CONTROLLED SITE

ADVANCED TECHNOLOGY DEMONSTRATION PROGRAM

PHASE III

U.S. ARMY JEFFERSON PROVING GROUND
MADISON, INDIANA

Prepared for U.S. Army Environmental Center

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13. ABSTRACT (*Maximum 200 words*)

The third in a series of unexploded ordnance (UXO) technology demonstrations at Jefferson Proving Ground, Madison IN, was conducted September through November, 1996. An existing controlled site was modified to incorporate geographically defined UXO scenarios, including an aerial gunnery range, artillery and mortal range, grenade and submunition range and an interrogation and burial area. The performance of 15 companies in detecting, localizing, characterizing or excavating UXO on these sites is documented in this report. In general, demonstrators detected and localized a significant portion of the emplaced UXO. Remotely operated excavation systems also demonstrated their capabilities to remove ordnance from the ground. A strong technology initiative is recommended to address needed improvements in the capability to distinguish ordnance and nonordnance.

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EXECUTIVE SUMMARY

The U.S. Army Environmental Center (USAEC) has an established program to assess technologies suitable for the detection, identification, and excavation of unexploded ordnance (UXO). This report presents the results of the third series (Phase III) of UXO Advanced Technology Demonstrations (ATD) completed at Jefferson Proving Ground (JPG) in Madison, Indiana. The analysis documents the performance capabilities of 15 demonstrators who participated in the Phase III ATD, and compares their overall performance to what was achieved in two earlier Phases. Demonstrators in all three Phases were required to either search/detect/characterize or excavate inert ordnance that was deliberately emplaced for the ATD. The performance data define the capabilities and limitations of UXO technologies, as demonstrated under the JPG test conditions and evaluated by the ATD methodology. This data will be useful to those who wish to better understand the challenges posed by UXO, and to those who may have to respond to those challenges.

The need...

UXO technology deficiencies came to the forefront of our nation’s newspapers with the public’s realization that the base realignment and closure (BRAC) process would not result in the immediate turnover of formerly used, Department of Defense (DoD) properties. A legacy of bombs, missiles, and rockets decades old, and even cannonballs from the past century restricts unlimited public use or access to these lands. In addition, active DoD installations considering alternative land uses must face unknown hazards, as record keeping of past ordnance usage was nonexistent or incomplete. Installation managers need to know the capabilities of UXO technologies. There is an enormous demand to characterize properties just so the extent of the UXO hazard can be defined. In addition, there is a demand for lands to be returned to the public domain through UXO remediation efforts. UXO cleanup efforts are estimated to cost in the tens of billions of dollars.

The response...

The U.S. Congress established the UXO-ATD program to focus technology on reducing the unfunded liability and the time needed to characterize and remediate property. Congress recognized the need for more cost-effective and safer technologies. The USAEC manages the ATD program at JPG under the Congressional mandate to demonstrate advanced and innovative UXO technologies. A meaningful framework for understanding UXO technology performance was established by publishing public criteria and metrics. The ATD program would not only benefit restoration managers, who need to know more than just how to spell “ordnance” correctly, but also technology developers who would have quantifiable goals to seek against published performance.

Phases I and II...

In the first two phases, conducted in 1994 and 1995 respectively, ordnance was emplaced that was representative of different UXO conditions. Two sites, 16 and 32 hectares, were established for ground-based and airborne technology demonstrations. There were 29 demonstrations in Phase I and 17 demonstrations in Phase II. These demonstrations showed that airborne platforms and ground penetrating radar (GPR) sensors did not perform well under the test conditions at JPG. Demonstrators who used a combination of sensors (electromagnetic induction and magnetometry) had the best performance. The better performers in Phase II detected over 80 percent of the ordnance, but they also reported three to twenty times more targets (false alarms) than actual ordnance. The inability to distinguish ordnance from the prevalent farming debris at the site was noted, because this would likely be a major cost factor in remediating UXO properties. Excavation demonstrations of remotely operated systems were also demonstrated at the two Phases. Excavators could unearth ordnance at only a fractional rate (<5%) of how fast demonstrators could detect it.

Phase III ...

In Phase III, the ordnance layout was changed from the earlier Phases to represent geographically-defined UXO scenarios. An Aerial Gunnery Range (1), Artillery and Mortar Range (2), Grenade and Submunition Range (3), and Interrogation and Burial Area (4) were established on the 16 hectare site. Demonstrators were allowed to select the scenarios that best represented their system’s capabilities for detection, localization and or characterization of the UXO. Remote excavation technologies were also solicited. Fifteen proposals were funded at a maximum of $75K. One company, Sanford Cohen and

Associates (SC&A) formed a teaming arrangement with three survey demonstrators (ADI, Geo-Centers Inc., and Geometrics) to apply SC&A's advanced data processing to their data. Geophysical Research Institute (GRI) reported their magnetometer (Mag), electromagnetic induction (EM), and combined sensor (Combined) target data separately. ADI used a Mag in (1) and (2) and EM and Mag in (3). The overall detection performance of the Phase III demonstrations is summarized in **Table ES-1**, as categorized by sensor technology.

TABLE ES-1

DEMONSTRATOR ORDNANCE DETECTION BY SENSOR TECHNOLOGY
COMBINED SCENARIOS (1, 2, AND/OR 3)

Sensor Type	**Demonstrator (Scenario #)**	**P_D**	**False Alarm (FA) Rate (#/Hectare)**	**FA Ratio (#/Ordnance Detected)**
Electromagnetic Induction (EM)	CHEMRAD (1,2)	0.50	12.90	1.91
	GRI (EM) (1,2,3)	0.87	123.89	8.46
	GeoPotential (1,2,3)	0.06	9.04	8.54
Gradiometer (Grad)	Foerster (1)	0.60	36.46	4.85
Magnetometer (Mag)	Battelle (2)	0.12	1.71	1.00
	GRI (Mag) (1,2,3)	0.70	223.68	18.82
	Rockwell (1,2)	0.34	25.93	5.70
EM & Grad	Geophex (1,2)	0.77	32.44	3.11
EM & Mag	ADI (3; Mag only in 1,2)	0.78	109.48	8.30
	GRI (Combined) (1,2,3)	0.93	240.53	15.23
	Geo-Centers (1,2,3)	0.93	81.80	5.18
	Geometrics (2)	0.90	38.44	3.00
	NAEVA (1,2)	0.94	24.84	1.96
	SCA_ADI (3; Mag only in 1,2)	0.63	46.80	4.36
	SCA_Geo-Centers (1,2,3)	0.76	43.55	3.36
	SCA_Geometrics (2)	0.96	41.86	3.06
Ground Penetrating Radar & EM & Grad	ENSCO (1,2)	0.70	48.66	5.14
	Averages:	0.68	67.18	6.00

Note: Detection probabilities are based on detecting all the ordnance within a given Scenario. Battelle, CHEMRAD, Foerster, Geo-Centers, and GRI did not survey their entire Scenario(s).

The table shows that overall performance was satisfactory, as many demonstrators found more than 90 percent of the baseline ordnance. The comparison of these results to the earlier Phases is shown in **figure ES-1**, the probability of ordnance detection versus the false alarm rate in false alarms per hectare. Good performance is in the upper-left hand corner of the plot. The general trend is that detection is improving (movement up the plot) but target discrimination (false alarm rate) has not changed (no movement to the left edge of the plot). Localization performance for ground-based demonstrators continues to improve since Phase I as shown in **figure ES-2**. Remote target excavation feasibility was shown, but target excavation can take one half hour or better per target.

In Summary...

The strengths and capabilities of UXO technologies were demonstrated to show continued and satisfactory improvement in detection performance. Because there has been no substantial change in the ability of demonstrators to discriminate UXO from the clutter at JPG, a focused effort is needed to resolve this issue. A poor target discrimination capability means remediation efforts will likely suffer from excessive expenditures of time and money. A strong initiative is needed to encourage the further development of advanced data processing and new approaches that can address this technology deficiency. It is recommended that:

- Target discrimination goals be established.
- Standard formats for raw sensor data be established.
- Factors that affect ordnance and nonordnance discrimination be identified.
- Raw sensor data with ground truth be made available to the developers of discrimination algorithms.
- Innovative and high-risk technologies be funded for further development.
- Facilities and a test area at JPG be made available to those who wish to use it for technology development.

Figure ES-1

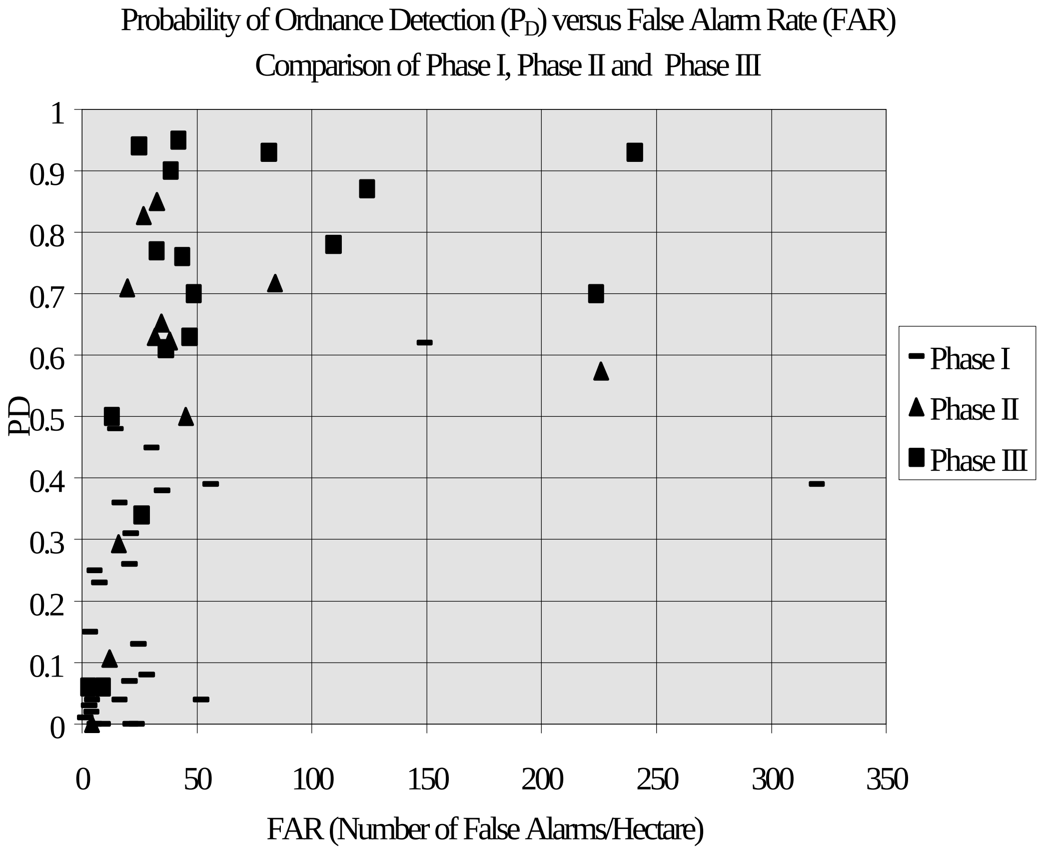
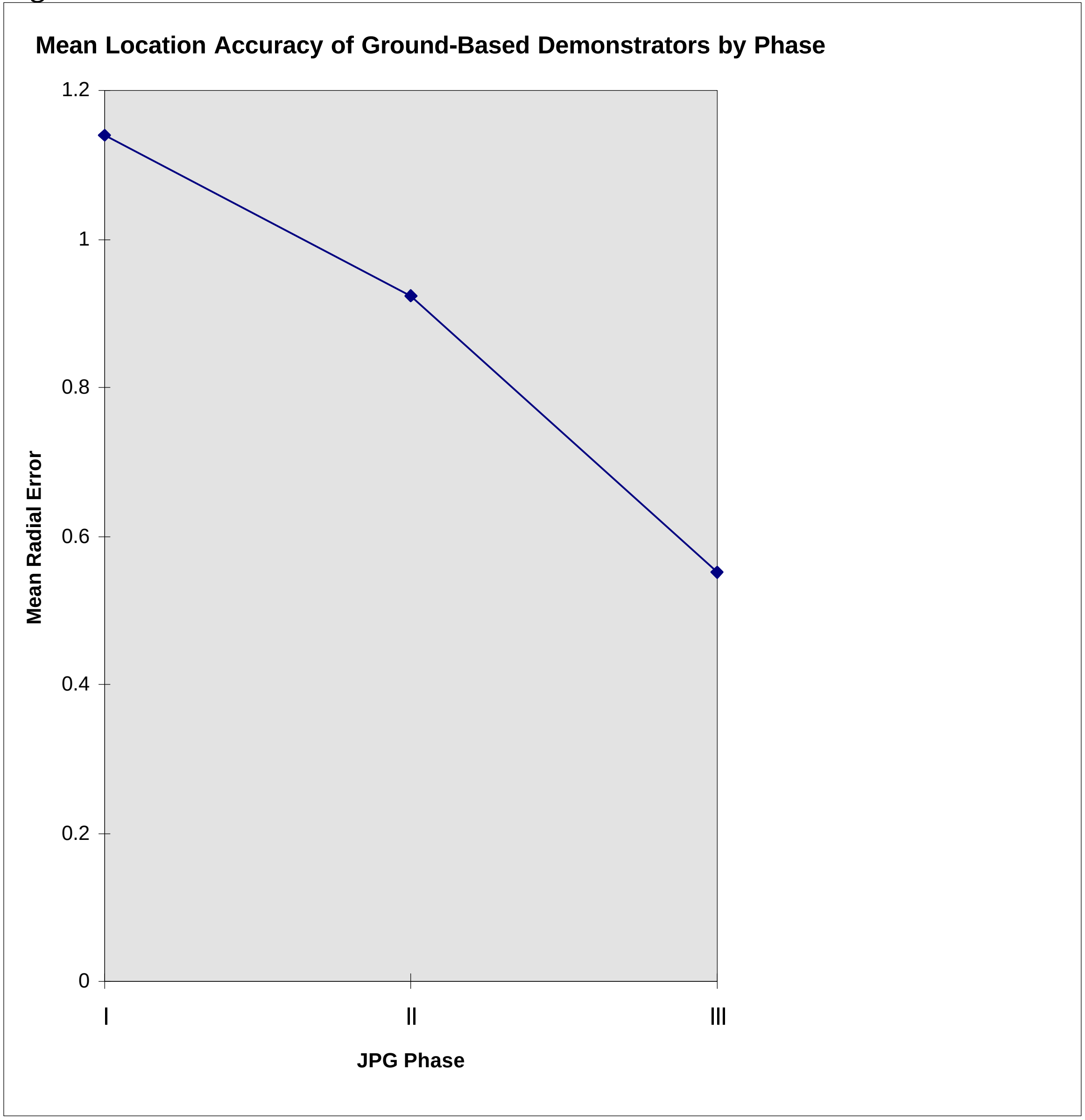

Probability of Ordnance Detection (P_D) versus False Alarm Rate (FAR)
Comparison of Phase I, Phase II and Phase III
PD
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
50
100
150
200
250
300
350
FAR (Number of False Alarms/Hectare)
Phase I
Phase II
Phase III

Figure ES-2



Mean Location Accuracy of Ground-Based Demonstrators by Phase
Mean Radial Error
1.2
1
0.8
0.6
0.4
0.2
0
I
II
III
JPG Phase

1.0 INTRODUCTION

The U.S. Army Environmental Center (USAEC) has an established program to assess technologies suitable for the detection, identification, and excavation of unexploded ordnance (UXO). The U.S. Congress initiated this program to identify innovative technologies that would provide more effective, economical, and safer methods for removing ordnance from lands once used for U.S. Department of Defense (DoD) military training and testing activities. USAEC has established a project to meet the congressional mandate by:

- Establishing public criteria and metrics that provide a meaningful framework for understanding and assessing UXO technology;
- Providing an opportunity with funding for demonstrators to undergo an unbiased assessment of their UXO technologies, and providing these demonstrators target data so that they could undertake system improvements;
- Documenting the performance of advanced technologies demonstrated on controlled sites with inert ordnance and live (ordnance) sites so that decision makers have a better understanding of the capabilities and limitations;
- Seeking to improve the demonstration methodology so that the results are more applicable to actual UXO clearance operations and decision making.

This report covers Phase III, the third in a series of controlled site demonstrations that have been conducted at Jefferson Proving Ground (JPG) in Madison, Indiana. The Naval Explosive Ordnance Disposal Technology Division, PRC Environmental Management Inc. (EMI), and Litton/PRC Inc. provided technical assistance.

1.1 PROGRAM BACKGROUND

The Base Realignment and Closure process brought increased attention to the problem of UXO on Department of Defense (DoD) properties and Formerly Used Defense Sites (FUDS). The methods for removing UXO from the land were of questionable effectiveness, labor-intensive, and costly. HR 5504 established the Advanced Technology Demonstration (ATD) program to identify and evaluate technologies for UXO detection and remediation (U.S. House of Representatives [USHR] 1992a, 1992b, 1992c). In 1994, Phase I demonstrations were carried out in at JPG on two sites seeded with representative UXO targets. Meaningful criteria were established for UXO detection, localization, and classification. In 1995, the Phase II controlled site program was continued at JPG while additional technology demonstrations were being conducted on five live ranges across the United States. The conclusion of these trials and the limited funding available led to a re-examination of the ATD program objectives for Phase III. Congress (USHR 1994) had noted in their funding authorization that this would be the last year that they would direct the Army to continue the JPG Project.

The JPG ATD philosophy has been to measure the system performance of selected technology demonstrators and not examine the subsystem (e.g. sensor) data or the intermediate data steps. System performance evaluations are relevant to the needs of Government decision makers and Installation managers. With this results-oriented approach, the burden is placed on the demonstrators to use adequate search procedures and to make those tradeoffs needed to accomplish the task at hand. The JPG proposal selection process, demonstration methodology, and evaluation criteria are intended to influence the choices technology users make to solve the “UXO problem”. By reviewing publicized criteria and technological capabilities, developers and customers of these technologies have a better sense of what is available and what is needed in the competitive market environment. The Phase III ATD goals are designed to represent the needs of the UXO community as guided by the Congressional charter. In order to put Phase III in perspective, it is first necessary to review the objectives of the earlier phases and some of the issues surrounding the ATDs.

1.1.1 JPG Phase I.

The objectives for JPG Phase I included evaluating existing and promising UXO technologies. Two controlled test site areas were prepared: a 16-hectare (40-acre) site for ground system demonstrations and a 32-hectare (80-acre) site for airborne system demonstrations. A variety of inert ordnance and nonordnance items were emplaced at depths and orientations representative of formerly used defense sites and active military ranges with impact sites and disposal areas. The position of each item was surveyed to provide a means to measure demonstrator performance. Technologies were solicited that could be used to survey either site within five days, or that could be used to remotely excavate ordnance.

There were 29 system demonstrations (some companies did multiple demonstrations) conducted from April through October 1994 (USAEC 1995). These demonstrations showcased a variety of sensor platforms, including man-portable, vehicle, combinations of man-portable and vehicle, and airborne, and also included three remote excavation demonstrations. Sensor technologies included magnetometer systems, electromagnetic induction systems, ground penetrating radar (GPR) systems, infrared systems, and variants or combinations of the above.

The results showed that demonstrators could not detect more than two-thirds of all the emplaced ordnance (less than 40 percent was more typical), and that few companies (four demonstrations of twenty) were able to complete a search goal of 16 hectares in five days. Airborne systems performed poorly per the detection evaluation protocol, having 0 to 8 percent detection probability. No significant target classification capabilities were demonstrated in Phase I, and multiple false targets (typically three to ten) were detected for every baseline ordnance item detected. The excavation systems were generally slow (averaging just under one hour to excavate a target), prone to breakdowns (the three systems were able to excavate only 4 to 11 targets in 40 hours), but at least proved successful in remotely excavating targets. After the trials, demonstrators stressed the need for pre-survey site visits and Phase II was changed to accommodate this recommendation.

1.1.2 Phase II

The objectives of Phase II included the continued efforts to advance the UXO technology performance baseline established in Phase I, and to identify those sensor technologies that provide more effective clearance. All technology developers were invited to submit proposals to participate in Phase II; however, Phase I demonstrators also had to document significant improvements to their systems. Proposals for ground-based technologies that did not support a survey capability of 16 hectares in 5 days were rejected because of the desire to link the proposal cost to a level of effort.

A total of 17 demonstrations were conducted from May through September, 1995 (USAEC 1996). These included three airborne systems, six man-portable systems, two vehicle-towed systems, four combined man-portable and vehicle-towed systems, and two excavation systems. The 15 detection technologies used magnetometer, electromagnetic induction, and/or ground penetrating radar sensors. Most companies were able to complete the 16 hectare survey in the allotted five days, while the airborne systems completed their 32 hectare surveys under the allotted three days. Detection probabilities improved to a high of 85 percent with most ground-based demonstrators above 50 percent.

The results showed that the more effective demonstrators used electromagnetic induction sensors and/or magnetometers. Airborne systems that used sensors similar to ground based technologies failed to show any significant detection capability (less than 5 percent), suggesting that the platform altitude, speed or other parameters degraded performance. Target discrimination continued to be a problem, as demonstrators typically reported between 4 and 20 times more targets as ordnance than the number of ordnance items they had actually detected. The production rate of excavation systems improved with 11 and 18 targets remotely excavated by two systems over an allotted 24 hours.

1.1.3 Live Site ATDs

Five ATDs were conducted on ordnance ranges in Yuma Proving Ground (Arizona), Eglin Air Force Base (Florida), JPG (Indiana), McChord Air Force Base (Washington), and Fort Jackson, South Carolina (UXO Forum, 1996). The objective was to ascertain the performance of selected JPG Phase I demonstrators surveying working on 160 hectare sites with different environmental and debris conditions than the JPG Controlled Site.

The ranges were surface swept of hazards and surface debris. A small controlled set of baseline inert ordnance was emplaced on each of the live ranges and used to measure detection performance. Each range had at least two demonstrations of different technologies, and no demonstrator participated in more than two ATDs. The detection results for the demonstrators were comparable to those achieved in the Phase I controlled site trials. Demonstrators who performed well in JPG Phase I also performed well at the live sites. Demonstrators who performed poorly in Phase I likewise performed poorly on the live sites. Thus geophysical conditions did not significantly affect demonstrator search performance. Excavation demonstration performance was degraded at the live sites. Selected-target validation (excavation) proceeded at the rate of 2 to 6 holes a day on “live targets”. This was a serious concern, because survey demonstrators reported tens of thousands of targets on some sites.

1.1.4 ATD Controlled Site Issues/Limitations to Scope

The relevance of JPG performance data to other sites has to be regarded in light of the demonstration objectives and methodology, and the dependency on the local environmental conditions. One objective of conducting ATDs at a fixed site such as JPG is to highlight differences in performance that are dependent on demonstrators' technologies. For example, performance parameters such as a demonstrator's false alarms (detected nonordnance) can be monitored over time, as these tend to be influenced by the sensor technology and local debris conditions.

ATD resource limitations restrict the scope of testing to small acreage, so that technologies may not be distinguished based on economies of scale. That is, technologies that can economically survey large acres will not be highlighted. In addition, other artificial conditions were imposed upon the demonstrators so that the "playing field was level." Both JPG Phase I and II afforded demonstrators advantages and constraints that could otherwise affect performance. For example, demonstrators were not allowed to disturb the surface as they might do to characterize noise sources or to remove magnetic debris, lest they affect the performance of demonstrators that followed. Several geodetic monuments were established within the controlled site so that a geodetic reference (WGS-84 datum) was available to multiple demonstrators on the site at one time. The monuments were used by demonstrators as sites for differential GPS base stations and also to geolocate relative navigation systems. A local 30.5 meter (100 ft.) square grid was laid out within the controlled site to facilitate ordnance emplacement and to control multiple demonstrators on the site at one time. Many demonstrators used the convenient grid to manage and control their search activities. Demonstrators were provided the location and depth of four known ordnance targets in an adjacent demonstrator reference area, so that they could make equipment checks at their convenience. The controlled site was surface swept by Explosive Ordnance Disposal personnel so the demonstrators could also operate at JPG with a reduced level of concern for UXO risk (unintended detonation).

Other site conditions likely affected performance. The metallic debris on the controlled site was typical of past farming activity and not the abundant shrapnel usually found on live sites. The heavy clay soil adversely affected ground penetrating radar technologies and the vegetation likely affected infrared technology. Finally, ATD results may improve just from learning curve experience - repeat demonstrators can be expected to be better prepared logistically, as well as new demonstrators who have learned from the problems of others.

Significant progress has been made in understanding the capabilities and limitations of UXO technologies. The Phase I ATD allowed meaningful performance comparisons to be made for different demonstrators attempting similar tasks. The Phase II ATD was also able to mark technological progress against the Phase I benchmark.

While these two trials established that no “magic wand” was demonstrated that could make the JPG soil “transparent”, other issues remain. First, the mandate of the program, “Advanced Technology Demonstration” allowed only those innovative or proven technologies that had a reasonable chance to complete the required level of search effort. The search effort requirements in the proposal selection process may have eliminated unique technologies that have other merits. Since target characterization capabilities have proven poor, technologies that do not support a search methodology should be considered for this application. Another issue is that the JPG Phases I and II challenged demonstrators to search all depths for the entire baseline ordnance target set that ranged from mines and small mortar rounds to large bombs. This broad level of UXO concentration is not usually collocated in a single site. The performance of survey technologies, operated under time constraints, may have been affected by opposing strategies to localize both small and large ordnance. The U.S. Army Engineering and Support Center, Huntsville, provided suggestions to make the ATD more realistic. USAEC incorporated their comments and modified Phase III to address many of the above concerns.

1.2 PHASE III PROGRAM GOAL AND OBJECTIVES

The primary goal for Phase III is to provide relevant information to Government decision makers on the performance of UXO technologies demonstrated in more realistic situations. Customers of these technologies will be able to use this information to make choices of appropriate UXO technologies based on demonstrated capabilities and limitations. In addition, the Phase III results may be useful for establishing clearance requirements. Another objective for Phase III is to continue the characterization of UXO technologies. Developers and users of UXO technologies will have a better understanding of the progress that has been made since the inception of the ATD, and the gaps that remain. Government resource managers may also be able to use the Phase III results to establish priorities for research and development investments.

2.0 ADVANCED TECHNOLOGY DEMONSTRATION METHODOLOGY

The general approach to the ATD Phase III was similar to that developed in the earlier two phases. Controlled sites with deliberately implanted ordnance and nonordnance were established at JPG. Survey demonstrators were invited to propose how they would collect and process sensor data on the buried ordnance. Proposals that offered “best value” were accepted and scheduled at the site. Excavation proposals were accepted that offered site-acceptable (e.g. non-explosive) techniques for remotely excavating ordnance. After the demonstrations were conducted, the detection, localization, classification and excavation results were evaluated based on the methodology implemented in Phase II. Phase III was modified from earlier phases to make the ATD “more realistic”. Specific details of this approach follow.

2.1 SITE LOCATION AND DESCRIPTION

JPG is located about 5 miles north of Madison, Indiana, in Jefferson, Ripley, and Jennings counties. The facility covers about 22,365 hectares (55,265 acres) and includes former firing lines and impact areas. The base was used for over 50 years to test ordnance and related systems up to 1995. The Indiana Air National Guard still uses the facility. The Phase III demonstrations were conducted on a 16 hectare area in the northwest quarter of Section 36, Township 6 North, Range 10 East, the same area used for Phase I and Phase II demonstrations of ground systems. The site is located adjacent to access roads on the east side of the facility. Detailed information on the site and its preparation are contained in **Appendix A.**

2.2 TECHNICAL APPROACH

There was a desire to allow demonstrators the opportunity to operate as they would normally do so in the field, and with as few restrictions imposed as practical. The demonstrator reference area, geodetic monuments, and the 30.5 meter grid established for the earlier phases (see Section 1.1.3) were retained for Phase III. The time constraints were relaxed from earlier phases, in that demonstrators were allowed to propose how much time they would require within limits. Survey demonstrators were also allowed to select an intrusive or non-intrusive aspect to their proposed effort. “Intrusive” demonstrators would be allowed to excavate to a depth of 15 cm to characterize noise sources, remove shrapnel, etc. Intrusive demonstrations were required to have an acceptable site safety plan containing detailed procedures for soil removal and identifying qualified personnel for (potential) UXO removal. Since no proposals to conduct an intrusive demonstration were submitted, further discussion of this aspect of the ATD is limited in the report. Sites for non-intrusive demonstrations were established in a 16 hectare controlled area. Non-intrusive demonstrations did not allow demonstrators to disturb the site.

There was also the desire to establish scenarios and survey requirements that were representative of realistic UXO problems. Specific scenarios were established for Phase III that bounded the range of UXO sizes and the required search depths for the demonstrators. The scenarios had representative UXO that would be found on an aerial gunnery range, artillery and mortar range, and a grenade and submunitions range. Another scenario, an interrogation/burial area, contained a wider variety of ordnance. The first three scenarios were reserved for demonstrators who could search, localize and classify targets. The fourth scenario was set up to determine the capability of systems that could classify marked targets. Excavation demonstrators would be assigned targets at all four scenarios. Demonstrators were allowed to select the scenario(s) that matched their capabilities and were allowed to propose up to a maximum of 40 hours on site. Demonstrators were not required to propose how they would allocate their hours among two or more scenarios.

The funding of proposals was limited to $75K, and proposed efforts that exceeded this figure would not be considered within the scope of the ATD. Since the average cost in Phase II was $102K for ground based survey systems and $176K for airborne systems, the $75K funding ceiling was expected to limit demonstrators' proposed efforts and possibly restrict responses. A "best value" proposal acceptance criteria was used to obligate demonstrators to consider cost sharing. That is, all things being equal, a proposal encompassing two scenarios would be rated more highly than a single scenario proposal.

2.3 SITE LAYOUT

The four UXO scenarios were established to represent conditions at U.S. military installations that are candidates for restoration or alternative use. The Phase III Area Layout Plan (PRC EMI, 1996a) defined the target composition for each scenario. The specific target positions of the Area Layout Plan are not presented in this report to protect the integrity of future demonstrations. The Phase III layout was completed approximately one month prior to the start of demonstrations on 3 September 1996. The Phase III layout resulted in major design changes to the emplaced Phase II baseline target layout:

- Ordnance targets were geographically segregated to simulate more uniform contamination within identifiable areas.
- The separation distance between ordnance items increased to reduce the clustering of ordnance: the percentage of targets with a separation distance of less than 2 meters decreased from 38 to 2 percent and the median separation distance increased from 5 to 7 meters. (see **figure 2.3-1)**
- The average depth of the baseline target set decreased from 0.9 meters in Phase II to 0.4 meters in Phase II.
- Targets previously identified as "cluster" (many small items within a confined area), were excavated and removed from the baseline.

As a result of target relocation efforts and scenario construction, 1 nonordnance and 12 ordnance Phase II target positions were defined as “no contest” areas within the areas designated for use by Phase III search systems. “No contest” means no credit or penalties are assigned for demonstrator target detection reports associated with these positions. The “no contest” designation for the one nonordnance target resulted from the failure to find and remove brass shell casings. The 12 ordnance positions were designated “no contest” accordingly:

- (3) were ordnance items deeper than described for the scenario. These targets were too deep to economically excavate and were intentionally left in situ;
- (9) were associated with unsuccessful removal attempts during scenario construction and resulted in the government no longer having confidence in the target positions.

The 9 targets that had been the object of unsuccessful scenario excavation attempts included:

- (2) partially removed 30mm clusters whereby 4 of 8, and 7 of 8 of the individual ordnance items were recovered;
- (1) 8 inch projectile that had been a Phase II excavation target. The projectile was exposed and identified in the Phase II excavation attempt, and then covered up;
- (1) 60mm mortar round that the excavators had dug to 0.5 feet, not realizing that the target was at 2.56 feet.
- (3) targets that had been detected in 1995 by Phase II demonstrators: a 90mm projectile, a 152mm projectile, and 500 pound bomb. The 500 pound bomb was excavated to a planned depth of 10.6 feet, and a subsequent record search showed it was actually at 6.56 feet - the target disposition is unknown. A Phase III excavator also failed to locate the 90mm projectile;
- (2) 30mm ordnance clusters that had not been detected by any Phase II demonstrators;

In addition to the above, two excavations on the Interrogation/Burial site resulted in only partial recovery of multiple targets, but these two targets have no consequence on demonstrator performance evaluations in that scenario.

(UXO excavation is not a trivial task as evidenced by above problems in finding and removing known targets at known positions. There were 168 attempted excavations of Phase II targets for the Phase III site preparation. These excavations were hindered at times by wet conditions and further constrained by the nominal one hour maximum allotted to complete each excavation task). The guidance provided to the survey and excavation demonstrators and the descriptions of the scenarios are described in the following respective sections.

2.3.1 Scenario 1, Aerial Gunnery Range

The Aerial Gunnery Range scenario was described to demonstrators as a 4 hectare site with helicopter and fixed wing aircraft delivered ordnance. Ordnance could range in size from 2.75 inch rockets to 2000 pound bombs. Demonstrators were required to search the area for ordnance to a depth of 3 meters. There were 43 ordnance targets and 78 nonordnance items emplaced at the site. There are 7 “no contest” locations within this scenario.

2.3.2 Scenario 2, Artillery and Mortar Range

The Artillery and Mortar Range scenario was described to demonstrators as a 4 hectare site with assorted types of ground ordnance that would be fired at fixed targets. Ordnance could range in size from 60mm mortars to 8 inch projectiles. Demonstrators were required to search the area to a depth of 1.2 meters. There were 67 ordnance targets and 50 nonordnance items emplaced at the site. There are 3 “no contest” locations within this scenario.

2.3.3 Scenario 3, Grenade and Submunition Range

The Grenade and Submunitions Range scenario was described to demonstrators as 4 hectares of a former impact area that was converted into a range for small sensitively fuzed ordnance. Consequently the existence of larger ordnance could not be ruled out. Demonstrators were required to search the area for all ordnance to a depth of 0.5 meters. There were 98 ordnance targets and 39 nonordnance items emplaced at the site. There are 2 “no contest” locations within the scenario.

2.3.4 Scenario 4, Interrogation/Burial Area

The Interrogation/Burial Area scenario was described to demonstrators as a 4 hectare site with assorted aerial and ground delivered ordnance, burn and burial pits, and nonordnance debris. The air delivered ordnance could range in size from 2.75 inch rockets to 2000 pound bombs, and the ground delivered ordnance could range in size from 60mm to 8 inch projectiles. The site had been surveyed, and target reports needed localization and classification. Demonstrators were given 20 surface-marked targets and their geodetic positions for characterization and told that the depth of the targets of interest did not exceed 2 meters.

There were 53 ordnance targets and 72 nonordnance items emplaced at the site. Three sets of baseline targets were surface marked by color coding for characterization. All three sets had the identical number of ordnance and nonordnance targets. The ordnance size and class distribution was the same for all three sets.

2.3.5 Excavation Demonstrations

The entire 16 hectare site was available to demonstrators who could demonstrate remote excavation. The demonstrators were to be provided ordnance to excavate that was within the stated capabilities of their systems. Demonstrators were provided baseline target positions to excavate as many targets as practical within their proposed hours. After 10 baseline targets were attempted, target positions of “no contest” ordnance targets were to be included.

2.4 DEMONSTRATOR SELECTION PROCESS

Candidates for Phase III demonstrations were sought through a *Commerce Business Daily* solicitation **(CBD 1995)**. Interested parties were then sent information packages that included program background, Phase I and II summaries, Phase III goals and requirements, and the criteria for selection. A total of 32 proposals were received for Phase III consideration.

Criteria for the proposal evaluation included the following:

- Cost in terms of best value to the Government;
- Applicability in meeting Phase III (scenario) objectives;
- Proposed technology;
- Key personnel, alliances, and relevant experience.

The Government selection panel selected 15 proposals for participation in Phase III. Fourteen other proposals were rated acceptable, but had to be rejected because of limited funding. Three proposals were determined to be outside of the scope of the ATD.

2.5 DEMONSTRATION PROCEDURES

All demonstrators chosen were provided with a demonstration work plan (DWP) (PRC EMI 1996b) that outlined the responsibilities for the parties involved in the demonstrations. The DWP provided site background, evaluation criteria, and data validation information. The Safety, Health, and Emergency Response Plan (SHERP) was included in the DWP and served as a guide for day to day activities.

Demonstrations were generally scheduled to start on-site by Wednesday or Thursday and conclude by the following Sunday or Monday. The day preceding the start of demonstrations was available for system set up and check out on the Demonstrator Reference Area, a small area outside the controlled site that had four ordnance targets at known depths. Demonstrators were provided daily weather forecasts, including data collected from an on-site weather station at an 0700 safety briefing. Detection demonstrators were given the specified amount of time on site to collect data based on their proposals. They could budget their time as they saw fit for the different scenarios. Demonstrators on the Interrogation/Burial Area were provided 20 surfaced marked targets for characterization. Excavation technology demonstrators had 40 hours on site to demonstrate their system's capability. These demonstrators were provided with baseline target positions to excavate. Demonstrators were not permitted to remove any objects from the site during the demonstration. A Site Manager recorded demonstrator day to day activities in a field log.

2.6 DEMONSTRATION DELIVERABLES

Demonstrators were required to supply three categories of data within 30 days of demonstration completion:

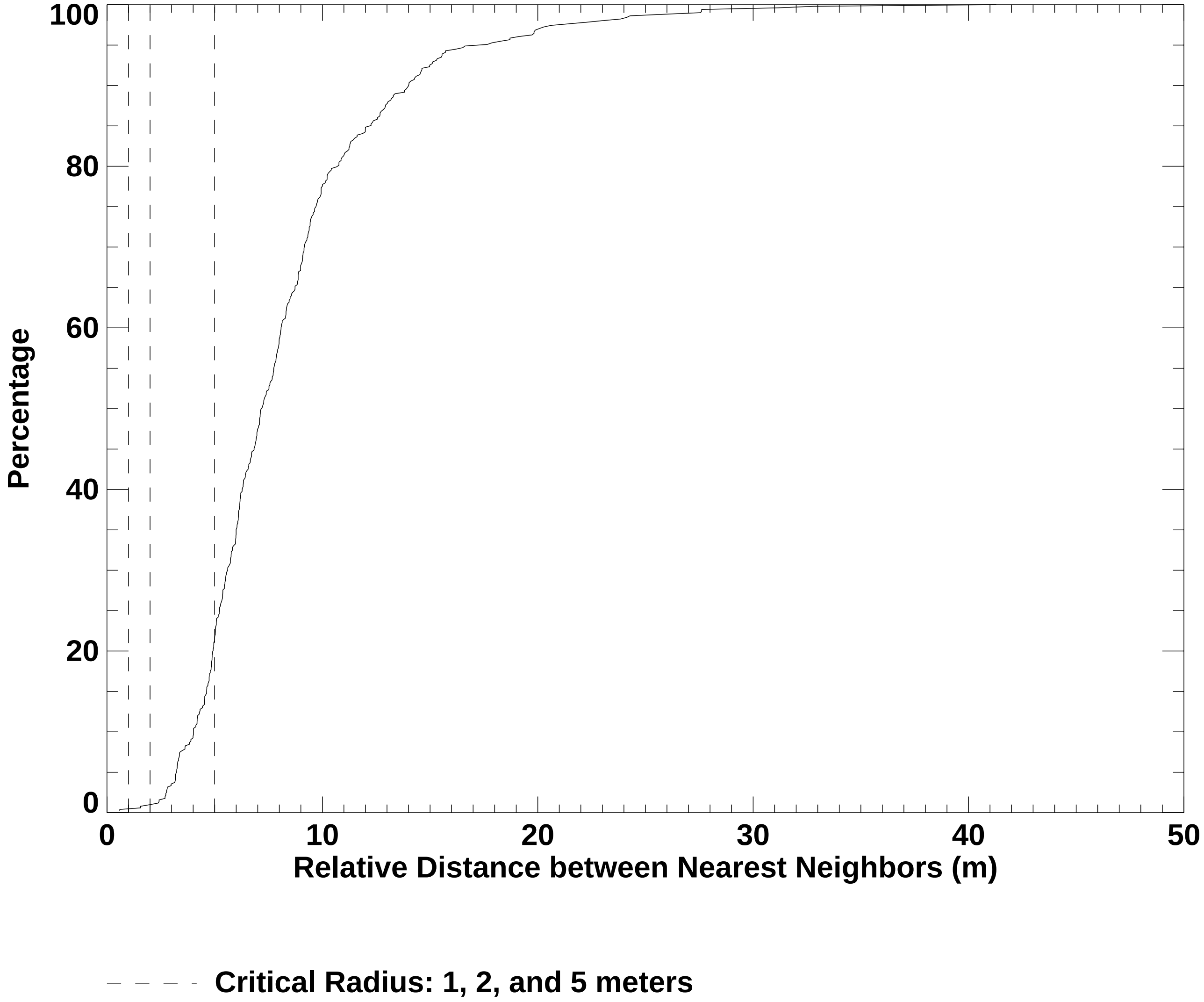
- Administrative data that identified the company and roles of the project team.
- Equipment data that identified the technologies used in the demonstration.
- Results data that the government used to evaluate demonstrator performance.

The administrative and equipment data was provided to the government in a Demonstrator Summary Report. A data entry disk was provided to each demonstrator to ensure standard data submission to the government for evaluation.

2.7 QUALITY ASSURANCE

The quality assurance program plan (QAPP) for Phase III outlined quality assurance (QA) and quality control (QC) procedures for the UXO ATD program. The primary focus of the QAPP was on the integrity of the emplaced baseline target set (target and position) and the transmission of data from the demonstrator to the government. A validation of the algorithms used to assess system performance was also conducted.

Phase III Controlled Site: Combined



3.0 EVALUATION METHODOLOGY FOR JPG III DEMONSTRATORS

The data analysis for Phase III performance is based largely on the methodology originally developed by Automation Research Systems Ltd. (USAEC 1994) and the Institute for Defense Analyses (USAEC 1995), and applied in JPG Phase II (USAEC 1996). Survey and excavation demonstrators are separately evaluated.

The evaluation of demonstrators who participated in the three Phase III search scenarios (Aerial Gunnery Range, Artillery and Mortar Range, and Grenade and Submunition Range) is based on their ability to detect, localize, and characterize the ordnance/nonordnance baseline target set within each respective scenario. Demonstrators who participated in the Interrogation/Burial Area Scenario are evaluated on their ability to localize and characterize targets that had been surface-marked for them. Excavation demonstrators are evaluated on their ability to acquire and excavate marked and unmarked targets.

3.1 DETECTION

The ability to detect subsurface ordnance is critical to the success of UXO site characterization and remediation efforts. There is the need to know “where” a UXO problem exists and a more precise need of “where to put the shovel”. Demonstrators can meet these requirements by using a variety of sensors to sample the environment for anomalous changes in the background caused by the presence of ordnance. Their sensor sampling strategy is influenced by economics and determined in part by their decisions regarding the sensor technology, numbers of sensors used, sensor sampling rate, lane spacing, search speed, and quality assurance with respect to a desired search objective. The evaluation of detection capability at JPG is based on the results of those decisions made to accomplish a predetermined level of search effort, constrained by time and funding. The evaluation process does not include the demonstrator's hidden decision making processes, nor an evaluation of their sensor data.

3.1.1 Basis for Detection

Demonstrators report their search results in a tabular format of target positions with associated characteristics. The basis for declaring that a demonstrator has made an ordnance detection is dependent on the decision that the demonstrator's target report "matches" an emplaced baseline ordnance target. The principal criteria is the horizontal separation distance between a baseline target (center of volume) and the location in a demonstrator target report. The requirement to accurately estimate the location of an emplaced target places a burden on a demonstrator's sensor/navigation integration. For example, demonstrators who would normally "mag and flag" (manually interpret magnetic/electromagnetic anomalies and surface mark them with flags for later excavation) are required to provide geodetic target positions of their marks in the Universal Transverse Mercator (UTM) grid reference. One consequence of this evaluation methodology is that any capable sensor is only as good as the navigation technique.

3.1.2 Criteria for Detection

A detection is credited when the separation between a target report and baseline target position is less than or equal to a critical distance (critical radius, R*crit*). R*crit* should be based in part on the uncertainty one can tolerate in relocating targets. Detection is not dependent on characterization, so an ordnance detection is credited regardless whether the demonstrator categorizes ("types") the target report as an ordnance item (true positive) or nonordnance item ("mistyped", not "false negative" which has been corrupted in the vernacular to mean an excavation that yields no ("negative") target). Likewise a nonordnance detection is credited whether the baseline nonordnance target is typed as ordnance (false positive) or nonordnance (true negative). The criteria established in earlier phases, and retained in Phase III, require ground-based demonstrators to localize baseline targets to within 2 meters and airborne system demonstrators to localize targets to within 5 meters. (All demonstrator reports are analyzed at 1, 2, and 5 meters R*crit*, but these results are not all included in the report because of the volume of information).

An automated Target Matching Algorithm (TMA) is used to do the comparison of demonstrator target reports to the baseline target set in a consistent manner. A variety of TMAs were developed in earlier phases because of the different options available to associate demonstrator target reports with adjacent baseline targets. TMA *Group* is used to produce demonstrator detection statistics for Phase III as it had been used for JPG Phase II. TMA *Group* associates baseline ordnance targets within a given distance (group radius) of each other as a single group target. Nonordnance baseline targets can also be associated with an ordnance group. (The specifics of this process are presented in USAEC, 1996). The group radius used for Phase III is 2 meters, the same as had been used for Phase II. Targets in close proximity to each other contribute to the overall detection signature of the group, and may increase the group signature over that of the individual targets. A case is made for using this algorithm in that when a detected target is excavated, the excavation is usually checked for additional anomalies. In theory, detecting one target is as good as finding the rest. However, there is the concern that collocated targets are likely easier to detect than single targets. Consequently, the baseline target set for Phase III was spread out relative to that of Phase II to focus more on single target detection versus group target detection. Because the baseline ordnance targets of Scenarios 1, 2, and 3 were separated by more than 2 meters in Phase III, TMA *Group* does not cause any baseline ordnance to “group” at a 2m group radius. It does group one nonordnance item with an ordnance target in the Aerial Gunnery Range, Scenario 2.

