Report No. SFIM-AEC-ET-CR-96171

U.S. ARMY ENVIRONMENTAL CENTER
COMPLIANCE • RESTORATION • PREVENTION • CONSERVATION

Live Site Unexploded Ordnance Advanced Technology Demonstration Program

June 1996

DEPARTMENT OF THE ARMY
UNITED STATES OF AMERICA
1775

DISTRIBUTION STATEMENT A
Approved for public release
Distribution Unlimited

Distribution Unlimited; Approved for Public Release

AEC Form 45, 1 Feb 93 replaces THAMA Form 45 which is obsolete.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave Blank)

2. REPORT DATE
30 June 1996

3. REPORT TYPE AND DATES COVERED

4. TITLE AND SUBTITLE
Live Site Unexploded Ordnance Advanced Technology Demonstration Program

5. FUNDING NUMBERS

6. AUTHOR(S)

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Naval EOD Technology Division
UXO Countermeasures Department
2008 Stump Neck Road
Indian Head, MD 20640-5070

Proj. Mgr.:	Gerard Snyder	301/743-6850, ext. 260
Sr. Engr.:	Hien Dinh	301/743-6850, ext. 267

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

U.S. Army Environmental Center
Aberdeen Proving Ground, MD 21010-5401

Proj. Off.: Kelly Rigano 410/612-6868

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
SFIM-AEC-ET-CR-96171

11. SUPPLEMENTARY NOTES

Supporting Contractors:

PRC Environmental Management, Inc.
200 East Randolph Drive
Suite 4700
Chicago, IL 60601

PRC Inc.
801 N. Strauss Avenue
Indian Head, MD 20640

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Unlimited distribution

12b. DISTRIBUTION CODE
"A"

13. ABSTRACT (Maximum 200 words)

The report summarizes the results of live site unexploded ordnance advanced technology demonstrations (ATD) conducted from May through November 1995 at Jefferson Proving Ground, Indiana; Yuma Proving Ground, Arizona; Eglin Air Force Base, Florida; Fort Jackson Military Reservation, South Carolina; and McChord Air Force Base, Washington. The purpose of this Congressionally-mandated program was to evaluate unexploded ordnance (UXO) detection technologies that had already been tested within a controlled environment. The technologies were evaluated under different topographic, geologic, and climatic settings at military ranges containing actual but unknown quantities of UXO. The report summarizes data gathered during the live site ATDs. The report will make it possible for technology users and developers to (1) identify capable technologies for UXO cleanup efforts, (2) establish achievable policy directed toward UXO clearance, (3) conduct more realistic cost-benefit analyses, and (4) identify research and development projects that will yield the greatest return on investment.

14. SUBJECT TERMS
Live Site, Advanced Technology, Innovative Technology, Technology Demonstration, Unexploded Ordnance, Munitions, Detection, Characterization, Classification, Magnetometer, Electromagnetic Induction, Ground-Penetrating Radar, Cleanup, Remediation

15. NUMBER OF PAGES

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	Unlimited

NSN 7540-01-280-5500

Standard Form 298 (Rev 12-94)
Prescribed by ANSI Sta 239-18
298-102

DTIC QUALITY INSPECTED 4

Report No. SFIM-AEC-ET-CR-96171

Live Site Unexploded Ordnance Advanced Technology Demonstration Program

June 1996

Distribution Unlimited; Approved for Public Release

This Page Intentionally Left Blank

TABLE OF CONTENTS

Section Page

TABLE OF CONTENTS
(continued)

TABLE OF CONTENTS
(continued)

Section Page

LIST OF APPENDIXES

Appendix

LIST OF FIGURES

LIST OF FIGURES
(continued)

LIST OF TABLES

LIST OF TABLES
(continued)

This Page Intentionally Left Blank

EXECUTIVE SUMMARY

This report presents the results of the live site unexploded ordnance (UXO) advanced technology demonstration (ATD) project, which was conducted at five active or formerly active military impact ranges. The purpose of the overall UXO ATD program is to assess the capabilities of state-of-the-art UXO detection, classification, and remediation technologies. Performance data from the ATDs can be used by the Government to select effective and efficient systems for UXO clearance to address the global UXO problem.

Problem Statement and Description of the UXO Clearance Technology Program

The pervasive and persistent problem of UXO at former battle sites, military practice ranges, and mine fields affects hundreds of thousands of civilians worldwide. In the United States alone, more than 4 million hectares (11 million acres) of land used by the Department of Defense (DoD) for military training and testing activities are known or are suspected to contain UXO. Some of this land has been identified for base realignment and closure, some is on formerly used defense sites, and some is on active installations considering alternate uses for areas containing UXO. DoD has estimated that UXO cleanup efforts in the United States alone may cost tens of billions of dollars.

In addition, more than 60 countries report a need to remediate a wide range of UXO problems, including land mines and ordnance from World Wars I and II. As of December 1994, the U.S. State Department estimated that 80 to 110 million land mines remain uncleared, resulting in about 10,000 deaths and 30,000 injuries each year worldwide. The UXO problem is compounded in developing countries where land containing UXO cannot be used for agriculture.

In response to the need for UXO clearance, the U.S. Army Environmental Center (USAEC) and the Naval Explosive Ordnance Disposal Technology Division (NAVEODTECHDIV) established the UXO Clearance Technology Program to demonstrate, evaluate, and characterize advanced technologies that can be used to address the global UXO problem.

Program Objective and Program Background

In recent years, the U.S. Congress has recognized the need for UXO clearance technology development and demonstration. In fiscal year 1993, USAEC's UXO clearance technology program responsibilities were greatly expanded by congressional mandate to demonstrate and evaluate the performance of commercially available and government-enhanced systems designed for UXO clearance. In 1994, USAEC created a controlled test site containing inert ordnance at U.S. Army Jefferson Proving Ground (JPG), Indiana.

A series of Phase I controlled site ATDs were conducted at JPG in 1994 to establish a baseline for UXO detection and remediation system performance. Congress appropriated additional funding to continue the program during a second phase and to evaluate the performance of selected technologies at live impact ranges. The objectives of the controlled and live site ATDs include identifying and establishing off-the-shelf and innovative technologies for UXO detection, classification, and remediation; establishing a technology performance baseline; and defining the current state of the art of UXO technology.

Live Site Advanced Technology Demonstration Objectives and Process

All UXO clearance technology firms that participated in the Phase I controlled site ATDs were invited to participate in the live site ATDs. After evaluating the bidder proposals based on the requirements outlined in the request for proposal, the Government invited nine technology vendors to participate in the live site ATDs; eight firms elected to participate (see Table ES-1). These firms demonstrated magnetometer systems, ground penetrating radar (GPR) systems, and GPR systems paired with electromagnetic induction (EM) systems (multisensor systems). The different systems were mounted on a variety of man-portable, vehicle-towed, and aerial platforms.

In response to the Congressional mandate, the Government evaluated many military ranges for use as live site ATD ranges. Five installations were selected for the ATDs, including JPG, Indiana; U.S. Army Yuma Proving Ground (YPG), Arizona; Eglin Air Force Base (AFB), Florida; U.S. Army Fort Jackson Military Reservation (Fort Jackson), South Carolina; and McChord AFB, Washington (see Figure ES-1).

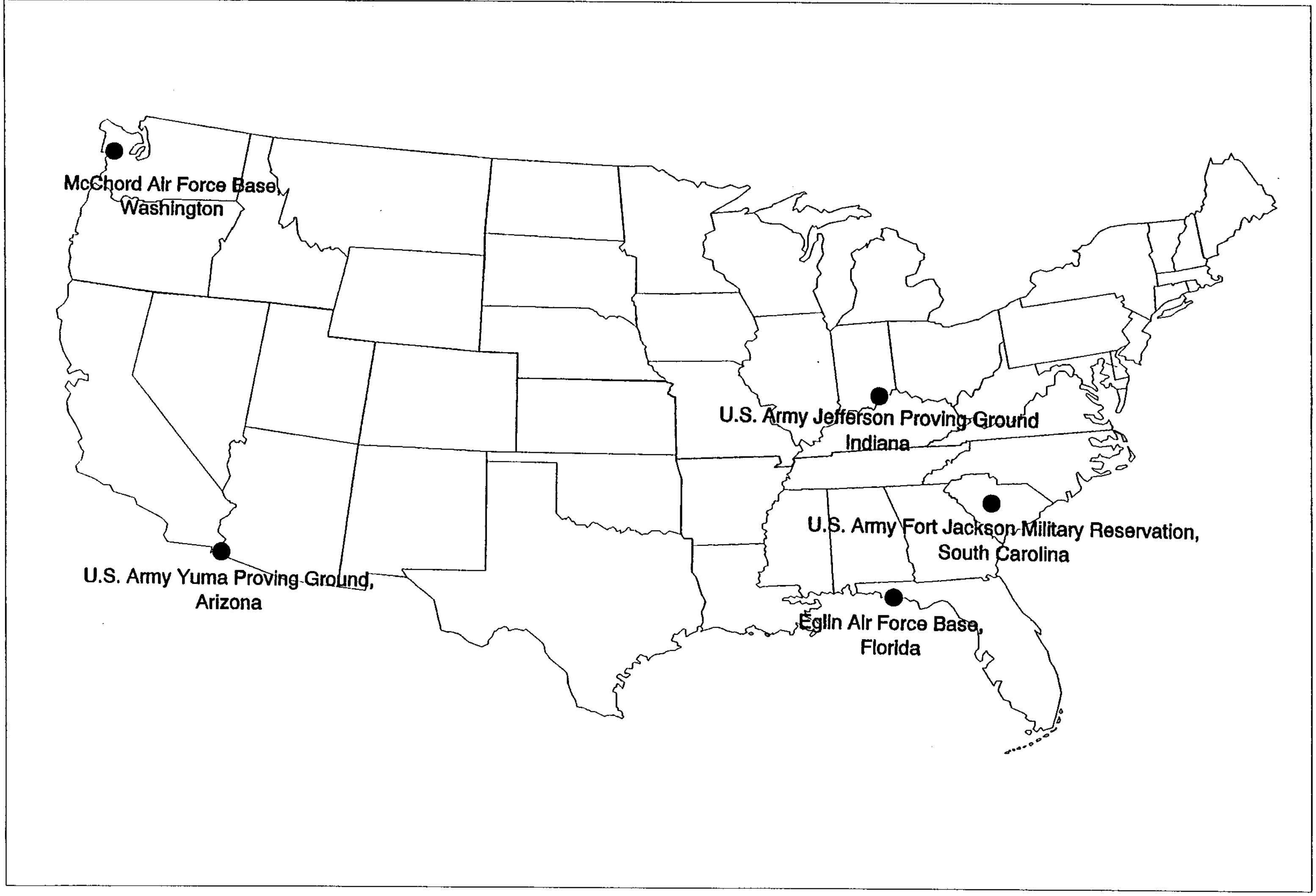
Table ES-1
Summary of Detection Systems Demonstrated

	Platform						
	Ground		Aerial		Sensor System		
Demonstrator	Vehicle-Towed	Man-Portable	Rotary-Wing	Fixed-Wing	Magnet-ometer	GPR[a]	EM[b]
Aerodat, Inc.			✓		✓		
Australian Defence Industries, Pty. Ltd.		✓			✓		
Chemrad Tennessee Corporation		✓			✓		
Coleman Research Corporation	✓	✓				✓	✓
Geo-Centers, Inc.	✓	✓			✓		
Metratek, Inc.	✓					✓	✓
SRI International, Inc.				✓		✓	
Vallon GmbH	✓	✓			✓		

Notes:

a Ground penetrating radar (GPR)
b Electromagnetic induction (EM)
c Differential global positioning system (GPS)

Figure ES-1
Live Site Location Map



To evaluate the effectiveness of systems in locating and classifying UXO, areas of 24 to 120 hectares were prepared at the sites. Various inert ordnance items, known as the baseline target set, were buried at precisely defined locations, depths, and orientations that are typical of positions expected of live ordnance fired or dropped on the sites. In addition, nonordnance was buried at some sites; these nonordnance items included ordnance fragmentation, ammunition cans, and other steel objects. All demonstrators were allowed between 80 and 120 hours to survey up to 120 hectares. Detection system data were then compared to the baseline target locations to determine which systems were more effective at detecting the known UXO targets. Some demonstrator target declarations that did not correspond with the baseline target set were excavated by Government-developed systems designed for UXO recovery. These excavations provided a validation tool to measure demonstrator declarations at locations where UXO was not emplaced.

Measured Performance Results

The data presented in this report should be considered in light of the testing and evaluation goals of this project; while some technologies clearly outperformed others, each of the technologies represents promising new approaches to solving the worldwide UXO problem. In addition, these data are representative only of each demonstrator's performance at the live sites where surveys were conducted. Demonstrator performance at other sites with different environmental characteristics will most likely vary from the performance summarized in this report. As a result, the data presented herein should not be solely used to evaluate demonstrator abilities under different environmental conditions.

Table ES-2 summarizes demonstrator performance with respect to baseline target detection, localization, and field survey rate. Figure ES-2 compares Phase I controlled site ATD performance with live site ATD performance. Figure ES-3 depicts demonstrator detection capability by plotting the demonstrator probability of detection for ordnance ($P_{D,ord}$) against the P_{random} statistic (a measure of performance to compare demonstrator results with the results of a hypothetical demonstrator making random target declarations). Demonstrators plotted toward the upper left corner of Figure ES-3 are preferred over demonstrators near or below the bold line in the figure.

Table ES-2
Summary of Demonstrator Measures of Performance

Site	Demonstrator	Detection		Localization			Field Survey Rate (hectares/hour)	Cost per Unit Area Surveyed ($/hectare)
		$P_{D,ord}$	P_{random}	Radial Error (meters)	Mean Depth Error (meters)	Mean Square Depth Error (meters)		
JPG	Aerodat	0.07	0.11	4.25	0.78	0.61	1.52	1,059
	ADI	0.71	0.08	0.68	0.08	0.16	1.01	2,137
	Coleman	0.54	0.18	1.14	0.31	1.20	0.67	3,671
YPG	Geo-Centers	0.60	0.21	0.89	0.20	0.61	0.89	3,950
	Metratek	0.30	0.08	1.13	0.69	0.92	0.56	6,084
	SRI	0.00	0.02	—[a]	—	—	7.58	3,250
Eglin AFB	Coleman	0.55	0.40	1.30	0.14	2.27	0.39	6,154
	Vallon	0.74	0.59	1.09	0.09	0.89	0.33	5,669
Fort Jackson	ADI	0.69	0.12	0.73	-0.80	0.97	0.76	2,290
	Geo-Centers	0.45	0.21	0.75	0.00	0.33	0.44	5,255
	SRI	0.00	0.01	—	—	—	18.20	1,786
McChord AFB	Chemrad	0.14	0.14	1.22	0.26	0.66	0.30	10,209
	Metratek	0.61	0.05	1.13	0.14	0.43	0.31	10,653

Note:

a Statistic could not be calculated (—) because the demonstrator did not detect any baseline targets.

Figure ES-2
Demonstrator Performance History

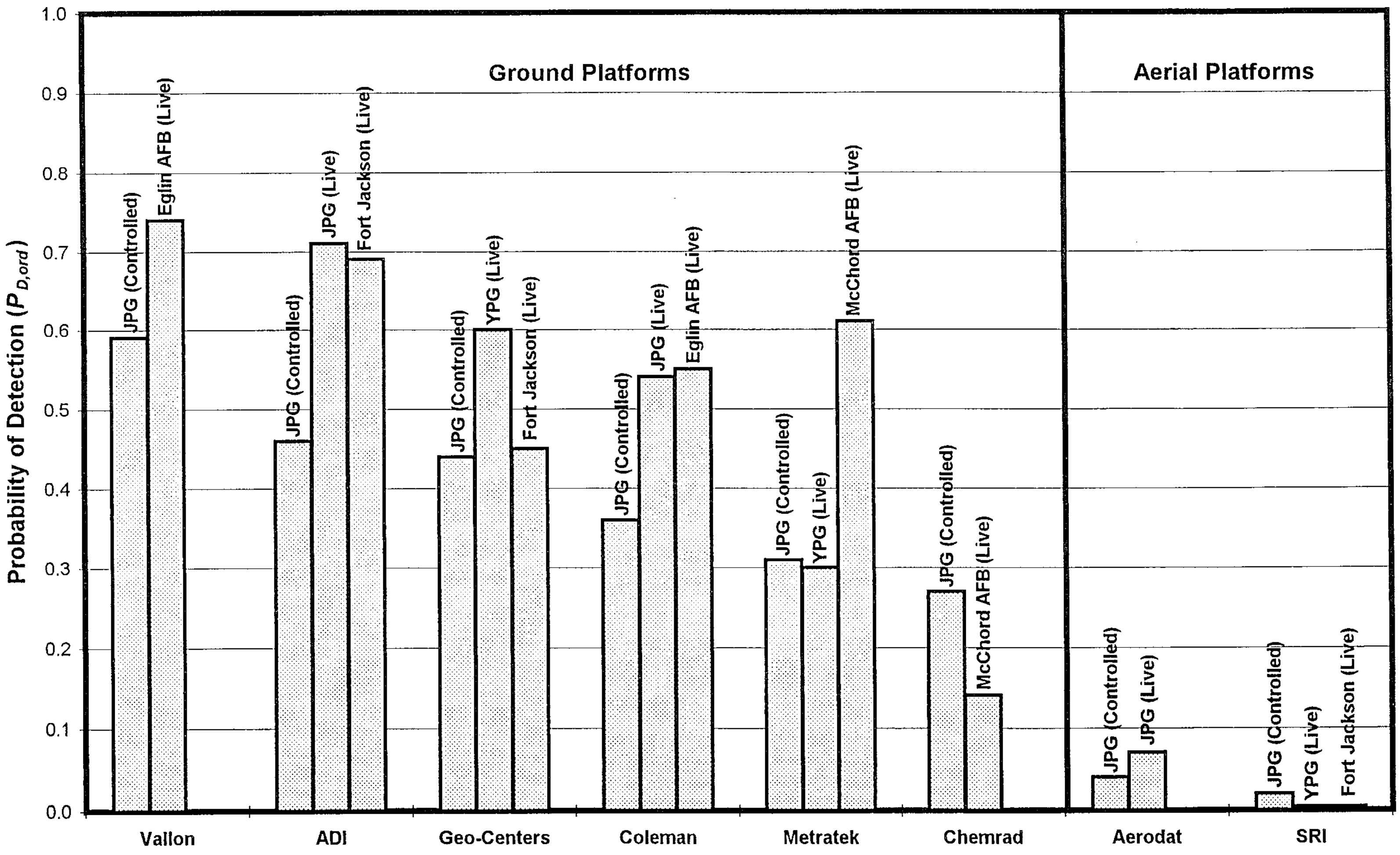
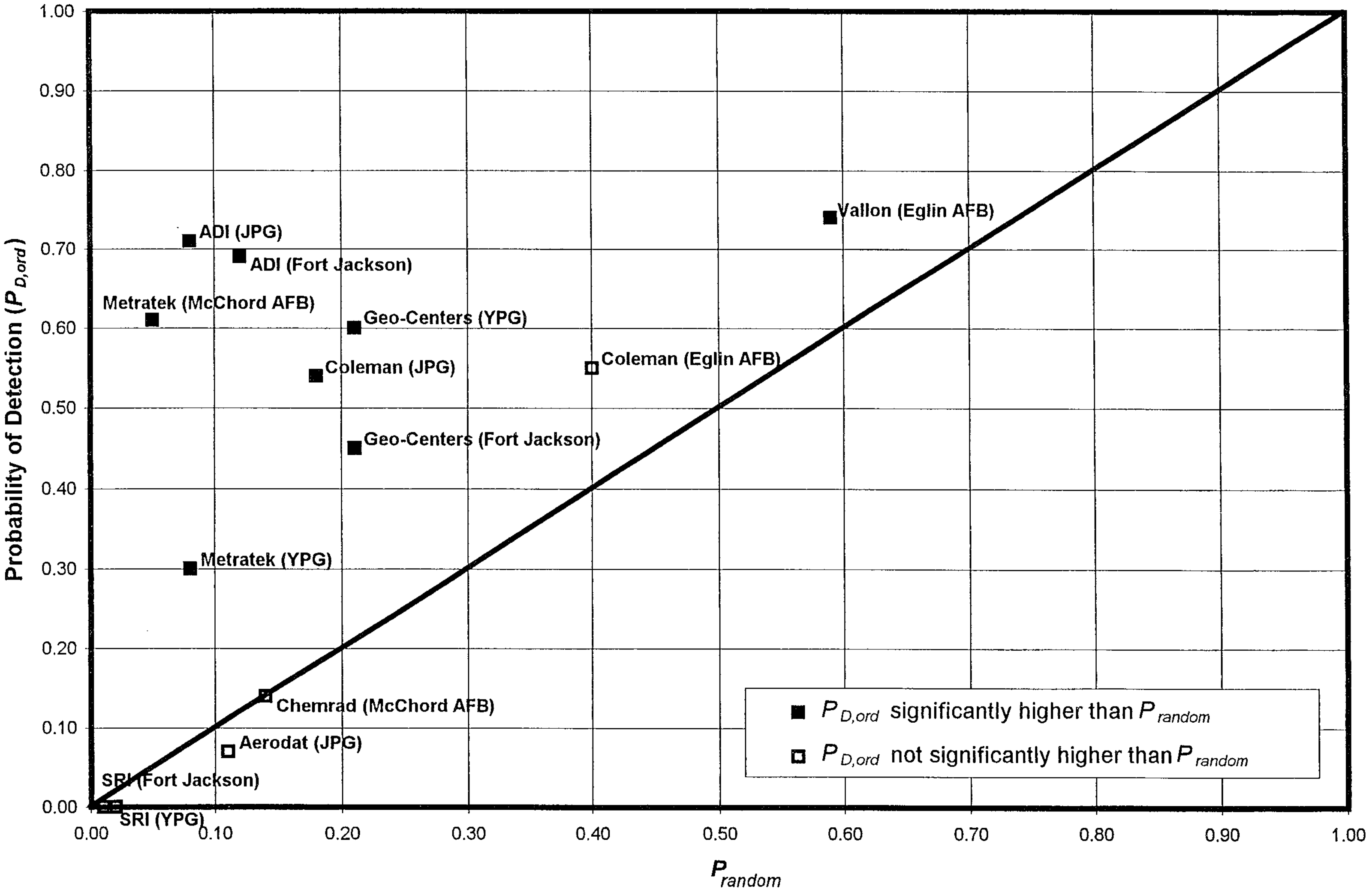


Figure ES-3
Plot of $P_{D,ord}$ vs. P_{random} by Demonstrator



Based on these data, several conclusions can be drawn. First, technology vendors have not significantly improved their target detection capabilities since they demonstrated at the Phase I controlled site ATDs. Ground platform magnetometer and multisensor systems had similar detection capabilities, with a $P_{D,ord}$ range of 0.14 to 0.74. Of the 10 ground platform demonstrations, only 5 had $P_{D,ord}$ values of 0.60 or higher. The utility of aerial platforms for subsurface UXO detection has not been proven; aerial platform demonstrator performance was no better than that expected for random target declarations at a site.

The ground platforms had similar localization capabilities. All ground platform demonstrators were able to localize targets to within 1.2 meters radially; man-portable systems localized targets to within 0.75 meter. All ground platform demonstrators (except Coleman) had mean square depth errors of 1 meter or less. Localization capabilities for aerial platform demonstrators were not evaluated because of the few baseline targets detected by these systems.

Only one demonstrator classified baseline target type (ordnance or nonordnance), and only four of the eight demonstrators classified baseline targets by size (large, medium, or small) and class (bomb, mortar, projectile, cluster, or submunition). In general, these four demonstrators properly classified small targets more than targets in other size categories. They also correctly classified projectiles more often than other target classes.

All remediation systems were capable of excavating targets; excavation rates averaged about 1 to 4 hours per hole excavated.

Field Performance: Terrain was the primary factor in determining survey rate. Man-portable systems could access vegetated, muddy, and rutted areas that could not be accessed by the vehicle-towed systems. There was no appreciable difference in survey rates for ground platforms; man-portable systems were able to survey sites at about the same rates as vehicle-towed systems. Overall, ground platform systems had field survey rates of about 0.3 to 1 hectare per hour. Aerial systems had the fastest survey rates (up to 18 hectares per hour), but they had essentially no detection capabilities.

The excavation systems were all capable of excavating ordnance and nonordnance targets. However, they all experienced delays in the excavation process, usually due to radiofrequency or differential global positioning system (GPS) interference.

Summary

Currently available site characterization and remediation tools are not adequate to effectively and economically respond to the UXO problem. First, survey rates for the fastest systems are on the order of 1 hectare per hour (which is higher than at the Phase I and Phase II controlled site ATDs). At this rate, UXO surveys at large sites will not make efficient use of resources. Second, classification ability is poor; many of the targets recovered during the validation process were nonordnance, making the effort spent to excavate the targets more costly than necessary to excavate UXO. Third, the excavation process itself is slow, limiting the site clearance process to a great degree.

As it becomes necessary to address the growing number of UXO sites worldwide, advanced technologies will be needed to assist in site restoration and the risk reduction process. The UXO ATD program constitutes an important first step in a series of testing and evaluation projects to help meet this need. The live site ATD project confirmed several key technology issues identified during the controlled site ATD project; it also identified several other issues related to the site survey process at uncontrolled sites. Some of the more significant issues can be summarized as follows:

- Detection capability must be improved. The results of the live site ATDs show that current technology does not meet the Government's need for safe, effective, and reliable detection of subsurface UXO. Although some demonstrators showed slightly better detection capabilities at the live site ATDs than at the Phase I controlled site ATD, their capabilities were statistically comparable.

- Classification ability must also be improved. Current technology has not demonstrated the ability to discriminate between UXO and non-UXO items such as debris and ordnance fragmentation. However, many non-UXO items are found at live ranges. Furthermore, the demonstrated technologies did not exhibit any significant ability to classify UXO targets by size or class.

- The effects of soil type, ground clutter, and other environmental conditions on system performance should be quantified through further testing. Demonstrator performance at the live sites was consistent with the JPG Phase I controlled site ATDs, even though site conditions varied greatly from the JPG controlled site. Correlations between sensor performance, site soils, and other environmental conditions were not readily observed at the live sites.

- The performance of aerial systems must be improved drastically. The two aerial platform demonstrators that participated in the live site ATDs used different sensor types and conducted the surveys under optimum conditions. Neither system reliably detected subsurface UXO, which is consistent with the findings of the Phase I controlled site ATDs. However, aerial systems exhibit the potential to survey very large areas quickly, efficiently, and safely.

- The benefits of surveying a site using complementary man-portable and vehicle-towed systems should be evaluated. Man-portable systems had survey rates as high as the vehicle-towed systems, with lower survey costs per unit area. In addition, man-portable systems are less prone to breakdown and can be used to survey areas that are difficult to access by the vehicle-towed systems. However, vehicle-towed systems allow for real-time data analysis with on-board computers. In addition, vehicle-towed systems provide more safety to the survey team than man-portable systems, protecting them from the elements as well as distancing them from UXO on the ground.

- Improvements in remediation system performance, including target acquisition speed and excavation efficiency, must be realized. Although current UXO remediation technologies offer more safety to heavy equipment operators and other field personnel because of their remote control capabilities, they are slow, inefficient, and expensive.

The live site ATD project provided the Government with a unique opportunity to evaluate the performance of several technologies under varying geophysical and other environmental conditions. The results of this program showed that demonstrator UXO detection performance is comparable to that of the JPG Phase I controlled site ATDs. Current technology does not meet the Government's needs for safe, effective, reliable, and cost-effective UXO clearance. Even when operating in favorable conditions, the systems did not demonstrate a high detection capability. Moreover, none of the systems were able to reliably classify the UXO that was detected. The remediation process was slow and often exposed equipment operators to hazards that could have been mitigated with improved technology.

To address the UXO problem, the Government must continue to evaluate the capabilities and limitations of available and developing UXO detection and remediation technologies. To help in this effort, this report will make it possible for technology users and developers to (1) identify capable technologies for UXO cleanup efforts, (2) establish achievable policy directed toward UXO clearance, (3) conduct more realistic cost-benefit analyses, and (4) identify research and development projects that will yield the greatest return on investment.

This Page Intentionally Left Blank

1.0 INTRODUCTION

The pervasive and persistent problem of unexploded ordnance (UXO) at former battle sites, military practice ranges, and mine fields affects hundreds of thousands of civilians worldwide. In the United States alone, more than 4 million hectares of land that have been used by the Department of Defense (DoD) for military training and testing activities contain UXO. The types of UXO at these sites range from centuries-old cannonballs to more current ordnance, including rockets, projectiles, bombs, mortars, submunitions, and mines.

UXO clearance is a high priority issue for all branches of the DoD. In fact, in a 1994 survey of the military branches, UXO contamination was ranked as a high priority issue by 44 percent of all Army, 35 percent of all Navy, and 36 percent of all Air Force respondents (DoD 1994). In support of this need, the U.S. Army Environmental Center (USAEC) has established and currently manages the UXO Clearance Technology Program. The goal of this program is to enhance, demonstrate, and evaluate UXO detection, classification, and remediation technologies to give the Government more reliable, accurate, safe, and cost-effective methods for UXO clearance. USAEC has designated the Naval Explosive Ordnance Disposal Technology Division (NAVEODTECHDIV) as the technical lead for this program.

1.1 PROGRAM BACKGROUND

In response to the 1992 congressional mandate in House Resolution (HR) 5504, USAEC and NAVEODTECHDIV established the Advanced Technology Demonstration (ATD) program to identify and evaluate technologies for UXO detection, identification, and remediation (USHR 1992a). In 1994, USAEC and NAVEODTECHDIV created two controlled demonstration sites at the U.S. Army Jefferson Proving Ground (JPG) in Madison, Indiana.

Phase I of the controlled site ATD program was conducted from April through October 1994; 29 detection and remediation systems participated in the controlled site ATDs. The types of sensors tested included magnetometer, electromagnetic induction (EM), ground penetrating radar (GPR), and infrared (IR) sensors, as well as several combinations of these sensor types. The sensors were mounted on man-portable, vehicle-towed, combined man-portable and vehicle-towed (multimodal), and airborne platforms.

The Phase I controlled site ATDs made it clear that the state of the art in UXO clearance technology is much less practical than was previously thought. To continue the technology assessment process, Phase II controlled site ATDs were conducted from May through September 1995. Details about the Phase I and Phase II controlled site ATDs are provided in the reports documenting the ATDs (IDA 1995; USAEC 1994, 1996).

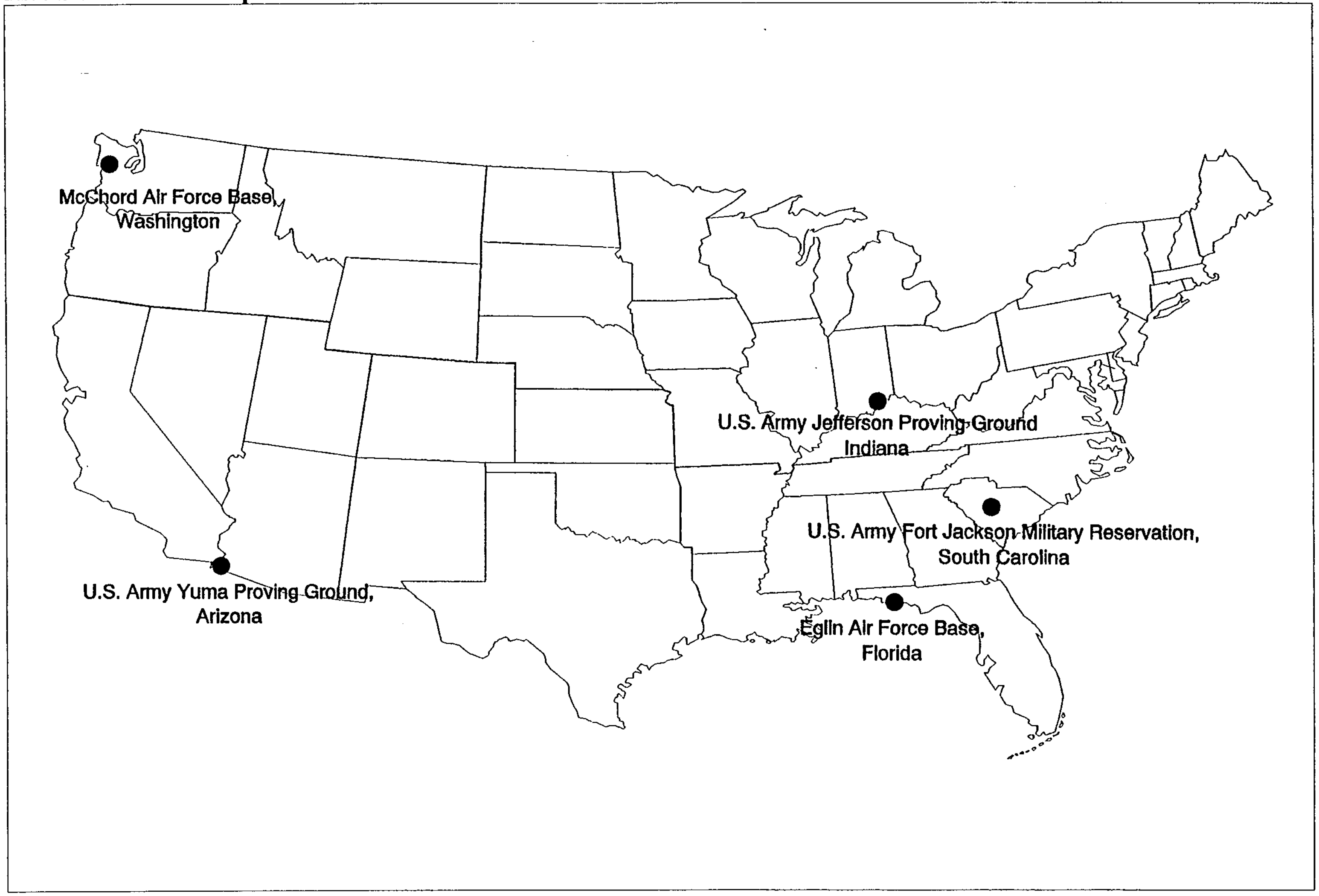
Concurrent with the Phase II controlled site ATDs, several technologies tested during the Phase I controlled site ATDs were evaluated in live ordnance environments. These live site ATDs were conducted from May through November 1995 at five active or formerly active DoD training ranges. This report documents the live site ATDs.

The ranges used for the live site ATDs were selected from the many potentially available DoD sites based on a variety of factors. The sites represent areas that are geologically, topographically, and climatically diverse, and they contain varying types and quantities of UXO. Sites selected for the live site ATDs include JPG, Indiana; U.S. Army Yuma Proving Ground (YPG), Arizona; Eglin Air Force Base (AFB), Florida; U.S. Army Fort Jackson Military Reservation (Fort Jackson), South Carolina; and McChord AFB, Washington (see Figure 1-1). Section 2.0 provides more information about the live sites and describes how they were selected.

Nine UXO detection systems were chosen to conduct a total of 14 UXO surveys at the live sites. However, only eight demonstrators opted to participate in the program; these eight demonstrators conducted 13 live site ATDs at the five sites. Five demonstrators conducted two live site ATDs each; the other three demonstrators conducted one live site ATD each. The following firms participated in the live site ATD project:

- Aerodat, Inc. (Aerodat)
- Australian Defence Industries, Pty. Ltd. (ADI)
- Chemrad Tennessee Corporation (Chemrad)
- Coleman Research Corporation (Coleman)
- Geo-Centers, Inc. (Geo-Centers)
- Metratek, Inc. (Metratek)
- SRI International, Inc. (SRI)
- Vallon GmbH, in partnership with Security Search Product Sales, Inc. (Vallon)

Figure 1-1
Live Site Location Map



To validate some of the demonstrator target reports, four remediation technologies conducted excavation activities at the sites. The U.S. Air Force/Wright Laboratory (USAF/WL) used its autonomously operated excavator (AOE) system at JPG and Fort Jackson. At YPG, Eglin AFB, and McChord AFB, installation explosive ordnance disposal (EOD) personnel conducted remediation activities using installation-specific excavator systems. Section 3.0 thoroughly describes the detection and remediation systems that conducted work at the live sites and discusses how the detection systems were selected for the live site ATDs.

The detection system demonstrators were required to conduct UXO surveys at the live sites, covering (1) areas where inert ordnance had been emplaced for demonstrator evaluation and (2) areas containing unknown quantities and types of UXO. Demonstrators were required to submit target declaration lists containing target location (latitude and longitude); depth; type (ordnance or nonordnance); class (bomb, cluster, mortar, projectile, or other); size (large, medium, or small); and demonstrator confidence in the reported target's existence (high, moderate, or low). To ensure data uniformity, each demonstrator was required to submit its data in a standardized data entry format using Microsoft® Excel® software.

Measures of performance were developed to provide a technically meaningful framework for assessing demonstrator performance. The measures were based on a target-matching algorithm (TMA) developed for this project and were expressed as probabilities of detecting (P_D) and correctly classifying (P_C) the emplaced ordnance. Demonstrator data were analyzed using the TMA, which is described in Section 4.0.

Demonstrator performance data are presented in Section 5.0 and analyzed in Section 6.0. Conclusions are presented in Section 7.0. The following appendixes supplement the information presented in this report:

- Appendix A contains the baseline target sets against which demonstrator performance was measured.
- Appendix B contains the validation target sets; these target sets contain the list of items recovered from the live sites when demonstrator target declaration locations were excavated.
- Appendix C contains a description of one of the statistics used in demonstrator performance evaluation (P_{random}).
- Appendix D contains information about the efforts expended by military EOD teams to prepare the live sites and conduct validation activities.

- Appendix E contains maps showing demonstrator target declaration densities at each of the live sites.

1.2 PROGRAM AND PROJECT OBJECTIVES

The primary purpose of the ATD program is to obtain baseline system capability and performance data on various UXO detection, identification, and remediation technologies. The purpose of the live site ATDs is to evaluate detection technologies that had already been tested within a controlled environment under different topographic, geologic, and climatic settings at ranges containing actual but unknown quantities of UXO.

At the live sites, detection system demonstrators were required to report the locations and characteristics of inert ordnance targets emplaced on the sites as well as unknown, possibly live ordnance targets. To provide limited validation of detection system performance, subsets of each demonstrator's declared targets were excavated using various remediation systems.

Detailed performance and reliability data were gathered during the live site ATDs to provide potential technology users with adequate information to make sound judgments regarding a technology's applicability to a specific site. The objectives of the live site ATDs include evaluating each UXO detection system technology in the following areas:

- Ability to locate and classify known and unknown targets
- Ability to operate within the constraints of the site topography, geology, climate, and other unique site characteristics
- Requirements for logistics and resource support
- Performance compared with other live site ATD demonstrators
- Performance compared with past performance at the Phase I controlled site ATD

Data obtained from the demonstrations can be used to help decision makers select effective UXO detection technologies to support DoD's cleanup efforts. This report summarizes the data for technology developers and cleanup technology end users by (1) evaluating overall system and technology performance, (2) evaluating individual sensor performance, and (3) suggesting potential directions for future sensor technology development.

2.0 DESCRIPTION OF LIVE SITES AND PROJECT

For the live site ATD project, Congress mandated that five sites containing or suspected to contain UXO be selected for demonstration activities. The following selection criteria were used:

- The sites were to represent varying geologic and soil conditions. Sites having glacial soils, ocean sediment deposits, and desert environments were considered for the live site ATDs. These sites contained soils that often consisted predominantly of gravel, sand, or silt and clay mixtures. In addition, sites with varying levels of magnetic noise were evaluated.
- The types of UXO at the sites were to be different, and the ranges selected were to have differing uses. Mortar impact ranges, artillery ranges, bombing ranges, and air-to-ground ranges were considered during the site selection process.
- Property use was to be considered. Active and inactive ranges as well as ranges of progressively different use were to be evaluated.
- Logistics support was to be considered. Installations with the ability to provide considerable support to the project were favored over those that could not.
- Facility needs were to be evaluated. Installations with needs for UXO surveys at various ranges were given priority over those installations with no particular need for limited site assessment.
- Ranges with sizes of 120 to 200 hectares were to be selected for the live site ATDs, if possible. Because most installations could not provide this much area for the demonstrations, other factors were weighted more heavily in the site selection process.

2.1 SITE BACKGROUND INFORMATION

The following subsections provide general background information about each of the five live sites selected for the live site ATDs, including topography, soils, geology, climate, and historic site use.

2.1.1 Jefferson Proving Ground

JPG is located in southeastern Indiana within Jefferson, Ripley, and Jennings Counties. The proving ground is located about 8 kilometers (km) north of Madison, Indiana, and about 11 km north of the Indiana-Kentucky border. JPG has been used as a U.S. Army proving ground since 1941. Based on available historic data, more than 27 million munition items were tested on its ranges between 1941 and

1995. The Army estimates that 1.5 million UXO items may still exist at the installation. Ordnance size varies from small-caliber firearm projectiles to 2,000-pound bombs (Mason & Hanger 1992).

Parts of two adjacent, inactive impact ranges were selected for the live site ATDs at JPG. These ranges include Ranges 21000 West and 18000 West (21000W and 18000W, respectively) (see Figure 2-1). About 26.2 hectares of Range 21000W and about 151.2 hectares of Range 18000W were used for the ATDs. Based on site features such as tree lines and roads, Range 18000W was separated into three parts for the demonstration. The first part, Range 18000W (Main), has an area of 54.1 hectares.[1] The second part, Range 18000W (Birdfoot), has an area of 6.3 hectares. The third part, Range 18000W (Aerial), has an area of 90.8 hectares. When considered collectively, the parts are referred to simply as Range 18000W.

Range 21000W is a clear, grassy field. The range is bordered by K Road to the south, Shape Charge Road to the west, and heavily wooded areas to the north and east. Heavily wooded areas also lie beyond K Road to the south and beyond Shape Charge Road to the west.

Portions of Range 18000W consist of clear, grassy fields, and other parts of the range are sparsely to heavily wooded. Range 18000W is bordered to the north by K Road and by wooded areas to the east, south, and west. The east portion of Range 18000W is heavily wooded; sparsely wooded areas are located on the south end of Range 18000W. Emergency Landing Field Road passes through Range 18000W. Aboveground utility cables are located along the south side of K Road.

Topography, Soils, and Geology: JPG is in the Muscatatuck Regional Slope physiographic province of southern Indiana. Topography at JPG is gently rolling, and surrounding land is primarily agricultural. Soils at JPG are primarily silty loams (Nutting 1995a; USDA 1982), and bedrock consists of cherty and dolomitic limestones of Silurian age (Gray 1972). Bedrock is at least 5 meters below ground surface at the demonstration sites.

Climate: The climate at JPG is characteristic of areas in the midlatitude United States. Summers are warm, and winters are cool. The average annual temperature at nearby Madison is about 14.0 degrees Celsius (°C), while the average annual precipitation is about 112 centimeters (cm) (WIC 1974a). During the demonstration period, the average daily temperature was 21.3 °C, and the average daily maximum temperature was about 26.9 °C.

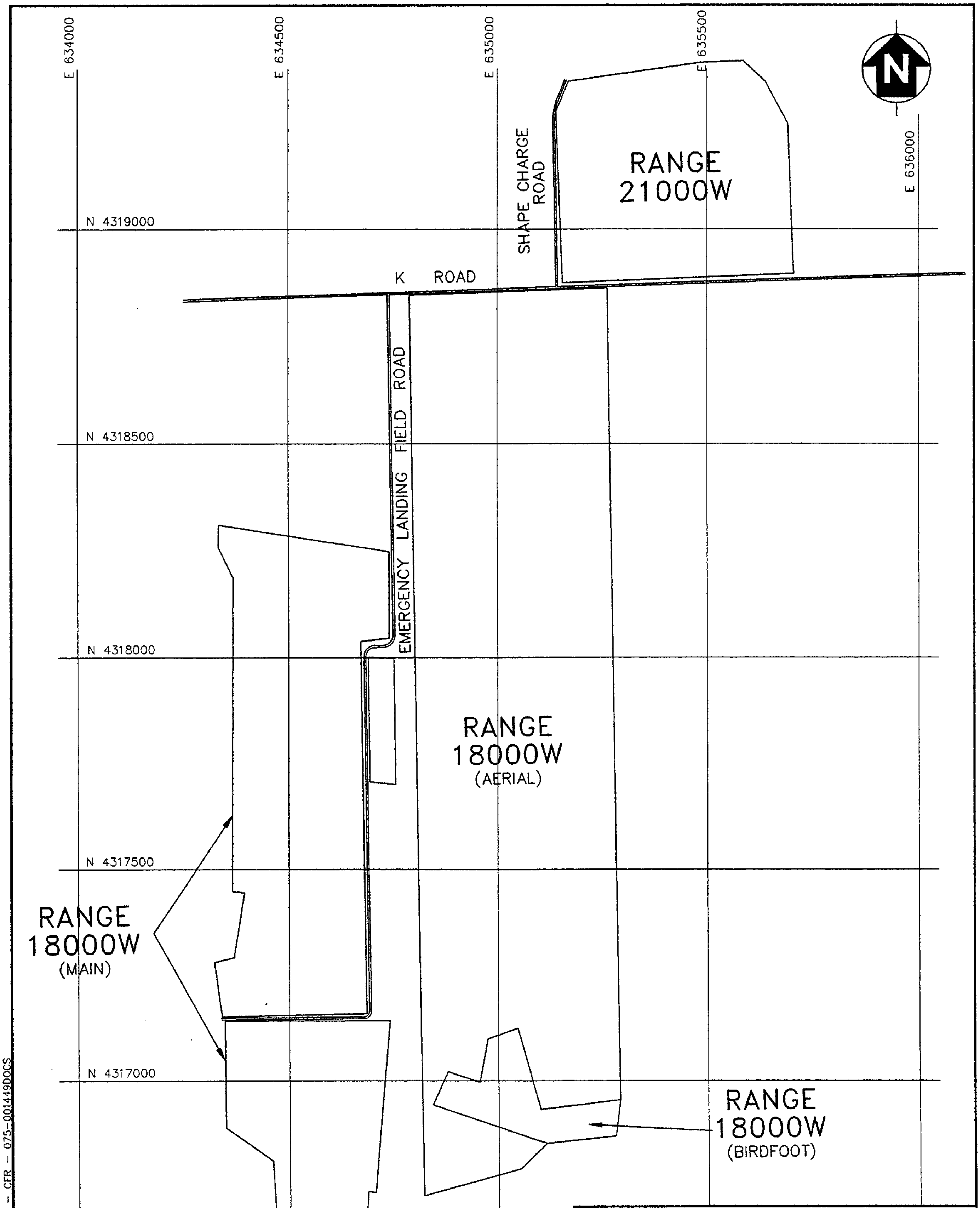


FIGURE 2-1

MAP OF JPG LIVE SITES

PRC ENVIRONMENTAL MANAGEMENT, INC.

NOTE: COORDINATE SYSTEM IS UTM
(NAD 83, ZONE 16).

SCALE
1:12500

JPG-SITE.DWG - 06/28/96 - CFR - 075-001449DOCS

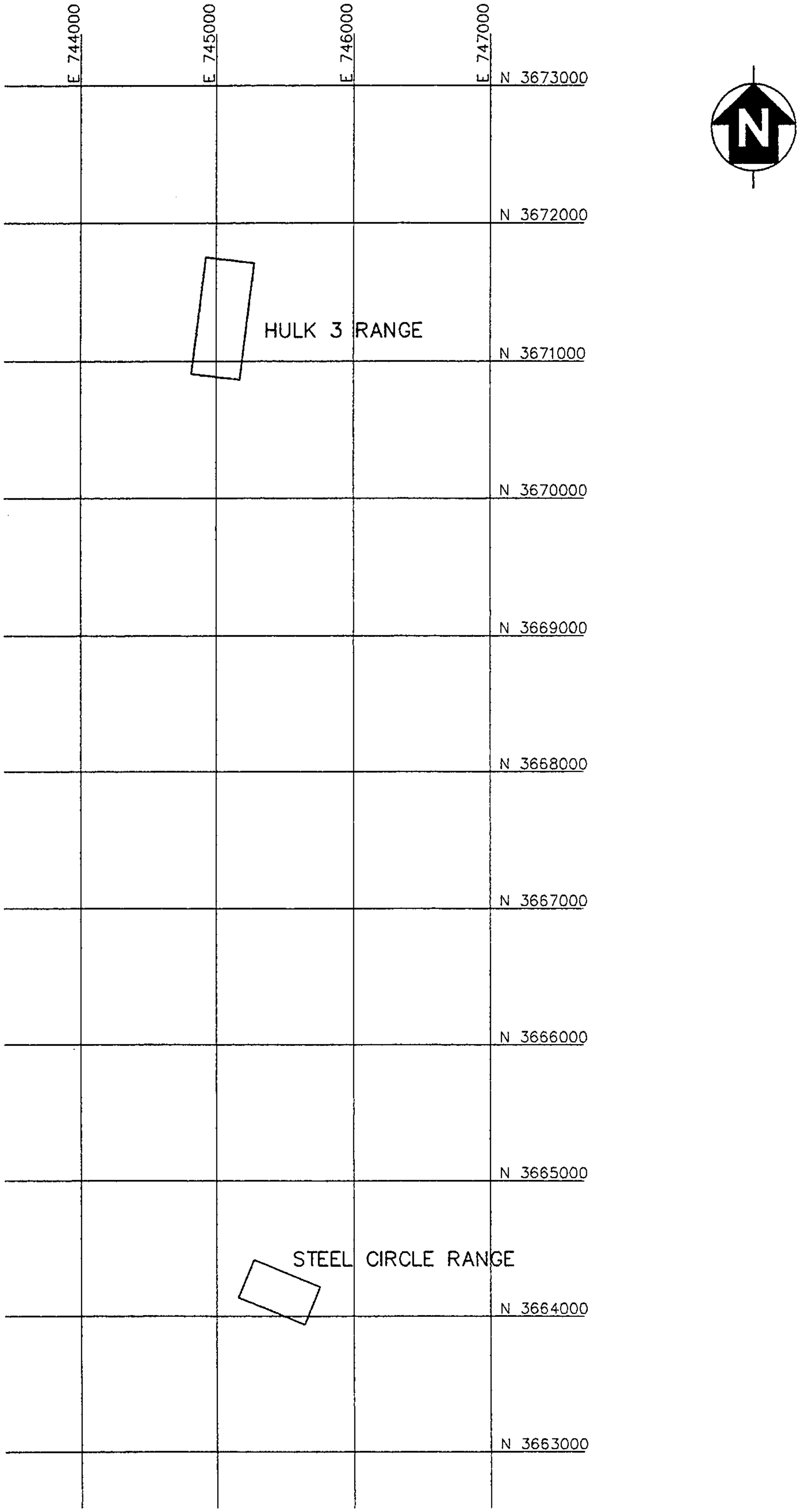
Historic Site Use: Available site-specific records indicate that JPG used Range 21000W as a test site for rocket-assisted M180 cratering charges. JPG has indicated that the cratering charges all functioned properly, but the rocket motors may not have fired. Available site-specific records indicate that JPG used Range 18000W as a test site for a variety of fuzes. The total quantity of ordnance fired at Range 18000W is not known. However, based on several interviews, some of the fuze tests conducted at Range 18000W included live and inert fuzes on 60-millimeter (mm) mortar rounds, 81-mm mortar rounds, 4.2-inch (in.) projectiles, and live and inert 155-mm projectiles. In addition, some of the projectiles and mortar rounds were illumination and white phosphorus rounds.

2.1.2 Yuma Proving Ground

YPG occupies about 352,143 hectares in the southwest corner Yuma County, Arizona. Military use of YPG can be traced back to 1943, when the U.S. Army Corps of Engineers opened the Yuma Test Branch to test equipment. YPG is a DoD Major Range and Test Facility and is the Army's center for desert environment tests. As a Major Range and Test Facility, YPG is available to all DoD military services, other government agencies, commercial industry, and foreign countries for the testing of munitions and weapons systems. The majority of installation testing activities have been conducted in the southern and west central portions of the proving ground in the Kofa and Cibola Ranges. Both ranges contain UXO.

The Government selected two areas in the central part of the Cibola Range for the live site ATDs. The areas selected are known as the Steel Circle and Hulk 3 Ranges (see Figure 2-2). Both are characterized by flat, gravel-covered, piedmont surfaces incised by numerous northeast-southwest trending vegetated washes. A 15.8-hectare parcel in the northwest portion of the Steel Circle Range and a 29.9-hectare parcel in the southern portion of the Hulk 3 Range were used during the live site ATDs.

Topography, Soils, and Geology: YPG is located in the Sonoran Desert and is characterized by narrow, low, rugged, north-northwest trending mountain ranges separated by extensive desert plains (Higginbotham and Associates 1978). Gently sloping piedmont surfaces dissected by 12-meter-deep washes are the prominent landform encountered at the demonstration sites (USGS 1986). Most exposures of the piedmont surface are characterized by an armor of closely spaced gravel to cobble-sized material that is called "desert pavement" (USGS 1974). Depth to bedrock below the piedmont surfaces is not known; bedrock underling the demonstration areas is assumed to consist predominantly of volcanic deposits.



SCALE
1:50000

NOTE: COORDINATE SYSTEM IS UTM (NAD 27, ZONE 11–MODIFIED BY YPG).

FIGURE 2-2

MAP OF YPG LIVE SITES

PRC ENVIRONMENTAL MANAGEMENT, INC.

YUMASITE.DWG – 06/28/96 – CFR – 075-001449DOCS

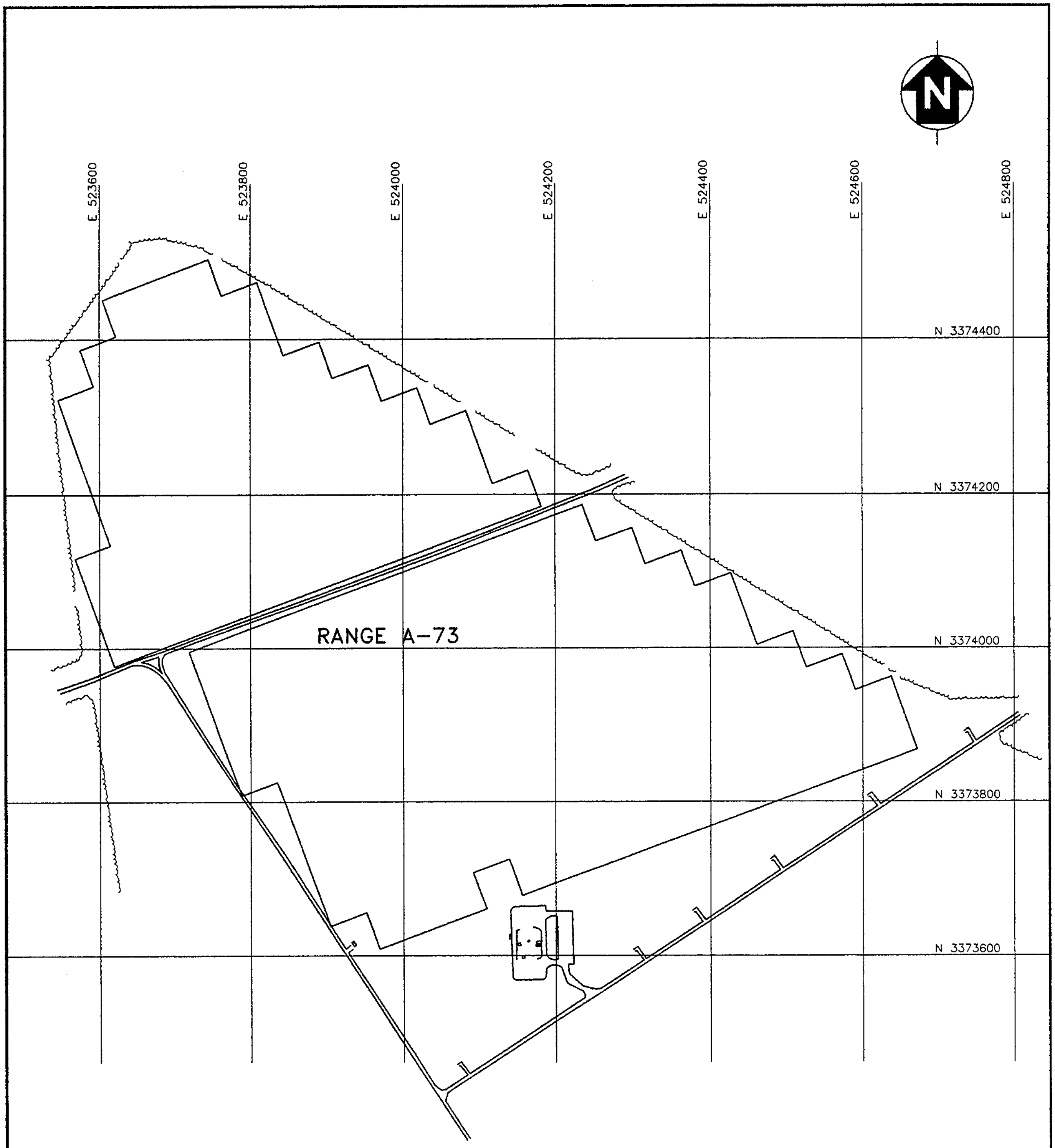
Climate: The climate at YPG is characteristic of the arid desert southwest. Summers are long and very hot; winters are brief and mild. The average annual temperature at Yuma is about 23.5 °C, while the average annual precipitation is about 7.7 cm, making the Yuma area one of the hottest and driest parts of the United States (WIC 1974b). During the demonstration period, the average daily temperature was 35.6 °C, and the average daily maximum temperature was about 42.2 °C.

Historic Site Use: Before the project began, YPG personnel indicated that the Steel Circle Range had not been used for ordnance testing and therefore is likely free of surface or subsurface ordnance. Historical data about the Hulk 3 range before 1980 is limited. More accurate firing records for the range are available from about 1980 to present. These records indicate that YPG used the range for AC-130 aircraft live gun fire testing during a 4-year period from March 1988 to March 1992. In addition, Cobra and Apache helicopters fired on 60 targets positioned in the northern half of the Hulk 3 site. Exact dates and quantities of ordnance fired into the range are not available; however, range logbooks indicate that the primary ordnance items used at Hulk 3 include 2.75-in. rockets with M150 warheads as well as 20-mm, 25-mm, 30-mm, 40-mm, and 105-mm projectiles.

2.1.3 Eglin Air Force Base

Eglin AFB is located in the northwestern panhandle of Florida within Santa Rosa, Okaloosa, and Walton Counties. The base covers more than 186,000 hectares of land area and 22.4 million hectares of associated joint-use airspace and water area in the Gulf of Mexico. The land and water areas of Eglin AFB are used to support the Air Force Development Test Center (AFDTC); the total area includes many individual test areas that encompass a variety of environments and provide the flexibility of integrating test areas for multisite instrumentation support (AFDTC 1991).

For the Eglin AFB live site ATDs, Lesser Test Range A-73 was selected (see Figure 2-3). Range A-73 is part of a group of land test areas used for specialized mission support and for absorbing overflow from the main land test areas. Range A-73 consists of about 520 hectares of cleared land.



NOTE: COORDINATE SYSTEM IS UTM
(NAD 27, ZONE 16).

SCALE
1:7500

FIGURE 2-3

MAP OF EGLIN AFB LIVE SITE

PRC ENVIRONMENTAL MANAGEMENT, INC.

EG-SITE.DWG – 06/28/96 – CFR – 075-001449DOCS

About 49 hectares of Range A-73 was used for the live site ATDs. A gravel road bisects the site from east to west. An asphalt road, Range Road 234, is located along the south side of the demonstration site. The site is relatively clear, and site vegetation consists primarily of scrub oak about 1 meter in height. The site is surrounded by forested areas to the north and east. Test areas A-30 and A-31, which house radar dishes and associated work compounds, are located to the south. Cleared land is located to the west. Overhead power lines are located along the site's eastern side, and buried electrical and communication cables are located near the site's southwest corner.

Topography, Soils, and Geology: Eglin AFB is located in two physiographic provinces, the Western Highlands and the Gulf Coastal Lowlands. The land at Eglin AFB is gently rolling; land surrounding the installation is forested or used for agricultural purposes. The surface geology at Eglin AFB consists primarily of sediments that thicken more than 1,000 meters toward the southwest of the Florida panhandle. These deposits consist of the post-Miocene Citronelle Formation, which consists of fine- to coarse-grained sands with gravel, silt, and clay, as well as a number of sand and clayey sand units (Scott 1993). Soils at Range A-73 are of the Lakeland Association, which consists of sandy soils 2 meters and greater in thickness (AFDTC 1991; Nutting 1995b). Bedrock consists of Bruce Creek Limestone, which is a white to light gray, moderately indurated, granular limestone located about 120 to 210 meters below ground surface at the base. There are no outcrops of bedrock on Eglin AFB (Clark 1982).

Climate: The climate at Eglin AFB is characteristic of the Gulf Coastal region of the United States, where the warm waters of the Gulf of Mexico moderate temperatures. Summers are long, hot, and humid; winters are mild. The average annual temperature in the Florida Panhandle near Eglin AFB is about 20.2 °C (USDA 1989; WIC 1974a). During the demonstration period, the average daily temperature was 26.6 °C, and the average daily maximum temperature was about 32.0 °C. The average annual precipitation is about 160 cm (USDA 1989; WIC 1974a); Eglin AFB is located in the Gulf Coast's "Hurricane Belt" and is prone to hurricanes.

Historic Site Use: Historical records indicate that Range A-73 was constructed in 1955 and was used as a tactical training area for air-to-ground gunnery, rocketry, and bombing. With the exception of air-to-ground gunnery, only inert munitions with spotting charges were authorized for use in the test area. The total quantity of ordnance fired at the range is not known. Based on personal interviews conducted during site preparation activities, Range A-73 was used for 20-mm projectile target practice and as a grenade impact range; it may also have been used indiscriminately as a ground assault training area.

