data analysis, and preparation of remediation documents. Also included are parts of the logistics costs directly related to these activities. The Remediation/disposal costs include labor costs for reacquiring/flagging targets, digging targets, blowing ordnance, stockpiling, sorting, and certifying OE scrap. Other costs include logistics costs directly related to these activities, costs of explosives and related materials, and costs of scrap disposal. The post analysis and reporting activities include costs incurred after all on-site activities were completed. They include analyses and mods in the *MTADS* DAS software to incorporate changes made during this demonstration. They also include the analysis, organization and writing costs, costs of making document revisions, and printing and distribution costs.

Table 8. ***MTADS*** **cost breakout for survey and target remediation on the Impact Area of the BBR.**

Mobilization/Logistics		Survey/Analysis		Remediation/Disposal		Post Analysis/Reporting	
Activity	**$K**	**Activity**	**$K**	**Activity**	**$K**	**Activity**	**$K**
Travel							
Hughes	3.3						
Geocenters	0.7						
AETC	6.5						
NRL	3.6						
EOTI	12.2						
Logistics							
Truck/Trailer	3.7						
Backhoes				Rental	5.2		
Fuel/Generator		*MTADS* Gas/Diesel	1.8	Diesel	1.8		
Shelter		Tents/Offices	4.0	Storage	1.2		
Hazardous Waste Hauler				Drums/Haul/Disposal	2.7		
Misc	6.2			Expl./Equip	4.9		
Labor							
Nova	1.8					Writing Support	5.0
Hughes	2.0	Survey Support	5.0	Way Pointing	2.5		
Geocenters	2.0	Survey Support	10.0				
AETC		On-site Analysis	18.0	Remediation Support	4.5	Analysis/Software Mods	21.0
EOTI				Dig/Blow/Scrap Cert	53.8		
NRL		Survey/Anal./Oversight	18.0	Way Pointing	3.0	Writing/Printing/Distributi	40.0
OST	0.7	Survey Support	11.3	Dig/Blow/Scrap Cert	6.6		
Total	43.7		62.1		86.2		66.0

If the mobilization/logistics costs are assigned to survey/analysis and remediation/disposal activities the relative production costs for these activities can be estimated. For this purpose the EOTI and one-half of the NRL travel costs were assigned to remediation/disposal, the remainder of the costs were allocated to the survey/analysis activities.

Using this division, the survey/analysis costs for this demonstration were $96.8K. A total of 153.5 acres were surveyed with the two arrays, giving a survey and analysis cost of $630/acre. These costs included carrying out all analyses on site and generating the survey products to support a concurrent remediation operation.

The target remediation/disposal costs were $100.2K. These costs include reacquisition and flagging of all targets for digging, digging the targets, clearing and refilling the holes, blowing of all ordnance in place, collection, sorting, certification and disposal of all OE scrap. Incidentally, also included are OST labor costs to support soil sampling from blast craters for explosives and metals analysis. From the magnetometry, analysis 362 targets were dug. In addition, from the fusion analysis, 109 targets were dug. The target remediation/disposal costs were $212.75 per target dug.

A total of 15 fuzed, HE-filled projectiles were discovered and destroyed. Separate from the subsequent reporting costs, the survey and remediation cost of $197K corresponds to a cost per discovered projectile of $13,300. With the exception of the immediate vicinity of the bull's eye and the area beneath and adjacent to the foundation of the destroyed homestead, we are confident that all ordnance 105-mm and larger have been removed from the surveyed areas.

6.2 Cost Comparisons

Cost comparisons can be made with more conventional technologies. A traditional Mag and Flag survey would likely be bid by a major UXO commercial service provider at $1,000-$1,500 per acre for this size demonstration. If the survey was comprehensively conducted using good magnetometers, and if the surveyors were instructed to flag <u>all</u> 105-mm (and larger) projectiles to their maximum penetration depths, it is likely that 6,000-10,000 targets would be flagged for digging on the area that the *MTADS* surveyed. This number is very large because in this environment determination of size or depth is very difficult, or impossible, when the targets are clusters of shrapnel from projectiles that have exploded after impact. Just surveying and flagging targets by Mag and Flag would likely cost $150K. Comprehensively digging the number of targets suggested above would likely be a million dollar job.