3.1.3 Detection Performance

Probabilities of detection (P_D) are computed for each demonstrator from the reported targets that match baseline ordnance and nonordnance targets within the scenario searched. These detection probabilities are defined as follows:

$P_{D,ord}$ = Probability of detection for ordnance
= (# ordnance detected)/(# baseline ordnance in scenario surveyed)

$P_{D,nonord}$ = Probability of detection for nonordnance
= (# nonordnance detected)/(# baseline nonordnance in scenario surveyed)

(In Phase II, P_D was based on area searched. Phase III P_Ds are presented in charts and tables, based on the entire scenario(s). Results based on area searched are noted for a few demonstrators in the text of Section 6). The methodology of determining detection opens up the possibility for a demonstrator to achieve a high P_D solely by generating a large number of target reports. Likewise, demonstrators with poor technique and a low P_D, can also expect some success just from the random chance that a target report is coincident with a baseline target. A detection probability, P_{random}, was calculated for each survey demonstrator and included in the statistical data charts as a reference to this issue. P_{random} is the expected fraction of baseline ordnance targets that would be detected if the total number of target reports of a demonstrator were randomly distributed within the search area, as opposed to being specified by the demonstrator. It is calculated as follows:

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

where $\lambda = np$

n = number of demonstrator reports
p = probability of having a report within $Rcrit$

$$p = \frac{\pi \left(R_{crit}\right)^2}{A}$$

A = Area surveyed

A P_{random} that is close to or exceeds $P_{D,ord}$ is indicative of a detection capability that may be due to chance. Overlay plots of demonstrator reports and baseline targets are useful indicators of randomness or navigation error and bias, but are not provided in the report to protect the baseline integrity.

Another issue with detection performance is that a system with a high probability of detection may be of little practical value if it generates an excessive number of target reports that do not correspond to ordnance. Demonstrators who detect and report the debris from historic farming activity at the 16 hectare site will have many targets that do not correspond to the baseline target set. Because target excavation/investigation of nonordnance targets may represent significant wasted resources in site remediation efforts, various related "false alarm" measures are presented in the results charts. "False alarms" are defined as *demonstrator target reports that do not correspond to baseline ordnance targets*. This definition includes detected farm debris declared as such in demonstrator reports and true negatives, detected nonordnance baseline targets that were correctly typed nonordnance. (It may be argued that true negatives do not belong in "false alarms", but generally, the number of true negatives is small compared to the number of target reports that do not correspond to baseline targets. Also, the number of true negative targets is often comparable to the number of "mistyped" characterizations - ordnance detections typed as "nonordnance". Mistyped ordnance characterizations are not excluded from ordnance detection statistics. It is conceded that demonstrators would have better false alarm metrics by not reporting their nonordnance declarations, and that demonstrators used different nonordnance reporting strategies). The definition of "false alarm" does not include any demonstrator target reports that fall outside the defined boundaries of the scenario, nor any demonstrator target reports matched to the "no contest" locations discussed in **Section 2.3**. Thus there are differences in the number of targets a demonstrator reports for a scenario and the numbers that are presented in the results summaries.

The false alarm ratio is the number of false alarms divided by the number of detected ordnance targets. This ratio is the number of excavations that yield no ordnance per productive (yielding ordnance) excavation. The ratio assumes that all target reports get investigated and that excavators are 100 percent efficient. (There may be a hidden cost with a “high” false alarm ratio, in that excavator success with ordnance may decrease if the general expectation is not to find any ordnance). The false alarm ratio of 4 is arbitrarily used to distinguish demonstrators in the discussion of results. Demonstrators whose false alarm ratio is less than 4 would have ordnance in more than 20 percent of their target excavations. The probability of false alarm, P_{FA}, is the fractional area of the surveyed area, A, that is covered by the number of false alarms, N_{FA}, and defined accordingly:

$$P_{FA} = \frac{N_{FA} \quad \pi \quad (R_{crit})^2}{A}$$

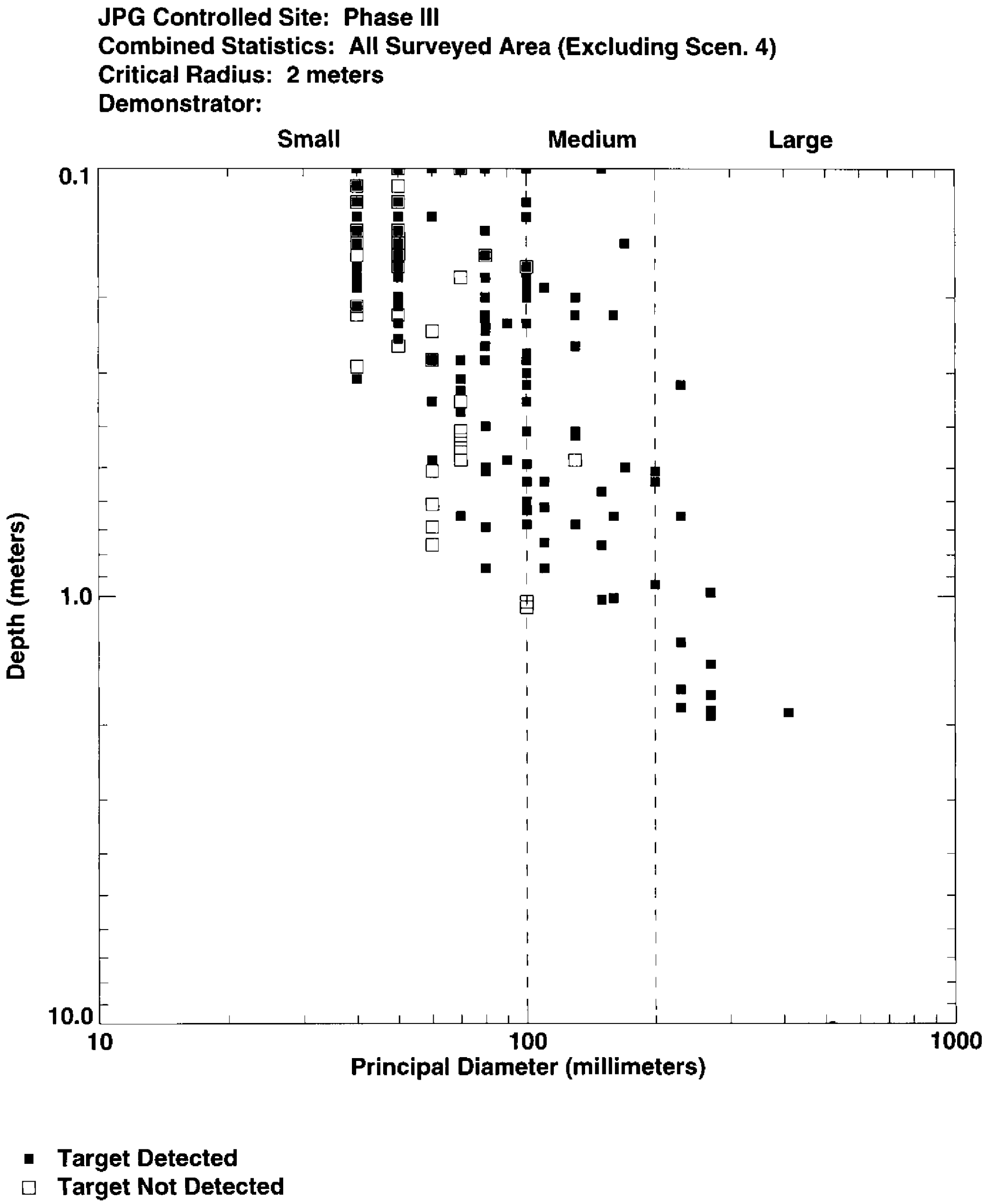
The probability of false alarm represents a measure used to determine the Receiver Operating Characteristics (ROC) curve of a detection system, a standard method of comparing detection performance of different systems. ROC curves define a relationship of P_D and P_{FA} over various detection threshold values. However, they require more data than developed in this report to have any statistical significance, and are not presented. Detection performance results for scenarios are provided in the demonstrator statistical data charts of **Section 5**. Demonstrator statistical performance summaries are provided in **Appendix B**.

3.1.4 Performance Assessment Plots

Demonstrator detection ability as a function of target depth and size are represented in log-log scatter plots for each demonstrator. **Figure 3.1.4-1** shows a sample plot. The top of the plot shows the near surface targets, the left side of the plot contains the smaller targets. Targets that were detected are represented by filled in squares, while missed targets are left blank. Performance assessment plots can quickly highlight the capabilities or limitations of demonstrators in detecting small or deep ordnance. Scenario specific performance assessment plots are provided in **Section 5.** Demonstrator summary plots of combined survey data are presented in **Appendix B** with each demonstrator.

Demonstrator detection ability should not be considered without the associated false alarm metrics. While readers may wish to focus on this one statistic to compare performance, they are cautioned against doing so because of the methodology that is used to define detection. Plots of P_D versus the false alarm rate and P_D versus the false alarm ratio are presented in the discussion of overall results, **Section 6.2**, to represent the significance of their relationship. A sample plot of one of these plots is shown in **figure 3.1.4-2**. In this plot, better performance is in the upper left hand corner - a high probability of detection with a low false alarm ratio. This region defines capable technologies suitable for remediation. The left side of the plot defines low false alarm technologies that may be suitable for statistical site sampling, even with poor detection performance. Systems in the top right section of the plot may require an auxiliary target interrogation system to reduce false alarms, and so make them economically feasible for remediation efforts. Systems in the bottom right section of the plot represent detection technologies that are unsuitable.

Figure 3.1.4-1 Sample Performance Assessment Plot



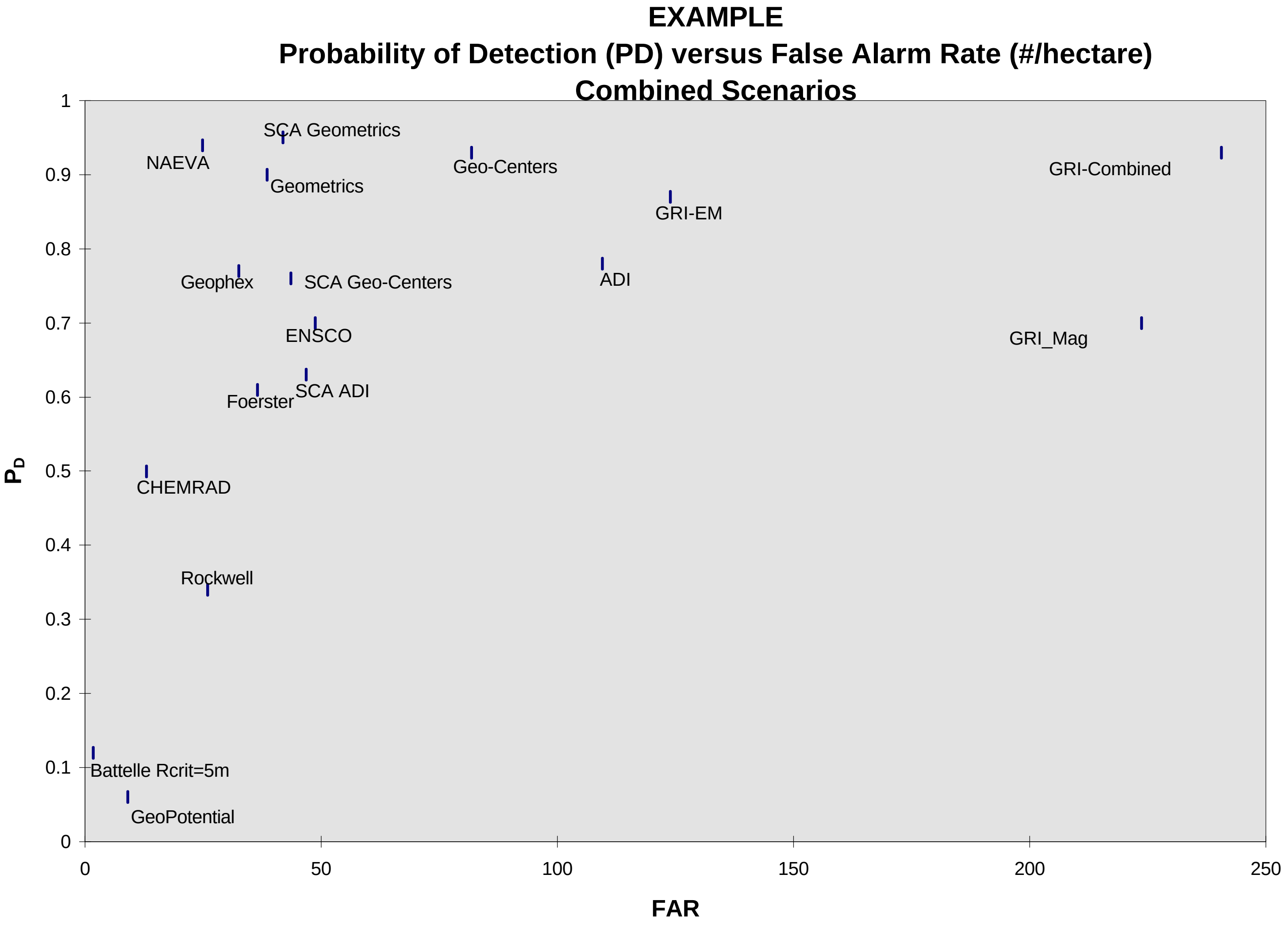

EXAMPLE
Probability of Detection (PD) versus False Alarm Rate (#/hectare)
Combined Scenarios
P_D
FAR
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
50
100
150
200
250
SCA Geometrics
NAEVA
Geo-Centers
GRI-Combined
Geometrics
GRI-EM
Geophex
SCA Geo-Centers
ADI
ENSCO
GRI_Mag
SCA ADI
Foerster
CHEMRAD
Rockwell
Battelle Rcrit=5m
GeoPotential

Figure 3.1.4-2

3.2 LOCALIZATION

Localization statistics define the accuracy demonstrators achieved in determining the position of *detected* ordnance targets in three dimensional space, (x, y, z) or (easting, northing, and depth). Localization statistics were computed for all four scenarios. However, demonstrators in Scenario 4 were provided the positions of the targets they interrogated; consequently, Scenario 4 is not used in any combined scenario statistical data.

Horizontal target location determines where and how wide a hole to dig to ensure that a target gets unearthed. Accurate depth positioning can speed the excavation process, as excavators can slow down as they near an ordnance item so as to minimize disturbance. The target depth can also determine whether a target even needs excavation for surveys with a depth limitation. Positioning inaccuracy impacts excavation efficiency, ordnance safety issues, and Occupational Safety and Health Administration considerations. Thus, there is a need to characterize demonstrator localization performance.

3.2.1 Basis for Localization

The demonstrator target report data used to determine baseline ordnance target detection is also used to measure localization performance. Demonstrators who participated in the Interrogation/Burial Area Scenario are required to locate targets within the critical radius for evaluation. Whereas TMA *Group* is used for detection statistics, it is not useful for determining localization statistics because of the need to determine which item in an ordnance group likely corresponds to the demonstrator target report. TMA *Closest* was developed in earlier phases, with the simple rule that a demonstrator target report is assigned to the nearest ordnance target in horizontal space, and is used in Phase III for localization and characterization statistics. (Because the baseline ordnance target set was dispersed in Phase III, TMA *Group* and TMA *Closest* are equivalent for all practical purposes).

3.2.2 Localization Performance

Positioning errors for each demonstrator were computed from the set of baseline ordnance targets that were detected using TMA *Closest*. As a result, horizontal location errors are constrained by the *Rcrit* (2 or 5 meters) used in the detection algorithm. Depth errors are also somewhat constrained because search depths were limited in each of the four scenarios. The error of the demonstrator report relative to the approximate center of volume of the detected baseline ordnance target is computed as follows:

easting error: $dx = x_r - x_b$
northing error: $dy = y_r - y_b$
depth error: $dz = z_r - z_b$

where the subscript "r" refers to the demonstrator report and "b" refers to the baseline target. Negative values in dx, dy and dz refer to demonstrator reports that are west and south of, and shallower than, the baseline target. In addition, the horizontal radial error, r, is computed for each target report accordingly:

radial error: $r = \sqrt{dx^2 + dy^2}$

The mean and standard deviations are provided for dx, dy, dz, and r as computed by standard mathematics. In addition, the root mean absolute depth error is provided:

absolute depth error: $|dz| = \sqrt{\frac{\sum dz_i^2}{N}}$

where N is the number of baseline ordnance items detected.

Localization performance results are provided in the demonstrator statistical data charts of **Section 5**.

3.3 CHARACTERIZATION

Characterization studies define the ability of demonstrators to provide additional information on their *detected* targets and they also provide some discrimination on demonstrator's detection capabilities. Characterization statistics were computed for all four scenarios.

Target characterization is necessary because large amounts of nonordnance debris that do not require removal are usually encountered where UXO is present. The ability to discriminate between ordnance and nonordnance items (referred to as "typing" in this analysis) is very important in reducing the number of nonordnance items (false alarms) that are excavated. In addition, excavators would benefit from target descriptions so they are aware of the potential hazards, employ proper safety precautions, and have a better idea of what to look for in the hole or overburden. Thus, there is a need to measure demonstrator characterization performance.

3.3.1 Basis for Characterization

Demonstrators were requested to characterize their target reports, but not all did so or they only reported ordnance detections. Demonstrator targets that corresponded to the emplaced baseline target set per TMA *Closest* were used to assess "typing" performance. Typing required demonstrators to declare a target report as ordnance or nonordnance.

Detected baseline ordnance targets were used to assess sizing and classifying capabilities. Targets are sized by their principal diameter as small ($\leq$ 100 mm), medium (between 100 and 200 mm) and large ($\geq$ 200 mm). Demonstrators were asked to estimate the mass of their targets, but this data was not evaluated and consequently is not incorporated into the report.

Demonstrators could further classify targets as bomb, projectile, mortar, submunition or rocket. (Note: while Scenario 4, the Interrogation/Burial Area, was identified as having potential UXO burial pits and burn pits in the baseline ordnance target set, demonstrators had no such classification option. No burial pit or burn pit targets were provided to demonstrators to interrogate).

3.3.2 Characterization Performance

To assess demonstrator characterization performance, the following statistics were computed from detected baseline items:

Ability to Type:

P_{CO} = Probability of correct characterization of ordnance
= (# ordnance correctly typed)/(# ordnance detected)

P_{CNO} = Probability of correct characterization of nonordnance
= (# nonordnance correctly typed)/(# nonordnance detected)

Ability to Size:

P_{CSM} = Probability of correct size determination of small ordnance
= (# small ordnance correctly sized)/(# small ordnance detected)

P_{CMED} = Probability of correct size determination of medium ordnance
= (# medium ordnance correctly sized)/(# medium ordnance detected)

P_{CLG} = Probability of correct size determination of large ordnance
= (# large ordnance correctly sized)/(# large ordnance detected)

Ability to Classify:

P_{CB} = Probability of correct bomb classification
= (# bombs correctly classified)/(# bombs detected)

P_{CPRO} = Probability of correct projectile classification
= (# projectiles correctly classified)/(# projectiles detected)

P_{CMOR} = Probability of correct mortar classification
= (# mortars correctly classified)/(# mortars detected)

P_{CSUB} = Probability of correct submunition classification
= (# submunitions correctly classified)/(# submunitions detected)

P_{CR} = Probability of correct rocket classification
= (# rockets correctly classified)/(# rockets detected)

In addition to the above characterization ratios, the detection ratios are also computed for the respective categories using TMA *Closest*. Characterization performance results are provided in the demonstrator statistical data charts of **Section 5**. Some precautions are necessary in viewing these statistics and assumptions are necessary in determining a demonstrator's capability:

> No distinction is provided for demonstrators who didn't try to characterize targets versus those who tried and failed. (If all values are "0" in the "# correct" for type, size, or classify characterizations, then the demonstrator probably elected not to attempt that particular characterization).
>
> It is possible to achieve a 100 percent correct characterization of ordnance targets as ordnance, true positives, just by declaring all targets as ordnance. This in itself is not a true measure of ordnance typing capability. If a demonstrator only reported targets believed to be ordnance and therefore had no reason to declare any targets as nonordnance, then their baseline nonordnance detection statistics need to be examined to infer their typing ability. In this later case, given that the demonstrator has a nominal ordnance detection capability (50 percent or better), a probability of nonordnance detection less than one half of their ordnance detection probability is assumed to indicate an ability to type. For example, a demonstrator who only reports ordnance targets has a P_{CO} of 0.80; it is presumed that the demonstrator would need a P_{CNO} of less than 0.40 to have demonstrated a typing capability. That is an indication that the demonstrator is rejecting nonordnance targets as ordnance.

A demonstrator's measured ability to size and classify baseline ordnance may be biased because two of the scenarios narrowed the range of expected sizes and classes of ordnance. Finally, the characterization ratios are presented as point estimates, and they may lack significant statistical confidence because of the small sample size. Also, the value of a demonstrator's classification statistics is questionable, if demonstrators lack the basic ability to distinguish ordnance from nonordnance.

3.4 EXCAVATION

The ability to excavate targets is essential for target identification and UXO remediation. Excavation technology is needed that can traverse uneven terrain, operate safely, operate against a variety of targets at different depths, minimize human intervention, and achieve high production rates. Excavation demonstrators were assigned target positions to excavate that were within their system's capabilities. They were required to provide the travel time, dig time, target depth, and target identity.

4.0 DEMONSTRATION SUMMARY

This section is a brief introduction to the demonstrations that took place at JPG in Phase III. Not all demonstrators participated in all scenarios, nor did all demonstrators completely survey each assigned scenario. **Section 5** presents the performance data for each demonstrator separated by scenario. The results of the excavation demonstrations are presented in **Section 6**, the Results Summary, Analysis and Conclusions. Combined statistical data charts and performance assessment plots (Scenarios 1, 2, and 3 only) for each demonstrator are provided in **Appendix B, Demonstrator Summary Reports and Results**. **Appendix B** also contains detailed information on the demonstrators and their technologies, as provided by the demonstrators.

4.1 NON-INTRUSIVE SURVEY DEMONSTRATIONS

Twelve demonstrators conducted non-intrusive demonstrations in September through November 1996, in one or more of the three survey scenarios (1, 2, and 3). One of these companies, Geophysical Research Institute (GRI), submitted three separate target reports for data gathered with two sensors: magnetometer (Mag), electromagnetic (EM), and combined sensors (Combined). GRI's results were treated as separate demonstrations and are annotated as GRI (Mag), GRI (EM) and GRI (Combined). A thirteenth company, Sanford Cohen and Associates (SC&A, or SCA) made agreements with three demonstrators, ADI Limited (ADI), Geo-Centers, and Blackhawk Geometrics (Geometrics), to post-process their respective raw sensor data and submit it independently. These results are treated as separate demonstrations and are annotated respectively as SCA_ADI, SCA_Geo-Centers, and SCA_Geometrics.

Battelle Pacific Northwest Laboratories (Battelle), CHEMRAD, Foerster, Geo-Centers, and GRI (EM) partially surveyed their respective scenario(s). Since Foerster had originally proposed to survey only half (2 hectares) of Scenario 1, their ordnance detection performance based on the actual area searched is noted in **Section 6.1.1**. Foerster also elected to survey half of Scenario 2 while at JPG; however, these results are not provided in this report. CHEMRAD was the only company whose detection performance was significantly affected by the scenario-based evaluation methodology, and their results are noted in the respective scenarios.

Eight of the thirteen companies that participated in the survey portion of Phase III ATD had prior, on-site experience. SC&A also had prior experience analyzing JPG demonstrator data. **Table 4.1-1** lists the survey demonstrators, sensor and navigation technologies used, proposed scenarios, hours proposed, funding, and past JPG Phase experience.

4.2 INTRUSIVE SURVEY DEMONSTRATIONS

No proposals for intrusive demonstrations were received. Demonstrators were allowed to propose an intrusive demonstration that would allow them to dig into the soil to a depth of 15 cm to characterize and/or remove debris. Possible reasons for the lack of proposals include: a $75K ceiling on funding would limit the money that could be allocated to intrusive efforts; the 40 hour demonstration time limit may have been too restrictive for realizing benefits from intrusion; and the scope of nonordnance debris at the JPG site is not the unknown as it was to Phase I demonstrators.

4.3 CHARACTERIZATION DEMONSTRATIONS

One of the goals of the ATD was to seek technologies that could better localize and/or characterize ordnance without necessarily being suitable for conducting general search. Scenario 4, the Interrogation/Burial Area, was specifically established to test these technologies. One proposal was received that was directed only to this scenario, and it was not funded. There were 5 demonstrations of systems in Scenario 4 that had also participated in one or more of the search scenarios. SC&A evaluated two of these data sets for a total of 7 demonstrations.

4.4 EXCAVATION DEMONSTRATIONS

The ATD restricts excavation technology proposals to remote techniques and to what is considered suitable for the site. Two demonstrations of remote excavation technology were conducted in November 1997. OAO had proposed 40 hours of effort for $28.9K and Lockheed Martin had proposed 24 hours of effort for $74.4K.

TABLE 4.1-1 DEMONSTRATION SUMMARY

Demonstrator	Sensor Platform	Sensor Technology	Navigation Technology	Scenarios	Proposed Hours	Funding ($K)	Past JPG Experience
ADI	Man-Portable	Magnetometer (Mag)	Local Grid	1,2,3,4	40	73.4	I,II
Battelle	Airborne	Mag	Differential GPS	2,4	40	75.0	
CHEMRAD	Man-Portable	Electromagnetic Induction (EM)	Differential GPS	1,2	40	62.3	I
ENSCO	Man-Portable	Radar and EM and Mag	Local Grid	1,2,4	32	43.6	I
Foerster	Vehicle & man-portable	Gradiometer	Differential GPS	Part of 1,4	24	34.0	I
Geo-Centers	Vehicle towed	EM and Mag	Differential GPS	1,2,3	40	58.6	I,II
Geometrics	Man-Portable	EM and Mag	Local Grid	2,4	40	74.9	I,II
Geophex	Man-Portable	EM	Local Grid	1,2	40	58.4	II
GeoPotential	Man-Portable	EM	Differential GPS	1,2,3	32	26.2	II
GRI	Man-Portable	EM	Local Grid	1,2,3,4	40	69.4	
NAEVA	Man-Portable	EM and Mag	Local Grid	1,2	40	47.9	
Rockwell	Man-Portable	Mag	Differential GPS	1,2	32	54.0	
SC&A	Not Applicable (N/A)	Advanced Data Processing	N/A	1,2,3,4	N/A	31.1	

5.0 RESULTS - SCENARIO ASSESSMENTS

This section presents the individual demonstrator results data for the four scenarios. A statistical data chart and performance assessment plot are provided for each survey demonstration. The statistical data charts are provided for Scenario 4. A combined statistical summary of the survey scenarios (1, 2, and 3) is provided for each demonstrator in Appendix B.

5.1 AERIAL GUNNERY RANGE

This section presents the performance of the following demonstrators that participated in this scenario:

5.1.1 ADI
5.1.2 CHEMRAD
5.1.3 ENSCO
5.1.4 Foerster
5.1.5 Geo-Centers
5.1.6 Geophex
5.1.7 GeoPotential
5.1.8 GRI (Combined)
5.1.9 GRI (EM)
5.1.10 GRI (Mag)
5.1.11 NAEVA
5.1.12 Rockwell
5.1.13 SCA_ADI
5.1.14 SCA_GeoCenters

ADI - Aerial Gunnery Range

Detection Statistics (TMA[a] *Group*)

	# Baseline	# Detected	P_D[b]	P_{random}
Ordnance	43	34	0.79	0.134
Nonordnance	77	67	0.87	
Total	120	101		
Number False Alarms	360			
False Alarm Rate (#/Hectare)	104.16			
False Alarm Ratio (#/Ord.)	10.59			
Probability False Alarms	0.131			

Localization Statistics (TMA *Closest*) (in meters)

	Mean	Std Deviation
Position (x,y)		
dx - easting error	-0.05	0.37
dy - northing error	0.24	0.41
Radial error	0.48	0.36
Depth (z)		
dz - averaged depth error	0.29	0.6
|dz|[c] - absolute depth error	0.66	

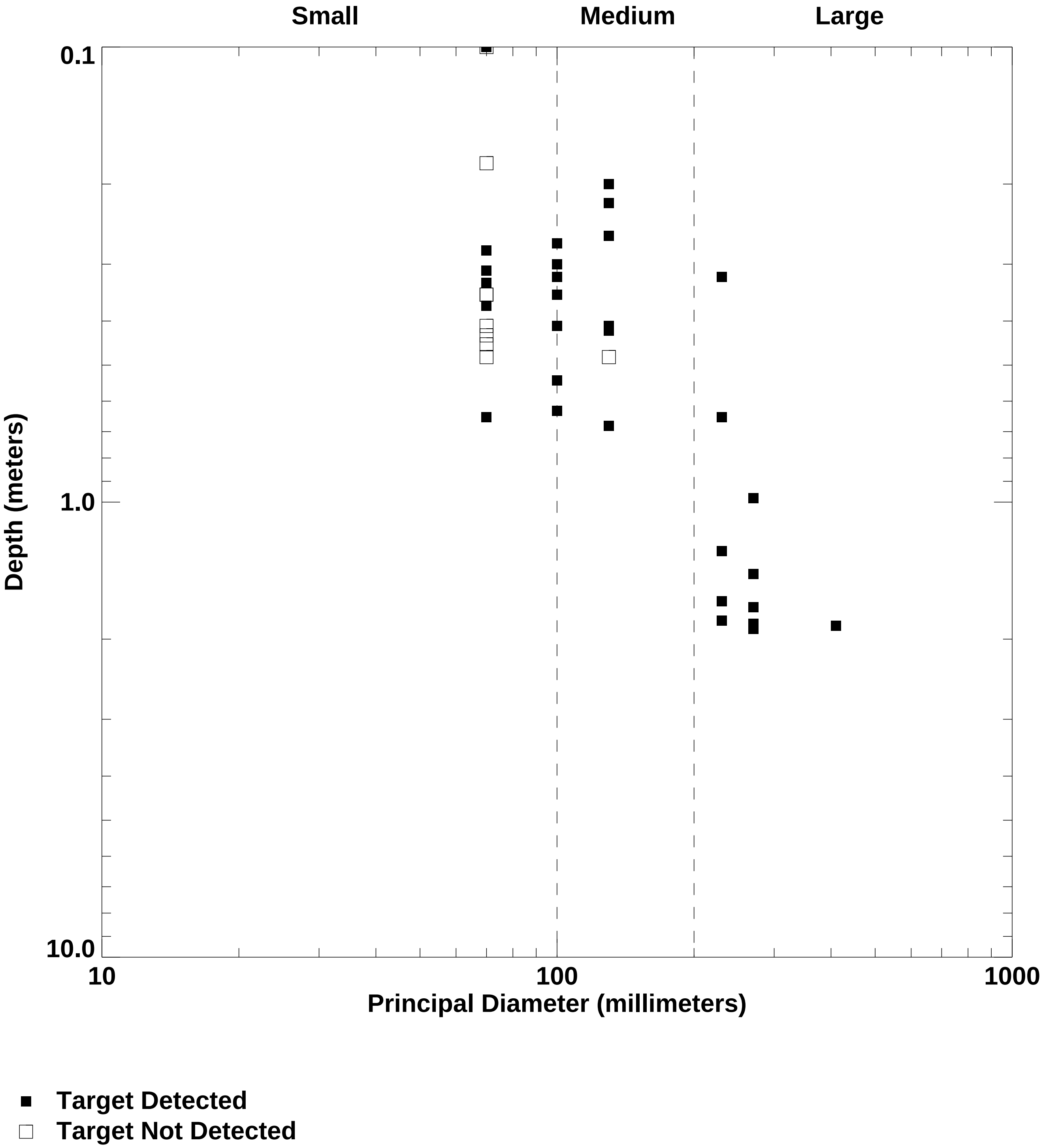
Characterization Statistics (TMA *Closest*)

	# Baseline	# Detected	Pd	# Correct	P_C[d]
Ability to Type					
Ordnance	43	34	0.79	31	0.91
Nonordnance[e]	78	67	0.86	2	0.03
Ability to Size					
Large	11	11	1.00	10	0.91
Medium	7	6	0.86	0	0.00
Small	25	17	0.68	1	0.06
Ability to Classify					
Bomb	21	21	1.00	13	0.62
Projectile	0	0	NA	0	NA
Mortar	0	0	NA	0	NA
Submunition	0	0	NA	0	NA
Rocket	22	13	0.59	2	0.15

Notes:

[a] **Target Matching Algorithm**
[b] **Probability of detection**
[c] **Square root of the mean square depth error**
[d] **Probability of correct characterization**
[e] **TMA affects how nonordnance baseline targets are counted**
NA - not applicable

JPG Controlled Site: Phase III
Scenario 1: Aerial Gunnery Range
Critical Radius: 2 meters
Demonstrator: ADI



CHEMRAD - Aerial Gunnery Range

Detection Statistics (TMA[a] *Group*)

	# Baseline	# Detected	P_D[b]	P_{random}
Ordnance	43	26	0.60	0.03
Nonordnance	77	27	0.35	
Total	120	53		
Number False Alarms	57			
False Alarm Rate (#/Hectare)	16.49			
False Alarm Ratio (#/Ord.)	2.19			
Probability False Alarms	0.021			

Localization Statistics (TMA *Closest*) (in meters)

	Mean	Std Deviation
Position (x,y)		
dx - easting error	-0.17	0.67
dy - northing error	0.2	0.9
Radial error	1.02	0.51
Depth (z)		
dz - averaged depth error	0.31	0.32
|dz|[c] - absolute depth error	0.45	

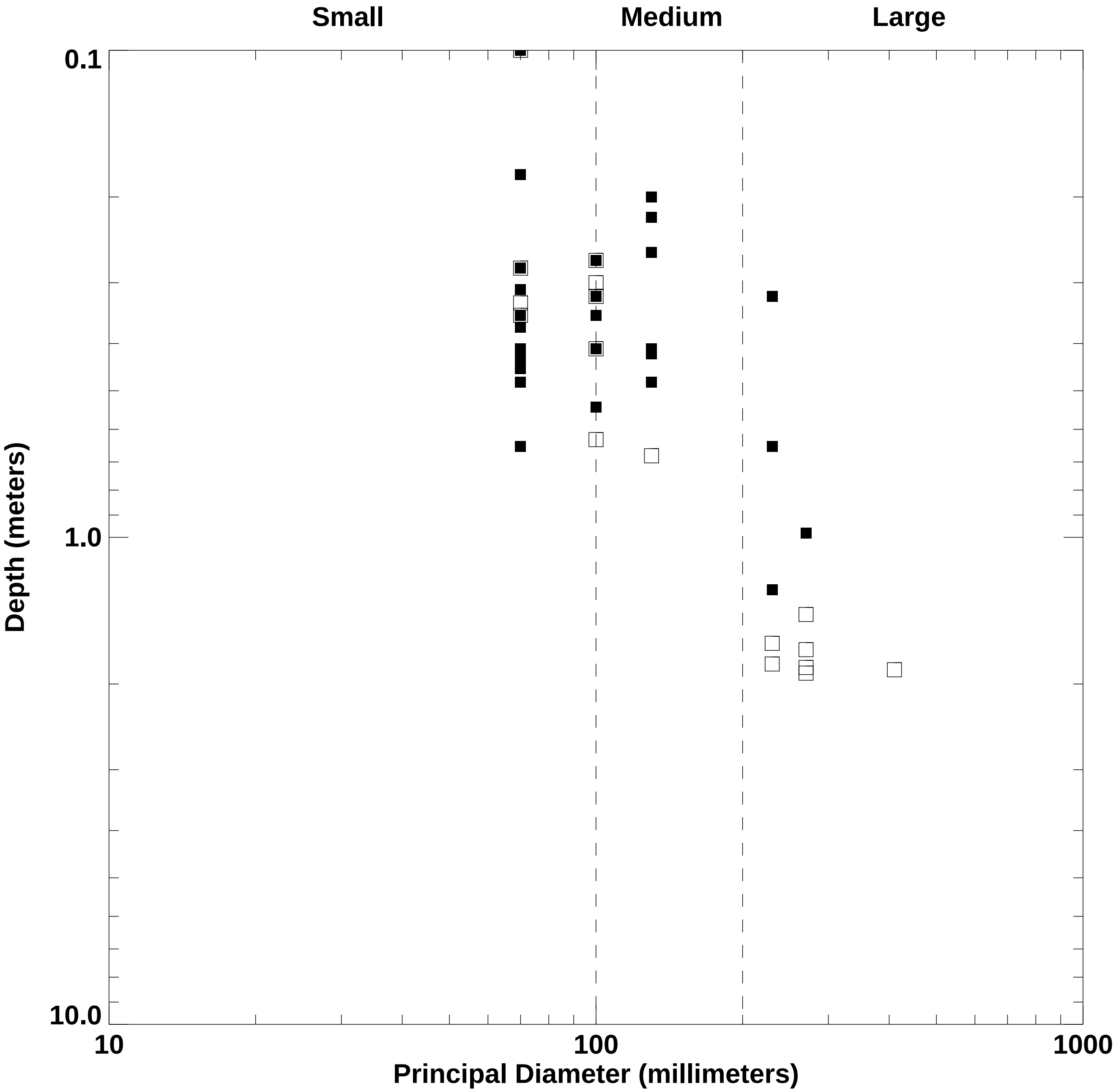
Characterization Statistics (TMA *Closest)*

	# Baseline	# Detected	Pd	# Correct	P_C[d]
Ability to Type					
Ordnance	43	26	0.60	0	0.00
Nonordnance[e]	78	27	0.35	0	0.00
Ability to Size					
Large	11	4	0.36	0	0.00
Medium	7	6	0.86	0	0.00
Small	25	16	0.64	0	0.00
Ability to Classify					
Bomb	21	9	0.43	0	0.00
Projectile	0	0	NA	0	NA
Mortar	0	0	NA	0	NA
Submunition	0	0	NA	0	NA
Rocket	22	17	0.77	0	0.00

Notes:

[a] **Target Matching Algorithm**
[b] **Probability of detection**
[c] **Square root of the mean square depth error**
[d] **Probability of correct characterization**
[e] **TMA affects how nonordnance baseline targets are counted**
NA - not applicable

JPG Controlled Site: Phase III
Scenario 1: Aerial Gunnery Range
Critical Radius: 2 meters
Demonstrator: CHEMRAD



■ **Target Detected**
□ **Target Not Detected**

ENSCO - Aerial Gunnery Range

Detection Statistics (TMA[a] *Group*)

	# Baseline	# Detected	P_D[b]	P_{random}
Ordnance	43	30	0.70	0.079
Nonordnance	77	54	0.70	
Total	120	84		

Number False Alarms	192
False Alarm Rate (#/Hectare)	55.55
False Alarm Ratio (#/Ord.)	6.40
Probability False Alarms	0.069

Localization Statistics (TMA *Closest*) (in meters)

	Mean	Std Deviation
Position (x,y)		
dx - easting error	-0.24	0.33
dy - northing error	0.13	0.61
Radial error	0.58	0.46
Depth (z)		
dz - averaged depth error	-0.02	0.34
|dz|[c] - absolute depth error	0.35	

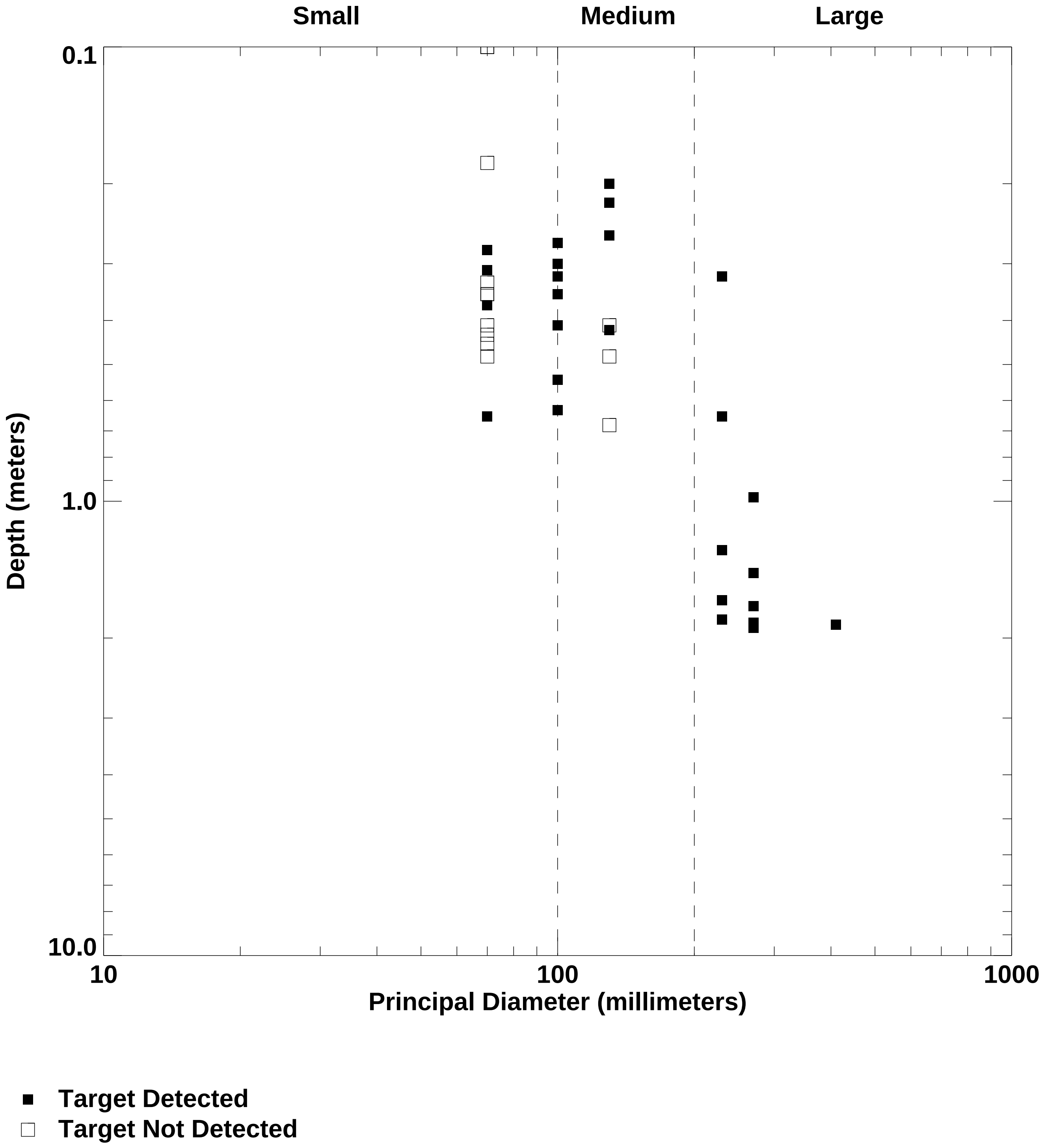
Characterization Statistics (TMA *Closest)*

	# Baseline	# Detected	Pd	# Correct	P_C[d]
Ability to Type					
Ordnance	43	30	0.70	0	0.00
Nonordnance[e]	78	54	0.69	0	0.00
Ability to Size					
Large	11	11	1.00	0	0.00
Medium	7	4	0.57	0	0.00
Small	25	15	0.60	0	0.00
Ability to Classify					
Bomb	21	21	1.00	0	0.00
Projectile	0	0	NA	0	NA
Mortar	0	0	NA	0	NA
Submunition	0	0	NA	0	NA
Rocket	22	9	0.41	0	0.00

Notes:

[a] Target Matching Algorithm
[b] Probability of detection
[c] Square root of the mean square depth error
[d] Probability of correct characterization
[e] TMA affects how nonordnance baseline targets are counted
NA - not applicable

JPG Controlled Site: Phase III
Scenario 1: Aerial Gunnery Range
Critical Radius: 2 meters
Demonstrator: ENSCO



Foerster - Aerial Gunnery Range

Detection Statistics (TMA[a] *Group*)

	# Baseline	# Detected	P_D[b]	P_{random}
Ordnance	43	26	0.60	0.054
Nonordnance	77	49	0.64	
Total	120	75		
Number False Alarms	126			
False Alarm Rate (#/Hectare)	36.46			
False Alarm Ratio (#/Ord.)	4.85			
Probability False Alarms	0.458			

Localization Statistics (TMA *Closest*) (in meters)

	Mean	Std Deviation
Position (x,y)		
dx - easting error	-0.05	0.35
dy - northing error	-0.04	0.3
Radial error	0.35	0.31
Depth (z)		
dz - averaged depth error	0.15	0.22
|dz|[c] - absolute depth error	0.26	