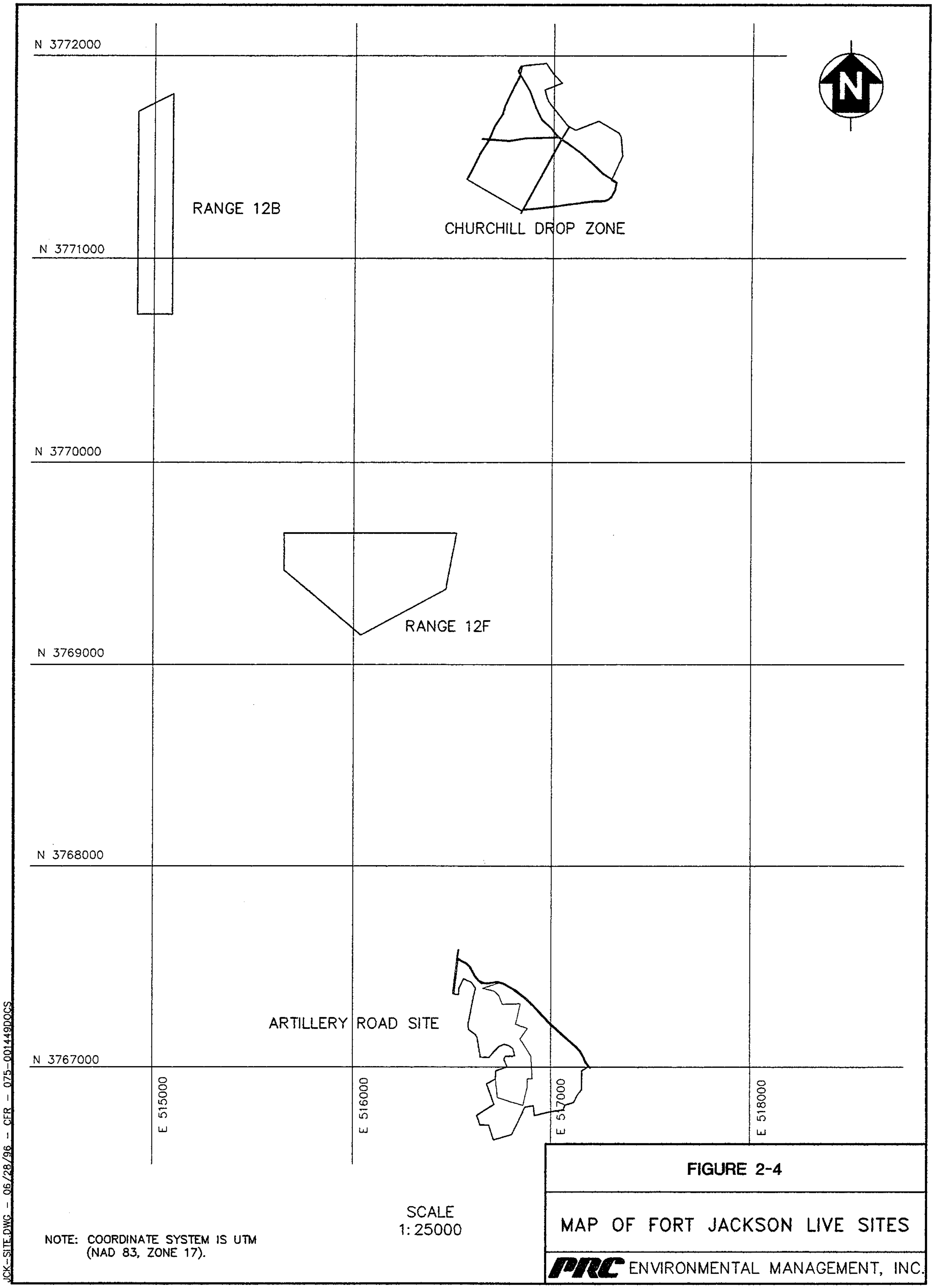
2.1.4 Fort Jackson Military Reservation

Fort Jackson is situated within the city limits of Columbia, in Richland County, South Carolina. The U.S. Army Training Center was established at Fort Jackson in 1917 to provide basic infantry training before World War I. The installation was again used for training during World War II, the Korean War, and the Vietnam Conflict.

For the live site ATDs, four sites covering about 109 hectares were selected. These sites include the Churchill Drop Zone, Artillery Road Site, Range 12B, and Range 12F (see Figure 2-4). The Churchill Drop Zone contains about 32.8 hectares of open fields as well as moderately forested areas. The Artillery Road Site was created from a section of land within the Main Impact Area at Fort Jackson. It contains about 27.7 hectares of open fields and moderately forested areas; parts of the range contain scrub brush. Ranges 12B and 12F contain about 48.7 hectares of heavily forested areas with thick underbrush. All areas are flat to hilly and contain sandy soils.

Topography, Soils, and Geology: Fort Jackson is located within the Piedmont Plateau and Upper Coastal Plain physiographic provinces. The topography of Fort Jackson is characterized by rolling sand hills with interfluvial ridges. Ridge elevations typically range from about 90 to 100 meters. Valley floor elevations range from about 45 to 55 meters. Surrounding land use is residential, commercial, and agricultural. Surface geology at the demonstration sites consists of post-Eocene sand units or Tuscaloosa Formation arkosic sand. Bedrock consists of the low-grade metamorphic Carolina Slate Belt rocks (greenschist to amphibolite) and is typically located more than 30 meters below ground surface.

Climate: The climate at Fort Jackson is characteristic of the Appalachian Piedmont Plateau and Atlantic Seaboard climate. Summers are hot and quite humid; winters are typically mild. The average annual temperature in neighboring Columbia is about 18.1 °C, while the average annual precipitation is about 119 cm (WIC 1974a). During the demonstration period, the average daily temperature was 23.4 °C, and the average daily maximum temperature was about 27.3 °C.



SCALE
1:25000

NOTE: COORDINATE SYSTEM IS UTM
(NAD 83, ZONE 17).

FIGURE 2-4

MAP OF FORT JACKSON LIVE SITES

PRC ENVIRONMENTAL MANAGEMENT, INC.

JCK-SITE.DWG - 06/28/96 - CFR - 075-001449DOCS

Historic Site Use: The ranges selected for the live site ATDs were last used extensively during the Korean War, although usage during this time period is not adequately documented. After the Korean War era, the sites were used infrequently, if they were used at all. Records for the area cannot be used to determine the amounts and types of ordnance fired or dropped on the range. The age and historical use of the selected sites are such that discovery of unique ordnance, including chemical agents, is possible. Containers of mustard gas have reportedly been unearthed in other areas of the installation.

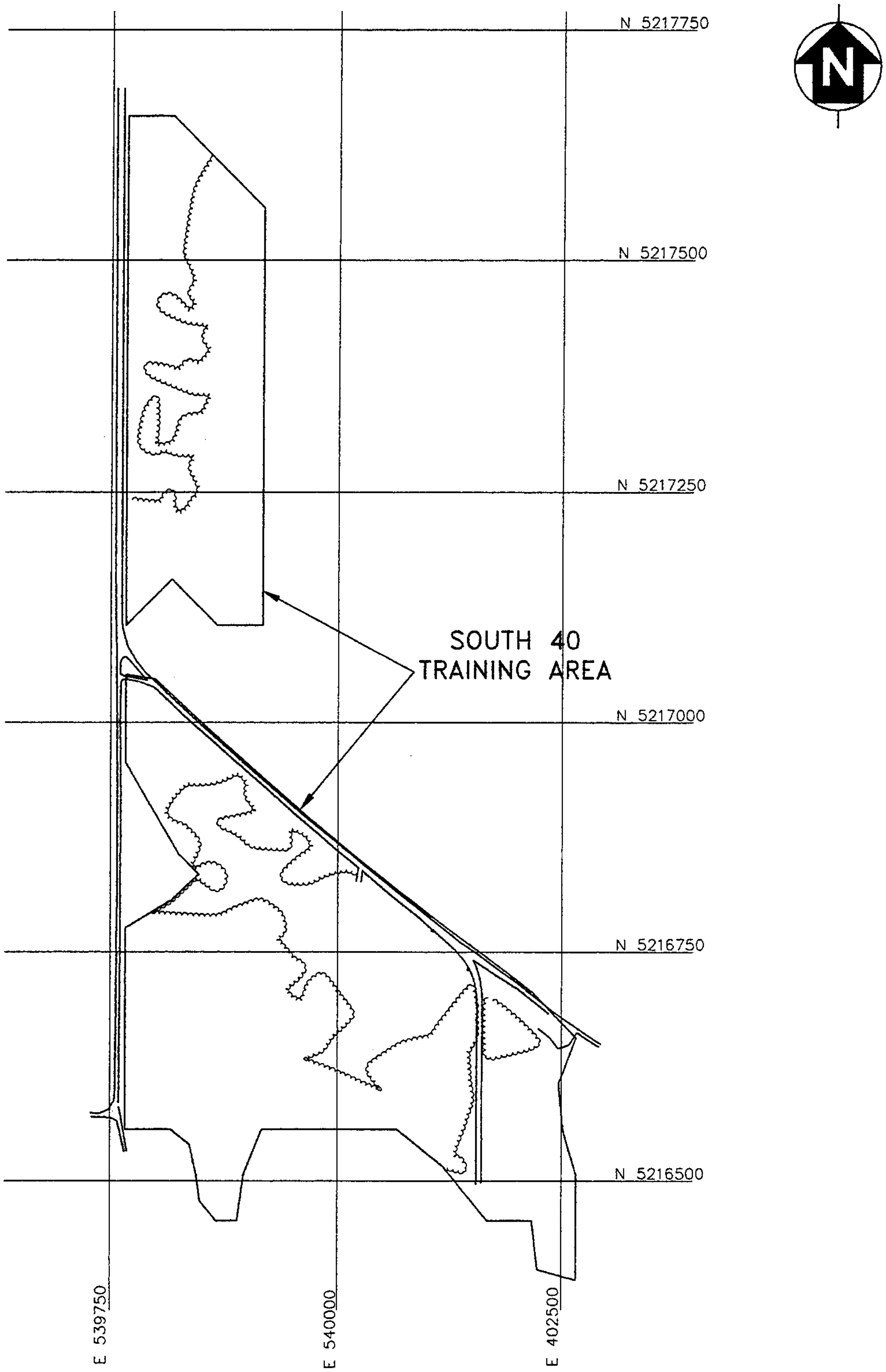
Based on the limited written history reviewed and the site preparation activities, the Churchill Drop Zone was probably used as an artillery impact area in the 1940s and 1950s. More recently, the range has been used for troop maneuver and bivouac areas. The Artillery Road Site was probably used as an artillery impact area and aerial bombing range, possibly before and since the early 1940s. The area was also probably used as an antitank gunnery range from the early 1940s through the late 1950s. Limited historical data indicate that Ranges 12B and 12F were used for grenade practice and 40-mm submunition deployment. Due to the substantial hazards associated with conducting ground surveys at Ranges 12B and 12F, they were selected for aerial survey only.

2.1.5 McChord Air Force Base

McChord AFB occupies about 1,860 hectares in Pierce County, Washington. The base is situated about 1.6 km south of Tacoma, Washington, and about 11 km east of Puget Sound. The U.S. Army Fort Lewis Military Reservation is located adjacent to and southeast of the base.

McChord Field was formally dedicated on May 5, 1938. Prior to this time, the area was a small dirt-strip airport known as Tacoma Field. From 1938 to 1941 and during World War II, McChord Field served as a bomber training base. In 1948, McChord Field was redesignated McChord AFB and served as an Air Force processing station for the region. In 1958, the base assumed the air defense of the northwestern United States as part of the 25th Air Division. Its current mission is to provide airlift support for troops, cargo, military equipment, mail, and passengers during peacetime or wartime.

For the live site ATDs, a site of about 24 hectares was selected (see Figure 2-5). The live site, known as the South 40 Training Area, is located in the southern portion of McChord AFB. According to base



NOTE: COORDINATE SYSTEM IS UTM
(NAD 83, ZONE 10).

SCALE
1:7500

FIGURE 2-5

MAP OF McCHORD AFB LIVE SITE

PRC ENVIRONMENTAL MANAGEMENT, INC.

MCR-SITE.DWG - 06/28/96 - CFR - 075-001449DOCS personnel, the South 40 Training Area was part of the Army's Fort Lewis as early as 1917. McChord AFB acquired the land between 1940 and 1942.

Topography, Soils, and Geology: McChord AFB is located in the central part of the Puget Sound Lowland physiographic province. This province is characterized as a flat plain area between the Cascade Mountain Range and the Pacific Ocean. The geology of the South 40 Training Area is consistent with the regional geology; unconsolidated fluvial, glacial, and shallow marine sediments at the site are up to 600 meters thick. Within the upper 2 meters of the relatively flat site, soils are predominantly cobbles and gravel with lesser amounts of sand and silt.

Climate: McChord AFB has a temperate maritime climate due to the influence of the Pacific Ocean. Summers are cool and comparatively dry; winters are cloudy, wet, and mild. The average annual temperature in the McChord AFB area is about 10.6 °C, while the average annual precipitation is about 99 cm (WIC 1974b). During the demonstration period, the average daily temperature was 8.6 °C, and the average daily maximum temperature was about 16.9 °C.

Historic Site Use: Historical records are not available for the South 40 Training Area during the time it was part of Fort Lewis. Since it became part of McChord AFB, the South 40 Training Area has been used for troop and vehicle maneuvers and as a small arms range.

The South 40 Training Area is currently used for combat maneuvers; several bunkers and wooden tent frame structures are located on site. In addition, McChord AFB uses the area as a sand and gravel storage area.

2.2 SITE PREPARATION

Demonstration preparation activities included UXO sweeps and surface clearance, site survey, controlled target selection and emplacement, site operations plan preparation, and a predemonstration site visit. At a minimum, each of the installations provided environmental and logistics assistance as well as coordination with base chain of command. In addition, some of the installations provided surveyors, military EOD personnel, excavation equipment, and inert ordnance. The following sections describe preparation activities at each site.

2.2.1 Unexploded Ordnance Sweep and Surface Clearance

The military EOD teams assigned to each live site conducted UXO sweeps at the sites to clear surface UXO, mitigating hazards to demonstrator personnel. As the UXO clearance was performed, the EOD teams attempted to remove ferrous debris and other miscellaneous rubbish that could adversely affect demonstrator performance, although this was not a primary goal of the sweep. Table 2-1 summarizes the various active-duty units that conducted these activities.

Table 2-1
EOD Teams Used for Range Clearance

Site	EOD Team	Base of Operations
JPG	Army 43rd EOD	Fort Knox, Kentucky
YPG	YPG ETO	Yuma Proving Ground, Arizona
Eglin AFB	Air Force 96th EOD	Eglin Air Force Base, Florida
Fort Jackson	Army 48th EOD	Fort Jackson, South Carolina
McChord AFB	Air Force 62nd EOD	McChord AFB, Washington

Most ordnance-related items recovered during the site sweeps were either inert or expended. Hazardous ordnance-related materials were either blown in place or removed from the range for off-site destruction, at the discretion of the EOD team conducting the sweep. The EOD team stockpiled nonhazardous items near the ranges where they were found or removed them from the site.

After the UXO sweeps were completed, vegetation was cleared at some of the sites. JPG personnel conducted a controlled burn of the live site ranges before the UXO sweeps were conducted. Eglin AFB and McChord AFB personnel mowed the live sites to reduce the amount of shrubs and vegetation. Vegetation at the YPG and Fort Jackson sites was not cleared for the demonstrations because of safety or environmental concerns.

The following paragraphs summarize the types and quantity of UXO-related materials removed from each site during sweep activities.

Jefferson Proving Ground: Before the live site ATDs were conducted at JPG, the U.S. Army 43rd EOD performed a surface sweep of Ranges 18000W and 21000W. During the sweep, EOD technicians removed nearly 4 metric tons of UXO items from the ranges. Types of ordnance removed from the sites are summarized below.

Range 18000W

- 100-pound practice bombs (not fuzed)
- 155-mm projectiles
- 155-mm projectiles (white phosphorus)
- 4.2-in. mortar rounds (illuminating)
- 81-mm mortar rounds
- 60-mm mortar rounds
- M42 submunitions

Range 21000W

- 100-pound practice bombs (not fuzed)
- Flare canisters
- M42 submunitions
- M75 RAMMS AT mines
- 8-in. projectiles with possible live rocket motors

Yuma Proving Ground: When YPG Explosive Test Operations (ETO) personnel performed the site sweep at the Hulk 3 range, 40 to 50 semitrailer loads of UXO items and scrap metal were removed from the site. YPG did not indicate the exact types and quantities of ordnance removed; however, based on visual observations made during the ATDs, the Hulk 3 site in particular most likely contains a relatively dense concentration of UXO, especially near the 60 formerly-used gunnery and rocketry target locations at the north end of the site.

Eglin Air Force Base: Before live site activities were conducted, the U.S. Air Force (USAF) 96th EOD conducted a surface sweep of Range A-73. About 250 kilograms (kg) of UXO-related items were recovered and removed from the site; these items are summarized below.

- BDU-33 practice bombs
- 2.75-in. rocket warheads
- M74 subcaliber training rockets
- 40-mm practice grenades
- 40-mm grenade fragmentation (HE, TP)
- Metal links from 7.62-mm and 5.56-mm machine guns

Fort Jackson Military Reservation: The U.S. Army 48th EOD, with assistance from the South Carolina Army National Guard (ARNG), performed UXO sweeps at the Churchill Drop Zone and Artillery Road Site before the demonstrations. Because of expected hazards associated with Ranges 12B and 12F, these areas did not undergo UXO clearance. About 100 to 150 kg of the UXO-related items listed below were recovered from the Churchill Drop Zone and Artillery Road Site.

<u>Churchill Drop Zone</u>

- Smoke grenades
- Illumination flares
- M500 series TSQ artillery fuzes, expended
- M57 series PD artillery fuzes, expended

<u>Artillery Road Site</u>

- 75-mm projectiles (AP)
- 75-mm projectiles (HE, AP)
- 155-mm projectiles (illumination)
- 75-mm projectiles (HEAT)
- 105-mm projectiles (HE)
- 3-in. Stokes mortar rounds (TP)
- 37-mm projectiles (AP)
- 100-pound bombs (GP)
- M61 base-detonating fuzes
- Hand-held illumination flares
- 155-mm projectile fragmentation

McChord Air Force Base: During site preparation activities, USAF 62nd EOD personnel removed less than 50 kg of UXO-related items from the site; these items are summarized below.

- 5.56-mm blank cartridges
- 7.62-mm blank cartridges
- 40-mm signal white star cartridges
- 40-mm practice cartridges
- Signal white star ground illumination flares
- Hand smoke grenades
- Surface trip flares
- Ground burst projectiles

With the exception of the 5.56-mm blank cartridges and one surface trip flare recovered at the site, all of the above items were expended. USAF 62nd EOD personnel removed all ordnance items from the demonstration area.

2.2.2 Site Survey

After the UXO sweep and surface clearance activities were completed, at least two survey control points were established on or near each of the ranges used for the live site ATDs. A minimum of three survey control monuments were established at each installation. Control monuments were established by certified professional land surveyors or military surveyors to provide demonstrators with a frame of reference to accurately report target declarations. In general, the control monuments established for the live site ATDs are of First Order horizontal and Second Order (First Class) vertical accuracy. However, the benchmarks at YPG are of Second Order (First Class) horizontal and Third Order (First Class) vertical accuracy.

At each range selected for ground platform demonstrations, surveyors established a 25- or 50-meter grid over the entire site. Grid nodes were surveyed to Third Order (First Class) horizontal and vertical accuracy, and wooden stakes were placed at each grid node. Survey data was loaded into a computer-aided drafting software program for data manipulation and map production.

2.2.3 Controlled Target Selection and Emplacement

To evaluate each demonstrator's performance, inert ordnance items (baseline targets) were emplaced at each of the live sites. The baseline targets selected for each site were generally typical of the ordnance used at that site. However, some baseline targets were atypical of the sites where they were emplaced.

Emplaced ordnance items ranged in size from 20-mm projectiles to 2,000-pound bombs. Based on data from site remediation activities at other sites with geologies similar to the live sites, baseline targets were emplaced at depths where they would be expected to be found if they had actually been fired or dropped at the site. General information about baseline UXO targets is provided in Table 2-2. Detailed information about each site's baseline target set is provided in Appendix A.

Before emplacement, each baseline target was stamped with a unique target identification number that provides a permanent tracking number for the ordnance items. Ordnance was emplaced at locations previously screened by EOD technicians to ensure the locations were free of UXO. Holes were excavated with a hand shovel for depths less than about 0.5 meter and with a backhoe for greater depths.

Table 2-2
Summary of Emplaced Ordnance Targets

Target Description	Quantity	Class	Size	Depth Range (meters)
Jefferson Proving Ground				
2,000-pound bomb (Mk84)	1	bomb	large	2.68
25-pound bomb (Mk76)	16	bomb	small	0.33 - 0.99
57-mm projectiles (7)	1	cluster, projectile	small	0.39
81-mm mortar round	3	mortar	small	0.35 - 0.72
8-in. projectile	2	projectile	large	1.75 - 2.30
175-mm projectile	6	projectile	medium	0.66 - 1.60
155-mm projectile	6	projectile	medium	0.73 - 1.43
152-mm projectile	5	projectile	medium	0.56 - 0.78
105-mm projectile	1	projectile	medium	0.42
Yuma Proving Ground				
2,000-pound bomb (Mk84)	1	bomb	large	2.43
25-pound bomb (Mk76)	14	bomb	small	0.41 - 1.59
81-mm mortar round	8	mortar	small	0.32 - 1.16
60-mm mortar round	9	mortar	small	0.28 - 0.86
8-in. projectile	2	projectile	large	1.80 - 2.30
105-mm projectile	14	projectile	medium	0.28 - 1.24
40-mm projectile	3	projectile	small	0.29 - 0.47

Table 2-2 (Continued)
Summary of Emplaced Targets

Target Description	Quantity	Class	Size	Depth Range (meters)
Eglin Air Force Base				
2,000-pound bomb (Mk84)	1	bomb	large	2.44
500-pound bomb (Mk82)	6	bomb	large	1.48 - 2.91
220-pound bomb	3	bomb	large	1.97 - 2.53
20-mm projectiles (10)	1	cluster, projectile	small	0.18
WAMUM submunitions (3-4)	3	cluster, other	small	0.09 - 0.18
5-in. rocket warhead	2	projectile	medium	1.06 - 1.30
105-mm projectile	10	projectile	medium	0.71 - 1.87
2.75-in. rocket warhead	10	projectile	small	0.14 - 0.62
WAMUM submunition	17	other	small	0.05 - 0.13
Fort Jackson				
1,000-pound bomb (Mk83)	2	bomb	large	1.63 - 2.38
81-mm mortar round	6	mortar	small	0.03 - 0.36
8-in. projectile	6	projectile	large	1.17 - 1.67
175-mm projectile	6	projectile	medium	0.99 - 1.56
155-mm projectile	2	projectile	medium	1.12 - 1.52
4.2-in. projectile	2	projectile	medium	0.38 - 0.47
106-mm projectile	2	projectile	medium	0.04 - 0.13
105-mm projectile	3	projectile	medium	0.43 - 0.63
60-mm projectile	6	projectile	small	0.09 - 0.52

Table 2-2 (Continued)
Summary of Emplaced Targets

Target Description	Quantity	Class	Size	Depth Range (meters)
McChord Air Force Base				
500-pound bomb (Mk82)	2	bomb	large	2.34 - 2.59
81-mm mortar round	10	mortar	medium	0.35 - 0.86
8-in. projectile	2	projectile	large	0.87 - 0.99
175-mm projectile	6	projectile	medium	0.44 - 1.06
5-in. rocket warhead	3	projectile	medium	0.61 - 0.95
4.2-in. projectile	9	projectile	medium	0.37 - 1.03
105-mm projectile	20	projectile	medium	0.26 - 1.49
76-mm projectile	3	projectile	small	0.32 - 0.60
57-mm projectile	4	projectile	small	0.09 - 0.38

The baseline ordnance was then emplaced at a predetermined depth, azimuth, and declination. The location and elevation of the ordnance item was surveyed to Third Order (First Class) horizontal and vertical accuracy. After each baseline target was surveyed, the excavation was backfilled, and the elevation of the ground surface over the ordnance item was surveyed.

Because excavation activities typically resulted in a semipermanent scar on the ground surface and a permanent subsurface disturbance, similar disturbances were created at numerous other locations at each live site to discourage demonstrators from identifying target locations based on visual observations. No ordnance items were emplaced at these additional locations.

2.2.4 Preparation of Site Operations Plan

Before each demonstration began, site operations plans were developed to ensure safe, efficient, and effective operations at each site and to ensure that procedures for all demonstrators were consistent (PRC 1995a, 1995b, 1995c, 1995d, 1995e). The site operations plans were prepared with input from installation EOD, safety, environmental, and logistics personnel.

The site operations plans address, but are not limited to, the following operational and administrative issues:

- Demonstrator check-in procedures
- Daily operations schedule
- Briefing schedule
- Guidelines for deployment of the demonstrators' systems
- Guidelines for making up downtime
- Conflict resolution
- Required reports
- Data deliverable due dates

2.2.5 Predemonstration Site Visit

Technology demonstrators were given the option of predemonstration tours of the live sites, and several demonstrators participated in these tours. During the tours, demonstrators were informed of site-specific issues and were provided opportunities to ask questions. The demonstration schedule and range hours were described to the demonstrators, and an initial review of the safety, health, and emergency response plan (SHERP) was conducted. Based on demonstrator comments and concerns, minor modifications to the test setup and site operating procedures were occasionally made before the demonstration started. Such modifications included the addition of survey control monuments, relocation of shade tents and site entry corridors, and modification of site operations hours.

2.3 TECHNOLOGY DEMONSTRATIONS

Each live site ATD was scheduled during a continuous 3-week period beginning on a Monday and ending on the third Friday following. The demonstration schedule for each site is shown in Table 2-3. During the 3-week period, each demonstrator was allowed between 80 and 120 hours to survey between 24 and 120 hectares.

On the first day of the demonstration at each site, demonstrator, support, and oversight personnel underwent an explosive ordnance indoctrination training course conducted by military EOD personnel assigned to the project. The training included a UXO identification session as well as detailed commentary on the types of UXO recovered during the site sweeps or deployed at the ranges during their years of operation.

After the EOD briefing, the site manager and site safety officer briefed demonstrator and support personnel on site safety and operations before any personnel were allowed to enter the demonstration area. Site entry and exit corridors were clearly identified with brightly-colored flagging; personnel were instructed to use these corridors for site access and to remain within the site-swept boundary or face possible eviction from the site.

After the introductory briefings were completed, each demonstrator was allowed to enter the live site area to assemble equipment and begin their survey. Demonstrator progress was monitored during equipment setup, but setup time was not counted against the demonstrator's allotted survey time. After the surveys began, equipment repair time or unexpected downtime was not counted against the demonstrator's allotted survey time unless the time spent repairing equipment was minimal (less than 15 minutes).

Table 2-3
Demonstrator Requirements

Site	Demonstration Period (1995)	Demonstrator	Time Allotted (hours)	Survey Area (hectares)
JPG	May 22 to June 9	Aerodat	120	123.3
		ADI	120	64.5
		Coleman	120	63.9
YPG	July 12 to July 28	Geo-Centers	80	45.5
		Metratek	80	45.5
		SRI	80	45.5
Eglin AFB	July 31 to August 18	Coleman	80	48.8
		Vallon	80	48.8
Fort Jackson	September 11 to September 26	ADI	120	60.5
		Geo-Centers	80	32.8
		SRI	120	109.2
McChord AFB	October 24 to November 9	Chemrad	80	24.0
		Metratek	80	24.0

To assist demonstrators in calibrating their equipment, each demonstrator was provided with the survey coordinates of survey control monuments as well as the coordinates of two of the baseline targets. In addition, demonstrators were offered electronic copies of the site maps. Most demonstrators accepted the maps in this format for their use.

Site access was restricted to the clearly demarcated live site demonstration area. The site manager acted as a liaison between demonstrators working in the same area and kept careful records of the areas surveyed by the demonstrators as well as the time required to perform the surveys. When rescheduling was required, the site manager coordinated with the demonstrators to ensure that they were given the opportunity to work at the site on makeup days.

Demonstrators were generally required to leave the site for a certain period of time each day, typically about 1 hour around mid-day. Demonstrators were allowed to leave their equipment in the work areas during the break. Demonstrators were likewise required to leave the site at a predetermined time at the end of the day, but they were allowed to use the field office for another 30 minutes after they left the field. Daily start, break, and end times varied by site and by day, depending on site-specific conditions and demonstrator concurrence with planned times.

2.4 VALIDATION OF DEMONSTRATOR TARGET DECLARATIONS

A limited number of demonstrator target declarations were validated in the field at the conclusion of each live site ATD. Data validation involved excavation at demonstrator target declaration locations. Validation activities were conducted using remote excavation equipment at all sites except McChord AFB, where manually-operated excavation equipment was used.

Two terms used extensively throughout this section are defined below.

- *Target declaration* refers to a position at which a demonstrator declares a target, either UXO or non-UXO.
- *Validation position* refers to a demonstrator target declaration selected for validation (the methods used to select validation positions are described in Section 4.0).

Before beginning validation activities, selected validation positions were marked with survey flags or wooden stakes. Validation positions were surveyed to Third Order (First Class) horizontal accuracy. At JPG and Fort Jackson, the excavator's navigation system was checked with the survey flags at the validation positions. At the other sites, excavator operators used the survey flags as navigational guides. Excavator operators were provided with a list of validation positions and were given full responsibility for path planning and field logistics. Excavation operations were monitored remotely by video camera.

At all validation positions, excavator operators were instructed to excavate hole with a 2-meter radius to a depth equal to the demonstrator target declaration. If an anomaly was observed in the excavation (by video), the excavation was to be stopped while the EOD team investigated the hole. If no anomalies were observed in the excavation or in the spoils pile, the excavator operators were instructed to excavate to a depth 1 meter greater than the depth estimated in the demonstrator target declaration reports. The EOD team then checked for magnetic anomalies in the hole and in the spoils piles. If no anomalies were observed, the hole was declared to be empty.

The on-site EOD team disposed of UXO items identified during the validation operations by either destroying them in place or removing them from the range, in accordance with their own standard operating procedures. The excavator operator filled all holes excavated during validation activities with the soil removed during the excavation.

2.5 SITE RESTORATION

At the conclusion of validation activities, each site was restored to predemonstration conditions to the maximum extent possible. Survey stakes and flags were removed from the sites, and any holes not filled during the validation were backfilled with native soils. At sites where vegetation was disturbed during field activities, the sites were graded, reseeded, and raked to promote revegetation. UXO or scrap material encountered during the ATDs was stockpiled with the materials previously cleared during the site sweep.

Following field activities, field structures that were erected for the demonstrations were removed. If utility lines were established for the ATDs, services were discontinued. In addition, unless otherwise requested by military installation personnel, utility lines were removed.

EOD teams at YPG, Eglin AFB, Fort Jackson, and McChord AFB excavated most emplaced targets and returned them to the installation EOD unit or to NAVEODTECHDIV facilities in Indian Head, Maryland. Because JPG has been closed, and the ranges may be used for various testing and evaluation programs in the future, the baseline targets were left in place at Range 21000W. YPG and McChord AFB requested that several UXO items be left in place for training purposes. Each military installation was responsible for the ultimate disposal of all UXO-related items found on the ranges during the live site ATD project.

2.6 LOGISTICS AND HEALTH AND SAFETY ISSUES

This section provides details about logistics and health and safety issues that affected the demonstrations at each of the live sites.

Logistics Issues: Demonstrators were assigned areas to conduct surveys based on contractual requirements. Table 2-3 summarizes the time allotted to each demonstrator and their required area coverage. To ensure that demonstrators were allowed adequate time to complete the surveys, site access was provided to the demonstrators for at least 8 hours per day (120 hours over the demonstration period), unless inclement weather or other unforeseen factors prevented work from being conducted during part of a day. These factors include work stoppages required when EOD teams were called from the site or when other programs at adjacent impact ranges were ranked by the military installation as having higher priority than the live site ATD project. When work delays occurred, demonstrators were allowed to continue their surveys during weekends to make up for lost time. Most demonstrators took advantage of weekend time to survey their assigned area.

To control site access, staging areas and entry and exit corridors were created and maintained at the live sites. Staging areas were typically located near the entry and exit corridors and were equipped with first aid equipment, water, carbohydrate drinks, portable sanitary facilities, and shade structures. Before entering or exiting a demonstration area, demonstrator and support personnel were required to log on and off the site. At times, more than one demonstrator collected data simultaneously in the same area. Demonstrators were assigned specific grid cells when this was the case, and the site manager coordinated their efforts.

Aerial platform demonstrators at JPG, YPG, and Fort Jackson were occasionally hampered by air missions over the installations. At JPG, the Indiana Air National Guard (ANG) routinely schedules up to 10 air missions per day; as a result, the aerial platform demonstrator at JPG experienced several lengthy delays while Indiana ANG missions were flown. At YPG, the aerial platform demonstrator conducted its surveys early in the morning, typically beginning at 0400 hours, to avoid interference with active military missions. At Fort Jackson, limited aerial platform demonstrator scheduling conflicts occurred when airspace was restricted over active firing ranges. No aerial demonstrators conducted surveys at Eglin AFB or McChord AFB.

Health and Safety Issues: Site-specific SHERPs were developed for each of the live sites. The SHERPs were provided to all demonstrators. Demonstrator personnel were also required to attend a comprehensive health, safety, and operations briefing before entering the live site. Each demonstration site was assigned a site safety officer who ensured SHERP compliance.

Local emergency medical technicians (EMT) provided on-site emergency care on a continuous basis during the demonstrations at JPG and YPG. Response times for local emergency support at Eglin AFB, Fort Jackson, and McChord AFB were about 5 minutes, so EMT services were not provided at those sites.

Demonstrators were provided with daily weather forecasts, including data collected from on-site weather stations (where available) and reports from nearby National Oceanic and Atmospheric Administration (NOAA) weather centers. Shelter and necessary health and safety equipment were provided to demonstrators at all sites; if mobile trailers could not be installed, shade tents were erected for use as rest and staging areas. Demonstrators were provided with two-way radios for communication between the site management team and demonstrator personnel. Typically, installation personnel also monitored demonstration channels for safety purposes.

All demonstrators were instructed to report possible surface UXO items to the on-site EOD team. EOD teams provided UXO hazard identification and removal activities at each site. Most ordnance-related items recovered from the sites during the demonstrations were inert or expended. Ground platform demonstrators experienced some delays during the EOD team investigations.

Most health and safety issues were weather-related; physical effects included dehydration, heat rash, sunburn, and blistered feet. Ticks, snakes, and scorpions were present at some of the sites, but they did not affect the project to a major degree. No UXO-related incidents occurred during the demonstrations.

This Page Intentionally Left Blank

3.0 SYSTEMS EVALUATED

All of the Phase I controlled site ATD participants were given the opportunity to submit proposals for the live site ATD project. The Government panel selected detection system demonstrators to conduct live site ATDs based on the following criteria:

- Demonstrators were required to demonstrate the same system that was demonstrated at the Phase I controlled site ATD. Although minimal system modifications were allowed, broad changes were not allowed because such changes would constitute an unproven technology and would have no baseline against which to measure performance.
- Demonstrators were required to exhibit an ability to complete the live site ATDs by providing reasonable resources to complete the work.
- Demonstrator cost was considered, and preference was given to lower bids.

Fifteen detection system demonstrators submitted proposals to the Government to conduct live site ATDs. Of these proposals, nine detection system demonstrators were selected to conduct 14 ATDs at the five live sites. However, one demonstrator could not complete its demonstration; after mobilizing to the site, this firm elected not to participate in the demonstration due to equipment failure. As a result, eight detection system demonstrators conducted a total of 13 ATDs.

Four different Government remediation systems were used to conduct the live site ATDs. These systems include the USAF/WL AOE, which participated in the Phase I controlled site ATD and was used at JPG and Fort Jackson. Remediation systems developed by on-post EOD teams were used at YPG and Eglin AFB. The McChord AFB EOD team used standard construction equipment to conduct remediation activities at the McChord live site.

Table 3-1 shows the sites where each UXO detection demonstrator performed. Table 3-2 summarizes the technologies used by detection system demonstrators.

Table 3-1
Detection System Demonstrators and Demonstration Sites

Demonstrator	JPG	YPG	Eglin AFB	Fort Jackson	McChord AFB
Aerodat	✓				
ADI	✓			✓	
Chemrad					✓
Coleman	✓		✓		
Geo-Centers		✓		✓	
Metratek		✓			✓
SRI		✓		✓	
Vallon			✓		

Table 3-2
Summary of Detection Systems Demonstrated

	Platform				Sensor System			Navigation System		
	Ground		Aerial							
Demonstrator	Vehicle-Towed	Man-Portable	Rotary-Wing	Fixed-Wing	Magnetometer	GPR[a]	EM[b]	GPS[c]	Manual	Ultrasonic
Aerodat			✓		✓			✓		
ADI		✓			✓				✓	
Chemrad		✓			✓					✓
Coleman	✓	✓				✓	✓	✓		
Geo-Centers	✓	✓			✓			✓		
Metratek	✓					✓	✓	✓		
SRI				✓		✓		✓		
Vallon	✓	✓			✓			✓	✓	

Notes:

a Ground penetrating radar (GPR)
b Electromagnetic induction (EM)
c Differential global positioning system (GPS)

The following sections describe the live site detection and remediation systems. Included in the discussions are technology descriptions and resource requirements for technology implementation. If a demonstrator conducted demonstrations at more than one site, applicable site-specific data are provided.

3.1 DETECTION SYSTEMS

The following sections describe the systems used by the eight UXO detection system demonstrators that conducted live site ATDs. For each demonstrator, a technology description is provided, resources required to implement the technology are summarized, and any necessary logistics arrangements required to complete the site surveys are discussed.

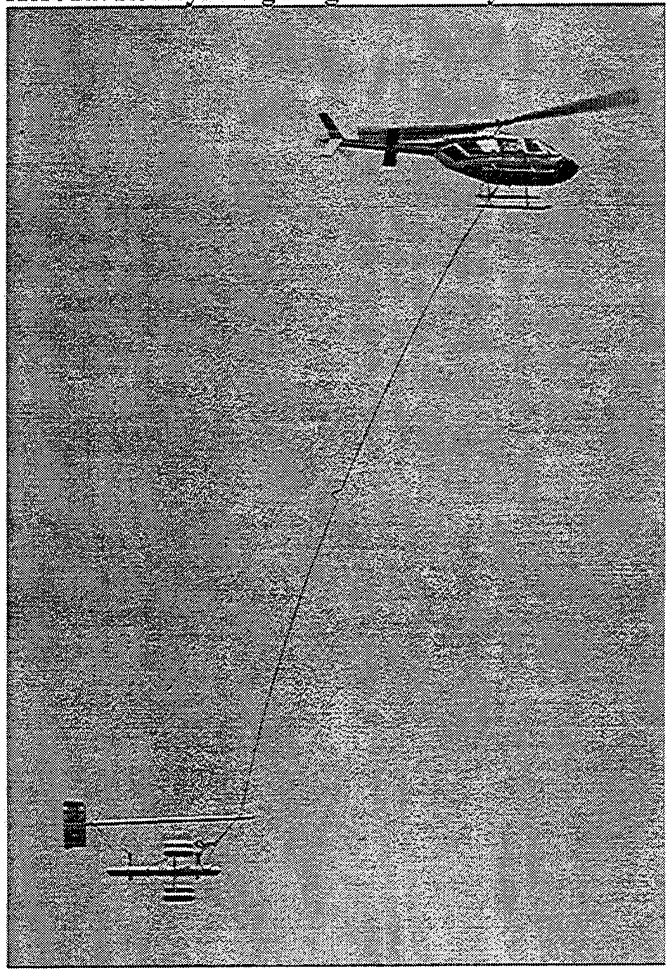
3.1.1 Aerodat, Inc.

From May 22 through June 6, Aerodat conducted a demonstration at JPG Ranges 18000W (Aerial) and 21000W.

Technology Description: Aerodat used a rotary-wing aircraft to tow a rigid, composite platform containing two cesium-vapor, total-field magnetic sensors and a three-component fluxgate magnetometer (see Figure 3-1). The fluxgate magnetometer is used to calculate the pitch, roll, and yaw of the towed platform. The platform is attached to the aircraft by a 30-meter cable and is towed across the site in orthogonal lanes spaced about 10 meters apart. Optimal survey altitude is 5 to 10 meters above ground surface, but Aerodat varies sensor height where trees or other flight path impediments preclude flying at this optimal altitude.

Platform altitude is monitored by a laser altimeter, and aircraft altitude is monitored by a radar altimeter. Although the laser altimeter is a more accurate measure of altitude, it cannot penetrate foliage or tree cover as accurately as the radar altimeter. However, the radar altimeter cannot be mounted on the towed array because it disrupts magnetic readings. The differential GPS unit mounted on the platform allows for real-time navigational data collection.

Figure 3-1
Aerodat Rotary Wing Magnetometer System



A base station magnetometer situated in a magnetically stable area monitors fluctuations in the earth's magnetic field to determine if magnetic conditions are suitable for data collection; the base station also allows for magnetic diurnal correction of collected data.

Resource Requirements: Aerodat used five people for the JPG ATD. In addition to Aerodat personnel, subcontractor Pacific Western Helicopter, of Salt Lake City, Utah, supplied a helicopter, pilot, mechanic, maintenance tools, and parts. All necessary aircraft maintenance work was performed at the municipal airport in Madison, Indiana. Aviation fuel was purchased from the airport.

For the demonstration, Aerodat was provided with air-to-ground radios that allowed the field observation team to communicate with the pilot as the survey was conducted. Using the radios, ground observers maintained communication with Aerodat on issues relating to flight schedule and safety issues.

Logistics Requirements: The JPG Director of Materials Command approved the use of JPG airspace for the project's duration. However, when the demonstration period began, the Indiana ANG objected to Aerodat's airspace use. JPG and the Indiana ANG compromised on this issue, and Aerodat was required to coordinate its daily schedule with the Indiana ANG flight controller. Aerodat was not allowed to survey for the first 2 days of available survey time.

3.1.2 Australian Defence Industries, Pty. Ltd.

From May 22 through June 3, ADI conducted a demonstration at JPG Ranges 18000W (Main), 18000W (Birdfoot), and 21000W. From September 11 through 27, ADI conducted a demonstration at Fort Jackson's Churchill Drop Zone and Artillery Road Site.

Technology Description: ADI demonstrated its portable TM-4 Imaging Magnetometer (see Figure 3-2), an array of optically-pumped, cesium-vapor magnetometers that measure total magnetic field and field changes caused by ferrous material. The array is connected by cable to a computer that interprets data and provides a list of located targets with target position, depth, and approximate mass. A base station magnetometer is used for equipment calibration, reference, and diurnal correction.

The TM-4 platform is mounted on a frame and shoulder harness carried by one individual. The adjustable frame maintains the platform at 0.75 to 1.0 meter above ground. A second individual carries the data collection computer and positioning equipment behind the individual carrying the TM-4. Data are collected every 0.2 meter along parallel survey paths about 1 meter apart. Data are recorded to a resolution of 0.1 nanoTesla (nT).

Navigational data are gathered using known survey points and control lines that ADI places on the site. To mark areas already surveyed and to measure offset from the control lines, the equipment leaves a trail of thin, biodegradable, cotton string.

least three SRs must receive the ultrasonic signal from the USRADS® backpack. The magnetometer location is then determined by triangulation.

As data are collected, the USRADS® backpack wirelessly transmits magnetometer and location data to a field computer. USRADS® uses spread-spectrum radio-frequency transmissions (1, 10, 100, or 1,000 milliwatts) that increase the transmission range and number of data channels that can be recorded (USRADS® can record up to 100 data channels). During USRADS® transmission, the field computer collects magnetic data at a rate of 10 samples per second and location data at a rate of 1 sample per second. The survey path is shown on the field computer with a 5-second delay.

Each of Chemrad's two survey teams usually surveyed one 50- by 50-meter cell at a time; however, the system was also set up on 50- by 100-meter cells and various odd-shaped cells at the demonstration area boundaries. The two survey teams shared 21 SRs that were set up around the cells being surveyed. When the site is clear, Chemrad uses seven SRs per survey cell, four on the corners and three inside the cell. The number of trees, shrubs, slopes, and buildings at McChord required using more than three SRs within several grid cells. As a result, additional setup time was required.

Off-the-shelf software packages are used to analyze magnetometer data using Fourier processing programs for anomaly localization and depth determination.

Resource Requirements: Chemrad used six people for the McChord ATD; four had no prior experience using USRADS® equipment. The six people were split into two teams of two to conduct the survey (one field operator and one field computer monitor), with two personnel acting as support technicians. During the first two days of surveying, both support personnel were present; however, only one Chemrad employee was needed after the equipment was set up. A truck used by each team housed the field computer and transported USRADS® equipment. Two USRADS® units were used simultaneously at McChord AFB. Each consisted of a USRADS® backpack, magnetometer, field computer, multiple SRs and a utility vehicle. The survey teams used hand-held radios to communicate with each other.

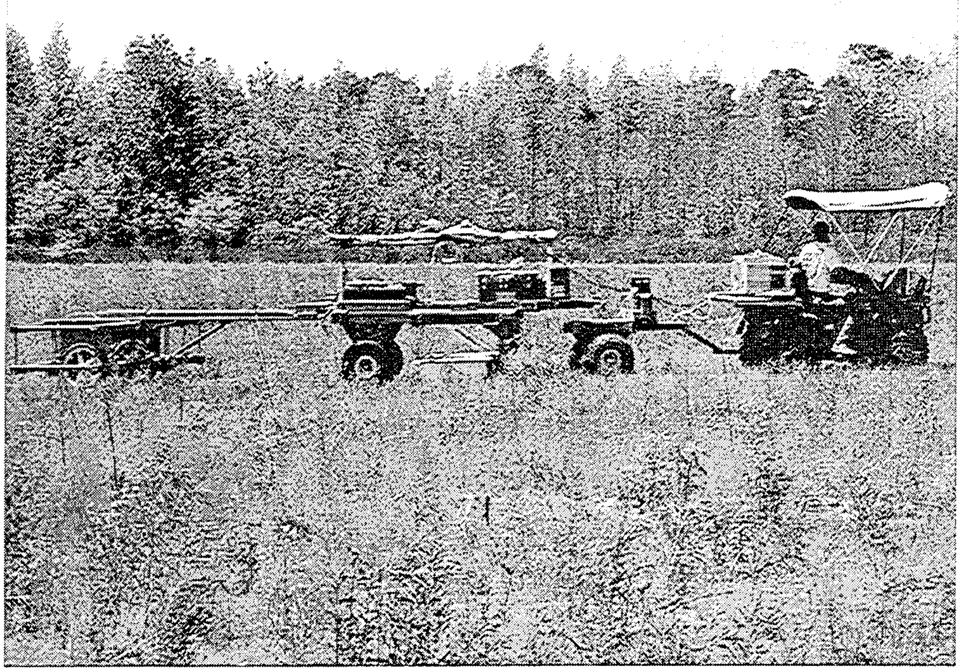
Logistics Requirements: No exceptional logistics requirements were noted.

3.1.4 Coleman Research Corporation

From May 22 through June 9, Coleman conducted a demonstration at JPG Ranges 18000W (Main), 18000W (Birdfoot), and 21000W. From July 31 through August 18, Coleman conducted a demonstration at Eglin AFB Range A-73.

Technology Description: Coleman used the Towed Multi-Sensor Array System (ToMAS), a vehicle-towed, nonintrusive, multimodal detection system (see Figure 3-4). ToMAS consists of two sensor arrays equipped with frequency-stepped GPR and time-domain electromagnetic (TDEM) sensors. ToMAS is capable of detecting metallic and nonmetallic anomalies as well as changes in soil characteristics.

Figure 3-4
Coleman Towed Multi-Sensor Array System



The GPR sensor array is a wide-band, coherent stepped-frequency radar (100 to 1,000 MHz) with receiver and transmitter antennae. Coleman claims that frequency-stepped radar can provide instantaneous dynamic range and greater sensitivity than most sensors. The current configuration uses two transmitter and three receiver spiral antennae, but the number of receiver and transmitter antennae can vary as dictated by scan rate requirements and scan width limitations. The GPR sensors maintain ground contact during the site survey.

The ToMAS TDEM sensor array consists of three Geonics Inc. Model EM-61 high-sensitivity metal detectors. The EM-61 units generate electromagnetic pulses at 15 hertz (Hz) and take measurements between pulses. The EM-61 units pause until the conductive earth response dissipates and then measure the prolonged response from buried metal objects. The TDEM array is mounted about 0.2 meter above the ground. Coleman surveyed along tracks with a width of about 2.7 meters. To augment ToMAS, Coleman uses portable GPR and TDEM arrays in areas where the tow vehicle cannot gain access due to rough terrain and physical obstructions.

Differential GPS data and data from a linear position encoder wheel on the ToMAS system are combined for location scanning, grid layout, and vehicle guidance. The GPS unit is mounted on the tow vehicle. When Coleman uses the portable sensor arrays, a differential GPS system is used for navigation.

Data gathered in the field are recorded on an on-board computer and transferred to a personal computer. Using proprietary algorithms, the data are synthesized, and a three-dimensional multisensor reconstruction of the data is created.

Resource Requirements: Coleman used seven people for the JPG demonstration and five people for the Eglin AFB demonstration. Coleman subcontracted with an EOD specialty company to provide its own EOD specialist in the field.

At JPG and Eglin AFB, Coleman required office space and an equipment storage area. Electricity was provided for computers at the office space and for battery charging at the equipment storage area. For equipment storage at JPG, Coleman used a storage barn at the Indiana ANG headquarters east of Range 21000W; at Eglin AFB, Coleman stored equipment in a fenced area adjacent to the office trailer.

Coleman used a rental van to transport personnel and equipment during field activities and a large rental truck to transport equipment from its offices in Orlando, Florida, to the live sites for the demonstration. In addition, fuel for the tow vehicle was brought and stored on site.

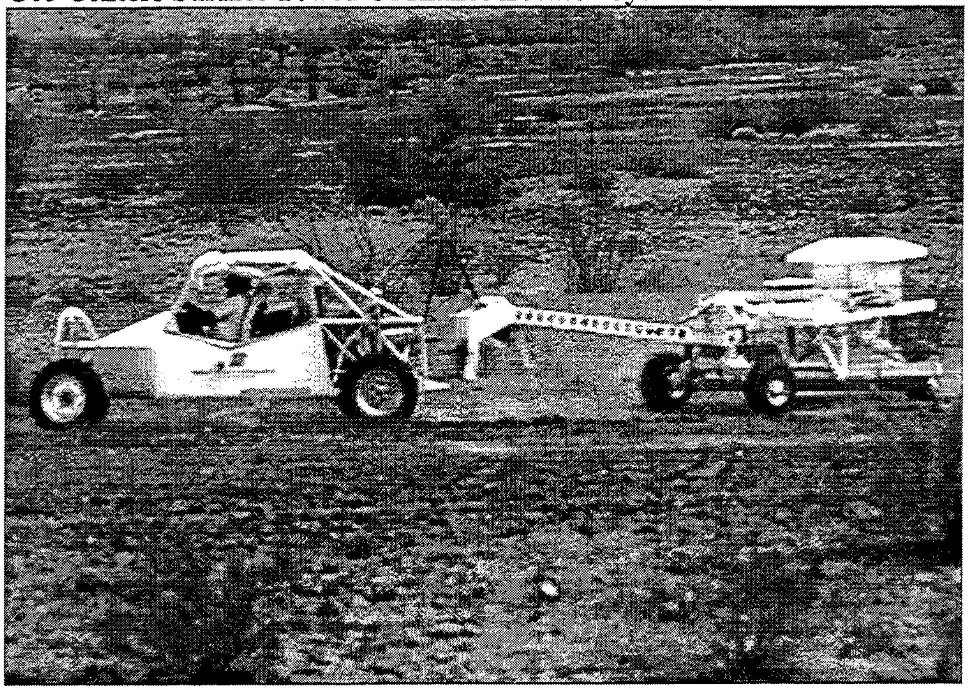
Logistics Requirements: No exceptional logistics requirements were noted.

3.1.5 Geo-Centers, Inc.

From July 12 through 27, Geo-Centers conducted a demonstration at YPG's Steel Circle and Hulk 3 Ranges. From September 11 through 26, Geo-Centers conducted a demonstration at the Fort Jackson Churchill Drop Zone.

Technology Description: Geo-Centers demonstrated the Surface Towed Ordnance Locator System (STOLS®), a vehicle-towed sensor platform (see Figure 3-5). STOLS® is equipped with seven cesium-vapor, total-field magnetometers to detect metallic objects; a real-time differential GPS for vehicle navigation and target location; and proprietary data acquisition hardware and software. The vehicle is guided by flags placed along survey paths by Geo-Centers personnel. The STOLS® platform is towed by an off-road, two-wheel-drive, single-passenger vehicle.

Figure 3-5
Geo-Centers Surface Towed Ordnance Locator System®



The STOLS® magnetometer sensors are spaced at 0.5-meter intervals on a boom mounted on the STOLS® platform. The boom provides magnetometer sensor protection and adjusts to provide adequate clearance in a variety of terrains. Magnetometer measurement data are collected at a rate of 20 Hz.

In areas at Fort Jackson where STOLS® could not negotiate the terrain, Geo-Centers used its STOLS® adjunct, which is a man-portable multisensor search and survey system equipped with differential GPS for navigation. The adjunct detects both ferrous and nonferrous metals and detects changes in subsurface conductivity. Data collected with the adjunct may be downloaded into a PC computer and processed in a manner similar to data from STOLS®.

In the field, sensor data are periodically downloaded for preliminary processing to ensure that survey areas are adequately covered and that the collected data are usable. The STOLS® trailer serves as a self-contained data processing center. Magnetic data are processed to provide color output of the variations in the total magnetic field and the positions of targets based on magnetic model matching. Data processing includes data interpolation, data filtering, and postprocessing model matching.

Resource Requirements: Geo-Centers used eight people for the YPG ATD, including five field flaggers, one tow vehicle driver, one data processor, and one field supervisor. Geo-Centers used seven people at Fort Jackson. At Fort Jackson, the portable STOLS® adjunct required a team of three to four people.

The STOLS® equipment was transported to and around both sites in an enclosed trailer that was also used for STOLS® storage. During field activities, the trailer functioned as a maintenance depot and data analysis center. Trailer electricity was provided by gasoline-powered generators on the trailer. Gasoline sources were established for STOLS® and the electrical generators before both demonstrations. During the YPG demonstration period, Geo-Centers used electricity from an aircraft hangar located nearby. During the Fort Jackson ATD, Geo-Centers personnel required a secure area for STOLS® storage.

At the beginning of the YPG and Fort Jackson ATDs, Geo-Centers required less than 1 day to complete system setup and calibration. However, Geo-Centers required about 1 hour for start-up activities each morning and again after lunch if STOLS® was shut down for the lunch hour. At the end of each day, 30 to 45 minutes were required to download data and secure equipment. The Geo-Centers man-portable units required 20 to 60 minutes of system setup activities.

Before surveying began, field personnel marked 3-meter lanes for the STOLS® vehicle. Field personnel held flagged poles at each end and at intermediate points along each path to guide the vehicle-towed system in a straight line.

Logistics Requirements: No exceptional logistics requirements were noted.

3.1.6 Metratek, Inc.

From July 12 through 28, Metratek conducted a demonstration at YPG's Steel Circle and Hulk 3 Ranges. From October 24 through November 8, Metratek conducted a demonstration at McChord AFB's South 40 Training Area.

Technology Description: Metratek demonstrated an integrated-sensor platform towed behind a four-wheel-drive vehicle (see Figure 3-6). The sensor arrays consist of three GPR antennae for target imaging and three EM metal detectors for low-frequency metal detection. Both sensors are integrated with differential GPS for navigation and target location. The GPR antennae are mounted on polyethylene sheeting and dragged on the ground surface directly behind the tow vehicle. The EM metal detectors are mounted on a wheeled cart with a ground clearance of about 0.75 meter; the EM detectors are pulled by the tow vehicle directly behind the GPR antennae. The GPR and EM sensor configuration provides a coverage width of about 4.5 meters. Processing electronics and monitoring components for the GPR and EM sensors are housed in the tow vehicle.

The GPR sensor array is a Metratek Model 200 coherent stepped-frequency radar capable of operating between 0.1 and 1.8 GHz. The polyethylene "sled" that carries the antennae provides near-ground contact as it trails behind the tow vehicle. The near-ground position allows the antennae to radiate preferentially into the ground instead of into the air, and it may result in reduced ground surface return.

Figure 3-6
Metratek Integrated Sensor Platform

The EM sensor array used by Metratek is a Geonics Inc. Model EM-61, designed to detect metal objects at depths up to 1.5 meters below ground surface. The EM-61 creates a pulsed, primary magnetic field that induces eddy currents in nearby metallic objects. The decay of the eddy currents in these objects is measured by two sets of receiver coils. The EM sensor coils are mounted on the cart frame and consist of two 1- by 1-meter horizontal bars positioned about 40 cm apart. The bottom half of the frame holds both transmitter and receiver coils, while the top half holds a secondary receiver (focusing) coil used to determine target depth.

Responses are recorded and displayed by an integrated datalogger as two sources of information (one from each set of receiver coils). An odometer mounted on the axle of the trailer wheel automatically triggers the datalogger to record the measurements. Data are processed in a program that displays targets detected by both coil antennae.

Data collected by the sensors and differential GPS are processed through custom software that provides real-time target detection capabilities. Additional data analysis and processing may be conducted in an on-site support trailer. GPR data processing can be performed in real time and off-line, using matched filtering or combinations of coherent or noncoherent integration. The radar return signals are recorded to disk so that they can be processed into synthetic aperture radar (SAR) strip maps to locate and identify particular UXO items. The data recording system can digitize, integrate, and record complex video outputs and process them off-line using a variety of SAR and coherent radar-processing algorithms.

Resource Requirements: Metratek used six people for the YPG ATD: one field supervisor, two data analysts, and three people in the tow vehicle (driver, data processor, and GPS operator). Metratek used five people for the McChord AFB ATD: three people in the tow vehicle and two data analysts. One additional person was present for the first week of the McChord ATD to assist in system setup and debugging.

At YPG and McChord AFB, Metratek used a rented flat-bed truck to transport the GPR sled, EM sensors, supplies, and spare parts around the site. The flat-bed truck also served as a data analysis and processing center. Electricity was provided to the flat-bed truck by a gasoline-powered generator. Another gasoline-powered generator was mounted on the front of the tow vehicle to provide electricity to the GPR sled, data acquisition equipment, and the tow vehicle air conditioner. Batteries were used to supply electricity to the EM sensors and the differential GPS base station. Gasoline for the tow vehicle and generators was brought and stored on site.

In addition to the equipment that Metratek brought to McChord AFB, Metratek was provided with an indoor area for system assembly and equipment storage, an on-site tent for overnight trailer storage, and the use of an additional flat-bed truck to haul the fiberglass cart to the demonstration area.

Metratek required 2 days to complete initial system assembly and setup at YPG and McChord AFB.

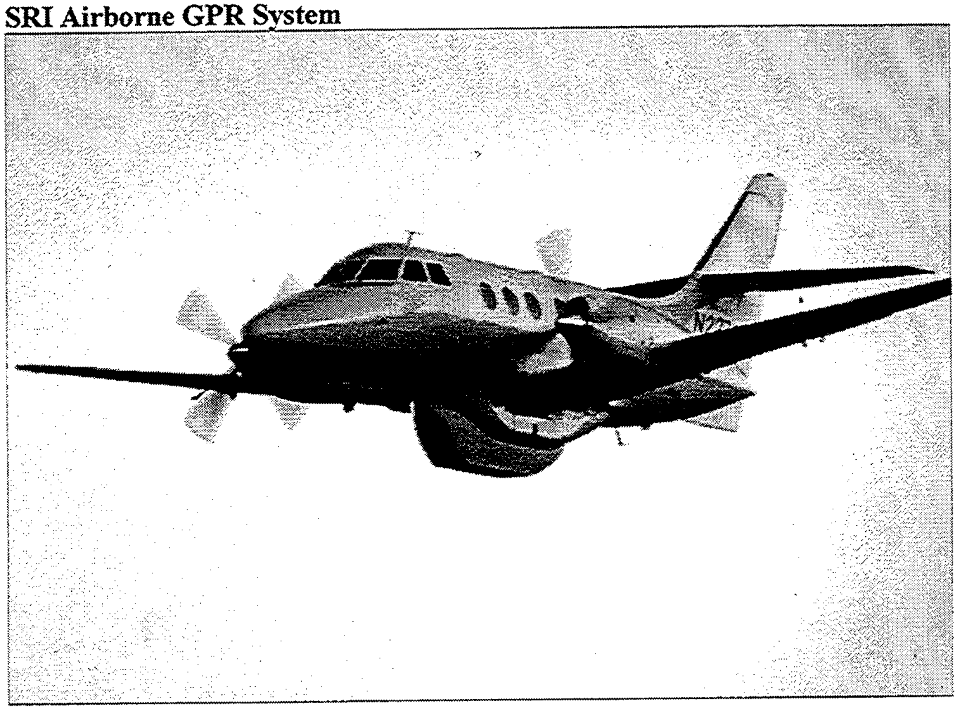
Logistics Requirements: No exceptional logistics requirements were noted.

3.1.7 SRI International, Inc.

From July 17 through 20, SRI conducted a demonstration at YPG's Steel Circle and Hulk 3 Ranges. From September 11 through 19, SRI conducted a demonstration at Fort Jackson's Churchill Drop Zone, Artillery Road Site, and Ranges 12B and 12F.

Technology Description: SRI used a Jet Stream 31 fixed-wing aircraft to demonstrate its airborne GPR system (see Figure 3-7). The GPR transmitter antenna, receiver antenna, and auxiliary equipment are housed in a modified cargo pod mounted on the aircraft belly. Auxiliary equipment, including data collection, system control, and navigation systems, is mounted on two racks in the aircraft's cabin. Differential GPS is used for on-board navigation and is linked by radio to a ground station to control aircraft track and velocity.

Figure 3-7
SRI Airborne GPR System



The GPR is dual polarization; both polarizations are transmitted from a single quad-ridge horn antenna and are received in a similar antenna. At both live sites, SRI collected data using a 300-MHz center frequency and near-simultaneous polarization. The radar's long wavelengths are intended to increase the system's soil penetration capabilities. The radar's fully polarimetric capability enables the sensor to refract more energy into the soil and onto targets; this increased energy allows for more sophisticated processing to help reduce cluttered signatures.

Large aluminum reflectors can be set up at the survey site to provide benchmarks for the site survey and provide information on site topography. Radar returns are generated from UXO, terrain, and various surface features such as trees, vehicles, and the reflectors. These returns are recorded by a data acquisition system and stored on tape for postflight data processing into SAR images. By integrating returns from a linear range of aircraft positions, two-dimensional images are generated showing regions of high and low radar return. Three-dimensional stereo image pairs can also be generated through minor changes in data collection patterns. Analysis of these images gives an indication of target depth.

Resource Requirements: SRI used five people for the YPG ATD: an aircraft pilot and copilot, aircraft GPS operator, aircraft GPR operator, and ground GPS operator. In addition, the ground GPS operator at Fort Jackson took extensive photographs to compare with radar images for feature identification. Four aluminum reflectors were installed to provide radar returns at known locations for GPS calibration.

At YPG and Fort Jackson, SRI required electricity to power the ground GPS station and the base station for the differential GPS. SRI also requires a nearby air strip to house and fuel its aircraft.

SRI required 1 day to complete site preparation activities at both locations, including installation of the on-board radar system and auxiliary equipment. Each demonstration day, SRI required about 1 hour to set up and test support equipment.

Logistics Requirements: At YPG, SRI was required to submit a weekly flight plan for coordination with other missions. At Fort Jackson, SRI submitted daily flight plans to the Range Controller to ensure that flight paths did not cross active impact ranges or safety fans. Occasional schedule conflicts occurred at YPG, but SRI planned its activities around conflicted times.

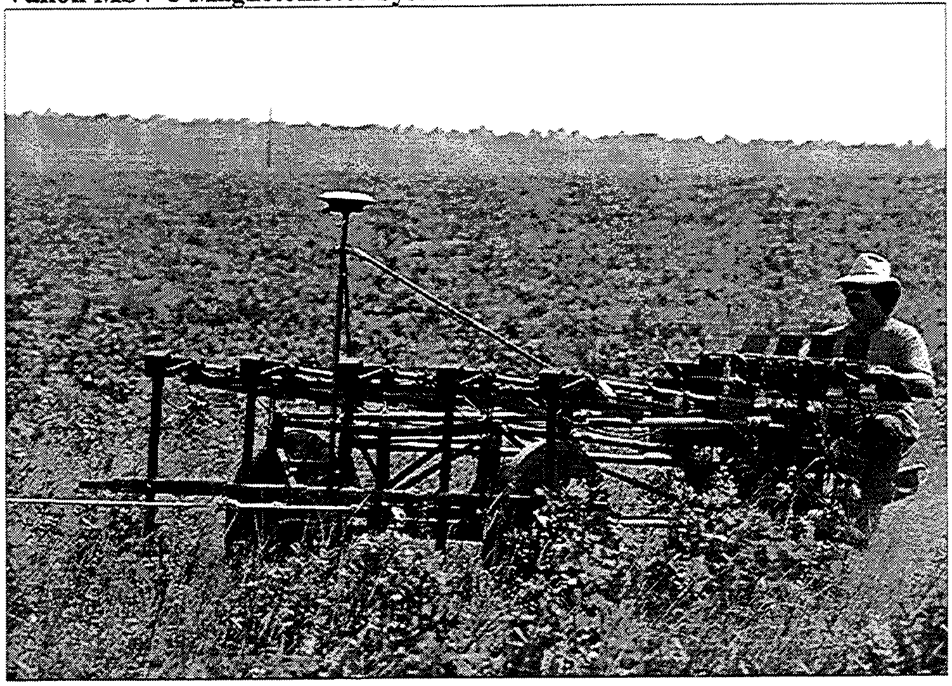
3.1.8 Vallon GmbH

From July 31 through August 16, Vallon conducted a demonstration at Eglin AFB Range A-73.