At the other extreme of traditional approaches for UXO clearances is the 1997 survey and clearance conducted by active duty Air Force EOD teams carried out in conjunction with the Ellsworth AFB Civil Engineering Squadron.[13-15] This operation surveyed almost 2,500 acres of the Impact Area. Since the labor of the active duty EOD staff was billed at no cost, the stated cost for the clearance was $180,650. As documented, this correlates with the relatively modest cost of $73.16 per acre for the clearance. On the basis of recovered ordnance, this operation expended $45,164.44 per recovered projectile (without labor costs). The downside of this approach is that it left effectively all the HE-filled and fuzed ordnance buried in the field.

It is a legitimate question as to what the costs of using other modern digitally-referenced UXO survey approaches might be at this site. Blackhawk-Geometrics, currently a fully-equipped *MTADS* UXO service provider, is bidding magnetometry survey jobs at $350-600 per acre depending upon the size and complexity of the job. This job site is almost ideal for vehicular towed-array surveys. It would likely be bid toward the lower end of the range. At this price, the survey product is just a target list with UTM coordinates. Reacquisition, flagging and digging costs are separate. One presumes that with the experience provided by this demonstration, future *MTADS* UXO surveys would have a similar, or better, performance record. Digging costs might be marginally reduced if a dig could be halted once it was shown that a flagged target was OE scrap (shrapnel) and there was no attempt to recover scrap. Overall, if the mandate is to recover all intact projectiles from the Impact Area, survey and remediation costs are unlikely to be significantly lower than those quoted for the *MTADS* demonstration.

7.0 REGULATORY ISSUES

The Impact Area of the BBR is a FUDS area. For the past several years environmental studies have been ongoing that would qualify the site for ultimate disposal and return to the OST.[16, 17] With the exception of the UXO issues raised in this report, all studies have resulted in relatively benign findings, none of which would impede ultimate disposal back to civilian control for unrestricted use. The demonstrated near-surface presence of live, HE-filled and fuzed ordnance requires appropriate mitigation, however, before disposal can take place. Because of the significant danger associated with these live and armed shells it is doubtful that the site can ever be confidently returned without restrictions relating to future use. Some form of institutional controls will likely have to be considered in the return of this area. This might include request for UXO assistance for any future digging operations. At the extreme, a decision will have to be made relative to certifying the land as suitable for the tilling associated with cultivated crops. Many of the recovered projectiles were buried at depths less than those typical for cultivation of row crops. There is the added consideration of what the effects of frost heave would be on these projectiles. All these issues should be considered before disposal is finalized.

8.0 TECHNOLOGY IMPLEMENTATION

8.1 DoD Need

This demonstration represents a head-to-head evaluation of the performance of traditional Mag and Flag UXO clearances in comparison with modern digital, geo-referenced, mapping surveys employing state-of-the-art sensors and analysis software. In this particular case, the Mag and Flag clearance was conducted by Air Force active duty EOD teams, effectively in a training exercise. A strong case can be made that this is an inappropriate use of active duty EOD detachments. The mission of these groups is the projection of force, creation of battlefield access for ground operations, and in some cases maintenance of active ranges. Their training appropriately centers around these activities. If they are going to do range clearance on FUDS/BRAC sites they should

be appropriately trained and their performance evaluated by application of QA/QC controls.

Traditionally, FUDS and BRAC clearances are contracted to civilian commercial concerns. In this scenario, performing contractors are required to demonstrate capabilities on qualifying prove-out sites containing the challenges that will be faced on the survey sites. Moreover, all commercial UXO clearance activities are evaluated against strictly-defined QA/QC performance standards. The contractor's work is not accepted until it is demonstrated that he has met the performance standard. These types of controls were not used in the 1997 Air Force EOD clearance.

It is becoming apparent that neither military nor commercial Mag and Flag survey operations can approach the performance standards consistently demonstrated by *MTADS*-type UXO survey. Moreover, until recently it was generally thought that the use of Mag and Flag surveys still represented cost advantages over automated towed-array surveys. On areas appropriate for the use of vehicle towed-arrays, their use is proving to be 2-3 times less costly than traditional Mag and Flag bid operations. When the quality of the survey products of the two approaches are compared there is no justification for conducting Mag and Flag surveys. The exception to this sweeping statement might be in situations where the terrain is just too difficult for the use of towed-arrays or man-portable adjuncts to these sensor arrays.