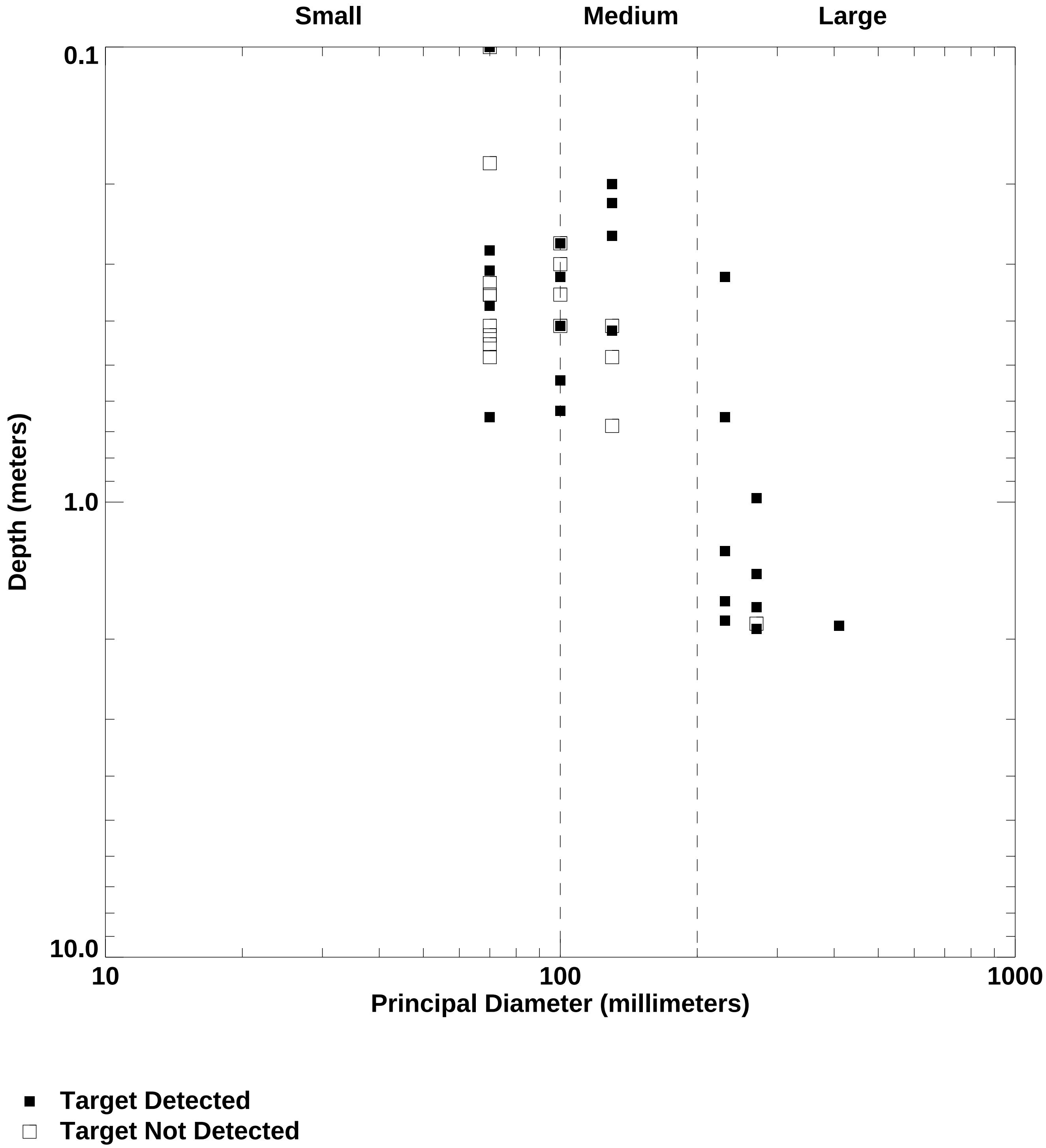
Characterization Statistics (TMA *Closest)*

	# Baseline	# Detected	Pd	# Correct	P_C[d]
Ability to Type					
Ordnance	43	26	0.60	0	0.00
Nonordnance[e]	78	49	0.63	0	0.00
Ability to Size					
Large	11	10	0.91	10	1.00
Medium	7	4	0.57	3	0.75
Small	25	12	0.48	1	0.08
Ability to Classify					
Bomb	21	16	0.76	0	0.00
Projectile	0	0	NA	0	NA
Mortar	0	0	NA	0	NA
Submunition	0	0	NA	0	NA
Rocket	22	10	0.45	0	0.00

Notes:

[a] Target Matching Algorithm
[b] Probability of detection
[c] Square root of the mean square depth error
[d] Probability of correct characterization
[e] TMA affects how nonordnance baseline targets are counted
NA - not applicable

JPG Controlled Site: Phase III
Scenario 1: Aerial Gunnery Range
Critical Radius: 2 meters
Demonstrator: Foerster



Geo-Centers - Aerial Gunnery Range

Detection Statistics (TMA[a] *Group*)

	# Baseline	# Detected	P_D[b]	P_{random}
Ordnance	43	43	1.00	0.109
Nonordnance	77	63	0.82	
Total	120	106		
Number False Alarms	271			
False Alarm Rate (#/Hectare)	78.41			
False Alarm Ratio (#/Ord.)	6.30			
Probability False Alarms	0.099			

Localization Statistics (TMA *Closest*) (in meters)

	Mean	Std Deviation
Position (x,y)		
dx - easting error	-0.38	0.3
dy - northing error	0.09	0.34
Radial error	0.53	0.27
Depth (z)		
dz - averaged depth error	0.59	0.32
|dz|[c] - absolute depth error	0.68	

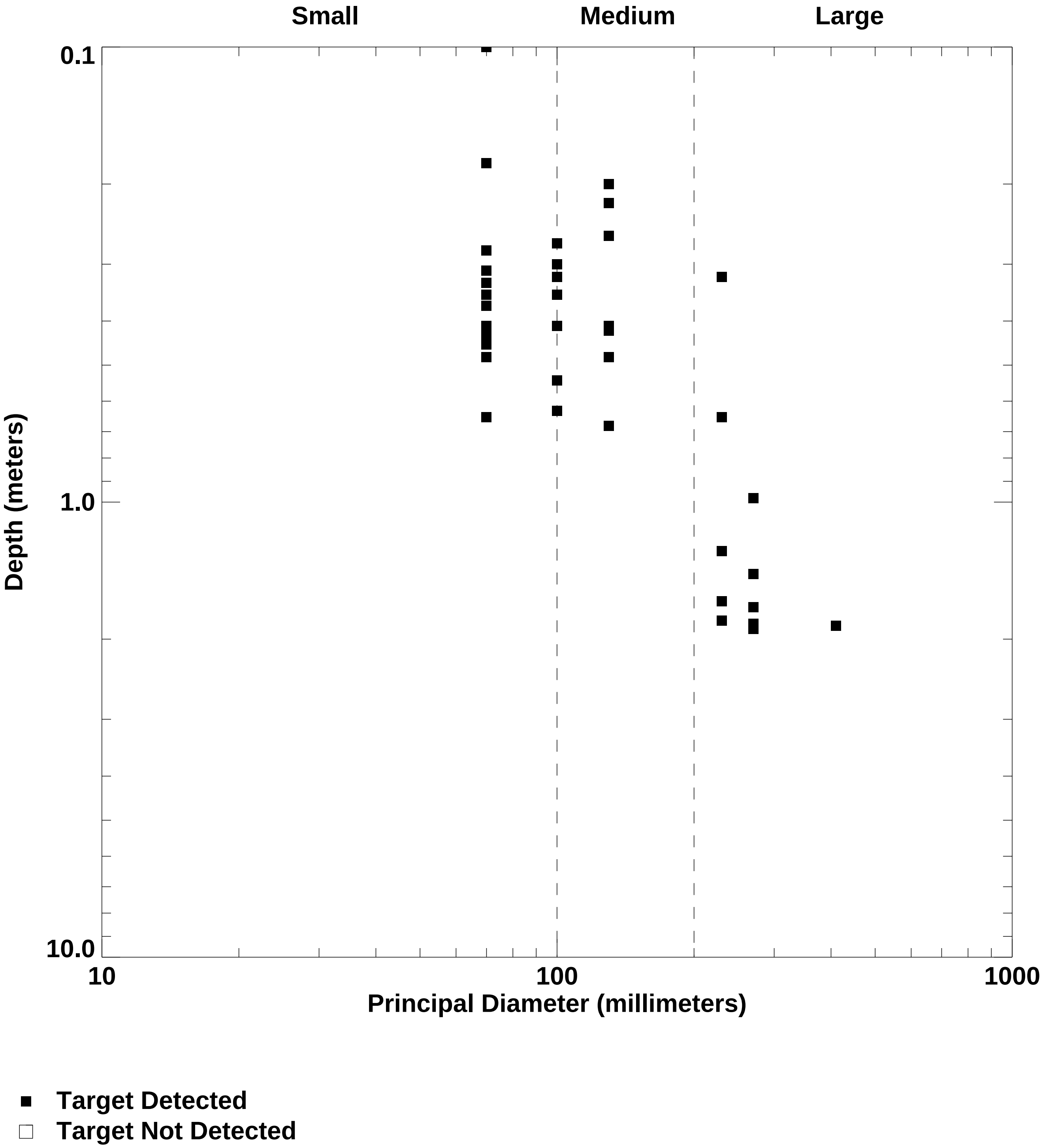
Characterization Statistics (TMA *Closest*)

	# Baseline	# Detected	Pd	# Correct	P_C[d]
Ability to Type					
Ordnance	43	43	1.00	43	1.00
Nonordnance[e]	78	63	0.81	0	0.00
Ability to Size					
Large	11	11	1.00	7	0.64
Medium	7	7	1.00	3	0.43
Small	25	25	1.00	4	0.16
Ability to Classify					
Bomb	21	21	1.00	21	1.00
Projectile	0	0	NA	0	NA
Mortar	0	0	NA	0	NA
Submunition	0	0	NA	0	NA
Rocket	22	22	1.00	0	0.00

Notes:

[a] Target Matching Algorithm
[b] Probability of detection
[c] Square root of the mean square depth error
[d] Probability of correct characterization
[e] TMA affects how nonordnance baseline targets are counted
NA - not applicable

JPG Controlled Site: Phase III
Scenario 1: Aerial Gunnery Range
Critical Radius: 2 meters
Demonstrator: GEO-CENTERS



Geophex - Aerial Gunnery Range

Detection Statistics (TMA[a] *Group*)

	# Baseline	# Detected	P_D[b]	P_{random}
Ordnance	43	40	0.93	0.073
Nonordnance	77	59	0.77	
Total	120	99		
Number False Alarms	165			
False Alarm Rate (#/Hectare)	47.74			
False Alarm Ratio (#/Ord.)	4.13			
Probability False Alarms	0.060			

Localization Statistics (TMA *Closest*) (in meters)

	Mean	Std Deviation
Position (x,y)		
dx - easting error	-0.12	0.45
dy - northing error	0.13	0.4
Radial error	0.52	0.35
Depth (z)		
dz - averaged depth error	-0.13	0.26
|dz|[c] - absolute depth error	0.28	

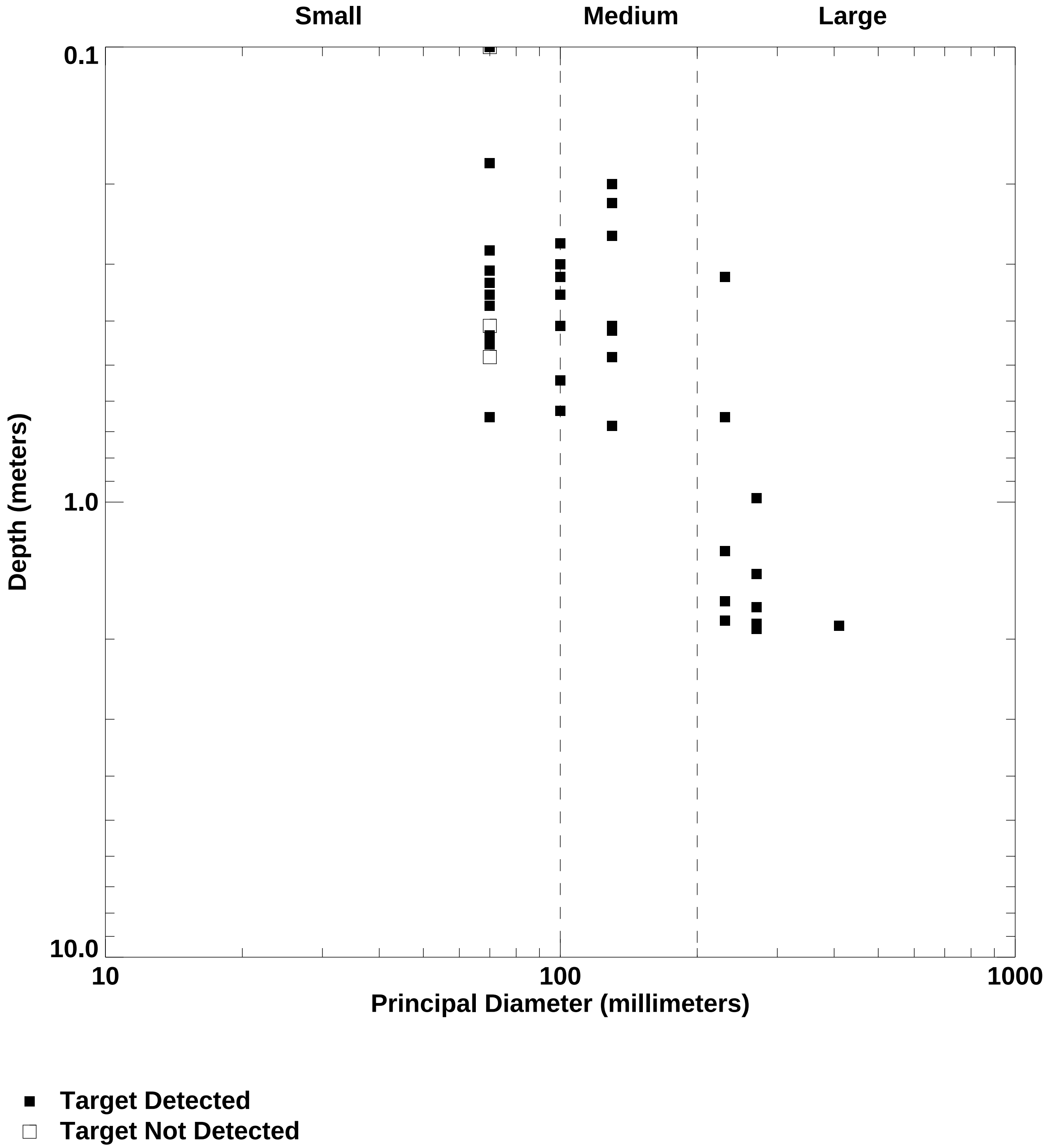
Characterization Statistics (TMA *Closest)*

	# Baseline	# Detected	Pd	# Correct	P_C[d]
Ability to Type					
Ordnance	43	40	0.93	40	1.00
Nonordnance[e]	78	59	0.76	2	0.03
Ability to Size					
Large	11	11	1.00	5	0.45
Medium	7	7	1.00	7	1.00
Small	25	22	0.88	6	0.27
Ability to Classify					
Bomb	21	21	1.00	0	0.00
Projectile	0	0	NA	0	NA
Mortar	0	0	NA	0	NA
Submunition	0	0	NA	0	NA
Rocket	22	19	0.86	0	0.00

Notes:

[a] Target Matching Algorithm
[b] Probability of detection
[c] Square root of the mean square depth error
[d] Probability of correct characterization
[e] TMA affects how nonordnance baseline targets are counted
NA - not applicable

JPG Controlled Site: Phase III
Scenario 1: Aerial Gunnery Range
Critical Radius: 2 meters
Demonstrator: Geophex



GeoPotential - Aerial Gunnery Range

Detection Statistics (TMA[a] *Group*)

	# Baseline	# Detected	P_D[b]	P_{random}
Ordnance	43	10	0.23	0.028
Nonordnance	77	14	0.18	
Total	120	24		
Number False Alarms	64			
False Alarm Rate (#/Hectare)	18.52			
False Alarm Ratio (#/Ord.)	6.40			
Probability False Alarms	0.023			

Localization Statistics (TMA *Closest*) (in meters)

	Mean	Std Deviation
Position (x,y)		
dx - easting error	0.18	0.6
dy - northing error	-0.22	0.62
Radial error	0.73	0.52
Depth (z)		
dz - averaged depth error	0.36	0.64
|dz|[c] - absolute depth error	0.72	

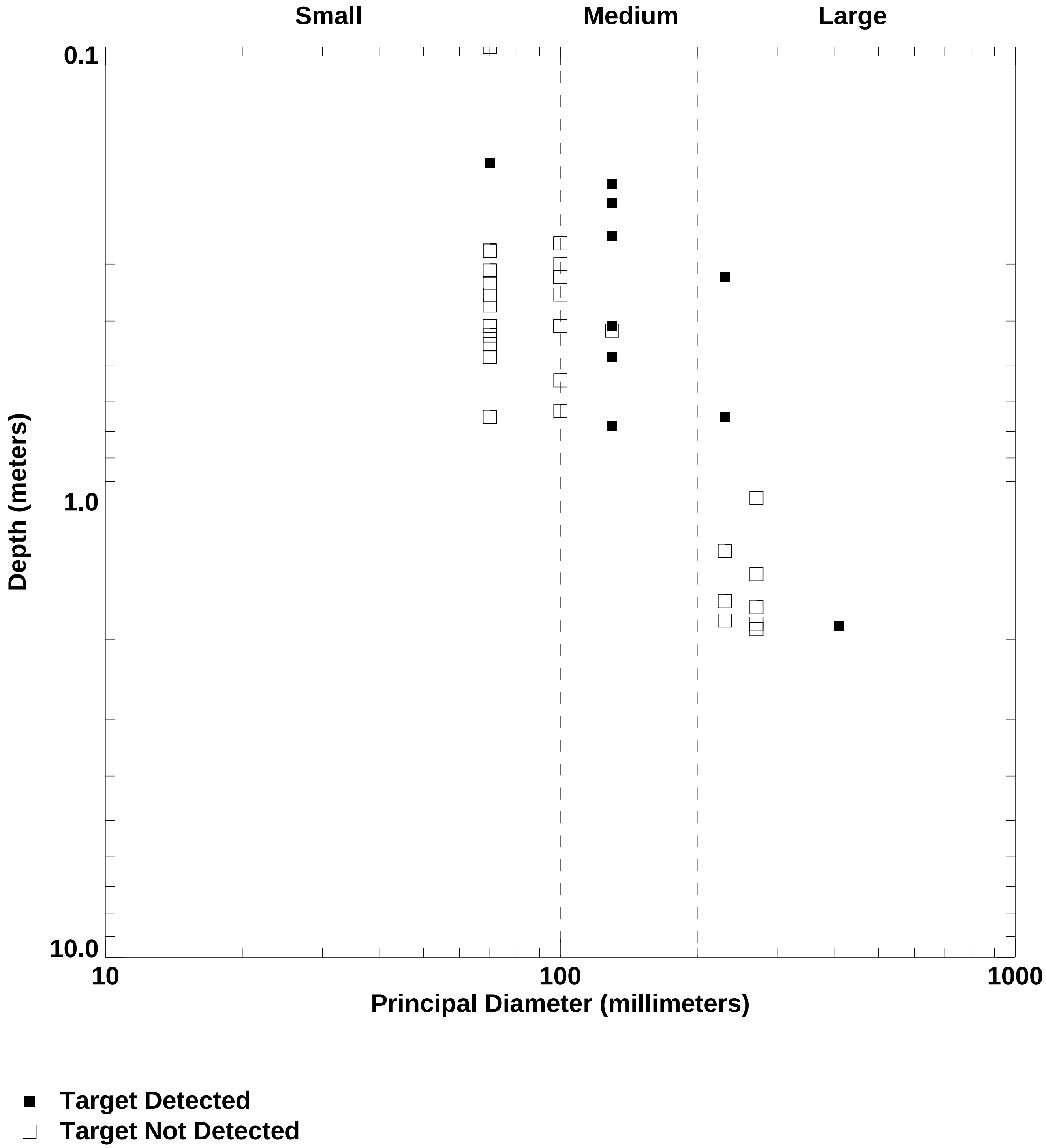
Characterization Statistics (TMA *Closest)*

	# Baseline	# Detected	P_D[b]	# Correct	P_C[d]
Ability to Type					
Ordnance	43	10	0.23	10	1.00
Nonordnance[e]	78	14	0.18	1	0.07
Ability to Size					
Large	11	3	0.27	1	0.33
Medium	7	6	0.86	5	0.83
Small	25	1	0.04	0	0.00
Ability to Classify					
Bomb	21	3	0.14	0	0.00
Projectile	0	0	NA	0	NA
Mortar	0	0	NA	0	NA
Submunition	0	0	NA	0	NA
Rocket	22	7	0.32	0	0.00

Notes:

[a] **Target Matching Algorithm**
[b] **Probability of detection**
[c] **Square root of the mean square depth error**
[d] **Probability of correct characterization**
[e] **TMA affects how nonordnance baseline targets are counted**
NA - not applicable

JPG Controlled Site: Phase III
Scenario 1: Aerial Gunnery Range
Critical Radius: 2 meters
Demonstrator: GeoPotential



GRI (Combined) - Aerial Gunnery Range

Detection Statistics (TMA[a] *Group*)

	# Baseline	# Detected	P_D[b]	P_{random}
Ordnance	43	41	0.95	0.258
Nonordnance	77	69	0.90	
Total	120	110		
Number False Alarms	773			
False Alarm Rate (#/Hectare)	223.66			
False Alarm Ratio (#/Ord.)	18.85			
Probability False Alarms	0.281			

Localization Statistics (TMA *Closest*) (in meters)

	Mean	Std Deviation
Position (x,y)		
dx - easting error	0.02	0.38
dy - northing error	0	0.38
Radial error	0.43	0.33
Depth (z)		
dz - averaged depth error	0.13	0.34
|dz|[c] - absolute depth error	0.36	

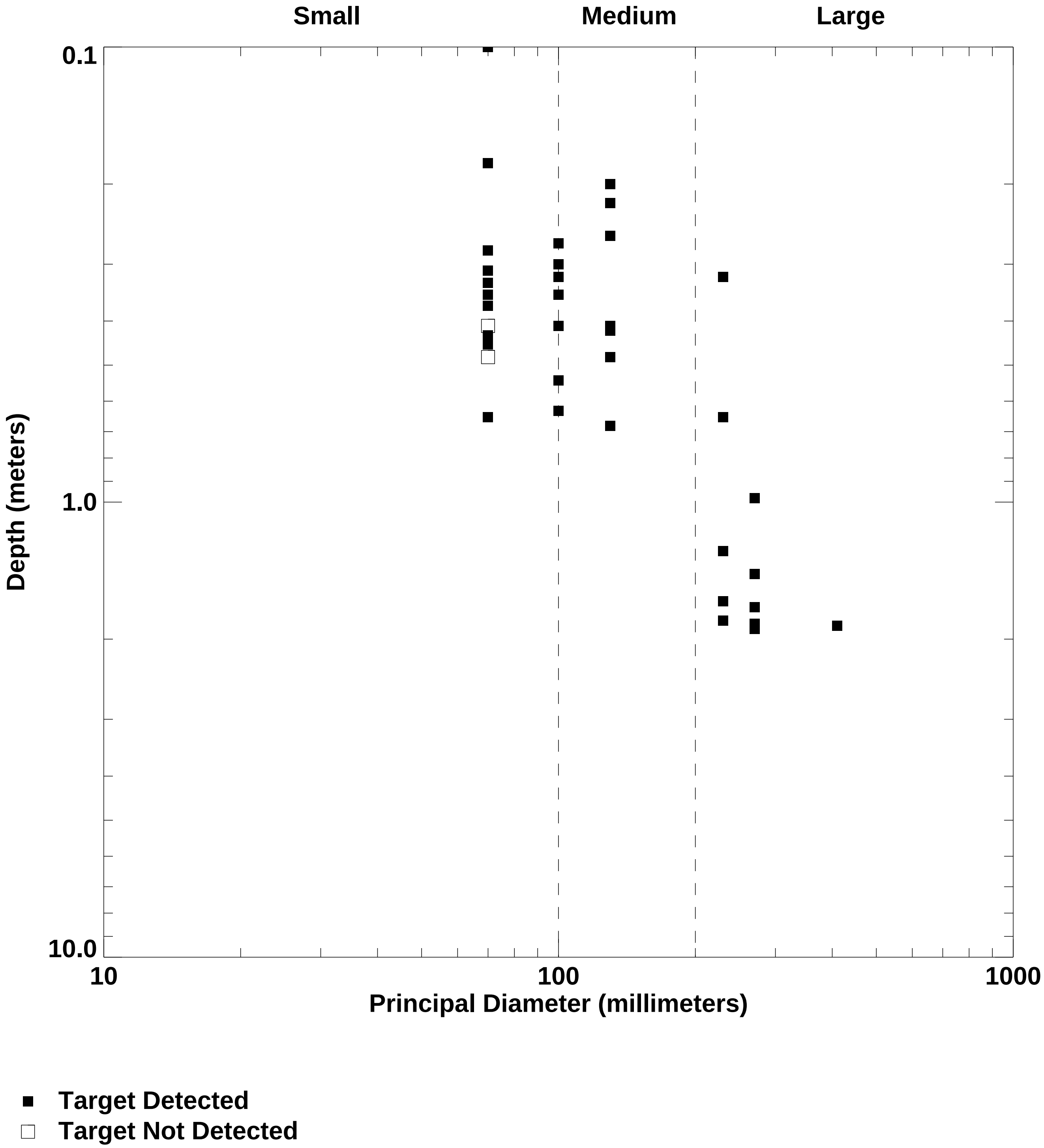
Characterization Statistics (TMA *Closest)*

	# Baseline	# Detected	Pd	# Correct	P_C[d]
Ability to Type					
Ordnance	43	41	0.95	38	0.93
Nonordnance[e]	78	69	0.88	4	0.06
Ability to Size					
Large	11	11	1.00	7	0.64
Medium	7	7	1.00	0	0.00
Small	25	23	0.92	13	0.57
Ability to Classify					
Bomb	21	21	1.00	10	0.48
Projectile	0	0	NA	0	NA
Mortar	0	0	NA	0	NA
Submunition	0	0	NA	0	NA
Rocket	22	20	0.91	10	0.50

Notes:

[a] Target Matching Algorithm
[b] Probability of detection
[c] Square root of the mean square depth error
[d] Probability of correct characterization
[e] TMA affects how nonordnance baseline targets are counted
NA - not applicable

JPG Controlled Site: Phase III
Scenario 1: Aerial Gunnery Range
Critical Radius: 2 meters
Demonstrator: GRI-Combined



GRI (EM) - Aerial Gunnery Range

Detection Statistics (TMA[a] *Group*)

	# Baseline	# Detected	P_D[b]	P_{random}
Ordnance	43	32	0.74	0.138
Nonordnance	77	62	0.81	
Total	120	94		
Number False Alarms	372			
False Alarm Rate (#/Hectare)	107.64			
False Alarm Ratio (#/Ord.)	11.63			
Probability False Alarms	0.135			

Localization Statistics (TMA *Closest*) (in meters)

	Mean	Std Deviation
Position (x,y)		
dx - easting error	0.01	0.41
dy - northing error	0.14	0.4
Radial error	0.45	0.38
Depth (z)		
dz - averaged depth error	-0.06	0.23
|dz|[c] - absolute depth error	0.24	

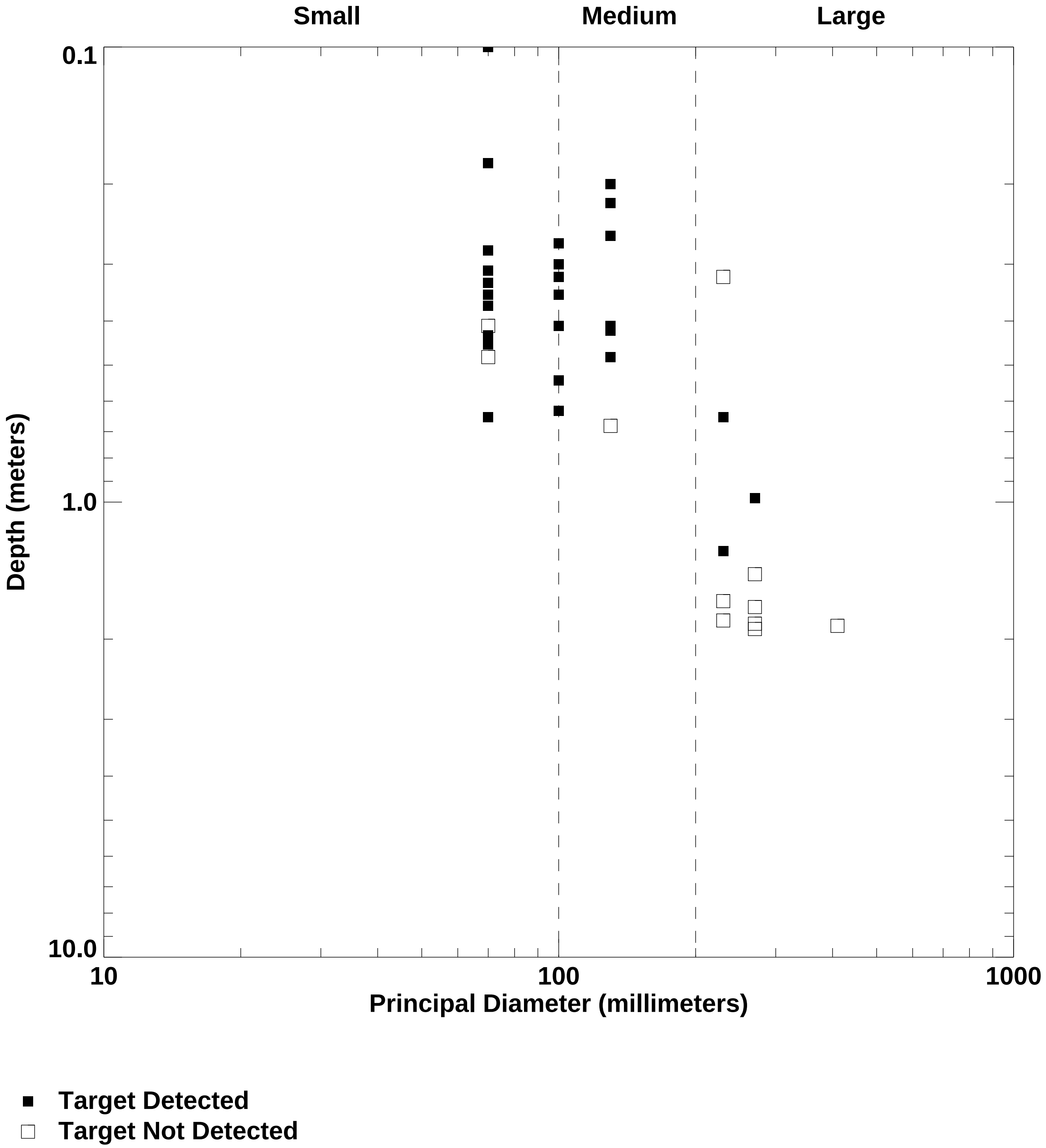
Characterization Statistics (TMA *Closest)*

	# Baseline	# Detected	Pd	# Correct	P_C[d]
Ability to Type					
Ordnance	43	32	0.74	32	1.00
Nonordnance[e]	78	62	0.79	2	0.03
Ability to Size					
Large	11	3	0.27	0	0.00
Medium	7	6	0.86	0	0.00
Small	25	23	0.92	0	0.00
Ability to Classify					
Bomb	21	13	0.62	0	0.00
Projectile	0	0	NA	0	NA
Mortar	0	0	NA	0	NA
Submunition	0	0	NA	0	NA
Rocket	22	19	0.86	0	0.00

Notes:

[a] **Target Matching Algorithm**
[b] **Probability of detection**
[c] **Square root of the mean square depth error**
[d] **Probability of correct characterization**
[e] **TMA affects how nonordnance baseline targets are counted**
NA - not applicable

JPG Controlled Site: Phase III
Scenario 1: Aerial Gunnery Range
Critical Radius: 2 meters
Demonstrator: GRI-EM



GRI (Mag) - Aerial Gunnery Range

Detection Statistics (TMA[a] *Group*)

	# Baseline	# Detected	P_D[b]	P_{random}
Ordnance	43	38	0.88	0.273
Nonordnance	77	72	0.94	
Total	120	110		
Number False Alarms	834			
False Alarm Rate (#/Hectare)	241.31			
False Alarm Ratio (#/Ord.)	21.95			
Probability False Alarms	0.303			

Localization Statistics (TMA *Closest*) (in meters)

	Mean	Std Deviation
Position (x,y)		
dx - easting error	0.03	0.4
dy - northing error	-0.03	0.44
Radial error	0.47	0.36
Depth (z)		
dz - averaged depth error	0.14	0.32
|dz|[c] - absolute depth error	0.45	

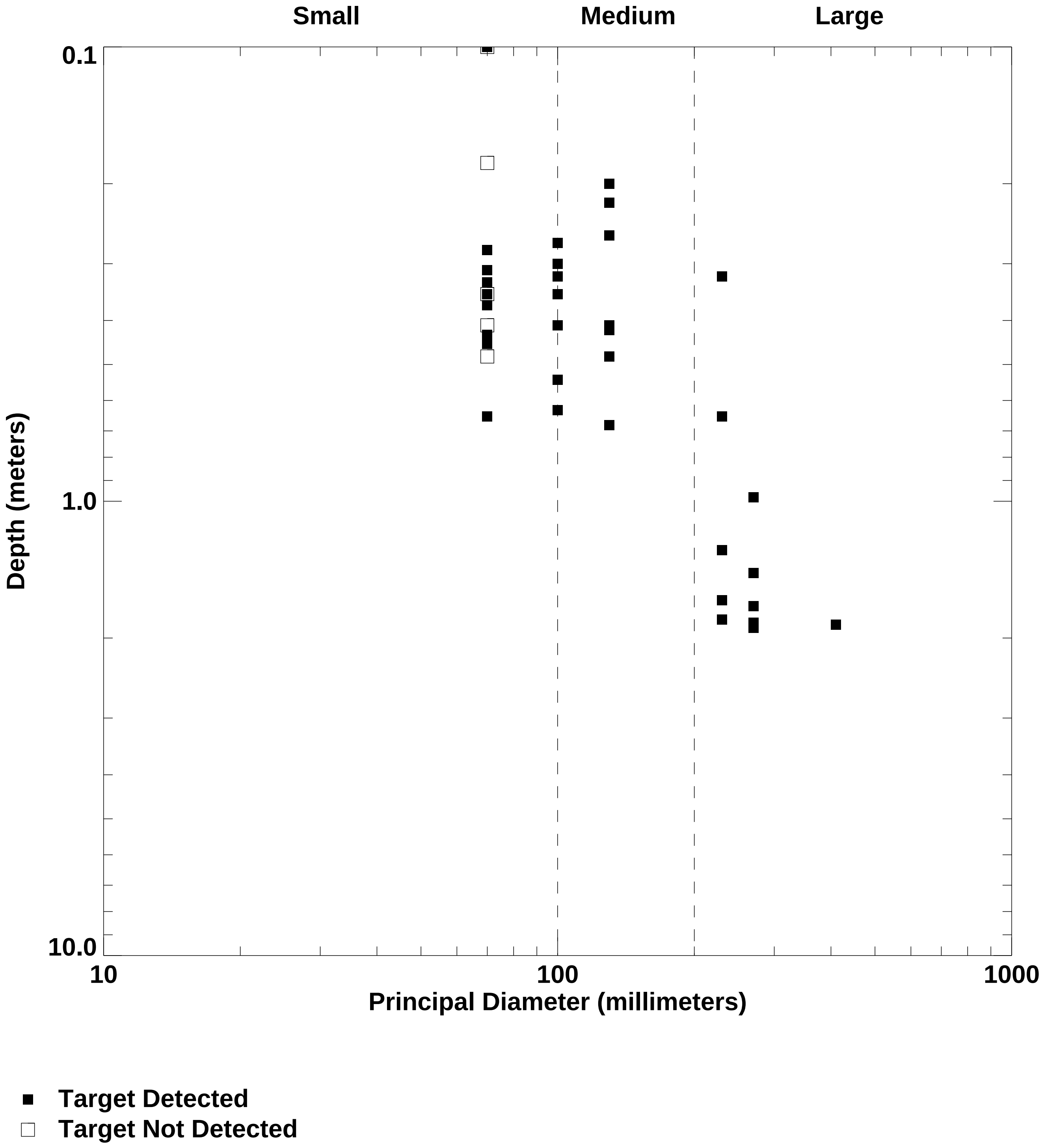
Characterization Statistics (TMA *Closest*)

	# Baseline	# Detected	Pd	# Correct	P_C[d]
Ability to Type					
Ordnance	43	38	0.88	34	0.89
Nonordnance[e]	78	72	0.92	4	0.06
Ability to Size					
Large	11	11	1.00	7	0.64
Medium	7	7	1.00	0	0.00
Small	25	20	0.80	17	0.85
Ability to Classify					
Bomb	21	21	1.00	10	0.48
Projectile	0	0	NA	0	NA
Mortar	0	0	NA	0	NA
Submunition	0	0	NA	0	NA
Rocket	22	17	0.77	12	0.71

Notes:

[a] Target Matching Algorithm
[b] Probability of detection
[c] Square root of the mean square depth error
[d] Probability of correct characterization
[e] TMA affects how nonordnance baseline targets are counted
NA - not applicable

JPG Controlled Site: Phase III
Scenario 1: Aerial Gunnery Range
Critical Radius: 2 meters
Demonstrator: GRI-Magnetometer



NAEVA - Aerial Gunnery Range

Detection Statistics (TMA[a] *Group*)

	# Baseline	# Detected	P_D[b]	P_{random}
Ordnance	43	38	0.88	0.054
Nonordnance	77	61	0.79	
Total	120	99		
Number False Alarms	113			
False Alarm Rate (#/Hectare)	32.70			
False Alarm Ratio (#/Ord.)	2.97			
Probability False Alarms	0.041			

Localization Statistics (TMA *Closest*) (in meters)

	Mean	Std Deviation
Position (x,y)		
dx - easting error	-0.33	0.36
dy - northing error	0.03	0.4
Radial error	0.56	0.29
Depth (z)		
dz - averaged depth error	0.12	0.24
|dz|[c] - absolute depth error	0.28	

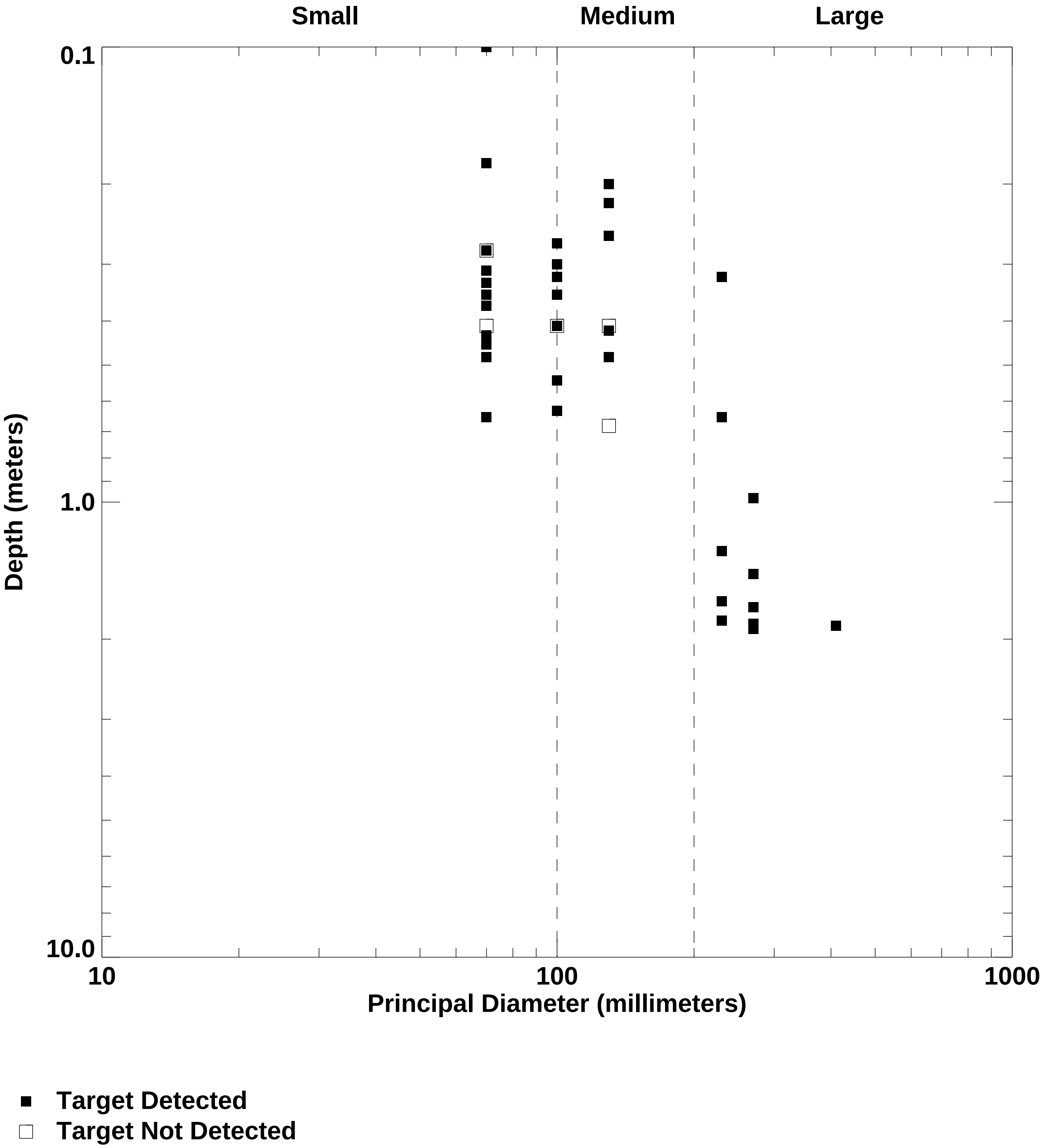
Characterization Statistics (TMA *Closest)*

	# Baseline	# Detected	Pd	# Correct	P_C[d]
Ability to Type					
Ordnance	43	38	0.88	38	1.00
Nonordnance[e]	78	61	0.78	0	0.00
Ability to Size					
Large	11	11	1.00	11	1.00
Medium	7	5	0.71	0	0.00
Small	25	22	0.88	0	0.00
Ability to Classify					
Bomb	21	20	0.95	20	1.00
Projectile	0	0	NA	0	NA
Mortar	0	0	NA	0	NA
Submunition	0	0	NA	0	NA
Rocket	22	18	0.82	0	0.00

Notes:

[a] **Target Matching Algorithm**
[b] **Probability of detection**
[c] **Square root of the mean square depth error**
[d] **Probability of correct characterization**
[e] **TMA affects how nonordnance baseline targets are counted**
NA - not applicable

JPG Controlled Site: Phase III
Scenario 1: Aerial Gunnery Range
Critical Radius: 2 meters
Demonstrator: NAEVA



Rockwell - Aerial Gunnery Range

Detection Statistics (TMA[a] *Group*)

	# Baseline	# Detected	P_D[b]	P_{random}
Ordnance	43	23	0.53	0.038
Nonordnance	77	25	0.32	
Total	120	48		
Number False Alarms	84			
False Alarm Rate (#/Hectare)	24.30			
False Alarm Ratio (#/Ord.)	3.65			
Probability False Alarms	0.031			

Localization Statistics (TMA *Closest*) (in meters)

	Mean	Std Deviation
Position (x,y)		
dx - easting error	0.09	0.47
dy - northing error	0.03	0.78
Radial error	0.76	0.51
Depth (z)		
dz - averaged depth error	-0.01	0.26
|dz|[c] - absolute depth error	0.24	

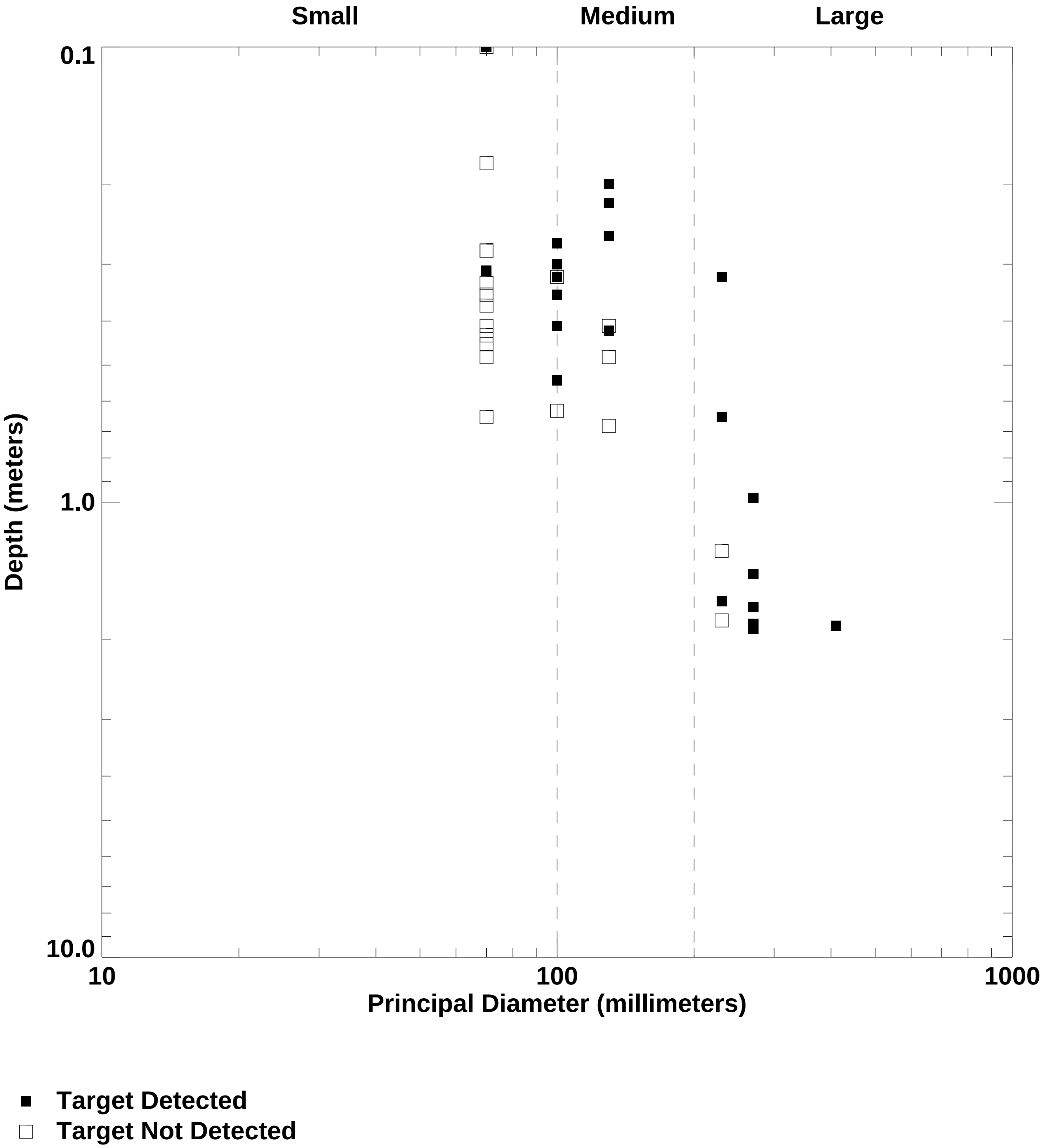
Characterization Statistics (TMA *Closest)*