Technology Description: Vallon demonstrated vehicle-towed and portable magnetometer systems. The vehicle-towed system is the Multi-Sensor Vehicle (MSV-5) (see Figure 3-8). The MSV-5 uses an all-terrain vehicle (ATV) to tow a platform containing an array of five magnetometers (Vallon Model

EL1302A1 ferrous locators) spaced 0.5 meter apart. The EL1302A1 is a high-sensitivity differential magnetometer to detect iron. Each magnetic sensor is connected to a separate data analysis microcomputer and a base GPS receiver. Using a proprietary algorithm, the microcomputer provides real-time illustration of survey data to provide immediate analysis. Data may be stored and downloaded for further processing to produce target lists and field maps.

Figure 3-8
Vallon MSV-5 Magnetometer System



The man-portable detection system (MANPODS) is used to survey areas that the MSV-5 cannot access. MANPODS consists of a single magnetometer and an operator backpack containing a data acquisition microcomputer. To navigate, MANPODS can use either a differential GPS or the Vallon sensor positioning system (SEPOS). SEPOS operation requires marking a known location with GPS, where GPS satellite signals are available, and then using measuring tape for further positioning information.

Resource Requirements: Vallon used seven people for the ATD at Eglin AFB. Two people were required to operate the MSV-5: one to drive the tow vehicle and one to steer and control the magnetometer array. Two people were required to operate the MANPODS unit. Three other people provided computer, equipment, and office support.

Vallon's system required shipment to Eglin AFB from its headquarters in Germany. System shipment required specially designed crates and a flat-bed truck for transportation from the Eglin AFB Main Base to the ATD site. System operation requires that a fuel source be established for the tow vehicle. In addition, Vallon identified suppliers for spare tires, tools, and spare parts.

Logistics Requirements: No exceptional logistics requirements were noted.

3.2 REMEDIATION SYSTEMS

Remediation of emplaced targets and demonstrator-declared targets required excavation to uncover the UXO. The purpose of remediating baseline UXO targets was to ensure that emplaced UXO items were removed from the ranges. The purpose of remediating demonstrator-declared targets was to validate a limited number of unknown targets and to subsequently evaluate demonstrator performance based on the validated targets.

Remediation activities were conducted at each live site demonstration area by one of four remediation teams. USAF/WL, in conjunction with NAVEODTECHDIV, conducted remediation activities at two of the five live sites. At the other three sites, installation-specific remediation teams conducted these activities.

3.2.1 U.S. Air Force/Wright Laboratory

From July 17 through 31, USAF/WL conducted excavation activities at JPG Range 21000W. From October 31 through November 9, USAF/WL conducted excavation activities at Fort Jackson's Churchill Drop Zone and Artillery Road Site.

Technology Description: USAF/WL used the AOE, a modified, remote-controlled Caterpillar Model 325L excavator (see Figure 3-9). The AOE has an extended reach of 18.4 meters, a bucket capacity of about 1 cubic meter (m^3), and can dig to a depth of 14.8 meters. The system is designed to excavate and remove ordnance while maintaining personnel at a safe distance from the excavation.

Figure 3-9
USAF/WL Autonomously Operated Excavator

The AOE is equipped with a teleoperated remote control system designed for an operational range of up to 3.2 km under clear line-of-sight conditions. For excavation viewing and guidance, video cameras are mounted on the excavator and video monitors are mounted in the mobile command station. The remote control system provides control of all functions normally executed by a cab operator.

The AOE utilizes differential GPS on the bucket to position the excavator within centimeters of the target location. Other hardware provides real-time information regarding boomstick configuration to determine dig depth and bucket motion. An additional radio link is used to transfer GPS data to a mobile command station, where the excavator's location is displayed.

Resource Requirements: USAF/WL used four people for the JPG and Fort Jackson ATDs. In addition, a NAVEODTECHDIV field program manager assisted USAF/WL.

The AOE required transportation by truck and trailer from Tyndall AFB, Florida, to both JPG and Fort Jackson. A truck was used to transport AOE personnel, field equipment, tools, and fuel to and from the sites each day. A USAF/WL utility truck served as the mobile command station for AOE operations.

Electrical power for the mobile command station was provided by the utility truck's gasoline engine. The AOE and command station required fuel sources at both sites.

For the JPG validation, USAF/WL could not maintain line-of-sight between the AOE and the mobile command station because of the trees surrounding Range 21000W. To compensate for this situation, a plate metal blast shield was constructed on the periphery of the range to mitigate hazards to the command station and personnel that might have resulted from an explosion during remediation activities. Small tools, batteries, a portable air compressor, and other types of field maintenance equipment were supplied to USAF/WL. JPG provided a bulldozer for backfilling excavations, but base closure activities prevented using the bulldozer for more than 2 weeks. As a result, another bulldozer was obtained from a local construction equipment leasing firm to backfill excavations and prepare an area at Range 21000W for ordnance destruction. JPG personnel operated the bulldozer for USAF/WL.

Logistics Requirements: No unusual logistics requirements were noted.

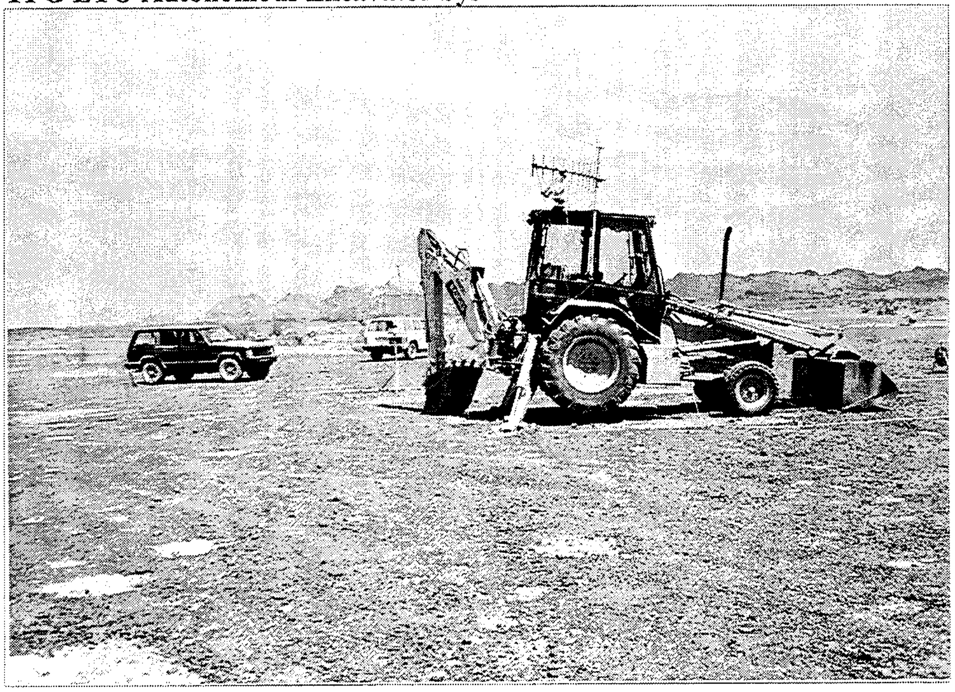
3.2.2 Yuma Proving Ground Explosive Test Operations

YPG ETO personnel conducted excavation activities from August 28 through September 22 at the YPG Steel Circle and Hulk 3 Ranges.

Technology Description: YPG ETO personnel used an autonomous excavator that consisted of a remote-controlled Ford Model 655C loader-backhoe (see Figure 3-10). The backhoe has a 4.6-meter arm and a bucket capacity of 0.17 m^3. At a safe distance from the excavation, a control trailer contains excavator and video camera controls, camera monitors, video recording equipment, transmitters, receivers, and antennae.

Two video cameras are used for excavation viewing and system guidance. One camera is mounted on top of the excavator cab, and the second is mounted on a tripod about 10 meters from the excavation. From the trailer, cameras are adjusted using switches on the control board. The backhoe boom, stick, and bucket are also controlled with control board joysticks. Camera images are wirelessly transmitted to the control trailer, while excavator commands are transmitted from the trailer to the system.

Figure 3-10
YPG ETO Autonomous Excavator System



For effective transmission of video camera and excavator control signals, a direct line of sight is required between the trailer and the excavator. Excavator control signals are sensitive to physical and electronic obstructions. The telemetry system has a range of 1.6 km; outside this range, electronic signals become weak, and the system cannot operate.

Because the YPG ETO system cannot be navigated remotely, the YPG remediation team was required to drive the excavator to each target location. After the excavator was positioned at the target location, the YPG remediation team manually set up the cameras.

Resource Requirements: Three YPG personnel were on site continually for the demonstration: an excavator operator, a field assistant, and a video specialist who changed video cassettes in the videocassette recorders and checked to ensure the cameras were operational at each excavation position. Other YPG personnel were on site intermittently to provide assistance with logistics issues and to observe operations.

The excavator and control trailer required a four-wheel-drive truck and flat-bed trailer for transportation. The truck was also used to transfer equipment and personnel to and from target locations. A YPG fuel truck delivered fuel to the control booth generator and excavator. YPG personnel conducted minimal daily maintenance on the autonomous excavator.

The video cameras required rechargeable batteries, which were changed every 4 to 5 hours during the demonstration. Control trailer electricity was provided by a gasoline-powered generator.

Logistics Requirements: No unusual logistics requirements were noted.

3.2.3 U.S. Air Force 96th Explosive Ordnance Disposal Division

From September 18 through 29, USAF 96th EOD conducted excavation activities with its remotely operated excavator at Eglin AFB Range A-73.

Technology Description: The USAF 96th EOD excavator consists of a modified, remote-controlled, John Deere 690D-LC excavator (see Figure 3-11). The diesel-powered excavator has been modified by the addition of electronics, making the system autonomous. Three video cameras are mounted on the excavator for surveillance and system guidance. Camera images and system commands are wirelessly transmitted to the control trailer, located at a safe distance from the excavation.

Resource Requirements: USAF 96th EOD typically used three personnel to conduct excavation activities. One member of the EOD team operated the excavator. The other two members of the team checked each excavation for magnetic anomalies if none were observed on the television monitor; they also moved recovered UXO from the excavation area to the on-site UXO stockpile. Unlike the excavation teams at the other live sites, the USAF 96th EOD excavation team used numerous equipment operators, including several who had never used the equipment before. According to USAF 96th EOD personnel, learning how to use the excavator controls was fairly easy if the operator had experience with similar manual excavation equipment.

Figure 3-11
USAF 96th EOD Autonomous Excavator System

The excavation team used a four-wheel-drive truck to transport personnel, tools, and equipment between the control trailer and the excavator. Electricity for the control trailer, equipment, and air conditioning unit was provided by a gasoline-powered generator. Fuel sources for the diesel excavator and the gasoline generator were established by Eglin AFB.

Logistics Requirements: No unusual logistics requirements were noted.

3.2.4 U.S. Air Force 62nd Explosive Ordnance Disposal Division

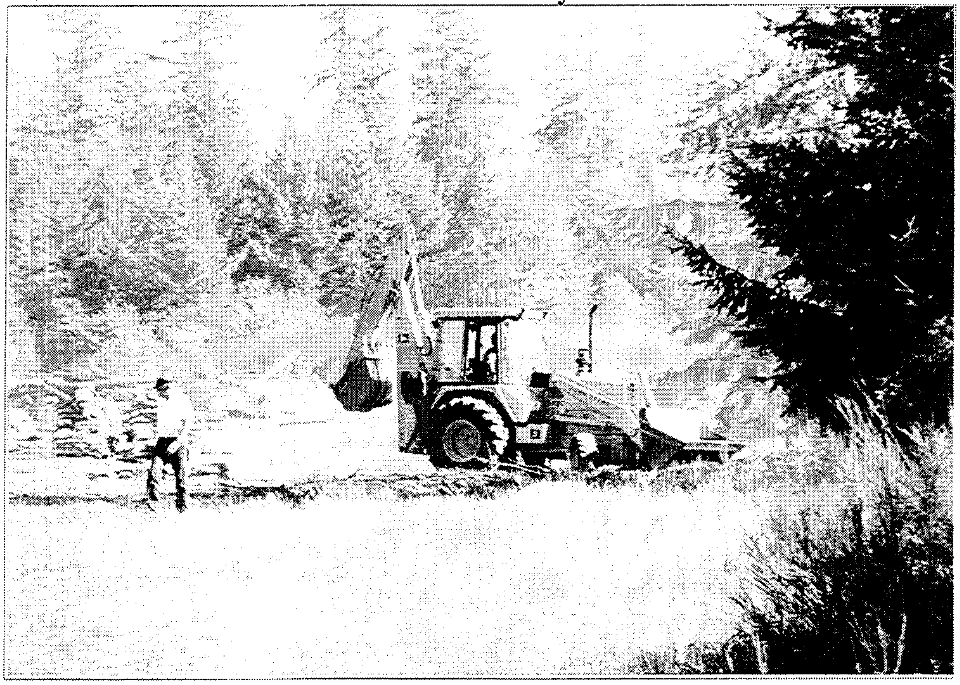
USAF 62nd EOD conducted excavation activities at McChord AFB's South 40 Training Area from December 4 through 6. The South 40 Training Area is believed to present minimal risk because with the exception of small arms training, ordnance has not been deployed at the site. Consequently, USAF 62nd EOD elected to perform the validation activities at McChord AFB using manual excavation techniques.

Technology Description: USAF 62nd EOD used a John Deere Model 510C backhoe for excavation activities (see Figure 3-12). No modifications to the John Deere off-the-shelf system were made before the validation began.

Resource Requirements: USAF 62nd EOD used three people to conduct validation activities at McChord AFB. Of these personnel, one operated the backhoe, and the other two directed operations and provided logistics support. The backhoe required diesel fuel for operation. Other resource requirements were not noted.

Logistics Requirements: No unusual logistics requirements were noted.

Figure 3-12
USAF 62nd EOD Conventional Excavator System



4.0 PERFORMANCE EVALUATION

This section presents the methodology and criteria used to evaluate the performance of individual demonstrators for the live site ATD project. Three aspects of demonstrator performance were addressed: (1) ability to detect, locate, and classify emplaced baseline targets; (2) ability to detect and locate other targets that were not part of the baseline; and (3) survey rate.

The methods, criteria, and statistics used to assess individual demonstrator performance against the emplaced baseline are discussed in Section 4.1. Because there were not sufficient resources to validate every demonstrator declaration at the live sites, criteria were developed to randomly select validation locations and determine whether these demonstrator-declared locations contained UXO. The criteria used to select these locations are presented in Section 4.2. The methods used to calculate demonstrator survey rates are outlined in Section 4.3.

4.1 PERFORMANCE WITH KNOWN BASELINE TARGETS

Detection system effectiveness depends on three areas of performance: (1) detection, or the ability to detect a high percentage of targets with a low number of false target reports (false alarms); (2) localization, or the ability to accurately determine the location of the target in three-dimensional space; and (3) classification, or the ability to provide descriptive information about the detected target. These performance categories are similar to those used to score the demonstrators at the Phase II controlled site ATDs (USAEC 1996), and they roughly parallel the evaluation criteria used to compare demonstrator performance during the Phase I controlled site ATDs (IDA 1995; USAEC 1994, 1995).

Before evaluating a demonstrator's performance in each of these areas, the set of baseline targets against which the demonstrator was to be scored was determined. Because some demonstrators did not survey the entire site, demonstrators were evaluated only on the area they completed. Areas that the demonstrators did not survey were identified, and the baseline targets within those regions were eliminated from the scoring.

After restricting the baseline target set to the areas covered by the demonstrator, a target matching algorithm (TMA) was applied to the demonstrator target reports to determine which reports match items in the baseline target set. After matching demonstrator target reports to baseline targets, the demonstrator's detection, localization, and classification performance was calculated.

4.1.1 Target Matching Algorithm

Automation Research Systems, Ltd. (ARS), and the Institute for Defense Analysis (IDA) developed a number of TMAs to match demonstrator target reports to baseline targets. These algorithms were developed and tested during the Phase I controlled site ATDs. Based on Phase I data, two TMAs are believed to provide the best representation of a demonstrator's capability in a controlled test environment: "Closest" and "Group." Both TMAs are thoroughly described in IDA's report on the Phase I controlled site ATDs (IDA 1995).

The Group TMA was developed to address the impact a demonstrator's spatial resolution might have on detection performance, because a significant number of baseline items at the Phase I controlled site were in close proximity to another baseline item. The Group TMA was not used in the live site analysis because most of the baseline targets were spaced far enough apart that spatial resolution was not an issue.

To use the Closest TMA, a circle of radius R_{crit} is centered about each baseline target's geometric midpoint in the horizontal (x-y) plane. The closest demonstrator report falling within this circle is matched to the baseline target. If a demonstrator target report can be matched to multiple baseline items, a tie-breaking scheme is used to minimize the average distance between targets while maximizing the number of matches. However, tie-breaking procedures were not required during the live site data analysis. If no demonstrator target reports are within the circle, the baseline target is evaluated as having been undetected by the demonstrator being evaluated.

To be consistent with the data analysis methods used for the Phase I and Phase II controlled site ATDs, ground platform demonstrators were evaluated using a 2-meter R_{crit} value; aerial platform demonstrators were evaluated using a 5-meter R_{crit} value. The rationale for selecting 2- and 5-meter R_{crit} values is described in the reports summarizing the Phase I and Phase II controlled site ATDs (IDA 1995; USAEC 1996).

4.1.2 Detection Performance

To evaluate system performance, one must consider how the system reacts to both signal and noise. A system with a high probability of detection may be of limited practical use if the number of false alarms is high, because false alarms require investigation and use resources. Probabilities of detection are computed by matching demonstrator target reports of both ordnance and nonordnance items to the number of baseline targets in the area surveyed. In addition to an overall probability of detection (P_D), probabilities of detection are calculated for the following target type, size, and class categories:

$P_{D,ord}$ = Probability of detecting ordnance
= Ratio of ordnance targets detected to ordnance targets in area surveyed

$P_{D,nonord}$ = Probability of detecting nonordnance
= Ratio of nonordnance targets detected to nonordnance targets in area surveyed

$P_{D,small}$ = Probability of detecting small ordnance
= Ratio of small targets detected to small targets in area surveyed

$P_{D,medium}$ = Probability of detecting medium-sized ordnance
= Ratio of medium-sized targets detected to medium-sized targets in area surveyed

$P_{D,large}$ = Probability of detecting large ordnance
= Ratio of large targets detected to large targets in area surveyed

$P_{D,bomb}$ = Probability of detecting bombs
= Ratio of bombs detected to bombs in area surveyed

$P_{D,mortar}$ = Probability of detecting mortars
= Ratio of mortars detected to mortars in area surveyed

$P_{D,projo}$ = Probability of detecting projectiles
= Ratio of projectiles detected to projectiles in area surveyed

$P_{D,cluster}$ = Probability of detecting ordnance clusters
= Ratio of ordnance clusters detected to ordnance clusters in area surveyed

$P_{D,submun}$ = Probability of detecting submunitions
= Ratio of submunitions detected to submunitions in area surveyed

Because the possibility exists that a demonstrator could be credited with a baseline target detection from a random target declaration, the computed P_D values may include a mixture of true detections and random sensor or environmental noise. Therefore, a measure of the fraction of baseline targets that would be detected if the total number of demonstrator target reports were randomly distributed over the area surveyed is calculated; this measure is termed P_{random}. The purpose of the P_{random} measure is to evaluate how a demonstrator with no detection capability would perform at the live site. P_{random} is used to determine whether demonstrator P_D values are statistically different from the detection probability that would result from a random placement of points. P_{random} is discussed in detail in Appendix C and is calculated as follows:

$$P_{random} = 1 - e^{-\lambda}$$

where

$\lambda = np$
n = Number of demonstrator reports
p = Probability of having a report within R_{crit} of a baseline target
$= \dfrac{\pi R_{crit}^2}{A}$
A = Area surveyed

In a true performance assessment, the false alarm rate must also be considered. A false alarm is defined as a demonstrator UXO target declaration that does not correspond to an actual UXO target; the false alarm rate is defined as the number of false alarms per hectare. Because the quantity of demonstrator target declarations that could be reasonably excavated in the 3- or 4-week validation period at each site is not statistically significant at any practical level, each demonstrator's false alarm rate could not be measured. As a result, false alarm rates could not be addressed for the live site ATDs.

4.1.3 Localization Performance

Localization is a measure of how accurately a demonstrator can determine a target's horizontal (*x*-*y* plane) and vertical (*z*-axis) positions. The horizontal position is generally determined during the detection process; vertical position is often estimated from the sensor response.

Using the Closest TMA, localization errors were computed from the set of baseline targets detected by each demonstrator. As a result, horizontal localization errors are constrained by the critical radius used in the evaluation process (2 meters for ground platforms and 5 meters for aerial platforms). For each target detected, the error relative to the baseline target's geometric midpoint is computed for the horizontal and depth components as follows:

$$dx = x_r - x_b$$
$$dy = y_r - y_b$$
$$dz = z_r - z_b$$

The "r" subscript is associated with the demonstrator-reported target coordinates in three-dimensional space; the "b" subscript is associated with the actual baseline target coordinates. Negative values of *dx*, *dy*, and *dz* indicate that the demonstrator report is west of, south of, and shallower than the baseline target, respectively. The *x* direction is represented by universal transverse mercator (UTM) "easting" ordinates, the *y* direction is represented by UTM "northing" ordinates, and the *z* direction refers to the depth below ground surface.

The error associated with determining target position and depth has two components: a constant offset or bias known as the mean error ($\overline{dx}$, $\overline{dy}$, $\overline{dz}$) and a randomly fluctuating component known as the standard deviation of the error (σ_x, σ_y, σ_z). The radial distance error in the horizontal plane ($\overline{dr}$) and the mean square depth error ($\overline{|dz|}$) represent total error in location estimates and are due to the effects of offset and randomly fluctuating errors. These statistics are computed below.

Mean and standard deviation of the *x*, *y*, and *z* errors:

$$\overline{dx} = \frac{\sum dx_i}{N} \qquad \sigma_x = \sqrt{\frac{\sum (dx_i - \overline{dx})^2}{N}}$$

$$\overline{dy} = \frac{\sum dy_i}{N} \qquad \sigma_y = \sqrt{\frac{\sum (dy_i - \overline{dy})^2}{N}}$$

$$\overline{dz} = \frac{\sum dz_i}{N} \qquad \sigma_z = \sqrt{\frac{\sum (dz_i - \overline{dz})^2}{N}}$$

Mean and standard deviation of the radial distance error r:

$$\overline{dr} = \frac{\sum dr_i}{N} \qquad \sigma_r = \sqrt{\frac{\sum (dr_i - \overline{dr})^2}{N}}$$

$$dr_i = \sqrt{dx_i^2 + dy_i^2}$$

Mean square depth error:

$$|dz| = \sqrt{\frac{\sum dz_i^2}{N}}$$

The value N in the above equations represents the number of baseline ordnance targets detected by the demonstrator.

4.1.4 Classification Performance

The ability to correctly discriminate between ordnance and nonordnance targets is important to the remediation process, because large quantities of natural or man-made nonordnance targets are typically present at most live ranges. The ability to discriminate between target types will reduce the number of false alarms that require remediation. In addition, estimates of ordnance size and class can provide guidance on what precautions should be taken during the remediation process.

Live site demonstrators were requested to classify their detections by type, size, and class. However, some demonstrators opted not to classify target reports; others did so only partially. For the live site ATD, demonstrators were allowed the following classification categories:

Type: Ordnance
Nonordnance

Size: Small (less than 100 mm in diameter)
Medium (between 100 mm and less than 200 mm in diameter)
Large (200 mm or greater in diameter)

Class: Bomb
Mortar
Projectile
Cluster
Other (submunition)

To assess each demonstrator's classification performance, the following statistics were computed from the set of detected baseline targets:

$P_{C,ord}$ = Probability of correctly classifying ordnance
= Ratio of correctly classified ordnance targets to detected ordnance targets

$P_{C,nonord}$ = Probability of correctly classifying nonordnance
= Ratio of correctly classified nonordnance targets to detected nonordnance targets

$P_{C,small}$ = Probability of correctly classifying small ordnance
= Ratio of correctly classified small targets to detected small targets

$P_{C,medium}$ = Probability of correctly classifying medium-sized ordnance
= Ratio of correctly classified medium-sized targets to detected medium-sized targets

$P_{C,large}$ = Probability of correctly classifying large ordnance
= Ratio of correctly classified large targets to detected large targets

$P_{C,bomb}$ = Probability of correctly classifying bombs
= Ratio of correctly classified bombs to detected bombs

$P_{C,mortar}$ = Probability of correctly classifying mortars
= Ratio of correctly classified mortars to detected mortars

$P_{C,projo}$ = Probability of correctly classifying projectiles
= Ratio of correctly classified projectiles to detected projectiles

$P_{C,cluster}$ = Probability of correctly classifying ordnance clusters
= Ratio of correctly classified cluster targets to detected cluster targets

$P_{C,submun}$ = Probability of correctly classifying submunitions
= Ratio of correctly classified submunitions to detected submunitions

4.2 PERFORMANCE WITH UNKNOWN TARGETS

Each demonstrator surveyed the live site and generated a list of suspected targets, including target location and classification data. Most demonstrators declared more than 1,000 targets, and some declared more than 10,000 targets per site surveyed. Because of the high number of target reports as well as the limited resources available to investigate and validate the target declarations, it was impossible to validate every suspected target location within the allotted 3- or 4-week validation period at each site. Instead, an attempt was made to gain insight into the accuracy of demonstrator target reports using randomly selected points from each of the demonstrators. The process for selecting validation locations was intended to recover UXO, and although the validation data may indicate trends in demonstrator performance, the data are biased and are of low statistical confidence.

The first step was to eliminate from each demonstrator list the subset of targets reported within 0.5 meter of the surface. This step eliminated surface clutter, which was ubiquitous and considerable at all of the live sites. Targets reported at deeper than 2 meters were also eliminated because of the greater excavation time required for holes of this depth. Next, all target reports to which demonstrators assigned a low confidence were eliminated. Targets classified as small were removed from the demonstrator target lists because small targets were difficult to observe on the video monitor during the excavation process. Finally, target reports within 2 meters of a baseline target were removed from the target lists. These targets were not validated because they were considered to correspond to the baseline targets.

After the demonstrator target lists had been shortened, target lists from different demonstrators at each site were compared. For the comparison, if any two target declarations were within 2 meters of each other, they were considered to be at the same location. Up to 10 targets declared by all demonstrators were selected randomly for validation. For locations where two demonstrators reported ordnance, a maximum of 10 validation positions were selected randomly for each pairing of demonstrators. Finally, up to 20 isolated target reports (those reports with no other demonstrator reports within a 2-meter radius) were selected for each demonstrator. Each of these validation positions were placed on a field validation list.

Both demonstrators at Eglin AFB identified several areas of high UXO density. The areas with the highest reported target density were earmarked for validation. The number of demonstrator reports within 4-meter squares was computed and ranked, and some of the 4-meter squares were excavated. However, demonstrators were not evaluated using this data because of the extremely high target density.

4.3 SURVEY RATE

Two survey rates were calculated for each demonstrator: the field survey rate and the total survey rate. The field survey rate is calculated by dividing the area surveyed by the time that demonstrator personnel physically conducted the survey. The total survey rate is calculated by dividing the area surveyed by the time that demonstrator personnel conducted the survey, set up equipment, and experienced downtime. The total survey rate represents the survey rates that would be expected at relatively small sites where a survey could be conducted in a few weeks; the field survey rate can be considered to approximate the survey rate at large sites.

This Page Intentionally Left Blank

5.0 RESULTS

5.1 DETECTION SYSTEM PERFORMANCE EVALUATION

5.1.1 Aerodat, Inc.

Aerodat demonstrated its airborne magnetic gradiometer system at JPG. The following sections describe the technology's measured performance as well as its observed capabilities and limitations.

Measured Performance at JPG: Between May 22 and June 6, Aerodat completed the entire assigned survey area of 123.3 hectares at JPG's Ranges 18000W (Aerial), 18000W (BirdFoot), and 21000W. Tall trees within and around the ranges prevented Aerodat from flying low enough to collect data under optimal conditions (Aerodat 1995a, 1995c). In fact, ground observers noted that Aerodat's sensor platform was in contact with the trees over Range 18000W (Aerial). Although Aerodat completely covered the assigned survey area, it reported that it collected unreliable data over the entire surveyed area of Range 18000W and about 50 percent of the surveyed area of Range 21000W (Aerodat 1995a, 1995c). Trees and other ground obstacles impeded Aerodat's performance in these areas.

Aerodat was on-range for a total of about 24 hours over 9 days. Aerodat used about 12 hours to set up its equipment and experienced about 45 hours of downtime due to equipment failure. In all, Aerodat spent about 81 hours conducting survey-related activities. Aerodat's field survey rate at JPG was 5.0 hectares per hour; its overall survey rate was 1.5 hectares per hour.

Figure 5-1 shows Aerodat's target declarations at Ranges 18000W and 21000W. Table 5-1 summarizes Aerodat's target declarations; Table 5-2 summarizes performance statistics calculated for Aerodat.

Aerodat surveyed the entire 26.2 hectares of JPG's Range 21000W, detecting 406 targets within the range but only detecting 3 of the 41 baseline ordnance targets. At the 95-percent confidence level, Aerodat's $P_{D,ord}$ of 0.07 is statistically indistinguishable from the P_{random} value of 0.11. With the baseline targets detected, Aerodat's mean radial error was 4.25 meters; its mean square depth error was not calculated because Aerodat merely averaged target depths. Because Aerodat detected only three of the baseline targets, the confidence in the distance error statistics is small, and the statistics should not be used as decision-making tools.

The confidence level that Aerodat assigned to its target declarations is a function of how low the aircraft could fly during the survey (Aerodat 1995a, 1995c). Aerodat's high-confidence targets are primarily those in the central portion of Range 21000W, away from the trees and power lines surrounding the range. Aerodat was not able to provide target depth accurately and reported the average target depth to be 1.5 meters (Aerodat 1995b). Aerodat reported all targets as "large," and was not able to differentiate between target types and classes (Aerodat 1995a). For scoring purposes, each Aerodat target declaration is assumed to be of type "ordnance."

During validation activities at JPG, USAF/WL excavated 19 of Aerodat's target declaration locations at Range 21000W. Table 5-3 summarizes the results of these excavation activities. Based on all three demonstrator's target reports, USAF/WL excavated a total of 53 locations at Range 21000W. Table 5-4 summarizes Aerodat's target predictions at these 53 locations.

Observed Capabilities and Limitations: Aerodat's surveying activities at JPG were hindered by lightning, hail, high winds, fog, and heavy rain that occurred intermittently during the demonstration period. The inclement weather delayed or stopped surveying activities altogether on several days. However, wet ground conditions did not prevent Aerodat from conducting the survey over the entire assigned area.

Aerodat experienced a number of technical difficulties that delayed the site survey. These technical problems were primarily related to equipment malfunctions and errors with the differential GPS system on the aircraft.

Aerodat's optimal sensor elevation is about 5 to 10 meters above the ground. However, the heavily forested area of Range 18000W and the trees and utility lines along the periphery of Range 21000W forced Aerodat to survey with the sensor platform about 35 meters above the ground at most of Range 18000W and more than 10 meters above the ground near the periphery of Range 21000W (Aerodat 1995c).

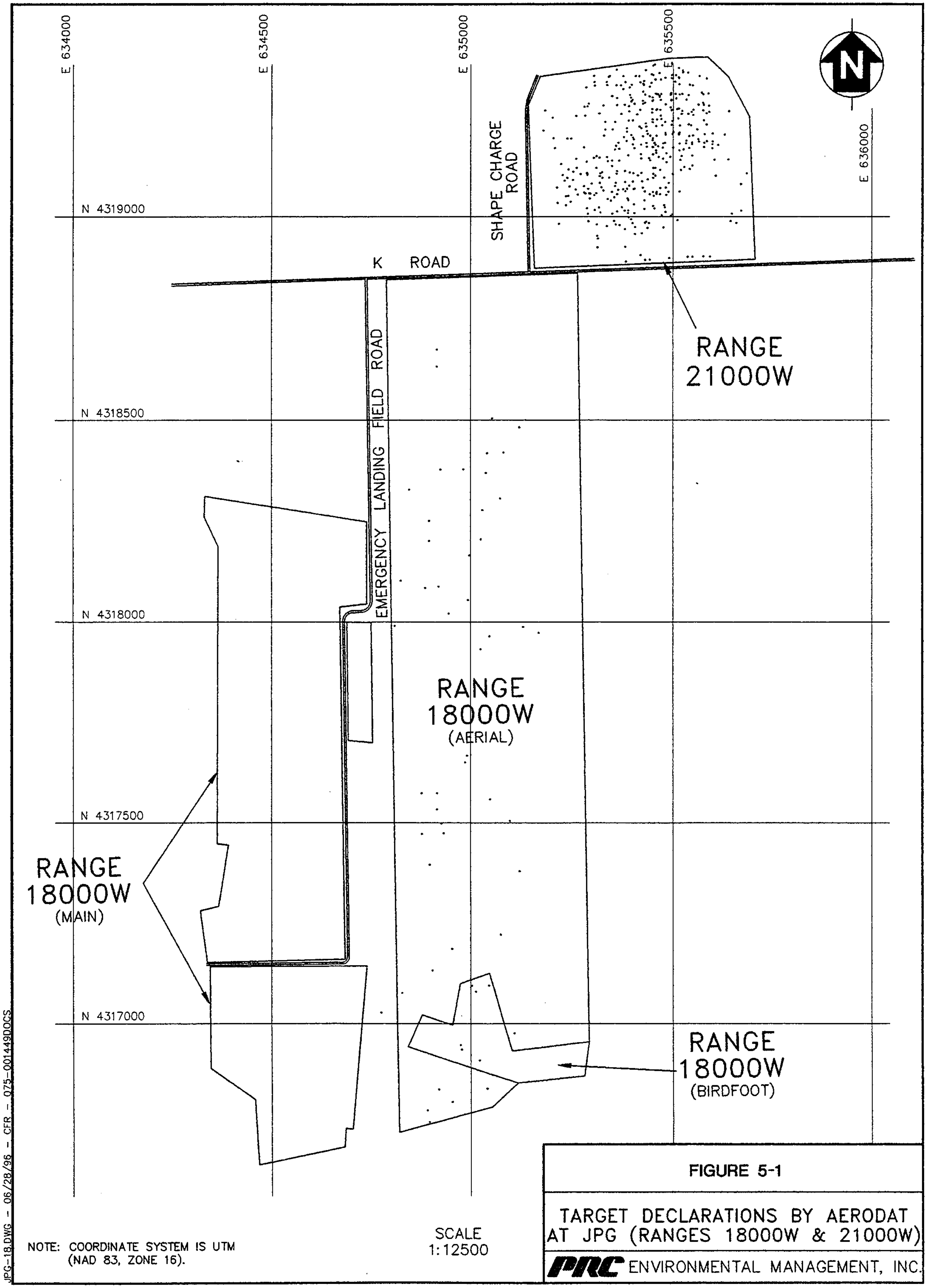


FIGURE 5-1

TARGET DECLARATIONS BY AERODAT AT JPG (RANGES 18000W & 21000W)

PRC ENVIRONMENTAL MANAGEMENT, INC.

Table 5-1
Summary of Target Declarations by Aerodat at JPG

Range	18000W	21000W	Combined
Area Surveyed (hectares)	97.1	26.2	123.3
Area Available (hectares)	97.1	26.2	123.3
Target Declarations	55	406	461
Confidence			
High	0	148	148
Moderate	0	166	166
Low	55	92	147
Unknown	0	0	0
Depth (meters)[a]			
0 to 0.5	0	0	0
> 0.5 to 2.0	55	406	461
> 2.0	0	0	0
Unknown	0	0	0
Target Type			
Ordnance[b]	55	406	461
Nonordnance	0	0	0
Target Size			
Large	55	406	461
Medium	0	0	0
Small	0	0	0
Unknown	0	0	0
Target Class			
Bomb	0	0	0
Mortar	0	0	0
Projectile	0	0	0
Cluster	0	0	0
Other	0	0	0
Unknown	55	406	461

Notes:

a Aerodat declared all targets to be 1.5 meter deep.
b Aerodat did not differentiate between target types; for scoring purposes, each target is assumed to be of type "ordnance."

Table 5-2
Performance Statistics for Aerodat at JPG

Overall Detection Statistics (R_{crit} = 5.0 meters)

Target Type	No. Detected/ No. in Baseline	$P_{D,ord}$	P_{random}
All targets	3/41	0.07	0.11

Distance Error Statistics

Error	Mean (meters)	Standard Deviation (meters)
Easting (x)	1.96	2.01
Northing (y)	0.50	4.18
Radial (r)	4.25	0.77
Depth (z)	0.78	0.11
Mean Absolute Depth ($\|z\|$)	0.61	NA

Detection and Classification Statistics

Category	No. Detected/ No. in Baseline	P_D	No. Correctly Classified/ No. Detected	P_C
Type				
Ordnance	3/41	0.07	3/3	1.00
Nonordnance	0/3	0.00	0/0	NA
Size				
Large	0/3	0.00	0/0	NA
Medium	1/18	0.06	0/1	0.00
Small	2/20	0.10	0/2	0.00
Class				
Bomb	2/17	0.12	0/2	0.00
Mortar	0/3	0.00	0/0	NA
Projectile	1/20	0.05	0/1	0.00
Cluster	0/1	0.00	0/0	NA
Other	0/0	NA	0/0	NA

Table 5-3
Excavated Target Positions Based on Aerodat Ordnance Declarations at JPG

Demonstrator Target Declaration	Excavated Target Position		
	Ordnance	Nonordnance	Empty
Ordnance	3/19	3/19	13/19

Table 5-4
Target Prediction Rates for Aerodat Based on All Excavated Locations at JPG

Demonstrator Target Declaration	Excavated Locations (n=53)[a]	
	Ordnance	Nonordnance
Ordnance	3/19	3/14
No declaration	16/19	11/14

Note:

[a] Of the 53 locations that were excavated during validation activities, 19 contained ordnance, 14 contained nonordnance, and the remaining 20 contained no discernable man-made materials.

5.1.2 Australian Defence Industries, Pty. Ltd.

ADI demonstrated its TM-4 magnetometer technology at JPG and Fort Jackson. The following sections describe the technology's measured performance as well as its observed capabilities and limitations.

Measured Performance at JPG: Between May 22 and June 3, ADI completed nearly all of the entire assigned survey area of 64.5 hectares at JPG Ranges 18000W (Main), 18000W (BirdFoot), and 21000W. ADI was on-range for a total of about 64 hours over 10 days. ADI used about 6 hours to set up its equipment, and it experienced no downtime due to equipment failure. In all, ADI spent about 70 hours conducting survey-related activities. ADI's field survey rate at JPG was 0.95 hectare per hour; its overall survey rate was 0.88 hectare per hour.

Figure 5-2 shows ADI's target declarations at Ranges 18000W and 21000W. Table 5-5 summarizes ADI's target declarations; Table 5-6 summarizes performance statistics calculated for ADI at JPG.

ADI surveyed the entire 26.2 hectares that comprise JPG's Range 21000W, reporting 1,755 targets within the range and detecting 29 of the 41 baseline ordnance targets. Although ADI detected 14,448 targets at Range 21000W, only a sample group of 12.2 percent of the targets were fully characterized and reported by ADI (ADI 1995a). At the 95-percent confidence level, ADI's $P_{D,ord}$ of 0.71 is statistically different from the calculated P_{random} value of 0.08. ADI's reported baseline target locations did not consistently exhibit any directional bias along the northing or easting directions. With the detected baseline targets, ADI's mean radial error was 0.68 meter; its mean square depth error was 0.16 meter.

ADI provided data on target confidence, depth, type, class, and size.

During validation activities at JPG, USAF/WL excavated 27 of ADI's target declaration locations at Range 21000W. Table 5-7 summarizes the results of these excavation activities. Based on all three demonstrator's target reports, USAF/WL excavated a total of 53 locations at Range 21000W. Table 5-8 summarizes ADI's target predictions at these 53 locations.

Measured Performance at Fort Jackson: Between September 11 and 27, ADI completed nearly all of the assigned survey area of 60.5 hectares at Fort Jackson's Churchill Drop Zone and Artillery Road Site.

ADI was on-range for a total of about 80 hours over 13 days. ADI used about 8 hours to set up its equipment, and it experienced about 1 hour of downtime due to equipment failure. In all, ADI spent about 89 hours conducting site survey-related activities. ADI's field survey rate at Fort Jackson was 0.76 hectare per hour; its overall survey rate was 0.68 hectare per hour.

Figures 5-3 and 5-4 show ADI's target declarations at the Churchill Drop Zone and Artillery Road Site. Table 5-9 summarizes ADI's target declarations at Fort Jackson; Table 5-10 summarizes performance statistics calculated for ADI.

ADI surveyed all of the 32.8 hectares of Fort Jackson's Churchill Drop Zone, declaring 3,223 targets within the range (ADI 1995b) and detecting 24 of the 35 baseline ordnance targets. At the 95-percent confidence level, ADI's $P_{D,ord}$ of 0.69 is statistically different from the calculated P_{random} value of 0.12. As shown in Table 5-10, ADI's reported baseline target locations did not consistently exhibit any directional bias along the northing or easting directions. With the detected baseline targets, ADI achieved a mean radial error of 0.73 meter and a mean square depth error of 0.97 meter.

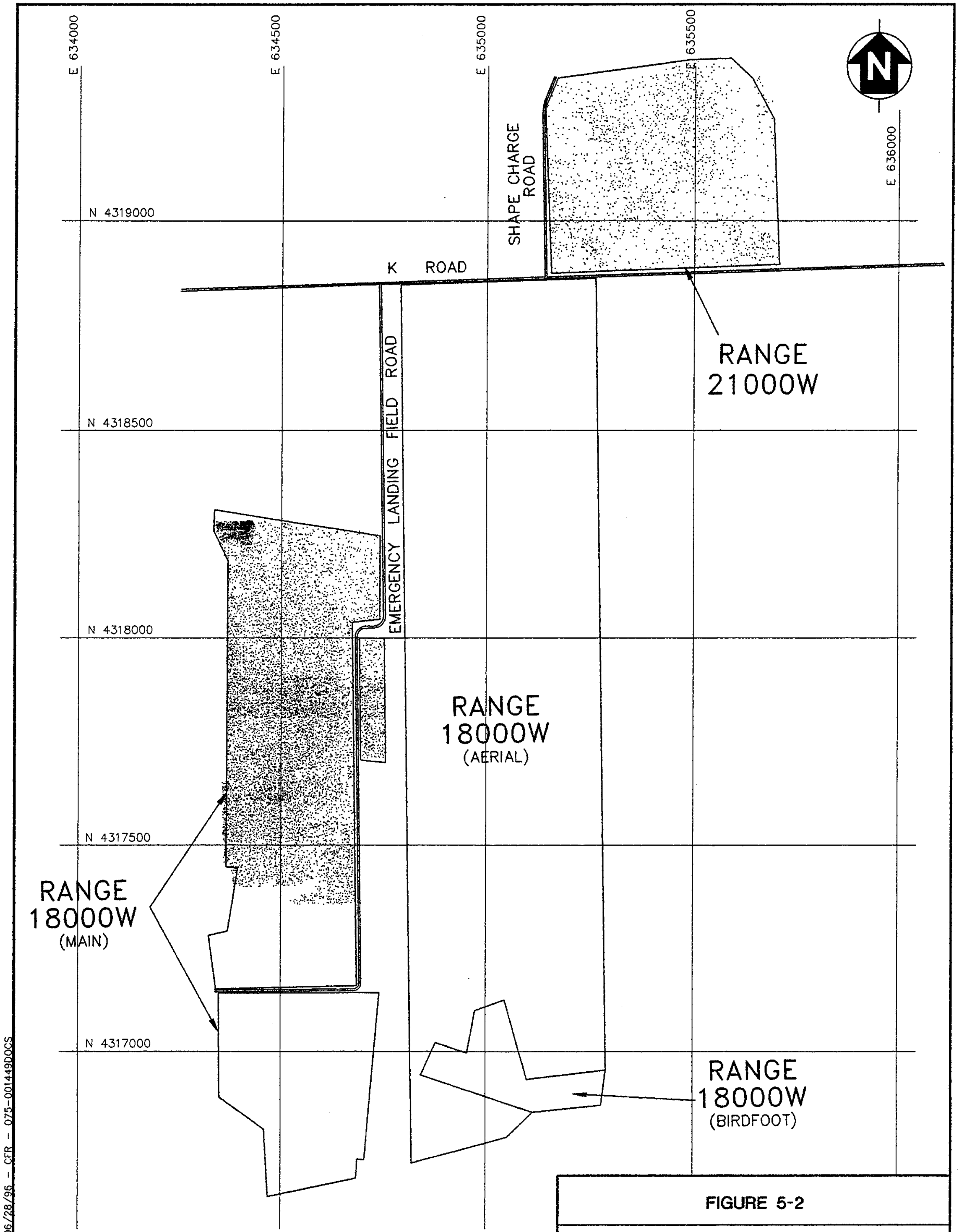
ADI provided data on target confidence, depth, type, class, and size.

During validation activities at Fort Jackson, USAF/WL excavated 30 of ADI's target declaration locations at the Churchill Drop Zone and Artillery Road Site. Table 5-11 summarizes the results of these excavation activities. Based on all three demonstrator's target reports, USAF/WL excavated a total of 43 locations at the ranges. Table 5-12 summarizes ADI's target predictions at these 43 locations.

Observed Capabilities and Limitations: At JPG, ADI was not required to survey the heavily wooded areas of Range 18000W, because this area did not undergo a UXO surface sweep. However, ADI did not encounter significant problems surveying the lightly wooded areas and a fairly steep gully at Range 18000W. At Fort Jackson, ADI was required to survey varying types of terrain, including clear, lightly wooded, and heavily wooded areas. Although ADI was slowed somewhat by the thick vegetation at the Artillery Road Site, it was able to complete the site survey.

ADI experienced occasional delays throughout the demonstration at JPG due to flooding. The man-portable unit could usually traverse flooded areas, but areas where water was more than 0.5 meter deep were deemed inaccessible by the ADI technician. As a result, ADI did not complete surveying activities in some of the flooded areas at JPG.

At Fort Jackson, the ADI system was subjected to fairly extreme heat (greater than 37 °C) and high relative humidity, but it was apparently unaffected by these climatic factors. Rain at Fort Jackson caused limited problems with the TM-4 system when water leaked into the sensors. ADI stopped surveying activities while these problems were identified and corrected. The manual navigation system used by ADI is not affected by trees, buildings, or other obstructions, which can cause problems with the differential GPS navigation systems used by other demonstrators.



NOTE: COORDINATE SYSTEM IS UTM
(NAD 83, ZONE 16).

SCALE
1:12500

FIGURE 5-2

TARGET DECLARATIONS BY ADI
AT JPG (RANGES 18000W & 21000W)

PRC ENVIRONMENTAL MANAGEMENT, INC.

JPG-18.DWG - 06/28/96 - CFR - 075-001449DOCS

Table 5-5
Summary of Target Declarations by ADI at JPG

Range	18000W	21000W	Combined
Area Surveyed (hectares)	38.3	26.2	64.5
Area Available (hectares)	38.3	26.2	64.5
Target Declarations[a]	10,804	1,755	12,559
Confidence			
High	3,792	765	4,557
Moderate	4,511	521	5,032
Low	2,498	469	2,967
Unknown	3	0	3
Depth (meters)			
0 to 0.5	5,059	720	5,779
> 0.5 to 2.0	5,546	875	6,421
> 2.0	199	160	359
Unknown	0	0	0
Target Type			
Ordnance	8,306	1,286	9,592
Nonordnance	2,498	469	2,967
Target Size			
Large	881	355	1,236
Medium	5,133	626	5,759
Small	2,292	305	2,597
Unknown	0	0	0
Target Class			
Bomb	574	278	852
Mortar	3,607	433	4,040
Projectile	4,125	575	4,700
Cluster	0	0	0
Other	0	0	0
Unknown	0	0	0

Notes:

[a] ADI detected a total of 51,293 ferrous targets at its assigned ranges at JPG. ADI provided detailed target information for only 24.5 percent of these anomalies. The reported anomalies are presented in this table.

Table 5-6
Performance Statistics for ADI at JPG

Overall Detection Statistics (R_{crit} = 2.0 meters)

Target Type	No. Detected/ No. in Baseline	$P_{D,ord}$	P_{random}
All targets	29/41	0.71	0.08

Distance Error Statistics

Error	Mean (meters)	Standard Deviation (meters)
Easting (*x*)	-0.14	0.46
Northing (*y*)	-0.27	0.55
Radial (*r*)	0.68	0.36
Depth (*z*)	0.08	0.16
Mean Absolute Depth ($\|z\|$)	0.16	NA

Detection and Classification Statistics

Category	No. Detected/ No. in Baseline	P_D	No. Correctly Classified/ No. Detected	P_C
Type				
Ordnance	29/41	0.71	28/29	0.97
Nonordnance	1/3	0.33	0/1	0.00
Size				
Large	1/3	0.33	0/1	0.00
Medium	13/18	0.72	8/13	0.62
Small	15/20	0.75	5/15	0.33
Class				
Bomb	15/17	0.88	0/15	0.00
Mortar	0/3	0.00	0/0	NA
Projectile	14/20	0.70	8/14	0.57
Cluster	0/1	0.00	0/0	NA
Other	0/0	NA	0/0	NA

Table 5-7
Excavated Target Positions Based on ADI Ordnance Declarations at JPG

Demonstrator Target Declaration	Excavated Target Position		
	Ordnance	Nonordnance	Empty
Ordnance	15/27	9/27	3/27

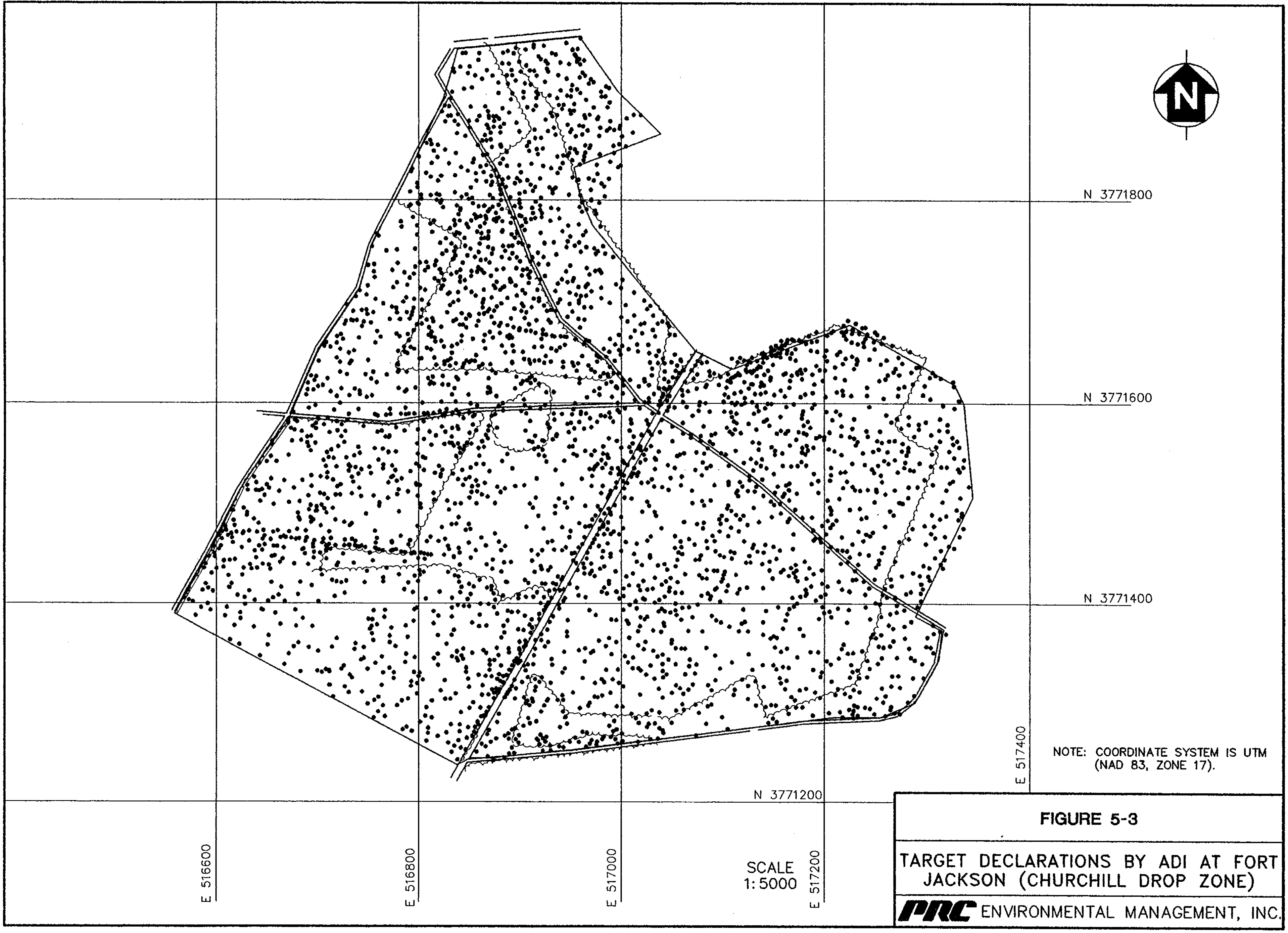
Table 5-8
Target Prediction Rates for ADI Based on All Excavated Locations at JPG

Demonstrator Target Declaration	Excavated Locations (n=53)[a]	
	Ordnance	Nonordnance
Ordnance	14/19	9/14
Nonordnance	1/19	0/14
No declaration	4/19	5/14

Note:

[a] Of the 53 locations that were excavated during validation activities, 19 contained ordnance, 14 contained nonordnance, and the remaining 20 contained no discernable man-made materials.

JACK-CDZ.DWG - 06/28/96 - CFR - 075-001449DOCS

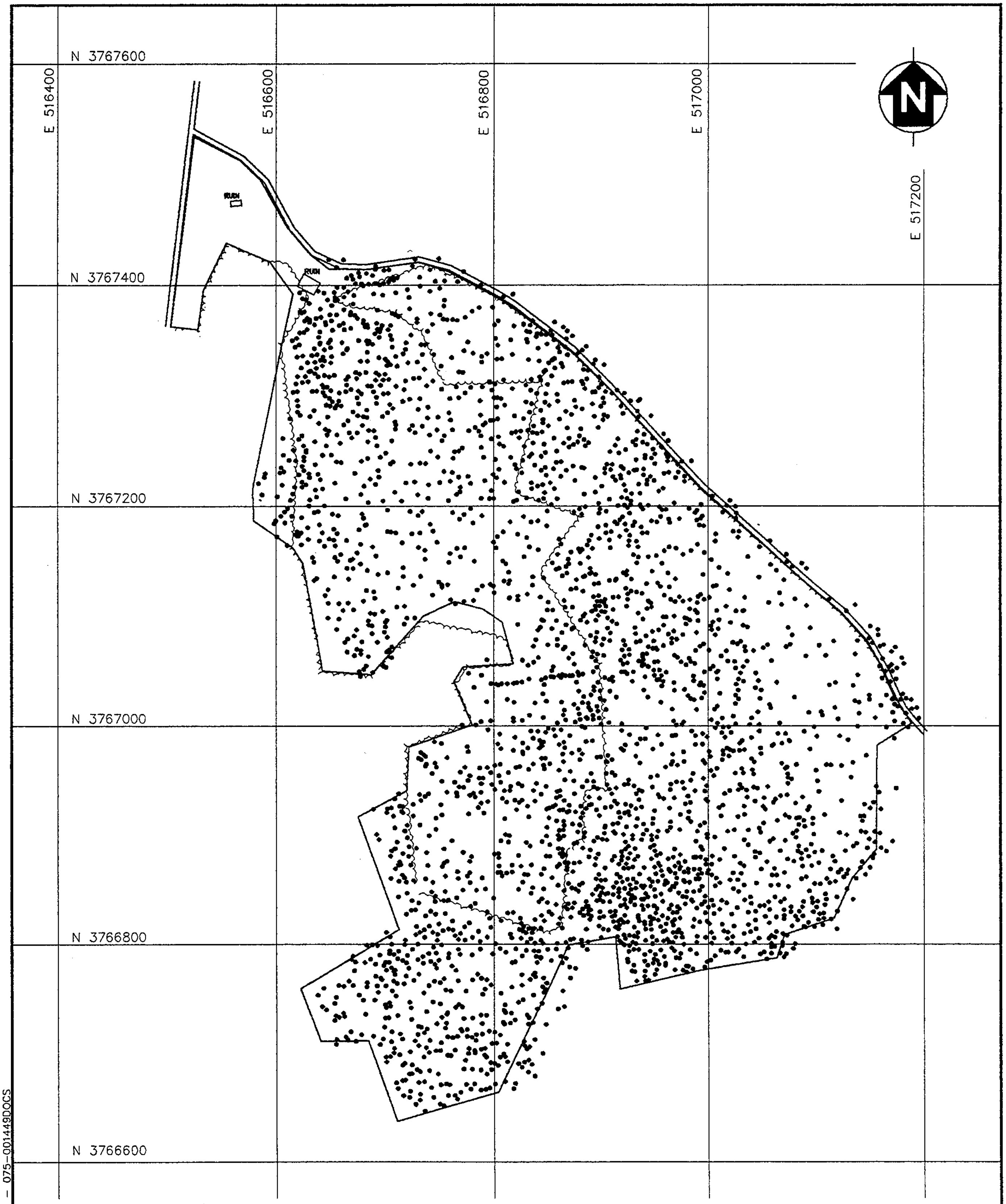


NOTE: COORDINATE SYSTEM IS UTM (NAD 83, ZONE 17).

FIGURE 5-3

TARGET DECLARATIONS BY ADI AT FORT JACKSON (CHURCHILL DROP ZONE)

PRC ENVIRONMENTAL MANAGEMENT, INC.



NOTE: COORDINATE SYSTEM IS UTM
(NAD 83, ZONE 17).

SCALE
1:5000

FIGURE 5-4

TARGET DECLARATIONS BY ADI AT FORT JACKSON (ARTILLERY ROAD SITE)

PRC ENVIRONMENTAL MANAGEMENT, INC.

JACK-AR.DWG - 06/28/96 - CFR - 075-001449DOCS

Table 5-9
Summary of Target Declarations by ADI at Fort Jackson

Range	Churchill Drop Zone	Artillery Road Site	Combined
Area Surveyed (hectares)	32.8	27.4	60.2
Area Available (hectares)	32.8	27.7	60.5
Target Declarations	3,223	2,967	6,190
Confidence			
High	244	225	469
Moderate	636	774	1,410
Low	2,343	1,968	4,311
Unknown	0	0	0
Depth (meters)			
0 to 0.5	1,735	1,596	3,331
> 0.5 to 2.0	1,469	1,293	2,762
> 2.0	19	78	97
Unknown	0	0	0
Target Type			
Ordnance	1,656	1,851	3,507
Nonordnance	1,567	1,116	2,683
Target Size			
Large	65	43	108
Medium	317	413	730
Small	1,274	1,395	2,669
Unknown	0	0	0
Target Class			
Bomb	55	32	87
Mortar	1,398	1,552	2,950
Projectile	203	267	470
Cluster	0	0	0
Other	0	0	0
Unknown	0	0	0

Table 5-10
Performance Statistics for ADI at Fort Jackson

Overall Detection Statistics (R_{crit} = 2.0 meters)

Target Type	No. Detected/ No. in Baseline	$P_{D,ord}$	P_{random}
All targets	24/35	0.69	0.12

Distance Error Statistics

Error	Mean (meters)	Standard Deviation (meters)
Easting (x)	0.27	0.54
Northing (y)	-0.08	0.57
Radial (r)	0.73	0.40
Depth (z)	-0.80	0.59
Mean Absolute Depth ($\|z\|$)	0.97	NA

Detection and Classification Statistics

Category	No. Detected/ No. in Baseline	P_D	No. Correctly Classified/ No. Detected	P_C
Type				
Ordnance	24/35	0.69	22/24	0.92
Nonordnance	2/2	1.00	0/2	0.00
Size				
Large	8/8	1.00	2/8	0.25
Medium	14/15	0.93	8/14	0.57
Small	2/12	0.17	2/2	1.00
Class				
Bomb	2/2	1.00	2/2	1.00
Mortar	4/14	0.29	1/4	0.25
Projectile	18/19	0.95	12/18	0.67
Cluster	0/0	NA	0/0	NA
Other	0/0	NA	0/0	NA

Table 5-11
Excavated Target Positions Based on ADI Ordnance Declarations at Fort Jackson

Demonstrator Target Declaration	Excavated Target Position		
	Ordnance	Nonordnance	Empty
Ordnance	1/30	18/30	11/30

Table 5-12
Target Prediction Rates for ADI Based on All Excavated Locations at Fort Jackson

Demonstrator Target Declaration	Excavated Locations (n=43)[a]	
	Ordnance	Nonordnance
Ordnance	1/1	18/22
No declaration	0/1	4/22

Note:

[a] Of the 43 locations that were excavated during validation activities, 1 contained ordnance, 22 contained nonordnance, and the remaining 20 contained no discernable man-made materials.

5.1.3 Chemrad Tennessee Corporation

Chemrad demonstrated USRADS® in conjunction with a Geometrics Model G-822L magnetometer at McChord AFB. The following sections describe the technology's measured performance as well as its observed capabilities and limitations.

Measured Performance at McChord AFB: Between October 24 and November 9, Chemrad completed nearly all of the assigned survey area of 24.0 hectares at McChord AFB's South 40 Training Area. Chemrad was on-range for a total of about 80 hours over 12 days. Chemrad used about 4 hours to set up its equipment, and it experienced about 4 hours of downtime due to equipment failure. In all, Chemrad spent about 88 hours conducting survey-related activities. Chemrad's field survey rate at McChord AFB was 0.30 hectare per hour; its overall survey rate was 0.27 hectare per hour.

Figure 5-5 shows Chemrad's target declarations at the site. Table 5-13 summarizes Chemrad's target declarations; Table 5-14 summarizes performance statistics calculated for Chemrad.

Chemrad surveyed all 24.0 hectares at McChord AFB's South 40 Training Area, declaring 2,944 targets within the range (Chemrad 1995) and detecting 8 of the 59 baseline ordnance targets. At the 95-percent confidence level, Chemrad's $P_{D,ord}$ of 0.14 is not statistically different from the calculated P_{random} value of 0.14. Chemrad's reported baseline target locations did not consistently exhibit any directional bias along the northing or easting directions. With the detected baseline targets, Chemrad had a mean radial error of 1.22 meters and a mean square depth error of 0.66 meter.