8.2 Transition

The *MTADS* has transitioned to a technology that is available as a commercial service.[28] The nearly-completed demonstrations for the Man-portable *MTADS* adjuncts using improved EM sensors will be available as a commercial service within a few months. Other companies, in addition to Blackhawk-Geometrics, are beginning to bid the use of automated towed-arrays for UXO surveys. Over the next few years others will inevitably enter the field with competitive approaches based upon advances made and demonstrated in these developments.

Currently, the greatest gains could be made if better discrimination could be made between ordnance and OE scrap. The work on this site represents an extreme situation in which we had to dig 362 targets to recover 15 intact projectiles. Digging 25 holes for each recovered projectile (at a cost of $225/hole) represents a potential for significant cost savings if digging decisions can be improved. Discrimination approaches (currently supported by ESTCP)[18] based upon simultaneous use of magnetometer and EM data were evaluated on this site. The 3-β Fusion analysis very convincingly classified more than 90% of the chosen targets as "not projectiles." Unfortunately, the discrimination performance could not be critically evaluated because no intact projectiles were included in the Fusion target data set. Other approaches incorporating different sensor data analysis approaches are still being developed and have yet to be evaluated.[19]

9.0 LESSONS LEARNED

The following suggestions are provided for consideration when planning *MTADS* (or other digitally-mapped geo-referenced) UXO surveys.

- Always, extensively and exhaustively pursue archived record searches to establish the scope of prior ordnance activities conducted on site,
- Establish good first-order survey benchmarks on site,
- Acquire current and historical aerial photography of the site,
- If the area was ever an active range, conduct a surface clearance preparatory to subsurface surveys,
- Acquire geophysical information about surface and subsurface soil types,
- Based upon the results of the surface clearance, be prepared to establish an on-site prove-out, particularly if ordnance is found which not in the current library,
- If the site is large, survey and dig a relatively small area (100 targets). Use the results to guide survey and analysis decisions for the remainder of the site,
- marking and digging targets on ranges using colored pin flags where cattle are present is problematical. Invariably, flags are removed or moved by cattle having a taste. A better solution which adds minimal time and cost needs to be found.
- Carry inventory of spare electronic parts and components to field activities. Be prepared to make repairs in the field.

10.0 REFERENCES

1. "*MTADS* TECHEVAL Demonstration," October 1996, H.H. Nelson, J.R. McDonald and Richard Robertson, NRL/PU/6110-97-348

2. "Results of the *MTADS* Technology Demonstration #2, Magnetic Test Range, Marine Ground Air Combat Center," Twentynine Palms, CA, December 1996, J.R. McDonald, H.H. Nelson, Russell A. Jefferies and Richard Robertson, NRL/PU/6110-97-349

3. "Results of the *MTADS* Technology Demonstration #3, Jefferson Proving Ground," January 1997, J.R. McDonald, H.H. Nelson, Russell Jeffries and Richard Robertson, NRL/PU/6110-99-375

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

5. "*MTADS* LIVE SITE DEMONSTRATION, Pueblo of Laguna, NM,6 July-7 August, 1998,"J.R. McDonald, H.H. Nelson, R. Robertson and R.A. Jeffries. NRL/PU/6110–00-398

6. "*MTADS* Demonstration at the Walker River Paiute Reservation, Schurz, NV," J.R. McDonald, H.H. Nelson, Russell A. Jeffries, NRL/PU/6110–00-406

7. "*MTADS* Demonstration at the Former Fort Pierce Amphibious Base", Vero Beach, FL, March 1998, J.R. McDonald, H.H. Nelson, R. Robertson, R.A. Jeffries and Karl Blankenship. NRLPU/6110-98-372

8. "*MTADS* Live Site Survey, Bombing Target #2 at the Former Buckley Field, Arapahoe County, CO, August 1998," J.R. McDonald, H.H. Nelson, R. Robertson, NRL/PU/6110–99-379