	# Baseline	# Detected	Pd	# Correct	P_C[d]
Ability to Type					
Ordnance	43	23	0.53	0	0.00
Nonordnance[e]	78	25	0.32	0	0.00
Ability to Size					
Large	11	9	0.82	0	0.00
Medium	7	4	0.57	0	0.00
Small	25	10	0.40	0	0.00
Ability to Classify					
Bomb	21	17	0.81	0	0.00
Projectile	0	0	NA	0	NA
Mortar	0	0	NA	0	NA
Submunition	0	0	NA	0	NA
Rocket	22	6	0.27	0	0.00

Notes:

[a] **Target Matching Algorithm**
[b] **Probability of detection**
[c] **Square root of the mean square depth error**
[d] **Probability of correct characterization**
[e] **TMA affects how nonordnance baseline targets are counted**
NA - not applicable

JPG Controlled Site: Phase III
Scenario 1: Aerial Gunnery Range
Critical Radius: 2 meters
Demonstrator: Rockwell



SCA_ADI - Aerial Gunnery Range

Detection Statistics (TMA[a] *Group*)

	# Baseline	# Detected	P_D[b]	P_{random}
Ordnance	43	32	0.74	0.074
Nonordnance	77	65	0.84	
Total	120	97		
Number False Alarms	175			
False Alarm Rate (#/Hectare)	50.64			
False Alarm Ratio (#/Ord.)	5.47			
Probability False Alarms	0.064			

Localization Statistics (TMA *Closest*) (in meters)

	Mean	Std Deviation
Position (x,y)		
dx - easting error	0.08	0.43
dy - northing error	-0.02	0.46
Radial error	0.54	0.34
Depth (z)		
dz - averaged depth error	-0.32	0.42
|dz|[c] - absolute depth error	0.53	

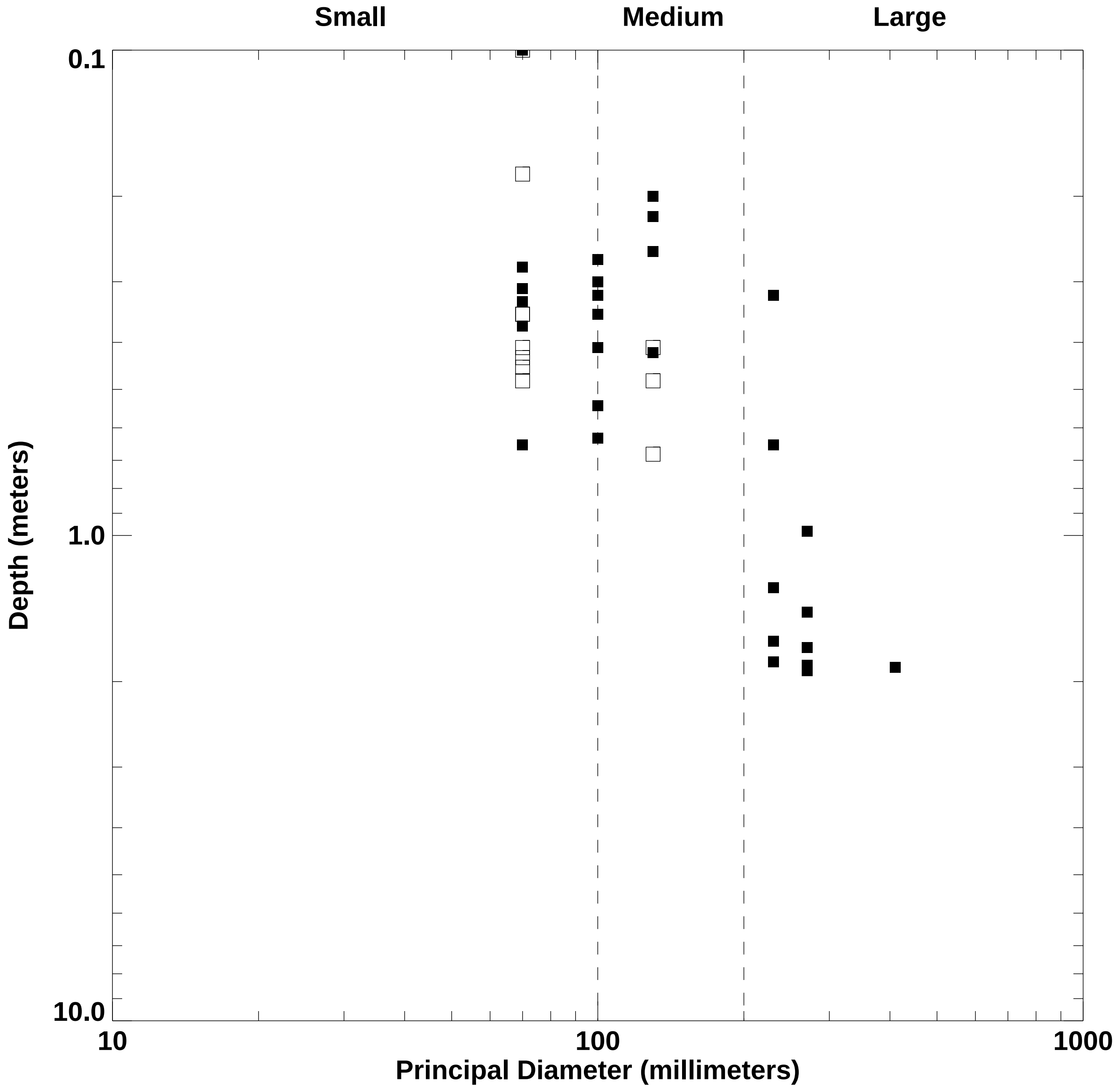
Characterization Statistics (TMA *Closest)*

	# Baseline	# Detected	Pd	# Correct	P_C[d]
Ability to Type					
Ordnance	43	32	0.74	29	0.91
Nonordnance[e]	78	65	0.83	1	0.02
Ability to Size					
Large	11	11	1.00	2	0.18
Medium	7	4	0.57	1	0.25
Small	25	17	0.68	14	0.82
Ability to Classify					
Bomb	21	21	1.00	0	0.00
Projectile	0	0	NA	0	NA
Mortar	0	0	NA	0	NA
Submunition	0	0	NA	0	NA
Rocket	22	11	0.50	0	0.00

Notes:

[a] **Target Matching Algorithm**
[b] **Probability of detection**
[c] **Square root of the mean square depth error**
[d] **Probability of correct characterization**
[e] **TMA affects how nonordnance baseline targets are counted**
NA - not applicable

JPG Controlled Site: Phase III
Scenario 1: Aerial Gunnery Range
Critical Radius: 2 meters
Demonstrator: SCA_ADI



■ **Target Detected**
□ **Target Not Detected**

SCA_Geo-Centers - Aerial Gunnery Range

Detection Statistics (TMA[a] *Group*)

	# Baseline	# Detected	P_D[b]	P_{random}
Ordnance	43	40	0.93	0.08
Nonordnance	77	62	0.81	
Total	120	102		
Number False Alarms	188			
False Alarm Rate (#/Hectare)	54.40			
False Alarm Ratio (#/Ord.)	4.70			
Probability False Alarms	0.068			

Localization Statistics (TMA *Closest*) (in meters)

	Mean	Std Deviation
Position (x,y)		
dx - easting error	-0.52	0.58
dy - northing error	0	0.5
Radial error	0.83	0.41
Depth (z)		
dz - averaged depth error	-0.26	0.31
|dz|[c] - absolute depth error	0.41	

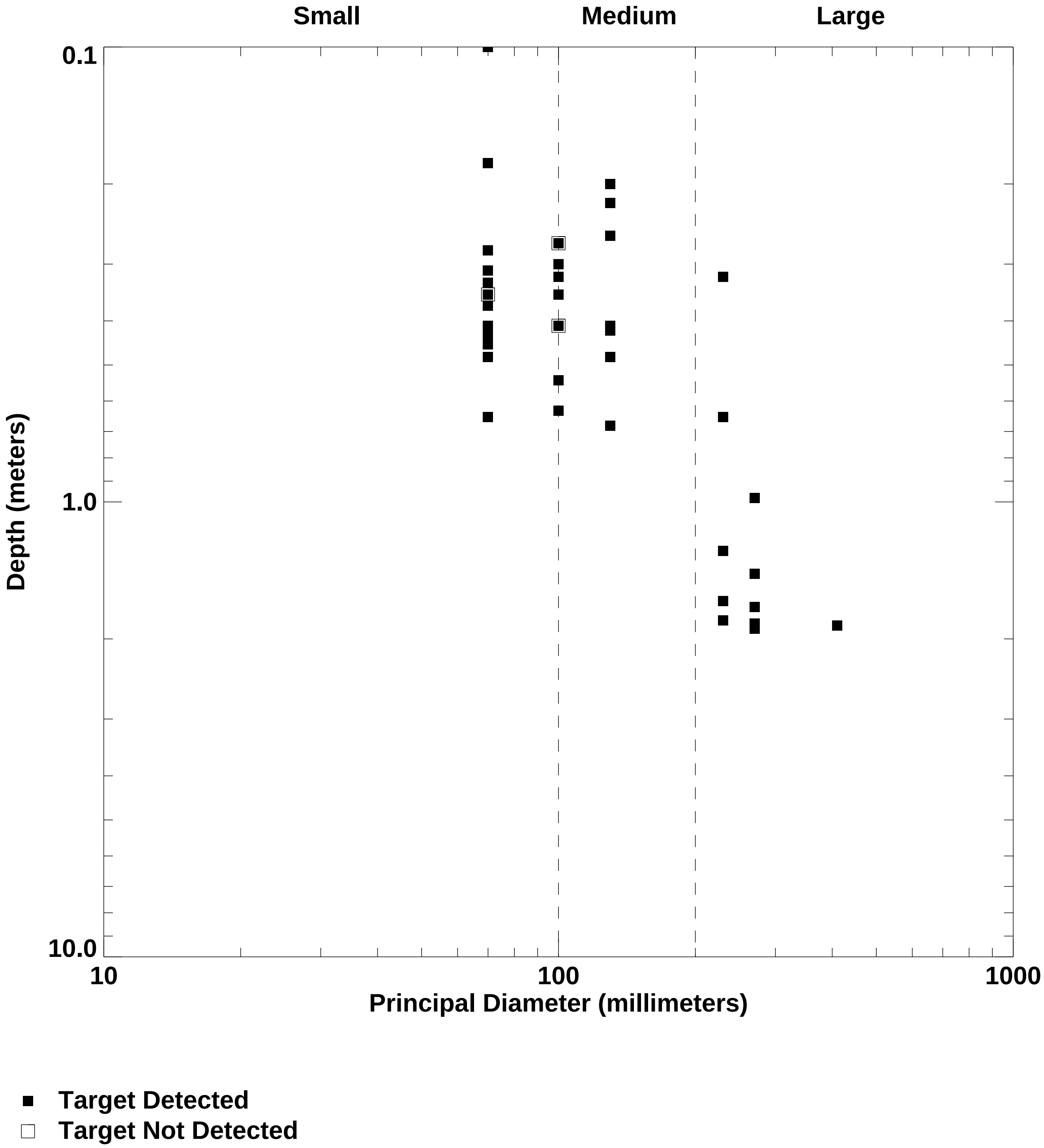
Characterization Statistics (TMA *Closest*)

	# Baseline	# Detected	Pd	# Correct	P_C[d]
Ability to Type					
Ordnance	43	40	0.93	36	0.90
Nonordnance[e]	78	62	0.79	3	0.05
Ability to Size					
Large	11	11	1.00	4	0.36
Medium	7	7	1.00	3	0.43
Small	25	22	0.88	18	0.82
Ability to Classify					
Bomb	21	19	0.90	0	0.00
Projectile	0	0	NA	0	NA
Mortar	0	0	NA	0	NA
Submunition	0	0	NA	0	NA
Rocket	22	21	0.95	0	0.00

Notes:

[a] Target Matching Algorithm
[b] Probability of detection
[c] Square root of the mean square depth error
[d] Probability of correct characterization
[e] TMA affects how nonordnance baseline targets are counted
NA - not applicable

JPG Controlled Site: Phase III
Scenario 1: Aerial Gunnery Range
Critical Radius: 2 meters
Demonstrator: SCA_Geocenters



5.2 ARTILLERY AND MORTAR RANGE

This section presents the performance of the following demonstrators that participated in this scenario:

5.2.1 ADI
5.2.2 Battelle
5.2.3 CHEMRAD
5.2.4 ENSCO
5.2.5 Geo-Centers
5.2.6 Geometrics
5.2.7 Geophex
5.2.8 GeoPotential
5.2.9 GRI (Combined)
5.2.10 GRI (EM)
5.2.11 GRI (Mag)
5.2.12 NAEVA
5.2.13 Rockwell
5.2.14 SCA_ADI
5.2.15 SCA_GeoCenters
5.2.16 SCA_Geometrics

ADI - Artillery and Mortar Range

Detection Statistics (TMA[a] *Group*)

	# Baseline	# Detected	P_D[b]	P_{random}
Ordnance	67	57	0.85	0.106
Nonordnance	50	39	0.78	
Total	117	96		
Number False Alarms	360			
False Alarm Rate (#/Hectare)	76.88			
False Alarm Ratio (#/Ord.)	6.32			
Probability False Alarms	0.097			

Localization Statistics (TMA *Closest*) (in meters)

	Mean	Std Deviation
Position (x,y)		
dx - easting error	0.03	0.35
dy - northing error	0.12	0.42
Radial error	0.43	0.35
Depth (z)		
dz - averaged depth error	0.17	0.2
|dz|[c] - absolute depth error	0.26	

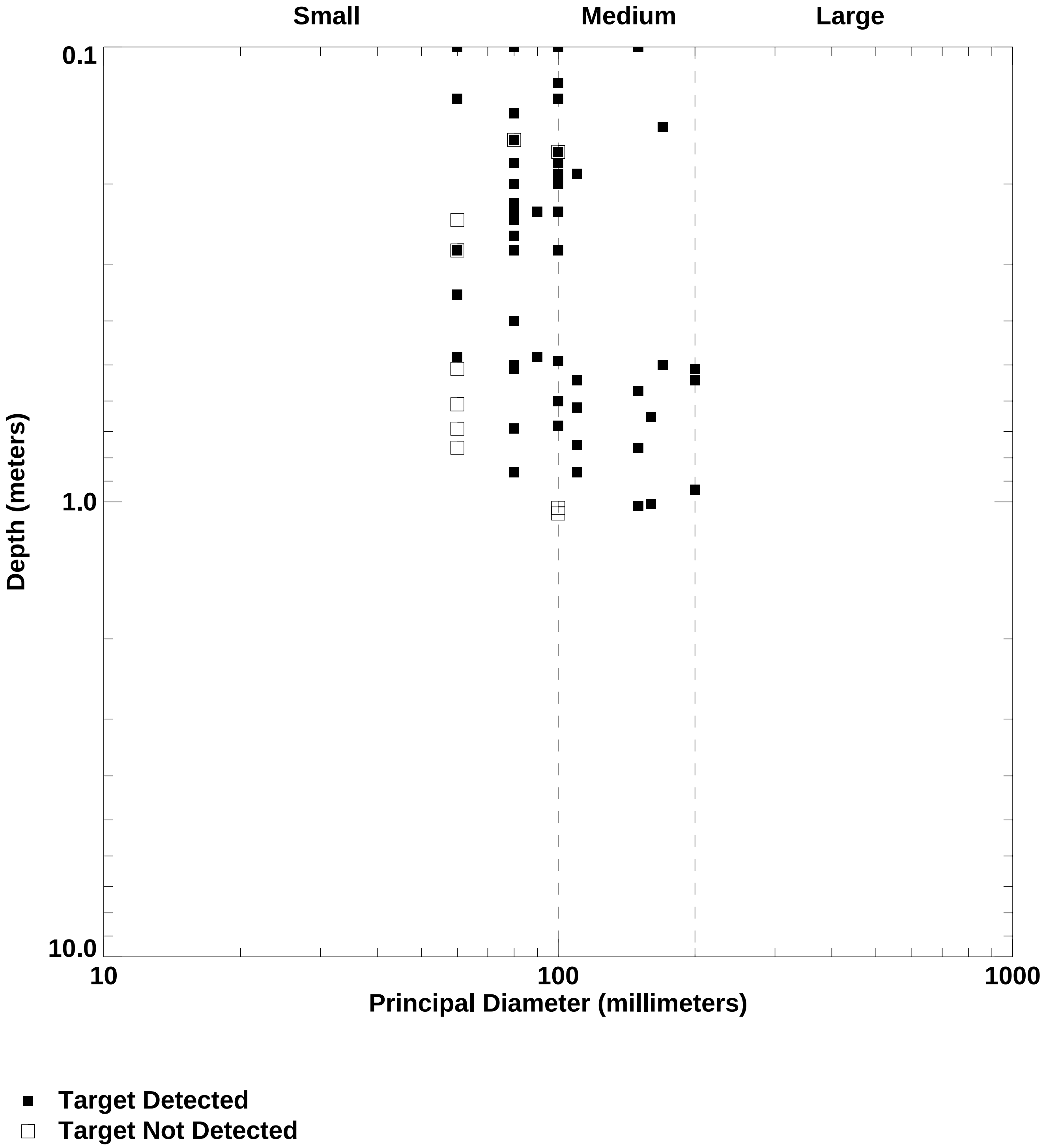
Characterization Statistics (TMA *Closest*)

	# Baseline	# Detected	P_D[b]	# Correct	P_C[d]
Ability to Type					
Ordnance	67	57	0.85	55	0.96
Nonordnance	50	39	0.78	1	0.03
Ability to Size					
Large	3	3	1.00	3	1.00
Medium	31	28	0.90	15	0.54
Small	33	26	0.79	2	0.08
Ability to Classify					
Bomb	0	0	NA	0	NA
Projectile	41	38	0.93	0	0.00
Mortar	26	19	0.73	7	0.37
Submunition	0	0	NA	0	NA
Rocket	0	0	NA	0	NA

Notes:

[a] **Target Matching Algorithm**
[b] **Probability of detection**
[c] **Square root of the mean square depth error**
[d] **Probability of correct characterization**
NA - not applicable

JPG Controlled Site: Phase III
Scenario 2: Artillery and Mortar Range
Critical Radius: 2 meters
Demonstrator: ADI



Battelle - Artillery and Mortar Range

Detection Statistics (TMA[a] *Group*, 5m critical radius)

	# Baseline	# Detected	P_D[b]	P_{random}
Ordnance	67	8	0.12	0.026
Nonordnance	50	5	0.10	
Total	117	13		
Number False Alarms	8			
False Alarm Rate (#/Hectare)	1.71			
False Alarm Ratio (#/Ord.)	1.00			
Probability False Alarms	0.013			

Localization Statistics (TMA *Closest*, 5m critical radius) (in meters)

	Mean	Std Deviation
Position (x,y)		
dx - easting error	-1.45	2.24
dy - northing error	0.64	2.39
Radial error	3.37	1.07
Depth (z)		
dz - averaged depth error	0.57	0.83
|dz|[c] - absolute depth error	0.98	

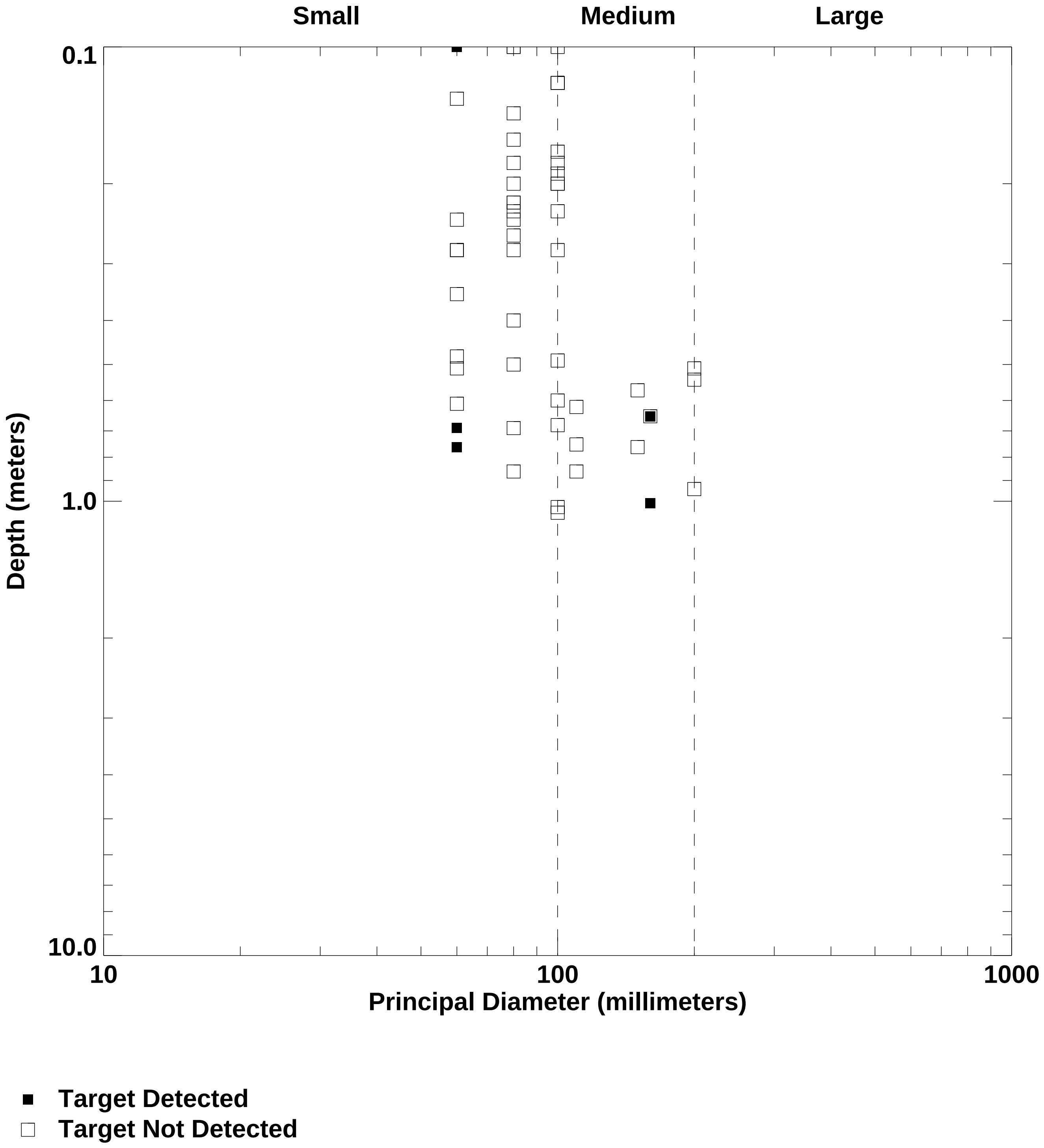
Characterization Statistics (TMA *Closest*, 5m critical radius)

	# Baseline	# Detected	P_D[b]	# Correct	P_C[d]
Ability to Type					
Ordnance	67	8	0.12	0	0.00
Nonordnance	50	5	0.10	0	0.00
Ability to Size					
Large	3	0	0.00	0	NA
Medium	31	4	0.13	0	0.00
Small	33	4	0.12	0	0.00
Ability to Classify					
Bomb	0	0	NA	0	NA
Projectile	41	4	0.10	0	0.00
Mortar	26	4	0.15	0	0.00
Submunition	0	0	NA	0	NA
Rocket	0	0	NA	0	NA

Notes:

[a] **Target Matching Algorithm**
[b] **Probability of detection**
[c] **Square root of the mean square depth error**
[d] **Probability of correct characterization**

JPG Controlled Site: Phase III
Scenario 2: Artillery and Mortar Range
Critical Radius: 5 meters
Demonstrator: Battelle



CHEMRAD - Artillery and Mortar Range

Detection Statistics (TMA[a] *Group*)

	# Baseline	# Detected	P_D[b]	P_{random}
Ordnance	67	29	0.43	0.02
Nonordnance	50	14	0.28	
Total	117	23		
Number False Alarms	48			
False Alarm Rate (#/Hectare)	10.25			
False Alarm Ratio (#/Ord.)	1.66			
Probability False Alarms	0.013			

Localization Statistics (TMA *Closest*) (in meters)

	Mean	Std Deviation
Position (x,y)		
dx - easting error	0.85	0.65
dy - northing error	-0.17	0.61
Radial error	1.14	0.49
Depth (z)		
dz - averaged depth error	0.73	0.44
|dz|[c] - absolute depth error	0.85	

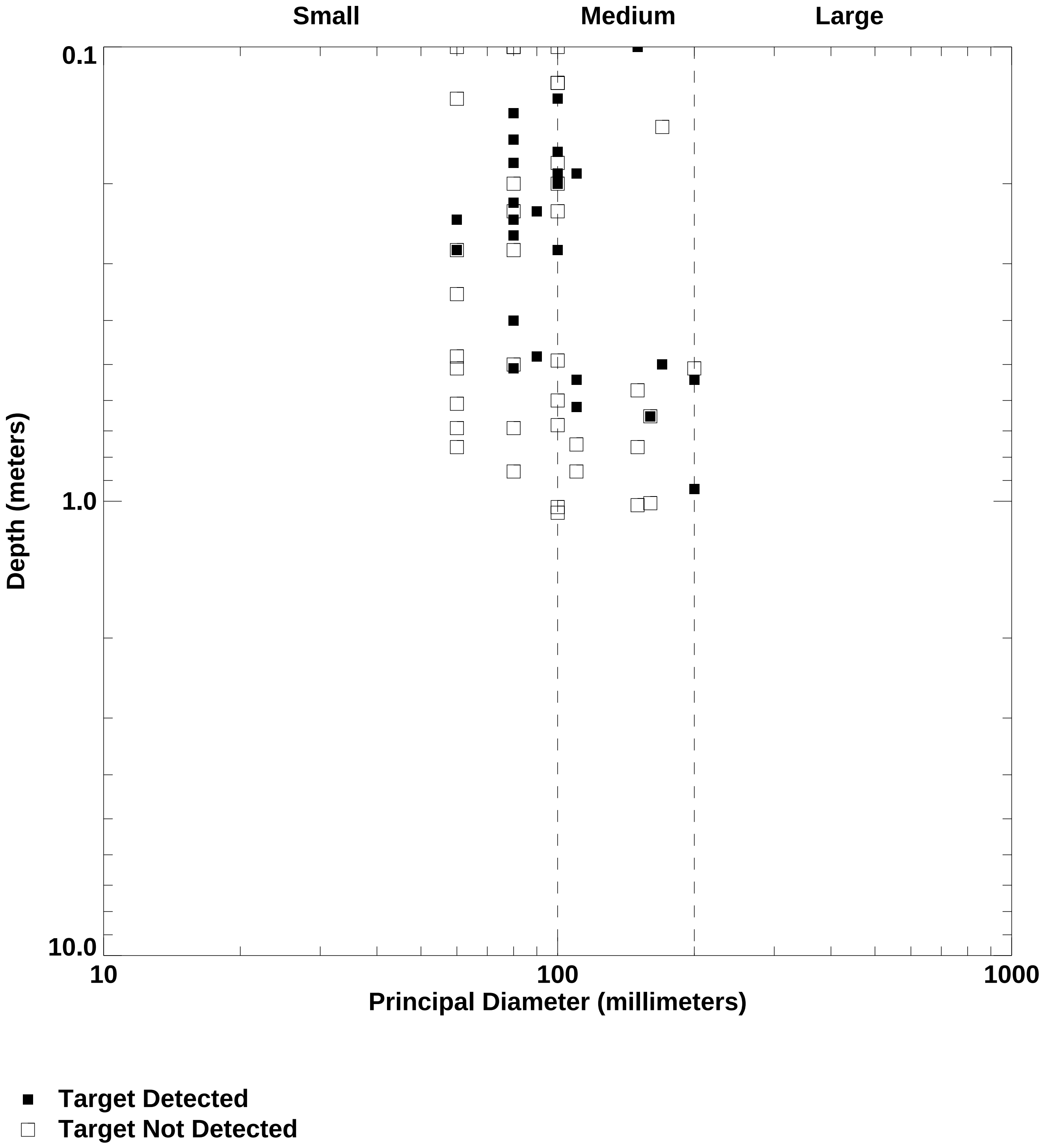
Characterization Statistics (TMA *Closest)*

	# Baseline	# Detected	P_D[b]	# Correct	P_C[d]
Ability to Type					
Ordnance	67	29	0.43	0	0.00
Nonordnance	50	14	0.28	0	0.00
Ability to Size					
Large	3	2	0.67	0	0.00
Medium	31	12	0.39	0	0.00
Small	33	15	0.45	0	0.00
Ability to Classify					
Bomb	0	0	NA	0	NA
Projectile	41	20	0.49	0	0.00
Mortar	26	9	0.35	0	0.00
Submunition	0	0	NA	0	NA
Rocket	0	0	NA	0	NA

Notes:

[a] Target Matching Algorithm
[b] Probability of detection
[c] Square root of the mean square depth error
[d] Probability of correct characterization
NA - not applicable

JPG Controlled Site: Phase III
Scenario 2: Artillery and Mortar Range
Critical Radius: 2 meters
Demonstrator: CHEMRAD



ENSCO - Artillery and Mortar Range

Detection Statistics (TMA[a] *Group*)

	# Baseline	# Detected	P_D[b]	P_{random}
Ordnance	67	47	0.70	0.065
Nonordnance	50	28	0.56	
Total	117	75		
Number False Alarms	204			
False Alarm Rate (#/Hectare)	43.56			
False Alarm Ratio (#/Ord.)	4.34			
Probability False Alarms	0.055			

Localization Statistics (TMA *Closest*) (in meters)

	Mean	Std Deviation
Position (x,y)		
dx - easting error	0.02	0.25
dy - northing error	-0.04	0.49
Radial error	0.42	0.36
Depth (z)		
dz - averaged depth error	-0.1	0.2
|dz|[c] - absolute depth error	0.22	

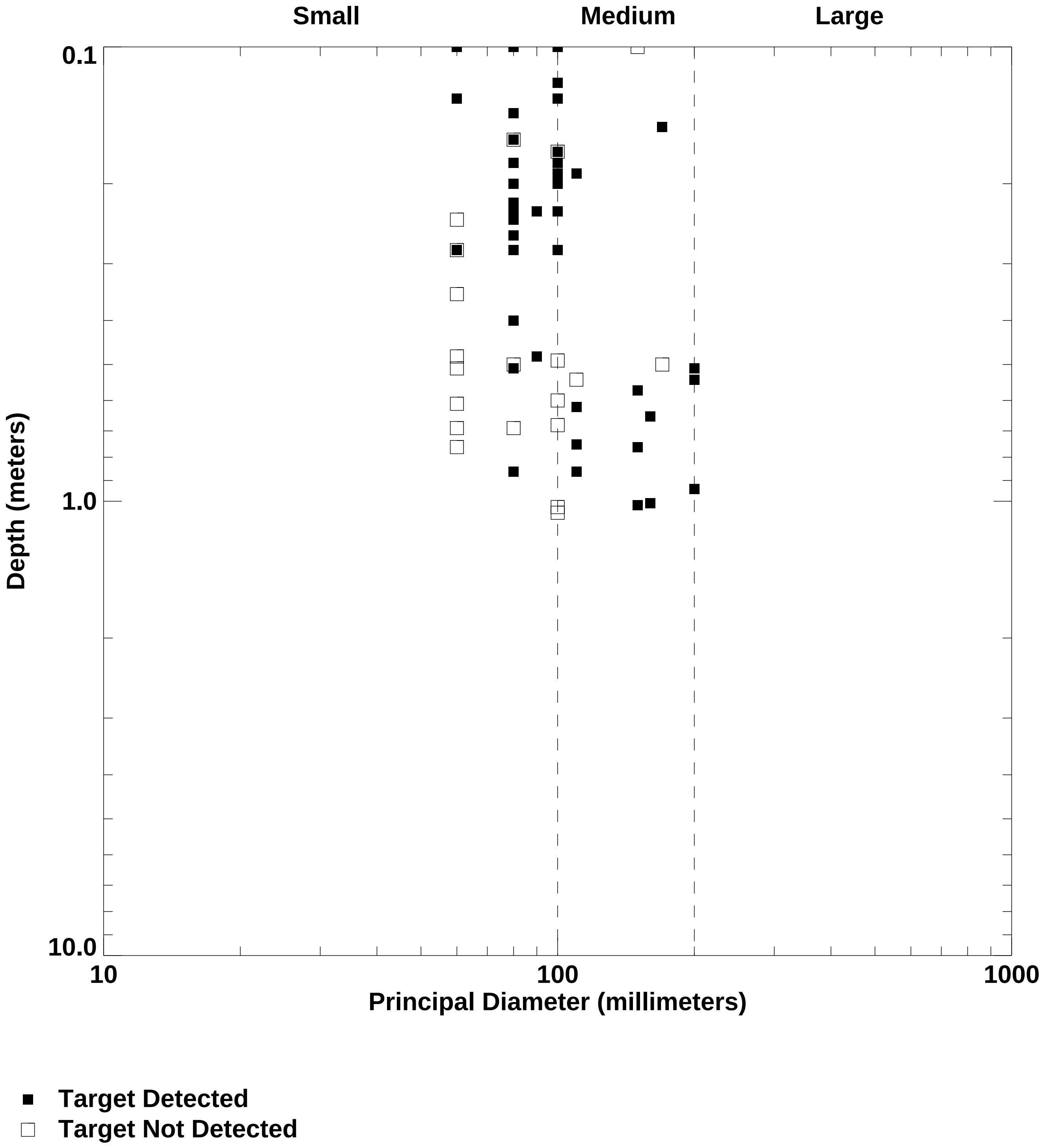
Characterization Statistics (TMA *Closest)*

	# Baseline	# Detected	P_D[b]	# Correct	P_C[d]
Ability to Type					
Ordnance	67	47	0.70	0	0.00
Nonordnance	50	28	0.56	0	0.00
Ability to Size					
Large	3	3	1.00	0	0.00
Medium	31	22	0.71	0	0.00
Small	33	22	0.67	0	0.00
Ability to Classify					
Bomb	0	0	NA	0	NA
Projectile	41	33	0.80	0	0.00
Mortar	26	14	0.54	0	0.00
Submunition	0	0	NA	0	NA
Rocket	0	0	NA	0	NA

Notes:

[a] **Target Matching Algorithm**
[b] **Probability of detection**
[c] **Square root of the mean square depth error**
[d] **Probability of correct characterization**
NA - not applicable

JPG Controlled Site: Phase III
Scenario 2: Artillery and Mortar Range
Critical Radius: 2 meters
Demonstrator: ENSCO



Geo-Centers - Artillery and Mortar Range

Detection Statistics (TMA[a] *Group*)

	# Baseline	# Detected	P_D[b]	P_{random}
Ordnance	67	62	0.93	0.112
Nonordnance	50	46	0.92	
Total	117	108		
Number False Alarms	378			
False Alarm Rate (#/Hectare)	80.72			
False Alarm Ratio (#/Ord.)	6.10			
Probability False Alarms	0.101			

Localization Statistics (TMA *Closest*) (in meters)

	Mean	Std Deviation
Position (x,y)		
dx - easting error	0.07	0.24
dy - northing error	0.33	0.29
Radial error	0.44	0.24
Depth (z)		
dz - averaged depth error	0.38	0.23
|dz|[c] - absolute depth error	0.45	

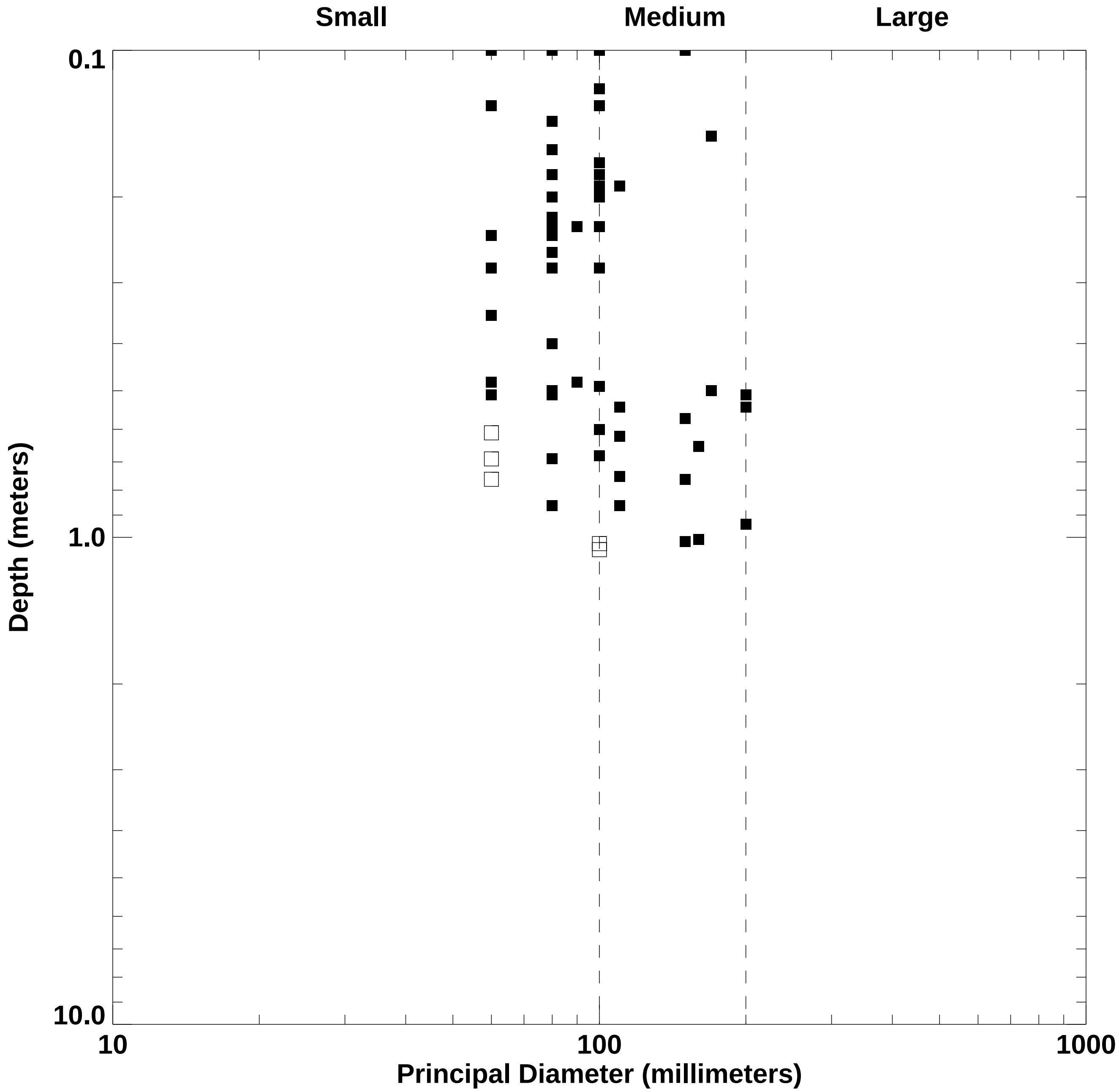
Characterization Statistics (TMA *Closest*)

	# Baseline	# Detected	P_D[b]	# Correct	P_C[d]
Ability to Type					
Ordnance	67	62	0.93	62	1.00
Nonordnance	50	46	0.92	0	0.00
Ability to Size					
Large	3	3	1.00	0	0.00
Medium	31	29	0.94	10	0.34
Small	33	30	0.91	24	0.80
Ability to Classify					
Bomb	0	0	NA	0	NA
Projectile	41	39	0.95	39	1.00
Mortar	26	23	0.88	0	0.00
Submunition	0	0	NA	0	NA
Rocket	0	0	NA	0	NA

Notes:

[a] **Target Matching Algorithm**
[b] **Probability of detection**
[c] **Square root of the mean square depth error**
[d] **Probability of correct characterization**
NA - not applicable

JPG Controlled Site: Phase III
Scenario 2: Artillery and Mortar Range
Critical Radius: 2 meters
Demonstrator: GEO-CENTERS



■ Target Detected
□ Target Not Detected

Geometrics - Artillery and Mortar Range

Detection Statistics (TMA[a] *Group*)

	# Baseline	# Detected	P_D[b]	P_{random}
Ordnance	67	60	0.90	0.063
Nonordnance	50	42	0.84	
Total	117	102		
Number False Alarms	180			
False Alarm Rate (#/Hectare)	38.44			
False Alarm Ratio (#/Ord.)	3.00			
Probability False Alarms	0.048			

Localization Statistics (TMA *Closest*) (in meters)

	Mean	Std Deviation
Position (x,y)		
dx - easting error	-0.01	0.23
dy - northing error	0.21	0.38
Radial error	0.39	0.30
Depth (z)		
dz - averaged depth error	0.12	0.29
|dz|[c] - absolute depth error	0.32	

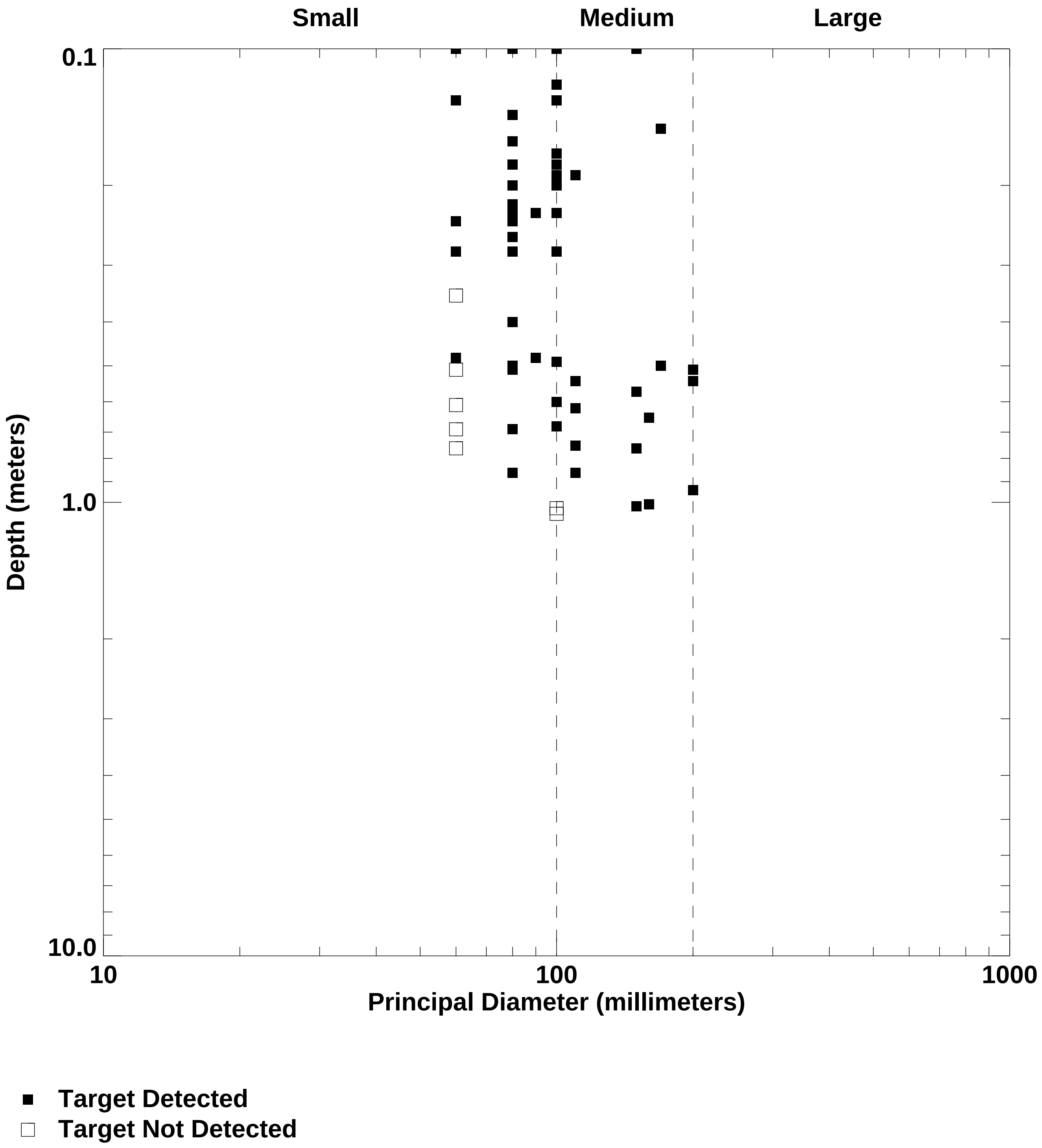
Characterization Statistics (TMA *Closest*)