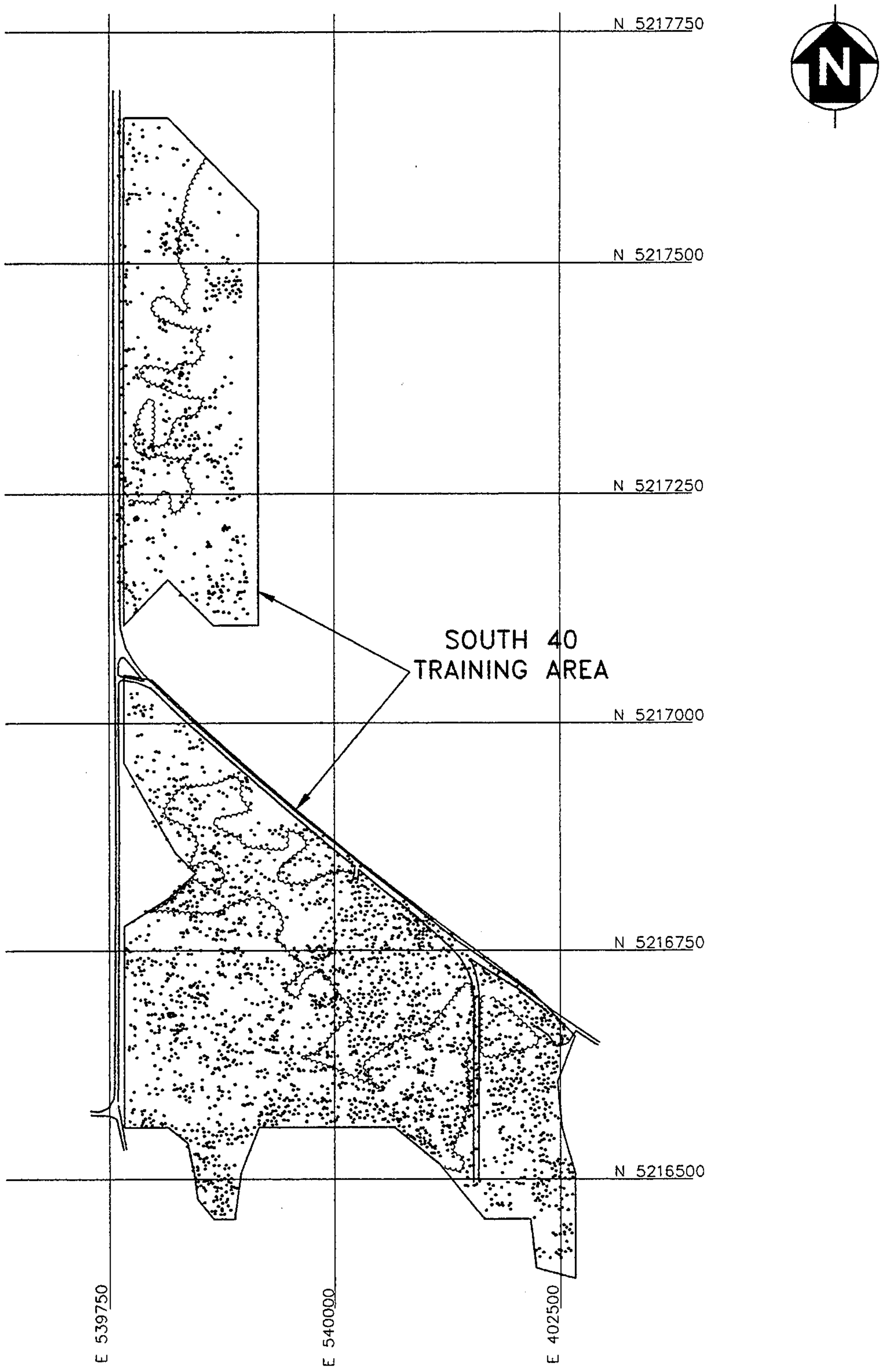
Chemrad did not provide data on target confidence, type, class, or size. For scoring purposes, each Chemrad declaration is assumed to be of type "ordnance."

During validation activities at McChord AFB, USAF 62nd EOD excavated seven of Chemrad's target declaration locations at the South 40 Training Area. Table 5-15 summarizes the results of these excavation activities. Based on both demonstrator's target reports, USAF 62nd EOD excavated a total of eight locations at the ranges. Table 5-16 summarizes Chemrad's target predictions at these eight locations.

Observed Capabilities and Limitations: Because the Chemrad system is man-portable, it can be used to survey rough terrain that is not accessible to vehicle-towed systems. However, Chemrad opted not to survey the areas covered by small buildings and gravel piles at the South 40 Training Area.

The USRADS® was not affected by the relatively cool ambient temperatures, which averaged about 4 °C during the demonstration. However, the SRs, base magnetometer, and compasses on the USRADS® backpack malfunctioned when rain leaked into the equipment. The compass malfunctions caused errant data to be recorded. Planes flying overhead and other factors caused miscommunication between the USRADS® backpack, SRs, and field computer, resulting in data loss. Chemrad also experienced limited equipment breakdown. Parts were typically replaced on site within several minutes of their malfunction.

For the McChord AFB demonstration, Chemrad used contracted EOD personnel who were not familiar with USRADS®. According to Chemrad, inexperienced personnel required about 8 hours of training before they could work independently (Chemrad 1995). This training was conducted before the demonstration began.



NOTE: COORDINATE SYSTEM IS UTM
(NAD 83, ZONE 10).

SCALE
1:7500

FIGURE 5-5

TARGET DECLARATION BY CHEMRAD AT McCHORD AFB (SOUTH 40 TRAINING AREA)

PRC ENVIRONMENTAL MANAGEMENT, INC.

MCR-SITE.DWG - 06/28/96 - CFR - 075-0014490CS

Table 5-13
Summary of Target Declarations by Chemrad at McChord AFB

Range	South 40 Training Area
Area Surveyed (hectares)	24.0
Area Available (hectares)	24.0
Target Declarations	2,944
Confidence	
High	0
Moderate	0
Low	0
Unknown	2,944
Depth (meters)	
0 to 0.5	1,835
> 0.5 to 2.0	1,013
> 2.0	96
Unknown	0
Target Type[a]	
Ordnance	2,944
Nonordnance	0
Target Size	
Large	0
Medium	0
Small	0
Unknown	2,944
Target Class	
Bomb	0
Mortar	0
Projectile	0
Cluster	0
Other	0
Unknown	2,944

Notes:

[a] Chemrad did not differentiate between target types; for scoring purposes, each target is assumed to be of type "ordnance."

Table 5-14
Performance Statistics for Chemrad at McChord AFB

Overall Detection Statistics (R_{crit} = 2.0 meters)

Target Type	No. Detected/ No. in Baseline	$P_{D,ord}$	P_{random}
All targets	8/59	0.14	0.14

Distance Error Statistics

Error	Mean (meters)	Standard Deviation (meters)
Easting (*x*)	0.16	1.02
Northing (*y*)	-0.09	0.89
Radial (*r*)	1.22	0.48
Depth (*z*)	0.26	0.81
Depth ($\|z\|$)	0.66	NA

Detection and Classification Statistics

Category	No. Detected/ No. in Baseline	P_D	No. Correctly Classified/ No. Detected	P_C
Type				
Ordnance	8/59	0.14	8/8	1.00
Nonordnance	2/9	0.22	0/2	0.00
Size				
Large	0/4	0.00	0/0	NA
Medium	8/38	0.21	0/8	0.00
Small	0.17	0.00	0/0	NA
Class				
Bomb	0/2	0.00	0/0	NA
Mortar	1/19	0.05	0/1	0.00
Projectile	7/38	0.18	0/7	0.00
Cluster	0/0	NA	0/0	NA
Other	0/0	NA	0/0	NA

Table 5-15
Excavated Target Positions Based on Chemrad Ordnance Declarations at McChord AFB

Demonstrator Target Declaration	Excavated Target Position		
	Ordnance	Nonordnance	Empty
Ordnance	0/7	3/7	4/7

Table 5-16
Target Prediction Rates for Chemrad Based on All Excavated Locations at McChord AFB

Demonstrator Target Declaration	Excavated Locations (n=8)[a]	
	Ordnance	Nonordnance
Ordnance	0/0	3/3
No declaration	0/0	0/3

Note:

[a] Of the 8 locations that were excavated during validation activities, none contained ordnance, 3 contained nonordnance, and the remaining 5 contained no discernable man-made materials.

5.1.4 Coleman Research Corporation

Coleman demonstrated its ToMAS technology at JPG and Eglin AFB. The following sections describe the technology's measured performance as well as its observed capabilities and limitations.

Measured Performance at JPG: Between May 22 and June 9, Coleman surveyed about 42.5 hectares (67 percent) of the 63.9-hectare assigned survey area at JPG Ranges 18000W (Main), 18000W (BirdFoot), and 21000W. Coleman was on-range for a total of about 95 hours over 17 days. Because the vegetation at the north end of Range 18000W was about 1 meter high toward the end of the demonstration period, the on-site EOD team would not allow Coleman to complete its survey of this area. Coleman spent about 15 hours setting up its equipment, and it experienced about 19 hours of downtime due to equipment failure. In all, Coleman spent about 129 hours conducting survey-related activities. Coleman's field survey rate at JPG was 0.44 hectare per hour; its overall survey rate was 0.33 hectare per hour.

Figure 5-6 shows Coleman's target declarations at JPG Ranges 18000W and 21000W. Table 5-17 summarizes Coleman's target declarations at JPG; Table 5-18 summarizes performance statistics calculated for Coleman at JPG.

Coleman surveyed about 76 percent of the 26.2 hectares that comprise JPG's Range 21000W, declaring 3,499 targets within the range (Coleman 1995a) and detecting 20 of the 37 baseline ordnance targets in the surveyed area. Coleman's $P_{D,ord}$ of 0.54 is statistically different than the calculated P_{random} value of 0.18 at the 95-percent confidence level. As shown in Table 5-18, Coleman's reported baseline target locations did not consistently exhibit any directional bias along the northing or easting directions. Coleman's mean radial error was 1.14 meters with the detected baseline targets; Coleman's mean square depth error was 1.20 meters.

Coleman provided data on target confidence, depth, class, and size; however, Coleman typed all target declarations as "ordnance" (Coleman 1995a).

During validation activities at JPG, USAF/WL excavated 28 of Coleman's target declaration locations at Range 21000W. Table 5-19 summarizes the results of these excavation activities. Based on all three demonstrator's target reports, USAF/WL excavated a total of 53 locations at Range 21000W. Table 5-20 summarizes Coleman's target predictions at these 53 locations.

Measured Performance at Eglin AFB: Between July 31 and August 18, Coleman surveyed about 29.2 hectares (60 percent) of the 48.8-hectare survey area at Eglin AFB Range A-73. Coleman was on-range for a total of about 74 hours over 15 days. Coleman spent about 32 hours setting up its equipment, and it experienced about 6 hours of downtime due to equipment failure. In all, Coleman spent about 112 hours conducting site survey-related activities. Coleman's field survey rate at Eglin AFB was 0.39 hectare per hour; its overall survey rate was 0.26 hectare per hour.

Figure 5-7 shows Coleman's target declarations at Eglin AFB Range A-73. Table 5-21 summarizes Coleman's target declarations; Table 5-22 summarizes performance statistics calculated for Coleman at Eglin AFB.

Coleman surveyed about 60 percent of the assigned 48.8 hectares at the site, declaring 11,894 targets within the range (Coleman 1995b) and detecting 18 of the 33 baseline targets in the surveyed area. At the 95-percent confidence level, Coleman's $P_{D,ord}$ of 0.55 is not statistically different from the calculated P_{random} value of 0.40. Due to the extremely high target density around the impact area (which was verified during target validation activities), the P_{random} analysis at Eglin AFB is less reliable than at the other sites.

Coleman's reported baseline target locations did not consistently exhibit any directional bias along the northing or easting directions. Coleman had a mean radial error of 1.30 meters and a mean square depth error of 2.27 meters for the baseline targets.

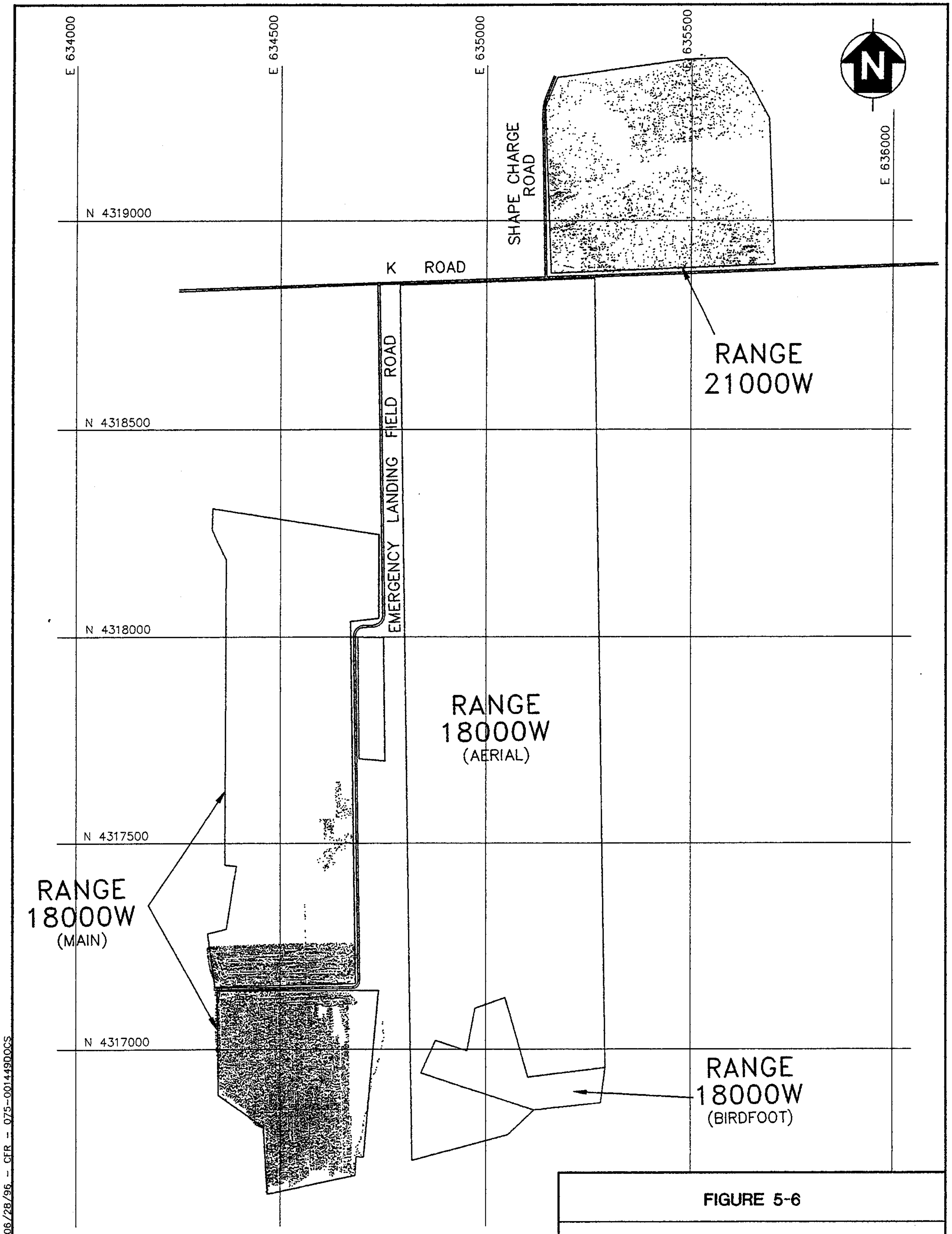
Coleman provided data on target confidence, depth, class, and size; as at JPG, Coleman typed all target declarations as "ordnance" (Coleman 1995b).

During validation activities at Eglin AFB, USAF 96th EOD excavated 23 of Coleman's target declaration locations at Range A-73. Table 5-23 summarizes the results of these excavation activities. Based on both demonstrator's target reports, USAF 96th EOD excavated a total of 40 locations within Coleman's survey area at Range A-73. Table 5-24 summarizes Coleman's target predictions at these 40 locations.

Observed Capabilities and Limitations: At both JPG and Eglin AFB, Coleman experienced a variety of mechanical and electronic problems. The rough terrain at both sites caused flat tires and broken axles on the ToMAS vehicle, and jarring action on the system caused problems with the on-board computer system. Batteries for the computer and electronics systems on the ToMAS unit were limited to 4 hours of use and typically required recharging and changing at least once daily. At JPG, Coleman was not required to survey the heavily wooded area of Range 18000W, but it was required to survey the lightly wooded area of Range 18000W (Birdfoot). Because the vegetation limited its use of ToMAS, Coleman performed part of the survey using a man-portable variation of the system. Coleman also performed part of its survey at Eglin AFB with the man-portable unit, although the area surveyed probably could have been surveyed with the vehicle-towed unit.

Coleman's surveying activities at JPG were hindered by lightning, hail, high winds, fog, heavy rain, and flooding that occurred intermittently during the demonstration. Coleman's all-terrain tow vehicle was mired in the mud during the demonstration on at least one occasion, but Coleman personnel were able to extricate the vehicle manually. Coleman was generally able to traverse flooded or muddy areas with its man-portable unit, but some flooded areas of JPG were deemed inaccessible to both the ToMAS and man-portable units.

Coleman frequently stopped survey activities to download data from the on-board computer to a more stable off-site computer, especially at Eglin AFB, where ambient temperatures exceeding 37 °C caused delays due to excessive heat buildup in electrical equipment. This heat buildup caused data to be lost, and Coleman resurveyed some areas as many as three times to collect accurate data (Coleman 1995b). To alleviate the heat buildup, Coleman eventually removed portions of the plastic housing from the electrical systems. To prevent moisture buildup in the system at Eglin AFB, Coleman covered the electronics systems with a tarpaulin during rain showers.



NOTE: COORDINATE SYSTEM IS UTM
(NAD 83, ZONE 16).

SCALE
1:12500

FIGURE 5-6

TARGET DECLARATIONS BY COLEMAN AT JPG (RANGES 18000W & 21000W)

PRC ENVIRONMENTAL MANAGEMENT, INC.

JPG-18.DWG - 06/28/96 - CFR - 075-001449DOCS

Table 5-17
Summary of Target Declarations by Coleman at JPG

Range	18000W	21000W	Combined
Area Surveyed (hectares)	22.5	20.0	42.5
Area Available (hectares)	41.9	22.0	63.9
Target Declarations	18,579	3,499	22,078
Confidence			
High	12,164	1,816	13,980
Moderate	1,300	356	1,656
Low	5,115	1,327	6,442
Unknown	0	0	0
Depth (meters)			
0 to 0.5	14,290	1,749	16,039
> 0.5 to 2.0	1,945	467	2,412
> 2.0	2,344	1,283	3,627
Unknown	0	0	0
Target Type			
Ordnance	18,579	3,499	22,078
Nonordnance	0	0	0
Target Size			
Large	3,449	336	3,785
Medium	8,067	1,447	9,514
Small	7,063	1,716	8,779
Unknown	0	0	0
Target Class			
Bomb	405	103	508
Mortar	0	0	0
Projectile	15,185	3,290	18,475
Cluster	2,989	106	3,095
Other	0	0	0
Unknown	0	0	0

Table 5-18
Performance Statistics for Coleman at JPG

Overall Detection Statistics (R_{crit} = 2.0 meters)

Target Type	No. Detected/ No. in Baseline	$P_{D,ord}$	P_{random}
All targets	20/37	0.54	0.18

Distance Error Statistics

Error	Mean (meters)	Standard Deviation (meters)
Easting (x)	0.10	0.72
Northing (y)	0.55	0.89
Radial (r)	1.14	0.53
Depth (z)	0.31	1.07
Mean Absolute Depth ($\|z\|$)	1.20	NA

Detection and Classification Statistics

Category	No. Detected/ No. in Baseline	P_D	No. Correctly Classified/ No. Detected	P_C
Type				
Ordnance	20/37	0.54	20/20	1.00
Nonordnance	2/2	1.00	0/2	0.00
Size				
Large	0/3	0.00	0/0	NA
Medium	11/17	0.65	5/11	0.45
Small	9/17	0.58	8/9	0.89
Class				
Bomb	7/14	0.50	0/7	0.00
Mortar	1/3	0.33	0/1	0.00
Projectile	11/19	0.58	10/11	0.91
Cluster	1/1	1.00	0/1	0.00
Other	0/0	NA	0/0	NA

Table 5-19
Excavated Target Positions Based on Coleman Ordnance Declarations at JPG

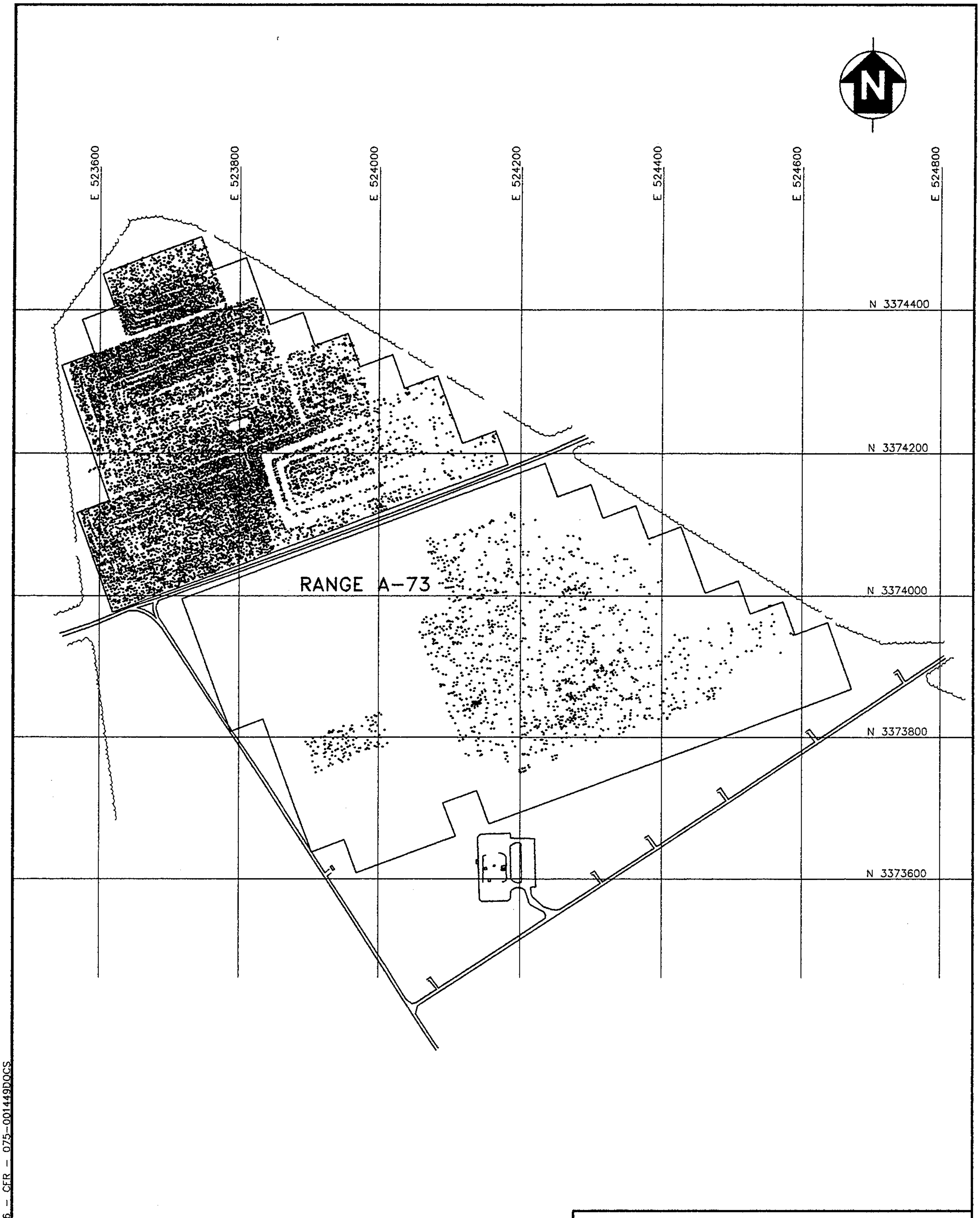
Demonstrator Target Declaration	Excavated Target Position		
	Ordnance	Nonordnance	Empty
Ordnance	13/28	6/28	9/28

Table 5-20
Target Prediction Rates for Coleman Based on All Excavated Locations at JPG

Demonstrator Target Declaration	Excavated Locations (n=53)[a]	
	Ordnance	Nonordnance
Ordnance	13/19	6/14
No declaration	6/19	8/14

Note:

[a] Of the 53 locations that were excavated during validation activities, 19 contained ordnance, 14 contained nonordnance, and the remaining 20 contained no discernable man-made materials.



NOTE: COORDINATE SYSTEM IS UTM
(NAD 27, ZONE 16).

SCALE
1:7500

FIGURE 5-7

TARGET DECLARATIONS BY COLEMAN AT EGLIN AFB (RANGE A-73)

PRC ENVIRONMENTAL MANAGEMENT, INC.

EG-SITE.DWG - 06/28/96 - CFR - 075-001449DOCS

Table 5-21
Summary of Target Declarations by Coleman at Eglin AFB

Range	A-73
Area Surveyed (hectares)	29.2
Area Available (hectares)	48.8
Target Declarations	11,894
Confidence	
High	3,941
Moderate	4,005
Low	3,948
Unknown	0
Depth (meters)	
0 to 0.5	7,595
> 0.5 to 2.0	2,963
> 2.0	1,336
Target Type	
Ordnance	11,894
Nonordnance	0
Target Size	
Large	2,583
Medium	3,282
Small	6,029
Unknown	0
Target Class	
Bomb	1,031
Mortar	0
Projectile	8,886
Cluster	1,977
Other	0
Unknown	0

Table 5-22
Performance Statistics for Coleman at Eglin AFB

Overall Detection Statistics (R_{crit} = 2.0 meters)

Target Type	No. Detected/ No. in Baseline	$P_{D,ord}$	P_{random}
All targets	18/33	0.55	0.40

Distance Error Statistics

Error	Mean (meters)	Standard Deviation (meters)
Easting (x)	0.03	0.90
Northing (y)	-0.08	1.10
Radial (r)	1.30	0.49
Depth (z)	0.14	1.54
Depth ($\|z\|$)	2.27	NA

Detection and Classification Statistics

Category	No. Detected/ No. in Baseline	P_D	No. Correctly Classified/ No. Detected	P_C
Type				
Ordnance	18/33	0.55	18/18	1.00
Nonordnance	0/4	0.00	0/0	NA
Size				
Large	2/7	0.29	0/2	0.00
Medium	3/7	0.43	2/3	0.67
Small	13/19	0.68	8/13	0.62
Class				
Bomb	2/7	0.29	0/2	0.00
Mortar	0/0	NA	0/0	NA
Projectile	8/13	0.62	8/8	1.00
Cluster	3/4	0.75	0/3	0.00
Other	5/9	0.56	0/5	0.00

Table 5-23
Excavated Target Positions Based on Coleman Ordnance Declarations at Eglin AFB

Demonstrator Target Declaration	Excavated Target Position		
	Ordnance	Nonordnance	Empty
Ordnance	20/23	0/23	3/23

Table 5-24
Target Prediction Rates for Coleman Based on All Excavated Locations at Eglin AFB

Demonstrator Target Declaration	Excavated Locations (n=40)[a]	
	Ordnance	Nonordnance
Ordnance	20/31	0/1
No declaration	11/31	1/1

Note:

[a] Of the 40 locations that were excavated during validation activities, 31 contained ordnance, 1 contained nonordnance, and the remaining 8 contained no discernable man-made materials.

5.1.5 Geo-Centers, Inc.

Geo-Centers demonstrated its STOLS® technology at YPG and Fort Jackson. The following sections describe the technology's measured performance as well as its observed capabilities and limitations.

Measured Performance at YPG: Between July 12 and 27, Geo-Centers surveyed about 39.2 hectares (86 percent) of the assigned survey area of 45.5 hectares at YPG's Steel Circle and Hulk 3 Ranges. Geo-Centers was on-range for a total of about 44 hours over 11 days. Geo-Centers used about 19 hours to set up its equipment, and it experienced about 11 hours of downtime due to equipment failure. In all, Geo-Centers spent about 74 hours conducting site survey-related activities. Geo-Centers's field survey rate at YPG was 0.89 hectare per hour; its overall survey rate was 0.53 hectare per hour.

Figures 5-8 and 5-9 show Geo-Centers's target declarations at YPG's Steel Circle and Hulk 3 Ranges. Table 5-25 summarizes Geo-Centers's target declarations at YPG; Table 5-26 summarizes performance statistics calculated for Geo-Centers.

Geo-Centers surveyed about 85 percent of the 15.8 hectares at YPG's Steel Circle Range, declaring 2,688 targets within the range and detecting 29 of the 48 baseline targets in the surveyed area. At the 95-percent confidence level, Geo-Centers's $P_{D,ord}$ of 0.60 is significantly different from the calculated P_{random} value of 0.21. As shown in Table 5-26, Geo-Centers's reported baseline target locations did not consistently exhibit any directional bias along the northing or easting directions. Comparing demonstrator declarations to the baseline targets, Geo-Centers had a mean radial error of 0.89 meter and a mean square depth error of 0.61 meter.

Geo-Centers provided data on target confidence, depth, type, class, and size.

During validation activities at YPG, YPG ETO personnel excavated 25 of Geo-Centers's target declaration locations at the Hulk 3 and Steel Circle Ranges. Table 5-27 summarizes the results of these excavation activities. Based on all three demonstrator's target reports, YPG ETO personnel excavated a total of 40 locations within Geo-Centers's survey area at the ranges. Table 5-28 summarizes Geo-Centers's target predictions at these 40 locations.

Geo-Centers identified a large area at the Hulk 3 site that contains a cable-like anomaly; the area of 3.5 hectares containing this anomaly is about 12 percent of the entire Hulk 3 site. Geo-Centers confirmed the existence of the cable-like anomaly using a hand-held magnetometer (Geo-Centers 1995a). During the validation activities, several trenches were excavated to a depth of 1 meter in the anomalous areas outlined by Geo-Centers; no trace of subsurface cables or other cable-like magnetic anomalies were identified. The source of this magnetic signature is unknown.

Measured Performance at Fort Jackson: Between September 11 and 26, Geo-Centers completed 30.2 hectares (92 percent) of the assigned survey area of 32.8 hectares at Fort Jackson's Churchill Drop Zone. Geo-Centers was on-range for a total of about 69 hours over 13 days. Geo-Centers used about 24 hours to set up its equipment, and it experienced about 4 hours of downtime due to equipment failure. In all, Geo-Centers spent about 97 hours conducting survey-related activities. Geo-Centers's field survey rate at Fort Jackson was 0.44 hectare per hour; its overall survey rate was 0.31 hectare per hour.

Figure 5-10 shows Geo-Centers's target declarations at Fort Jackson's Churchill Drop Zone. Table 5-29 summarizes Geo-Centers's target declarations at Fort Jackson; Table 5-30 summarizes performance statistics calculated for Geo-Centers.

Geo-Centers surveyed 92 percent of the 32.8 hectares at Fort Jackson's Churchill Drop Zone, declaring 5,790 targets within the range and detecting 14 of the 31 baseline ordnance targets in the surveyed area. At the 95-percent confidence level, Geo-Centers's $P_{D,ord}$ of 0.45 is significantly different than the calculated P_{random} value of 0.21. As shown in Table 5-30, Geo-Centers's reported baseline target locations did not consistently exhibit any directional bias along the northing or easting directions. At Fort Jackson, Geo-Centers was able to locate the baseline targets with a mean radial error of 0.75 meter and a mean square depth error of 0.33 meter.

Geo-Centers provided data on target confidence, depth, type, class, and size.

The effectiveness of the Geo-Centers system decreased in the forested areas because the differential GPS units had difficulty maintaining a lock on the GPS satellites (Geo-Centers 1995b). In fact, Geo-Centers detected 9 of the 12 baseline targets (75 percent) that were emplaced outside the forested areas, but only 5 of the 19 baseline targets (26 percent) that were emplaced within the forested areas.

During validation activities at Fort Jackson, USAF/WL excavated 27 of Geo-Centers's target declaration locations at the Churchill Drop Zone. Table 5-31 summarizes the results of these excavation activities. Based on all three demonstrator's target reports, USAF/WL excavated a total of 36 locations within Geo-Centers's survey area at the Churchill Drop Zone. Table 5-32 summarizes Geo-Centers's target predictions at these 36 locations.

Observed Capabilities and Limitations: At the YPG Steel Circle and Hulk 3 ranges, STOLS® could not survey the severe topography and heavily vegetated areas in the washes. However, Geo-Centers maneuvered STOLS® around bushes and trees in the demonstration areas. Terrain at Fort Jackson's Churchill Drop Zone also made complete coverage with the tow vehicle impossible. STOLS® was limited by its ability to negotiate areas of moderate tree stands because of its turning radius and the unit's length. At Fort Jackson, the tow vehicle also became stuck in rutted areas on several occasions. Despite the fact that STOLS® can cover large areas of ground with favorable conditions, the unit's ability to collect data is curtailed by trees, scrub brush, and uneven terrain (Geo-Centers 1995b).

Although the rough terrain at YPG could have been surveyed by the STOLS® man-portable adjunct, Geo-Centers did not deploy this system because of concerns over the effects the severe heat may have had on the operators. However, Geo-Centers did use STOLS® man-portable adjuncts in areas at Fort Jackson that the vehicle-towed unit could not negotiate.

YPG-STEL.DWG - 06/28/96 - CFR - 075-001449DOCS

SCALE
1:5000

NOTE: COORDINATE SYSTEM IS UTM (NAD 27,
ZONE 11-MODIFIED BY YPG).

FIGURE 5-8

TARGET DECLARATIONS BY GEO-CENTERS
AT YPG (STEEL CIRCLE RANGE)

PRC ENVIRONMENTAL MANAGEMENT, INC.

SCALE
1:5000

NOTE: COORDINATE SYSTEM IS UTM (NAD 27, ZONE 11—MODIFIED BY YPG).

FIGURE 5-9

TARGET DECLARATIONS BY GEO-CENTERS AT YPG (HULK 3 RANGE)

PRC ENVIRONMENTAL MANAGEMENT, INC.

YPG-H3.DWG – 06/28/96 – CFR – 075-001449DOCS

Table 5-25
Summary of Target Declarations by Geo-Centers at YPG

Range	Steel Circle	Hulk 3	Combined
Area Surveyed (hectares)	13.9	25.3	39.2
Area Available (hectares)	15.8	29.7	45.5
Target Declarations	2,688	3,863	6,531
Confidence			
High	1,533	1,528	3,061
Moderate	0	0	0
Low	1,155	2,335	3,490
Unknown	0	0	0
Depth (meters)			
0 to 0.5	955	531	1,486
> 0.5 to 2.0	1,068	3,009	4,097
> 2.0	278	221	499
Unknown	367	102	469
Target Type			
Ordnance	2,688	3,863	6,551
Nonordnance	0	0	0
Target Size			
Large	573	896	1,469
Medium	1,021	1,125	2,146
Small	977	1,453	2,430
Unknown	117	389	506
Target Class			
Bomb	579	1,071	1,650
Mortar	0	0	0
Projectile	2,007	2,416	4,423
Cluster	0	0	0
Other	0	0	0
Unknown	102	376	478

Table 5-26
Performance Statistics for Geo-Centers at YPG

Overall Detection Statistics (R_{crit} = 2.0 meters)

Target Type	No. Detected/ No. in Baseline	$P_{D,ord}$	P_{random}
All targets	29/48	0.60	0.21

Distance Error Statistics

Error	Mean (meters)	Standard Deviation (meters)
Easting (x)	0.13	0.66
Northing (y)	0.07	0.80
Radial (r)	0.89	0.53
Depth (z)	0.20	0.80
Depth ($\|z\|$)	0.61	NA

Detection and Classification Statistics

Category	No. Detected/ No. in Baseline	P_D	No. Correctly Classified/ No. Detected	P_C
Type				
Ordnance	29/48	0.60	29/29	1.00
Nonordnance	0/0	NA	0/0	NA
Size				
Large	2/3	0.67	1/2	0.50
Medium	10/13	0.77	4/10	0.40
Small	17/32	0.53	7/17	0.41
Class				
Bomb	12/15	0.80	5/12	0.42
Mortar	6/15	0.40	0/6	0.00
Projectile	11/18	0.61	10/11	0.91
Cluster	0/0	NA	0/0	NA
Other	0/0	NA	0/0	NA

Table 5-27
Excavated Target Positions Based on Geo-Centers Ordnance Declarations at YPG

Demonstrator Target Declaration	Excavated Target Position		
	Ordnance	Nonordnance	Empty
Ordnance	1/25	1/25	23/25

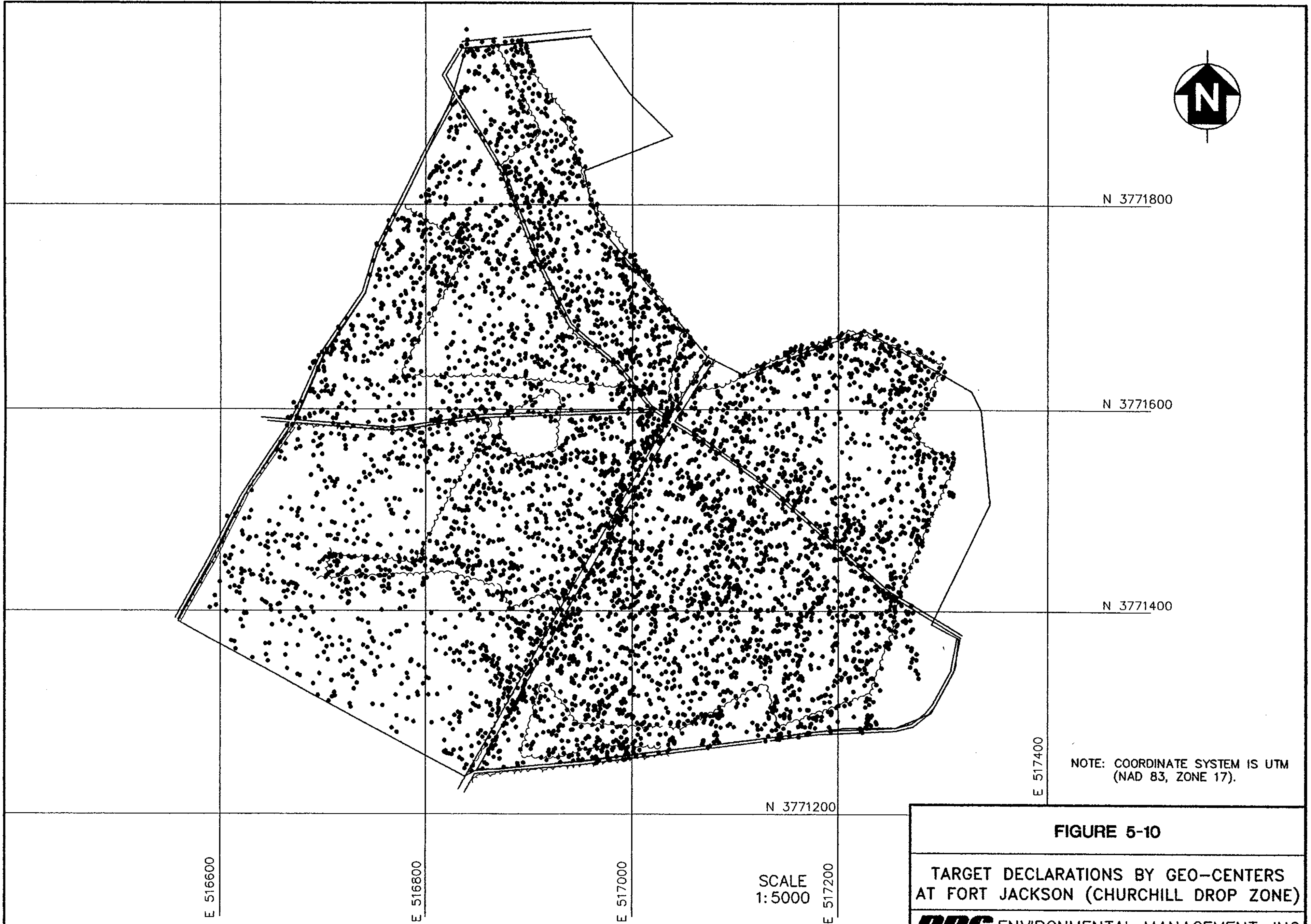
Table 5-28
Target Prediction Rates for Geo-Centers Based on All Excavated Locations at YPG

Demonstrator Target Declaration	Excavated Locations (n=40)[a]	
	Ordnance	Nonordnance
Ordnance	1/1	1/2
No declaration	0/1	1/2

Note:

[a] Of the 40 locations that were excavated during validation activities, 1 contained ordnance, 2 contained nonordnance, and the remaining 37 contained no discernable man-made materials.

JACK-CDZ.DWG - 06/28/96 - CFR - 075-001449DOCS



NOTE: COORDINATE SYSTEM IS UTM
(NAD 83, ZONE 17).

FIGURE 5-10

TARGET DECLARATIONS BY GEO-CENTERS
AT FORT JACKSON (CHURCHILL DROP ZONE)

PRC ENVIRONMENTAL MANAGEMENT, INC.

Table 5-29
Summary of Target Declarations by Geo-Centers at Fort Jackson

Range	Churchill Drop Zone
Area Surveyed (hectares)	30.2
Area Available (hectares)	32.8
Target Declarations	5,790
Confidence	
High	2,726
Moderate	0
Low	3,064
Unknown	0
Depth (meters)	
0 to 0.5	3,372
> 0.5 to 2.0	1,742
> 2.0	46
Unknown	630
Target Type	
Ordnance	5,790
Nonordnance	0
Target Size	
Large	54
Medium	529
Small	4,522
Unknown	685
Target Class	
Bomb	96
Mortar	0
Projectile	5,062
Cluster	0
Other	0
Unknown	632

Table 5-30
Performance Statistics for Geo-Centers at Fort Jackson

Overall Detection Statistics (R_{crit} = 2.0 meters)

Target Type	No. Detected/ No. in Baseline	$P_{D,ord}$	P_{random}
All targets	14/31	0.45	0.21

Distance Error Statistics

Error	Mean (meters)	Standard Deviation (meters)
Easting (x)	-0.14	0.53
Northing (y)	-0.41	0.57
Radial (r)	0.75	0.46
Depth (z)	0.00	0.67
Depth ($\|z\|$)	0.33	NA

Detection and Classification Statistics

Category	No. Detected/ No. in Baseline	P_D	No. Correctly Classified/ No. Detected	P_C
Type				
Ordnance	14/31	0.45	14/14	1.00
Nonordnance	1/2	0.50	0/1	0.00
Size				
Large	7/8	0.88	2/7	0.29
Medium	7/13	0.54	1/7	0.14
Small	0/10	0.00	0/0	NA
Class				
Bomb	2/2	1.00	1/2	0.50
Mortar	1/12	0.08	0/1	0.00
Projectile	11/17	0.65	7/11	0.64
Cluster	0/0	NA	0/0	NA
Other	0/0	NA	0/0	NA

Table 5-31
Excavated Target Positions Based on Geo-Centers Ordnance Declarations at Fort Jackson

Demonstrator Target Declaration	Excavated Target Position		
	Ordnance	Nonordnance	Empty
Ordnance	1/27	18/27	8/27

Table 5-32
Target Prediction Rates for Geo-Centers Based on All Excavated Locations at Fort Jackson

Demonstrator Target Declaration	Excavated Locations (n=36)[a]	
	Ordnance	Nonordnance
Ordnance	1/1	18/20
No declaration	0/1	2/20

Note:

[a] Of the 36 locations that were excavated during validation activities, 1 contained ordnance, 20 contained nonordnance, and the remaining 15 contained no discernable man-made materials.

5.1.6 Metratek, Inc.

Metratek demonstrated its combination of GPR, EM, and real-time kinematic differential GPS system at YPG and McChord AFB. The following sections describe the technology's measured performance as well as its observed capabilities and limitations.

Measured Performance at YPG: Between July 12 and 28, Metratek surveyed 33.9 hectares (75 percent) of the assigned survey area of 45.5 hectares at YPG's Steel Circle and Hulk 3 Ranges. Metratek was on-range for a total of about 61 hours over 12 days. Metratek used about 22 hours to set up its equipment, and it experienced about 3 hours of downtime due to equipment failure. In all, Metratek spent about 86 hours conducting site survey-related activities. Metratek's field survey rate at YPG was 0.56 hectare per hour; its overall survey rate was 0.39 hectare per hour.

Figures 5-11 and 5-12 show Metratek's target declarations at YPG's Steel Circle and Hulk 3 Ranges. Table 5-33 summarizes Metratek's target declarations; Table 5-34 summarizes performance statistics calculated for Metratek at the YPG sites.

Metratek surveyed about 85 percent of the 15.8 hectares at YPG's Steel Circle range, declaring 857 targets within the range and detecting 13 of the 44 baseline targets in the surveyed area. At the 95-percent confidence level, Metratek's $P_{D,ord}$ of 0.30 is statistically different from the calculated P_{random} value of 0.08. Metratek's reported baseline target locations did not consistently exhibit any directional bias along the northing or easting directions. With the baseline targets, Metratek had a mean radial error of 1.13 meters and a mean square depth error of 0.92 meter.

Metratek provided data on target confidence and depth. However, Metratek did not differentiate between target type, class, or size. For scoring purposes, each Metratek declaration is assumed to be of type "ordnance."

Unlike the other demonstrators, Metratek submitted its data three times after discovering various errors following the demonstration. Metratek deemed its first data set invalid after discovering a transposition error in the target location data. After performing its survey at McChord AFB, Metratek then identified an error in the target listing algorithm used for the YPG demonstration and submitted a second data set

(Metratek 1995b). In early March 1996, Metratek submitted another data set after realizing that significant error was incorporated into the second data set as well (Metratek 1996a). However, based on information supplied by Metratek in May 1996, it appears that the third Metratek data set remains incorrect. Metratek claims that post-processing errors and not detection or navigation errors are responsible for its low $P_{D,ord}$ value at YPG (Metratek 1996b).

Metratek indicated in its data set that most of its target declarations along the eastern 100 meters of the Steel Circle Range are "position approximate" because the differential GPS unit was not functioning properly (Metratek 1996a). When this area is removed from the data evaluation, Metratek detected 12 of 31 baseline targets (39 percent). Metratek detected only 1 of the 13 baseline targets (8 percent) in the "position approximate" area (Metratek 1996a).

During validation activities at YPG, YPG ETO personnel excavated four of Metratek's target declaration locations at the Hulk 3 and Steel Circle Ranges. Table 5-35 summarizes the results of these excavation activities. Based on all three demonstrator's target reports, YPG ETO personnel excavated a total of 40 locations within Metratek's survey area at the ranges. Table 5-36 summarizes Metratek's target predictions at these 40 locations.

Measured Performance at McChord AFB: Between October 24 and November 8, Metratek surveyed about 20.4 hectares (85 percent) of the assigned 24.0-hectare survey area at the McChord AFB South 40 Training Area. Metratek was on-range for about 66 hours over 13 days. Metratek used about 16 hours to set up its equipment, and it experienced about 7 hours of downtime due to equipment failure. In all, Metratek spent about 89 hours conducting survey-related activities. Metratek's field survey rate at McChord AFB was 0.31 hectare per hour; its overall survey rate was 0.23 hectare per hour.

Figure 5-13 shows Metratek's target declarations at the McChord AFB South 40 Training Area. Table 5-37 summarizes Metratek's target declarations at the McChord AFB site; Table 5-38 summarizes performance statistics calculated for Metratek.

Metratek surveyed 85 percent of the 24.0 hectares at the McChord AFB South 40 Training Area, declaring 902 targets within the range (Metratek 1995c) and detecting 36 of the 59 baseline ordnance targets in the survey area. At the 95-percent confidence level, Metratek's $P_{D,ord}$ of 0.61 is significantly different than the calculated P_{random} value of 0.05. With the detected baseline targets, Metratek had a mean radial error of 1.13 meters and a mean square depth error of 0.43 meter.

Metratek provided data on target confidence and depth; however, it did not differentiate between target type, class, or size. For scoring purposes, each Metratek declaration is assumed to be of type "ordnance."

During validation activities at McChord AFB, USAF 62nd EOD excavated eight of Metratek's target declaration locations at the South 40 Training Area. Table 5-39 summarizes the results of these excavation activities. Based on both demonstrator's target reports, USAF 62nd EOD excavated a total of eight locations at the range. Table 5-40 summarizes Metratek's target predictions at these eight locations.

Observed Capabilities and Limitations: Metratek was unable to survey the severe topography and heavy vegetation located in the washes at YPG's Steel Circle and Hulk 3 Ranges. The Metratek tow vehicle was forced to maneuver around the bushes and trees encountered in the demonstration areas, and some of the thorny bushes on site punctured tires on the tow vehicle (Metratek 1995a). Metratek's system can be modified for various terrains, and Metratek adjusted the unit's size to fit site conditions at the McChord AFB site. Metratek first covered as much of the South 40 Training Area as possible with the original equipment configuration. Metratek then decreased the sensor trailer width to survey areas where obstacles prevented it from surveying wide lanes. Two instead of three EM carts were pulled behind the trailer, and the three pairs of GPR transmitter and receiver disks were moved closer together. This modification allowed Metratek to complete most of its site survey using the vehicle-towed system, although Metratek still experienced difficulty surveying around stumps and other obstacles (Metratek 1995c).

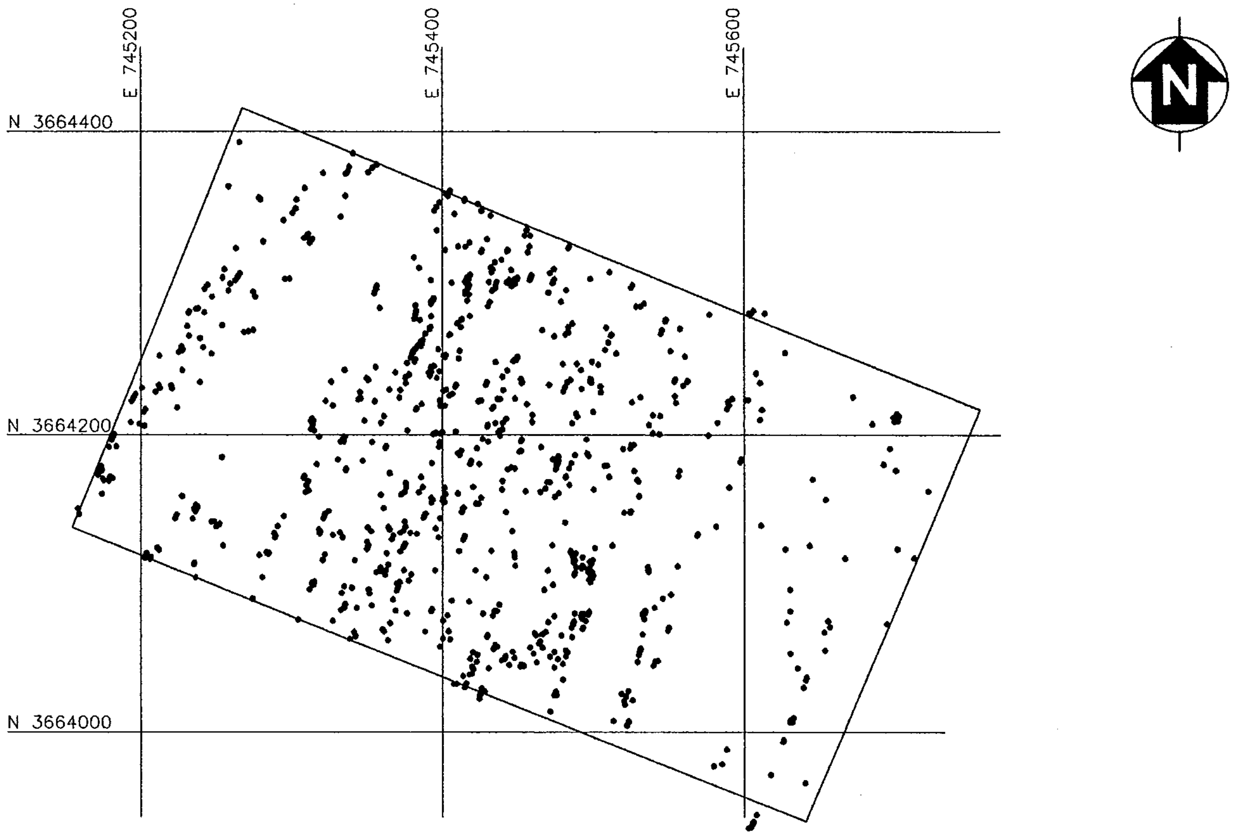
Metratek's differential GPS did not function for portions of the survey time at YPG and McChord AFB. Anomalies registered when the GPS was not functioning were resurveyed, and anomaly locations were determined by measuring the distance from grid nodes with a measuring tape. Metratek personnel stated in the field that at the northern latitude of McChord AFB, it is often difficult to establish and maintain contact with GPS satellites, especially in the afternoon. Trees and other obstructions also impeded GPS satellite lock.

The GPR and EM equipment used by Metratek did not appear to be adversely affected by the extreme ambient temperatures at YPG. The Metratek system was also not affected by the chilly ambient temperatures at McChord AFB. During the McChord AFB demonstration, rain and moisture on frosty mornings caused several equipment failures outside of the tow vehicle. These problems were remedied by waterproofing electrical connections (Metratek 1995c).

Metratek's GPR and EM systems both encountered difficulty resolving subsurface targets because of the high amount of near surface aluminum rocket shrapnel on the Hulk 3 range (Metratek 1995a).

During the last day of the McChord AFB demonstration, Metratek deployed a man-portable backpack system to survey a small area of the range. Metratek used this configuration for about 15 minutes, covering less than 0.1 hectare; no other areas were surveyed in this manner. With the man-portable unit, Metratek was able to maneuver between trees and shrubs. Metratek personnel stated in the field that surveying with a man-portable GPR system requires a 40-foot cable to tether the unit to the electronics in the surveying vehicle.

YPG-STEL.DWG - 06/28/96 - CFR - 075-001449DOCS



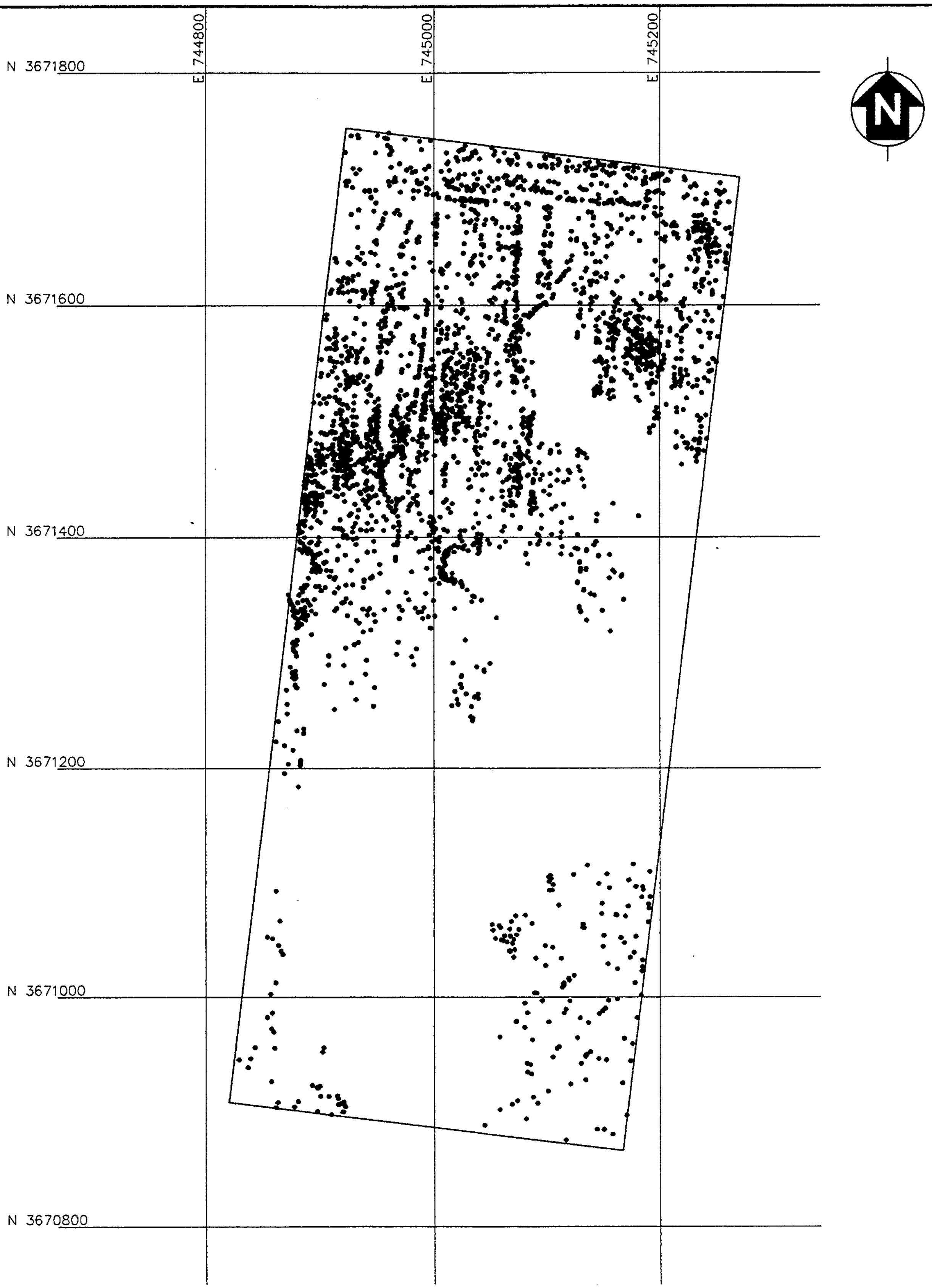
SCALE
1:5000

NOTE: COORDINATE SYSTEM IS UTM (NAD 27,
ZONE 11–MODIFIED BY YPG).

FIGURE 5-11

TARGET DECLARATIONS BY METRATEK
AT YPG (STEEL CIRCLE RANGE)

PRC ENVIRONMENTAL MANAGEMENT, INC.



SCALE
1:5000

NOTE: COORDINATE SYSTEM IS UTM (NAD 27,
ZONE 11–MODIFIED BY YPG).

FIGURE 5-12

TARGET DECLARATIONS BY METRATEK
AT YPG (HULK 3 RANGE)

PRC ENVIRONMENTAL MANAGEMENT, INC.

YPG-H3.DWG - 06/28/96 - CFR - 075-001449DOCS

Table 5-33
Summary of Target Declarations by Metratek at YPG

Range	Steel Circle	Hulk 3	Combined
Area Surveyed (hectares)	13.4	20.5	33.9
Area Available (hectares)	15.8	29.7	45.5
Target Declarations	857	3,191	4,048
Confidence			
High	16	491	507
Moderate	57	1,124	1,908
Low	784	1,576	1,633
Unknown	0	0	0
Depth (meters)			
0 to 0.5	281	1,822	2,098
> 0.5 to 2.0	375	1,038	1,415
> 2.0	201	331	535
Unknown	0	0	0
Target Type[a]			
Ordnance	857	3,191	4,048
Nonordnance	0	0	0
Target Size			
Large	0	0	0
Medium	0	0	0
Small	0	0	0
Unknown	857	3,191	4,048
Target Class			
Bomb	0	0	0
Mortar	0	0	0
Projectile	0	0	0
Cluster	0	0	0
Other	0	0	0
Unknown	857	3,191	4,048

Notes:

[a] Metratek did not differentiate between target types; for scoring purposes, each target is assumed to be of type "ordnance."

Table 5-34
Performance Statistics for Metratek at YPG

Overall Detection Statistics (R_{crit} = 2.0 meters)

Target Type	No. Detected/ No. in Baseline	$P_{D,ord}$	P_{random}
All targets	13/44	0.30	0.08

Distance Error Statistics

Error	Mean (meters)	Standard Deviation (meters)
Easting (x)	-0.17	0.89
Northing (y)	0.20	0.84
Radial (r)	1.13	0.45
Depth (z)	0.69	0.69
Mean Absolute Depth ($\|z\|$)	0.92	NA

Detection and Classification Statistics

Category	No. Detected/ No. in Baseline	P_D	No. Correctly Classified/ No. Detected	P_C
Type				
Ordnance	13/44	0.30	13/13	1.00
Nonordnance	0/0	NA	0/0	NA
Size				
Large	0/2	0.00	0/0	NA
Medium	6/12	0.50	0/6	0.00
Small	7/30	0.23	0/7	0.00
Class				
Bomb	4/13	0.31	0/4	0.00
Mortar	2/14	0.14	0/2	0.00
Projectile	7/17	0.41	0/7	0.00
Cluster	0/0	NA	0/0	NA
Other	0/0	NA	0/0	NA

Table 5-35
Excavated Target Positions Based on Metratek Ordnance Declarations at YPG

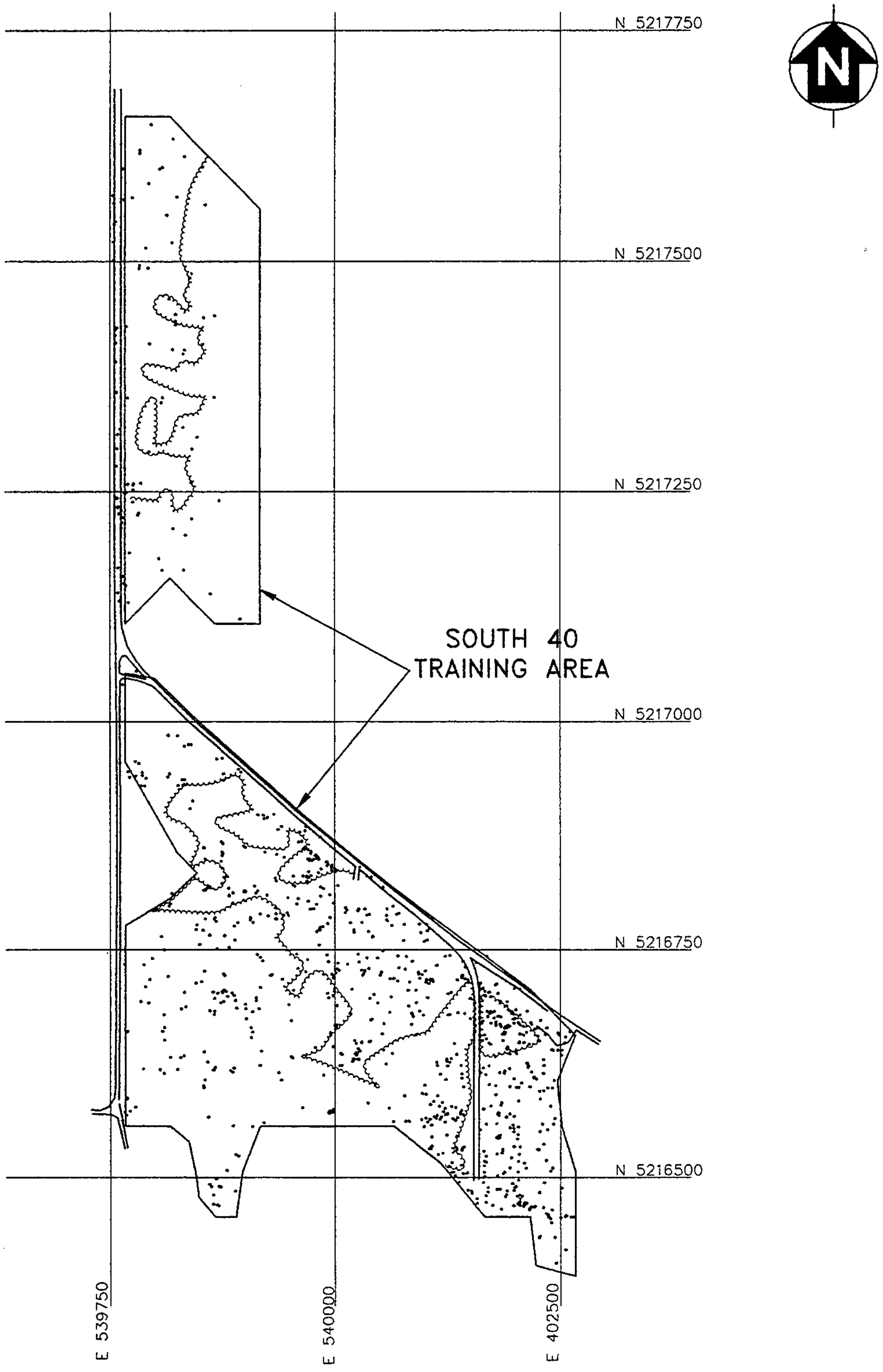
Demonstrator Target Declaration	Excavated Target Position		
	Ordnance	Nonordnance	Empty
Ordnance	0/4	0/4	4/4

Table 5-36
Target Prediction Rates for Metratek Based on All Excavated Locations at YPG

Demonstrator Target Declaration	Excavated Locations (n=40)[a]	
	Ordnance	Nonordnance
Ordnance	0/1	0/2
No declaration	1/1	2/2

Note:

[a] Of the 40 locations that were excavated during validation activities, 1 contained ordnance, 2 contained nonordnance, and the remaining 37 contained no discernable man-made materials.