9. "Report of Clearance, Badlands Air Force Range (Oglala Tribal Lands) Air Force Logistics Command, United States Air Force, Wright-Patterson Air Force Base, Ohio, 21 November 1963

10. "Report of Clearance, Badlands Air Force Range, South Dakota, 21 September 1964," Ogden Air Materiel Area, United States Air Force, Hill Air Force Base, Utah, 2 October 1964

11. "Range Survey Report – Badlands Air Force Range, South Dakota, 2701st Explosive Ordnance Disposal Squadron (AFLC), Hill Air Force Base, Utah, May 1975

12. "Range Clearance Report, Badlands Air Force Range, South Dakota, 7 July 1975 to 5 December 1975," Capt. George J. Kishigian, 2701st Explosive Ordnance Disposal Squadron, Hill Air Force Base, Utah, 5 December 1975

13. HQ Air Combat Command Clearance Plan for the Badlands Bombing and Gunnery Range Impact Area (BBR-IA), submitted 23 December 1996

14. Approval of the HQ Air Combat Command Clearance Plan issued by the DDESB, 10 March 1997

15a. Range Decontamination Report, Chief, Explosive Ordnance Disposal Flight, Ellsworth Air Force Base, SD, 22 January 1999

15b. "Certificate of Clearance for the Badlands Bombing and Gunnery Range Impact Area (BBR-IA)," 28 CES/CED, Ellsworth Air Force Base, SD, 2 July 1999

16. "Final Field Sampling Plan, Preliminary Assessment/Site Investigation, Burial Site: Nos 1, 2, 3, 4, Former Badlands Bombing Range, Shannon & Jackson Counties, South Dakota., U.S. Army Corps of Engineers, Omaha District, Project No. 30400-4, 20 June 1996

17. "Preliminary Assessment/Site Inspection Report, Badlands Bombing Range-Impact Area;" Ellsworth AFB, SD; Draft-Final; U.S. Air Force Air Combat Command; Prepared for U.S. Army Corps of Engineers under Contract No. DACW 45-94-D-0001, Delivery Order 26, Project Number FXBM 98-7006, Rust Environmental & Infrastructure, January 1999

18. "Electromagnetic Induction and Magnetic Sensor Fusion for Enhanced UXO Target Classification," H.H. Nelson, P.I., ESTCP Project 199812

19. Model-Based Data Fusion & Discrimination of UXO in Magnetometry and EM Surveys," J.R. McDonald, P.I., SERDP Project CU-1092

20. "TECHNOLOGY DEMONSTRATION PLAN, *MTADS* Demonstration on the Impact Area of the Badlands Bombing Range," J.R. McDonald, 31 August 1999. An electronic copy of the Test Plan is included as an Appendix on CD Rom attached to this document

21. Dr. Anne Andrews, Institute for Defense Analyses, 1801 N. Beauregard St. Alexandria, VA, 22311

22. Mr. Del Petersen, 28th CES/CEVR, 2103 Scott Dr., Ellsworth AFB, SD, 57706

23. "QUALITY CONTROL SUMMARY REPORT (QCSR), in situ DETONATION OF MUNITIONS, Badlands Bombing Area- Impact Area, Ellsworth AFB, SD," Rust Environment & Infrastructure, Inc., DRAFT, November 1999

24. "Computer Program for calculation of complex chemical equilibrium compositions, rocket performance, incident and reflected shocks, and Chapman-Jouguet Detonations," S. Gordon and B.J. McBride, NASA SP-273, National Aeronautics and Space Administration, Washington, DC 1971

25. "Analysis of Magnetic and EMI Signatures from Impacted, Intact Ordnance and Exploded Fragments," Bruce Barrow and Herbert H. Nelson, Proceedings of the UXO Forum 2000

26. "Model-Based Characterization of EM Induction Signatures Obtained with the *MTADS* EM Array," Bruce Barrow and H.H. Nelson, IEEE Transactions On Geoscience and Remote Sensing, submitted

27. "Electromagnetic Induction and Magnetic Sensor Fusion for Enhanced UXO Target Classification," H.H. Nelson, ???, NRL/PU/6110--00-423, in press

28. Blackhawk Geometrics Web Site: http://www.blackhawkgeo.com

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