	# Baseline	# Detected	P_D[b]	# Correct	P_C[d]
Ability to Type					
Ordnance	67	60	0.90	59	0.98
Nonordnance	50	42	0.84	0	0.00
Ability to Size					
Large	3	3	1.00	1	0.33
Medium	31	29	0.94	12	0.41
Small	33	28	0.85	26	0.93
Ability to Classify					
Bomb	0	0	NA	0	NA
Projectile	41	39	0.95	11	0.28
Mortar	26	21	0.81	19	0.90
Submunition	0	0	NA	0	NA
Rocket	0	0	NA	0	NA

Notes:

[a] Target Matching Algorithm
[b] Probability of detection
[c] Square root of the mean square depth error
[d] Probability of correct characterization
NA - not applicable

JPG Controlled Site: Phase III
Scenario 2: Artillery and Mortar Range
Critical Radius: 2 meters
Demonstrator: Geometrics



Geophex - Artillery and Mortar Range

Detection Statistics (TMA[a] *Group*)

	# Baseline	# Detected	P_D[b]	P_{random}
Ordnance	67	45	0.67	0.038
Nonordnance	50	30	0.60	
Total	117	75		
Number False Alarms	99			
False Alarm Rate (#/Hectare)	21.14			
False Alarm Ratio (#/Ord.)	2.20			
Probability False Alarms	0.027			

Localization Statistics (TMA *Closest*) (in meters)

	Mean	Std Deviation
Position (x,y)		
dx - easting error	0.02	0.44
dy - northing error	0.22	0.36
Radial error	0.51	0.34
Depth (z)		
dz - averaged depth error	0.05	0.24
|dz|[c] - absolute depth error	0.24	

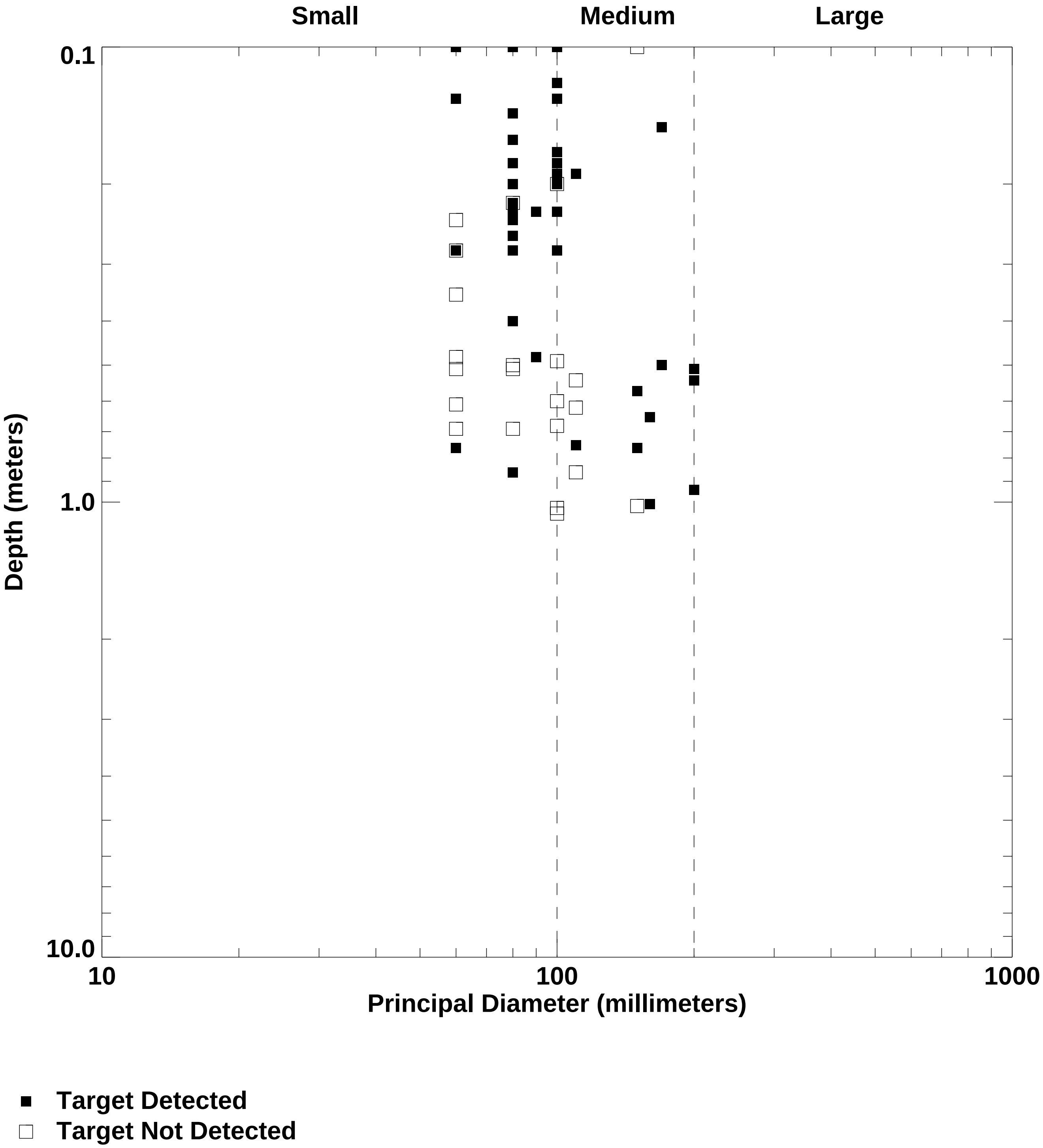
Characterization Statistics (TMA *Closest*)

	# Baseline	# Detected	P_D[b]	# Correct	P_C[d]
Ability to Type					
Ordnance	67	45	0.67	45	1.00
Nonordnance	50	30	0.60	0	0.00
Ability to Size					
Large	3	3	1.00	0	0.00
Medium	31	20	0.65	9	0.45
Small	33	22	0.67	16	0.73
Ability to Classify					
Bomb	0	0	NA	0	NA
Projectile	41	30	0.73	0	0.00
Mortar	26	15	0.58	0	0.00
Submunition	0	0	NA	0	NA
Rocket	0	0	NA	0	NA

Notes:

[a] **Target Matching Algorithm**
[b] **Probability of detection**
[c] **Square root of the mean square depth error**
[d] **Probability of correct characterization**
NA - not applicable

JPG Controlled Site: Phase III
Scenario 2: Artillery and Mortar Range
Critical Radius: 2 meters
Demonstrator: Geophex



GeoPotential - Artillery and Mortar Range

Detection Statistics (TMA[a] *Group*)

	# Baseline	# Detected	P_D[b]	P_{random}
Ordnance	67	2	0.03	0.006
Nonordnance	50	1	0.02	
Total	117	3		
Number False Alarms	20			
False Alarm Rate (#/Hectare)	4.27			
False Alarm Ratio (#/Ord.)	10.00			
Probability False Alarms	0.005			

Localization Statistics (TMA *Closest*) (in meters)

	Mean	Std Deviation
Position (x,y)		
dx - easting error	-0.4	0.73
dy - northing error	-0.16	0.54
Radial error	0.81	0.32
Depth (z)		
dz - averaged depth error	0.24	0.21
|dz|[c] - absolute depth error	0.30	

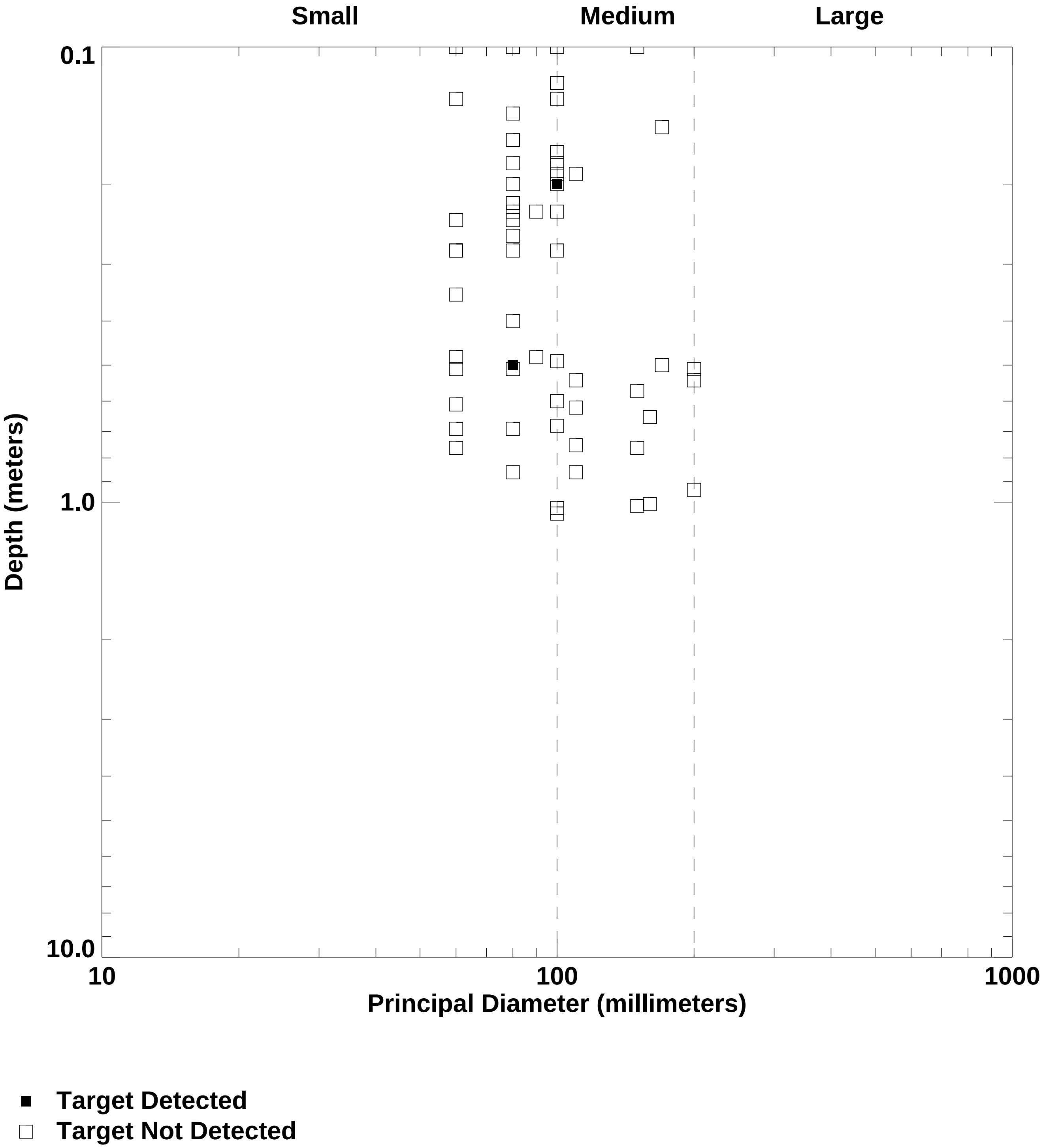
Characterization Statistics (TMA *Closest*)

	# Baseline	# Detected	P_D[b]	# Correct	P_C[d]
Ability to Type					
Ordnance	67	2	0.03	2	1.00
Nonordnance	50	1	0.02	0	0.00
Ability to Size					
Large	3	0	0.00	0	NA
Medium	31	1	0.03	1	1.00
Small	33	1	0.03	0	0.00
Ability to Classify					
Bomb	0	0	NA	0	NA
Projectile	41	1	0.02	0	0.00
Mortar	26	1	0.04	0	0.00
Submunition	0	0	NA	0	NA
Rocket	0	0	NA	0	NA

Notes:

[a] Target Matching Algorithm
[b] Probability of detection
[c] Square root of the mean square depth error
[d] Probability of correct characterization
NA - not applicable

JPG Controlled Site: Phase III
Scenario 2: Artillery and Mortar Range
Critical Radius: 2 meters
Demonstrator: GeoPotential



GRI-Combined - Artillery and Mortar Range

Detection Statistics (TMA[a] *Group*)

	# Baseline	# Detected	P_D[b]	P_{random}
Ordnance	67	60	0.90	0.289
Nonordnance	50	50	1.00	
Total	117	110		
Number False Alarms	1209			
False Alarm Rate (#/Hectare)	258.18			
False Alarm Ratio (#/Ord.)	20.15			
Probability False Alarms	0.324			

Localization Statistics (TMA *Closest*) (in meters)

	Mean	Std Deviation
Position (x,y)		
dx - easting error	-0.05	0.22
dy - northing error	0.1	0.35
Radial error	0.37	0.21
Depth (z)		
dz - averaged depth error	0.15	0.32
|dz|[c] - absolute depth error	0.35	

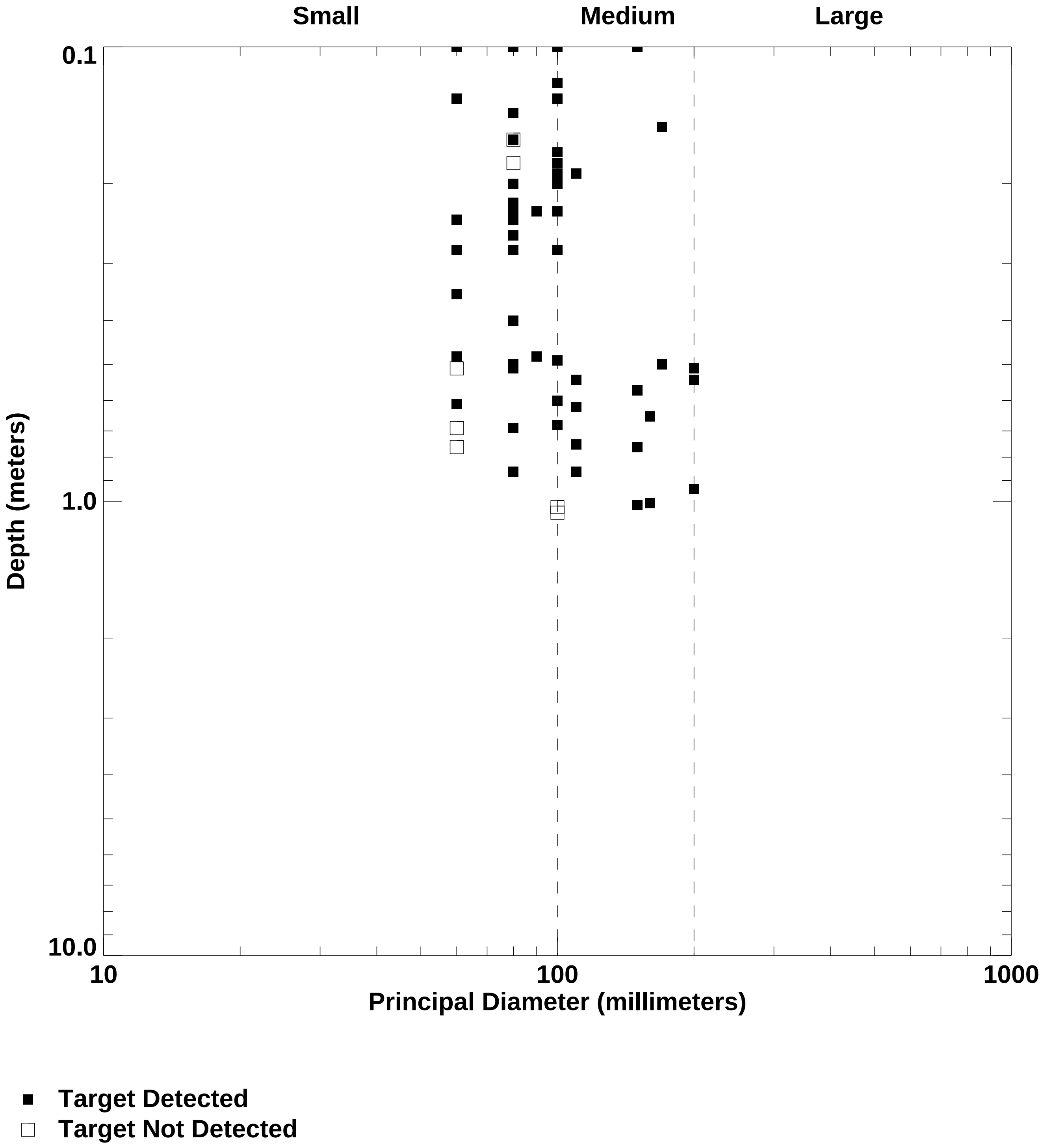
Characterization Statistics (TMA *Closest)*

	# Baseline	# Detected	P_D[b]	# Correct	P_C[d]
Ability to Type					
Ordnance	67	60	0.90	58	0.97
Nonordnance	50	50	1.00	2	0.04
Ability to Size					
Large	3	3	1.00	0	0.00
Medium	31	29	0.94	7	0.24
Small	33	28	0.85	15	0.54
Ability to Classify					
Bomb	0	0	NA	0	NA
Projectile	41	38	0.93	11	0.29
Mortar	26	22	0.85	10	0.45
Submunition	0	0	NA	0	NA
Rocket	0	0	NA	0	NA

Notes:

[a] Target Matching Algorithm
[b] Probability of detection
[c] Square root of the mean square depth error
[d] Probability of correct characterization
NA - not applicable

JPG Controlled Site: Phase III
Scenario 2: Artillery and Mortar Range
Critical Radius: 2 meters
Demonstrator: GRI-Combined



GRI-EM - Artillery and Mortar Range

Detection Statistics (TMA[a] *Group*)

	# Baseline	# Detected	P_D[b]	P_{random}
Ordnance	67	58	0.87	0.151
Nonordnance	50	49	0.98	
Total	117	107		
Number False Alarms	549			
False Alarm Rate (#/Hectare)	117.24			
False Alarm Ratio (#/Ord.)	9.47			
Probability False Alarms	0.147			

Localization Statistics (TMA *Closest*) (in meters)

	Mean	Std Deviation
Position (x,y)		
dx - easting error	-0.06	0.25
dy - northing error	0.02	0.32
Radial error	0.38	0.16
Depth (z)		
dz - averaged depth error	0.28	0.22
|dz|[c] - absolute depth error	0.36	

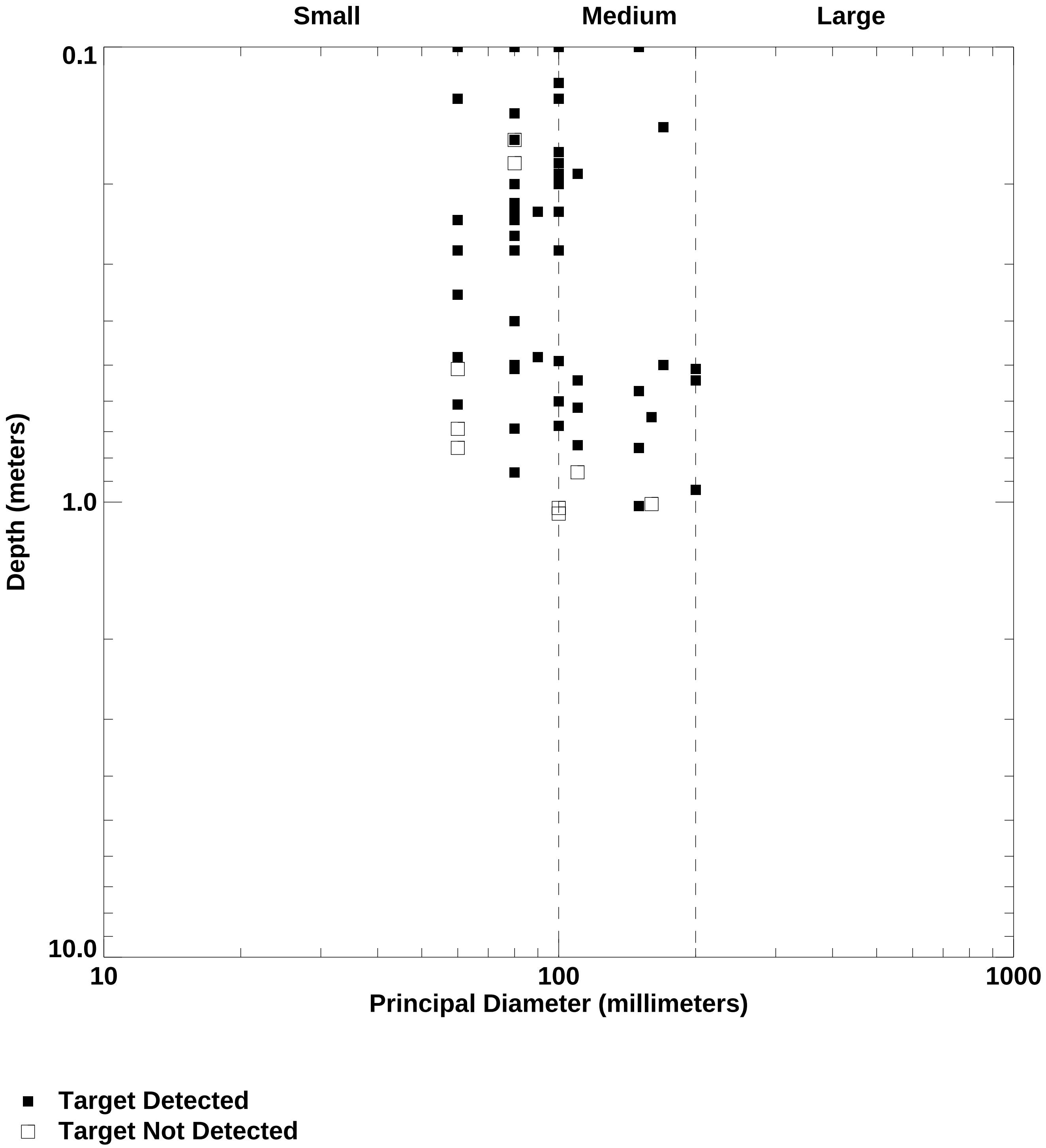
Characterization Statistics (TMA *Closest)*

	# Baseline	# Detected	P_D[b]	# Correct	P_C[d]
Ability to Type					
Ordnance	67	58	0.87	57	0.98
Nonordnance	50	49	0.98	0	0.00
Ability to Size					
Large	3	3	1.00	0	0.00
Medium	31	27	0.87	0	0.00
Small	33	28	0.85	0	0.00
Ability to Classify					
Bomb	0	0	NA	0	NA
Projectile	41	36	0.88	0	0.00
Mortar	26	22	0.85	0	0.00
Submunition	0	0	NA	0	NA
Rocket	0	0	NA	0	NA

Notes:

[a] Target Matching Algorithm
[b] Probability of detection
[c] Square root of the mean square depth error
[d] Probability of correct characterization
NA - not applicable

JPG Controlled Site: Phase III
Scenario 2: Artillery and Mortar Range
Critical Radius: 2 meters
Demonstrator: GRI-EM



GRI-Mag - Artillery and Mortar Range

Detection Statistics (TMA[a] *Group*)

	# Baseline	# Detected	P_D[b]	P_{random}
Ordnance	67	62	0.93	0.27
Nonordnance	50	41	0.82	
Total	117	103		

Number False Alarms	1111
False Alarm Rate (#/Hectare)	237.25
False Alarm Ratio (#/Ord.)	17.92
Probability False Alarms	0.298

Localization Statistics (TMA *Closest*) (in meters)

	Mean	Std Deviation
Position (x,y)		
dx - easting error	-0.08	0.31
dy - northing error	0.18	0.43
Radial error	0.46	0.32
Depth (z)		
dz - averaged depth error	0.08	0.37
|dz|[c] - absolute depth error	0.37	

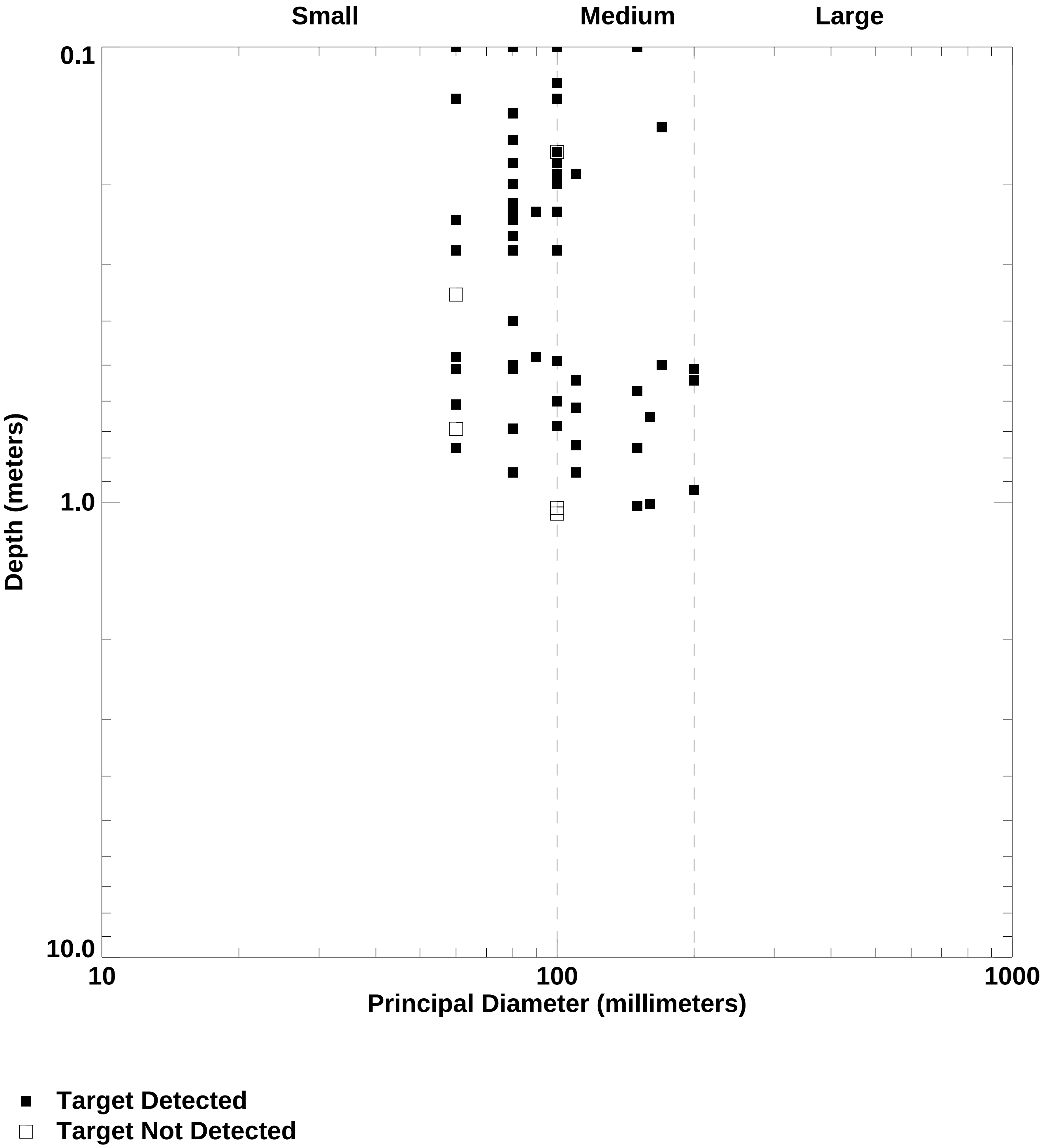
Characterization Statistics (TMA *Closest)*

	# Baseline	# Detected	P_D[b]	# Correct	P_C[d]
Ability to Type					
Ordnance	67	62	0.93	60	0.97
Nonordnance	50	41	0.82	3	0.07
Ability to Size					
Large	3	3	1.00	0	0.00
Medium	31	28	0.90	8	0.29
Small	33	31	0.94	25	0.81
Ability to Classify					
Bomb	0	0	NA	0	NA
Projectile	41	38	0.93	14	0.37
Mortar	26	24	0.92	20	0.83
Submunition	0	0	NA	0	NA
Rocket	0	0	NA	0	NA

Notes:

[a] Target Matching Algorithm
[b] Probability of detection
[c] Square root of the mean square depth error
[d] Probability of correct characterization
NA - not applicable

JPG Controlled Site: Phase III
Scenario 2: Artillery and Mortar Range
Critical Radius: 2 meters
Demonstrator: GRI-Magnetometer



NAEVA - Artillery and Mortar Range

Detection Statistics (TMA[a] *Group*)

	# Baseline	# Detected	P_D[b]	P_{random}
Ordnance	67	65	0.97	0.041
Nonordnance	50	48	0.96	
Total	117	113		
Number False Alarms	89			
False Alarm Rate (#/Hectare)	19.01			
False Alarm Ratio (#/Ord.)	1.37			
Probability False Alarms	0.024			

Localization Statistics (TMA *Closest*) (in meters)

	Mean	Std Deviation
Position (x,y)		
dx - easting error	-0.24	0.46
dy - northing error	0.12	0.43
Radial error	0.59	0.34
Depth (z)		
dz - averaged depth error	0.2	0.22
|dz|[c] - absolute depth error	0.30	

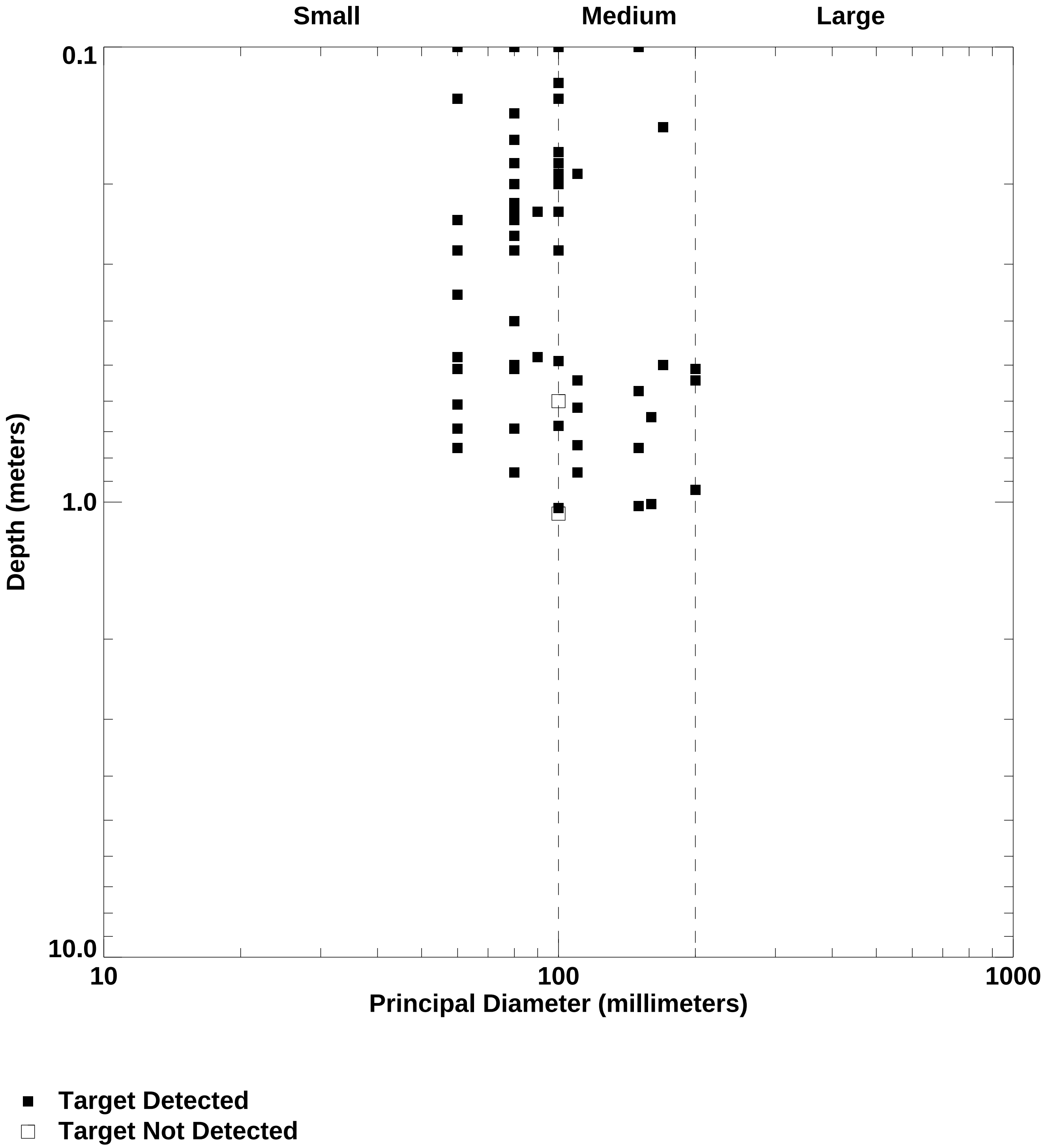
Characterization Statistics (TMA *Closest*)

	# Baseline	# Detected	P_D[b]	# Correct	P_C[d]
Ability to Type					
Ordnance	67	65	0.97	65	1.00
Nonordnance	50	48	0.96	0	0.00
Ability to Size					
Large	3	3	1.00	0	0.00
Medium	31	29	0.94	29	1.00
Small	33	33	1.00	0	0.00
Ability to Classify					
Bomb	0	0	NA	0	NA
Projectile	41	39	0.95	39	1.00
Mortar	26	26	1.00	0	0.00
Submunition	0	0	NA	0	NA
Rocket	0	0	NA	0	NA

Notes:

[a] Target Matching Algorithm
[b] Probability of detection
[c] Square root of the mean square depth error
[d] Probability of correct characterization
NA - not applicable

JPG Controlled Site: Phase III
Scenario 2: Artillery and Mortar Range
Critical Radius: 2 meters
Demonstrator: NAEVA



Rockwell - Artillery and Mortar Range

Detection Statistics (TMA[a] *Group*)

	# Baseline	# Detected	P_D[b]	P_{random}
Ordnance	67	14	0.21	0.037
Nonordnance	50	10	0.20	
Total	117	24		
Number False Alarms	127			
False Alarm Rate (#/Hectare)	27.12			
False Alarm Ratio (#/Ord.)	9.07			
Probability False Alarms	0.034			

Localization Statistics (TMA *Closest*) (in meters)

	Mean	Std Deviation
Position (x,y)		
dx - easting error	-0.12	0.32
dy - northing error	0.12	0.66
Radial error	0.61	0.42
Depth (z)		
dz - averaged depth error	0.14	0.28
|dz|[c] - absolute depth error	0.32	

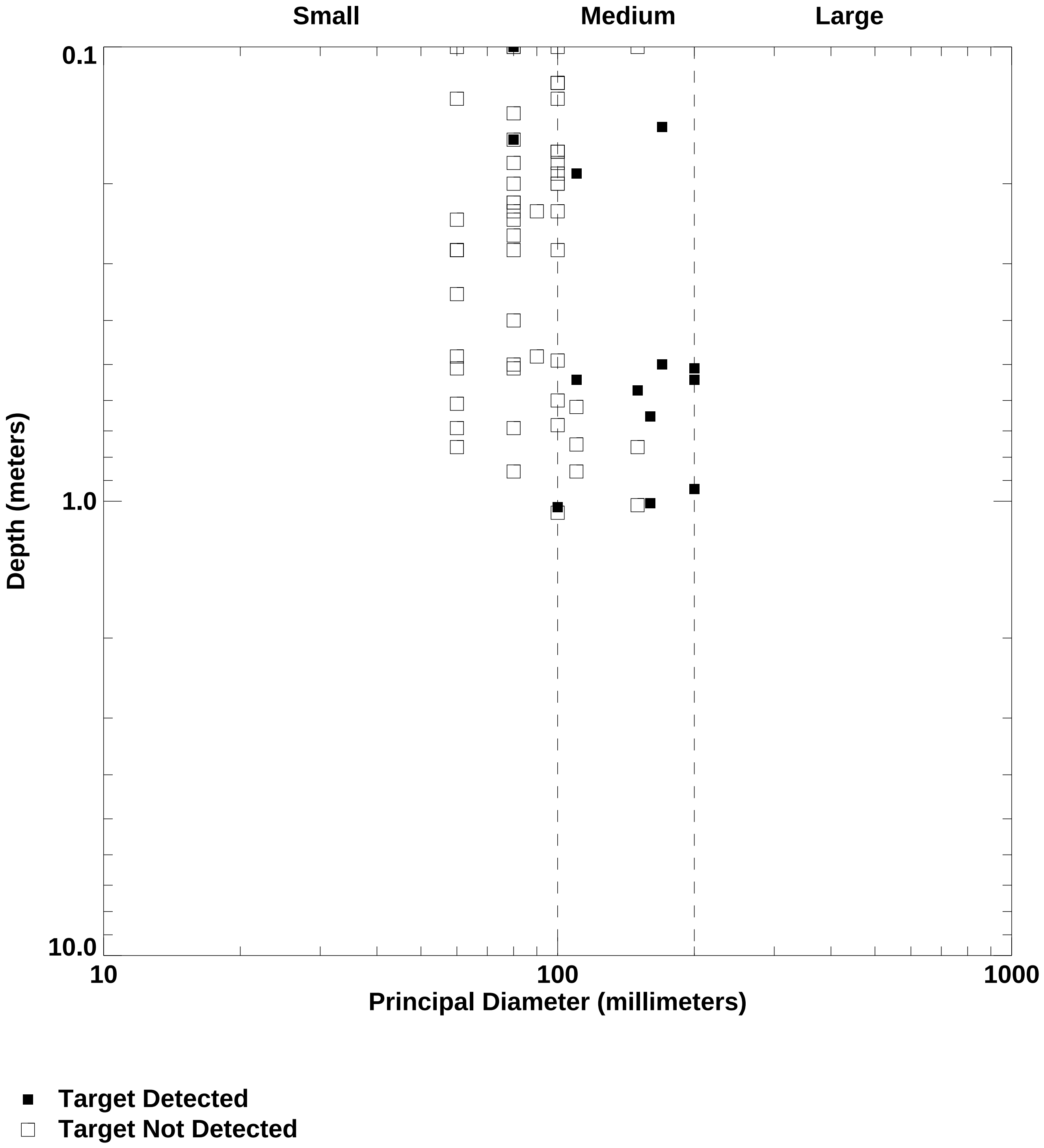
Characterization Statistics (TMA *Closest*)

	# Baseline	# Detected	P_D[b]	# Correct	P_C[d]
Ability to Type					
Ordnance	67	14	0.21	0	0.00
Nonordnance	50	10	0.20	0	0.00
Ability to Size					
Large	3	3	1.00	0	0.00
Medium	31	9	0.29	0	0.00
Small	33	2	0.06	0	0.00
Ability to Classify					
Bomb	0	0	NA	0	NA
Projectile	41	12	0.29	0	0.00
Mortar	26	2	0.08	0	0.00
Submunition	0	0	NA	0	NA
Rocket	0	0	NA	0	NA

Notes:

[a] Target Matching Algorithm
[b] Probability of detection
[c] Square root of the mean square depth error
[d] Probability of correct characterization
NA - not applicable

JPG Controlled Site: Phase III
Scenario 2: Artillery and Mortar Range
Critical Radius: 2 meters
Demonstrator: Rockwell



SCA_ADI - Artillery and Mortar Range

Detection Statistics (TMA[a] *Group*)

	# Baseline	# Detected	P_D[b]	P_{random}
Ordnance	67	55	0.82	0.058
Nonordnance	50	29	0.58	
Total	117	84		
Number False Alarms	168			
False Alarm Rate (#/Hectare)	35.88			
False Alarm Ratio (#/Ord.)	3.05			
Probability False Alarms	0.045			

Localization Statistics (TMA *Closest*) (in meters)

	Mean	Std Deviation
Position (x,y)		
dx - easting error	-0.07	0.45
dy - northing error	-0.21	0.44
Radial error	0.57	0.33
Depth (z)		
dz - averaged depth error	-0.08	0.22
|dz|[c] - absolute depth error	0.22	

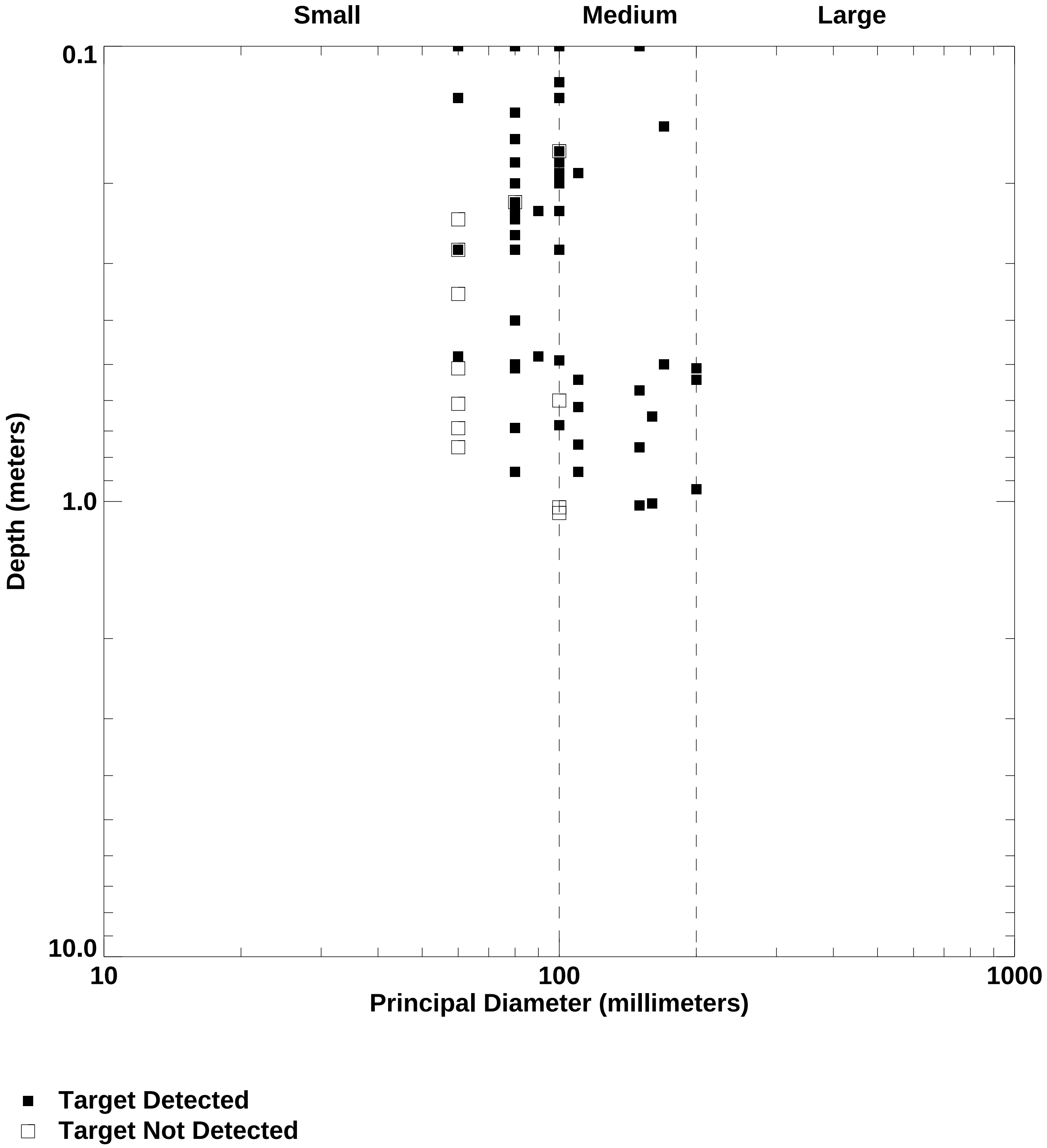
Characterization Statistics (TMA *Closest*)

	# Baseline	# Detected	P_D[b]	# Correct	P_C[d]
Ability to Type					
Ordnance	67	55	0.82	51	0.93
Nonordnance	50	29	0.58	0	0.00
Ability to Size					
Large	3	3	1.00	0	0.00
Medium	31	27	0.87	13	0.48
Small	33	25	0.76	22	0.88
Ability to Classify					
Bomb	0	0	NA	0	NA
Projectile	41	37	0.90	0	0.00
Mortar	26	2	0.08	0	0.00
Submunition	0	0	NA	0	NA
Rocket	0	0	NA	0	NA

Notes:

[a] **Target Matching Algorithm**
[b] **Probability of detection**
[c] **Square root of the mean square depth error**
[d] **Probability of correct characterization**
NA - not applicable

JPG Controlled Site: Phase III
Scenario 2: Artillery and Mortar Range
Critical Radius: 2 meters
Demonstrator: SCA_ADI



SCA_Geocenters - Artillery and Mortar Range

Detection Statistics (TMA[a] *Group*)

	# Baseline	# Detected	P_D[b]	P_{random}
Ordnance	67	51	0.76	0.06
Nonordnance	50	31	0.62	
Total	117	82		
Number False Alarms	178			
False Alarm Rate (#/Hectare)	38.01			
False Alarm Ratio (#/Ord.)	3.49			
Probability False Alarms	0.048			