NOTE: COORDINATE SYSTEM IS UTM
(NAD 83, ZONE 10).

SCALE
1:7500

FIGURE 5-13

TARGET DECLARATIONS BY METRATEK AT McCHORD AFB (SOUTH 40 TRAINING AREA)

PRC ENVIRONMENTAL MANAGEMENT, INC.

MCR-SITE.DWG - 06/28/96 - CFR - 075-0014490DCS

Table 5-37
Summary of Target Declarations by Metratek at McChord AFB

Range	South 40 Training Area
Area Surveyed (hectares)	20.4
Area Available (hectares)	24.0
Target Declarations	902
Confidence	
High	234
Moderate	188
Low	480
Unknown	0
Depth (meters)	
0 to 0.5	671
> 0.5 to 2.0	202
> 2.0	29
Unknown	0
Target Type[a]	
Ordnance	902
Nonordnance	0
Target Size	
Large	0
Medium	0
Small	0
Unknown	902
Target Class	
Bomb	0
Mortar	0
Projectile	0
Cluster	0
Other	0
Unknown	902

Notes:

a Metratek did not differentiate between target types; for scoring purposes, each target is assumed to be of type "ordnance."

Table 5-38
Performance Statistics for Metratek at McChord AFB

Overall Detection Statistics (R_{crit} = 2.0 meters)

Target Type	No. Detected/ No. in Baseline	$P_{D,ord}$	P_{random}
All targets	36/59	0.61	0.05

Distance Error Statistics

Error	Mean (meters)	Standard Deviation (meters)
Easting (x)	-0.02	0.72
Northing (y)	-0.27	1.03
Radial (r)	1.13	0.58
Depth (z)	0.14	0.65
Mean Absolute Depth ($\|z\|$)	0.43	NA

Detection and Classification Statistics

Category	No. Detected/ No. in Baseline	P_D	No. Correctly Classified/ No. Detected	P_C
Type				
Ordnance	36/59	0.61	0/36	0.00
Nonordnance	4/9	0.44	0/4	0.00
Size				
Large	4/4	1.00	0/4	0.00
Medium	22/38	0.58	0/27	0.00
Small	10/17	0.59	0/10	0.00
Class				
Bomb	2/2	1.00	0/2	0.00
Mortar	11/19	0.58	0/11	0.00
Projectile	23/38	0.61	0/23	0.00
Cluster	0/0	NA	0/0	NA
Other	0/0	NA	0/0	NA

Table 5-39
Excavated Target Positions Based on Metratek's Ordnance Declarations at McChord AFB

Demonstrator Target Declaration	Excavated Target Position		
	Ordnance	Nonordnance	Empty
Ordnance	0/8	3/8	5/8

Table 5-40
Target Prediction Rates for Metratek Based on All Excavated Locations at McChord AFB

Demonstrator Target Declaration	Excavated Locations (n=8)[a]	
	Ordnance	Nonordnance
Ordnance	0/0	3/3
No declaration	0/0	0/3

Note:

a Of the 8 locations that were excavated during validation activities, none contained ordnance, 3 contained nonordnance, and the remaining 5 contained no discernable man-made materials.

5.1.7 SRI International, Inc.

SRI demonstrated its airborne GPR technology at YPG and Fort Jackson. The following sections describe the technology's measured performance as well as its observed capabilities and limitations.

Measured Performance at YPG: Between July 17 and 20, SRI surveyed the entire 45.5 hectares of YPG's Steel Circle and Hulk 3 Ranges. SRI was in the air over the sites for about 6 hours over 2 days. SRI used about 16 hours to set up its equipment, and it experienced no downtime due to equipment failure. In all, SRI spent about 22 hours conducting survey-related activities. SRI's field survey rate at YPG was 7.6 hectares per hour; its overall survey rate was 2.1 hectares per hour.

Figures 5-14 and 5-15 show SRI's target declarations at YPG's Steel Circle and Hulk 3 Ranges. Table 5-41 summarizes SRI's target declarations at YPG; Table 5-42 summarizes SRI's performance statistics.

SRI surveyed 100 percent of the 15.8 hectares at YPG's Steel Circle range, declaring 42 targets within the range and three targets outside the range (SRI 1995a) and detecting none of the 51 baseline targets. Because SRI did not detect any baseline targets, distance error statistics were not evaluated.

SRI did not provide data on target confidence, type, class, or size. SRI did not have enough time to complete depth calculations before the target reports were due (SRI 1995a). For scoring purposes, each SRI declaration is assumed to be of type "ordnance," and each target's depth is assigned a value of 0 meter.

During validation activities at YPG, YPG ETO personnel excavated 13 of SRI's target declaration locations at the Hulk 3 and Steel Circle Ranges. Table 5-43 summarizes the results of these excavation activities. Based on all three demonstrator's target reports, YPG ETO personnel excavated a total of 42 locations at the ranges. Table 5-44 summarizes SRI's target predictions at these 42 locations.

Measured Performance at Fort Jackson: Between September 11 and 19, SRI surveyed the entire 109.2 hectares of Fort Jackson's Churchill Drop Zone, Artillery Road Site, and Ranges 12B and 12F. SRI was in the air over the sites for about 6 hours over 3 days. SRI used about 26 hours to set up its equipment, and it experienced about 9 hours of downtime due to equipment failure. In all, SRI spent about

41 hours conducting survey-related activities. SRI's field survey rate at Fort Jackson was 18.2 hectares per hour; its overall survey rate was 2.7 hectares per hour.

Figures 5-16 and 5-17 show SRI's target declarations at the Fort Jackson Churchill Drop Zone and Artillery Road Site. SRI claims that high tree density at Ranges 12B and 12F precluded making any target declarations, so data from these sites are not presented in this report. Table 5-45 summarizes SRI's target declarations at Fort Jackson's Churchill Drop Zone and Artillery Road Site. Table 5-46 summarizes performance statistics calculated for SRI at Fort Jackson.

SRI surveyed all of the 32.8 hectares at the Fort Jackson Churchill Drop Zone, declaring 42 targets within the range and detecting 0 of the 37 baseline targets in the surveyed area. Again, distance error statistics were not evaluated.

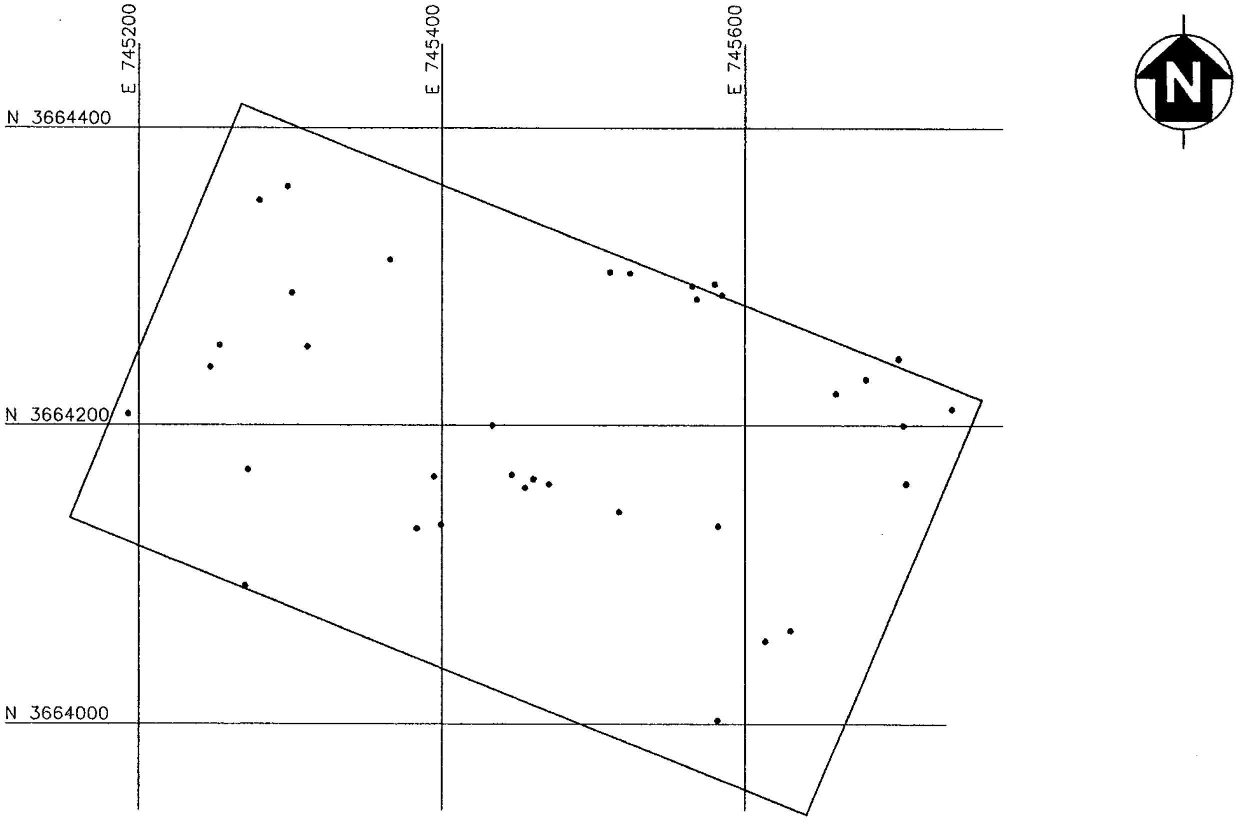
SRI did not provide data on target confidence, type, class, or size. For scoring purposes, each SRI declaration is assumed to be of type "ordnance." For each target, SRI could not reliably determine target depth. However, SRI provided two sets of coordinates, one corresponding to the target location if its depth is assumed to be 0 meter, the other if the depth is assumed to be 1 meter. For scoring purposes, the 0-meter depth coordinates are used. SRI's $P_{D,ord}$ value does not increase if the 1-meter target declarations are used instead of the 0-meter declarations.

During validation activities at Fort Jackson, USAF/WL excavated four of SRI's target declaration locations at the Churchill Drop Zone and Artillery Road Site. Table 5-47 summarizes the results of these excavation activities. Based on all three demonstrator's target reports, USAF/WL excavated a total of 43 locations at the ranges. Table 5-48 summarizes SRI's target predictions at these 43 locations.

Observed Capabilities and Limitations: SRI's surveying ability was not impeded by extreme topography, vegetation, or temperature, all of which affected ground platform demonstrators at both YPG and Fort Jackson. Adverse flight conditions (primarily turbulence) negatively affected the accuracy of SRI's GPR and differential GPS along some flight paths at both sites.

For safety reasons, SRI did not place retro reflectors on the YPG live site, causing a lack of complete topographic information and possibly causing some uncertainty in target positions (SRI 1995a). Detection capabilities of the GPR were adversely affected by vegetation and other ground obstacles at both sites, and ground moisture at Fort Jackson may have also adversely affected SRI's survey (SRI 1995b). Forested areas in parts of the Churchill Drop Zone and Artillery Road Site as well as in Ranges 12B and 12F precluded reliable target detection; unknown targets may exist in these areas (SRI 1995b).

YPG-STEL.DWG - 06/28/96 - CFR - 075-001449DOCS



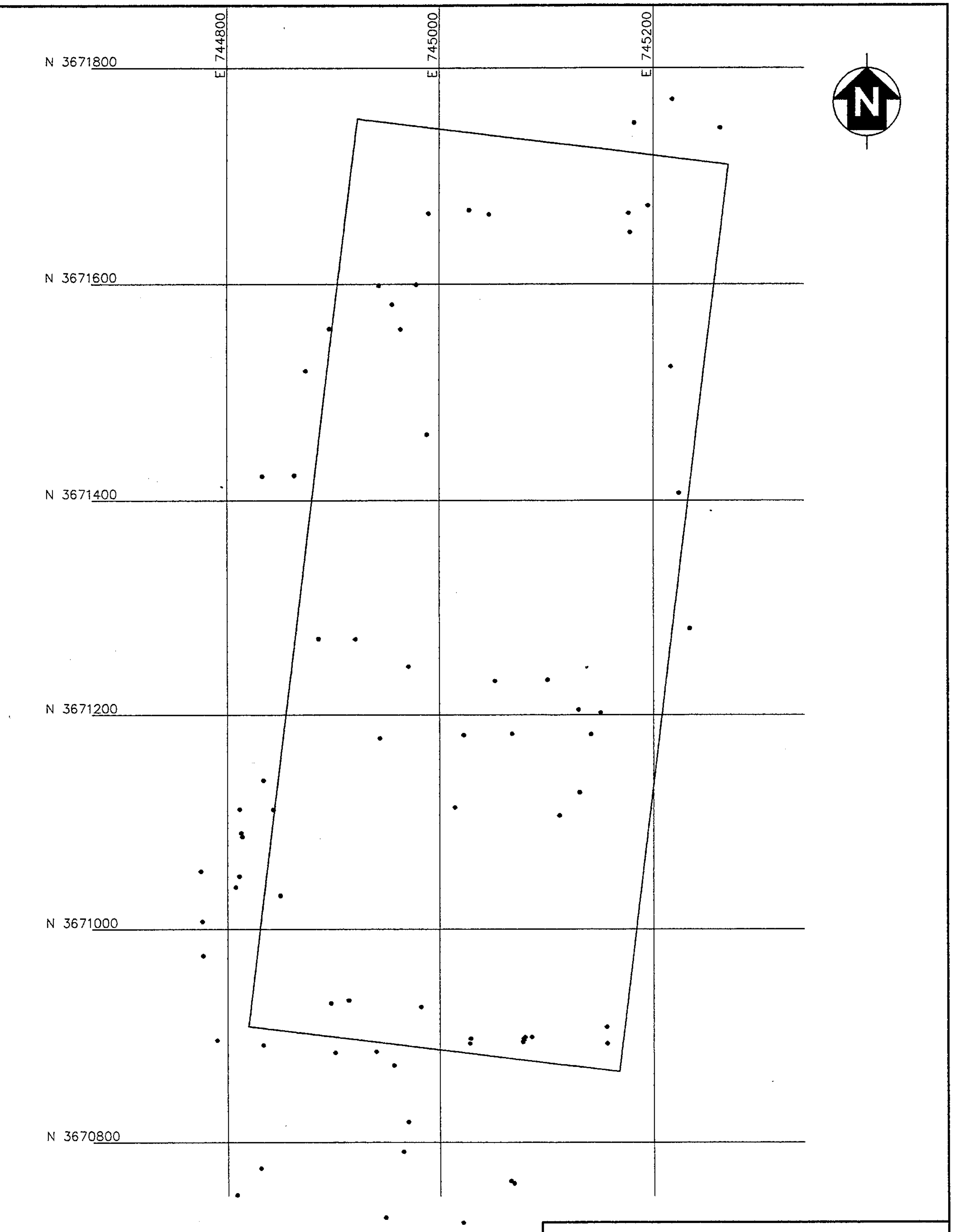
SCALE
1:5000

NOTE: COORDINATE SYSTEM IS UTM (NAD 27,
ZONE 11-MODIFIED BY YPG).

FIGURE 5-14

TARGET DECLARATIONS BY SRI
AT YPG (STEEL CIRCLE RANGE)

PRC ENVIRONMENTAL MANAGEMENT, INC.



SCALE
1:5000

NOTE: COORDINATE SYSTEM IS UTM (NAD 27, ZONE 11–MODIFIED BY YPG).

FIGURE 5-15

TARGET DECLARATIONS BY SRI
AT YPG (HULK 3 RANGE)

PRC ENVIRONMENTAL MANAGEMENT, INC.

YPG–H3.DWG – 06/28/96 – CFR – 075–001449DOCS

Table 5-41
Summary of Target Declarations by SRI at YPG

Range	Steel Circle	Hulk 3	Combined
Area Surveyed (hectares)	15.8	29.7	45.5
Area Available (hectares)	15.8	29.7	45.5
Target Declarations	35	40	75
Confidence			
High	0	0	0
Moderate	0	0	0
Low	0	0	0
Unknown	35	40	75
Depth (meters)			
0 to 0.5	35	40	75
> 0.5 to 2.0	0	0	0
> 2.0	0	0	0
Unknown	0	0	0
Target Type[a]			
Ordnance	35	40	75
Nonordnance	0	0	0
Target Size			
Large	0	0	0
Medium	0	0	0
Small	0	0	0
Unknown	35	40	75
Target Class			
Bomb	0	0	0
Mortar	0	0	0
Projectile	0	0	0
Cluster	0	0	0
Other	0	0	0
Unknown	35	40	75

Notes:

[a] SRI did not differentiate between target types; for scoring purposes, each target is assumed to be of type "ordnance."

Table 5-42
Performance Statistics for SRI at YPG

Overall Detection Statistics (R_{crit} = 5.0 meters)

Target Type	No. Detected/ No. in Baseline	$P_{D,ord}$	P_{random}
All targets	0/51	0.00	0.02

Distance Error Statistics

Error	Mean (meters)	Standard Deviation (meters)
Easting (x)	NA	NA
Northing (y)	NA	NA
Radial (r)	NA	NA
Depth (z)	NA	NA
Mean Absolute Depth ($\|z\|$)	NA	NA

Detection and Classification Statistics

Category	No. Detected/ No. in Baseline	P_D	No. Correctly Classified/ No. Detected	P_C
Type				
Ordnance	0/51	0.00	0.0	NA
Nonordnance	0/0	NA	0.0	NA
Size				
Large	0/3	0.00	0.0	NA
Medium	0/14	0.00	0.0	NA
Small	0/34	0.00	0.0	NA
Class				
Bomb	0/15	0.00	0/0	NA
Mortar	0/17	0.00	0/0	NA
Projectile	0/19	0.00	0/0	NA
Cluster	0/0	NA	0/0	NA
Other	0/0	NA	0/0	NA

Table 5-43
Excavated Target Positions Based on SRI Ordnance Declarations at YPG

Demonstrator Target Declaration	Excavated Target Position		
	Ordnance	Nonordnance	Empty
Ordnance	0/13	1/13	12/13

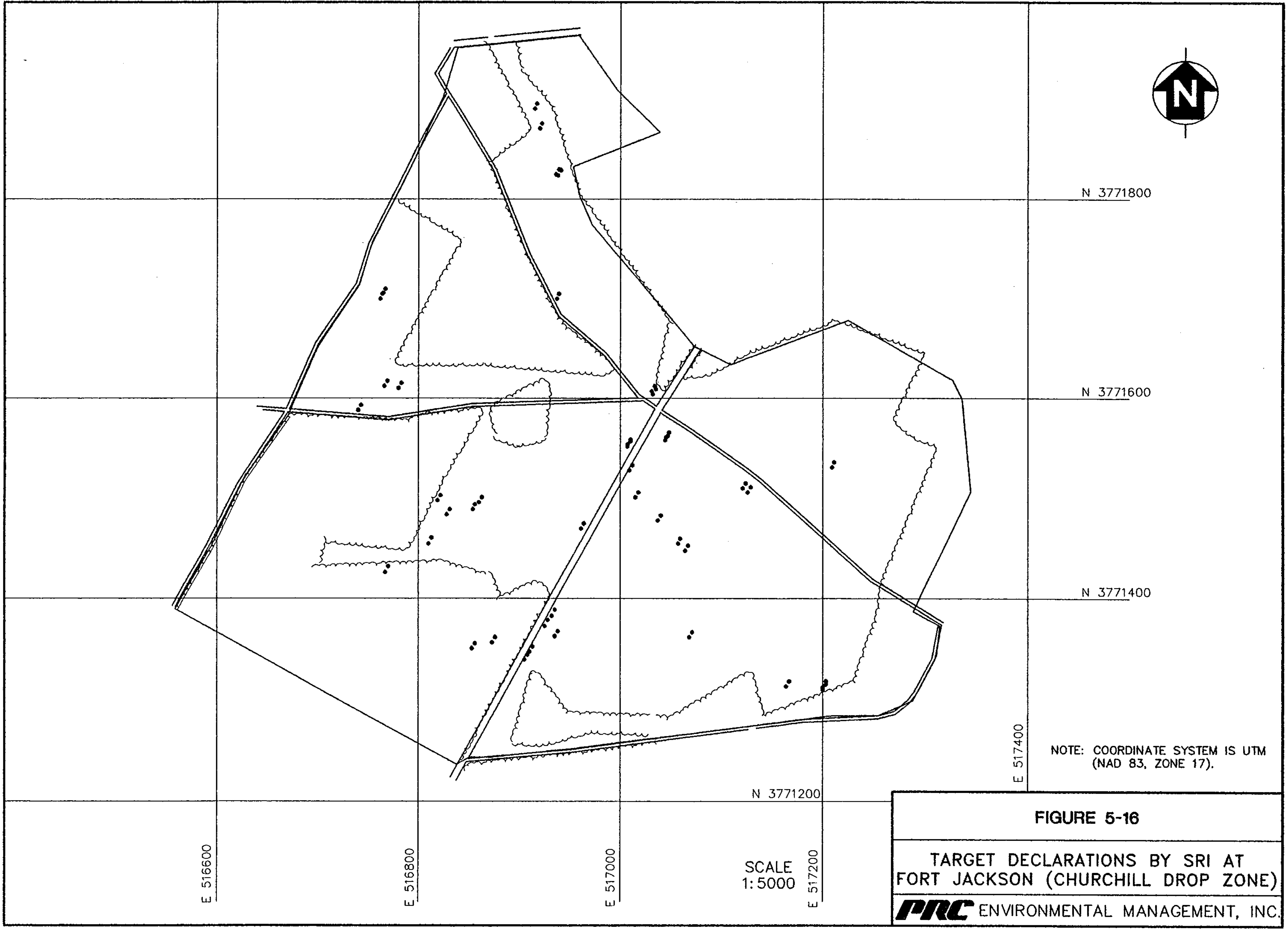
Table 5-44
Target Prediction Rates for SRI Based on All Excavated Locations at YPG

Demonstrator Target Declaration	Excavated Locations (n=40)[a]	
	Ordnance	Nonordnance
Ordnance	0/1	1/2
No declaration	1/1	1/2

Note:

[a] Of the 40 locations that were excavated during validation activities, 1 contained ordnance, 2 contained nonordnance, and the remaining 37 contained no discernable man-made materials.

JACK-CDZ.DWG – 06/28/96 – CFR – 075-001449DOCS

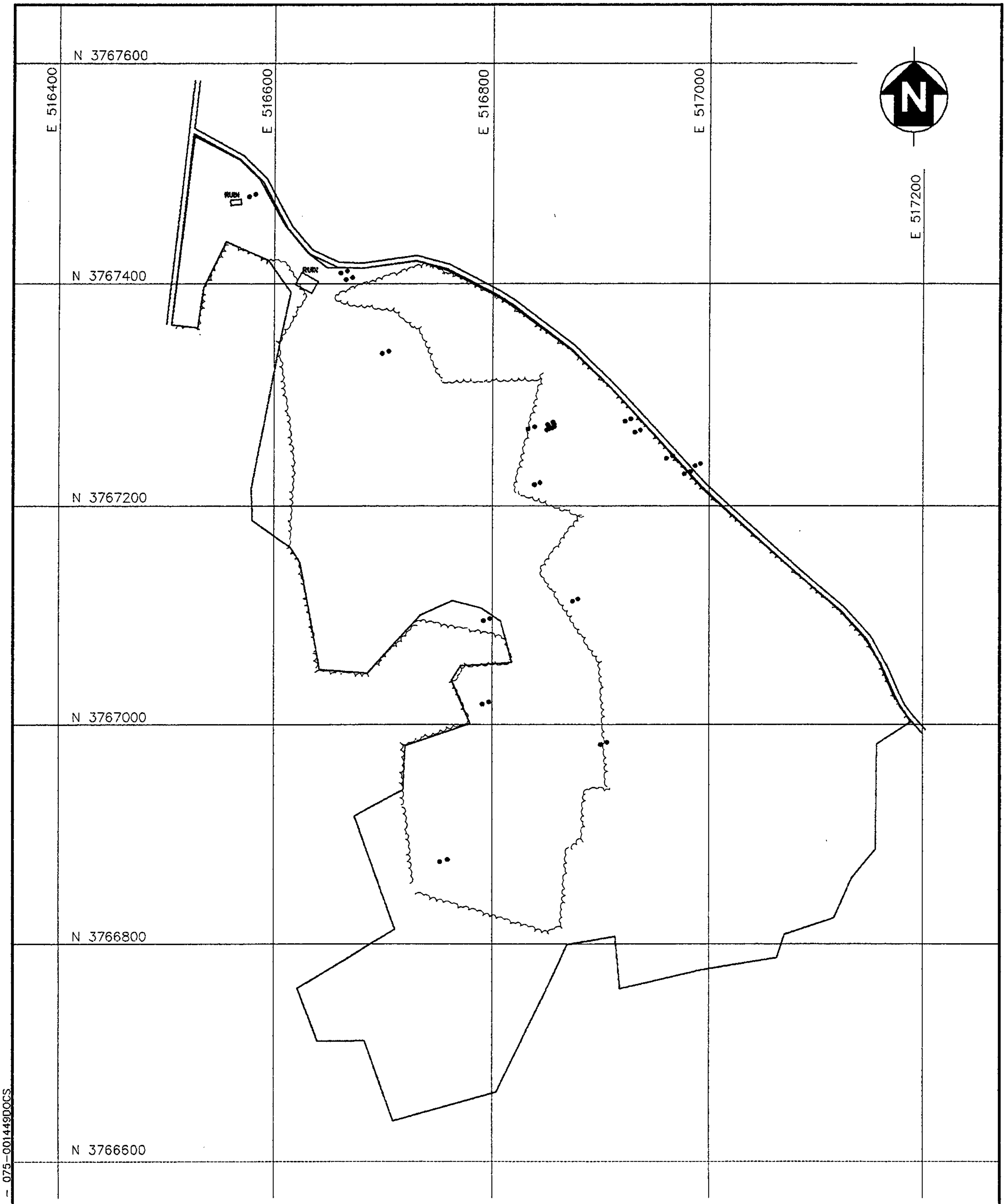


NOTE: COORDINATE SYSTEM IS UTM (NAD 83, ZONE 17).

FIGURE 5-16

TARGET DECLARATIONS BY SRI AT
FORT JACKSON (CHURCHILL DROP ZONE)

PRC ENVIRONMENTAL MANAGEMENT, INC.



NOTE: COORDINATE SYSTEM IS UTM
(NAD 83, ZONE 17).

SCALE
1:5000

FIGURE 5-17

TARGET DECLARATIONS BY SRI AT FORT JACKSON (ARTILLERY ROAD SITE)

PRC ENVIRONMENTAL MANAGEMENT, INC.

JACK-AR.DWG - 06/28/96 - CFR - 075-001449DOCS

Table 5-45
Summary of Target Declarations by SRI at Fort Jackson

Range	Churchill Drop Zone	Artillery Road	Combined
Area Surveyed (hectares)	32.8	27.7	60.5
Area Available (hectares)	32.8	27.7	60.5
Target Declarations	42	19	61
Confidence			
High	0	0	0
Moderate	0	0	0
Low	0	0	0
Unknown	42	19	61
Depth (meters)			
0 to 0.5	42	19	61
> 0.5 to 2.0	0	0	0
> 2.0	0	0	0
Unknown	0	0	0
Target Type[a]			
Ordnance	42	19	61
Nonordnance	0	0	0
Target Size			
Large	0	0	0
Medium	0	0	0
Small	0	0	0
Unknown	42	19	61
Target Class			
Bomb	0	0	0
Mortar	0	0	0
Projectile	0	0	0
Cluster	0	0	0
Other	0	0	0
Unknown	42	19	61

Notes:

[a] SRI did not differentiate between target types; for scoring purposes, each target is assumed to be of type "ordnance."

Table 5-46
Performance Statistics for SRI at Fort Jackson

Overall Detection Statistics (R_{crit} = 5.0 meters)

Target Type	No. Detected/ No. in Baseline	$P_{D,ord}$	P_{random}
All targets	0/35	0.00	0.01

Distance Error Statistics

Error	Mean (meters)	Standard Deviation (meters)
Easting (*x*)	NA	NA
Northing (*y*)	NA	NA
Radial (*r*)	NA	NA
Depth (*z*)	NA	NA
Mean Absolute Depth ($\|z\|$)	NA	NA

Detection and Classification Statistics

Category	No. Detected/ No. in Baseline	P_D	No. Correctly Classified/ No. Detected	P_C
Type				
Ordnance	0/35	0.00	0/0	NA
Nonordnance	0/2	0.00	0/0	NA
Size				
Large	0/8	0.00	0/0	NA
Medium	0/15	0.00	0/0	NA
Small	0/12	0.00	0/0	NA
Class				
Bomb	0/2	0.00	0/0	NA
Mortar	0/14	0.00	0/0	NA
Projectile	0/19	0.00	0/0	NA
Cluster	0/0	NA	0/0	NA
Other	0/0	NA	0/0	NA

Table 5-47
Excavated Target Positions Based on SRI Ordnance Declarations at Fort Jackson

Demonstrator Target Declaration	Excavated Target Position		
	Ordnance	Nonordnance	Empty
Ordnance	0/4	1/4	3/4

Table 5-48
Target Prediction Rates for SRI Based on All Excavated Locations at Fort Jackson

Demonstrator Target Declaration	Excavated Locations (n=43)[a]	
	Ordnance	Nonordnance
Ordnance	0/1	1/22
No declaration	1/1	21/22

Note:

[a] Of the 43 locations that were excavated during validation activities, 1 contained ordnance, 22 contained nonordnance, and the remaining 20 contained no discernable man-made materials.

5.1.8 Vallon GmbH

Vallon demonstrated its MSV-5 and MANPODS platforms for the Vallon EL1302A1 magnetometer sensor technology at Eglin AFB. The following sections describe the technology's measured performance as well as its observed capabilities and limitations.

Measured Performance at Eglin AFB: Between July 31 and August 16, Vallon surveyed about 26.4 hectares (54 percent) of the 48.8-hectare assigned survey area at Eglin AFB's Range A-73. Vallon was on-range for a total of about 80 hours over 11 days. Vallon used about 16 hours to set up its equipment, and it experienced about 5 hours of downtime due to equipment failure. In all, Vallon spent about 101 hours conducting survey-related activities. Vallon's field survey rate at Eglin AFB was 0.33 hectare per hour; its overall survey rate was 0.26 hectare per hour.

Figure 5-18 shows Vallon's target declarations at Eglin AFB Range A-73. Table 5-49 summarizes Vallon's target declarations at the site; Table 5-50 summarizes performance statistics calculated for Vallon.

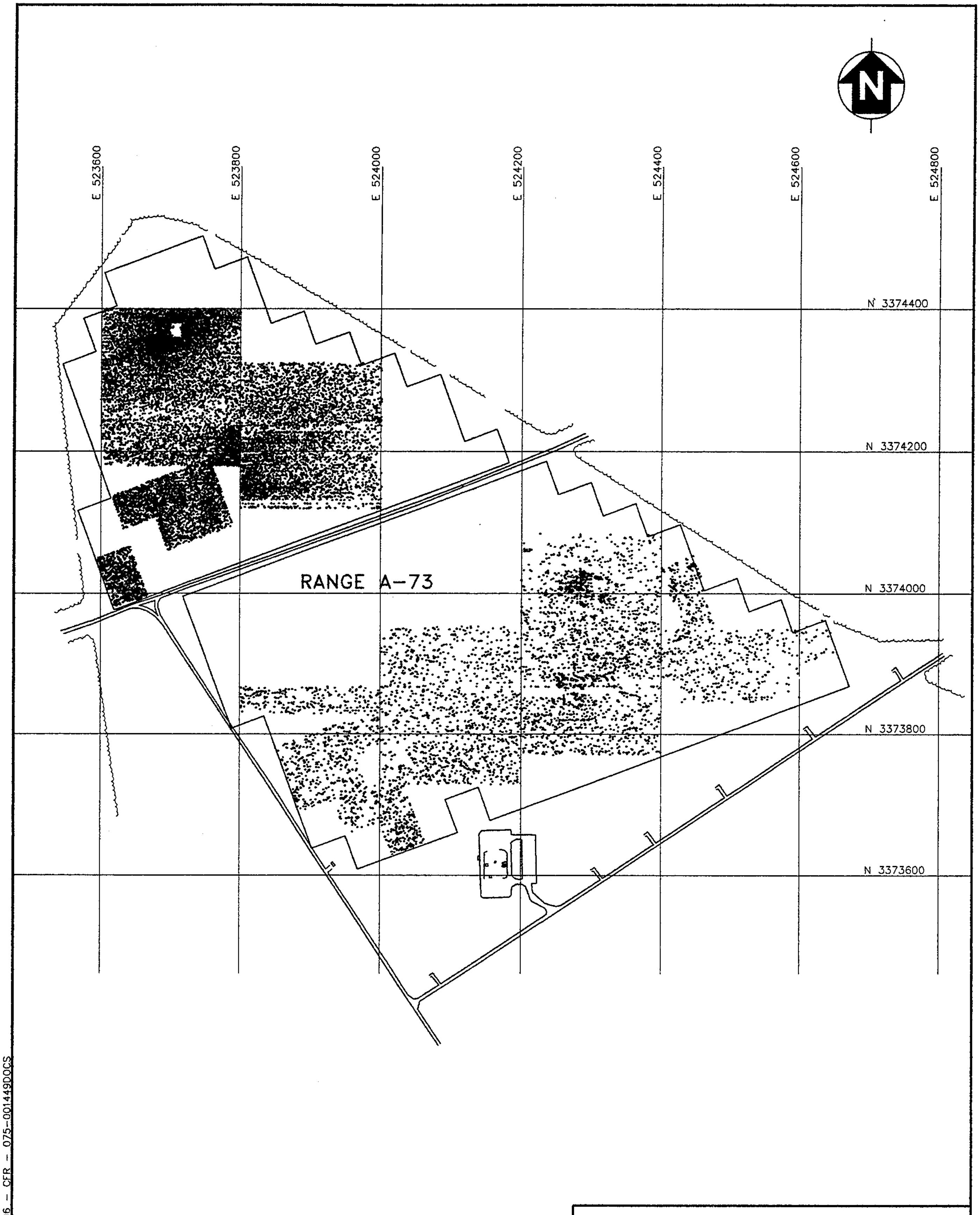
Vallon surveyed about 54 percent of the 48.8 hectares at the site, declaring 18,681 targets within the range (Vallon 1995) and detecting 23 of the 31 baseline ordnance targets in the surveyed area. At the 95-percent confidence level, Vallon's $P_{D,ord}$ of 0.74 is significantly different from the calculated P_{random} value of 0.59. Because of the extremely high target density at the Eglin AFB site, P_{random} analysis is less reliable than at the other sites. With the targets it detected, Vallon had a mean radial error of 1.09 meters and a mean square depth error of 0.89 meter.

Vallon provided data on target depth, type, class, and size. Vallon did not provide data on target confidence; for scoring purposes, each Vallon target declaration is assumed to be of "high" confidence.

During validation activities at Eglin AFB, USAF 96th EOD excavated 39 of Vallon's target declaration locations at Range A-73. Table 5-51 summarizes the results of these excavation activities. Based on both demonstrator's target reports, USAF 96th EOD excavated a total of 47 locations within Vallon's survey area at the range. Table 5-52 summarizes Vallon's target predictions at these 47 locations.

Observed Capabilities and Limitations: Operation of the MSV-5 was hindered by heavy vegetation, soft soils, uneven terrain, and other obstacles. Vallon remedied mobility problems by augmenting the MSV-5 system with the MANPODS units at Eglin AFB.

Rain during the demonstration caused a malfunction in one of Vallon's EL1302A1 sensors; a short delay was incurred while Vallon repaired the sensor. Vallon also experienced a delay when the MSV-5 tow vehicle broke down. Vallon's MANPODS team experienced delays when the SEPOS measuring tape snagged or broke. Extreme temperatures encountered during the demonstration (more than 37 °C) did not appear to affect Vallon's equipment.



NOTE: COORDINATE SYSTEM IS UTM
(NAD 27, ZONE 16).

SCALE
1:7500

FIGURE 5-18

TARGET DECLARATIONS BY VALLON
AT EGLIN AFB (RANGE A-73)

PRC ENVIRONMENTAL MANAGEMENT, INC.

EG-SITE.DWG - 06/28/96 - CFR - 075-001449DOCS

Table 5-49
Summary of Target Declarations by Vallon at Eglin AFB

Range	A-73
Area Surveyed (hectares)	26.4
Area Available (hectares)	48.8
Target Declarations	18,681
Confidence	
High	0
Moderate	0
Low	0
Unknown	18,681
Depth (meters)	
0 to 0.5	10,305
> 0.5 to 2.0	7,843
> 2.0	533
Unknown	0
Target Type	
Ordnance	18,681
Nonordnance	0
Target Size	
Large	2,015
Medium	7,522
Small	9,144
Unknown	0
Target Class	
Bomb	2,015
Mortar	0
Projectile	16,666
Cluster	0
Other	0
Unknown	0

Table 5-50
Performance Statistics for Vallon at Eglin AFB

Overall Detection Statistics (R_{crit} = 2.0 meters)

Target Type	No. Detected/ No. in Baseline	$P_{D,ord}$	P_{random}
All targets	23/31	0.74	0.59

Distance Error Statistics

Error	Mean (meters)	Standard Deviation (meters)
Easting (x)	0.16	0.81
Northing (y)	-0.17	0.92
Radial (r)	1.09	0.57
Depth (z)	0.09	0.96
Mean Absolute Depth ($\lvert z \rvert$)	0.89	NA

Detection and Classification Statistics

Category	No. Detected/ No. in Baseline	P_D	No. Correctly Classified/ No. Detected	P_C
Type				
Ordnance	23/31	0.74	23/23	1.00
Nonordnance	4/4	1.00	0/4	0.00
Size				
Large	5/6	0.83	3/5	0.60
Medium	3/7	0.43	1/3	0.33
Small	15/18	0.83	10/15	0.67
Class				
Bomb	5/6	0.83	3/5	0.60
Mortar	0/0	NA	0/0	NA
Projectile	9/15	0.60	6/9	0.67
Cluster	2/3	0.67	0/2	0.00
Other	7/7	1.00	0/7	0.00

Table 5-51
Excavated Target Positions Based on Vallon Ordnance Declarations at Eglin AFB

Demonstrator Target Declaration	Excavated Target Position		
	Ordnance	Nonordnance	Empty
Ordnance	29/39	2/39	8/39

Table 5-52
Target Prediction Rates for Vallon Based on All Excavated Locations at Eglin AFB

Demonstrator Target Declaration	Excavated Locations (n=47)[a]	
	Ordnance	Nonordnance
Ordnance	29/32	2/3
No declaration	3/32	1/3

Note:

[a] Of the 47 locations that were excavated during validation activities, 32 contained ordnance, 3 contained nonordnance, and the remaining 12 contained no discernable man-made materials.

5.2 REMEDIATION SYSTEM PERFORMANCE EVALUATION

Four Government UXO remediation systems conducted validation activities at the live sites. The remote excavation technology used at JPG and Fort Jackson was designed and developed by USAF/WL; the technologies used at YPG and Eglin AFB were developed by EOD personnel at those installations. Because of limited safety concerns, McChord AFB EOD personnel manually operated a backhoe to validate target positions.

The remediation systems are described in Section 3.0. Tables in this section summarize each remediation system's performance. In the tables, two excavation rates are summarized: the theoretical excavation rate and the actual excavation rate. In addition, theoretical excavation rates were calculated twice. The theoretical excavation rate (travel excluded) was calculated by dividing the number of holes excavated by the average excavation time for each hole. The theoretical excavation rate (travel included) was calculated by dividing the number of holes by the sum of the average time spent excavating and traveling between excavation locations. The actual excavation rate was calculated by dividing the number of holes excavated by the number of days spent excavating targets.

5.2.1 U.S. Air Force/Wright Laboratory

The USAF/WL AOE performed validation activities at JPG and Fort Jackson. The following sections describe the technology's measured performance as well as its observed capabilities and limitations.

Measured Performance: The AOE operated expediently in the field, excavating 53 validation target locations at JPG in 13 days between July 17 and 31. At JPG, the AOE had an average travel speed of 1.6 kilometers per hour (kph) over an average distance of 140 meters between targets. The average excavation depth at JPG was about 1.6 meters, and the average excavation time was about 18 minutes.

At Fort Jackson, USAF/WL excavated 43 validation target locations in 8 days between October 31 and November 9. The AOE had an average travel speed of 1.3 kph over an average distance of 83 meters between targets. The average excavation depth at Fort Jackson was about 1.7 meters, and the average excavation time was about 21 minutes. Longer excavation times at Fort Jackson were a result of the sandy soils caving into the holes as they were deepened.

At both sites, EOD personnel spent a significant amount of time manually inspecting the excavation for targets, making the rate of remediation slower than would be experienced without constant field checks for the declared targets. Table 5-53 summarizes remediation statistics for the USAF/WL AOE. Full validation information is provided in Appendix C.

Table 5-53
Performance Statistics for USAF/WL

Site	No. Holes	No. Days	Average Travel Time (min)	Average Excavation Time (min)	Theoretical Excavation Rate (holes/day)[a]		Actual Excavation Rate (holes/day)
					Travel Excluded	Travel Included	
JPG	53	13	5.2	18	20	16	4.1
Fort Jackson	43	8	3.8	21	17	15	5.4

Note:

[a] Theoretical excavation rates are calculated assuming a 6-hour day for excavation (EOD activity typically requires about 2 hours per day) with no downtime.

Observed Capabilities and Limitations: The AOE experienced relatively quick excavation and travel times between excavation points. Initial setup was time-intensive. Although the first few days of the validation effort were slow at JPG, USAF/WL personnel improved the AOE efficiency after the process was underway. Because the AOE is fully automated and equipped with a navigation system, validation positions did not require staking prior to the demonstration (although validation positions were marked). The AOE could have been used to backfill holes with some degree of effectiveness, but USAF/WL used a bulldozer for these earth-moving activities.

The dense clay soils at JPG required more earth-moving force than other soils the AOE had previously excavated. The increased effort resulted in increased maintenance requirements. In addition, fatigue on mechanical parts took its toll on some of the equipment. Although some maintenance and parts replacement were conducted in the field, USAF/WL was not adequately prepared for these events, and some downtime occurred to keep the equipment properly maintained. Mechanical fatigue was less of a problem at Fort Jackson.

Mechanically, the AOE sustained excellent performance, with few delays due to equipment repairs. At JPG, USAF/WL made minor mechanical modifications in the field to improve or accelerate the excavation process. These modifications included (1) repositioning the GPS antenna and modifying the GPS system, (2) bracketing excavation boundaries at the start of an excavation, and (3) modifying the AOE cabin to prevent overheating of the controls. At Fort Jackson, one of the track brakes failed, but it was successfully repaired. Also at Fort Jackson, several solders in the machinery's electronics systems failed, requiring USAF/WL to make in-field repairs.

A serious problem with the AOE involves the telemetry equipment required to make the excavator autonomous. Although the telemetry system is designed for a range of more than 3 km, at both JPG and Fort Jackson, the AOE control booth occasionally lost contact with the equipment with as little as 200 meters separation (less than 10 percent of the design range). USAF/WL field personnel indicated that this is a recurring problem and that a permanent solution has not yet been devised.

At JPG, the blast barrier erected to shield the control booth prevented the shortened operating range from becoming a critical safety issue. However, at Fort Jackson, the AOE's range decreased on a daily basis. In fact, the range of the equipment was so degraded by the end of the first week that safety concerns resulted from the required proximity of the control booth to the AOE. After discussing the situation with the on-site EOD team, USAF/WL agreed that if further degradation occurred, validation activities would be terminated until the problems were corrected. Although USAF/WL personnel attempted to troubleshoot the situation and some improvements were made, the performance of the remote control equipment continued to degrade. Therefore, validation activities were halted before completion.

Some downtime at both sites was also experienced due to GPS system failure. At JPG, GPS failure typically occurred on foggy mornings. At Fort Jackson, these failures occurred when the AOE operated near forested areas. At both sites, natural obstructions prevented the AOE's GPS system from maintaining contact with GPS satellites.

The AOE's large bucket moved large quantities of excavated materials, and it was difficult to detect man-made anomalies as they were removed from each excavation. This problem was compounded when the AOE operator "jogged" the bucket, releasing its entire contents at one time.

USAF/WL experienced few logistics problems at either site. Minimal delays were experienced when JPG personnel needed to travel past the excavation site. Excavation activities were stopped when road barriers were breached; the activities continued after the road was clear. Minimal delays also occurred when backfilling equipment could not be brought to the JPG live site as needed. These problems were not experienced at Fort Jackson.

5.2.2 Yuma Proving Ground Explosive Test Operations

YPG ETO personnel conducted the validation at YPG using a remotely-operated excavator developed on post. The following sections describe the technology's measured performance as well as its observed capabilities and limitations.

Measured Performance: The excavator was slow, excavating only 42 validation target locations at YPG in 18 days between August 29 and September 21. The excavator had an average travel speed of 3.0 kph over an average distance of 350 meters between targets. The average excavation depth at YPG was about 1.9 meters, and the average excavation time was about 105 minutes.

As with all the sites, EOD personnel spent significant time manually inspecting the excavations for UXO with hand-held magnetometer sensors. Difficulty in inspecting each hole was compounded at YPG because many of the cobbles and small boulders at the site exhibited considerable magnetic properties. As a result of these properties, EOD personnel were required to physically investigate tens or hundreds of potential anomalies within each excavation. Table 5-54 summarizes the remediation statistics for the YPG excavator. Full validation information is provided in Appendix C.

Observed Capabilities and Limitations: YPG completed initial excavator setup activities within 2 hours. In its current configuration, YPG's remotely-operated excavator is not autonomous; it requires an operator to drive it to and from each selected target validation position. In addition, because the excavator is not equipped with a positioning system, each validation position must be surveyed and staked before excavation activities begin.

Table 5-54
Performance Statistics for YPG ETO

Site	No. Holes	No. Days	Average Travel Time[a] (min)	Average Excavation Time (min)	Theoretical Excavation Rate (holes/day)[b]		Actual Excavation Rate (holes/day)
					Travel excluded	Travel included	
YPG	42	18	37	105	3.4	2.5	2.3

Note:

[a] The actual average travel time is 7 minutes, but the YPG excavator requires about 30 minutes of camera setup and manual excavator positioning at the excavation location.

[b] Theoretical excavation rates are calculated assuming a 6-hour day for excavation (EOD activity typically requires about 2 hours per day) with no downtime.

Two to three excavations were completed daily during the validation period. The excavator was used to spread soil spoilings and backfill the completed holes. According to YPG personnel, the backhoe can remotely excavate to a depth of about 4 meters below ground surface. However, the deepest hole excavated during the validation was 3 meters; deeper excavations were not performed because of the excessive time requirements. YPG personnel stated that the backhoe can be remotely operated at a maximum distance of about 1.6 km from the control trailer as long as line of sight is maintained between the excavator and control trailer.

The video images displayed on the television monitors in the control trailer were generally clear. However, video image distortions were caused by increasing the distance between the excavator and backhoe and by physical obstructions. The telelink signal was also affected by the use of hand-held radios and cellular telephones in the vicinity of excavation activities, and the gasoline-powered generator at the control trailer produced minor video interference. Heat caused the camera batteries to fail early; batteries were typically changed once daily. In addition, dust from the excavation occasionally became so thick that the view of the excavation was blocked.

During validation activities, YPG personnel conducted daily excavator maintenance. The system operates with minimal problems if routine maintenance is performed daily. No equipment failures were encountered, except when the extreme heat affected the camera batteries.

5.2.3 U.S. Air Force 96th Explosive Ordnance Disposal Division

The USAF 96th EOD conducted the validation at Eglin AFB using a remotely-operated remediation technology developed on post. The following sections describe the technology's measured performance as well as its observed capabilities and limitations.

Measured Performance: Excavator operations were quite fast; 69 validation positions were excavated in 11 days between September 18 and 29. The excavator had an average travel speed of 1.5 kph over an average distance of 110 meters between targets. The average excavation depth at Eglin AFB was about 1.4 meters, and the average excavation time was about 22 minutes.

As with all the sites, EOD personnel spent a significant amount of time manually inspecting each excavation. Table 5-55 summarizes the remediation statistics for the Eglin AFB excavator. Full validation information is provided in Appendix C.

Table 5-55
Performance Statistics for USAF 96th EOD

Site	No. Holes	No. Days	Average Travel Time (min)	Average Excavation Time (min)	Theoretical Excavation Rate (holes/day)[a]		Actual Excavation Rate (holes/day)
					Travel excluded	Travel included	
Eglin AFB	69	11	4.4	22	16	14	6.3

Note:

[a] Theoretical excavation rates are calculated assuming a 6-hour day for excavation (EOD activity typically requires about 2 hours per day) with no downtime.

Observed Capabilities and Limitations: USAF 96th EOD completed initial excavator setup activities relatively quickly. The Eglin AFB remotely-operated excavator can be navigated without a driver in the cab, which allows for shorter travel times between excavations. The excavator is not equipped with a positioning system; to correctly position the excavator, validation positions must be surveyed and staked before excavation activities begin.

During the validation, four to nine excavations were completed daily. The excavator was not used to spread soil or backfill the holes. The deepest hole excavated during the validation was about 2.5 meters deep; deeper excavations would have been difficult because the sandy soils at Eglin AFB caved into the hole as the excavation was deepened. Eglin AFB personnel claim that the backhoe can be remotely operated at a maximum distance of more than 1 km from the control booth, as long as line of sight between the excavator and the control booth is maintained. The control booth was moved several times during the validation activities to maintain the EOD-required safe standoff distance, and range problems with the excavator did not occur.

Video images displayed on television monitors in the control booth were occasionally distorted by thermal waves rising from the ground. In addition, line-of-sight between the control booth and the video transmitter was sometimes disrupted when the excavator was positioned with the excavator body between the two. Excavator vibration also caused camera malfunctions several times, but the cameras were easily repaired.

Some downtime was also experienced due to routine excavator maintenance. USAF 96th EOD frequently changed excavator air and fuel filters that became clogged with the fine, sandy soils.

5.2.4 U.S. Air Force 62nd Explosive Ordnance Disposal Division

Because the USAF 62nd EOD did not identify serious safety issues at McChord AFB, they performed validation activities using a manually operated excavator. The following sections describe the excavator's measured performance as well as its observed capabilities and limitations.

Measured Performance: Excavator operations were average compared with the other excavator systems; nine validation positions were excavated in 3 days between December 4 and 6. The excavator had an average travel speed of 4.8 kph over an average distance of 120 meters between targets. The average excavation depth at McChord AFB was about 1.1 meters, and the average excavation time was about 25 minutes.

Although EOD personnel were required to manually inspect each excavation, the gravelly soil did not hide excavated targets from sight as soil at other sites did. Table 5-56 summarizes the remediation statistics for the excavator used by the USAF 62nd EOD. Full validation information is provided in Appendix C.

Table 5-56
Performance Statistics for USAF 62nd EOD

Site	No. Holes	No. Days	Average Travel Time (min)	Average Excavation Time (min)	Theoretical Excavation Rate (holes/day)[a]		Actual Excavation Rate (holes/day)
					Travel excluded	Travel included	
McChord AFB	9	3	1.9	25	14	13	3.0

Note:

[a] Theoretical excavation rates are calculated assuming a 6-hour day for excavation (EOD activity typically requires about 2 hours per day) with no downtime. At McChord AFB, EOD personnel spent about 4 hours per day conducting the validation activities, resulting in an actual excavation rate of 4.5 holes per day.

Observed Capabilities and Limitations: Because the excavator used by USAF 62nd EOD was a rental unit with no special electronics systems, no initial setup time was required. The excavator was offloaded, and validation activities began almost immediately. Navigation and excavation operations were conducted manually. The excavator is not equipped with a positioning system; to correctly position the excavator, validation positions must be surveyed and staked before excavation activities begin.

The excavator was used to spread soil and backfill holes. The deepest hole excavated during the validation was about 2 meters deep. This is the practical limit on excavation depth at McChord AFB using this type of equipment because the rocky soil exerts great resistance on the excavator blade. In fact, excavation activities were stopped at two locations before the desired 2-meter depth could be achieved because of the resistant soil. Otherwise, no operational constraints were encountered.

Because a video system was not required to observe the excavation, no downtime was incurred due to faulty video systems. Likewise, no downtime was experienced due to maintenance requirements because the excavator was delivered in full working order by the rental company.

5.3 DEVIATIONS FROM ESTABLISHED PROTOCOL

Live site activities were carried out at five sites exhibiting different characteristics. Although every effort was made to ensure that a consistent approach was taken when preparing the sites and conducting the demonstrations, slight variations occurred at each site. The following sections describe these variations for each of the five sites. In general, exceptions were made to standard procedures in one of two areas: (1) logistics, health, and safety issues; and (2) quality control issues.

5.3.1 Jefferson Proving Ground

Logistics, Health, and Safety Issues: Activities at the site were somewhat hampered due to severe spring storms with lightning, hail, and heavy rain. At times, flooding and high water at the demonstration sites and on site access roads stopped field activities. Demonstrators using ground platforms experienced delays throughout the demonstration due to on-site flooding. Although ground platforms could occasionally traverse puddled areas, some were deemed inaccessible by demonstrators. Flooded or wet ground mired the vehicle-towed unit demonstrated at JPG, requiring the platform to be pushed off the field by demonstrator personnel. The aerial platform demonstrator also experienced delays due to weather; rainstorms, high wind, and ground fog delayed and stopped the aerial survey several times.

During the demonstration period, JPG was in the process of destroying stockpiled munitions at a site adjacent to Range 18000W. JPG typically conducted one “shot” daily, and demonstrator and support personnel were required to leave the range when shots were made.

Before the demonstration, JPG personnel indicated that the northern portion of Range 18000W had been fired upon by rounds containing white phosphorus, a chemical that produces toxic and potentially lethal fumes on contact with air. White phosphorus smoke in this area was observed on several occasions prior to the demonstrations. Personnel were not on site at the time, so the smoke did not pose a direct safety hazard. The area was monitored whenever demonstrators were near it.

By the end of the 3-week demonstration period, vegetation at the north end of Range 18000W had grown significantly (about 1 meter). Based on safety concerns expressed by the on-site EOD team, Coleman was not allowed to enter the range to complete its survey. The other demonstrators were not restricted because they were not required to survey this area.

Quality Control Issues: A large quantity of ordnance-related debris was removed from Ranges 18000W and 21000W during the site sweep. However, both ADI and Coleman reported that the upper 0.2 to 0.5 meter of soil at the ranges is essentially saturated with ferrous targets. The density is so extreme that ADI only processed 24.5 percent of its data (ADI 1995a); Coleman adjusted its target detection threshold to eliminate about 50 percent of the targets that would have been declared had no adjustment been made (Coleman 1995a). Because of these factors, the quantity of targets at JPG is probably under-reported. During the validation at Range 21000W, 19 UXO items were recovered from 53 validation positions. These UXO items include five 8-in. projectiles and fourteen 100-pound bombs. Some of the 8-in. projectiles contained possibly intact and live rocket motors. Most bombs were sand-filled practice bombs, but 3 of the 14 were fragmentation bombs. In addition to the ordnance targets, 14 nonordnance targets were recovered. Appendix E shows target declaration density maps for Ranges 18000W (Main), 18000W (Birdfoot), and 21000W based on ADI and Coleman data. Aerodat data were not used to construct target density maps because its $P_{D,ord}$ value is not significantly different than its calculated P_{random} value.

5.3.2 Yuma Proving Ground

Logistics, Health, and Safety Issues: Ambient temperatures during the demonstration period averaged 42.2 °C, and daily highs ranged from 40.3 °C to 53.3 °C. Because of the extreme temperature, heat stress was a major concern. To reduce the hazard to demonstrator and support personnel, demonstration activities were scheduled from 0430 to 1600 hours each day, reducing prolonged exposure to the heat. In addition, demonstrators were required to take numerous water and rest breaks throughout the day.

In addition to extreme heat, other environmental factors affected the demonstrations. In particular, the rough terrain and steep-walled washes caused mobility problems for the ground-based platforms. Flat tires were experienced by both ground-based platform demonstrators; these demonstrators were also unable to complete the site survey in several of the steep-walled washes.

Because some roads and parts of the live site demonstration areas were located in laser eye-safe zones, demonstrators were supplied with laser goggles, as required by YPG.

Quality Control Issues: Surveying activities were conducted by YPG Geodetics personnel. According to YPG, the control monuments were surveyed to Second Order (First Class) horizontal accuracy, and the fly points were surveyed to Third Order (First Class) horizontal accuracy. These control points were used by YPG Geodetics to construct the demonstration grids, locate the position and orientation of the baseline targets, and mark the location of the validation positions. Some demonstrators used the fly points as control monuments during their surveys as well. Although the project's accuracy requirements were not met by YPG Geodetics, the maximum error from any given monument or fly point to any point on the ranges is about 0.03 meter, well within the 2-meter R_{crit} value used to evaluate ground platform demonstrators.

Problems were encountered during conversion of the YPG-provided latitude and longitude coordinates (WGS 84) to universal transverse Mercator (UTM) coordinates (NAD 27 Zone 11). YPG claims that the U.S. Geological Survey algorithm is incorrect, and the installation uses its own site-specific coordinate conversion algorithm. This error was clarified only after the demonstrators were already at YPG, resulting in some confusion during the first 2 days of the survey. Demonstrators were provided with YPG's coordinate conversion process, but two of the three demonstrators experienced problems with this algorithm and were allowed to submit their data in latitude and longitude coordinates instead of in UTM coordinates. These coordinates were then converted for the demonstrators. To ensure that errors were not made in the conversion, known benchmark coordinates were also converted with the demonstrator data points. Conversion error was measured to be less than 0.005 meter, well within the 2-meter R_{crit} value used to evaluate ground platform demonstrators. In addition, survey data provided to the demonstrators were provided using consistent units of measurement.

To ensure that conversions were carried out correctly, six locations at the sites were surveyed, marked, and staked by survey crews using different coordinate systems as the basis for their surveys. YPG personnel successfully determined the location of these six targets during the validation effort, indicating that coordinate conversion did not affect data points.

Baseline targets emplaced at the Steel Circle Range were removed during validation activities except one 2,000-pound bomb, one 8-in. projectile, and several 40-mm projectiles. All removed targets were located at the horizontal and vertical coordinates provided to the demonstrators.

Based on visual observations made during the ATDs, it is likely that the Hulk 3 Range in particular contains relatively high quantities of UXO, especially near the 60 former gunnery and rocketry target locations at the north end of the range. Metratek's EM and GPR sensors probably could not clearly resolve subsurface targets in this part of the site because of the amount of aluminum rocket shrapnel near the targets (Metratek 1995a). The Geo-Centers magnetometer system is not capable of detecting nonferrous materials such as the aluminum rocket shrapnel.

Although both ground platform demonstrators identified significant quantities of suspected UXO at both ranges selected for the live site ATDs, the target validation did not confirm extensive quantities of UXO at either range. Magnetic anomalies of geologic origin existed at both sites, and nearly every validation position contained large rocks with high magnetic signatures. This may have caused Geo-Centers to declare more UXO targets than it would have if the test site had been magnetically clean. Because Metratek's data set may be invalid (see Section 5.1.6), Metratek's target declarations should not be used to interpret the UXO density at the YPG ranges.

During the validation activities at YPG's Steel Circle Range, no targets were recovered from eight validation positions. At the Hulk 3 Range, a cluster of 37-mm projectiles and 37-mm fragmentation were recovered from 1 of the 34 validation positions excavated. Nonordnance targets were recovered from 2 of the 34 validation positions at the Hulk 3 site. Appendix E shows target declaration density maps for the Steel Circle and Hulk 3 ranges based on Geo-Centers and Metratek data. SRI data were not used to construct target density maps, because its $P_{D,ord}$ values are not significantly different than its calculated P_{random} values.

5.3.3 Eglin Air Force Base

Logistics, Health, and Safety Issues: Activities at the site were somewhat hampered due to intermittent summer storms accompanied by lightning and heavy rain. At times, demonstrators were required to stop work and seek shelter due to severe lightning conditions common in the Gulf Coast area. In general, adverse weather caused short delays of about 1 hour per day when summer storms occurred. In addition, Hurricane Erin struck the Eglin AFB area during the first week of the demonstration. The site was closed for an entire day during the hurricane.

Quality Control Issues: After the demonstration was completed, Vallon indicated that it could not duplicate the conversions between the latitude and longitude coordinates (WGS 84) and the UTM coordinates (NAD 83) provided to them. Although Vallon was using an incorrect conversion model, it was discovered that the Eglin AFB latitude and longitude coordinates were incorrectly identified. Eglin AFB surveyor personnel stated that their conversion program is site-specific. Unlike the YPG conversion algorithm, the Eglin conversion is uniform in both the northing and easting directions across the site. Consequently, all demonstrator data were shifted appropriately. Again, known points were included in the conversions to ensure that errors did not arise. All conversion error is less than 0.005 meter, well within the 2-meter R_{crit} value used to evaluate ground platform demonstrators.

When Eglin AFB removed the emplaced baseline targets, they were located independently. All targets were located at the horizontal and vertical coordinates provided to the demonstrators.

The site surveys conducted by Coleman and Vallon revealed significant UXO densities in two former target rings at the north end of Range A-73. Of 69 validation positions that were investigated, 53 contained man-made targets. Three of the positions contained nonordnance targets, either barbed wire or other steel scrap material. The remaining 50 validation positions contained up to 88 targets each. In all, the 50 validation positions containing ordnance yielded one 40-mm projectile; 23 2.75-in. rocket warheads; 457 BDU-33 or Mk76 practice bombs; and one 1,000-pound bomb (designation unknown). Appendix E shows target declaration density maps for Range A-73 based on Coleman and Vallon data.

5.3.4 Fort Jackson Military Reservation

Logistics, Health, and Safety Issues: The site was closed several times during the demonstration due to severe lightning and thunderstorms in the area. However, no significant logistics delays were experienced.

Quality Control Issues: One of the ground platform demonstrators continually knocked over grid node stakes as it surveyed the site. To ensure that the other ground platform demonstrator was not affected by absent grid node stakes, grid nodes were restaked to Third Order (First Class) horizontal accuracy.

Based on the demonstrator reports, 43 validation positions were investigated. Of these positions, only one contained ordnance, a 155-mm high explosive (HE) projectile. Another 22 positions contained nonordnance targets, primarily metallic debris, wire, or small pieces of ordnance fragmentation. The remaining 20 validation positions did not yield a target. Many of the validation positions not yielding a man-made target contained small seams of ferrous material of geologic origin. Appendix E shows target declaration density maps for the Churchill Drop Zone based on ADI and Geo-Centers data, as well as a map of the Artillery Road Site based on ADI data. SRI data were not used to construct target declaration density maps because SRI's $P_{D,ord}$ value is not significantly different than its calculated P_{random} statistic. Geo-Centers did not survey the Artillery Road Site.

5.3.5 McChord Air Force Base

Logistics, Health, and Safety Issues: Although rain and cold weather during the demonstration period hampered demonstrators slightly, no significant weather-related problems arose during the demonstration. In addition, McChord AFB live site demonstrators did not experience logistics or other delays.