Localization Statistics (TMA *Closest*) (in meters)

	Mean	Std Deviation
Position (x,y)		
dx - easting error	0.05	0.49
dy - northing error	0.28	0.52
Radial error	0.65	0.39
Depth (z)		
dz - averaged depth error	0.02	0.29
|dz|[c] - absolute depth error	0.30	

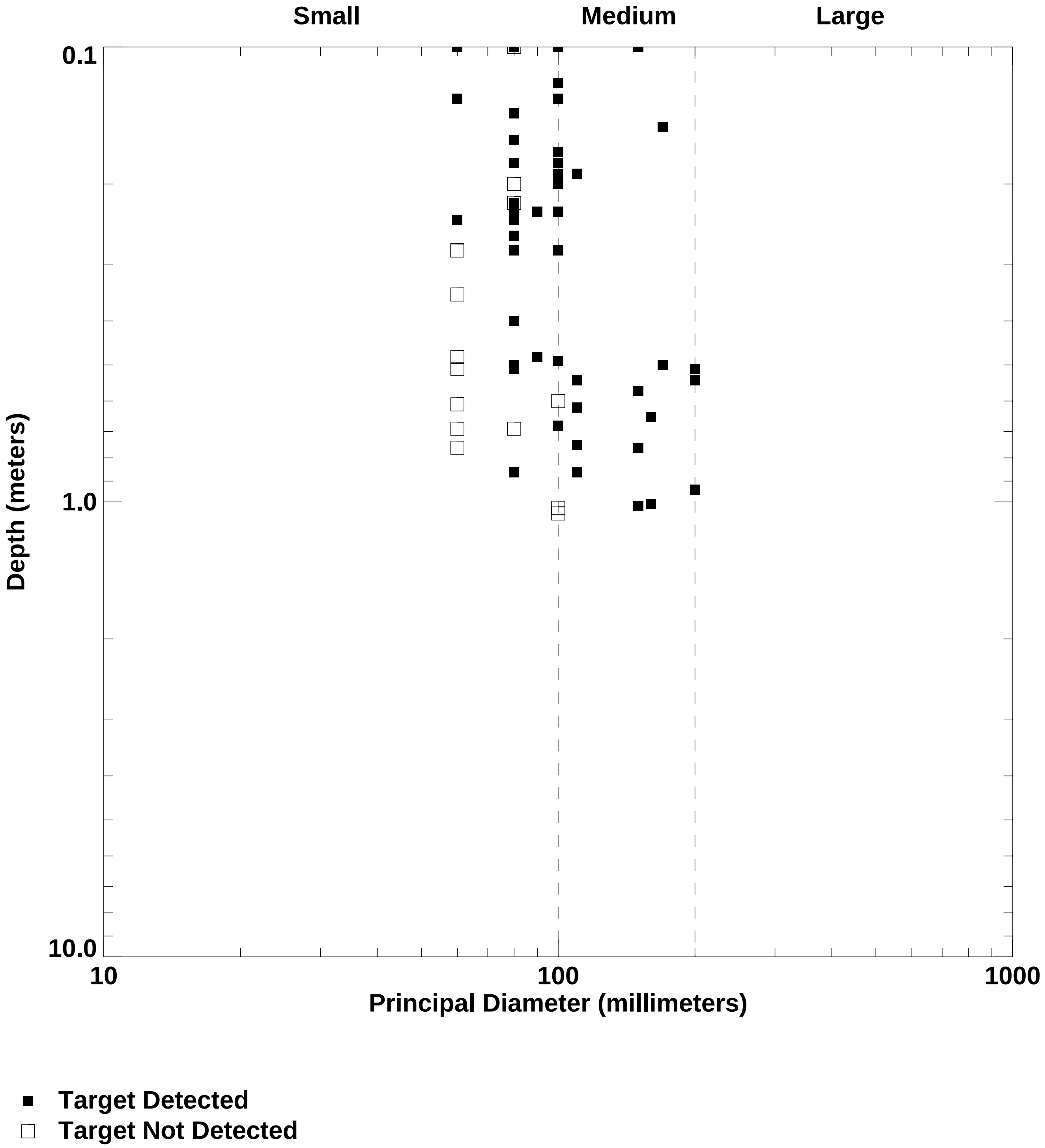
Characterization Statistics (TMA *Closest)*

	# Baseline	# Detected	P_D[b]	# Correct	P_C[d]
Ability to Type					
Ordnance	67	51	0.76	44	0.86
Nonordnance	50	31	0.62	0	0.00
Ability to Size					
Large	3	3	1.00	1	0.33
Medium	31	28	0.90	9	0.32
Small	33	20	0.61	16	0.80
Ability to Classify					
Bomb	0	0	NA	0	NA
Projectile	41	36	0.88	0	0.00
Mortar	26	15	0.58	0	0.00
Submunition	0	0	NA	0	NA
Rocket	0	0	NA	0	NA

Notes:

[a] Target Matching Algorithm
[b] Probability of detection
[c] Square root of the mean square depth error
[d] Probability of correct characterization
NA - not applicable

JPG Controlled Site: Phase III
Scenario 2: Artillery and Mortar Range
Critical Radius: 2 meters
Demonstrator: SCA_Geocenters



SCA_Geometrics - Artillery and Mortar Range

Detection Statistics (TMA[a] *Group*)

	# Baseline	# Detected	P_D[b]	P_{random}
Ordnance	67	64	0.96	0.068
Nonordnance	50	46	0.92	
Total	117	110		
Number False Alarms	196			
False Alarm Rate (#/Hectare)	41.86			
False Alarm Ratio (#/Ord.)	3.06			
Probability False Alarms	0.053			

Localization Statistics (TMA *Closest*) (in meters)

	Mean	Std Deviation
Position (x,y)		
dx - easting error	-0.09	0.35
dy - northing error	0.11	0.45
Radial error	0.49	0.32
Depth (z)		
dz - averaged depth error	-0.04	0.26
|dz|[c] - absolute depth error	0.26	

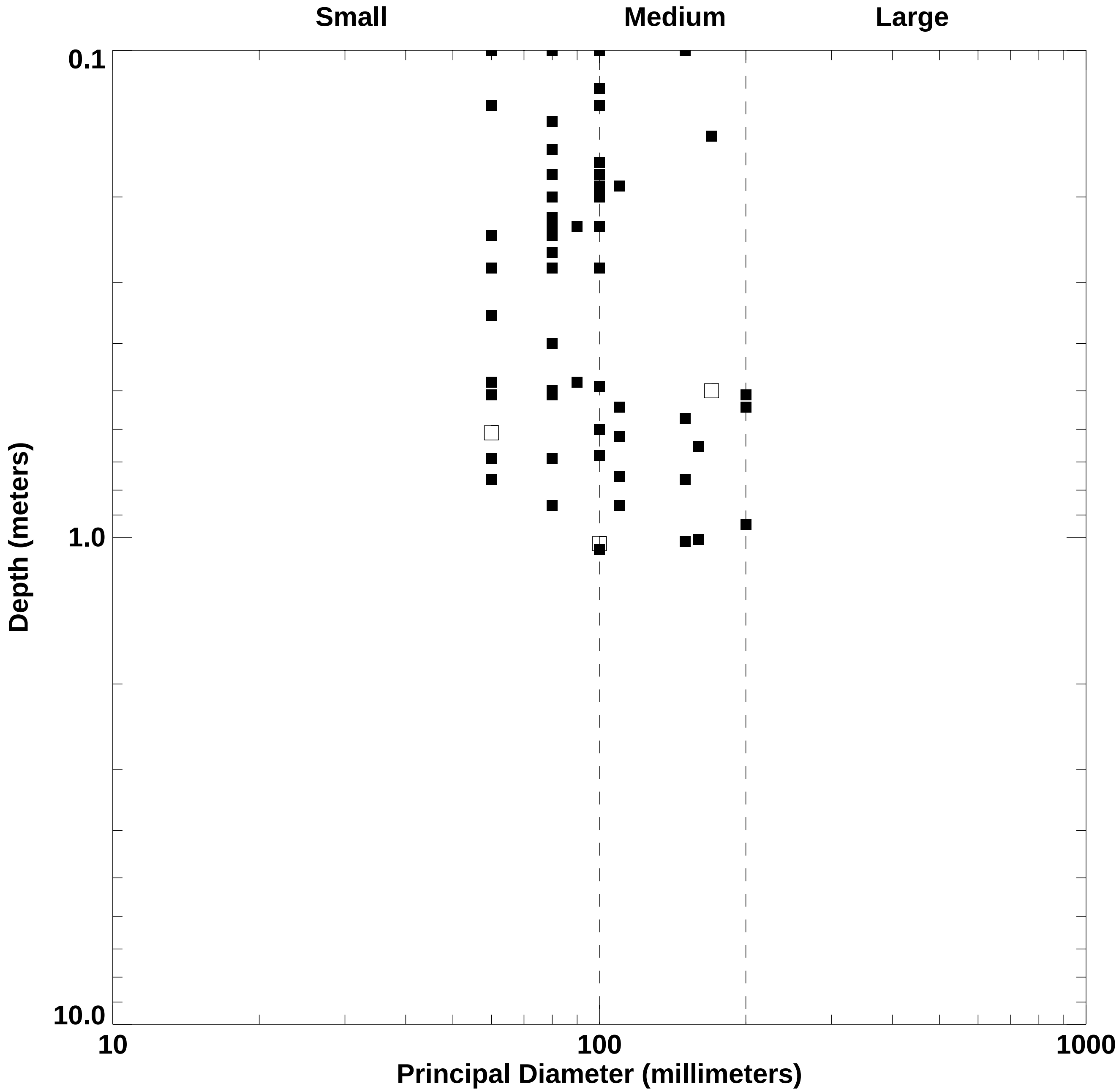
Characterization Statistics (TMA *Closest)*

	# Baseline	# Detected	P_D[b]	# Correct	P_C[d]
Ability to Type					
Ordnance	67	64	0.96	58	0.91
Nonordnance	50	46	0.92	3	0.07
Ability to Size					
Large	3	3	1.00	2	0.67
Medium	31	29	0.94	18	0.62
Small	33	32	0.97	18	0.56
Ability to Classify					
Bomb	0	0	NA	0	NA
Projectile	41	39	0.95	0	0.00
Mortar	26	25	0.96	0	0.00
Submunition	0	0	NA	0	NA
Rocket	0	0	NA	0	NA

Notes:

[a] **Target Matching Algorithm**
[b] **Probability of detection**
[c] **Square root of the mean square depth error**
[d] **Probability of correct characterization**
NA - not applicable

JPG Controlled Site: Phase III
Scenario 2: Artillery and Mortar Range
Critical Radius: 2 meters
Demonstrator: SCA_Geometrics



■ Target Detected
□ Target Not Detected

5.3 GRENADE AND SUBMUNITION RANGE

This section presents the performance of the following demonstrators that participated in this scenario:

5.3.1 ADI
5.3.2 Geo-Centers
5.3.3 GeoPotential
5.3.4 GRI (Combined)
5.3.5 GRI (EM)
5.3.6 GRI (Mag)
5.3.7 SCA_ADI
5.3.8 SCA_GeoCenters

ADI - Grenade and Submunition Range

Detection Statistics (TMA[a] *Group*)

	# Baseline	# Detected	P_D[b]	P_{random}
Ordnance	98	71	0.72	0.191
Nonordnance	39	27	0.69	
Total	137	98		
Number False Alarms	625			
False Alarm Rate (#/Hectare)	150.70			
False Alarm Ratio (#/Ord.)	8.80			
Probability False Alarms	0.189			

Localization Statistics (TMA *Closest*) (in meters)

	Mean	Std Deviation
Position (x,y)		
dx - easting error	0.01	0.37
dy - northing error	0.12	0.48
Radial error	0.48	0.38
Depth (z)		
dz - averaged depth error	0.32	0.14
|dz|[c] - absolute depth error	0.36	

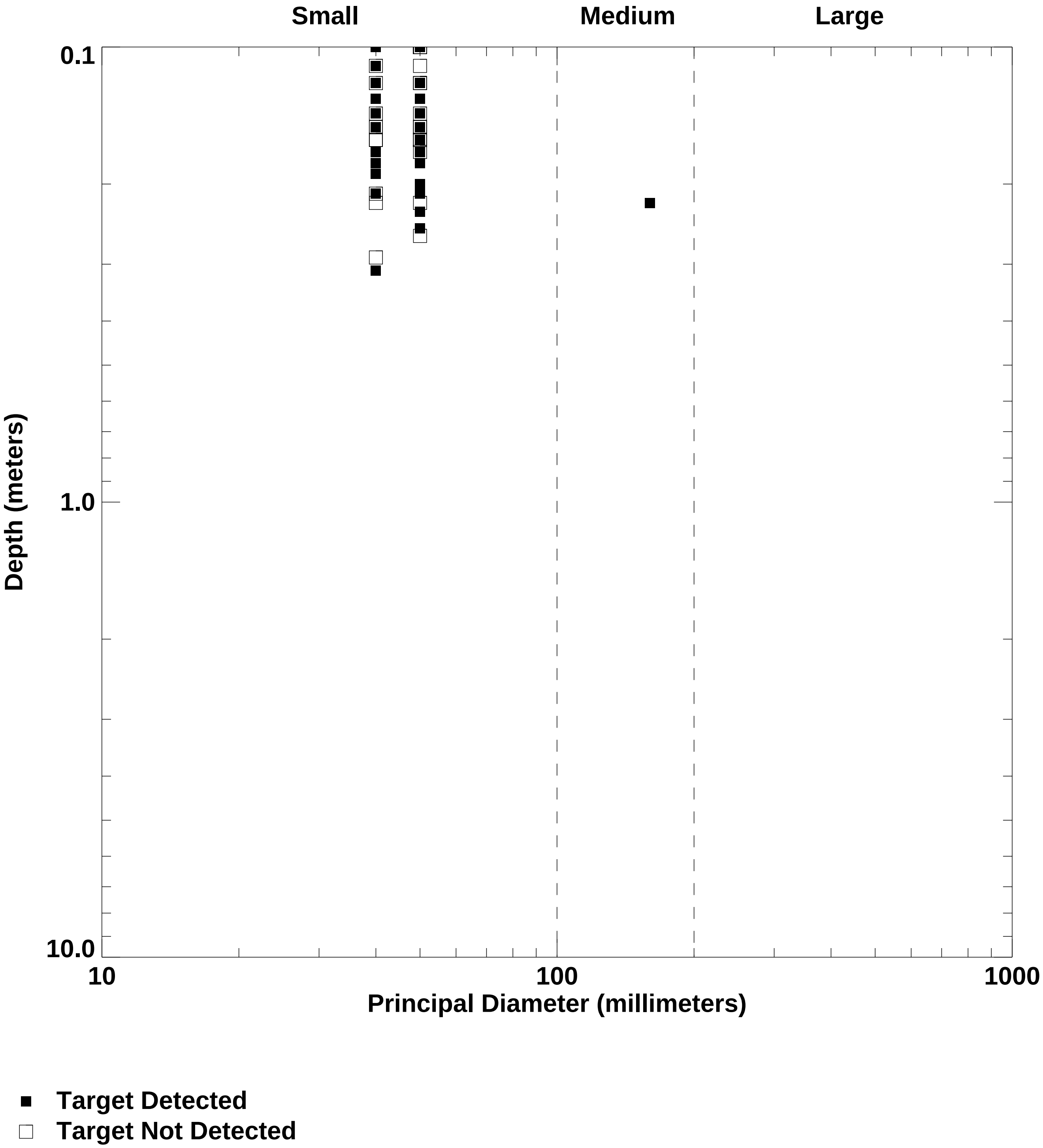
Characterization Statistics (TMA *Closest)*

	# Baseline	# Detected	P_D[b]	# Correct	P_C[d]
Ability to Type					
Ordnance	98	71	0.72	41	0.58
Nonordnance	39	27	0.69	2	0.07
Ability to Size					
Large	0	0	NA	0	NA
Medium	1	1	1.00	0	0.00
Small	97	70	0.72	68	0.97
Ability to Classify					
Bomb	0	0	NA	0	NA
Projectile	1	1	1.00	0	0.00
Mortar	0	0	NA	0	NA
Submunition	97	70	0.72	64	0.91
Rocket	0	0	NA	0	NA

Notes:

[a] Target Matching Algorithm
[b] Probability of detection
[c] Square root of the mean square depth error
[d] Probability of correct characterization
NA - not applicable

JPG Controlled Site: Phase III
Scenario 3: Grenade and Submunitions Range
Critical Radius: 2 meters
Demonstrator: ADI



Geo-Centers - Grenade and Submunition Range

Detection Statistics (TMA[a] *Group*)

	# Baseline	# Detected	P_D[b]	P_{random}
Ordnance	98	89	0.91	0.127
Nonordnance	39	24	0.62	
Total	137	113		
Number False Alarms	356			
False Alarm Rate (#/Hectare)	85.84			
False Alarm Ratio (#/Ord.)	4.00			
Probability False Alarms	0.108			

Localization Statistics (TMA *Closest*) (in meters)

	Mean	Std Deviation
Position (x,y)		
dx - easting error	-0.25	0.4
dy - northing error	0.3	0.43
Radial error	0.62	0.34
Depth (z)		
dz - averaged depth error	0.17	0.16
|dz|[c] - absolute depth error	0.24	

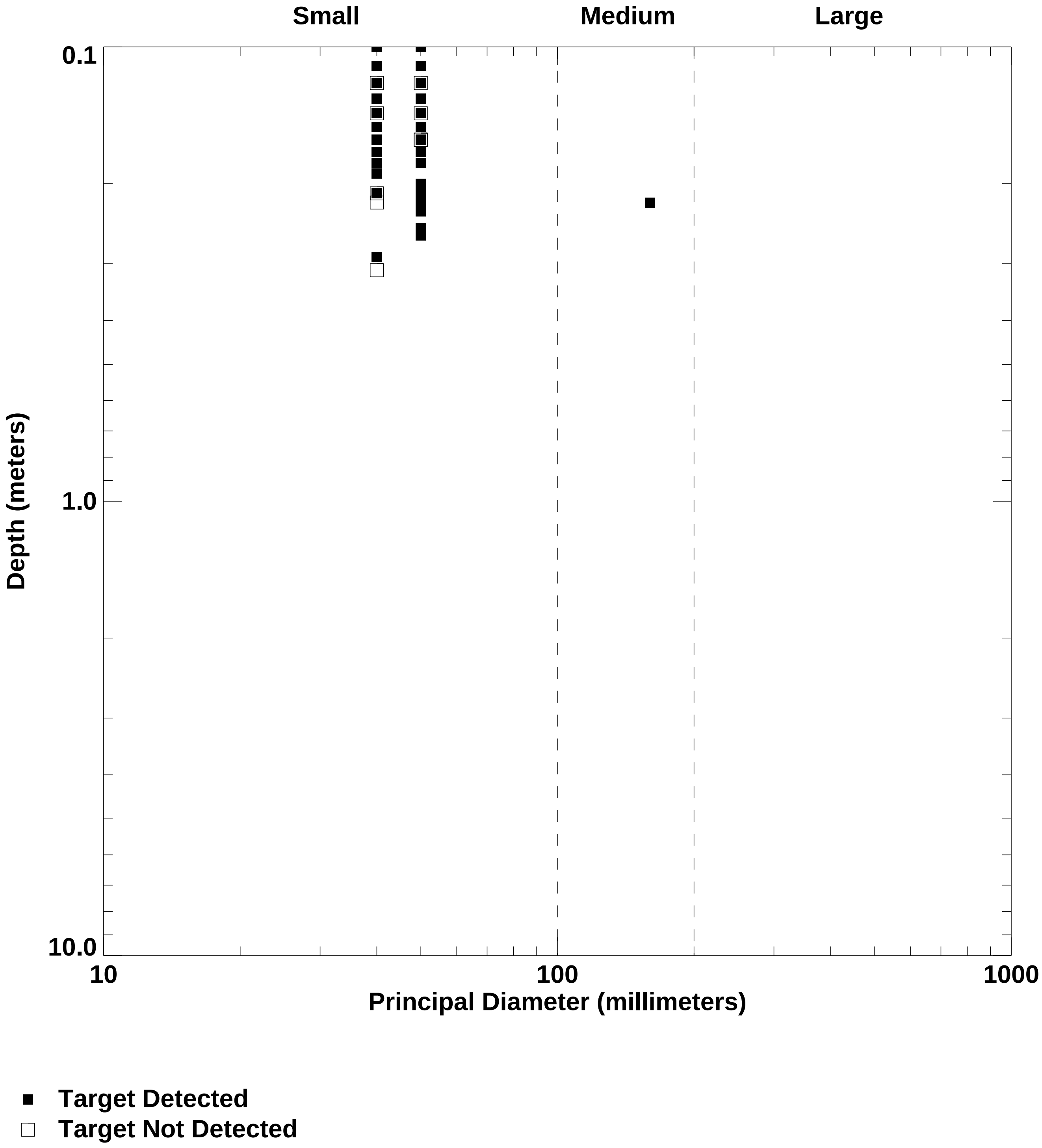
Characterization Statistics (TMA *Closest)*

	# Baseline	# Detected	P_D[b]	# Correct	P_C[d]
Ability to Type					
Ordnance	98	89	0.91	89	1.00
Nonordnance	39	24	0.62	0	0.00
Ability to Size					
Large	0	0	NA	0	NA
Medium	1	1	1.00	1	1.00
Small	97	88	0.91	87	0.99
Ability to Classify					
Bomb	0	0	NA	0	NA
Projectile	1	1	1.00	0	0.00
Mortar	0	0	NA	0	NA
Submunition	97	88	0.91	88	1.00
Rocket	0	0	NA	0	NA

Notes:

[a] **Target Matching Algorithm**
[b] **Probability of detection**
[c] **Square root of the mean square depth error**
[d] **Probability of correct characterization**
NA - not applicable

JPG Controlled Site: Phase III
Scenario 3: Grenade and Submunitions Range
Critical Radius: 2 meters
Demonstrator: GEO-CENTERS



GeoPotential - Grenade and Submunition Range

Detection Statistics (TMA[a] *Group*)

	# Baseline	# Detected	P_D[b]	P_{random}
Ordnance	98	1	0.01	0.009
Nonordnance	39	0	0.00	
Total	137	1		
Number False Alarms	27			
False Alarm Rate (#/Hectare)	6.51			
False Alarm Ratio (#/Ord.)	27.00			
Probability False Alarms	0.008			

Localization Statistics (TMA *Closest*) (in meters)

	Mean	Std Deviation
Position (x,y)		
dx - easting error	0.36	N/A
dy - northing error	0.35	N/A
Radial error	0.50	N/A
Depth (z)		
dz - averaged depth error	0.78	N/A
|dz|[c] - absolute depth error	0.78	

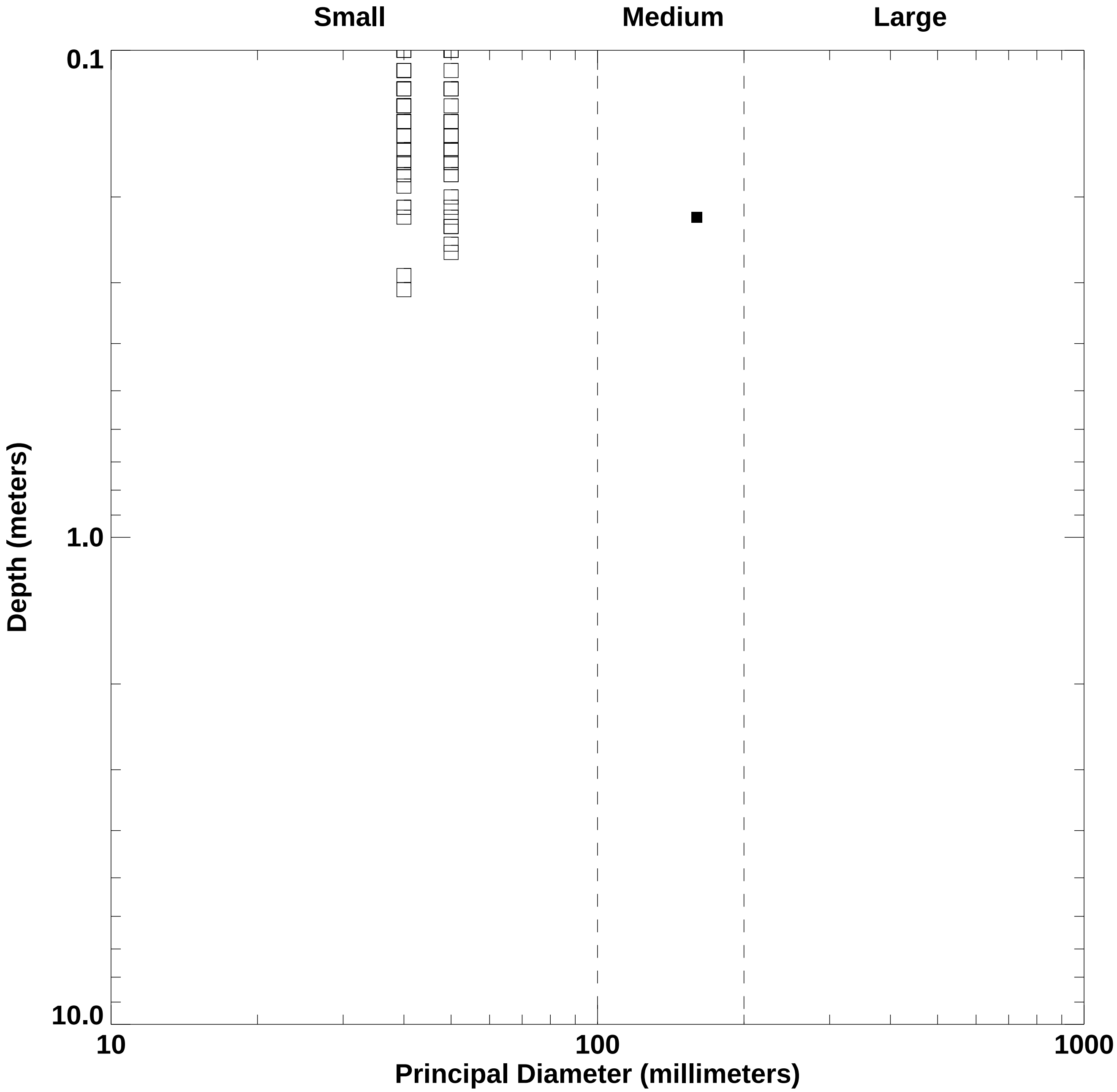
Characterization Statistics (TMA *Closest)*

	# Baseline	# Detected	P_D[b]	# Correct	P_C[d]
Ability to Type					
Ordnance	98	1	0.01	1	1.00
Nonordnance	39	0	0.00	0	NA
Ability to Size					
Large	0	0	NA	0	NA
Medium	1	1	1.00	1	1.00
Small	97	0	0.00	0	NA
Ability to Classify					
Bomb	0	0	NA	0	NA
Projectile	1	1	1.00	0	0.00
Mortar	0	0	NA	0	NA
Submunition	97	0	0.00	0	NA
Rocket	0	0	NA	0	NA

Notes:

[a] Target Matching Algorithm
[b] Probability of detection
[c] Square root of the mean square depth error
[d] Probability of correct characterization
NA - not applicable

JPG Controlled Site: Phase III
Scenario 3: Grenade and Submunitions Range
Critical Radius: 2 meters
Demonstrator: GeoPotential



■ **Target Detected**
□ **Target Not Detected**

GRI (Combined) - Grenade and Submunition Range

Detection Statistics (TMA[a] *Group*)

	# Baseline	# Detected	P_D[b]	P_{random}
Ordnance	98	93	0.95	0.277
Nonordnance	39	28	0.72	
Total	137	121		
Number False Alarms	973			
False Alarm Rate (#/Hectare)	234.62			
False Alarm Ratio (#/Ord.)	10.46			
Probability False Alarms	0.295			

Localization Statistics (TMA *Closest*) (in meters)

	Mean	Std Deviation
Position (x,y)		
dx - easting error	-0.08	0.29
dy - northing error	0.13	0.32
Radial error	0.37	0.26
Depth (z)		
dz - averaged depth error	0.39	0.32
|dz|[c] - absolute depth error	0.50	

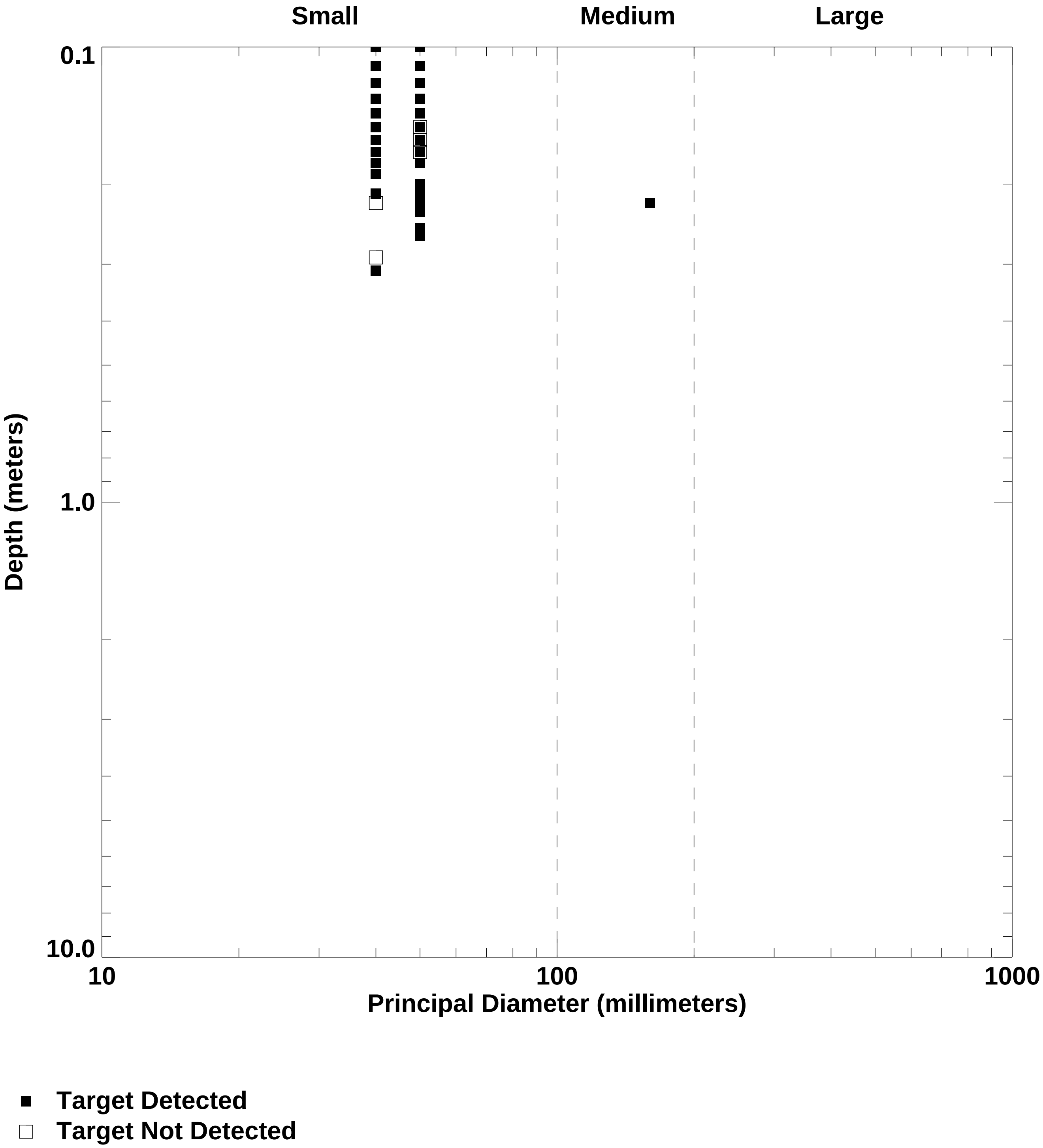
Characterization Statistics (TMA *Closest)*

	# Baseline	# Detected	P_D[b]	# Correct	P_C[d]
Ability to Type					
Ordnance	98	93	0.95	86	0.92
Nonordnance	39	28	0.72	10	0.36
Ability to Size					
Large	0	0	NA	0	NA
Medium	1	1	1.00	0	0.00
Small	97	92	0.95	32	0.35
Ability to Classify					
Bomb	0	0	NA	0	NA
Projectile	1	1	1.00	0	0.00
Mortar	0	0	NA	0	NA
Submunition	97	92	0.95	0	0.00
Rocket	0	0	NA	0	NA

Notes:

[a] Target Matching Algorithm
[b] Probability of detection
[c] Square root of the mean square depth error
[d] Probability of correct characterization
NA - not applicable

JPG Controlled Site: Phase III
Scenario 3: Grenade and Submunitions Range
Critical Radius: 2 meters
Demonstrator: GRI-Combined



GRI (EM) - Grenade and Submunition Range

Detection Statistics (TMA[a] *Group*)

	# Baseline	# Detected	P_D[b]	P_{random}
Ordnance	98	90	0.92	0.19
Nonordnance	39	24	0.62	
Total	137	114		
Number False Alarms	601			
False Alarm Rate (#/Hectare)	144.92			
False Alarm Ratio (#/Ord.)	6.68			
Probability False Alarms	0.182			

Localization Statistics (TMA *Closest*) (in meters)

	Mean	Std Deviation
Position (x,y)		
dx - easting error	-0.06	0.29
dy - northing error	0.15	0.26
Radial error	0.34	0.25
Depth (z)		
dz - averaged depth error	0.67	0.13
|dz|[c] - absolute depth error	0.69	

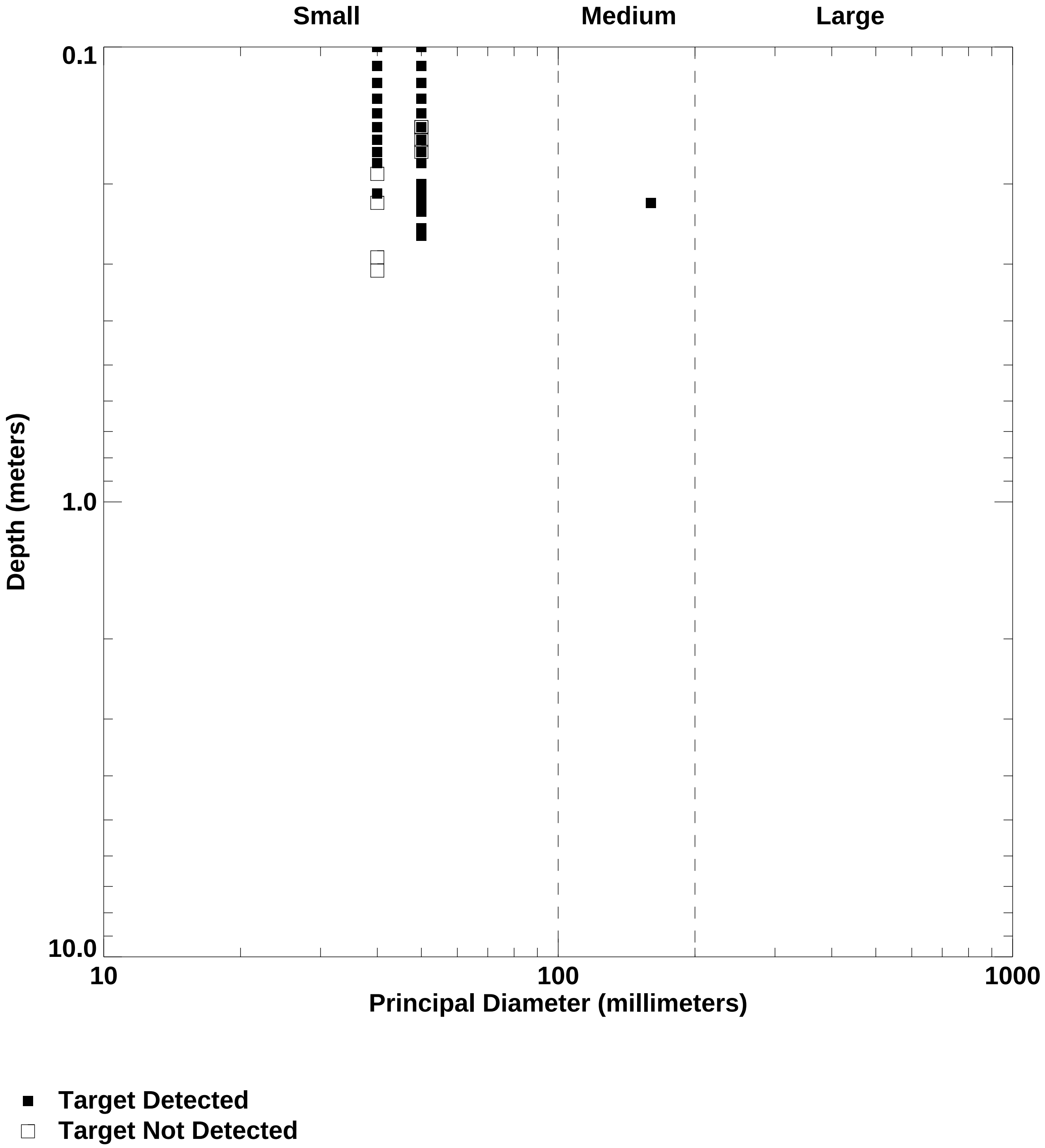
Characterization Statistics (TMA *Closest)*

	# Baseline	# Detected	P_D[b]	# Correct	P_C[d]
Ability to Type					
Ordnance	98	90	0.92	89	0.99
Nonordnance	39	24	0.62	5	0.21
Ability to Size					
Large	0	0	NA	0	NA
Medium	1	1	1.00	0	0.00
Small	97	89	0.92	0	0.00
Ability to Classify					
Bomb	0	0	NA	0	NA
Projectile	1	1	1.00	0	0.00
Mortar	0	0	NA	0	NA
Submunition	97	89	0.92	0	0.00
Rocket	0	0	NA	0	NA

Notes:

[a] **Target Matching Algorithm**
[b] **Probability of detection**
[c] **Square root of the mean square depth error**
[d] **Probability of correct characterization**
NA - not applicable

JPG Controlled Site: Phase III
Scenario 3: Grenade and Submunitions Range
Critical Radius: 2 meters
Demonstrator: GRI-EM



GRI (Mag) - Grenade and Submunition Range

Detection Statistics (TMA[a] *Group*)

	# Baseline	# Detected	P_D[b]	P_{random}
Ordnance	98	46	0.47	0.228
Nonordnance	39	27	0.69	
Total	137	73		
Number False Alarms	803			
False Alarm Rate (#/Hectare)	193.62			
False Alarm Ratio (#/Ord.)	17.46			
Probability False Alarms	0.243			

Localization Statistics (TMA *Closest*) (in meters)

	Mean	Std Deviation
Position (x,y)		
dx - easting error	-0.18	0.38
dy - northing error	0.12	0.5
Radial error	0.54	0.38
Depth (z)		
dz - averaged depth error	0.23	0.38
|dz|[c] - absolute depth error	0.45	

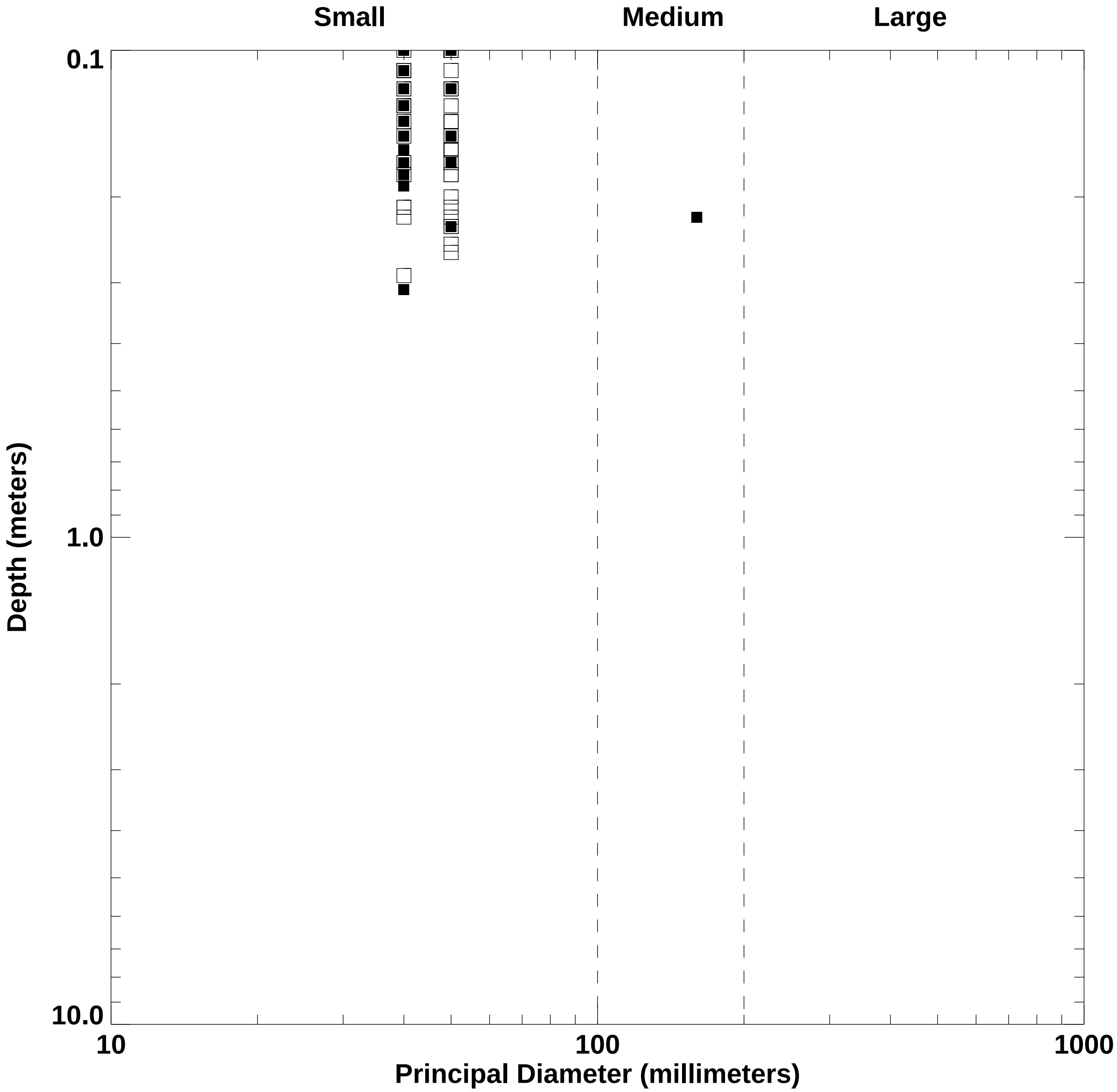
Characterization Statistics (TMA *Closest)*

	# Baseline	# Detected	P_D[b]	# Correct	P_C[d]
Ability to Type					
Ordnance	98	46	0.47	34	0.74
Nonordnance	39	27	0.69	9	0.33
Ability to Size					
Large	0	0	NA	0	NA
Medium	1	1	1.00	0	0.00
Small	97	45	0.46	45	1.00
Ability to Classify					
Bomb	0	0	NA	0	NA
Projectile	1	1	1.00	0	0.00
Mortar	0	0	NA	0	NA
Submunition	97	45	0.46	0	0.00
Rocket	0	0	NA	0	NA

Notes:

[a] Target Matching Algorithm
[b] Probability of detection
[c] Square root of the mean square depth error
[d] Probability of correct characterization
NA - not applicable

JPG Controlled Site: Phase III
Scenario 3: Grenade and Submunitions Range
Critical Radius: 2 meters
Demonstrator: GRI-Magnetometer



■ Target Detected
□ Target Not Detected

SCA_ADI - Grenade and Submunition Range

Detection Statistics (TMA[a] *Group*)

	# Baseline	# Detected	P_D[b]	P_{random}
Ordnance	98	45	0.46	0.081
Nonordnance	39	16	0.41	
Total	137	61		
Number False Alarms	232			
False Alarm Rate (#/Hectare)	55.94			
False Alarm Ratio (#/Ord.)	5.16			
Probability False Alarms	0.070			

Localization Statistics (TMA *Closest*) (in meters)

	Mean	Std Deviation
Position (x,y)		
dx - easting error	0.04	0.46
dy - northing error	0	0.46
Radial error	0.51	0.40
Depth (z)		
dz - averaged depth error	0.08	0.06
|dz|[c] - absolute depth error	0.10	

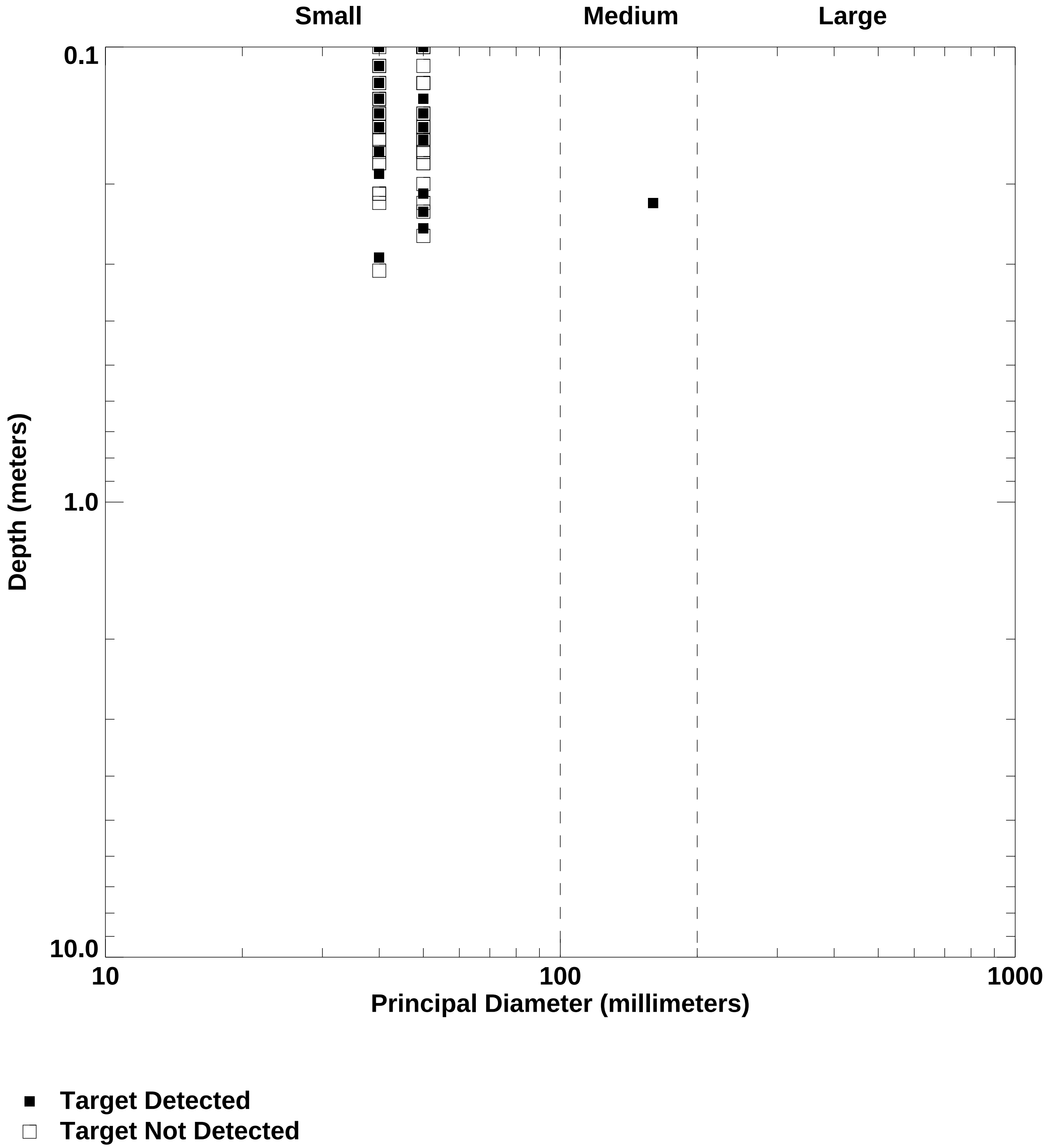
Characterization Statistics (TMA *Closest*)

	# Baseline	# Detected	P_D[b]	# Correct	P_C[d]
Ability to Type					
Ordnance	98	45	0.46	44	0.98
Nonordnance	39	16	0.41	0	0.00
Ability to Size					
Large	0	0	NA	0	NA
Medium	1	1	1.00	0	0.00
Small	97	44	0.45	44	1.00
Ability to Classify					
Bomb	0	0	NA	0	NA
Projectile	1	1	1.00	0	0.00
Mortar	0	0	NA	0	NA
Submunition	97	44	0.45	43	0.98
Rocket	0	0	NA	0	NA

Notes:

[a] Target Matching Algorithm
[b] Probability of detection
[c] Square root of the mean square depth error
[d] Probability of correct characterization
NA - not applicable

JPG Controlled Site: Phase III
Scenario 3: Grenade and Submunitions Range
Critical Radius: 2 meters
Demonstrator: SCA_ADI



SCA_Geo-Centers - Grenade and Submunition Range

Detection Statistics (TMA[a] *Group*)

	# Baseline	# Detected	P_D[b]	P_{random}
Ordnance	98	68	0.69	0.07
Nonordnance	39	19	0.49	
Total	137	87		

Number False Alarms	169
False Alarm Rate (#/Hectare)	40.75
False Alarm Ratio (#/Ord.)	2.49
Probability False Alarms	0.051

Localization Statistics (TMA *Closest*) (in meters)

	Mean	Std Deviation
Position (x,y)		
dx - easting error	-0.28	0.47
dy - northing error	0.44	0.44
Radial error	0.71	0.41
Depth (z)		
dz - averaged depth error	0.8	NA
|dz|[c] - absolute depth error	0.80	

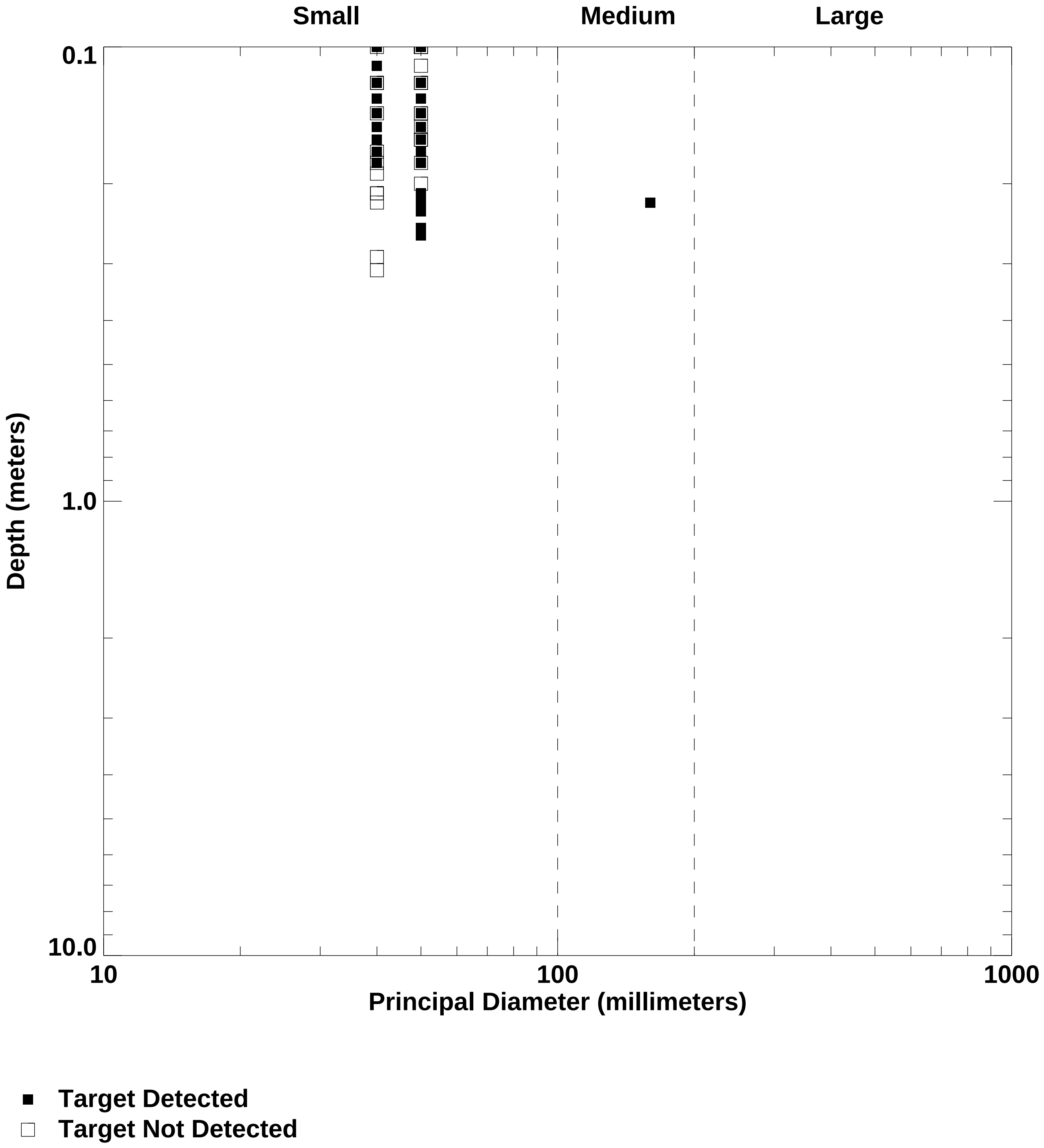
Characterization Statistics (TMA *Closest)*

	# Baseline	# Detected	P_D[b]	# Correct	P_C[d]
Ability to Type					
Ordnance	98	68	0.69	67	0.99
Nonordnance	39	19	0.49	0	0.00
Ability to Size					
Large	0	0	NA	0	NA
Medium	1	1	1.00	1	1.00
Small	97	67	0.69	67	1.00
Ability to Classify					
Bomb	0	0	NA	0	NA
Projectile	1	1	1.00	0	0.00
Mortar	0	0	NA	0	NA
Submunition	97	67	0.69	67	1.00
Rocket	0	0	NA	0	NA

Notes:

[a] Target Matching Algorithm
[b] Probability of detection
[c] Square root of the mean square depth error
[d] Probability of correct characterization
NA - not applicable

JPG Controlled Site: Phase III
Scenario 3: Grenade and Submunitions Range
Critical Radius: 2 meters
Demonstrator: SCA_Geocenters



5.4 INTERROGATION/BURIAL AREA

This section presents the performance of the following demonstrators that participated in this scenario:

5.4.1 ADI
5.4.2 Battelle
5.4.3 ENSCO
5.4.4 Foerster
5.4.5 Geometrics
5.4.6 SCA_ADI
5.4.7 SCA_Geometrics

ADI - Interrogation/Burial Area

Localization Statistics (in meters)

	Mean	Std Deviation
Position (x,y)		
dx - easting error	-0.03	0.2
dy - northing error	0.11	0.2
Radial error	0.26	0.14
Depth (z)		
dz - averaged depth error	0.25	0.34
$\lvert dz \rvert$[a] - absolute depth error	0.42	

Characterization Statistics

	# Baseline	# Correct	P_C[d]
Ability to Type			
Ordnance	17	17	1.00
Nonordnance	3	0	0.00
Ability to Size			
Large	5	5	1.00
Medium	7	2	0.29
Small	5	0	0.00
Ability to Classify			
Bomb	4	4	1.00
Projectile	9	0	0.00
Mortar	4	2	0.50
Submunition	0	0	NA
Rocket	0	0	NA

Notes:

[a] **Square root of the mean square depth error**

[b] **Probability of correct characterization**

Battelle - Interrogation/Burial Area

Localization Statistics (in meters)

	Mean	Std Deviation
Position (x,y)		
dx - easting error	-0.3	0.7
dy - northing error	0.36	0.47
Radial error	0.77	0.54
Depth (z)		
dz - averaged depth error	0.14	0.98
|dz|[a] - absolute depth error	0.92	

Characterization Statistics

	# Baseline	# Correct	P_C^d
Ability to Type			
Ordnance	4	0	0.00
Nonordnance	4	0	0.00
Ability to Size			
Large	3	0	0.00
Medium	1	0	0.00
Small	0	0	N/A
Ability to Classify			
Bomb	3	0	0.00
Projectile	1	0	0.00
Mortar	0	0	N/A
Submunition	0	0	NA
Rocket	0	0	NA

Notes:

[a] **Square root of the mean square depth error**

[b] **Probability of correct characterization**

ENSCO - Interrogation/Burial Area

Localization Statistics (in meters)

	Mean	Std Deviation
Position (x,y)		
dx - easting error	0.06	0.24
dy - northing error	-0.08	0.26
Radial error	0.30	0.20
Depth (z)		
dz - averaged depth error	0.07	0.36
|dz|[a] - absolute depth error	0.36	

Characterization Statistics

	# Baseline	# Correct	P_C^d
Ability to Type			
Ordnance	17	14	0.82
Nonordnance	3	0	0.00
Ability to Size			
Large	5	2	0.40
Medium	7	2	0.29
Small	5	4	0.80
Ability to Classify			
Bomb	4	0	0.00
Projectile	10	0	0.00
Mortar	3	0	0.00
Submunition	0	0	NA
Rocket	0	0	NA

Notes:

[a] **Square root of the mean square depth error**

[b] **Probability of correct characterization**

Foerster - Interrogation/Burial Area

Localization Statistics (in meters)

	Mean	**Std Deviation**
Position (x,y)		
dx - easting error	0.06	0.64
dy - northing error	-0.01	0.48
Radial error	0.52	0.60
Depth (z)		
dz - averaged depth error	0.39	0.73
$\lvert dz \rvert^a$ - absolute depth error	0.81	

Characterization Statistics

	# Baseline	**# Correct**	**P_C^d**
Ability to Type			
Ordnance	19	0	0.00
Nonordnance	5	0	0.00
Ability to Size			
Large	6	6	1.00
Medium	6	4	0.67
Small	7	0	0.00
Ability to Classify			
Bomb	5	0	0.00
Projectile	10	0	0.00
Mortar	4	0	0.00
Submunition	0	0	NA
Rocket	0	0	NA

Notes:

[a] Square root of the mean square depth error

[b] Probability of correct characterization

Geometrics - Interrogation/Burial Area

Localization Statistics (in meters)[a]

	Mean	Std Deviation
Position (x,y)		
dx - easting error	-0.08	0.09
dy - northing error	-0.07	0.13
Radial error	0.16	0.09
Depth (z)		
dz - averaged depth error	0.23	0.43
|dz|[b] - absolute depth error	0.48	

Characterization Statistics[a]

	# Baseline	# Correct	P_C[d]
Ability to Type			
Ordnance	10	10	1.00
Nonordnance	3	0	0.00
Ability to Size			
Large	3	2	0.67
Medium	3	2	0.67
Small	4	4	1.00
Ability to Classify			
Bomb	2	2	1.00
Projectile	6	4	0.67
Mortar	2	1	0.50
Submunition	0	0	NA
Rocket	0	0	NA

Notes:

[a] **Only 13 of 20 reported targets positions corresponded to baseline targets at R*crit* of 2 meters.**

[b] **Square root of the mean square depth error**

[c] **Probability of correct characterization**

SCA_ADI - Interrogation/Burial Area

Localization Statistics (in meters)

	Mean	Std Deviation
Position (x,y)		
dx - easting error	N/A	N/A
dy - northing error	N/A	N/A
Radial error	N/A	N/A
Depth (z)		
dz - averaged depth error	-0.24	0.36
$\lvert dz\rvert^a$ - absolute depth error	0.42	

Characterization Statistics

	# Baseline	# Correct	P_C^d
Ability to Type			
Ordnance	17	17	1.00
Nonordnance	3	0	0.00
Ability to Size			
Large	5	2	0.40
Medium	7	4	0.57
Small	5	5	1.00
Ability to Classify			
Bomb	4	2	0.50
Projectile	9	2	0.22
Mortar	4	0	0.00
Submunition	0	0	NA
Rocket	0	0	NA

Notes:

[a] **Square root of the mean square depth error**

[b] **Probability of correct characterization**

SCA_Geometrics - Interrogation/Burial Area

Localization Statistics (in meters)

	Mean	Std Deviation
Position (x,y)		
dx - easting error	-0.06	0.09
dy - northing error	-0.07	0.11
Radial error	0.15	0.08
Depth (z)		
dz - averaged depth error	0.09	0.5
|dz|[a] - absolute depth error	0.50	

Characterization Statistics

	# Baseline	# Correct	P_C[d]
Ability to Type			
Ordnance	17	16	0.94
Nonordnance	3	0	0.00
Ability to Size			
Large	5	2	0.40
Medium	6	4	0.67
Small	6	6	1.00
Ability to Classify			
Bomb	4	3	0.75
Projectile	8	3	0.38
Mortar	5	1	0.20
Submunition	0	0	NA
Rocket	0	0	NA

Notes:

[a] **Square root of the mean square depth error**
[b] **Probability of correct characterization**

6.0 RESULTS SUMMARY, ANALYSIS, AND CONCLUSIONS

The objectives of the Phase III ATD include the development of relevant performance information on UXO technologies demonstrated under realistic constraints. The discussions that follow summarize results based on demonstrator scenario performances. An analysis of overall survey and demonstrator excavation performance is also provided.

6.1 SCENARIO STATISTICAL PERFORMANCE SUMMARIES

The key technical issue in characterizing or remediating properties with UXO is the effectiveness of ordnance detection. Given that a target is detectable, target localization will affect the efficiency of target reacquisition for subsequent statistical sampling or identification and remediation. Ordnance characterization (typing) will further affect remediation costs, as it is a controlling parameter in the number of UXO unearthed per day by excavators.

The clearance or sampling depth requirements, ordnance characteristics, type and quantity of nonordnance debris, and geotechnical/environmental characteristics (e.g. accessibility, magnetic mineral deposits, topography, vegetation, etc.) will affect the detection performance of sensing technologies. The conditions at JPG can be described as favorable for the detection of ordnance. The assessment of demonstrator detection performance in the scenarios emphasizes the feasibility of detecting the baseline ordnance set. The false alarm metrics are a necessary consideration because of the evaluation methodology used for determining detection. Localization and characterization statistical summaries are provided for all scenarios. Demonstrators who perform better than chance are assumed to have a nominal capability to distinguish ordnance and nonordnance. GRI’s multiple data sets and SC&A’s teaming arrangements are treated as independent demonstrations. SC&A’s performance is occasionally highlighted because of the uniqueness of their approach in the ATD. SC&A post processed the raw data sets of ADI, Geo-Centers, and Geometrics in an effort to demonstrate SC&A’s unique detection, localization, and characterization capabilities.

6.1.1 Scenario 1, Aerial Gunnery Range

Fourteen demonstrations were conducted on Scenario 1. The baseline ordnance consisted of 43 targets, including large bombs (250 pound to 750 pound), rockets (2.75 inch and 5 inch), and MK 76 practice bombs - typical air-launched ordnance. Demonstrators were required to report ordnance targets to a depth of 3 meters; however, no baseline ordnance targets were emplaced deeper than 2 meters.

The detection performance of demonstrators, as grouped by their sensor technology, is summarized in **Table 6.1.1-1**. The detection probabilities are based on the demonstrator searching the entire scenario. It should be noted that Foerster's probability of ordnance detection, based on the area they searched, is 63 percent. Geo-Centers scored a commendable 100 percent detection of the baseline targets in this scenario, but at the expense of a moderate false alarm rate. Over 40 percent (6 of 14) of the demonstrators had P_D 's greater than 85 percent. The success of demonstrators who combined magnetometer or gradiometer with electromagnetic induction sensors should be noted, as they were all above average performance. The trend for false alarm rates and ratios is not as distinguishable by technology, but magnetometer or gradiometer combined with electromagnetic induction were generally below the demonstrator average. Only three of the demonstrators with P_D's of at least 0.60 had false alarm ratios below 4. SC&A processed ADI's magnetometer data and reduced ADI's false alarm rate by ~50 percent, while reducing ADI's probability of detection from 79 percent to 74 percent, a ~6 percent reduction ratio. Likewise SC&A reduced Geo-Centers' false alarm rate by ~30 percent at the expense of a 7 percent reduction in ordnance detection (100 percent to 93 percent). The relationship of the probability of detection to the false alarm metrics is shown in **figure 6.1.1-1** and **6.1.1-2.** Better performance is in the upper left hand corner of these plots, where NAEVA and Geophex lie.

The mean radial (horizontal) and depth errors for all demonstrators are presented in **figure 6.1.1-3**. Foerster had the best positioning performance in this scenario, using gradiometer technology to locate 26 targets with an average radial error of only 35 centimeters. Foerster and Rockwell were the top performers in depth positioning, with an approximate absolute depth error of 0.25 meters. SC&A data processing did not improve ADI's or Geo-Centers' localization results. Most demonstrators performed well as there should be little difficulty in re-locating the relatively large baseline ordnance of this scenario with horizontal position errors less than one meter, and depth errors less than 0.5 meters.

Figure 6.1.1-4 shows that no demonstrator has an ability to distinguish baseline ordnance and nonordnance from each other, as no demonstrator performed better than chance. Demonstrators who tried to characterize nonordnance targets as nonordnance generally mistyped a comparable percentage of their ordnance targets as nonordnance.

Demonstrators sizing performance is summarize in **figure 6.1.1-5**, which shows most demonstrators have a nominal capability to estimate the size (diameter) of the baseline ordnance in this scenario. The individual capabilities are dependent on the size of the ordnance being estimated. Because the baseline ordnance mix had a good size distribution, this scenario better represents the sizing capabilities of demonstrators than the other scenarios. Foerster, Geophex and SC&A_Geo-Centers and GRI (Mag) were among the better performers, each with an averaged probability of estimating the three sizes correctly 50 percent or more.

In summary, demonstrators performed well in detecting and localizing the baseline ordnance, and established the feasibility of detecting ordnance with this size and depth distribution. All baseline ordnance items were detected . The false alarm metrics provide only a relative index of performance specific to JPG and they may not be achievable on an actual range. No demonstrator showed any capability to distinguish ordnance and nonordnance, so excavation of false targets would likely consume a sizable portion of remediation resources where nonordnance is prevalent.

TABLE 6.1.1-1

DEMONSTRATOR ORDNANCE DETECTION METRICS BY SENSOR TECHNOLOGY

AERIAL GUNNERY RANGE

Sensor Type	Demonstrator	P_D	False Alarm Rate (#/Hectare)	False Alarm Ratio (#/Ordnance Detected)
Electromagnetic Induction (EM)	CHEMRAD	0.60	16.49	2.19
	GRI (EM)	0.74	107.64	11.63
	GeoPotential	0.23	18.52	6.40
Gradiometer (Grad)	Foerster	0.60	36.46	4.85
Magnetometer (Mag)	ADI	0.79	104.16	10.59
	GRI (Mag)	0.88	241.31	21.95
	Rockwell	0.53	24.40	3.65
	SCA_ADI	0.74	50.64	5.47
EM & Grad	Geophex	0.93	47.74	4.13
EM & Mag	GRI (Combined)	0.95	223.66	18.85
	Geo-Centers	1.00	78.41	6.30
	NAEVA	0.88	32.70	2.97
	SCA_Geo-Centers	0.93	54.40	4.70
Ground Penetrating Radar & EM & Grad	ENSCO	0.70	55.55	6.40
	Averages:	0.75	78.01	7.86

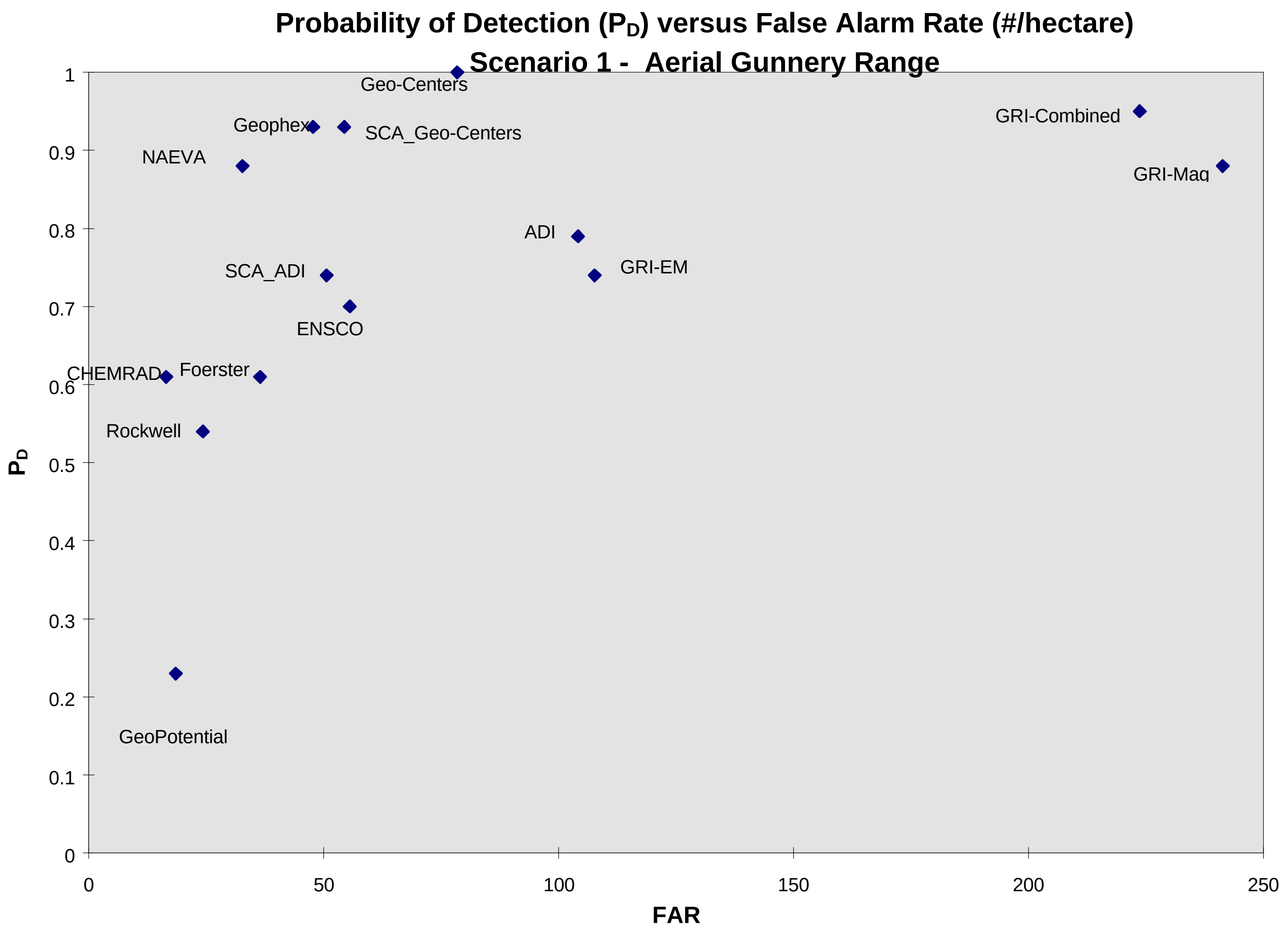

Probability of Detection (P_D) versus False Alarm Rate (#/hectare)
Scenario 1 - Aerial Gunnery Range
P_D
FAR
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
50
100
150
200
250
Geo-Centers
Geophex
SCA_Geo-Centers
NAEVA
GRI-Combined
GRI-Mag
ADI
SCA_ADI
GRI-EM
ENSCO
CHEMRAD
Foerster
Rockwell
GeoPotential

Figure 6.1.1-1

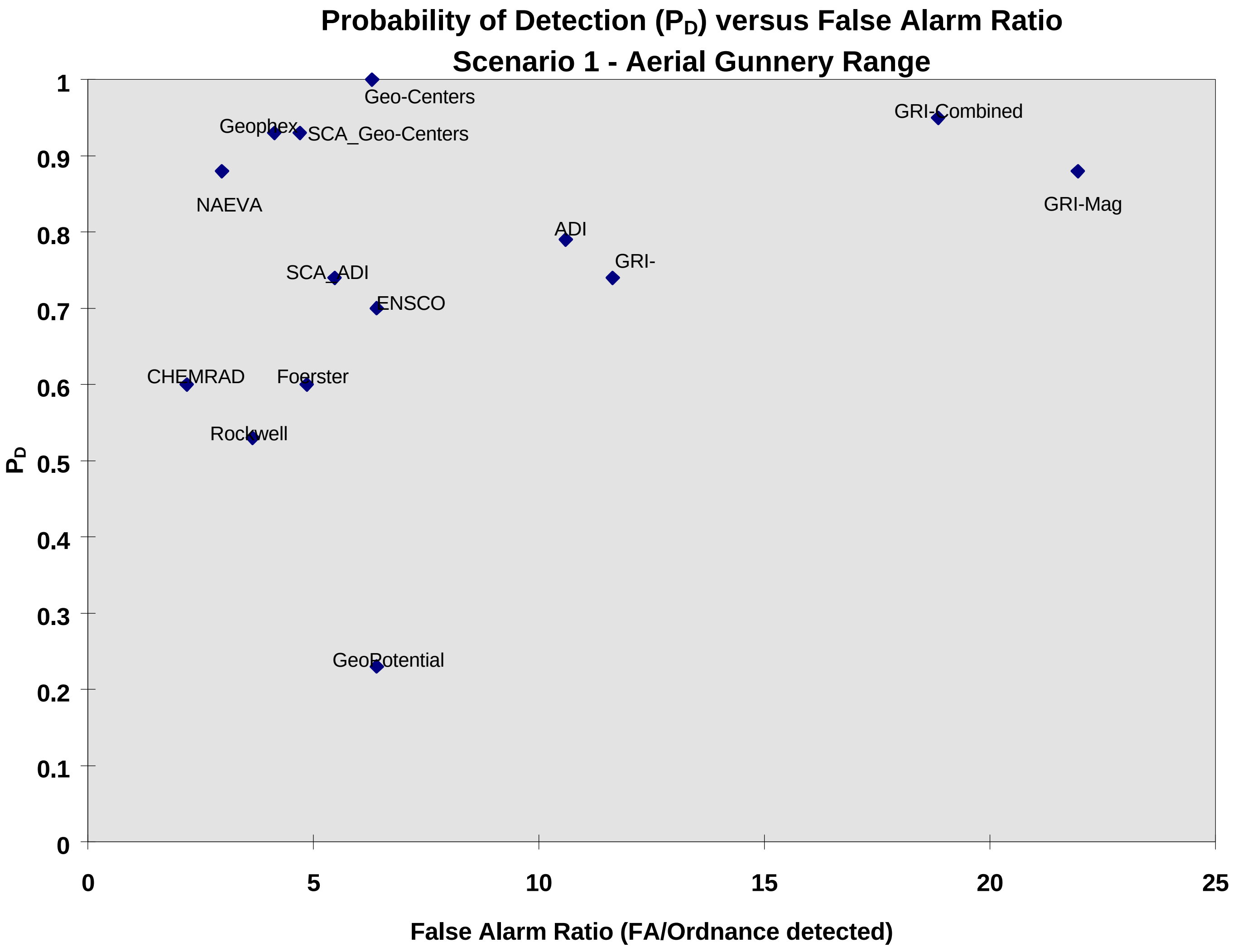

Probability of Detection (P_D) versus False Alarm Ratio
Scenario 1 - Aerial Gunnery Range
P_D
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
5
10
15
20
25
False Alarm Ratio (FA/Ordnance detected)
Geo-Centers
Geophex
SCA_Geo-Centers
GRI-Combined
NAEVA
GRI-Mag
ADI
GRI-
SCA_ADI
ENSCO
CHEMRAD
Foerster
Rockwell
GeoPotential

Figure 6.1.1-2

DEMONSTRATOR LOCALIZATION PERFORMANCE FOR THE AERIAL GUNNERY RANGE (SCENARIO 1)

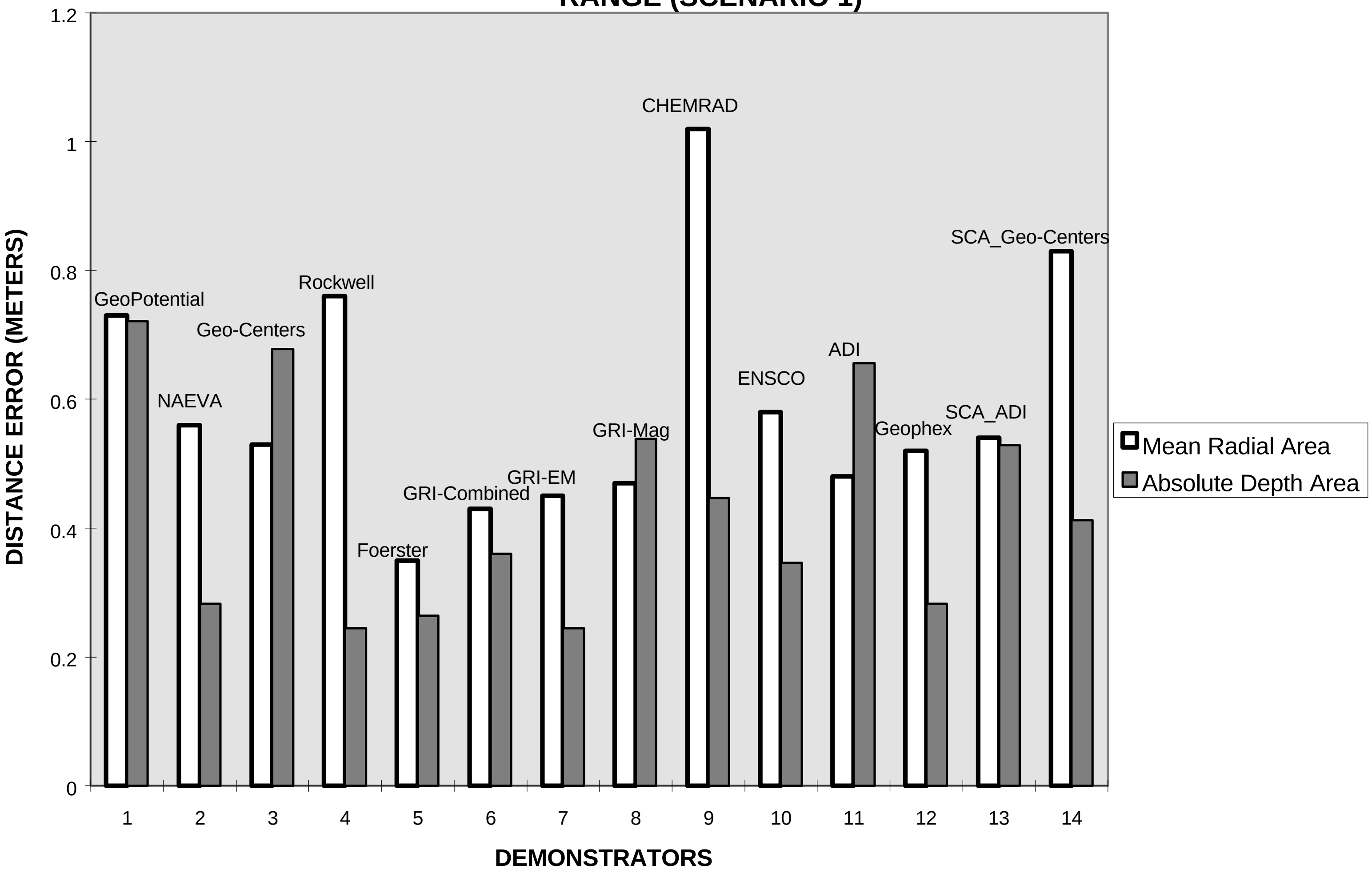
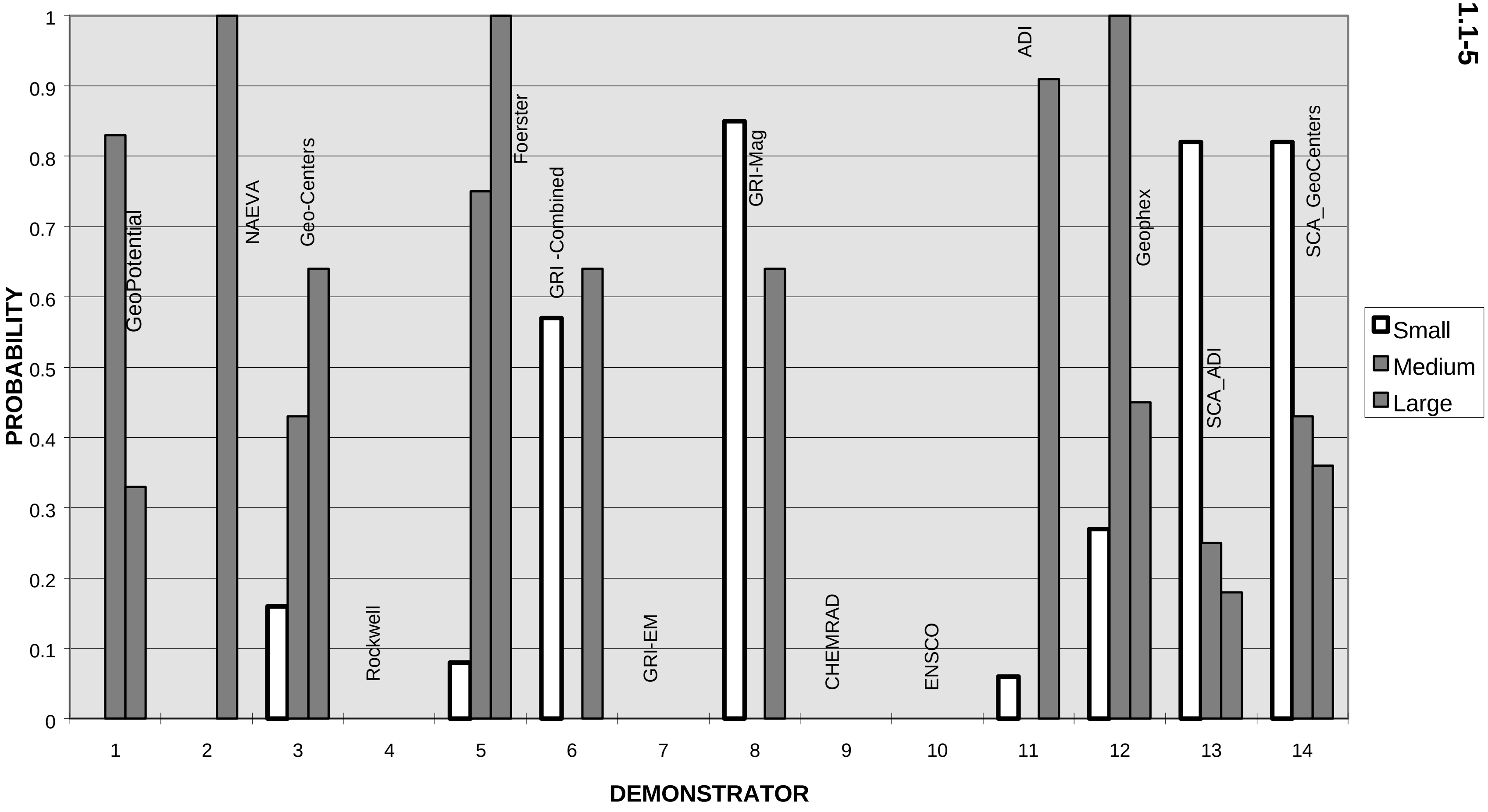


Figure 6.1.1-3

Figure 6.1.1-5

PROBABILITY OF CORRECT SIZE CLASSIFICATION FOR THE AERIAL GUNNERY RANGE (SCENARIO 1)



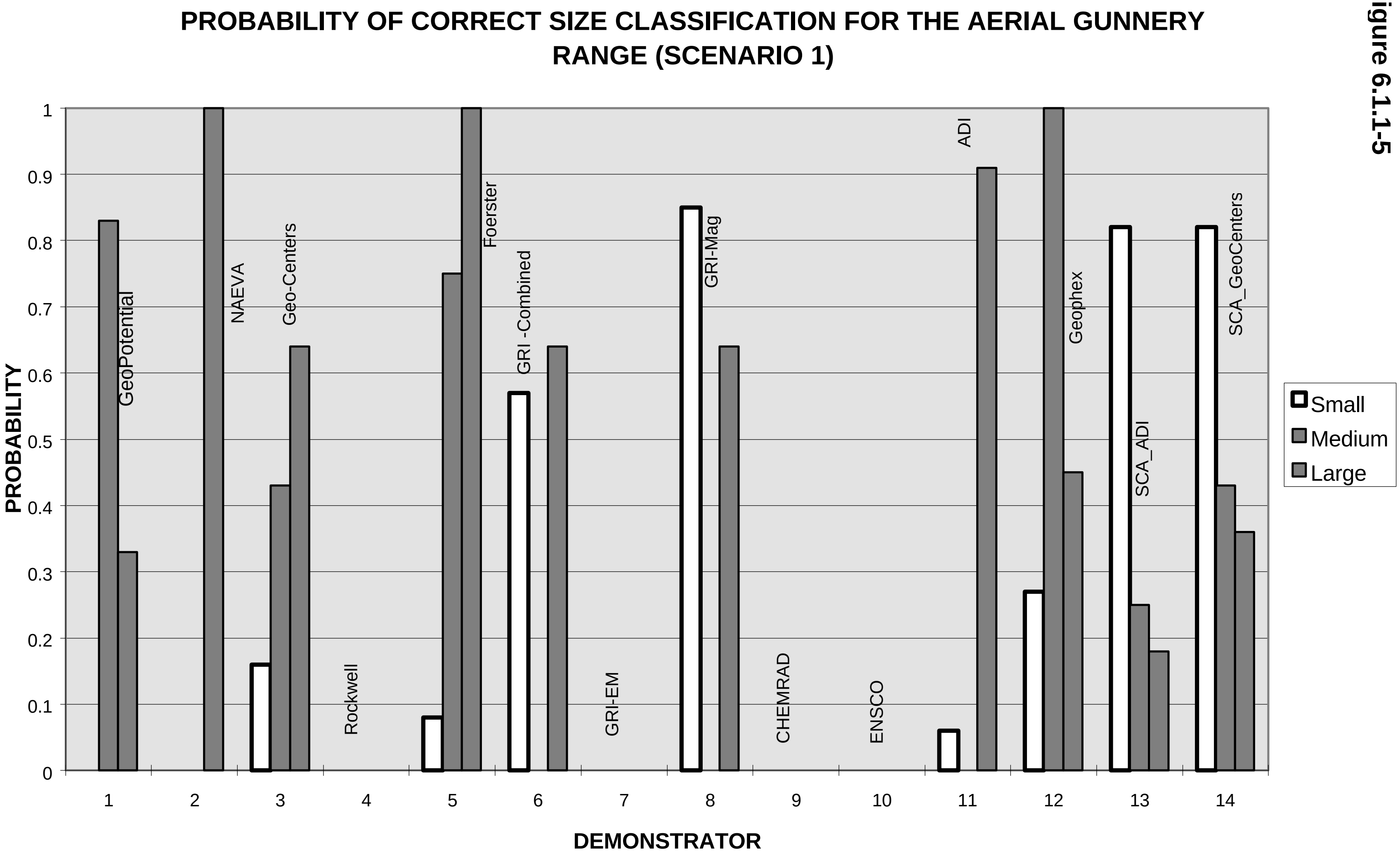

PROBABILITY OF CORRECT SIZE CLASSIFICATION FOR THE AERIAL GUNNERY RANGE (SCENARIO 1)
PROBABILITY
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
GeoPotential
NAEVA
Geo-Centers
Rockwell
Foerster
GRI -Combined
GRI-EM
GRI-Mag
CHEMRAD
ENSCO
ADI
Geophex
SCA_ADI
SCA_GeoCenters
1
2
3
4
5
6
7
8
9
10
11
12
13
14
DEMONSTRATOR
Small
Medium
Large

Figure 6.1.1-5

6.1.2 Scenario 2, Artillery and Mortar Range

Sixteen demonstrations were conducted on Scenario 2. The baseline ordnance consisted of 67 ordnance items, including mortars (60mm, 81mm, and 4.2 inch), projectiles (76mm to 8 inch) and rockets (66mm and 3.5 inch). Demonstrators were required to search to a depth of 1.2 meters, and no baseline ordnance was located below this depth.

The detection performance of demonstrators, as grouped by their sensor technology, is summarized in **Table 6.1.2-1** . NAEVA has a remarkable performance on this site, 97 percent ordnance detection with the low false alarm rate of 19 false alarms per hectare. One-half of the demonstrations (8 of 16) had P_D's of more than 85 percent. Electromagnetic induction sensors combined with magnetometers had the most consistent high detection performance. Six of the demonstrators with P_D's of at least 60 percent had false alarm ratios of less than 4. SC&A reduced both ADI's and Geo-Centers' false alarm rates by half, while respectively reducing detection by 4 percent (85 to 83 percent) and 19 percent (93 to 76 percent). SC&A increased Geometric's detection by ~7 percent (90 to 96 percent), but at the expense of a ~9 percent increase in the false alarm rate. The relationship of demonstrator ordnance detection probabilities and false alarm metrics is shown in **figures 6.1.2-1** and **6.1.2-2.** Better performance is in the upper left hand corner of these plots where NAEVA, SCA_Geometrics, and Geometrics lie.

The mean radial (horizontal) and depth errors for all demonstrators is summarized in **figure 6.1.2-3**. Nearly one-half of the demonstrators located the ordnance targets below a mean radial error of 0.5 meters. Five demonstrators determined ordnance depth to within a mean of 25 centimeters. The precision in depth may be due to the relatively shallow (<1.2 meters) target base. Most other demonstrators performed well in location and depth estimation. There should be little difficulty in re-locating UXO of the size found in this scenario, with horizontal position errors of less than one meter, and depth errors less than 0.5 meters.

Demonstrator typing performance is summarized in **figure 6.1.2-4.** No demonstrator showed any significant ability to distinguish baseline ordnance and nonordnance from each other. Demonstrators who tried to characterize nonordnance targets as such generally mistyped a greater percentage of their ordnance targets. Demonstrators who did not report nonordnance had reported a significant percentage of the nonordnance baseline targets relative to their ordnance detection.

Demonstrators sizing performance is summarized in **figure 6.1.2.4**. Many demonstrators have a nominal capability to estimate the size (diameter) of the baseline ordnance in this scenario. The target base consisted primarily of small and medium ordnance. SC&A performed best in that they correctly estimated the size of the small and medium ordnance more than 50 percent of the time with their Geo-Centers data.

In summary, demonstrators performed well in detecting and localizing the baseline ordnance, and established the feasibility of detecting ordnance with this size and depth distribution. All baseline ordnance targets were detected. The false alarm metrics provide only a relative index of performance specific to JPG and they may not be achievable on an actual range. No demonstrator showed any capability to distinguish ordnance and nonordnance, so excavation of false targets would likely consume a sizable portion of remediation resources where nonordnance is prevalent.