Quality Control Issues: Based on demonstrator results, eight validation positions were investigated during the validation process. Although significantly more targets were declared by the demonstrators, additional target reports were not investigated because (1) McChord AFB claims that the area is relatively free of UXO other than small-caliber munitions and (2) both demonstrators did not declare targets at locations other than the eight investigated by the remediation team. Of the eight excavations made at the site, three yielded nonordnance, scrap metal targets. The other five positions did not yield targets of man-made origins, although three of the five contained geologic materials with significant magnetic signatures. Appendix E shows target declaration density maps for the South 40 Training Area based on Metratek data. Chemrad data were not used to construct target density maps because Chemrad's $P_{D,ord}$ value is not significantly different than its calculated P_{random} value.

5.4 QUALITY CONTROL PROBLEMS RELATING TO VALIDATION

Geologic conditions at each of the live sites made identification of UXO in excavated holes or the excavated soil pile a tenuous process at best. Screening the excavation hole with a metal detector and physically looking for metal fragmentation pieces and other small anomalous items is an extremely difficult process, particularly considering the amount of soil excavated (typically at least 8 m^3).

The possibility exists that UXO or other anomalies were buried in the overburden piles and could not easily be located by the metal detector. Also, small anomalous materials were difficult to see during excavation activities; anomalies detected by the metal detector were visually investigated to minimize overlooking potential targets.

Field recognition and identification of ordnance was further compounded by the requirement that observations be made on the video monitor in the control booth (except at McChord AFB, where excavation was performed manually). At times, the use of the video monitor caused the excavator operator to experience eye fatigue and tunnel vision. On cloudy and overcast days, it was difficult to see into the excavation to observe any ordnance that may have been in the hole. Blowing dust also obscured the excavation at YPG, Eglin AFB, and Fort Jackson.

Remediation teams were not able to determine the exact position, depth, azimuth, or declination of a UXO item when it was encountered in the excavation, because UXO items were often dislodged. Small items were often not visually detected until the on-site EOD team checked the soil piles resulting from excavation activities.

6.0 ANALYSIS

The overall objective of the live site ATD was to evaluate UXO detection and classification systems. The systems were demonstrated at live sites with different geology, topography, climate, and quantities of UXO. The following subsections summarize demonstrator performance statistics with respect to the baseline target set as well as operational constraints experienced by the live site demonstrators. These statistics should be considered in light of the testing and evaluation goals of this project; while some technologies clearly outperformed others, all the technologies demonstrated represent promising new approaches to solving the worldwide UXO problem.

In addition, these data are representative only of each demonstrator's performance at the live sites where surveys were conducted. Demonstrator performance at other sites with different environmental characteristics will most likely vary from the performance summarized in this report. As a result, the data presented herein should not be used to evaluate demonstrator abilities under different environmental conditions.

6.1 PERFORMANCE STATISTICS SUMMARY

Although performance statistics varied widely between demonstrators, several comparisons can be made between demonstrators and sensor systems.

6.1.1 Detection and Classification Systems

Detection Performance: To evaluate sensor performance, UXO detection capability and false alarm rates should be considered. Because the live sites contained unknown quantities of UXO, assessing demonstrator false alarm rates was not possible. A limited number of demonstrator target declarations were excavated to evaluate false alarm rates, but the amount of targets that could be excavated given the time and resource constraints did not provide a large enough sample size to be statistically valid at a reasonable level of confidence. Because the sample size was not adequate, demonstrator P_{random} statistics were calculated to evaluate how many of a demonstrator's target declarations could be attributed to random processes (see Section 4.0 and Appendix C for a complete discussion of the P_{random} statistic). Individual demonstrator P_D values are summarized and compared in Table 6-1 and Figure 6-1.

Table 6-1

Summary of P_D Values for Each Demonstrator

Site	Demonstrator	No. Baseline UXO Targets Detected	Probability of Detection (P_D)									
			Target Type		Target Size			Target Classification				
			$P_{D,ord}$	$P_{D,nonord}$	$P_{D,large}$	$P_{D,medium}$	$P_{D,small}$	$P_{D,bomb}$	$P_{D,mortar}$	$P_{D,projo}$	$P_{D,cluster}$	$P_{D,submun}$
JPG	Aerodat	3	0.07	0.00	0.00	0.06	0.10	0.12	0.00	0.05	0.00	—[a]
	ADI	29	0.71	0.33	0.33	0.72	0.75	0.88	0.00	0.70	0.00	—
	Coleman	20	0.54	1.00	0.00	0.65	0.58	0.50	0.33	0.58	1.00	—
YPG	Geo-Centers	29	0.60	—	0.67	0.77	0.53	0.80	0.40	0.61	—	—
	Metratek	13	0.30	—	0.00	0.50	0.23	0.31	0.14	0.41	—	—
	SRI	0	0.00	—	0.00	0.00	0.00	0.00	0.00	0.00	—	—
Eglin AFB	Coleman	18	0.55	0.00	0.29	0.43	0.68	0.29	—	0.62	0.75	0.56
	Vallon	23	0.74	1.00	0.83	0.43	0.83	0.83	—	0.60	0.67	1.00
Fort Jackson	ADI	24	0.69	1.00	1.00	0.93	0.17	1.00	0.29	0.95	—	—
	Geo-Centers	15	0.45	0.50	0.88	0.54	0.00	1.00	0.08	0.65	—	—
	SRI	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	—	—
McChord AFB	Chemrad	8	0.14	0.22	0.00	0.21	0.00	0.00	0.05	0.18	—	—
	Metratek	36	0.61	0.44	1.00	0.58	0.59	1.00	0.58	0.61	—	—

Note:

[a] Statistic could not be calculated (—).

Figure 6-1
Plot of Demonstrator $P_{D,ord}$ Statistics

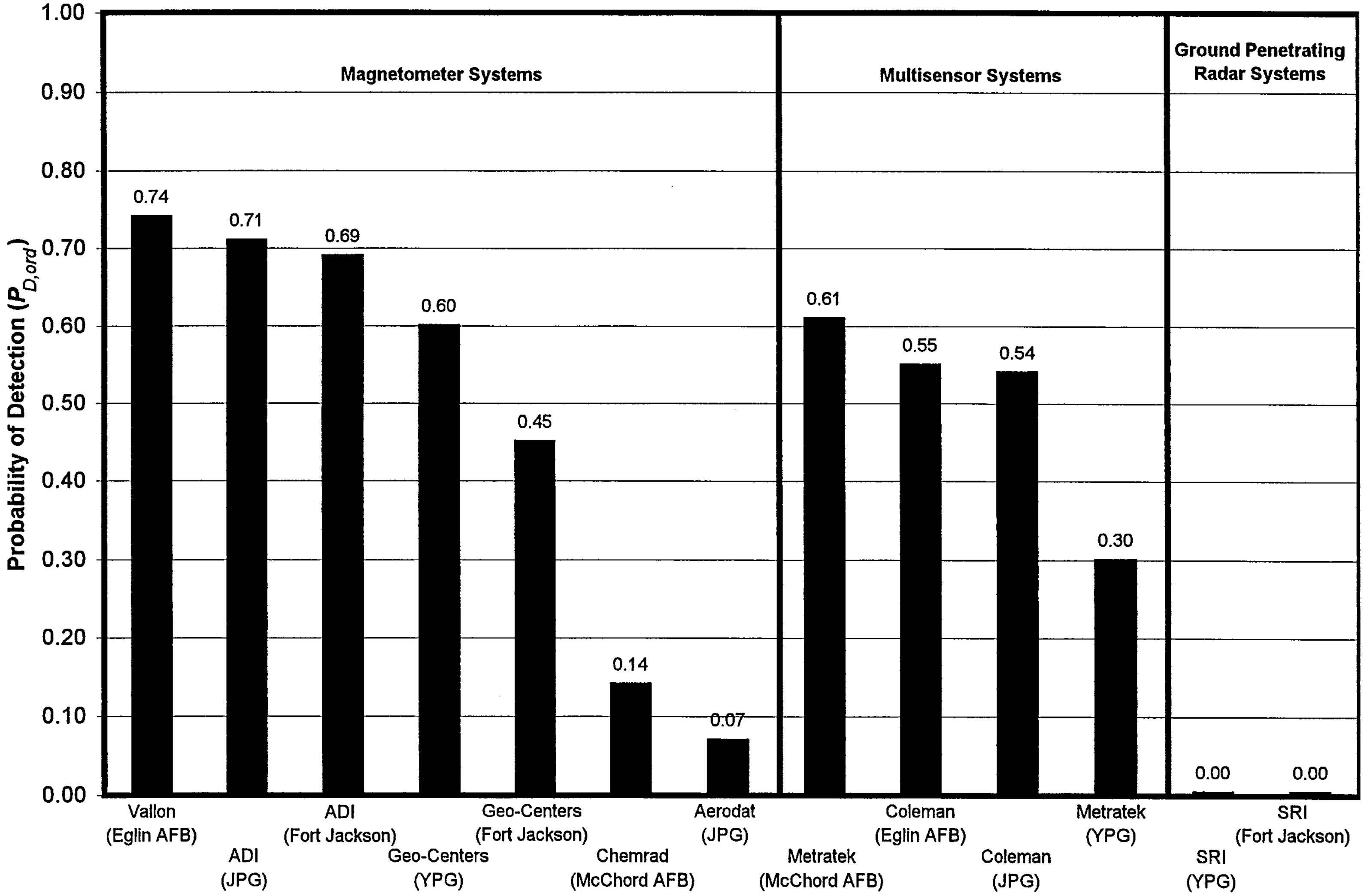


Figure 6-2 compares $P_{D,ord}$ values and P_{random} statistics for the demonstrators. Aerodat, Chemrad, Coleman, and SRI have $P_{D,ord}$ values that are not statistically different (at the 95-percent confidence level) from their P_{random} statistic, indicating that random processes cannot be ruled out as possible causes for these demonstrators detecting the baseline targets. In Figure 6-2, the bold line from the lower left corner to the upper right corner of the graph represents the situation where $P_{D,ord}$ is equal to P_{random}.

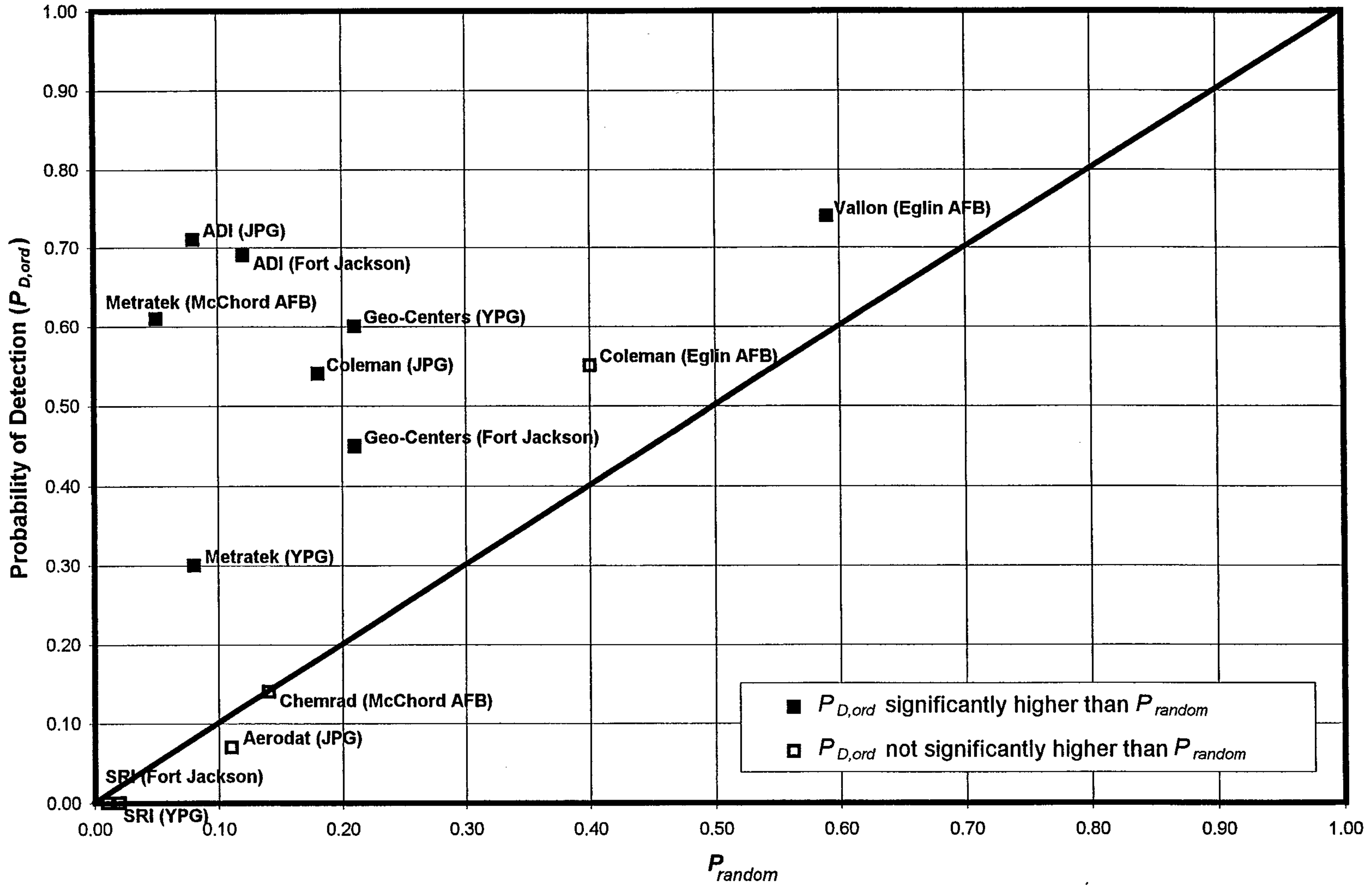
The best possible performance occurs when a demonstrator detects all baseline targets, and the random data set detects no baseline targets (upper left corner). Conversely, the worst possible performance occurs when a demonstrator detects no baseline targets, and a random set of target declarations detects all baseline targets (lower right corner). With respect to $P_{D,ord}$ and P_{random}, demonstrators in the upper left part of the graph performed better than those in the lower right. Demonstrators below or just above the bold line on the figure did not perform significantly differently than a demonstrator declaring targets randomly.

The demonstrators with the highest $P_{D,ord}$ values used magnetometer systems. However, a comparison of $P_{D,ord}$ values between magnetometer and multisensor systems shows that the difference in performance is small, and there is no statistically significant difference (at the 95-percent confidence level) between magnetometer and multisensor systems with respect to $P_{D,ord}$.

If high demonstrator $P_{D,ord}$ values alone are used as a metric for success, SRI's GPR system performed poorly at YPG and Fort Jackson. Aerodat also performed poorly with respect to $P_{D,ord}$ at JPG. The performance of these aerial platform demonstrators indicates that the utility of airborne platforms for subsurface UXO detection remains unproven. Ground platform sensors performed significantly better than aerial platforms with respect to $P_{D,ord}$, with vehicle-towed and man-portable platforms having comparable detection statistics.

Nearly all the demonstrators used differential GPS as a navigational system. However, Chemrad used ultrasonic navigation, ADI used manual navigation, and Vallon used differential GPS with its vehicle-towed unit and manual navigation with its man-portable unit. It is difficult to determine the effect of the navigation system on overall performance, because both navigation and the ability to detect UXO can significantly affect the way a demonstrator's performance is measured.

Figure 6-2
Plot of $P_{D,ord}$ vs. P_{random} by Demonstrator



For example, one demonstrator experienced poor differential GPS lock on its first day of survey at one of the live sites. According to the demonstrator, six baseline targets were detected, but all were declared at distances averaging 17 meters from the actual target location. Because the declarations were outside the 2-meter R_{crit}, the demonstrator was not credited with detecting these targets. Another demonstrator that used differential GPS reported that when GPS lock was lost in forested areas, the demonstrator interpolated data points between each survey line's starting and ending points. For points along each survey line to be plotted accurately under these conditions, the demonstrator would have had to travel through the forested area in a perfectly straight line at a constant rate of travel. It is highly unlikely that both of these criteria could be satisfied.

Notwithstanding these types of occurrences, which likely occurred with other demonstrators as well, several generalizations can be drawn regarding navigation system effects on demonstrator performance. First, the demonstrator using a manual navigation system alone (ADI) had higher $P_{D,ord}$ values than most of the other demonstrators. Second, the only demonstrator using an ultrasonic navigation system (Chemrad) had the lowest $P_{D,ord}$ value of the ground platform demonstrators.

- **Localization Performance:** A demonstrator's ability to localize ordnance is critical to the remediation process. Demonstrators capable of perfectly localizing UXO ensure that excavation systems dig only as much soil as necessary to expose the UXO. Assuming that remediation costs are proportional to the amount of soil excavated to expose a UXO item, it follows that as a demonstrator's localization performance decreases, the cost of remediation increases.

For example, assume that the known three-dimensional position of a UXO item is 2 meters deep in sandy soil. To reach this target, an excavator must dig a hole exactly 2 meters deep. To reach this depth in sandy soils, which typically have a repose angle of about 45 degrees, the hole must have a 2-meter radius at the ground surface. In this case, the quantity of soil excavated would be 8.4 m^3. Next, assume that a demonstrator always has a radial error of 1 meter. To reach the target, the excavator must excavate a hole with a 3-meter radius at the ground surface. The volume of soil excavated would then be 11.5 m^3; the volume increase is proportional to the square of the radial error. If the demonstrator has a constant depth error but no radial error, the volume of soil to be excavated is similarly proportional to the cube of the depth error. The quantity of soil excavated to recover a target declared by a demonstrator with poor localization ability can be quite large when compared to the amount of soil that must be excavated to reach the same target declared by a demonstrator with good localization ability; in practice, the cost of remediating sites based on data with low positional accuracy could quickly become cost-prohibitive.

Table 6-2 summarizes the localization statistics for all demonstrators except SRI. Because SRI did not detect any baseline targets at either of the sites it surveyed, its localization performance could not be assessed.

Figure 6-3 compares the mean radial and mean square depth errors for all demonstrators except Aerodat, Chemrad, and SRI. Data for these demonstrators are not shown because their $P_{D,ord}$ statistics are not significantly different from their P_{random} statistics at the 95-percent confidence level. Demonstrators in the lower left part of the graph in Figure 6-3 performed better than those in the upper right part. With the exception of Aerodat and Chemrad, whose detection ability is not statistically different from random declarations, it appears that magnetometer sensors as a group exhibited greater positional accuracy than the multisensor systems. Magnetometer systems exhibited radial errors of 0.68 to 1.09 meters; multisensor systems had radial errors of 1.13 to 1.30 meters. At the 95-percent confidence level, a statistically significant difference exists in localization performance between the two sensor types; the reason for this difference could not be determined.

However, at the 95-percent confidence level, there is no statistical discrepancy between the mean square depth error for these sensor types. Magnetometers had mean square depth errors of 0.16 to 0.97 meter; multisensor systems had mean square depth errors of 0.43 to 2.27 meters.

There does not appear to be any correlation between localization accuracy and sensor platform. ADI, the only demonstrator using a manual navigation system, located baseline targets within 0.75 meter horizontally, which is less radial error than any other demonstrator. Nevertheless, at the 95-percent confidence level, ADI's radial error is not statistically different from demonstrators using differential GPS for navigation. In addition, no clear differences exist between demonstrator mean square depth error for different navigation systems.

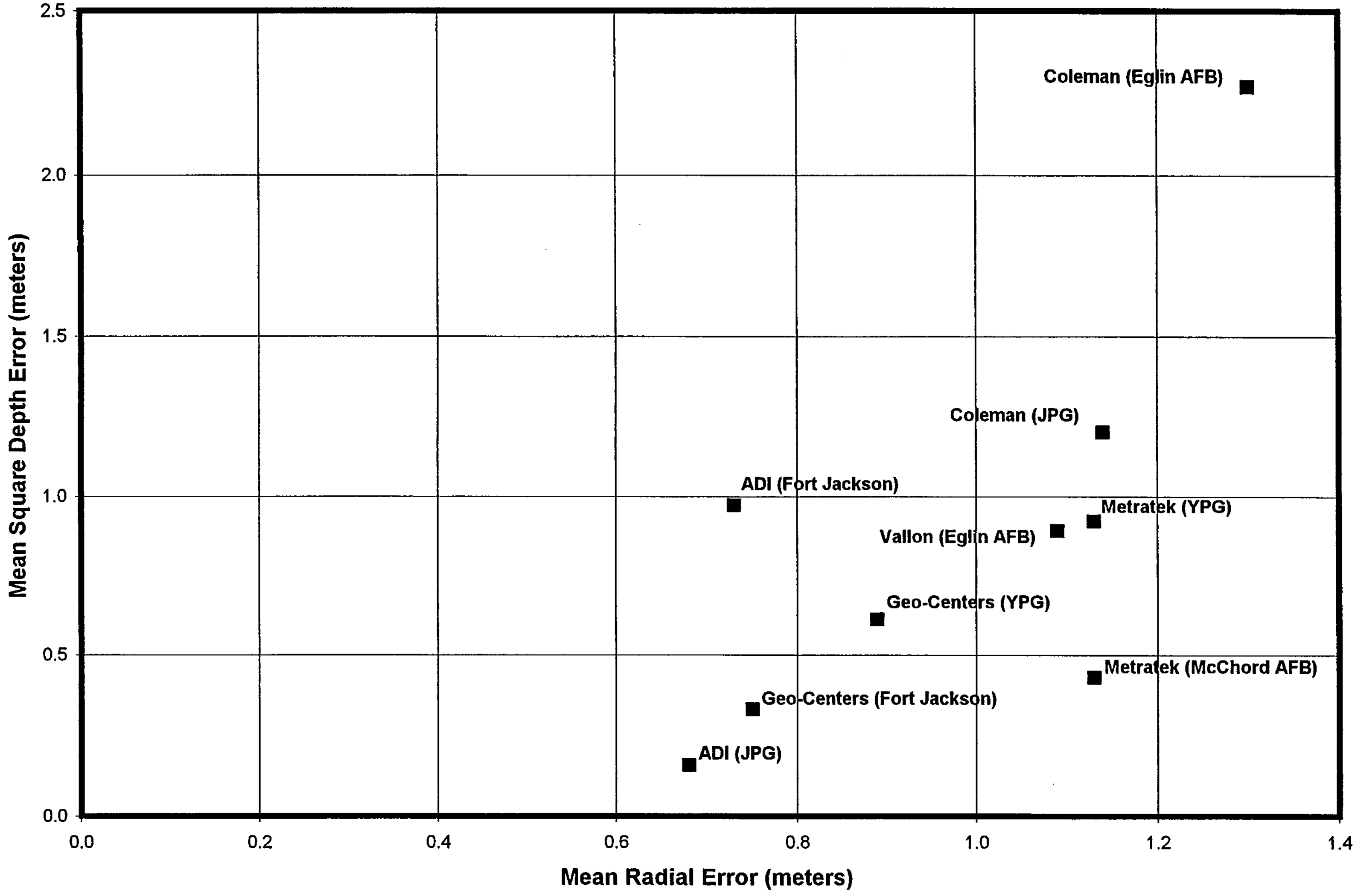
Table 6-2
Summary of Demonstrator Localization Statistics

Site	Demonstrator	Localization Evaluation Parameters (meters)		
		Mean Radial Error	Mean Depth Error	Mean Square Depth Error
JPG	Aerodat	4.25	0.78	0.61
	ADI	0.68	0.08	0.16
	Coleman	1.14	0.31	1.20
YPG	Geo-Centers	0.89	0.20	0.61
	Metratek	1.13	0.69	0.92
	SRI	—[a]	—	—
Eglin AFB	Coleman	1.30	0.14	2.27
	Vallon	1.09	0.09	0.89
Fort Jackson	ADI	0.73	-0.80	0.97
	Geo-Centers	0.75	0.00	0.33
	SRI	—	—	—
McChord AFB	Chemrad	1.22	0.26	0.66
	Metratek	1.13	0.14	0.43

Note:

a Statistic could not be calculated (—).

Figure 6-3
Plot of Demonstrator Localization Statistics



Classification Performance: Demonstrators providing classification information were evaluated based on their ability to determine each baseline target's type (ordnance or nonordnance); size (large, medium, or small); and class (bomb, mortar, projectile, cluster, or other). Classification performance statistics could be evaluated for only four demonstrators: ADI, Coleman, Geo-Centers, and Vallon. The other four demonstrators did not classify their target declarations. Because ADI was the only demonstrator to classify its target declarations by type, type classification was not evaluated.

If a demonstrator detected targets in any of the three size categories or in the class categories of "bomb," "mortar," or "projectile," the demonstrator's P_C values for each size or class category were calculated. P_C values for "cluster" and "submunition" targets were not calculated, because these items were not emplaced at all sites and were rarely detected or correctly classified. Demonstrator classification performance is summarized in Table 6-3.

Figures 6-4 through 6-7 show demonstrator detection and classification capabilities for baseline ordnance of different sizes and classes. If a demonstrator did not detect a particular ordnance size or class, P_C values could not be calculated for the classification. For example, at JPG, ADI did not detect any of the baseline targets classified as "mortar." In these cases, the term "NA" has been placed over the bar columns in the figures to indicate that the demonstrator's P_C value could not be calculated. If the figure does not show a bar column for a particular statistic, the statistic is equal to 0.

Few conclusions can be drawn regarding demonstrator ability to properly classify targets by size or class, partly because the baseline target sets contained relatively few of each target size and class at all of the live sites. Because all the demonstrators that classified target declarations also did not detect between 25 and 50 percent of the baseline targets, the set of baseline targets against which the P_C statistics were calculated was fairly small.

Table 6-3
Summary of Demonstrator Classification Statistics

Site	Demonstrator	Probability of Correctly Classifying (P_C)									
		Target Type		Target Size			Target Class				
		$P_{C,ord}$	$P_{C,nonord}$	$P_{C,large}$	$P_{C,medium}$	$P_{C,small}$	$P_{C,bomb}$	$P_{C,mortar}$	$P_{C,projo}$	$P_{C,cluster}$	$P_{C,submun}$
JPG	Aerodat	1.00	—[a]	—	0.00	0.00	0.00	—	0.00	—	—
	ADI	0.97	0.00	0.00	0.62	0.33	0.00	—	0.57	—	—
	Coleman	1.00	0.00	—	0.45	0.89	0.00	0.00	0.91	0.00	—
YPG	Geo-Centers	1.00	—	0.50	0.40	0.41	0.42	0.00	0.91	—	—
	Metratek	1.00	—	—	0.00	0.00	0.00	0.00	0.00	—	—
	SRI	—	—	—	—	—	—	—	—	—	—
Eglin AFB	Coleman	1.00	—	0.00	0.67	0.62	0.00	—	1.00	0.00	0.00
	Vallon	1.00	0.00	0.60	0.33	0.67	0.60	—	0.67	0.00	0.00
Fort Jackson	ADI	0.92	0.00	0.25	0.57	1.00	1.00	0.25	0.67	—	—
	Geo-Centers	1.00	0.00	0.29	0.14	—	0.50	0.00	0.64	—	—
	SRI	—	—	—	—	—	—	—	—	—	—
McChord AFB	Chemrad	1.00	0.00	—	0.00	0.00	—	0.00	0.00	—	—
	Metratek	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	—	—

Note:

[a] Statistic could not be calculated (—).

Figure 6-4
Plot of Demonstrator Detection Statistics by Baseline Ordnance Size

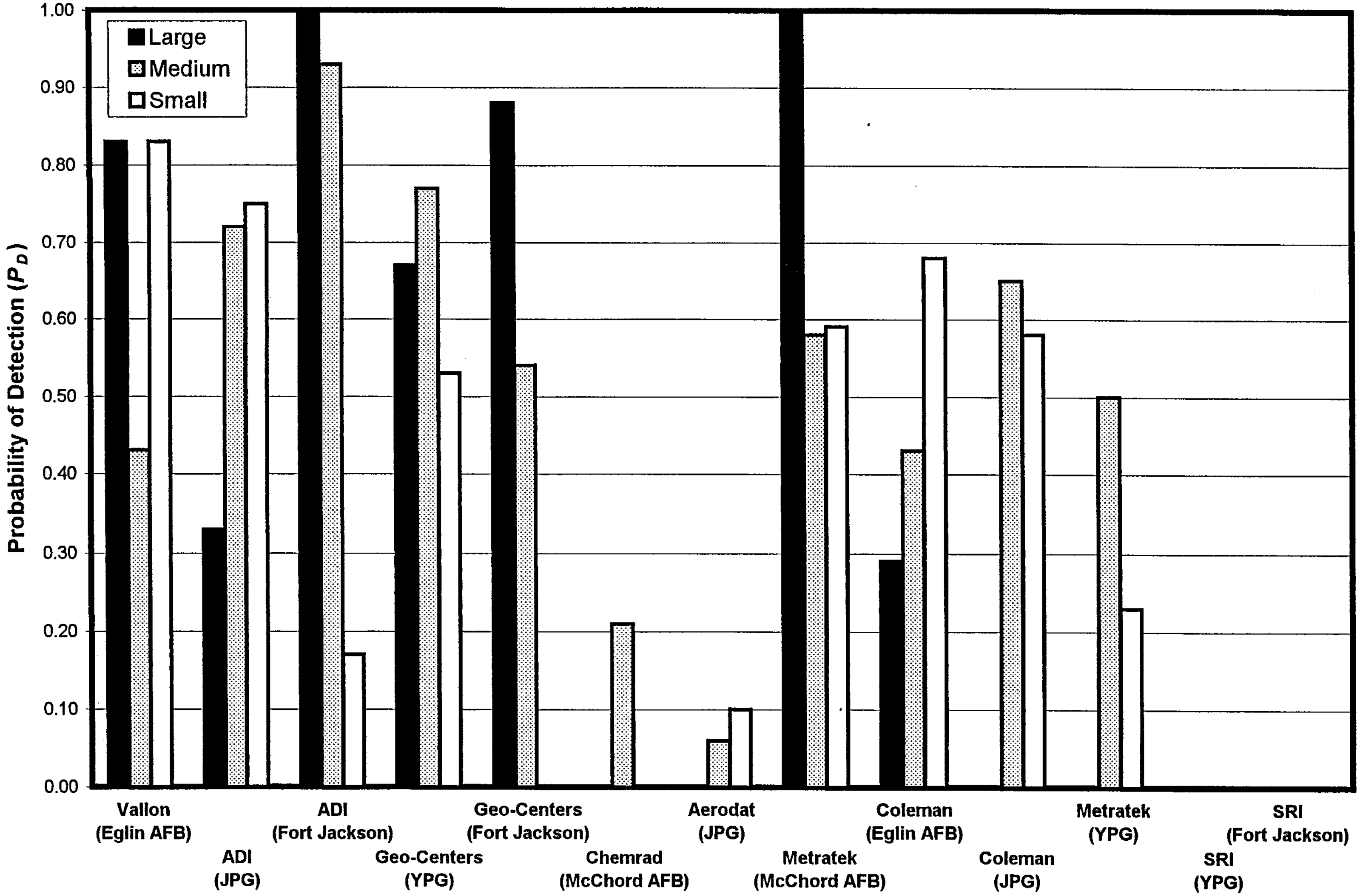


Figure 6-5
Plot of Demonstrator Classification Statistics by Baseline Ordnance Size

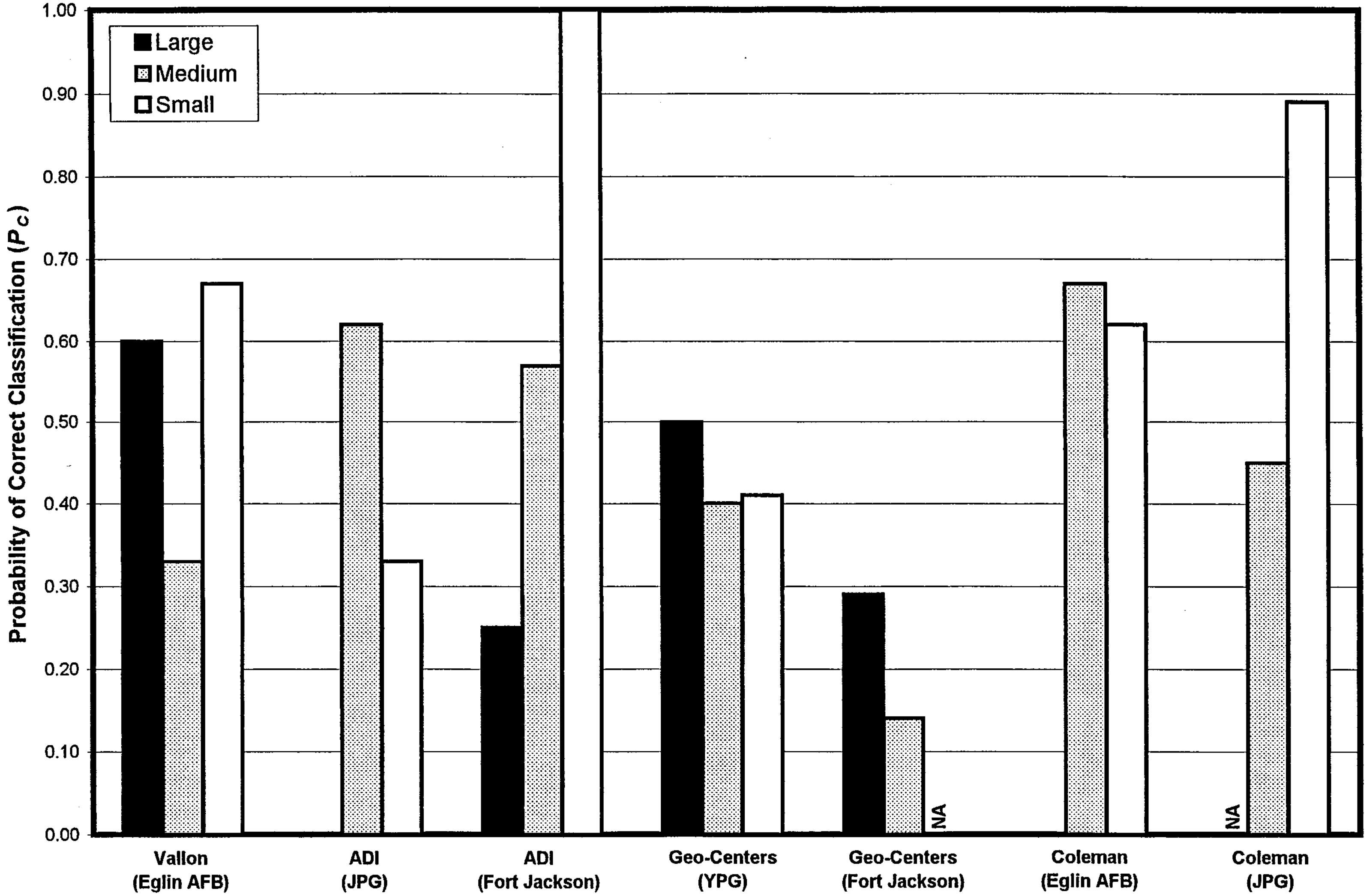


Figure 6-6
Plot of Demonstrator Detection Statistics by Baseline Ordnance Class

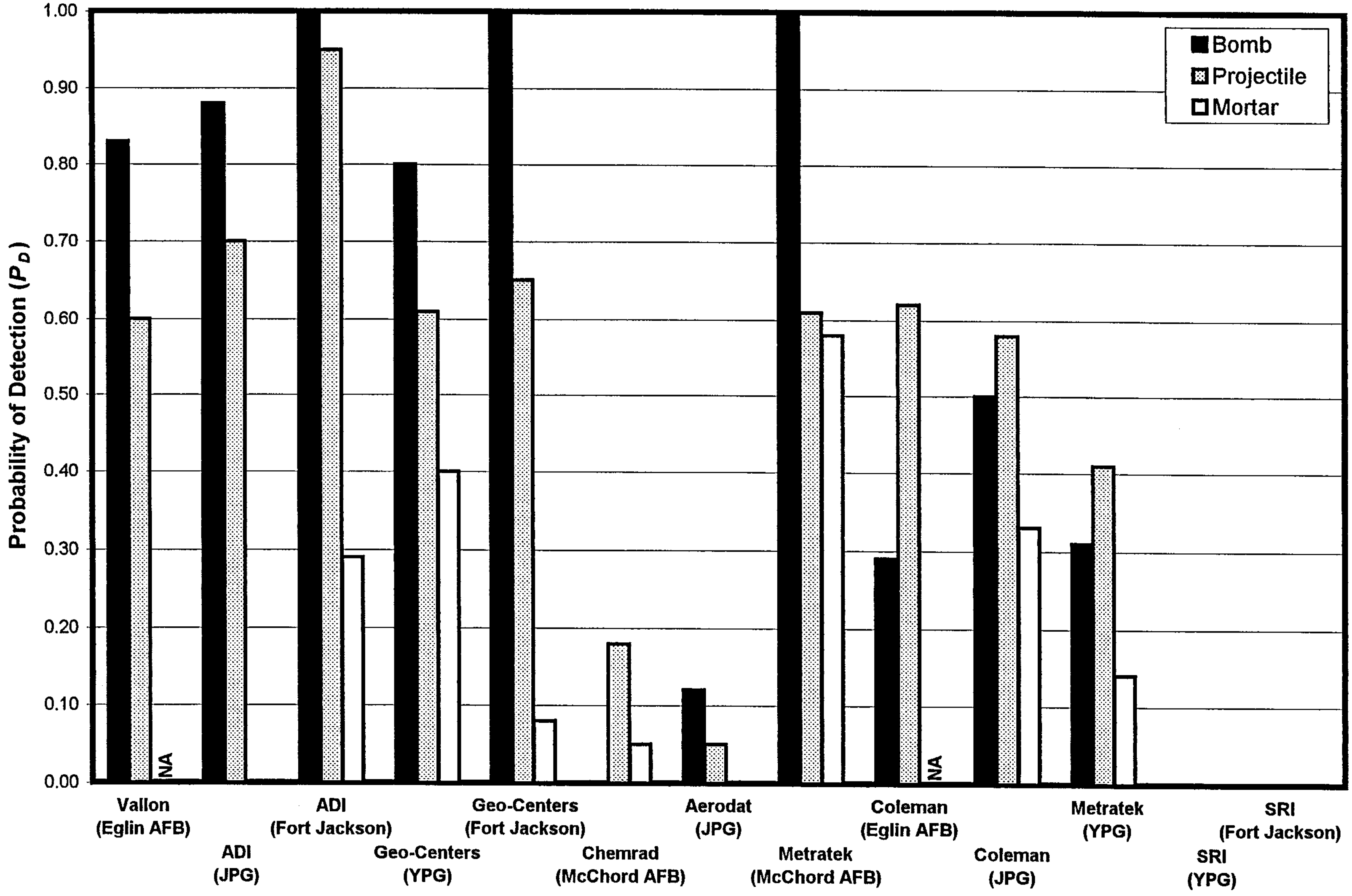
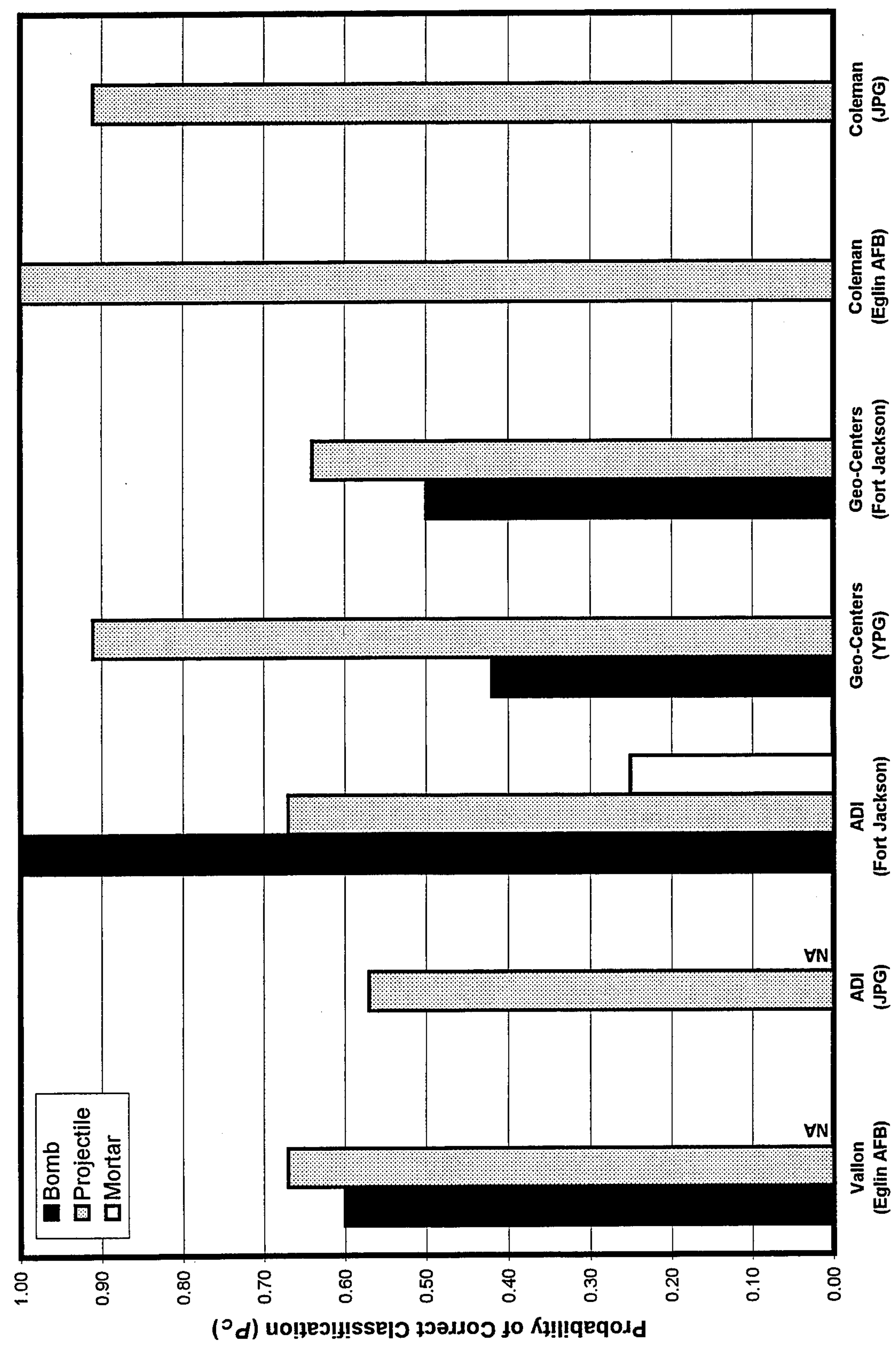


Figure 6-7
Plot of Demonstrator Classification Statistics by Baseline Ordnance Class



6.1.2 Remediation Systems

The remediation systems were all able to excavate and recover targets effectively. Table 6-4 summarizes excavation rates. The systems used at YPG and McChord AFB were backhoes with relatively small buckets (less than 0.2 m^3 capacity); the other two systems were full-scale excavators with relatively large buckets (more than 0.5 m^3 capacity). Only the system used at McChord AFB employed conventional off-the-shelf construction equipment; the other three had been modified by adding controls for remote operation. Only the USAF/WL system used at JPG and Fort Jackson had remote navigational ability.

Table 6-4
Remediation System Excavation Rates

Excavator	Site	Excavation rate (holes/day)		
		Theoretical[a] (travel included)	Theoretical[a] (travel excluded)	Actual
USAF/WL	JPG	20	16	4.1
	Fort Jackson	17	15	5.4
YPG ETO	YPG	3.4	2.5	2.3
USAF 96th EOD	Eglin AFB	16	14	6.3
USAF 62nd EOD	McChord AFB	14	13	3.0

Note:

a Theoretical excavation rates are calculated using actual dig times and travel time between excavation locations.

Actual excavation rates were affected considerably by the requirements of the ATD project, because the project required that care be taken to identify all anomalies observed in the excavation, including nonordnance items. Therefore, the discussion below is limited to the theoretical excavation rates provided in the table. Because only four remediation systems were used to conduct the validation activities, the discussion is intended to be general.

As expected, the two remotely operated excavators with large buckets were able to excavate holes at a much higher rate than the remotely operated backhoe with a small bucket. The two autonomous excavators were comparable in excavation rate, regardless of the excavator's ability to navigate to excavation sites remotely. The conventional backhoe equipment used at McChord AFB had a small bucket capacity, but its excavation rate was similar to remotely operated excavators. Conventional excavators with bucket capacities in excess of 0.5 m^3 may be even faster than remotely operated systems, but no such system was used during the live site ATD. In any case, the trade-off between excavation rate and risk to equipment operators must be considered. Risk is minimized by using systems with remote capabilities.

6.2 OPERATIONAL SUMMARY

The evaluation of technologies demonstrated at the live sites would not be complete without a description of the operational constraints of the systems. The various demonstrators all expressed different needs to the Government support team. In many cases, these needs had to be met for the demonstrator to complete its survey.

Limited on-site support was provided to all demonstrators. Storage areas, shade tents, portable toilets, office space, telephone lines (or cellular telephones), and computers were provided. Most demonstrators used the storage areas, shade tents, and portable toilets. Some demonstrators also used the office space provided, although their use of the office space depended on the distance from the office to the site. Office space at JPG, YPG, Fort Jackson, and McChord AFB was located several kilometers from the sites. Most demonstrators used their own computers for data analysis, which was typically performed in hotel rooms, portable field offices, or demonstrator vehicles.

Several demonstrators experienced equipment breakdowns that required repairs. Repairs were typically performed on site by the demonstration team, although local, off-site assistance was occasionally needed to complete the repairs. Several times during the demonstrations, tow or personnel transport vehicles got stuck in rutted areas. In these instances, the vehicles were freed by demonstrator personnel in the field and did not require the services of a tow truck or other heavy equipment.

Each site surveyed by the demonstrators posed its own unique problems. Site layout, topography, and forested areas created difficulties for the vehicle-towed systems. In cases where difficult terrain was encountered, man-portable systems fared the best because they were able to enter areas of shallow standing water, muddy areas, forested areas, rutted areas, and ravines and ditches. Man-portable systems were also better able to manage the difficulties posed by impact craters, particularly at JPG's Range 18000W (Birdfoot), which contained numerous craters up to 1 meter across and 0.5 meter deep. Multimodal systems were able to cope with these difficulties as well, especially when man-portable systems were employed in areas not accessible to vehicle-towed systems.

Aerial systems covered large areas quickly, regardless of the ground cover, but they also experienced difficulties with forested areas. Aerodat could not fly at its optimal survey altitude at JPG's Range 18000W (Aerial), and its magnetometer system could not penetrate the forested areas. Power lines near the JPG ranges also posed access problems for Aerodat. SRI also experienced problems, particularly at Fort Jackson's Ranges 12B and 12F, because of the heavy forest canopy. SRI's GPR system could not penetrate the canopy to locate UXO beneath the trees.

Forested areas also caused differential GPS systems to lose their satellite lock. At Fort Jackson, Geo-Centers had to estimate sensor position in forested areas because satellite lock was lost. Other demonstrators experienced similar difficulties when their systems neared forested areas. However, because Chemrad's ultrasonic system and ADI's manual system did not rely on GPS satellites, these navigation systems did not experience this type of problem. Chemrad occasionally had to set up several extra SRs to ensure that the USRADS® system could track the sensor over the entire site, particularly where hilly areas or trees interrupted clear line-of-sight between the SRs and the sensor.

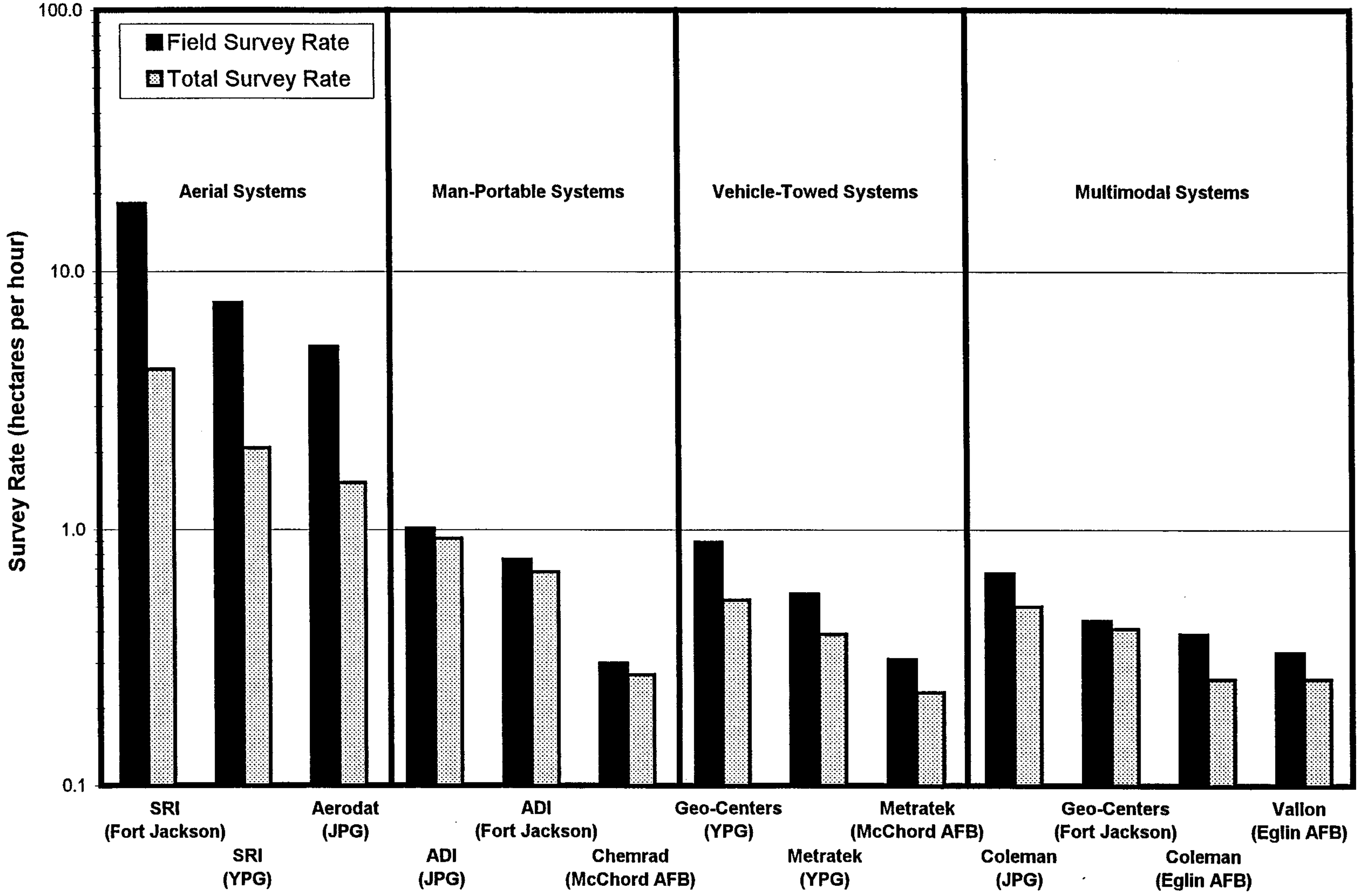
Two types of demonstrator survey rates were measured: the field survey rate and the total survey rate. As discussed in Section 4.0, the field survey rate is calculated by dividing the area surveyed by the amount of time demonstrator personnel physically conducted the survey. The total survey rate is calculated by dividing the area surveyed by the time that demonstrator personnel conducted the survey, set up equipment, and experienced downtime. The total survey rate is representative of the survey rates that would be expected at relatively small sites that could be surveyed in a few weeks. As the size of the survey site increases, the field survey rate is more representative of a demonstrator's capabilities.

As shown in Table 6-5 and Figure 6-8, aerial platforms had higher survey rates than ground platforms, as expected. However, survey rates for the different ground platforms were comparable. This result is somewhat surprising; vehicle-towed systems were expected to conduct surveys more quickly than man-portable systems and therefore have higher field survey rates, but this was not the case.

Table 6-5
Demonstrator Survey Time and Cost

Demonstrator	Site	Area Surveyed (hectares)	Field Survey Time (hours)	Field Survey Rate (hectares/hour)	Total Survey Time (hours)	Total Survey Rate (hectares/hour)	Cost ($)	Cost per Unit Area Surveyed ($/hectare)
Aerial Systems								
SRI	Fort Jackson	109.2	6	18.20	26	4.20	195,073	1,786
SRI	YPG	45.5	6	7.58	22	2.07	147,889	3,250
Aerodat	JPG	123.3	24	5.14	81	1.52	130,628	1,059
Man-Portable Systems								
ADI	JPG	64.5	64	1.01	70	0.92	137,861	2,137
ADI	Fort Jackson	60.5	80	0.76	89	0.68	138,519	2,290
Chemrad	McChord AFB	24.0	80	0.30	88	0.27	245,023	10,209
Vehicle-Towed Systems								
Geo-Centers	YPG	39.2	44	0.89	74	0.53	154,840	3,950
Metratek	YPG	33.9	61	0.56	86	0.39	206,258	6,084
Metratek	McChord AFB	20.4	66	0.31	89	0.23	217,323	10,653
Multimodal Systems								
Coleman	JPG	63.9	95	0.67	129	0.50	234,583	3,671
Geo-Centers	Fort Jackson	30.2	69	0.44	97	0.31	158,694	5,255
Coleman	Eglin AFB	29.2	74	0.39	112	0.26	179,688	6,154
Vallon	Eglin AFB	26.4	80	0.33	101	0.26	149,650	5,669

Figure 6-8
Demonstrator Survey Rates



Considering only the ground platform demonstrators, there was no statistical difference (at the 95-percent confidence level) between field survey rates for man-portable, vehicle-towed, and multimodal platforms. Two of the three highest field survey rates by a ground platform were achieved by ADI's man-portable system; this system also achieved the top two total survey rates by a ground platform system. It is not clear why the vehicle-towed systems did not conduct surveys more quickly than the man-portable systems, although several of the vehicle-towed systems had to survey areas several times because of poor data recovery.

Cost is an important operational metric related to the survey rate. Figure 6-9 shows demonstrator survey cost as a function of the area surveyed. The figure shows an important trend: an economy of scale appears to be realized as the site size increases. In other words, as the area surveyed by the live site demonstrators increases, the cost per hectare surveyed decreases. The bold curve on Figure 6-9 illustrates this point.

Figure 6-10 shows each demonstrator's performance at the Phase I controlled site and live sites. It appears that most demonstrators improved their detection performance since they participated in the 1994 Phase I controlled site trials. However, the changes in scores are not significant at the 95-percent confidence level for most demonstrators. The apparent improvements in performance may be because of several factors. First, many of the demonstrators gained experience in the UXO detection field in the year that elapsed between the Phase I controlled site ATD and the live site ATDs. This experience was gained by field operators and data analysts, and it was probably beneficial to the demonstration teams.

Second, site layout may have caused the differences in detection ability. The live site baseline UXO targets were probably not as difficult to detect as the controlled site baseline targets. Live site baseline targets were generally not placed in clusters, and relatively few baseline targets were placed in close proximity to each other. This was not the case at the controlled site, where many of the baseline UXO targets were emplaced within several meters of each other (IDA 1995; USAEC 1994, 1995, 1996).

Third, site-specific environmental conditions may have played a role in these apparent improvements in performance, although the role of such conditions in increased detection capability is unclear. With respect to climate, all of the sites except McChord AFB occasionally experienced extremely hot conditions. Except YPG, all of the hot sites also had humid weather during the demonstration periods. On the other hand, McChord AFB had chilly, damp weather.

Figure 6-9
Demonstrator Survey Cost per Hectare

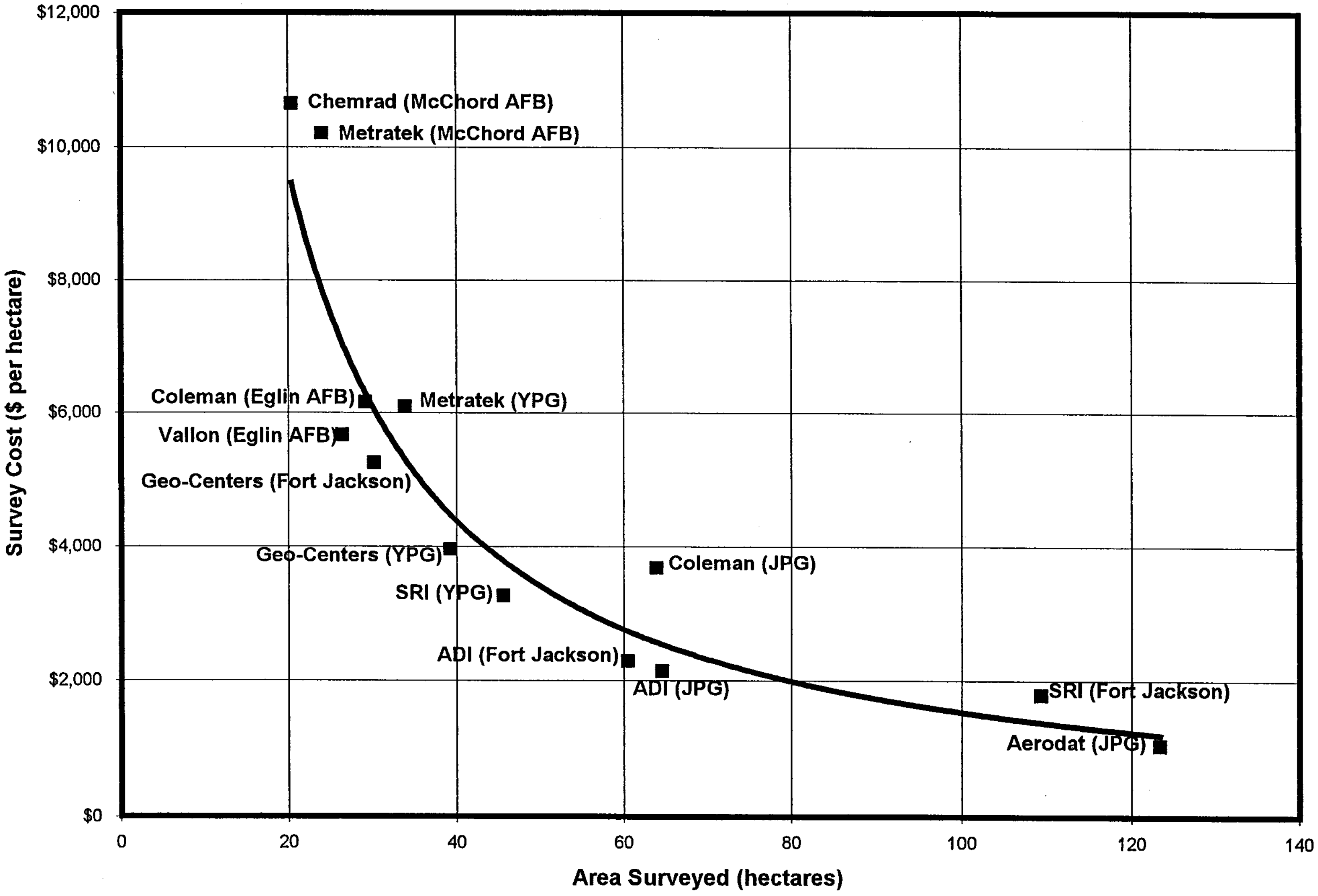
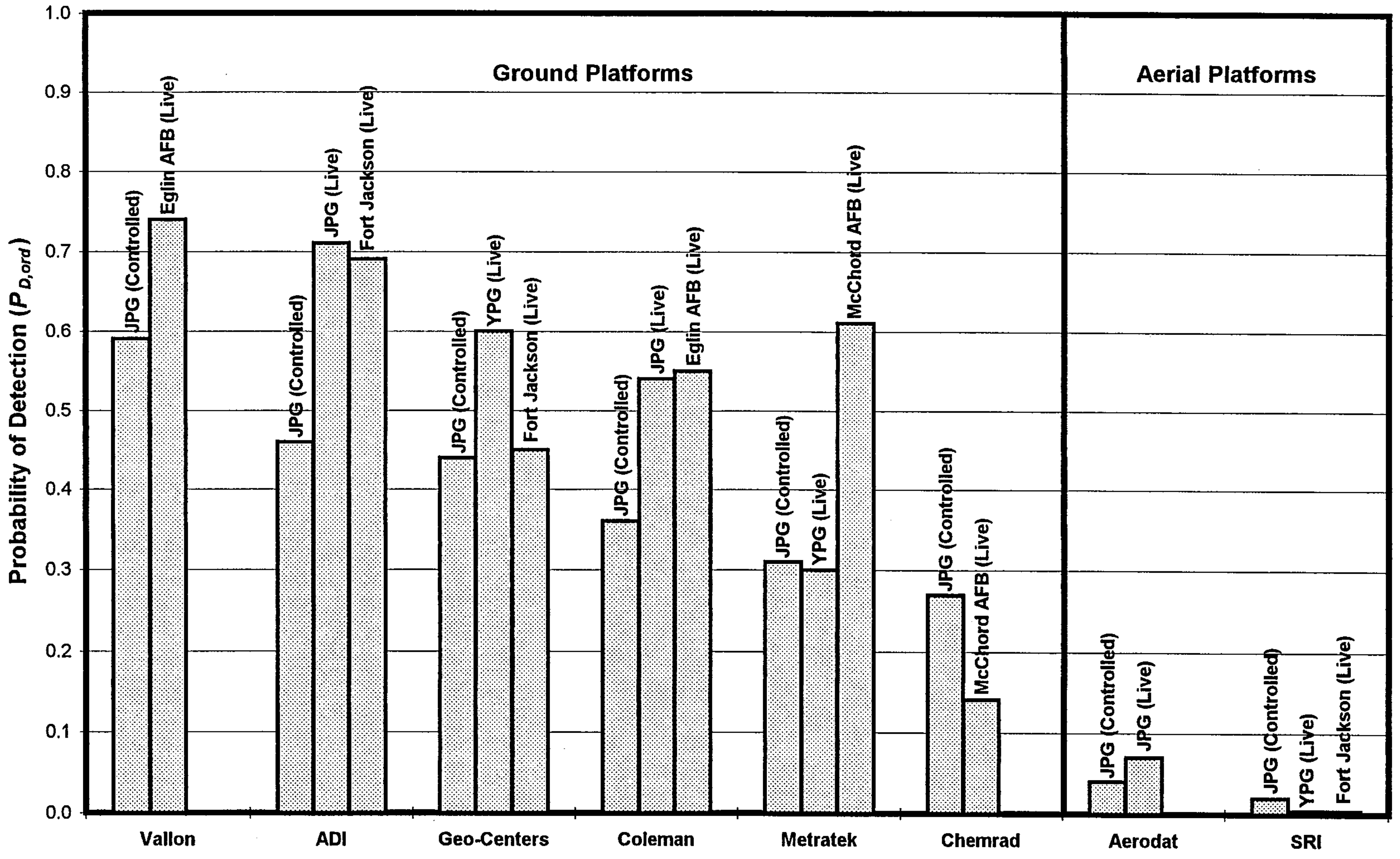


Figure 6-10
Demonstrator Performance History



Because the Phase I controlled site demonstrations were conducted in hot, humid weather during the summer of 1994, it was not expected that heat would play a significant factor in demonstrator $P_{D,ord}$ improvements. The cold weather apparently did not affect the demonstrators at McChord AFB consistently; Metratek's $P_{D,ord}$ nearly doubled from the Phase I controlled site ATD, but Chemrad's nearly halved.

There was also no clear relationship shown between detection capability and geology. The GPR and multisensor systems were expected to have higher $P_{D,ord}$ values at sites with nonclay soils. However, SRI's GPR performance at both live sites did not improve from the Phase I controlled site ATD, even though both of SRI's assigned live sites had sandy soils.

Coleman and Metratek both operated multisensor systems at the live sites. Coleman's $P_{D,ord}$ increased more than 50 percent from the clay soils at the Phase I controlled site to similar clay soils at the JPG live site. Coleman's detection ability at the Eglin AFB live site was also higher than at the Phase I controlled site, but it was slightly less than at the JPG live site, which may indicate that site geology did not affect Coleman as much as other factors. On the other hand, Metratek's results at the YPG live site were similar to its results at the Phase I controlled site. Metratek was expected to have a higher $P_{D,ord}$ at YPG because of the sandy soils there; however, this was not the case, possibly because of data errors (see Section 5.1.6). Metratek's $P_{D,ord}$ increased nearly 100 percent from the Phase I controlled site to the McChord AFB live site, which may be attributable in part to the site's gravel geology. However, the increase is most likely attributable to Metratek discovering an error in its data processing algorithms before the McChord AFB live site survey (Metratek 1995b, 1996a).

There is considerable debate in the sensor community about the effectiveness of various sensors in different soil types. Based on the live site ATD results, it appears that while this debate may apply to experiments conducted in controlled test beds and experimental site layouts, it clearly does not apply to sites containing significant quantities of ordnance, ordnance debris, and other man-made materials. It appears that the differences in $P_{D,ord}$ values are primarily related to increases in the level of demonstrator experience.

7.0 CONCLUSIONS

The live site ATDs have allowed the Government to address a number of important issues related to the detection and identification of UXO in environments typical of sites where UXO clearance work is or will be required. Key issues include the following:

- The results of the live site ATDs show that current technology does not meet the Government's need for effective and reliable detection of subsurface UXO. Although some demonstrators showed slightly better detection capabilities at the live site ATDs than at the Phase I controlled site ATD, their capabilities were statistically comparable.
- Aerial systems exhibit the potential to survey very large areas quickly, efficiently, and safely, but they are not yet able to detect subsurface UXO with consistency or accuracy.
- Some demonstrators were able to detect a majority of the targets recovered during the validation. However, validation activities revealed that other demonstrators declared false targets and failed to detect some of the UXO detected by other systems.
- Current technology has not demonstrated the ability to discriminate between UXO and non-UXO items such as ordnance fragmentation and other debris; only one demonstrator attempted to discriminate targets by type. As the validation showed, many non-UXO items are found at typical live ranges. Furthermore, the demonstrated technologies did not exhibit the ability to classify UXO targets by target size and class. Of the eight demonstrators evaluated at the live sites, only four attempted to classify UXO targets, and these four did so with only partial success.
- The effects of soil type, ground clutter, and other environmental conditions on system performance have not been fully characterized.
- The survey speeds of man-portable, vehicle-towed, and multimodal systems were comparable.
- The demonstrators had varying logistics and resource requirements. Aerial platform demonstrators experienced more logistics problems than ground platform demonstrators, usually because of conflicting missions at nearby ranges. Most demonstrators did not require Government-provided resources to complete their surveys.
- Although current UXO remediation technologies offer more safety to heavy equipment operators and other field personnel because of their remote control capabilities, they are slow, inefficient, and expensive.

The live site ATD project was crucial to acquiring a better understanding of how UXO clearance technologies perform when they are taken out of a controlled test environment and placed under conditions more closely approximating a site clearance project. Improvements are still needed in detection and classification ability, but the lessons learned from the live site ATD project can nevertheless be applied to future efforts, with the following recommendations:

- P_D values need to be increased. Of 13 ATDs, only five had $P_{D,ord}$ values of 0.60 or more. In general, demonstrator performance at the live sites was not statistically different (at the 95-percent confidence level) from demonstrator performance at the JPG Phase I controlled site.

- Classification ability also needs to be improved. Only one of the eight demonstrators discriminated between ordnance and nonordnance. This ability is critical to reducing the costs of site cleanup, because as false alarms decrease, the number of holes that must be dug to recover potential targets decreases as well. Four demonstrators classified UXO targets by size and class with some degree of success. These systems show promise, and further research and development of these technologies and associated data processing algorithms will result in better classification capability.

- Aerial systems must be improved drastically. The two aerial platform demonstrators that participated in the live site ATDs used different sensor types and conducted the surveys under optimum conditions. Neither system reliably detected subsurface UXO, which is consistent with the findings of the Phase I controlled site ATDs. However, aerial systems exhibit the potential to survey large areas quickly, efficiently, and safely.

- The benefits of surveying a site using complementary man-portable and vehicle-towed systems should be evaluated. Man-portable systems had survey rates as high as the vehicle-towed systems, with lower survey costs per unit area. In addition, man-portable systems are less prone to breakdown and can be used to survey areas that are difficult to access by the vehicle-towed systems. However, vehicle-towed systems allow for real-time data analysis with on-board computers. In addition, vehicle-towed systems provide more safety to the survey team than man-portable systems, protecting them from the elements as well as distancing them from UXO on the ground.

- A correlation between sensor performance, site soils, and other environmental conditions was not readily observed at the live sites. The effects of soils, ground clutter, and other environmental conditions on sensor performance should be quantified through further testing.

- To meet the Government's needs for UXO remediation technologies, improvements in target acquisition speed and excavation efficiency as well as a reduction in technology costs must be realized.

The live site ATD project provided a unique opportunity to evaluate several sensor systems under varying environments and conditions. The results presented in this report are certainly demonstrator- and site-specific; nevertheless, the data are useful at a basic, general level.

The UXO technology research and development community can use data from the live site ATDs to identify trends in sensor and system performance under realistic conditions. Government and industrial entities responsible for lands containing UXO can use the data to allocate resources to develop better systems for UXO site characterization. Government installation restoration managers can also use the data as an independent source of information to help identify potentially appropriate and cost-effective technologies for UXO detection and classification. Data from the live site ATDs can help focus future research and development on techniques that can be applied to make UXO site clearance safe, efficient, quick, and cost-effective.

This Page Intentionally Left Blank

REFERENCES

Aerodat, Inc. (Aerodat). 1995a. Text file (*READ.ME*) accompanying data deliverable for live site advanced technology demonstration (ATD) at U.S. Army Jefferson Proving Ground (JPG), Indiana. June 22.

Aerodat. 1995b. Text file (*READ.ME*) accompanying data deliverable for live site ATD at JPG, Indiana. June 30.

Aerodat. 1995c. "Report on a Live Site Advanced Technology Demonstration Program, U.S. Army Jefferson Proving Ground, Indiana." August 23.

Air Force Development Test Center (AFDTC). 1991. *AFDTC Technical Facilities, Vol II, Land Test Areas.* Eglin Air Force Base, Florida.

Australian Defence Industries, Pty. Ltd. (ADI). 1995a. "Final Report, Live Site Unexploded Ordnance Technology Demonstration Program, Jefferson Proving Ground (Indiana)." July 12.

ADI. 1995b. "Final Report, Live Site Unexploded Ordnance Detection and Identification Advanced Technology Demonstration, Fort Jackson (South Carolina)." October 27.

Clark, Murlene W. and Walter Schmidt. 1982. *Shallow Stratigraphy of Okaloosa County and Vicinity, Florida.* Florida Department of Natural Resources. Tallahassee, Florida.

Coleman Research Corporation (Coleman). 1995a. "Live Site Unexploded Ordnance Detection and Identification at the Jefferson Proving Ground." July 5.

Coleman. 1995b. "Phase II Detection, Identification, and Remediation Advanced Technology Demonstration at the Eglin Air Force Base, Demonstration Results Report." September 15.

Chemrad Tennessee Corporation (Chemrad). 1995. "Final Report for the Live Site Unexploded Ordnance Detection and Identification Advanced Technology Demonstration, McChord Air Force Base." December 4.

Feller, William. 1968. "An Introduction to Probability Theory and Its Application." Volume I. Wiley Interscience. New York City, New York.

Geo-Centers, Inc. (Geo-Centers). 1995a. "UXO Detection and Identification Advanced Technology Demonstration at U.S. Army Yuma Proving Ground, Arizona." August.

Geo-Centers. 1995b. "UXO Detection and Identification Advanced Technology Demonstration at U.S. Army Fort Jackson Military Reservation, South Carolina." October.

Gray, Henry H. 1972. *Geologic Map of the 1 x 2 Degree Louisville Quadrangle, Indiana, Showing Bedrock and Unconsolidated Deposits*. Indiana Department of Natural Resources.

Higginbotham and Associates. 1978. *Installation Environmental Impact Assessment For the United States Army Yuma Proving Ground.* October.

Institute for Defense Analysis (IDA). 1995. "Demonstrator Performance at the Unexploded Ordnance Advanced Technology Demonstration at Jefferson Proving Ground (Phase I) and Implications for UXO Clearance." IDA Paper P-3114. October.

Mason & Hanger-Silas Mason Co., Inc. (Mason & Hanger); Battelle Memorial Institute; and Automated Research Services, Ltd. 1992. "Draft Report - Cleanup and Reuse Options, U.S. Army Jefferson Proving Ground." April 30.

Metratek, Inc. (Metratek). 1995a. "Survey Data Analysis Report for UXO Advanced Technology Demonstration at Yuma Proving Ground." October 15.

Metratek. 1995b. Letter Regarding Resubmittal of Yuma Proving Ground Live Site Test Data. From Ed Stapel, Program Manager, Metratek. To Ken Valder, Live Site Task Manager, PRC EMI. December 7.

Metratek. 1995c. "Survey Data Analysis Report for UXO Advanced Technology Demonstration at McChord Air Force Base." December 22.

Metratek. 1996a. Letter Regarding Resubmittal of Yuma Proving Ground Live Site Test Data. From Ed Stapel, Program Manager, Metratek. To Ken Valder, Live Site Task Manager, PRC EMI. March 1.

Metratek. 1996b. Letter Regarding Errors Associated with Post-Processing of Yuma Proving Ground Live Site Test Data. From Ed Stapel, Program Manager, Metratek. To Ken Valder, Live Site Task Manager, PRC EMI. May 8.

Nutting, H.C. Company (Nutting). 1995a. Soil Classification Test Data. PRC EMI Job No. 075-001342JPG. Internal Work Order 15011.001.

Nutting. 1995b. Soil Classification Test Data. PRC EMI Job No. 075-001342EGLN. Internal Work Order 15011.001.

PRC Environmental Management, Inc. (PRC). 1995a. "Site Operations Plan for the Live Site Advanced Technology Demonstration at Jefferson Proving Ground, Indiana." May 11.

PRC. 1995b. "Site Operations Plan for the Live Site Advanced Technology Demonstration at the U.S. Army Yuma Proving Ground, Arizona." June 20.

PRC. 1995c. "Site Operations Plan for the Live Site Advanced Technology Demonstration at Eglin Air Force Base, Florida." July 10.

PRC. 1995d. "Site Operations Plan for the Live Site Advanced Technology Demonstration at U.S. Army Fort Jackson Military Reservation, South Carolina." August 22.

PRC. 1995e. "Site Operations Plan for the Live Site Advanced Technology Demonstration at McChord Air Force Base, Washington." September 29.

Scott, Tom. 1993. *Geologic Map of Okaloosa County, Florida.* Florida Department of Natural Resources. Tallahassee, Florida.

SRI International, Inc. (SRI). 1995a. "Unexploded Ordnance Detection and Identification – Live Site Advanced Technology Demonstration Program, Yuma Proving Ground, Arizona." August 24.

SRI. 1995b. "Unexploded Ordnance Detection and Identification – Live Site Advanced Technology Demonstration Program, Ft. Jackson, South Carolina." October 17.

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

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

USAEC. 1996. "Unexploded Ordnance Advanced Technology Demonstration Program at Jefferson Proving Ground (Phase II)." Report No. SFIM-AEC-ET-CR-96170. June.

U.S. Department of Agriculture (USDA). 1982. *Soil Survey of Jefferson County, Indiana.* Washington, DC.

USDA. 1989. *Soil Survey of Walton County, Florida.* Washington, DC.

USDA. 1991. *Soil Survey of Yuma Proving Ground, Arizona.* Washington, DC.

U.S. Department of Defense (DoD). 1994. "Tri-Service Environmental Research, Development, Test, and Evaluation Strategic Plan." January.

U.S. Geological Survey (USGS). 1974. *Geohydrology of the Yuma Area, Arizona and California.* Geological Survey Professional Paper 486-H. December.

USGS. 1986. *7.5-Minute Series Topographic Maps of Red Hill, Red Hill Northeast, Red Hill Southwest, and Middle Mountains North, Arizona.* Washington, D.C.

U.S. House of Representatives (USHR). 1992. House Resolution (HR) 5504. 102nd Congress, 2nd Session. July 21 (legislative day, July 20).

Vallon GmbH (Vallon). 1995. "Technical Report - Study/Services, Live Site Advanced Technology Demonstration Program, Eglin Air Force Base, Florida." September 10.

Water Information Center, Inc. (WIC). 1974a. "Climates of the States." Volume 1. Port Washington, New York.

WIC. 1974b. "Climates of the States." Volume 2. Port Washington, New York.

This Page Intentionally Left Blank

GLOSSARY

Abbreviations and Acronyms

ADI	Australian Defence Industries, Pty. Ltd.
Aerodat	Aerodat, Inc.
AFDTC	Air Force Development Test Center
AFB	Air Force Base
ANG	Air National Guard
AOE	autonomously-operated excavator
ARNG	Army National Guard
ARS	Automation Research Systems, Ltd.
ATD	advanced technology demonstration
ATV	all-terrain vehicle
Chemrad	Chemrad Tennessee Corporation
Coleman	Coleman Research Corporation
DoD	U.S. Department of Defense
EM	electromagnetic induction
EMT	emergency medical technician
EOD	explosive ordnance disposal
ETO	explosive test operations
Geo-Centers	Geo-Centers, Inc.
GPR	ground-penetrating radar
GPS	global positioning system
HR	House Resolution
IDA	Institute for Defense Analysis
IR	infrared
JPG	U.S. Army Jefferson Proving Ground
MANPODS	Man-Portable Ordnance Detection System
Metratek	Metratek, Inc.
MSV-5	Multi-Sensor Vehicle
NAD	North American Datum
NAVEODTECHDIV	Naval Explosive Ordnance Disposal Technology Division
NOAA	National Oceanic and Atmospheric Administration
P_C	probability of correct classification
P_D	probability of detection
$P_{D,ord}$	probability of detection for ordnance
P_{random}	random probability of detection statistic
PRC EMI	PRC Environmental Management, Inc.
R_{crit}	critical radius
SAR	synthetic aperture radar
SEPOS	Sensor Positioning System
SHERP	safety, health, and emergency response plan
SR	stationary receiver
SRI	SRI International, Inc.
STOLS®	Surface Towed Ordnance Locator System

Abbreviations and Acronyms (continued)

TDEM	time-domain electromagnetic
TMA	target matching algorithm
ToMAS	Towed Multi-Sensor Array System
USAEC	U.S. Army Environmental Center
USAF	U.S. Air Force
USAF/WL	U.S. Air Force/Wright Laboratory
USHR	U.S. House of Representatives
USRADS®	UltraSonic Ranging and Data System Model 2200
UTM	Universal Transverse Mercator
UXO	unexploded ordnance
Vallon	Vallon GmbH/Security Search Product Sales, Inc.
WGS	World Geodetic System
YPG	U.S. Army Yuma Proving Ground

Units and Measures

cm	centimeter
Hz	hertz
in.	inch
kg	kilogram
km	kilometer
kph	kilometers per hour
m^3	cubic meter
min	minute
mm	millimeter
nT	nanoTesla
°C	degrees Celsius

APPENDIX A

BASELINE TARGET SETS

This Page Intentionally Left Blank

Target No.	Easting	Northing	Depth	Type	Class	Weight	Size	Azimuth	Declination	Comments
X-01	635168.84	4318879.33	2.68	ordnance	bomb	heavy	large	0	0	Mk84 bomb
X-02	635344.92	4318972.79	2.30	ordnance	projectile	heavy	large	170	0	8-in projectile
X-03	635259.41	4318934.95	1.75	ordnance	projectile	heavy	large	0	90	8-in projectile
X-04	635345.79	4318884.66	1.60	ordnance	projectile	moderate	medium	0	0	175-mm projectile
X-05	635313.87	4318939.64	1.43	ordnance	projectile	moderate	medium	45	0	175-mm projectile
X-06	635208.50	4318914.72	1.39	ordnance	projectile	moderate	medium	0	90	155-mm projectile
X-07	635211.56	4318968.84	0.42	ordnance	projectile	moderate	medium	0	0	105-mm projectile
X-08	635161.84	4318968.45	0.39	ordnance	mortar	light	small	0	0	81-mm mortar
X-09	635312.42	4318917.93	0.72	ordnance	mortar	light	small	0	90	81-mm mortar
X-10	635260.96	4318883.44	0.35	ordnance	mortar	light	small	45	0	81-mm mortar
X-11	635263.62	4318963.59	0.39	ordnance	cluster	light	small	0	0	57-mm projectiles (7)
X-12	635180.76	4318938.07	0.50	nonordnance	--	--	--	--	--	Camouflet
X-13	635170.12	4318930.79	0.61	nonordnance	--	--	--	--	--	Camouflet
X-14	635439.15	4318980.64	0.60	ordnance	bomb	moderate	small	0	0	BDU-33/Mk76 bomb
X-15	635414.38	4318908.79	0.33	ordnance	bomb	moderate	small	0	0	BDU-33/Mk76 bomb
X-16	635473.30	4318899.07	0.76	ordnance	bomb	moderate	small	0	0	BDU-33/Mk76 bomb
X-17	635565.59	4318922.19	0.68	ordnance	bomb	moderate	small	90	0	BDU-33/Mk76 bomb
X-18	635661.78	4318905.96	0.69	ordnance	bomb	moderate	small	0	0	BDU-33/Mk76 bomb
X-19	635668.17	4318963.35	0.52	ordnance	bomb	moderate	small	0	0	BDU-33/Mk76 bomb
X-20	635615.97	4318973.31	0.81	ordnance	bomb	moderate	small	45	0	BDU-33/Mk76 bomb
X-21	635525.48	4318983.94	0.61	ordnance	bomb	moderate	small	0	0	BDU-33/Mk76 bomb
X-22	635362.65	4319044.54	0.73	ordnance	bomb	moderate	small	0	0	BDU-33/Mk76 bomb
X-23	635258.63	4319033.98	0.57	ordnance	bomb	moderate	small	0	0	BDU-33/Mk76 bomb
X-24	635215.10	4319160.29	0.57	ordnance	bomb	moderate	small	0	0	BDU-33/Mk76 bomb
X-25	635334.53	4319150.30	0.79	ordnance	bomb	moderate	small	0	0	BDU-33/Mk76 bomb
X-26	635619.01	4319165.31	0.99	ordnance	bomb	moderate	small	0	0	BDU-33/Mk76 bomb
X-27	635659.21	4319101.41	0.84	ordnance	bomb	moderate	small	0	0	BDU-33/Mk76 bomb
X-28	635653.17	4319307.88	0.81	ordnance	bomb	moderate	small	0	0	BDU-33/Mk76 bomb
X-29	635504.34	4319325.03	0.76	ordnance	bomb	moderate	small	0	0	BDU-33/Mk76 bomb
X-30	635400.43	4319274.57	0.78	ordnance	projectile	moderate	medium	0	0	152-mm projectile
X-31	635329.15	4319291.27	0.69	ordnance	projectile	moderate	medium	0	0	152-mm projectile
X-32	635254.09	4319218.08	0.66	ordnance	projectile	moderate	medium	0	0	152-mm projectile
X-33	635180.72	4319312.02	0.74	ordnance	projectile	moderate	medium	0	0	152-mm projectile
X-34	635196.19	4319220.38	0.56	ordnance	projectile	moderate	medium	0	0	152-mm projectile
X-35	635202.13	4319105.43	0.91	ordnance	projectile	moderate	medium	0	0	175-mm projectile
X-36	635190.45	4319067.50	0.90	ordnance	projectile	moderate	medium	0	0	175-mm projectile
X-37	635263.50	4319101.09	0.91	ordnance	projectile	moderate	medium	0	0	175-mm projectile

Target No.	Easting	Northing	Depth	Type	Class	Weight	Size	Azimuth	Declination	Comments
X-38	635157.25	4319299.52	1.34	ordnance	projectile	moderate	medium	0	0	155-mm projectile
X-39	635567.16	4319078.88	0.66	ordnance	projectile	moderate	medium	0	0	175-mm projectile
X-40	635530.26	4319020.66	0.73	ordnance	projectile	moderate	medium	0	0	155-mm projectile
X-41	635620.90	4319022.28	1.43	ordnance	projectile	moderate	medium	0	0	155-mm projectile
X-42	635163.80	4318979.96	1.01	ordnance	projectile	moderate	medium	0	0	155-mm projectile
X-43	635655.59	4319257.63	1.38	ordnance	projectile	moderate	medium	0	0	155-mm projectile
X-44	635603.30	4319188.10	0.29	nonordnance	--	--	--	--	--	fragmentation

Note: Easting and Northing coordinates are Universal Transverse Mercator (NAD 83, Zone 016)

Target No.	Easting	Northing	Depth	Type	Class	Weight	Size	Azimuth	Declination	Comments
X-01	745316.38	3664330.23	2.43	ordnance	bomb	heavy	large	0	0	Mk84 2000-lb bomb
X-02	745628.39	3664125.18	2.30	ordnance	projectile	heavy	large	45	0	8-in projectile
X-03	745372.32	3664127.73	1.80	ordnance	projectile	heavy	large	90	0	8-in projectile
X-04	745224.32	3664238.28	0.93	ordnance	bomb	moderate	small	0	0	Mk76 25-lb bomb
X-05	745399.24	3664238.41	0.88	ordnance	bomb	moderate	small	--	90	Mk76 25-lb bomb
X-06	745311.91	3664168.73	0.91	ordnance	bomb	moderate	small	180	0	Mk76 25-lb bomb
X-07	745685.54	3664212.19	0.96	ordnance	bomb	moderate	small	45	45	Mk76 25-lb bomb
X-08	745592.31	3664003.73	0.92	ordnance	bomb	moderate	small	90	0	Mk76 25-lb bomb
X-09	745517.29	3664227.29	0.53	ordnance	bomb	moderate	small	--	90	Mk76 25-lb bomb
X-10	745500.49	3664308.07	0.47	ordnance	bomb	moderate	small	135	0	Mk76 25-lb bomb
X-11	745459.61	3664051.88	0.95	ordnance	bomb	moderate	small	180	45	Mk76 25-lb bomb
X-12	745468.33	3664122.20	1.59	ordnance	bomb	moderate	small	45	0	Mk76 25-lb bomb
X-13	745330.36	3664384.47	0.89	ordnance	bomb	moderate	small	--	90	Mk76 25-lb bomb
X-14	745597.51	3664219.19	0.41	ordnance	bomb	moderate	small	135	0	Mk76 25-lb bomb
X-15	745673.39	3664045.21	0.92	ordnance	bomb	moderate	small	90	0	Mk76 25-lb bomb
X-16	745414.49	3664325.37	1.37	ordnance	bomb	moderate	small	0	45	Mk76 25-lb bomb
X-17	745550.39	3664090.38	1.39	ordnance	bomb	moderate	small	--	90	Mk76 25-lb bomb
X-18	745441.10	3664171.19	0.68	ordnance	projectile	moderate	medium	90	0	105-mm projectile
X-19	745668.29	3664121.28	0.70	ordnance	projectile	moderate	medium	--	90	105-mm projectile
X-20	745215.45	3664128.04	0.28	ordnance	projectile	moderate	medium	0	0	105-mm projectile
X-21	745321.53	3664246.62	0.41	ordnance	projectile	moderate	medium	45	45	105-mm projectile
X-22	745504.20	3664174.90	0.67	ordnance	projectile	moderate	medium	135	0	105-mm projectile
X-23	745516.44	3664005.53	0.35	ordnance	projectile	moderate	medium	--	90	105-mm projectile
X-24	745273.67	3664354.10	0.52	ordnance	projectile	moderate	medium	180	0	105-mm projectile
X-25	745715.03	3664164.98	0.69	ordnance	projectile	moderate	medium	45	45	105-mm projectile
X-26	745466.97	3664103.62	0.92	ordnance	projectile	moderate	medium	135	0	105-mm projectile
X-27	745362.08	3664286.83	0.72	ordnance	projectile	moderate	medium	--	90	105-mm projectile
X-28	745555.14	3664048.59	1.24	ordnance	projectile	moderate	medium	0	0	105-mm projectile
X-29	745585.79	3664252.08	1.09	ordnance	projectile	moderate	medium	0	45	105-mm projectile
X-30	745245.43	3664139.12	1.09	ordnance	projectile	moderate	medium	0	0	105-mm projectile
X-31	745462.35	3664216.07	0.74	ordnance	projectile	moderate	medium	--	90	105-mm projectile
X-32	745598.58	3664033.97	0.47	ordnance	mortar	light	small	45	45	81-mm mortar
X-33	745280.56	3664293.23	0.71	ordnance	mortar	light	small	--	90	81-mm mortar
X-34	745362.10	3664067.39	0.36	ordnance	mortar	light	small	0	0	81-mm mortar
X-35	745461.45	3664269.64	0.32	ordnance	mortar	light	small	45	0	81-mm mortar
X-36	745628.69	3664102.49	0.44	ordnance	mortar	light	small	--	90	81-mm mortar
X-37	745575.01	3664281.31	0.55	ordnance	mortar	light	small	90	0	81-mm mortar

Target No.	Easting	Northing	Depth	Type	Class	Weight	Size	Azimuth	Declination	Comments
X-38	745293.85	3664231.95	1.16	ordnance	mortar	light	small	135	45	81-mm mortar
X-39	745647.87	3664169.65	0.55	ordnance	mortar	light	small	--	90	81-mm mortar
X-40	745353.31	3664349.27	0.50	ordnance	mortar	light	small	180	0	60-mm mortar
X-41	745590.38	3664062.25	0.53	ordnance	mortar	light	small	90	45	60-mm mortar
X-42	745387.15	3664167.30	0.28	ordnance	mortar	light	small	0	0	60-mm mortar
X-43	745737.57	3664200.99	0.68	ordnance	mortar	light	small	135	45	60-mm mortar
X-44	745360.02	3664209.64	0.33	ordnance	mortar	light	small	--	90	60-mm mortar
X-45	745489.71	3664155.48	0.53	ordnance	mortar	light	small	45	0	60-mm mortar
X-46	745602.94	3663960.29	0.86	ordnance	mortar	light	small	45	45	60-mm mortar
X-47	745251.04	3664180.57	0.68	ordnance	mortar	light	small	--	90	60-mm mortar
X-48	745425.70	3664260.70	0.46	ordnance	mortar	light	small	0	45	60-mm mortar
X-49	745284.84	3664098.73	0.42	ordnance	projectile	light	small	135	0	40-mm projectile
X-50	745691.48	3664182.17	0.47	ordnance	projectile	light	small	90	0	40-mm projectile
X-51	745253.93	3664165.82	0.29	ordnance	projectile	light	small	--	90	40-mm projectile

Note: Easting and Northing coordinates are Universal Transverse Mercator (NAD 27, Zone 011 - Yuma modified)

Target No.	Easting	Northing	Depth	Type	Class	Weight	Size	Azimuth	Declination	Comments
X-01	523944.19	3374364.34	1.06	ordnance	projectile	moderate	medium	45	0	5-in rocket warhead
X-02	523963.58	3374408.28	1.48	ordnance	bomb	heavy	large	0	-90	500-lb HE bomb
X-03	523906.44	3374346.28	2.64	ordnance	bomb	heavy	large	90	0	500-lb HE bomb
X-04	523970.59	3374364.14	0.62	ordnance	projectile	light	small	30	0	2.75-in rocket warhead
X-05	523990.08	3374466.81	2.53	ordnance	bomb	moderate	large	45	45	220-lb fragmentation bomb
X-06	523907.78	3374441.23	0.60	ordnance	projectile	light	small	90	0	2.75-in rocket warhead
X-07	523836.85	3374329.56	0.19	ordnance	projectile	light	small	0	0	2.75-in rocket warhead
X-08	523985.06	3374374.17	0.14	ordnance	projectile	light	small	0	45	2.75-in rocket warhead
X-09	523882.26	3374390.34	1.87	ordnance	projectile	moderate	medium	45	-30	105-mm projectile
X-10	523961.49	3374430.69	1.30	ordnance	projectile	moderate	medium	0	-45	105-mm projectile
X-11A	523647.21	3374254.10	0.05	ordnance	other	light	small	--	--	WAMUM submunition
X-11B	523643.92	3374251.41	0.05	ordnance	other	light	small	--	--	WAMUM submunition
X-11C	523645.42	3374248.98	0.05	ordnance	other	light	small	--	--	WAMUM submunition
X-11D	523650.39	3374249.11	0.05	ordnance	other	light	small	--	--	WAMUM submunition
X-11E	523646.82	3374250.30	0.08	ordnance	other	light	small	--	--	WAMUM submunition
X-11F	523649.35	3374242.95	0.06	ordnance	other	light	small	--	--	WAMUM submunition
X-11G	523648.76	3374247.52	0.07	ordnance	other	light	small	--	--	WAMUM submunition
X-12	523922.29	3374412.28	0.56	nonordnance	--	--	--	--	--	steel washer
X-13	523870.04	3374432.69	0.44	ordnance	projectile	light	small	0	0	2.75-in rocket warhead
X-14	523949.91	3374423.70	0.53	nonordnance	--	--	--	--	--	steel washer
X-15	523891.75	3374342.93	0.15	ordnance	projectile	light	small	45	0	2.75-in rocket warhead
X-16A	523853.15	3374095.13	0.05	ordnance	other	light	small	--	--	WAMUM submunition
X-16B	523853.51	3374091.88	0.13	ordnance	other	light	small	--	--	WAMUM submunition
X-16C	523857.16	3374091.50	0.09	ordnance	other	light	small	--	--	WAMUM submunition
X-16D	523857.57	3374099.18	0.08	ordnance	other	light	small	--	--	WAMUM submunition
X-16E	523851.79	3374098.10	0.07	ordnance	other	light	small	--	--	WAMUM submunition
X-16F	523850.92	3374100.90	0.07	ordnance	other	light	small	--	--	WAMUM submunition
X-16G	523854.86	3374101.10	0.11	ordnance	other	light	small	--	--	WAMUM submunition
X-16H	523853.90	3374098.79	0.09	ordnance	other	light	small	--	--	WAMUM submunition
X-16I	523855.92	3374095.90	0.05	ordnance	other	light	small	--	--	WAMUM submunition
X-17	524126.15	3374237.24	0.13	ordnance	other	light	small	--	--	WAMUM submunition
X-18ABHE	524477.71	3374059.29	0.09	ordnance	cluster	light	small	--	--	WAMUM submunitions (4)
X-18DCI	524469.66	3374058.28	0.18	ordnance	cluster	light	small	--	--	WAMUM submunitions (3)
X-18FGL	524472.28	3374057.29	0.14	ordnance	cluster	light	small	--	--	WAMUM submunitions (3)
X-19	523880.06	3374489.94	0.79	nonordnance	--	--	--	--	--	scrap metal
X-20	523961.11	3374132.16	0.44	ordnance	other	light	small	--	--	snake eye fin assembly

Target No.	Easting	Northing	Depth	Type	Class	Weight	Size	Azimuth	Declination	Comments
X-21	523777.22	3374605.22	0.57	ordnance	other	light	small	--	--	conical fin assembly
X-22	523594.20	3374530.53	2.45	ordnance	bomb	moderate	large	0	0	220-lb fragmentation bomb
X-23	523921.71	3374085.30	1.97	ordnance	bomb	moderate	large	0	5	220-lb fragmentation bomb
X-24	523934.27	3374502.65	2.91	ordnance	bomb	moderate	large	45	0	500-lb HE bomb
X-25	524328.46	3373969.83	2.29	ordnance	bomb	moderate	large	0	-30	500-lb HE bomb
X-26	524206.45	3374315.13	2.56	ordnance	bomb	moderate	large	0	45	500-lb HE bomb
X-27	524261.25	3374081.93	2.23	ordnance	bomb	moderate	large	0	-30	500-lb HE bomb
X-28	523917.32	3373961.05	2.44	ordnance	bomb	heavy	large	90	0	2,000-lb HE bomb
X-29	524380.75	3374170.68	0.33	nonordnance	--	--	--	--	--	steel washer
X-30	524280.85	3374295.84	0.45	nonordnance	--	--	--	--	--	steel washer
X-31	524113.58	3374142.46	1.39	ordnance	projectile	moderate	medium	70	0	105-mm projectile
X-32	524443.04	3374004.16	1.14	ordnance	projectile	moderate	medium	90	-45	105-mm projectile
X-33	524073.02	3374017.33	1.30	ordnance	projectile	moderate	medium	0	-45	5-in rocket warhead
X-35	524047.56	3374315.93	1.11	ordnance	projectile	moderate	medium	90	0	105-mm projectile
X-36	523944.35	3374313.74	1.05	ordnance	projectile	moderate	medium	0	0	105-mm projectile
X-37	524252.19	3374328.62	1.02	ordnance	projectile	moderate	medium	90	-45	105-mm projectile
X-38	523983.79	3374065.33	0.71	ordnance	projectile	moderate	medium	90	0	105-mm projectile
X-39	524189.02	3374095.63	0.80	ordnance	projectile	moderate	medium	90	-45	105-mm projectile
X-40	523986.66	3374410.17	1.59	ordnance	projectile	moderate	medium	90	0	105-mm projectile
X-41	523892.56	3374590.67	0.29	ordnance	projectile	light	small	30	0	2.75-in rocket warhead
X-42	523756.82	3374125.12	0.48	ordnance	projectile	light	small	90	-15	2.75-in rocket warhead
X-43	524460.86	3374168.72	0.51	ordnance	projectile	light	small	90	0	2.75-in rocket warhead
X-44	524048.06	3374058.22	0.38	ordnance	projectile	light	small	0	0	2.75-in rocket warhead
X-45	523584.26	3374434.10	0.18	ordnance	cluster	light	small	--	--	20-mm projectiles (10)

Note: Easting and Northing coordinates are Universal Transverse Mercator (NAD 27, Zone 016)

Target No.	Easting	Northing	Depth	Type	Class	Weight	Size	Azimuth	Declination	Comments
X-01	516919.16	3771802.24	1.63	ordnance	bomb	heavy	large	300	-30	Mk83 1000-lb bomb
X-02	516864.15	3771711.96	2.38	ordnance	bomb	heavy	large	300	0	Mk83 1000-lb bomb
X-03	516941.52	3771837.11	0.47	ordnance	mortar	light	medium	340	-45	4.2-in mortar
X-04	516799.10	3771764.34	0.60	ordnance	projectile	moderate	medium	0	-45	105-mm projectile
X-05	516881.80	3771778.36	0.20	ordnance	mortar	light	small	180	-80	81-mm mortar
X-06	516878.05	3771887.95	0.03	ordnance	mortar	light	small	0	-90	81-mm mortar
X-07	516891.77	3771706.94	0.36	ordnance	mortar	light	small	270	-45	81-mm mortar
X-08	516957.43	3771916.52	0.20	ordnance	mortar	light	small	0	-80	81-mm mortar
X-09	516756.33	3771498.63	0.29	ordnance	mortar	light	small	290	-45	81-mm mortar
X-10	516794.60	3771727.48	0.13	ordnance	projectile	light	medium	100	0	106-mm projectile
X-11	516842.84	3771737.66	0.38	ordnance	mortar	light	small	0	-90	60-mm mortar
X-12	516862.65	3771816.83	0.23	ordnance	mortar	light	small	180	-35	60-mm mortar
X-13	516798.60	3771644.92	0.31	ordnance	mortar	light	small	180	-15	60-mm mortar
X-14	516981.40	3771707.44	0.09	ordnance	mortar	light	small	0	-90	60-mm mortar
X-15	516998.38	3771896.65	0.52	ordnance	mortar	light	small	90	-30	60-mm mortar
X-16	516930.12	3771876.39	0.43	ordnance	mortar	light	small	0	-90	60-mm mortar
X-17	516882.88	3771936.79	0.04	ordnance	projectile	light	medium	180	0	106-mm projectile
X-18	517027.59	3771648.50	0.43	ordnance	projectile	moderate	medium	300	0	105-mm projectile
X-19	516827.49	3771870.54	0.63	ordnance	projectile	moderate	medium	270	0	105-mm projectile
X-20	516645.31	3771438.86	0.38	ordnance	mortar	light	medium	300	0	4.2-in mortar
X-21	516731.31	3771475.06	0.35	ordnance	mortar	light	small	270	-45	81-mm mortar
X-22	516757.81	3771620.66	1.52	ordnance	projectile	moderate	medium	90	10	155-mm projectile
X-23	516726.05	3771409.38	1.12	ordnance	projectile	moderate	medium	0	0	155-mm projectile
X-24	516709.53	3771525.95	1.52	ordnance	projectile	moderate	medium	280	0	175-mm projectile
X-25	516660.40	3771472.27	1.48	ordnance	projectile	moderate	medium	220	0	175-mm projectile
X-26	516841.18	3771661.85	1.56	ordnance	projectile	moderate	medium	310	0	175-mm projectile
X-27	516800.61	3771685.46	1.52	ordnance	projectile	moderate	medium	45	15	175-mm projectile
X-28	516992.03	3771855.24	0.99	ordnance	projectile	moderate	medium	0	-85	175-mm projectile
X-29	516962.51	3771873.41	1.44	ordnance	projectile	moderate	medium	0	-30	175-mm projectile
X-30	516763.51	3771555.34	1.45	ordnance	projectile	heavy	large	180	15	8-in projectile
X-31	516840.47	3771778.31	1.67	ordnance	projectile	heavy	large	0	0	8-in projectile
X-32	516866.62	3771415.91	1.53	ordnance	projectile	heavy	large	270	-30	8-in projectile
X-33	516786.15	3771442.04	1.54	ordnance	projectile	heavy	large	200	0	8-in projectile
X-34	516828.30	3771837.24	1.30	ordnance	projectile	heavy	large	270	0	8-in projectile
X-35	516973.35	3771751.77	1.17	ordnance	projectile	heavy	large	300	-45	8-in projectile
X-36	516674.55	3771562.45	0.46	nonordnance	--	--	--	--	--	0.50-cal ammunition can (5)
X-37	516827.47	3771748.61	0.45	nonordnance	--	--	--	--	--	Metal banding/pallet

Target No.	Easting	Northing	Depth	Type	Class	Weight	Size	Azimuth	Declination	Comments

Note: Easting and Northing coordinates are Universal Transverse Mercator (NAD 83, Zone 017)

Target No.	Easting	Northing	Depth	Type	Class	Weight	Size	Azimuth	Declination	Comments
X-01	539763.76	5217598.88	2.59	ordnance	bomb	heavy	large	0	0	Mk82 500-lb bomb
X-02	540178.48	5216711.12	2.34	ordnance	bomb	heavy	large	0	0	Mk82 500-lb bomb
X-03	539767.76	5217429.98	0.99	ordnance	projectile	heavy	large	90	0	8-in projectile
X-04	539792.60	5217293.35	1.06	ordnance	projectile	moderate	medium	90	45	175-mm projectile
X-05	539760.14	5217647.23	0.83	ordnance	projectile	moderate	medium	45	0	175-mm projectile
X-06	539792.02	5217648.36	0.52	ordnance	mortar	light	medium	--	90	4.2-in mortar (illum)
X-07	539823.60	5217570.16	0.56	ordnance	projectile	moderate	medium	90	0	105-mm projectile (APDS)
X-08	539822.82	5217432.76	0.37	ordnance	mortar	light	medium	135	0	4.2-in mortar (illum)
X-09	539815.04	5217627.47	0.63	ordnance	mortar	light	small	45	0	81-mm mortar
X-10	539792.35	5217586.22	0.54	ordnance	mortar	light	small	90	0	81-mm mortar
X-11	540037.57	5216770.87	0.49	ordnance	projectile	moderate	small	--	90	76-mm projectile (HEAT)
X-12	539812.77	5217550.70	0.38	ordnance	projectile	light	small	90	0	57-mm projectile
X-13	540006.22	5216743.66	0.09	ordnance	projectile	light	small	135	0	57-mm projectile
X-14	540142.94	5216677.23	0.61	ordnance	projectile	moderate	medium	--	90	5-in rocket warhead
X-15	539792.96	5217410.20	0.86	ordnance	projectile	moderate	medium	90	45	5-in rocket warhead
X-16	539769.25	5217353.60	0.89	ordnance	mortar	light	medium	45	0	4.2-in mortar
X-17	539775.09	5217629.41	0.75	ordnance	projectile	moderate	medium	90	0	105-mm projectile (APDS-T)
X-18	539851.13	5217446.46	0.74	ordnance	projectile	moderate	medium	--	90	105-mm projectile (APDS-T)
X-19	539799.53	5217367.64	1.03	ordnance	mortar	light	medium	90	0	4.2-in mortar (illum)
X-20	540205.77	5216678.41	0.90	ordnance	projectile	moderate	medium	180	0	175-mm projectile
X-21	540192.17	5216641.93	0.66	ordnance	projectile	moderate	medium	45	0	175-mm projectile
X-22	539824.84	5217285.60	0.60	ordnance	projectile	moderate	small	--	90	76-mm projectile (HEAT)
X-23	539808.06	5216661.41	0.32	ordnance	projectile	moderate	small	90	0	76-mm projectile (HEAT)
X-24	540122.60	5216518.39	0.25	ordnance	projectile	light	small	90	0	57-mm projectile
X-25	539786.59	5216619.00	0.32	ordnance	projectile	light	small	90	0	57-mm projectile
X-26	539891.52	5216505.12	0.95	ordnance	projectile	moderate	medium	0	0	5-in rocket warhead
X-27	539839.91	5217485.10	0.59	ordnance	mortar	light	small	45	0	81-mm mortar
X-28	539817.51	5217349.29	0.86	ordnance	mortar	light	small	90	45	81-mm mortar
X-29	540076.94	5216759.85	0.53	ordnance	projectile	moderate	medium	0	0	175-mm projectile
X-30	540094.63	5216586.24	0.44	ordnance	projectile	moderate	medium	0	0	175-mm projectile
X-31	540210.27	5216668.01	0.67	ordnance	projectile	moderate	medium	0	45	105-mm projectile (APDS-T)
X-32	540026.16	5216793.81	0.75	ordnance	mortar	light	medium	--	45	4.2-in mortar (illum)
X-33	540184.84	5216581.87	0.80	ordnance	mortar	light	medium	180	0	4.2-in mortar (illum)
X-34	539944.95	5216692.22	0.52	ordnance	mortar	light	medium	0	90	4.2-in mortar
X-35	540111.76	5216734.20	0.87	ordnance	projectile	heavy	large	90	0	8-in projectile
X-36	539765.77	5217276.80	0.54	ordnance	mortar	light	small	90	0	81-mm mortar
X-37	540209.02	5216649.73	0.58	ordnance	mortar	light	small	0	0	81-mm mortar

Target No.	Easting	Northing	Depth	Type	Class	Weight	Size	Azimuth	Declination	Comments
X-38	540103.58	5216713.44	0.68	ordnance	projectile	moderate	medium	90	0	105-mm projectile (ATDS-T)
X-39	540029.87	5216728.98	0.59	ordnance	projectile	moderate	medium	45	0	105-mm projectile (ATDS-T)
X-40	540167.24	5216620.45	0.80	ordnance	projectile	moderate	medium	90	45	105-mm projectile (ATDS-T)
X-41	540061.69	5216718.06	0.54	ordnance	mortar	light	small	0	90	81-mm mortar
X-42	540207.25	5216598.74	0.70	ordnance	mortar	light	small	135	0	81-mm mortar
X-43	539861.49	5216683.20	0.55	ordnance	mortar	light	small	90	0	81-mm mortar
X-44	539927.70	5216720.20	0.35	ordnance	mortar	light	small	45	0	81-mm mortar
X-45	540099.33	5216634.10	0.57	ordnance	mortar	light	medium	90	45	4.2-in mortar
X-46	539906.58	5216659.24	0.55	ordnance	mortar	light	medium	0	0	4.2-in mortar
X-47	540198.16	5216557.25	0.43	ordnance	projectile	moderate	medium	90	0	105-mm projectile (HEP)
X-48	539981.70	5216771.84	0.54	ordnance	projectile	moderate	medium	45	0	105-mm projectile (HEP)
X-49	540178.77	5216540.37	0.26	ordnance	projectile	moderate	medium	135	45	105-mm projectile (HEP)
X-50	540203.18	5216519.83	0.57	ordnance	projectile	moderate	medium	90	0	105-mm projectile (HEP)
X-51	539781.85	5217495.71	0.68	ordnance	projectile	moderate	medium	90	0	105-mm projectile (HE)
X-52	539969.04	5216739.10	1.49	ordnance	projectile	moderate	medium	180	0	105-mm projectile (HE)
X-53	540161.45	5216709.32	0.65	ordnance	projectile	moderate	medium	0	90	105-mm projectile (HE)
X-54	539939.03	5216635.68	0.35	ordnance	projectile	moderate	medium	0	0	105-mm projectile
X-55	539832.88	5217402.08	0.52	ordnance	projectile	moderate	medium	135	0	105-mm projectile (HEP)
X-56	539793.45	5216692.49	0.46	ordnance	projectile	moderate	medium	0	45	105-mm projectile (HEP)
X-57	540126.66	5216699.85	0.72	ordnance	projectile	moderate	medium	90	0	105-mm projectile
X-58	540053.06	5216659.63	0.52	ordnance	projectile	moderate	medium	0	90	105-mm projectile
X-59	540088.03	5216659.69	0.33	ordnance	projectile	moderate	medium	90	0	105-mm projectile
X-60	540121.19	5216744.26		nonordnance	--	--	--	--	--	metal door
X-61	540061.80	5216683.36		nonordnance	--	--	--	--	--	scrap metal
X-62	539875.87	5216725.68		nonordnance	--	--	--	--	--	metal stake
X-63	539878.75	5216527.94		nonordnance	--	--	--	--	--	1-in cable (35-ft long)
X-64	539780.31	5217223.78		nonordnance	--	--	--	--	--	metal signs (2)
X-65	539816.86	5217210.18		nonordnance	--	--	--	--	--	18-in bolt
X-66	539806.70	5217599.70		nonordnance	--	--	--	--	--	metal drums (2)
X-67	539803.34	5217522.18		nonordnance	--	--	--	--	--	chicken wire fence
X-68	539813.20	5217473.19		nonordnance	--	--	--	--	--	small magnets (4)

Note: Easting and Northing coordinates are Universal Transverse Mercator (NAD 83, Zone 010)

APPENDIX B

VALIDATION TARGET SETS

This Page Intentionally Left Blank

Target No.	Easting	Northing	Depth	Type	Class	Weight	Size	Comments
T-01	635464.51	4319290.37	3.00	nonordnance	--	--	--	box fins from 100-lb bomb
T-02	635424.73	4319350.06	1.25	ordnance	projectile	heavy	large	8-in projectile
T-03	635375.39	4319148.67	1.50	nonordnance	--	--	--	fragmentation
T-04	635394.97	4319030.04	1.25	ordnance	projectile	heavy	large	8-in projectile (rocket-assisted)
T-05	635364.15	4319332.11	1.25	ordnance	bomb	moderate	medium	100-lb GP bomb VT fuze
T-06	635239.18	4319295.57	1.50	nonordnance	--	--	--	fragmentation
T-07	635660.06	4318934.88	1.00	nonordnance	--	--	--	bomb fragmentation
T-08	635295.81	4318970.02	1.00	nonordnance	--	--	--	1-m metal pipe, drain tile
T-09	635589.76	4319011.08	2.75	ordnance	projectile	heavy	large	8-in projectile (rocket-assisted)
T-10	635369.04	4319074.66	1.30	--	--	--	--	empty hole
T-12	635372.4	4319228.50	1.25	nonordnance	--	--	--	fragmentation
T-13	635505.3	4319334.00	1.25	--	--	--	--	empty hole
T-14	635515.4	4319200.80	1.50	ordnance	bomb	moderate	medium	100-lb GP bomb VT fuze
T-15	635264.1	4318947.30	1.00	ordnance	bomb	moderate	medium	100-lb GP bomb
T-16	635498.8	4319195.50	1.25	ordnance	bomb	moderate	medium	100-lb GP bomb
T-17	635540.3	4319229.90	2.25	--	--	--	--	empty hole
T-18	635520.1	4319310.80	1.75	ordnance	bomb	moderate	medium	100-lb GP bomb
T-19	635495.1	4319217.10	1.25	nonordnance	--	--	--	fragmentation
T-20	635521.9	4319065.70	1.00	--	--	--	--	empty hole
T-21	635449.7	4319285.50	1.50	--	--	--	--	empty hole
T-22	635357.5	4319083.00	2.25	--	--	--	--	empty hole
T-23	635575.8	4319260.50	1.50	nonordnance	--	--	--	fragmentation
T-24	635361.3	4319055.50	1.50	--	--	--	--	empty hole
T-25	635380.1	4319274.50	2.50	--	--	--	--	empty hole
T-26	635404.7	4319277.00	0.75	ordnance	projectile	heavy	large	8-in projectile
T-27	635429.2	4319018.50	1.75	nonordnance	--	--	--	fragmentation
T-28	635493.8	4319268.00	1.50	nonordnance	--	--	--	fragmentation
T-29	635429.9	4319279.50	1.75	--	--	--	--	empty hole
T-30	635348.5	4319060.50	1.50	nonordnance	--	--	--	1-in metal disc
T-32	635538.57	4319357.17	1.25	ordnance	bomb	moderate	medium	100-lb GP bomb VT fuze
T-33	635639.81	4319010.75	2.00	nonordnance	--	--	--	fragmentation
T-35	635443.75	4319203.55	2.00	ordnance	projectile	heavy	large	8-in projectile (rocket-assisted)
T-36	635596.68	4318973.60	1.75	nonordnance	--	--	--	fragmentation
T-38	635432.5	4319189.47	1.50	ordnance	bomb	moderate	medium	100-lb fragmentation bomb VT fuze
T-39	635642.84	4318934.98	1.25	nonordnance	--	--	--	fragmentation

Target No.	Easting	Northing	Depth	Type	Class	Weight	Size	Comments
T-40	635509.71	4319268.46	1.50	ordnance	bomb	moderate	medium	100-lb GP bomb
T-43	635477.7	4319276.20	0.50	ordnance	bomb	moderate	medium	100-lb GP bomb
T-44	635450.7	4319350.10	1.25	ordnance	bomb	moderate	medium	100-lb GP bomb
T-45	635520.1	4319207.30	2.25	--	--	--	--	empty hole
T-46	635508	4319334.30	1.00	nonordance	--	--	--	4-in fragmentation
T-48	635337.4	4319243.70	1.50	ordnance	bomb	moderate	medium	100-lb GP bomb
T-49	635473.3	4319331.20	1.75	--	--	--	--	empty hole
T-50	635647.9	4318933.60	0.70	--	--	--	--	empty hole
T-51	635480.9	4319205.50	1.75	--	--	--	--	empty hole
T-52	635380.1	4319014.50	2.25	--	--	--	--	empty hole
T-53	635510.3	4319264.00	1.50	--	--	--	--	empty hole
T-55	635270	4319104.50	2.00	--	--	--	--	empty hole
T-56	635584.5	4319339.00	0.50	nonordnance	--	--	--	metal pipe
T-57	635335.6	4319323.00	1.50	--	--	--	--	empty hole
T-58	635521.8	4319252.00	2.25	--	--	--	--	empty hole
T-59	635497	4319347.00	1.75	ordnance	bomb	moderate	medium	100-lb fragmentation bomb
T-65	635426.95	4319198.02	1.75	ordnance	bomb	moderate	medium	100-lb fragmentation bomb VT fuze
T-69	635447.33	4319251.70	2.50	ordnance	bomb	moderate	medium	100-lb GP bomb

Note: Easting and Northing coordinates are Universal Transverse Mercator (NAD 83, Zone 016)

Target No.	Easting	Northing	Depth	Type	Class	Weight	Size	Comments
H3-T01	745156.82	3671343.40	2.00	--	--	--	--	geologic anomaly
H3-T02	745003.75	3671205.46	1.75	--	--	--	--	geologic anomaly
H3-T03	744891.18	3671319.96	2.00	--	--	--	--	geologic anomaly
H3-T04	744952.90	3671200.90	1.75	--	--	--	--	geologic anomaly
H3-T07	744877.67	3670908.78	2.50	--	--	--	--	geologic anomaly
H3-T09	744913.72	3671384.35	2.75	--	--	--	--	geologic anomaly
H3-T10	744909.03	3670988.61	1.50	--	--	--	--	geologic anomaly
H3-T12	744937.98	3671433.95	2.25	--	--	--	--	geologic anomaly
H3-T15	744961.21	3671421.54	2.75	--	--	--	--	geologic anomaly
H3-T16	745137.75	3671665.35	2.00	--	--	--	--	geologic anomaly
H3-T17	744967.15	3671344.53	2.00	--	--	--	--	geologic anomaly
H3-T18	745175.57	3671518.57	1.50	--	--	--	--	geologic anomaly
H3-T19	745173.35	3671572.89	1.75	ordnance	projectile	light	small	37-mm projectiles (5), fragmentation
H3-T20	745068.94	3671610.44	2.25	--	--	--	--	geologic anomaly
H3-T21	745052.43	3671231.78	2.25	--	--	--	--	geologic anomaly
H3-T22	745155.58	3670908.29	1.00	--	--	--	--	geologic anomaly
H3-T23	745101.62	3671233.01	1.50	--	--	--	--	geologic anomaly
H3-T24	745079.11	3670896.43	1.00	--	--	--	--	geologic anomaly
H3-T25	745047.08	3671664.44	1.00	--	--	--	--	geologic anomaly
H3-T26	744970.68	3671244.86	1.50	--	--	--	--	geologic anomaly
H3-T27	744989.82	3671665.75	1.00	--	--	--	--	geologic anomaly
H3-T29	744901.44	3670884.12	1.75	--	--	--	--	geologic anomaly
H3-T30	744849.67	3671031.41	1.25	--	--	--	--	geologic anomaly
H3-T31	745177.76	3671648.75	1.75	--	--	--	--	geologic anomaly
H3-T32	744987.79	3671462.29	1.75	nonordnance	--	--	--	105-mm projectile fragmentation
H3-T35	745184.88	3671669.54	2.25	--	--	--	--	geologic anomaly
H3-T39	745154.21	3671563.98	3.00	--	--	--	--	geologic anomaly
H3-T44	745140.05	3670939.84	2.00	--	--	--	--	geologic anomaly
H3-T48	744967.26	3671657.09	1.50	--	--	--	--	geologic anomaly
H3-T49	745167.80	3671561.04	2.00	nonordnance	--	--	--	fragmentation
H3-T54	745163.57	3670957.66	1.75	--	--	--	--	geologic anomaly
H3-T58	744922.79	3671554.86	2.25	nonordnance	--	--	--	fragmentation
H3-T59	745084.99	3671429.64	2.00	nonordnance	--	--	--	30-mm projectile fragmentation
H3-T63	745177.30	3671551.95	2.00	--	--	--	--	geologic anomaly
SC-T03	745393.69	3664133.54	2.50	--	--	--	--	geologic anomaly

Target No.	Easting	Northing	Depth	Type	Class	Weight	Size	Comments
SC-T06	745585.39	3664206.95	1.50	--	--	--	--	geologic anomaly
SC-T12	745640.44	3664185.72	3.75	--	--	--	--	geologic anomaly
SC-T18	745644.95	3664166.22	1.75	--	--	--	--	geologic anomaly
SC-T21	745470.40	3664160.76	1.50	--	--	--	--	geologic anomaly
SC-T34	745279.05	3664352.07	2.00	--	--	--	--	geologic anomaly
SC-T40	745611.00	3664262.32	1.75	--	--	--	--	geologic anomaly
SC-T44	745598.87	3664267.58	2.00	--	--	--	--	geologic anomaly

Note: Easting and Northing coordinates are Universal Transverse Mercator (NAD 27, Zone 011 - Yuma modified)

Target No.	Easting	Northing	Depth	Type	Class	Weight	Size	Comments
T-01	523949.03	3374423.09	1.00	ordnance	bomb	moderate	small	BDU33
T-02	523915.03	3374425.39	1.25	ordnance	bomb	moderate	small	BDU33
T-03	523898.93	3374432.69	0.50	ordnance	bomb	moderate	small	BDU33 (2), 2.75-in rocket warhead (1)
T-04	523884.03	3374449.59	0.50	ordnance	bomb	moderate	small	BDU33, 40-mm projectile
T-05	523849.13	3374456.69	1.00	ordnance	bomb	moderate	small	BDU33
T-06	523846.43	3374464.89	1.00	ordnance	bomb	moderate	small	BDU33 (2)
T-07	523897.63	3374492.49	2.00	--	--	--	--	empty hole
T-08	523874.73	3374468.59	1.25	ordnance	bomb	moderate	small	BDU33
T-09	523782.83	3374598.39	0.50	ordnance	bomb	moderate	small	BDU33 (2)
T-10	523779.53	3374616.09	0.50	ordnance	bomb	moderate	small	BDU33
T-11	523746.13	3374632.49	1.00	ordnance	bomb	moderate	small	Mk76
T-12A	523801.22	3374575.64	0.25	ordnance	bomb	moderate	small	Mk76 (1), 2.75-in rocket warhead (1)
T-12B	523801.22	3374575.64	0.50	ordnance	bomb	moderate	small	Mk76
T-13	523922.99	3374526.37	0.25	ordnance	bomb	moderate	small	BDU33
T-14	523980.69	3374517.56	2.25	--	--	--	--	empty hole
T-15	524001.74	3374519.84	2.25	--	--	--	--	empty hole
T-16A	523963.90	3374421.72	0.25	ordnance	bomb	moderate	small	BDU33
T-16B	523963.90	3374421.72	1.50	ordnance	bomb	moderate	small	BDU33
T-17A	523973.71	3374395.24	0.50	ordnance	projectile	light	small	2.75-in rocket warhead
T-17B	523973.71	3374395.24	1.00	ordnance	bomb	moderate	small	BDU33
T-18	523957.98	3374344.00	1.00	ordnance	bomb	moderate	small	BDU33 (1), 2.75-in rocket warhead (1)
T-19	523917.66	3374334.30	1.25	ordnance	bomb	moderate	small	BDU33
T-20	523634.00	3374234.85	0.75	ordnance	bomb	moderate	small	BDU33
T-21	523653.05	3374235.14	1.25	ordnance	bomb	moderate	small	BDU33
T-22	523619.23	3374206.52	0.50	ordnance	bomb	moderate	small	BDU33
T-23	523749.73	3374327.89	2.25	ordnance	bomb	moderate	small	BDU33 (10), 2.75-in rocket warhead (1)
T-24	523821.73	3374344.29	1.25	ordnance	bomb	moderate	small	BDU33 (18)
T-25	523853.73	3374404.29	1.25	ordnance	bomb	moderate	small	BDU33 (15), 2.75-in rocket warhead (1)
T-26	523793.73	3374399.89	1.00	ordnance	bomb	moderate	small	BDU33 (18)
T-27	523801.73	3374423.89	1.00	ordnance	bomb	moderate	small	BDU33 (7)
T-28	523793.73	3374431.89	1.25	ordnance	bomb	moderate	small	BDU33 (3)
T-29	523789.73	3374431.89	1.00	ordnance	bomb	moderate	small	BDU33 (2)
T-30	523791.13	3374426.29	0.50	ordnance	bomb	moderate	small	BDU33
T-31	523769.73	3374419.89	1.75	ordnance	bomb	moderate	small	BDU33 (5)
T-32	523769.73	3374403.89	1.00	ordnance	bomb	moderate	small	BDU33 (9)
T-33	523701.73	3374528.29	1.25	ordnance	bomb	moderate	small	BDU33 (42)
T-34	523709.73	3374548.29	1.00	ordnance	bomb	moderate	small	BDU33 (70), 2.75-in rocket warhead (1)

Target No.	Easting	Northing	Depth	Type	Class	Weight	Size	Comments
T-35	523689.73	3374540.29	1.00	ordnance	bomb	moderate	small	BDU33 (76), 2.75-in rocket warhead (3)
T-36	523685.73	3374532.29	1.25	ordnance	bomb	moderate	small	BDU33 (65), 2.75-in rocket warhead (1)
T-37	523673.73	3374540.29	1.25	ordnance	bomb	moderate	small	BDU33 (86), 2.75-in rocket warhead (2)
T-38	523609.13	3374482.09	1.75	ordnance	bomb	moderate	small	BDU33
T-39	523652.83	3374471.59	1.75	ordnance	bomb	moderate	small	BDU33
T-40	523683.23	3374480.59	1.25	ordnance	bomb	moderate	small	BDU33
T-41	523716.53	3374435.29	1.00	ordnance	bomb	moderate	small	BDU33
T-42	523737.73	3374295.89	0.50	ordnance	projectile	light	small	2.75-in rocket warhead
T-43	523802.63	3374287.19	1.25	ordnance	bomb	moderate	small	BDU33
T-44	523774.43	3374252.89	1.75	--	--	--	--	empty hole
T-45	523659.83	3374253.59	2.50	--	--	--	--	empty hole
T-46	523662.23	3374232.59	2.25	--	--	--	--	empty hole
T-47	524528.84	3374057.15	1.75	--	--	--	--	empty hole
T-48	524555.64	3374131.83	2.00	--	--	--	--	empty hole
T-49	524461.03	3374168.77	0.50	ordnance	projectile	light	small	2.75-in rocket warhead
T-50	524421.64	3374083.49	1.75	--	--	--	--	empty hole (shell casing at surface)
T-51	524477.81	3374089.36	1.75	--	--	--	--	empty hole (link at surface)
T-52	524017.54	3374105.83	0.25	ordnance	projectile	light	small	2.75-in rocket warhead, barbed wire
T-53	524075.45	3374060.74	0.50	ordnance	projectile	light	small	2.75-in rocket warhead
T-54	524148.43	3374047.19	1.75	--	--	--	--	empty hole
T-55	524299.93	3374064.29	1.75	nonordnance				barbed wire
T-56	524304.23	3374067.19	0.25	nonordnance				shell casing, barbed wire, fence post
T-57	524425.71	3374241.38	1.75	--	--	--	--	empty hole
T-58	523864.25	3373964.94	2.50	ordnance	projectile	light	small	2.75-in rocket warhead
T-59	523913.43	3374067.06	1.75	ordnance	projectile	light	small	2.75-in rocket warhead
T-60	523984.45	3374012.49	1.75	--	--	--	--	empty hole
T-61	523916.39	3373986.88	0.25	ordnance	projectile	light	small	2.75-in rocket warhead
T-62	523943.39	3373998.42	0.25	nonordnance	--	--	--	shell casing
T-63	523827.46	3374038.85	2.25	--	--	--	--	empty hole
T-64	523954.50	3373954.06	0.50	nonordnance	--	--	--	3-in square sheet metal
T-65	523933.62	3373905.88	1.00	ordnance	bomb	heavy	large	1000-lb bomb
T-66	523963.28	3373894.26	2.25	--	--	--	--	empty hole
T-67	524015.16	3373896.85	0.50	ordnance	projectile	light	small	2.75-in rocket warhead
T-68	524026.25	3373848.46	1.00	ordnance	projectile	light	small	2.75-in rocket warhead (2)
T-69	523855.96	3374502.41	1.75	ordnance	bomb	moderate	small	Mk76

Note: Easting and Northing coordinates are Universal Transverse Mercator (NAD 27, Zone 016)

Target No.	Easting	Northing	Depth	Type	Class	Weight	Size	Comments
T-011	517183.90	3771581.96	2.00	nonordnance	--	--	--	wire, rust particles
T-012	517071.86	3771459.59	1.75	nonordnance	--	--	--	metal bucket, wire
T-013	517031.34	3771373.25	2.50	nonordnance	--	--	--	concrete-filled cans
T-014	517002.06	3771393.63	1.75	nonordnance	--	--	--	wire
T-015	517059.91	3771410.29	2.00	nonordnance	--	--	--	burn pit, nails, trash
T-017	517205.79	3771476.49	1.75	nonordnance	--	--	--	fragmentation
T-019	517239.74	3771409.01	1.25	nonordnance	--	--	--	wire
T-022	516971.90	3771460.72	2.00	nonordnance	--	--	--	fragmentation, metal cable
T-029	517161.93	3771492.53	1.75	nonordnance	--	--	--	wire
T-030	517215.93	3771439.28	1.75	nonordnance	--	--	--	wire
T-031	517201.57	3771470.07	1.50	nonordnance	--	--	--	fragmentation, rust particles
T-032	517216.09	3771567.69	2.00	ordnance	projectile	moderate	medium	155-mm HE projectile
T-033	517242.88	3771587.06	2.25	--	--	--	--	geologic anomaly
T-034	517254.89	3771638.11	1.75	--	--	--	--	empty hole
T-035	517227.13	3771646.26	2.00	nonordnance	--	--	--	fragmentation
T-038	516921.02	3771871.44	2.25	nonordnance	--	--	--	metal spring
T-045A	517057.00	3771455.00	2.50	--	--	--	--	empty hole
T-045B	517058.25	3771462.64	2.50	nonordnance	--	--	--	fragmentation
T-047	517201.50	3771313.50	1.25	nonordnance	--	--	--	fragmentation
T-050A	517047.00	3771563.00	1.00	--	--	--	--	geologic anomaly
T-050B	517044.00	3771558.00	1.25	--	--	--	--	geologic anomaly
T-051	517127.50	3771508.50	2.00	--	--	--	--	geologic anomaly
T-055	516783.00	3771615.00	2.00	--	--	--	--	empty hole
T-057A	516740.00	3771588.00	0.50	nonordnance	--	--	--	3/8-in cable
T-057B	516743.00	3771593.00	2.00	nonordnance	--	--	--	telephone pole
T-063A	516964.32	3771476.08	2.00	--	--	--	--	empty hole
T-063B	516961.00	3771470.00	2.25	--	--	--	--	geologic anomaly
T-065	517130.13	3771496.30	1.75	nonordnance	--	--	--	fragmentation, wire
T-066	517016.52	3771372.25	0.50	nonordnance	--	--	--	cans
T-067	517043.01	3771392.33	1.50	nonordnance	--	--	--	bricks, building materials
T-068	517214.44	3771505.29	1.75	nonordnance	--	--	--	fragmentation
T-069	517248.81	3771501.80	1.75	nonordnance	--	--	--	fragmentation, rust particles
T-070	517226.32	3771422.93	1.50	nonordnance	--	--	--	fragmentation, wire
T-071	517165.25	3771394.87	0.50	--	--	--	--	empty hole
T-117	516970.70	3771669.12	2.00	--	--	--	--	empty hole

Target No.	Easting	Northing	Depth	Type	Class	Weight	Size	Comments
T-129	517011.17	3771335.36	0.50	nonordnance	--	--	--	trash, metal cans
T-133	516677.46	3767165.86	1.75	nonordnance	--	--	--	fragmentation
T-134	516699.36	3767085.66	2.50	nonordnance	--	--	--	fragmentation
T-135	516736.83	3767152.18	2.25	nonordnance	--	--	--	nail
T-136	516764.95	3767111.55	2.50	--	--	--	--	empty hole
T-137	516747.97	3767167.54	1.75	--	--	--	--	geologic anomaly
T-140	516854.37	3767088.63	1.25	--	--	--	--	geologic anomaly
T-144	516789.24	3767191.37	1.75	--	--	--	--	geologic anomaly

Note: Easting and Northing coordinates are Universal Transverse Mercator (NAD 83, Zone 017)

Live Site ATD - McChord Air Force Base

Validation Target Set

Target No.	Easting	Northing	Depth	Type	Class	Weight	Size	Comments
T-01	5217514.14	539790.81	1.50	--	--	--	--	geologic anomaly
T-02	5216773.87	539846.25	1.50	--	--	--	--	empty hole
T-03A	5216774.90	539985.46	1.50	--	--	--	--	geologic anomaly
T-03B	5216774.59	539983.34	1.50	--	--	--	--	geologic anomaly
T-04	5216743.43	540123.21	0.50	nonordnance	--	--	--	metal door
T-05	5216668.24	540180.33	0.25	nonordnance	--	--	--	463L pallet
T-06	5216670.03	540217.79	2.00	--	--	--	--	empty hole
T-07A	5216672.76	540227.86	0.75	nonordnance	--	--	--	fender, part of metal chair
T-07B	5216674.16	540228.13	0.75	nonordnance	--	--	--	metal table, handlebars

Note: Easting and Northing coordinates are Universal Transverse Mercator (NAD 83, Zone 010)

APPENDIX C

DERIVATION OF P_{random}

APPENDIX C

DERIVATION OF P_{random}

Assessing the detection performance of any system requires considering not only how well it detects the desired UXO targets, but also how many false alarms occur in the process. A system with a high probability of detection ($P_{D,ord}$) and a high rate of false alarms would probably not be feasible for use in the field because excessive resources (such as time, money, and personnel) must be expended to remediate false detections. The most efficient and practical systems are those with high $P_{D,ord}$ values and low false alarm rates.

Demonstrator system $P_{D,ord}$ values can be quantified because of the reasonably large number of emplaced targets at each of the live sites. However, quantifying the false alarm rate at a live site is impossible because the actual number of targets is not known, and a statistically significant number of demonstrator target declarations cannot be investigated for the presence of UXO.

Although the ordnance density is not known at live ranges, comparing the number of reported targets from each demonstrator reveals large differences in the number of potential targets. For example, at U.S. Army Fort Jackson Military Reservation's (Fort Jackson) Churchill Drop Zone, Australian Defense Industries, Pty. Ltd. (ADI), declared 3,223 targets, and Geo-Centers, Inc. (Geo-Centers), declared 5,790 targets – nearly twice ADI's declarations. These differences occurred even though Geo-Centers surveyed less of the range than ADI, and both ADI and Geo-Centers used the same sensor type (magnetometer).

For demonstrators with large numbers of reports, possible causes for this type of difference must be examined. One cause of excessive target reports may be that lower noise levels allow more of the smaller or deeper targets to be detected. These lower noise levels could be due to lowered sensor levels, better signal processing, or more advanced data post-processing techniques. Another cause for excessive target reports may be that higher noise levels (due to sensor noise, electromagnetic interference, or motion contamination) would result in more false reports generated by spurious noise spikes, particularly if the noise were not Gaussian. This latter case is addressed in the following derivation.

If the number of demonstrator reports is assumed to be caused by random noise, one must determine how many targets would be detected by a random distribution of these reports. To quantify this hypothesis, a measure of effectiveness, P_{random}, was developed. P_{random} represents the probability of detection resulting from a random distribution of demonstrator reports.

To develop this measure, the demonstrator survey area A is divided into individual cells of area πR_{crit}^2, where R_{crit} is defined as the critical radius. For a single random declaration, the probability of hitting a specific cell is equivalent to $\pi R_{crit}^2 / A$. This process is repeated over n trials, which corresponds to the number of demonstrator reports. Experiments such as this are known as Bernoulli trials, and they have a wide range of applications. Bernoulli trials are defined as repeated independent trials in which there are only two outcomes (such as a "hit" or a "miss") for each trial, and the probabilities of a hit or miss remain constant throughout the trials (Feller 1968). After n trials, a particular cell may contain from 0 to n reports. According to Feller, the probability of a cell containing exactly k reports after n Bernoulli trials is denoted as $b(k{:}n,p)$ and is defined by the following equation:

$$b(k{:}n,p) = \begin{pmatrix} n \\ k \end{pmatrix} p^{n} q^{n-k}$$

where:

$$\begin{pmatrix} n \\ k \end{pmatrix} = \frac{n!}{(n-k)!\,k!}$$

$$p = \text{Probability of a hit} = \frac{\pi R_{crit}^2}{A}$$

$$q = \text{Probability of a miss} = 1 - p$$

Using the above equation, which is referred to as the binomial distribution, the probability of having no reports in a particular cell ($k = 0$) is q^{n}, and the probability of having at least one report within a cell is $1 - q^{n}$.

For most cases considered in this report, n is large (for Geo-Centers at Fort Jackson's Churchill Drop Zone, n is 5,790), and p is small (for the same example, p is 4.2×10^{-5}). In cases such as these, it is convenient to use the Poisson approximation of the binomial distribution. The Poisson approximation for the probability of a cell containing exactly k reports after n Bernoulli trials is calculated as follows:

$$p(k,\lambda) \approx b(k:n,p)$$

$$= e^{-\lambda} \frac{\lambda^k}{k!}$$

where:

$$\lambda = np$$

As before, the probability of having no reports in a particular cell ($k = 0$) is $e^{-\lambda}$, and the probability of having at least one report within a cell is $1 - e^{-\lambda}$, which is equal to P_{random}.

This Page Intentionally Left Blank

APPENDIX D

SITE SWEEP, VEGETATIVE CLEARANCE, AND REMEDIATION DATA

This Page Intentionally Left Blank

APPENDIX D

SITE SWEEP, VEGETATIVE CLEARANCE, AND REMEDIATION DATA

Military explosive ordnance disposal (EOD) teams participated in the live site advanced technology demonstration project by conducting unexploded ordnance (UXO) surface sweeps, clearing vegetation at sites with dense undergrowth, and excavating demonstrator target declarations. In some cases, military EOD teams were assisted by retired EOD technicians who were hired to support individual tasks.

Table D-1 summarizes data compiled for activities conducted by EOD personnel at U.S. Army Jefferson Proving Ground (JPG), U.S. Army Yuma Proving Ground (YPG), Eglin Air Force Base (AFB), U.S. Army Fort Jackson Military Reservation (Fort Jackson), and McChord AFB. The data may be useful to site managers who wish to conduct these activities as part of a site UXO clearance.

Table D-1
Site Sweep, Clearance, and Remediation Data

Activity and Data Type	JPG	YPG	Eglin AFB	Fort Jackson	McChord AFB
Sweep Data					
Site area (hectares)	86.6	45.7	49.0	60.5	24.0
Resources (personnel)					
EOD	5	Unknown	5	5	6
Non-EOD	25	Unknown	15	20	0
Time (days)	18	Unknown	5	5	3
Effort[a] (man-hours)	4,250	Unknown	1,000	1,250	40
Metal removed[a] (kilograms)	2,750	40-50 semitrailer loads	250	100-150	< 50
EOD targets[a,b]	10-30%	Unknown	< 5%	< 5%	< 5%
Time lost to injury (man-hours)	4[c]	Unknown	0	0	0
Labor intensity (man-hour/hectare)	49	Unknown	20	21	1.7
Debris density (kilograms/hectare)	32	Unknown	5.1	1.7 - 2.5	< 2.1
Vegetative Clearance (brush-hogging only)					
Site area (hectares)	86.6	0	44.0	0	15.0
Resources (personnel)					
EOD	0	0	0	0	0
Non-EOD	2	0	2	0	3
Time (days)	4	0	2	0	17
Effort[a] (man-hours)	64	0	40	0	160
Labor intensity (man-hours/hectare)	0.74	NA[d]	0.91	NA	11

Table D-1 (Continued)
Site Sweep, Clearance, and Remediation Data

Data Gathered	JPG	YPG	Eglin AFB	Fort Jackson	McChord AFB
Resources (personnel)					
EOD	2	0	3	2	2
Non-EOD	2	2	0	2	1
Time (days)	14	20	13	10	4
Effort[a] (man-hours)	450	400	310	320	84
Number of holes	53	42	73	63	16
Trenching[a] (meters)	0	95	0	0	0
Quantity soil excavated[a] (cubic meters)	1,300	1,300	2,300	3,900	500
Excavation rate (hours/hole)	2.1	4.8	1.4	1.3	1.8
Labor intensity (man-hours/hole)	8.5	9.5	4.2	5.1	5.3
Labor intensity (man-hours/cubic meter excavated)	0.35	0.31	0.13	0.08	0.17

Notes:

a Data are approximate.
b Ordnance is not differentiated from nonordnance.
c One individual sustained a sprained wrist during the site sweep.
d Not applicable (NA)

This Page Intentionally Left Blank

APPENDIX E

DEMONSTRATOR TARGET DECLARATION DENSITY PLOTS

This Page Intentionally Left Blank

APPENDIX E

DEMONSTRATOR TARGET DECLARATION DENSITY PLOTS

Data from the live site advanced technology demonstration (ATD) project can be plotted to show target declaration densities at each of the live sites. These plots do not represent the density of unexploded ordnance (UXO) at the sites; instead, the plots represent the density of demonstrator target declarations. Because each demonstrator has a false alarm rate that could not be quantified during the live site ATDs, the plots most likely overstate the quantities of UXO present at each site. Nevertheless, the plots show important subsurface anomalous features for each site, and they may help identify impact patterns or areas that contain more UXO than other areas.

To generate these plots, each site was divided into 5-meter-square cells. The density of demonstrator reports at each cell was computed by first counting the number of demonstrator reports within a 20-meter square centered on that cell, and then dividing by the area of the 20-meter square. The following categories were used to represent relative target declaration densities:

- Very low density: Less than 1 target declaration per acre
- Low density: 1 to less than 10 target declarations per acre
- Moderate density: 10 to less than 25 target declarations per acre
- High density: 25 to 40 target declarations per acre
- Very high density: 40 or more target declarations per acre

Demonstrator target reports outside the range boundary were not included in the density computation, and neither were areas not surveyed by the demonstrator.

Figure E-1
Target Declaration Density Plot for ADI at JPG (Range 18000W)

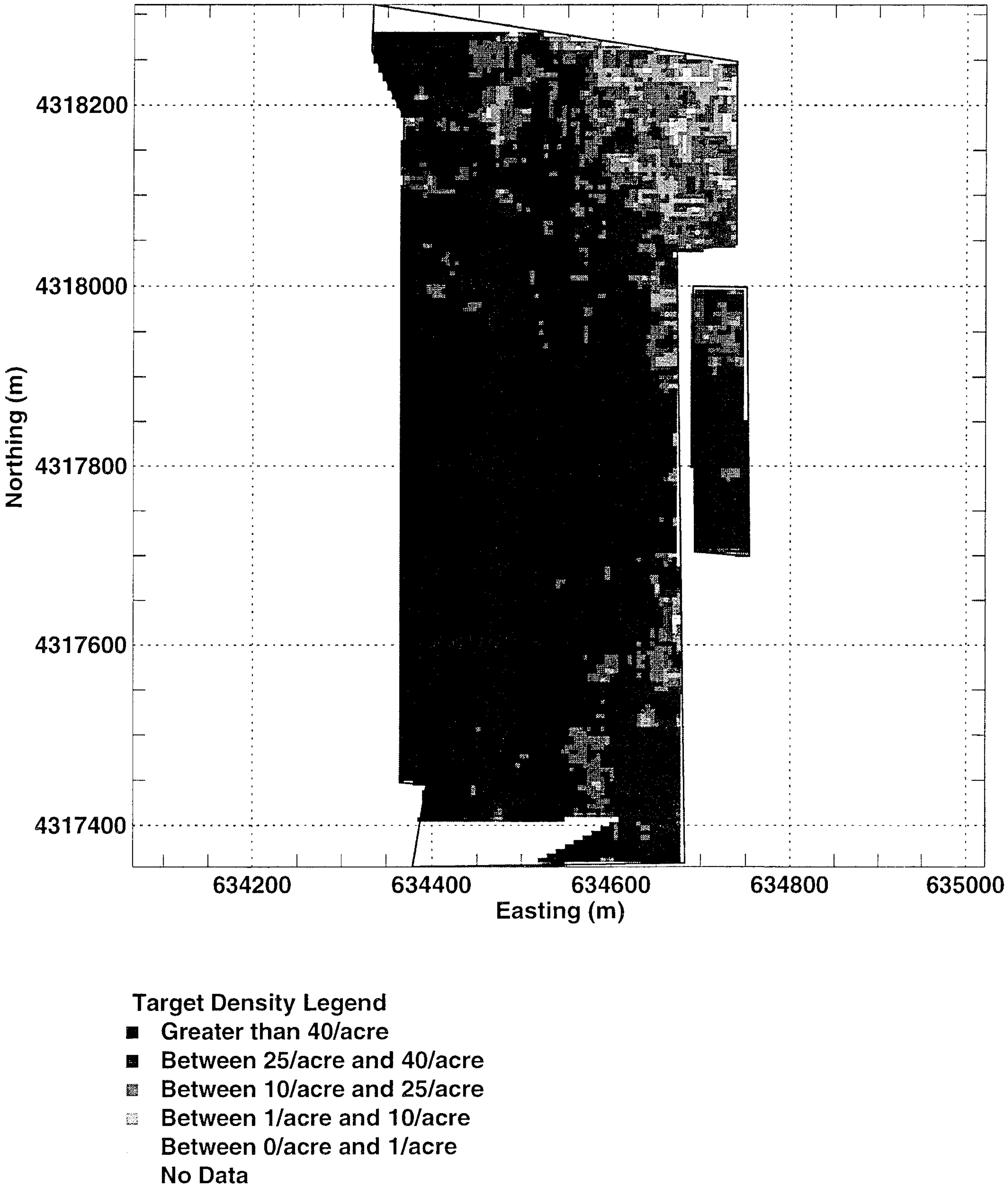
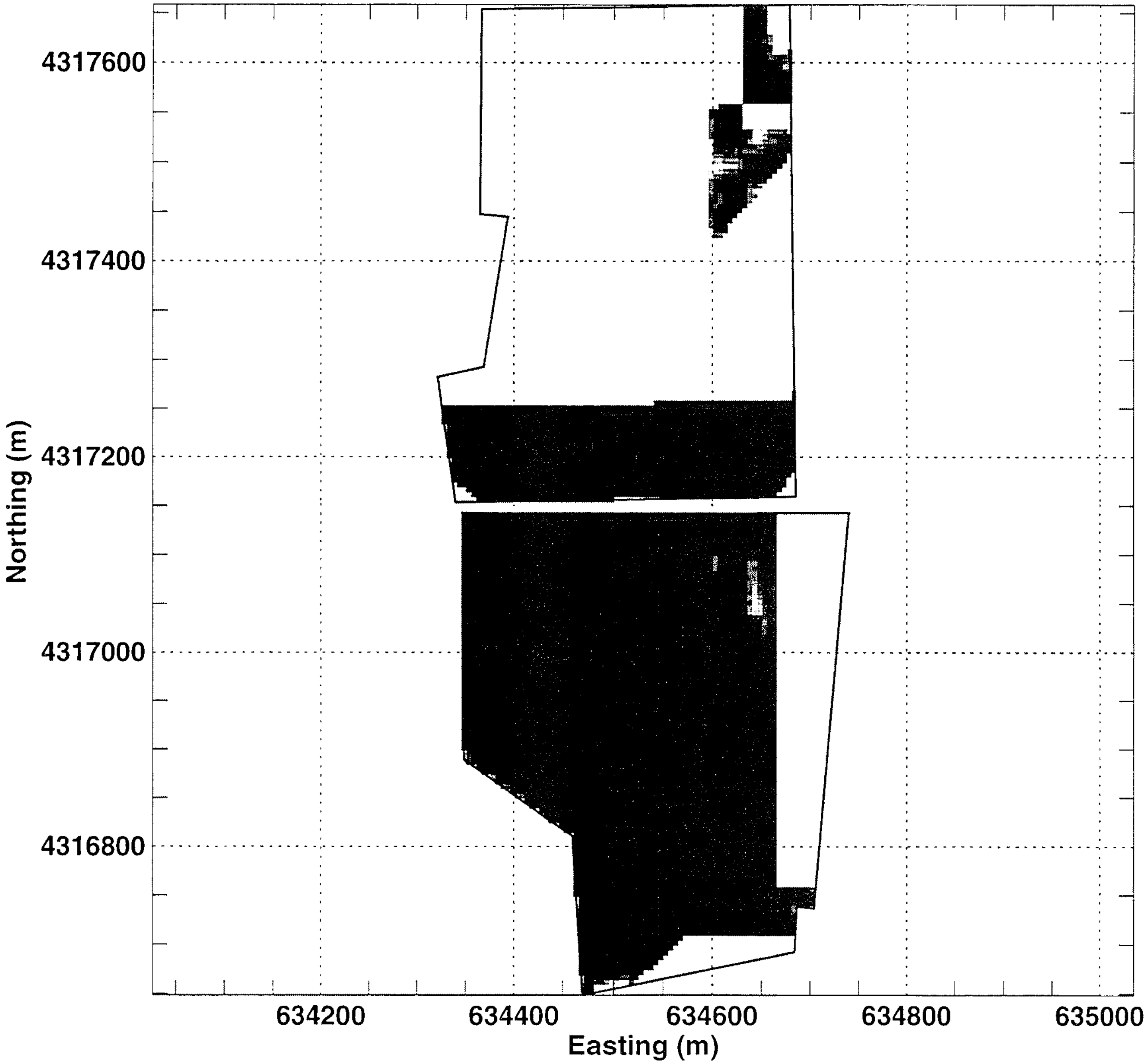


Figure E-2
Target Declaration Density Plot for Coleman at JPG (Range 18000W)



Target Density Legend
■ Greater than 40/acre
▩ Between 25/acre and 40/acre
▨ Between 10/acre and 25/acre
░ Between 1/acre and 10/acre
Between 0/acre and 1/acre
No Data

Figure E-3
Target Declaration Density Plot for ADI at JPG (Range 21000W)

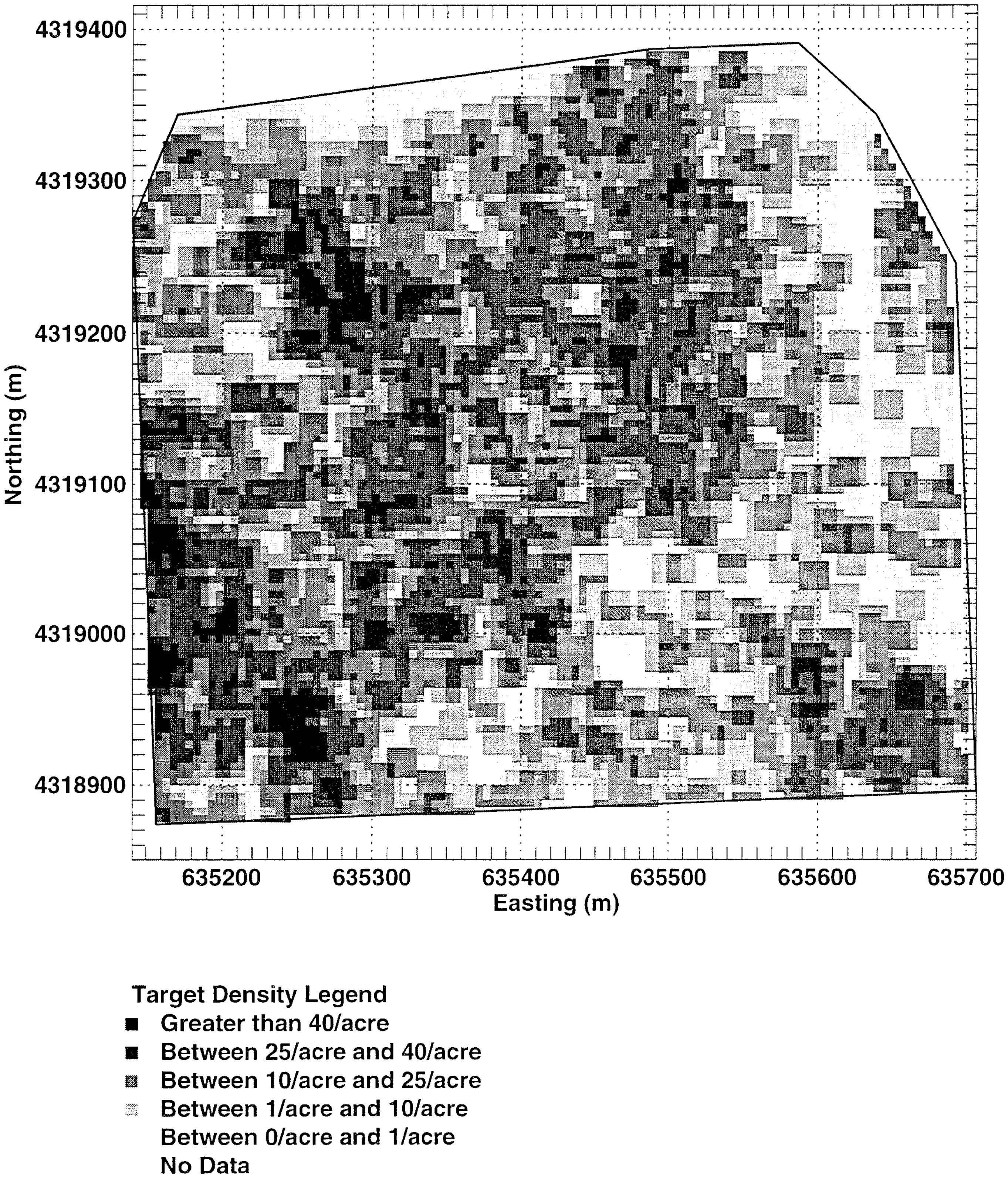


Figure E-4
Target Declaration Density Plot for Coleman at JPG (Range 21000W)

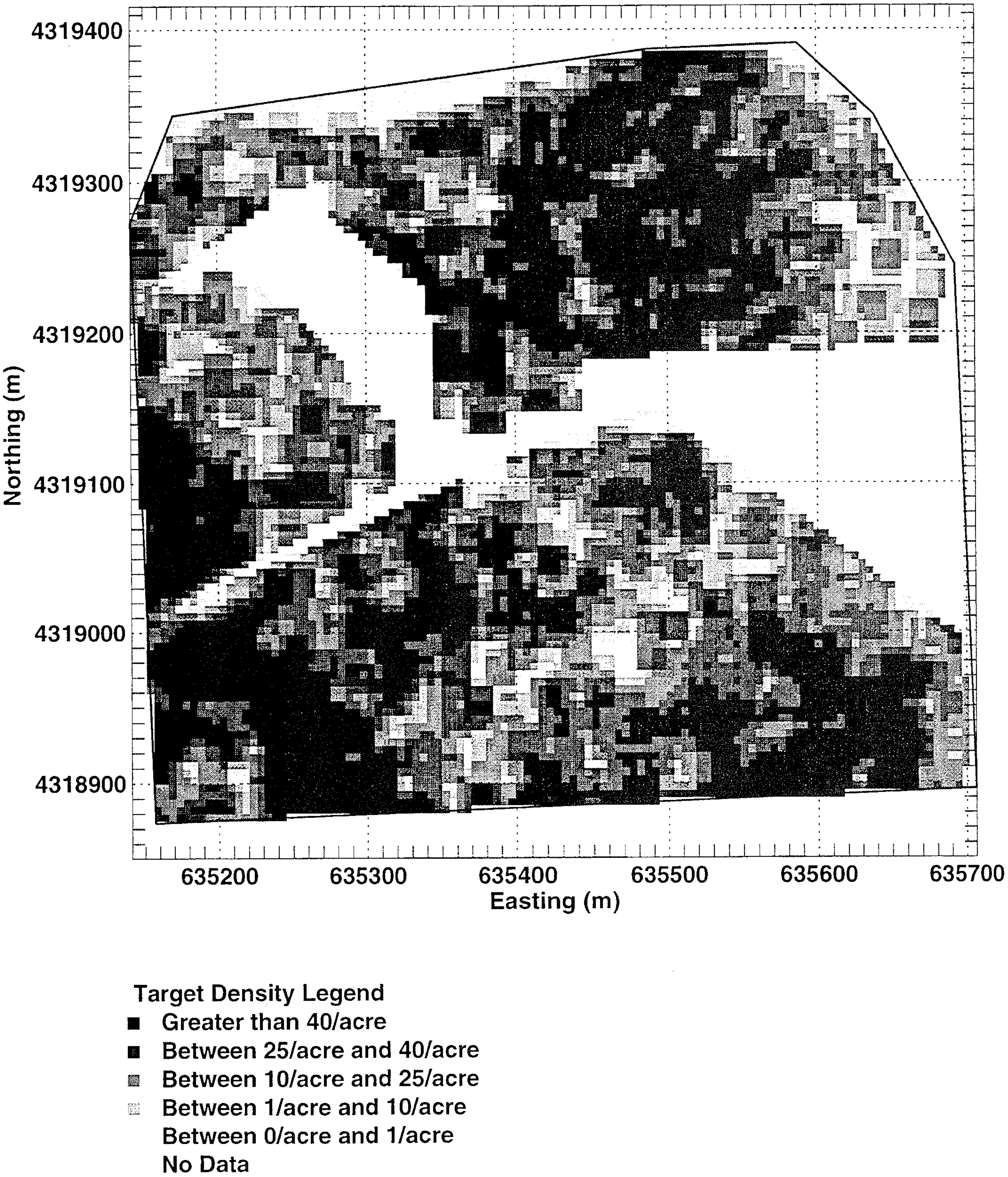


Figure E-5
Target Declaration Density Plot for Geo-Centers at YPG (Steel Circle Range)

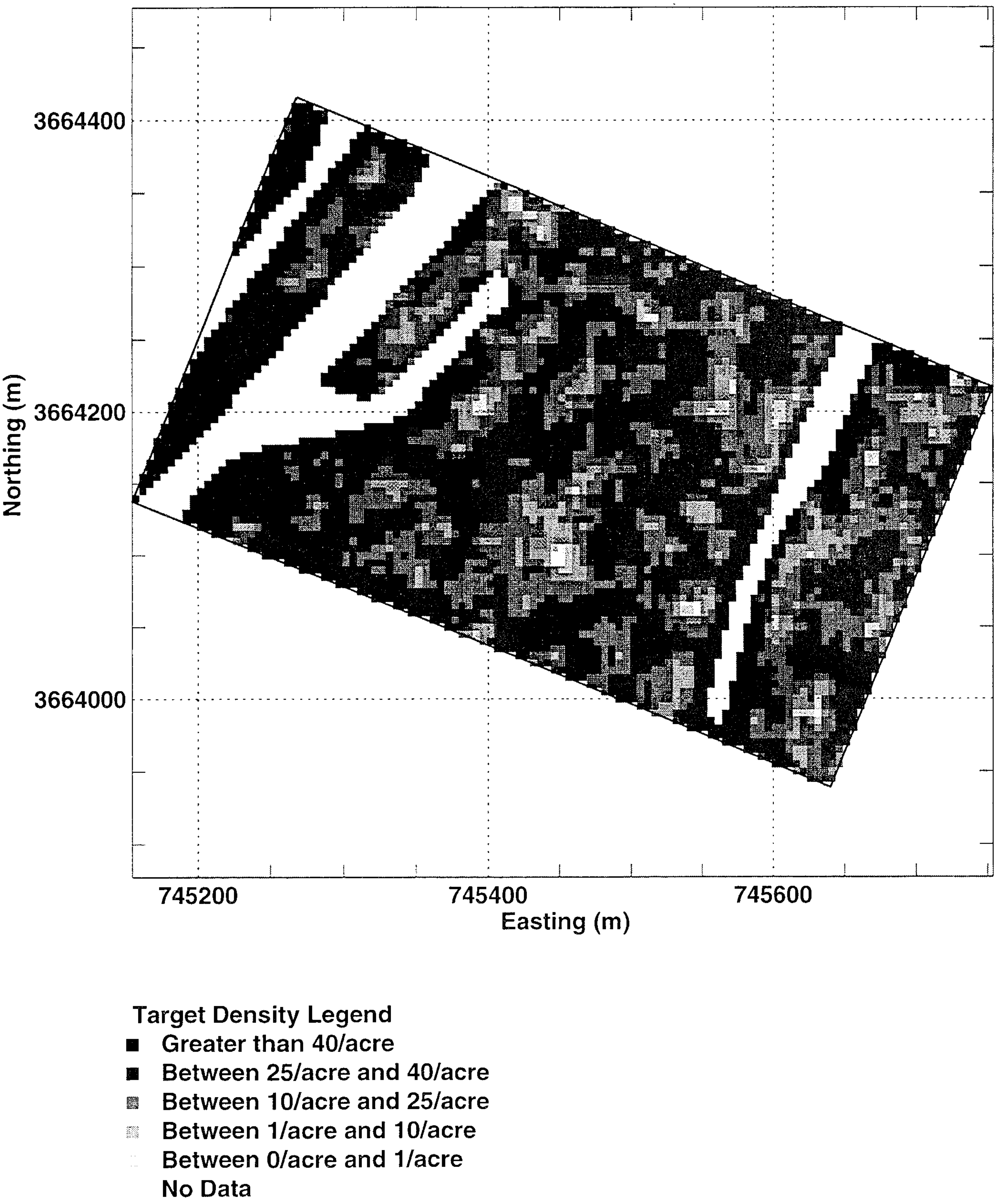


Figure E-6
Target Declaration Density Plot for Metratek at YPG (Steel Circle Range)

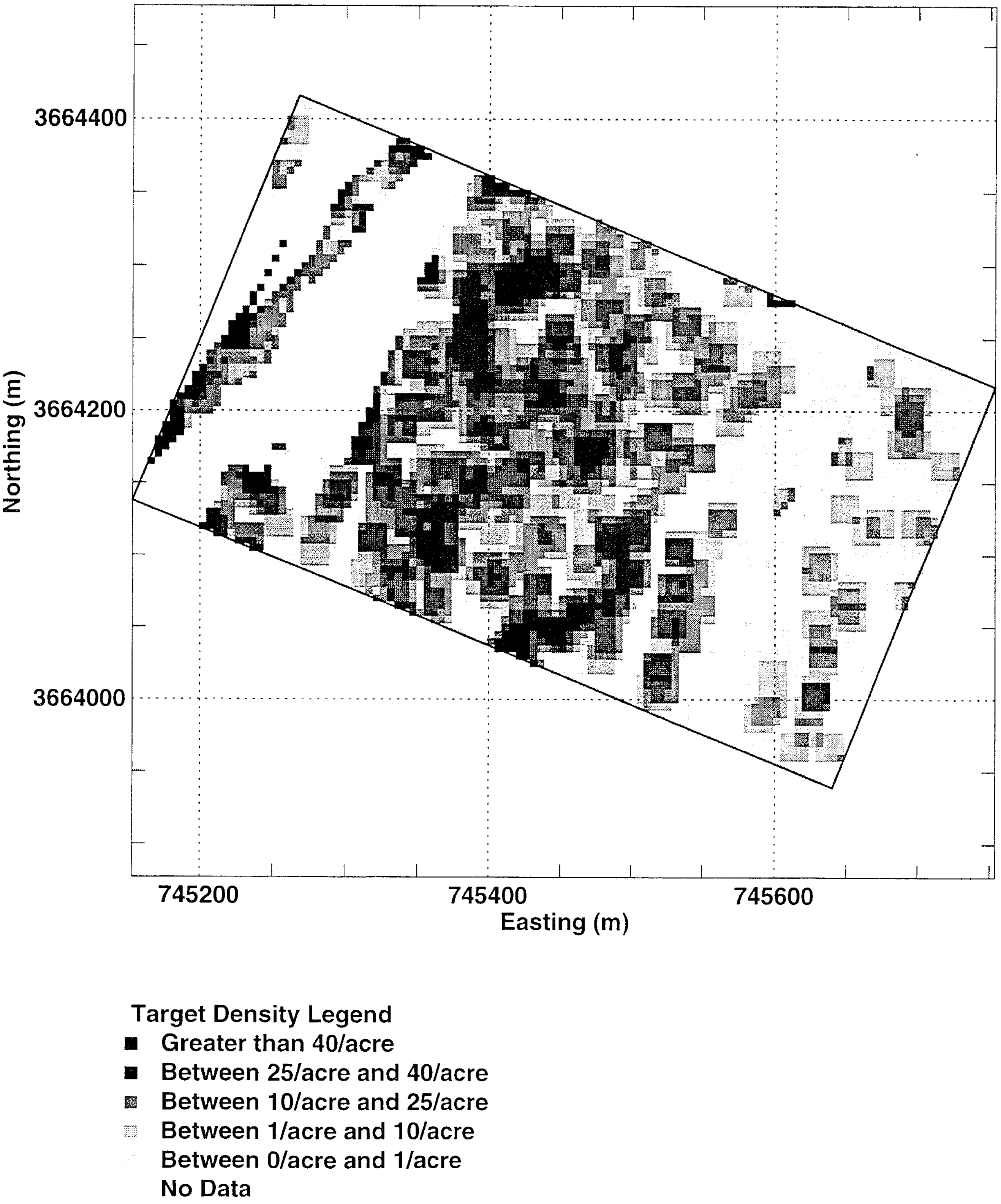
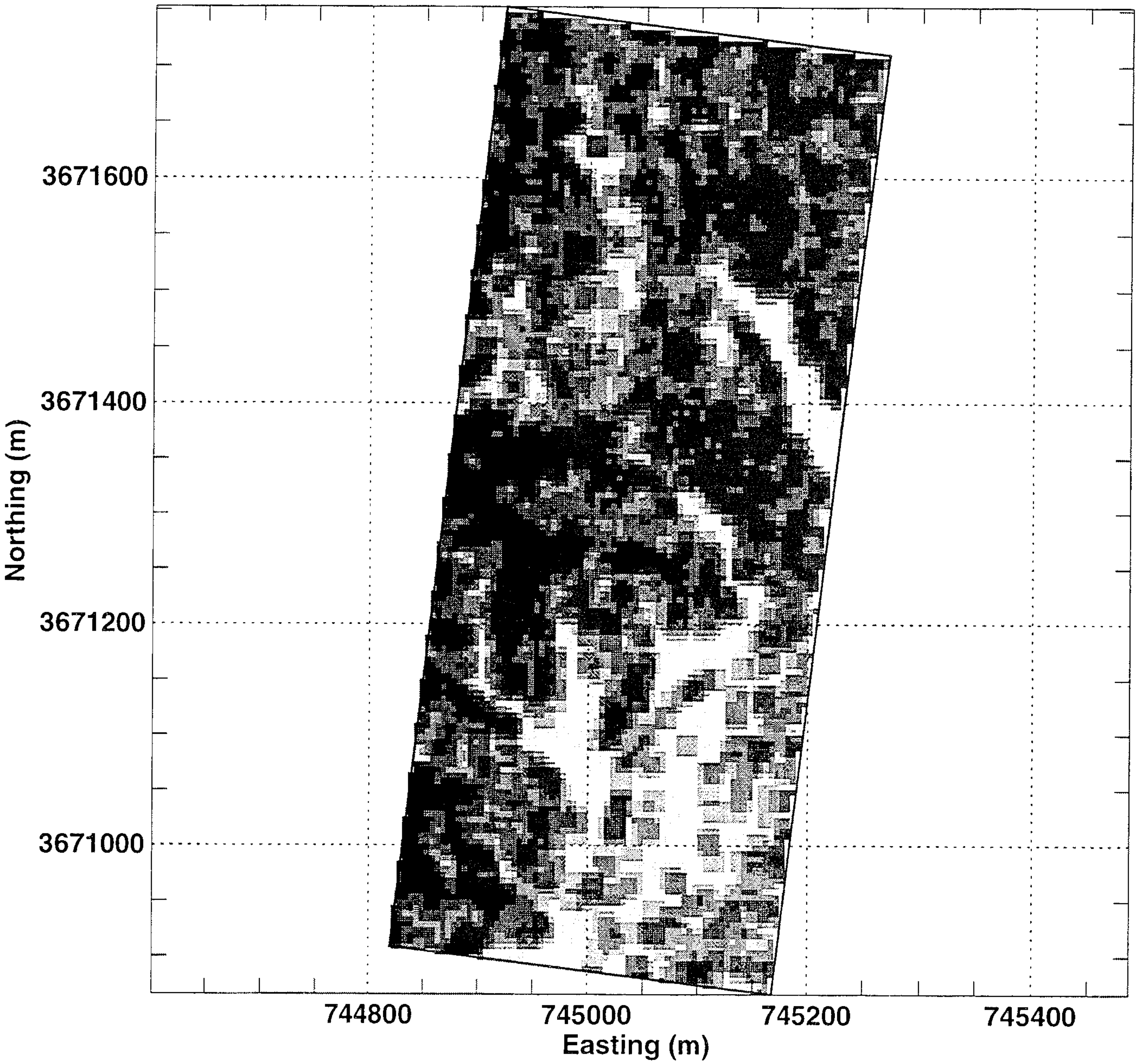
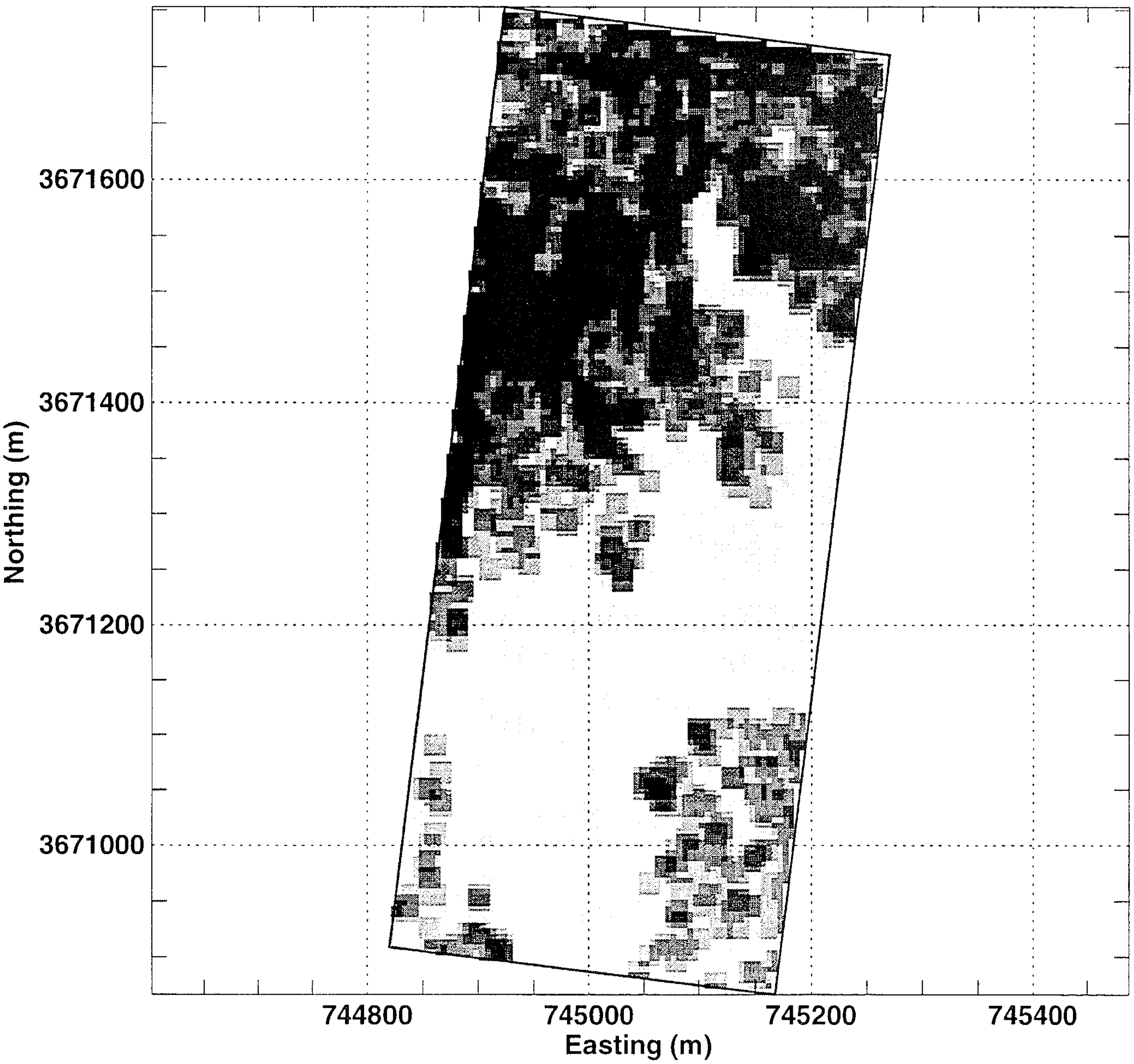


Figure E-7
Target Declaration Density Plot for Geo-Centers at YPG (Hulk 3 Range)



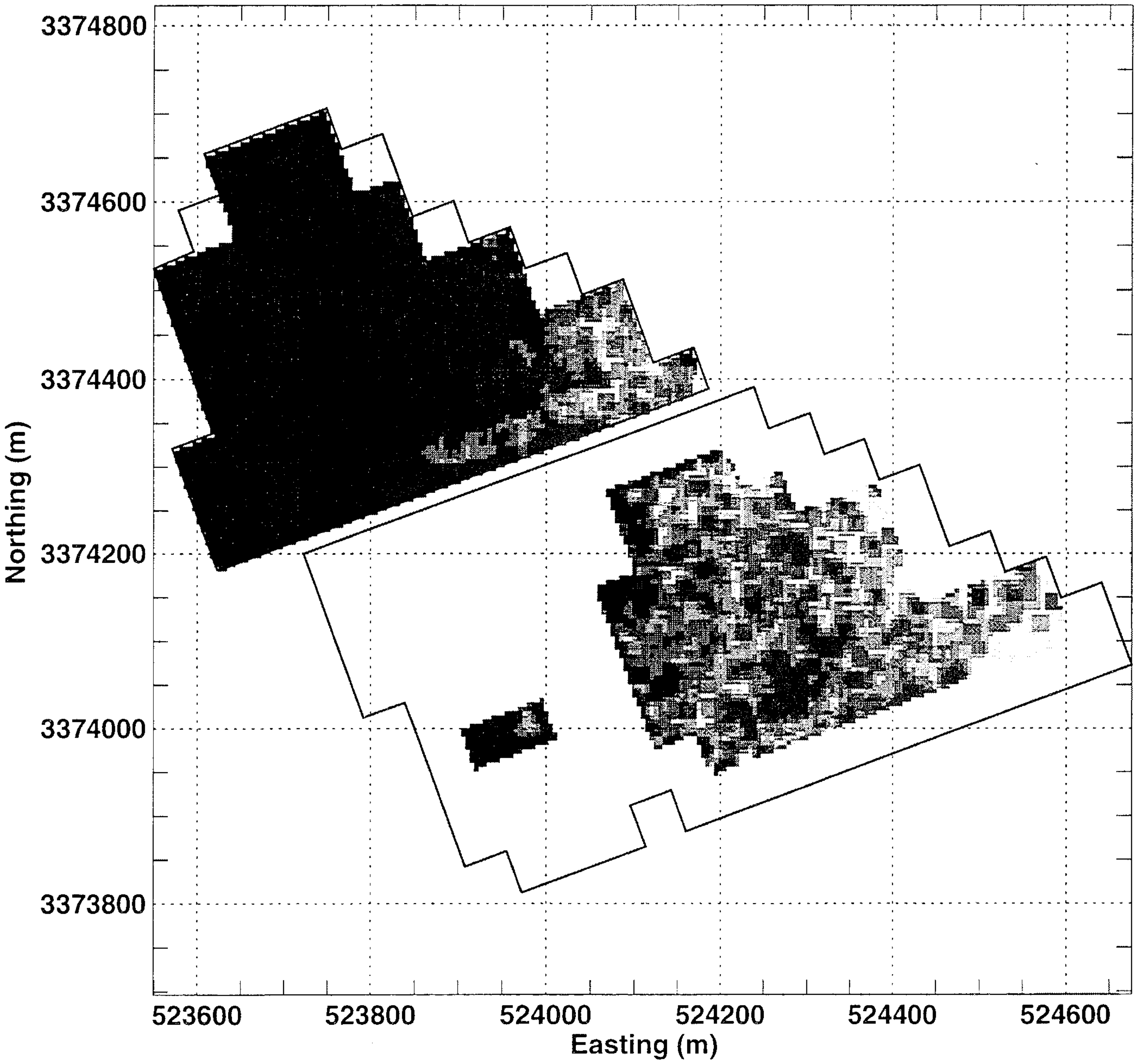
Target Density Legend
- ■ Greater than 40/acre
- ■ Between 25/acre and 40/acre
- ▨ Between 10/acre and 25/acre
- ░ Between 1/acre and 10/acre
- Between 0/acre and 1/acre
- No Data

Figure E-8
Target Declaration Density Plot for Metratek at YPG (Hulk 3 Range)



Target Density Legend
■ Greater than 40/acre
▩ Between 25/acre and 40/acre
▨ Between 10/acre and 25/acre
░ Between 1/acre and 10/acre
Between 0/acre and 1/acre
No Data

Figure E-9
Target Declaration Density Plot for Coleman at Eglin AFB (Range A-73)



Target Density Legend
- ■ Greater than 40/acre
- ▩ Between 25/acre and 40/acre
- ▨ Between 10/acre and 25/acre
- ░ Between 1/acre and 10/acre
- Between 0/acre and 1/acre
- No Data

Figure E-10
Target Declaration Density Plot for Vallon at Eglin AFB (Range A-73)

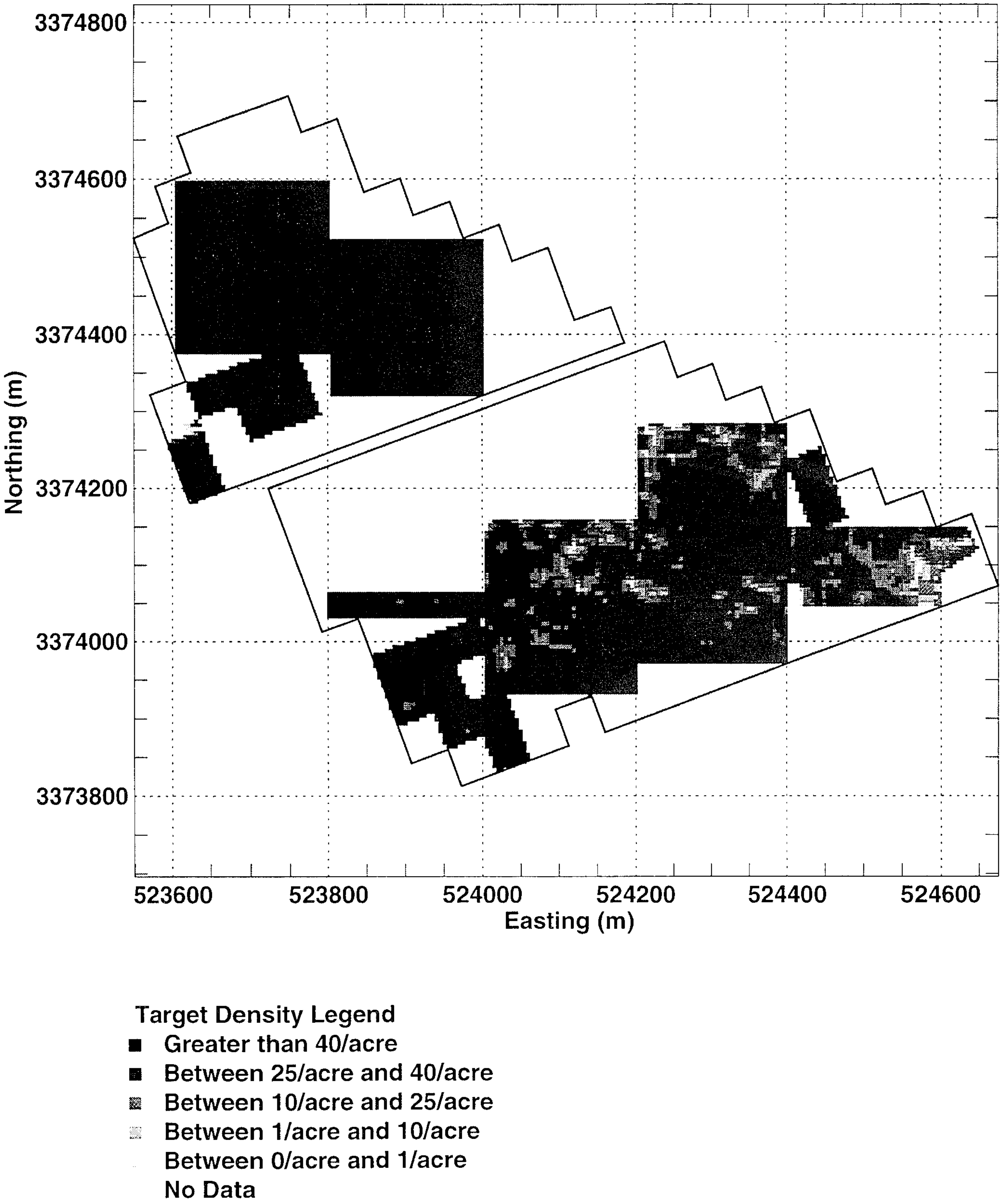


Figure E-11
Target Declaration Density Plot for ADI at Fort Jackson (Churchill Drop Zone)

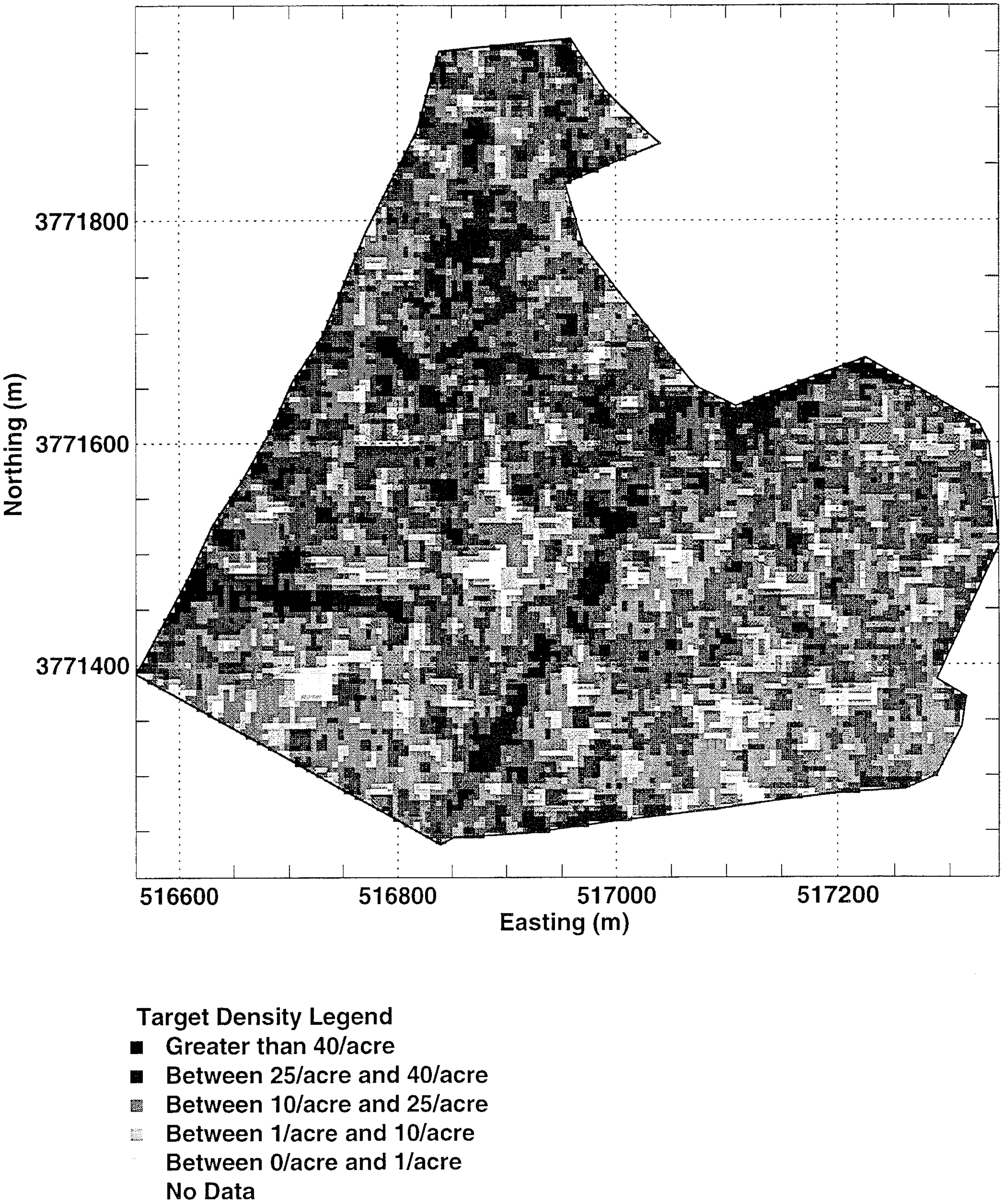


Figure E-12
Target Declaration Density Plot for Geo-Centers at Fort Jackson (Churchill Drop Zone)

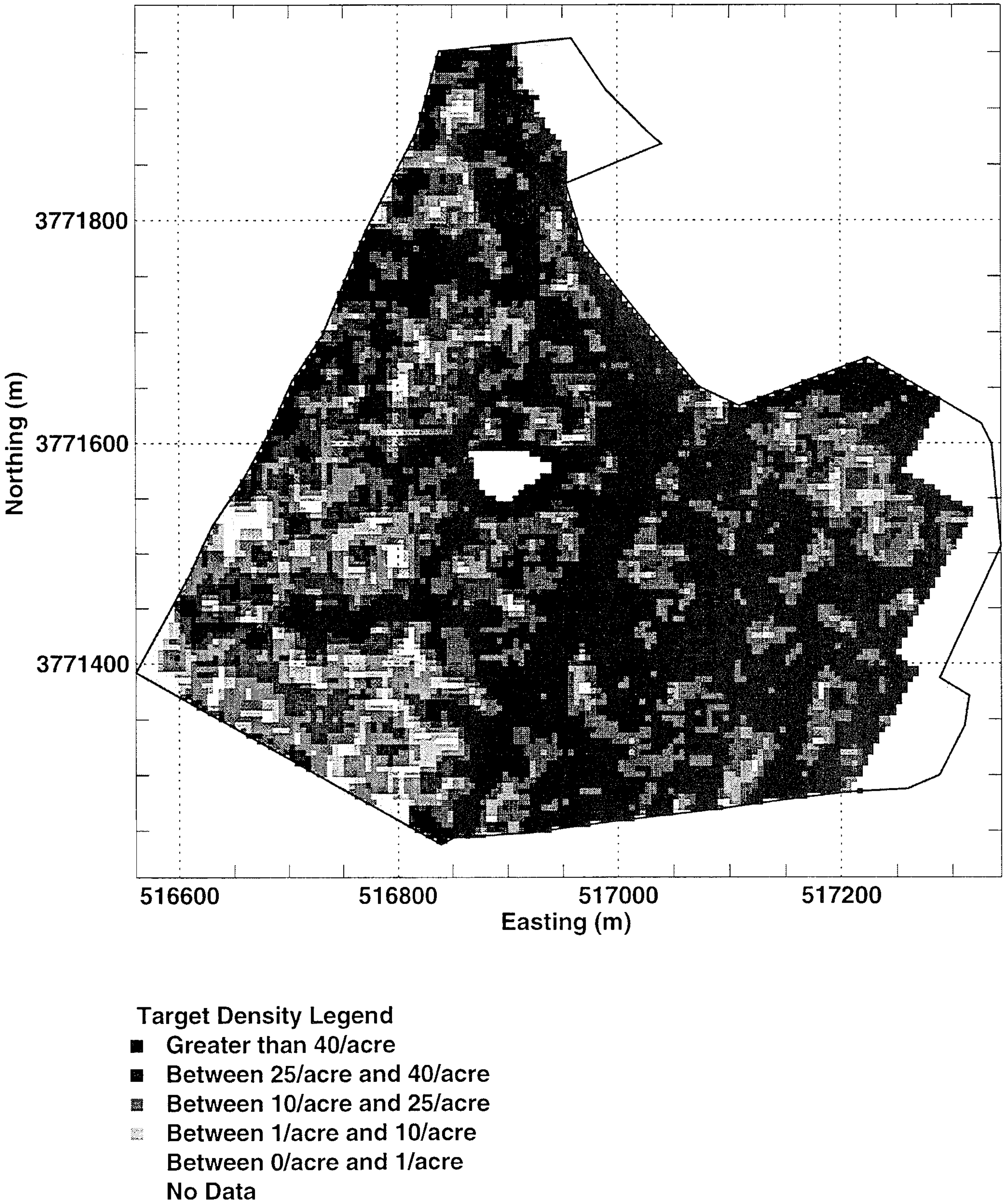
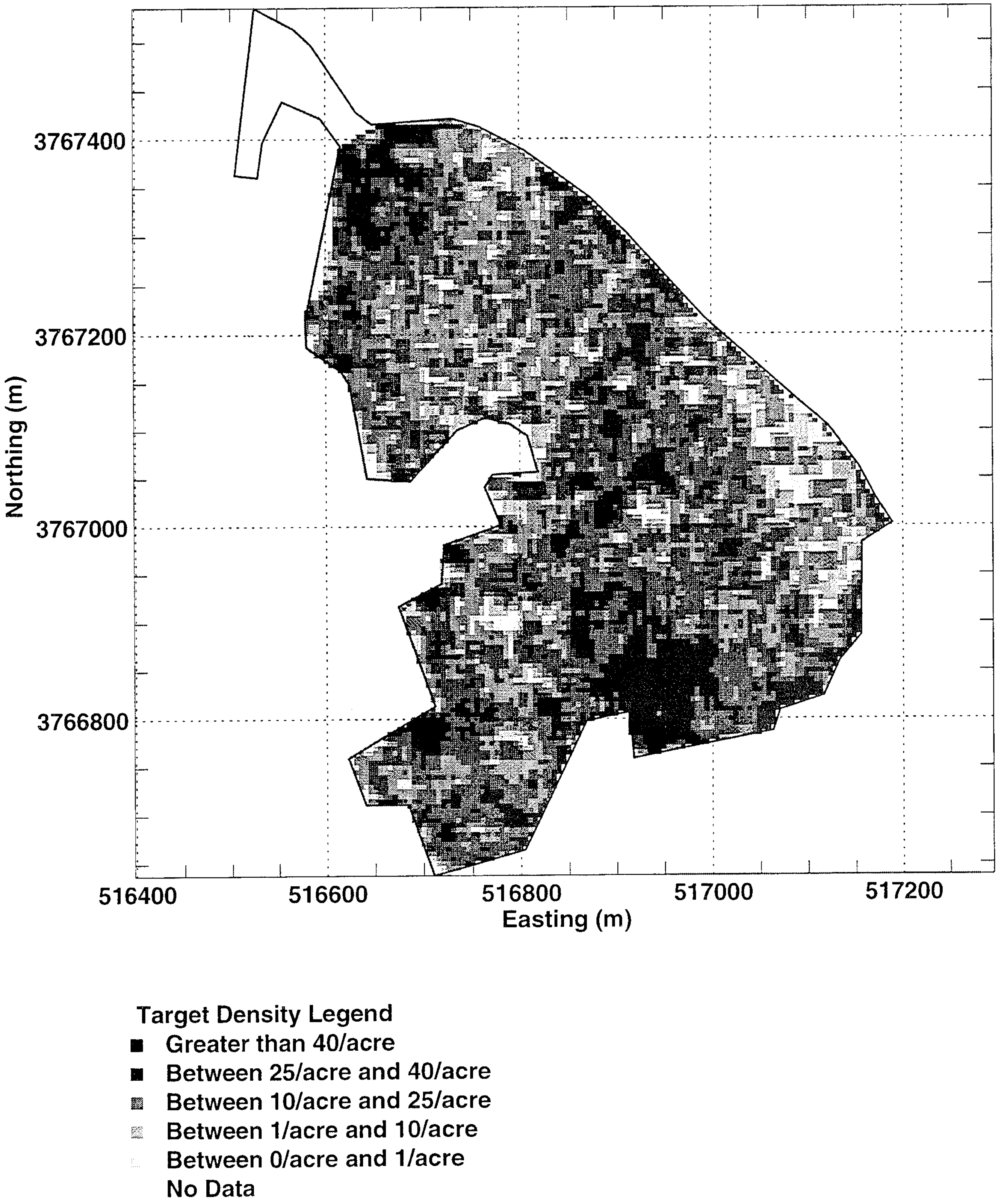


Figure E-13
Target Declaration Density Plot for ADI at Fort Jackson (Artillery Road Site)



This Page Intentionally Left Blank

Figure E-14
Target Declaration Density Plot for Metratek at McChord AFB (South 40 Training Area)