TABLE 6.1.2-1

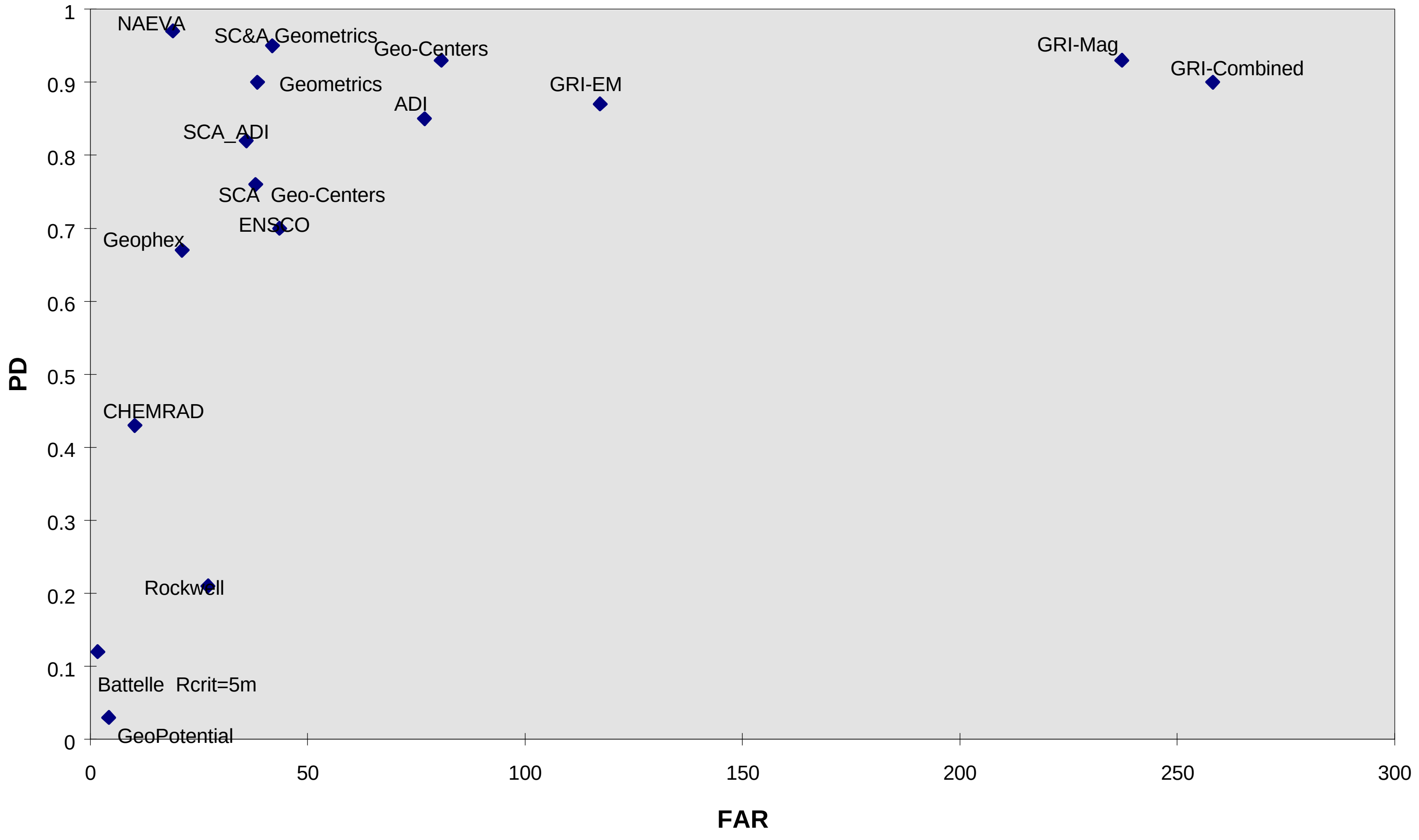
DEMONSTRATOR ORDNANCE DETECTION METRICS BY SENSOR TECHNOLOGY

ARTILLERY AND MORTAR RANGE

Sensor Type	Demonstrator	P_D	False Alarm Rate (#/Hectare)	False Alarm Ratio (#/Ordnance Detected)
Electromagnetic Induction (EM)	CHEMRAD	0.43	10.25	1.66
	GRI (EM)	0.87	117.24	9.47
	GeoPotential	0.03	4.27	10.00
Magnetometer (Mag)	ADI	0.85	76.88	6.32
	Battelle	0.12	1.71	1.00
	GRI (Mag)	0.93	237.25	17.92
	Rockwell	0.21	27.12	9.07
	SCA_ADI	0.82	35.88	3.05
EM & Gradiometer	Geophex	0.67	21.14	2.20
EM & Mag	GRI (Combined)	0.90	258.18	20.15
	Geo-Centers	0.93	80.72	6.10
	Geometrics	0.90	38.44	3.00
	NAEVA	0.97	19.01	1.37
	SCA_Geo-Centers	0.76	38.01	3.49
	SCA_Geometrics	0.96	41.86	3.06
Ground Penetrating Radar & EM & Grad	ENSCO	0.70	43.56	4.34
	Averages:	0.69	65.72	6.39

Figure 6.1.2-1

Probability of Detection (PD) versus False Alarm Rate (#/hectare)
Artillery and Mortar Range (Scenario 2)



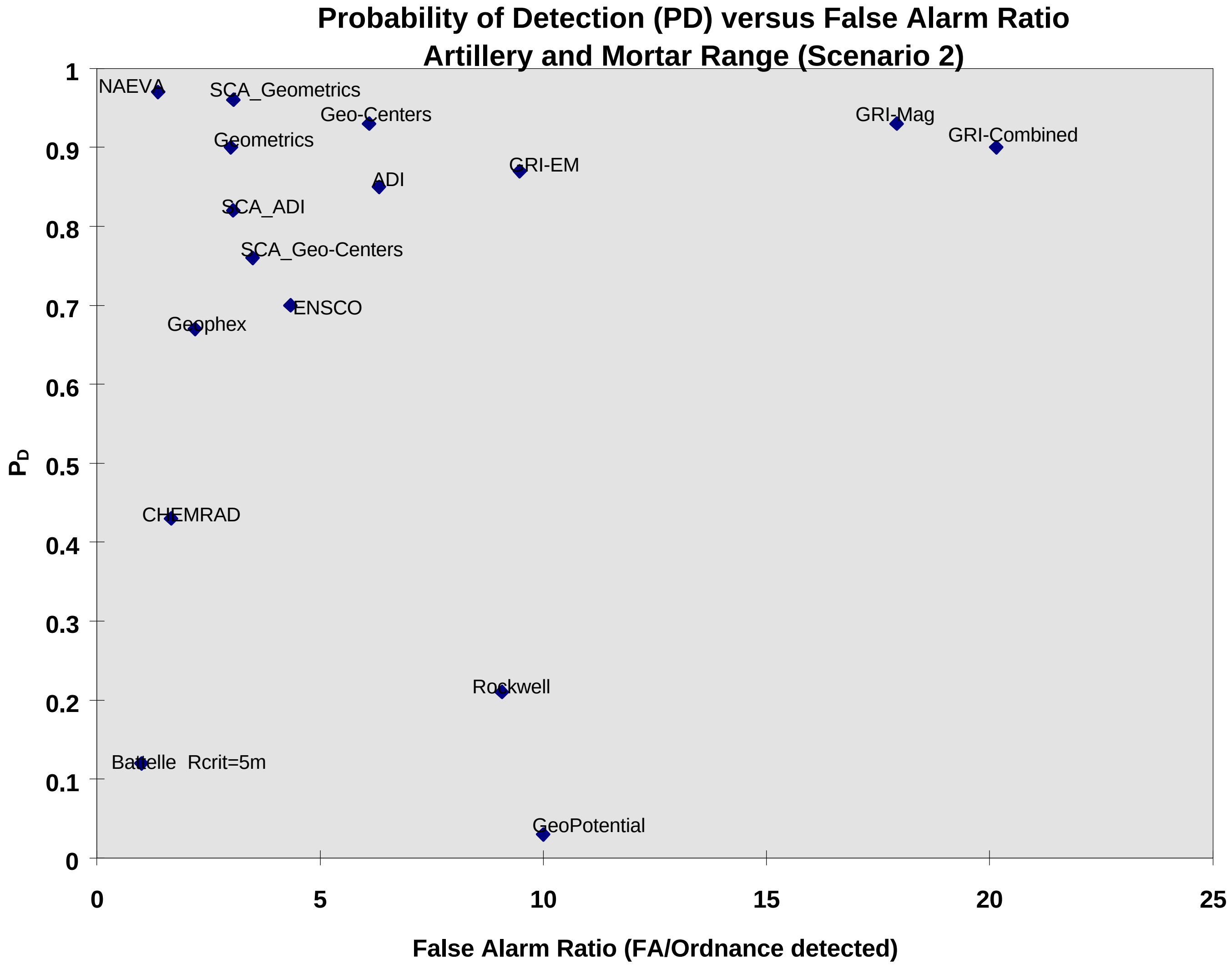

Probability of Detection (PD) versus False Alarm Ratio
Artillery and Mortar Range (Scenario 2)
P_D
False Alarm Ratio (FA/Ordnance detected)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
5
10
15
20
25
NAEVA
SCA_Geometrics
Geo-Centers
Geometrics
ADI
SCA_ADI
SCA_Geo-Centers
ENSCO
Geophex
GRI-Mag
GRI-Combined
GRI-EM
CHEMRAD
Rockwell
Battelle Rcrit=5m
GeoPotential

Figure 6.1.2-2

LOCALIZATION PERFORMANCE FOR THE ARTILLERY AND MORTAR RANGE (SCENARIO 2)

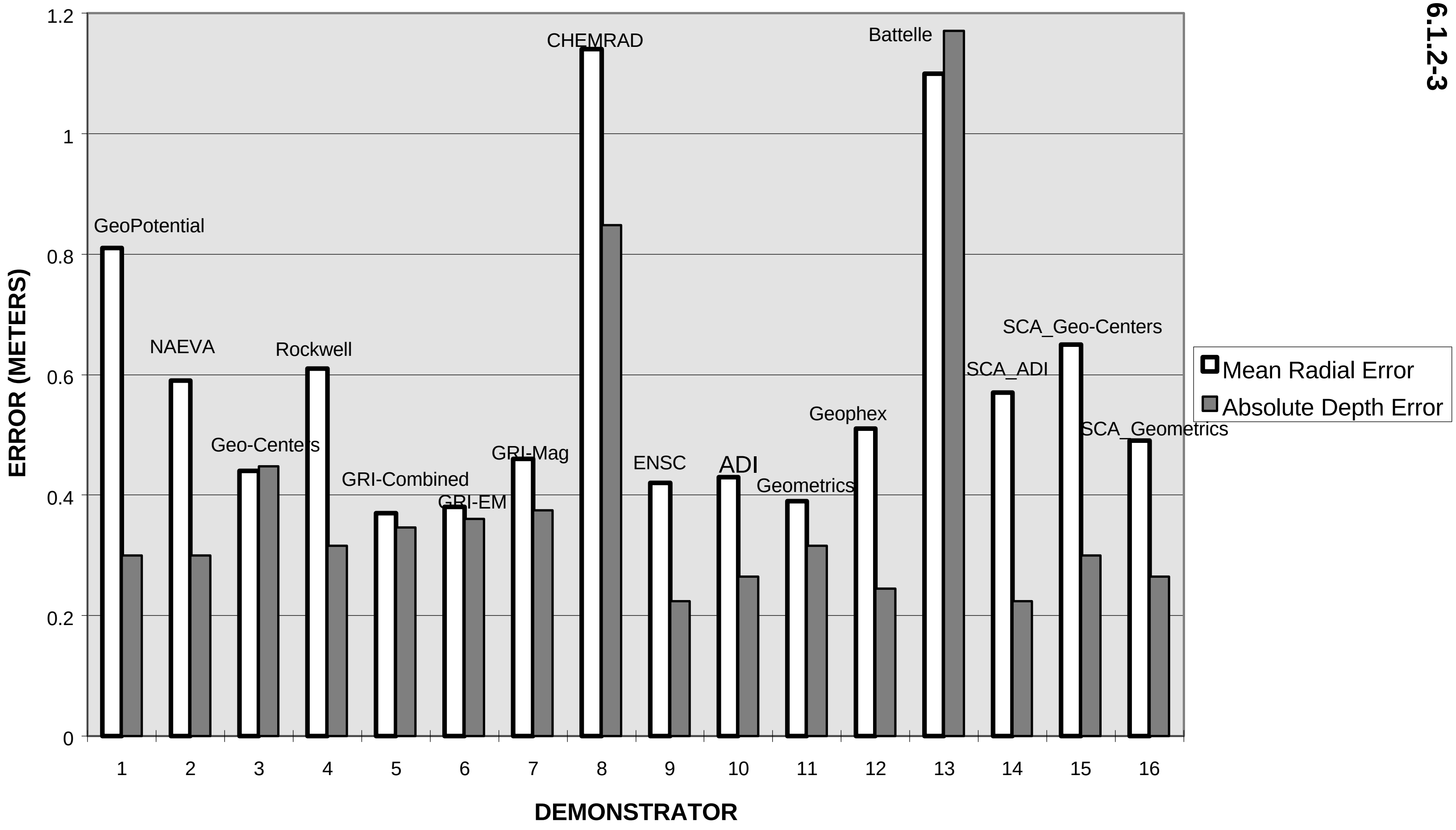
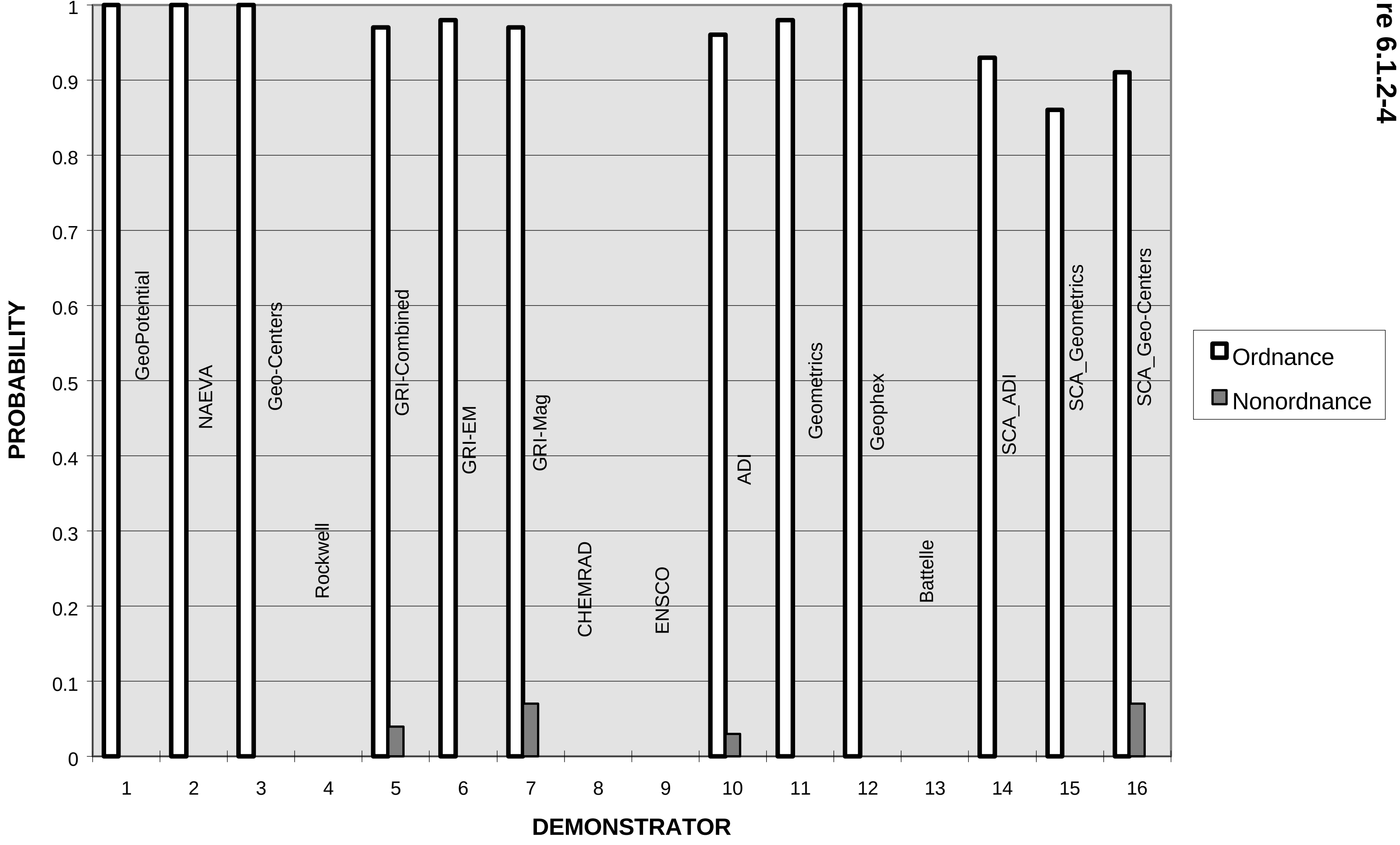


Figure 6.1.2-3

Figure 6.1.2-4

CONDITIONAL PROBABILITY OF CORRECT TYPE CLASSIFICATION FOR THE ARTILLERY AND MORTAR RANGE (SCENARIO 2)



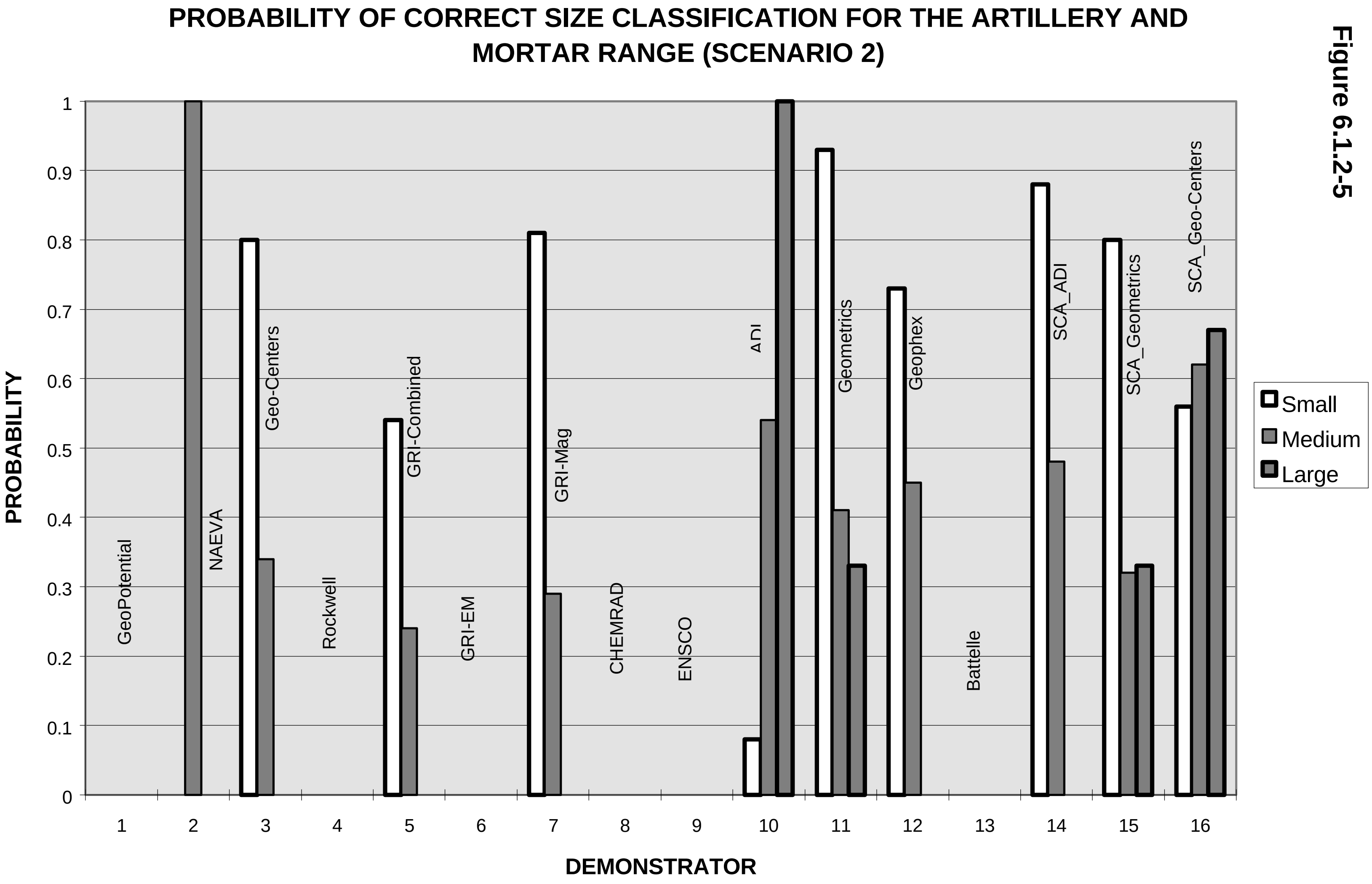

PROBABILITY OF CORRECT SIZE CLASSIFICATION FOR THE ARTILLERY AND MORTAR RANGE (SCENARIO 2)
PROBABILITY
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
GeoPotential
NAEVA
Geo-Centers
Rockwell
GRI-Combined
GRI-EM
GRI-Mag
CHEMRAD
ENSCO
ADI
Geometrics
Geophex
Battelle
SCA_ADI
SCA_Geometrics
SCA_Geo-Centers
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
DEMONSTRATOR
Small
Medium
Large

Figure 6.1.2-5

6.1.3 Scenario 3, Grenade and Submunition Mortar Range

Eight demonstrations were conducted for Scenario 3. The baseline ordnance consisted of 98 ordnance items, primarily small sized M42 and M32 series submunitions and MK118 Rockeyes. Demonstrators were required to search to a depth of 0.5 meters, and no baseline ordnance was located below 0.4 meters.

The detection performance of demonstrators, as grouped by their sensor technology, is summarized in **Table 6.1.3-1**. Geo-Centers, GRI (EM) and GRI (Combined) were the only demonstrators with ordnance detection above 85 percent. The difference in GRI's magnetometer performance (47 percent) and electromagnetic induction performance (92 percent) show the value of EM technology in detecting small, relatively shallow ordnance. Only two demonstrators (SCA_Geo-Centers and Geo-Centers) had P_D's of at least 60 percent with false alarm ratios less than or equal to 4. SC&A reduced both ADI's and Geo-Centers' false alarm rates by ~63 percent and ~53 percent, but with respective reductions of ~37 percent (from 72 to 46 percent) and ~24 percent (from 91 to 69 percent) in detection ratios. The relationship of demonstrator ordnance detection probabilities and false alarm metrics is shown in **figures 6.1.3-.1** and **6.1.3-2.** Better performance is in the upper left hand corner of these plots where Geo-Centers lies.

The mean radial (horizontal) and depth errors for all demonstrators is shown in **figure 6.1.3-3** in this scenario. Most demonstrators could localize the targets to within 0.5 mean radial error, and provide reasonable depth estimates for the small targets. (Note: GeoPotential's and SCA_Geo-Centers' depth data are not significant because both their statistics are based on one depth reported for evaluation). GRI (EM) and GRI (Combined) has the best performance in localizing the submunitions in this scenario. When the precision of location (34 centimeters or greater in this scenario) is many times the dimensions of a small target such as a M32 submunition (~ 30mm), then the adequacy of location is dependent on the site-specific spatial density of ordnance and "noise" sources. Precision in position is needed to the extent one has confidence that target excavations match detected anomalies.

Demonstrator typing performance is summarized in **figure 6.1.3-4**. No demonstrator showed an ability to distinguish baseline ordnance and nonordnance from each other, although GRI has some of the better performance seen in this category. GRI correctly declared 89 of 90 targets as ordnance (99 percent) and correctly declared 5 of 24 targets as nonordnance (21 percent).

Demonstrators sizing performance is summarized in **figure 6.1.3-5**. Most demonstrators performed well in declaring small targets correctly. However, demonstrators were informed to expect small ordnance on this site, so the data is probably biased in this regard.

In summary, demonstrators established the feasibility of detecting ordnance of this size and depth distribution. Only one submunition was not detected by any of the demonstrators. The false alarm metrics provide only a relative index of performance specific to JPG and they may not be achievable on an actual range. No demonstrator showed any significant capability to distinguish ordnance and nonordnance. The excavation of false targets would be a resource problem because the small submunitions may be difficult to distinguish from shrapnel and metallic scrap.

TABLE 6.1.3-1

DEMONSTRATOR ORDNANCE DETECTION METRICS BY SENSOR TECHNOLOGY

GRENADE AND SUBMUNITIONS RANGE

Sensor Type	Demonstrator	P_D	False Alarm Rate (#/Hectare)	False Alarm Ratio (#/Ordnance Detected)
Electromagnetic Induction (EM)	GRI (EM)	0.92	144.92	6.68
	GeoPotential	0.01	6.51	27.00
Magnetometer	GRI (Mag)	0.47	193.62	17.46
EM & Mag	ADI	0.72	150.70	8.80
	GRI (Combined)	0.95	234.62	10.46
	Geo-Centers	0.91	85.84	4.00
	SCA_ADI	0.46	55.94	5.16
	SCA_Geo-Centers	0.69	40.75	2.49
	Averages:	0.64	114.11	10.26

PROBABILITY OF DETECTION (P_D) VERSUS FALSE ALARM RATE FOR THE GRENADE AND SUBMUNITION RANGE (SCENARIO 3)

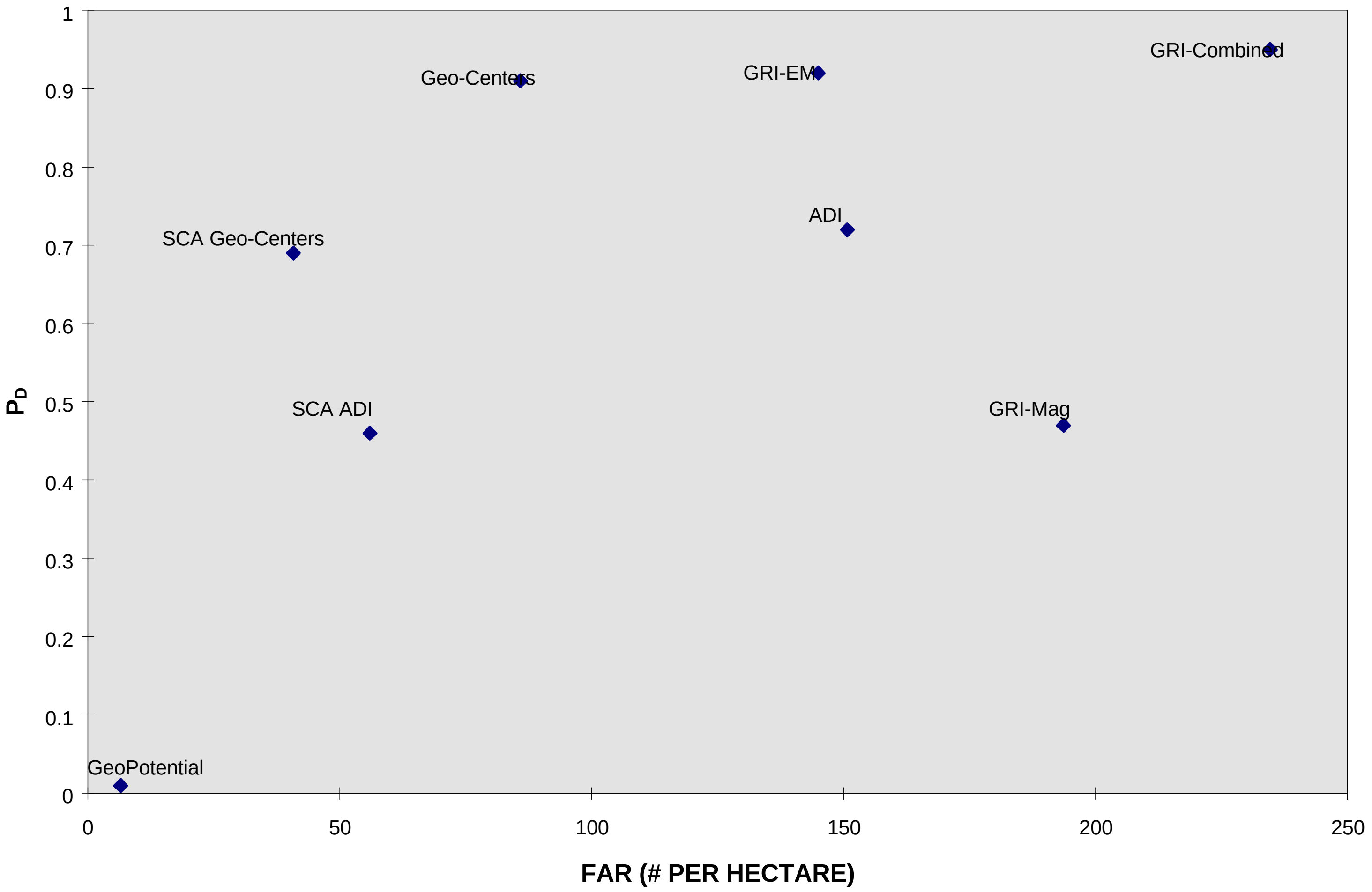
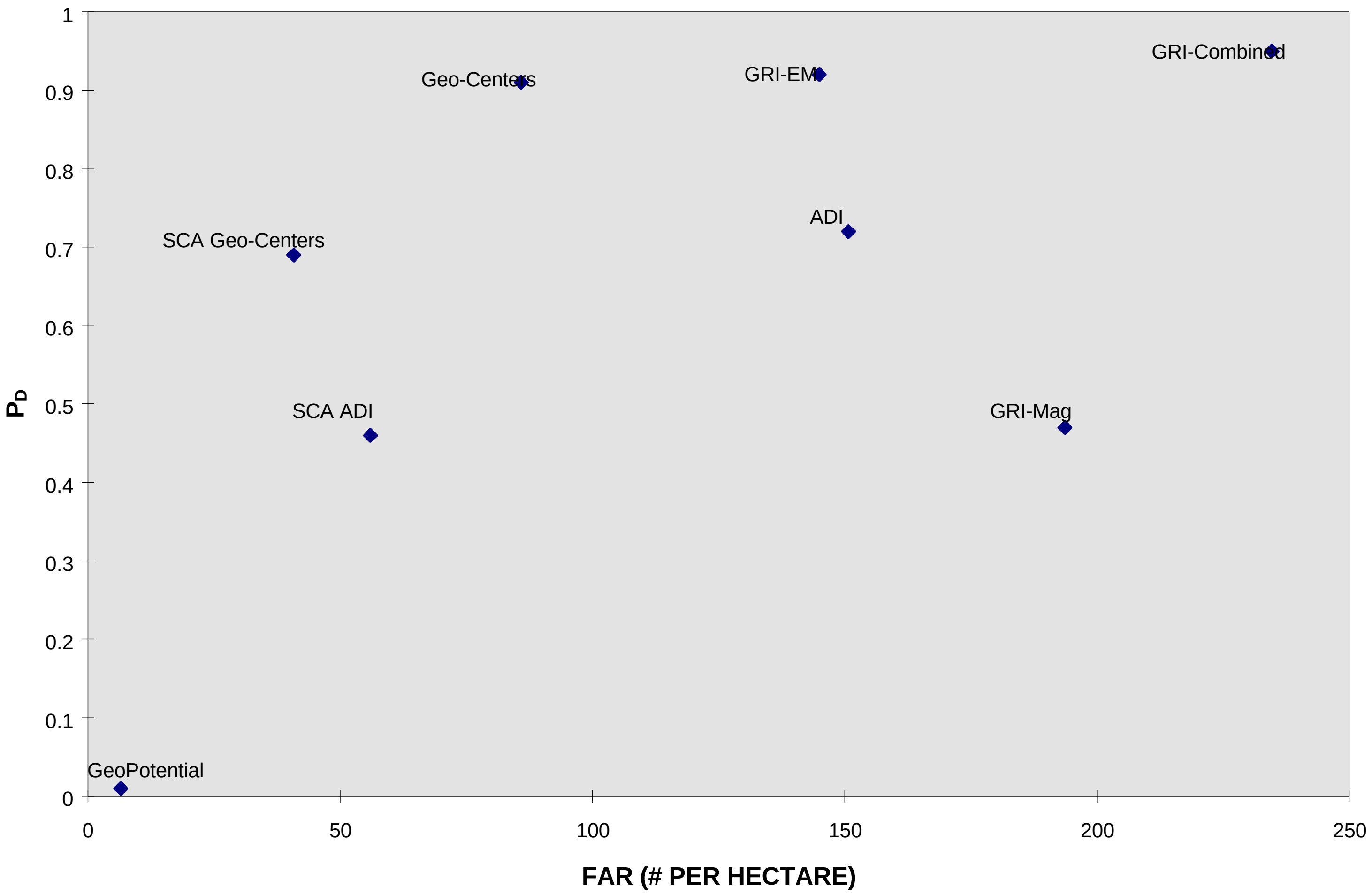


Figure 6.1.3-1

Figure 6.1.3-1

PROBABILITY OF DETECTION (P_D) VERSUS FALSE ALARM RATE FOR THE GRENADE AND SUBMUNITION RANGE (SCENARIO 3)



PROBABILITY OF DETECTION VERSUS FALSE ALARM RATIO FOR THE GRENADE AND SUBMUNITION RANGE (SCENARIO 3)

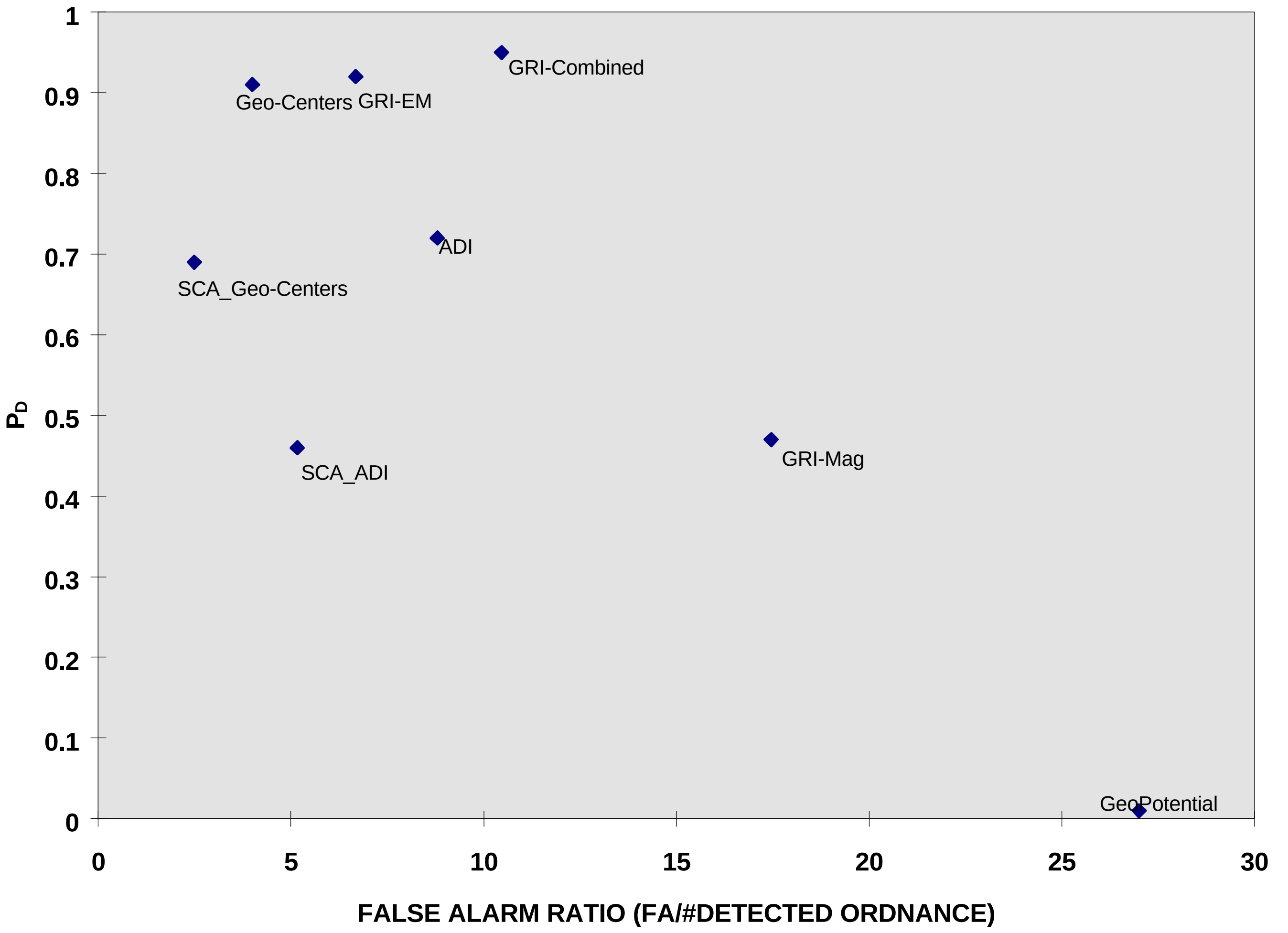


Figure 6.1.3-2

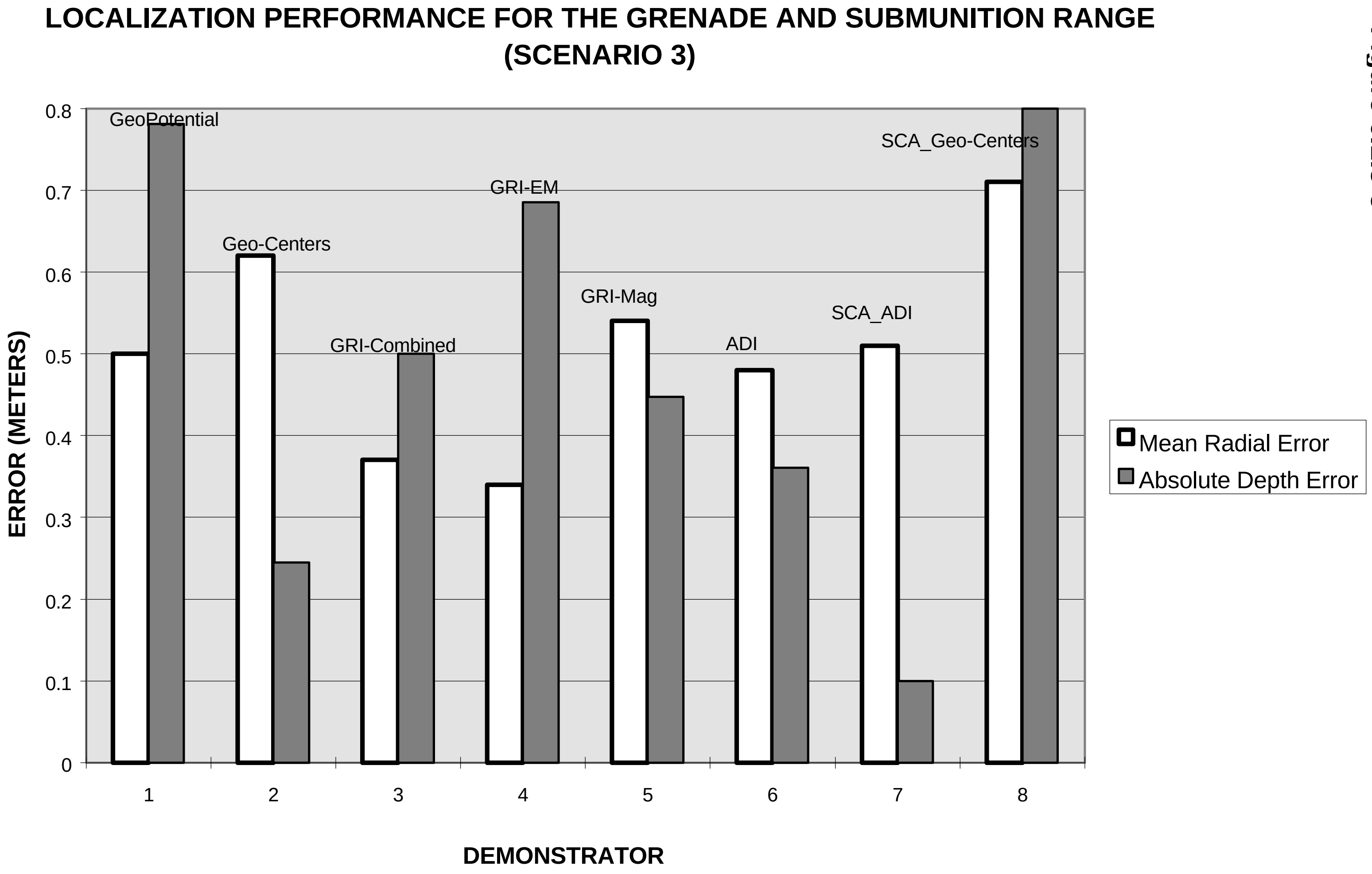

LOCALIZATION PERFORMANCE FOR THE GRENADE AND SUBMUNITION RANGE
(SCENARIO 3)
ERROR (METERS)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
GeoPotential
Geo-Centers
GRI-Combined
GRI-EM
GRI-Mag
ADI
SCA_ADI
SCA_Geo-Centers
1
2
3
4
5
6
7
8
DEMONSTRATOR
Mean Radial Error
Absolute Depth Error

Figure 6.1.3-3

PROBABILITY OF CORRECT TYPE CLASSIFICATION FOR THE GRENADE AND SUBMUNITION RANGE (SCENARIO 3)

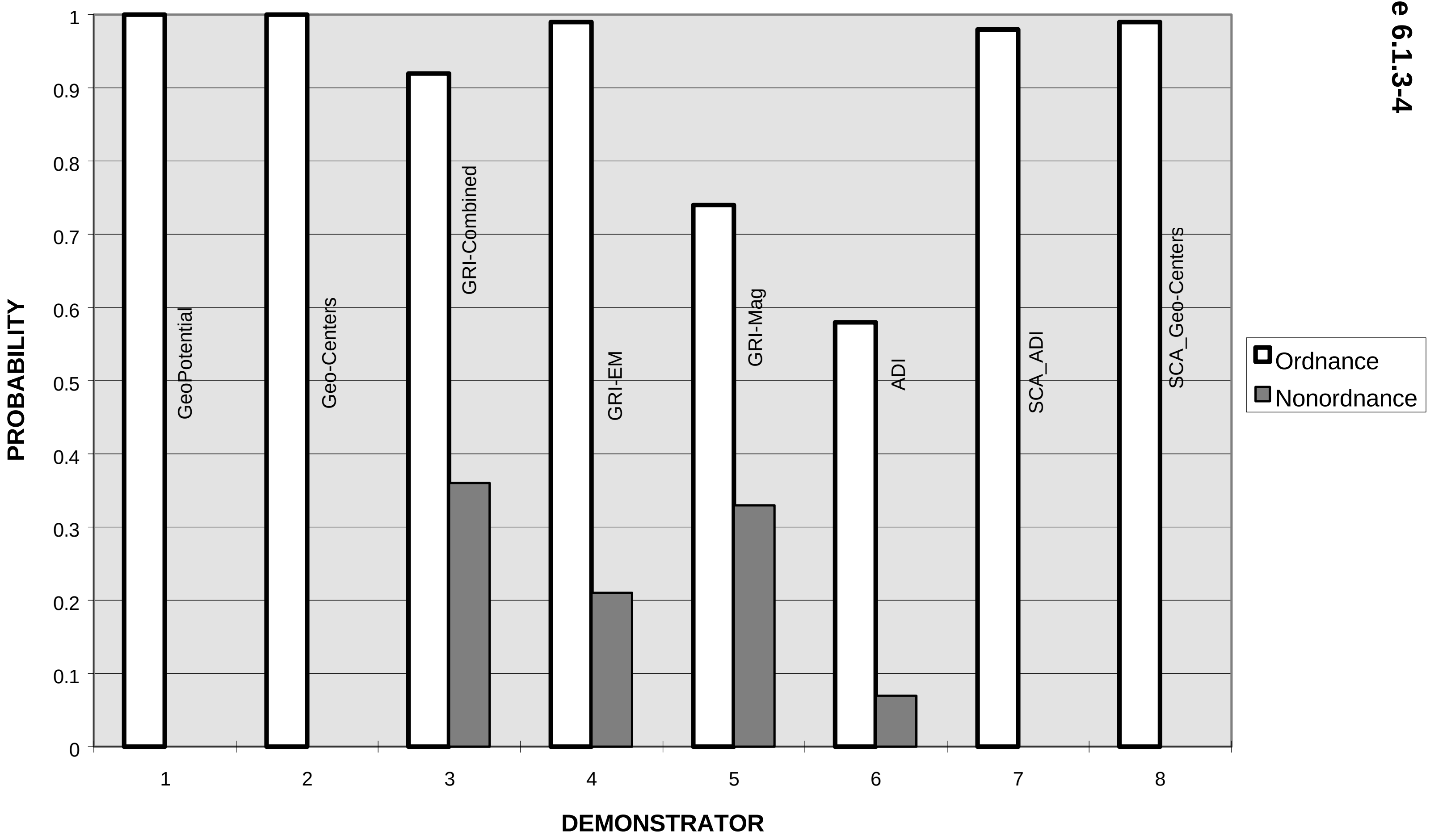


Figure 6.1.3-4

PROBABILITY OF CORRECT SIZE CLASSIFICATION FOR THE GRENADE AND SUBMUNITION RANGE (SCENARIO 3)

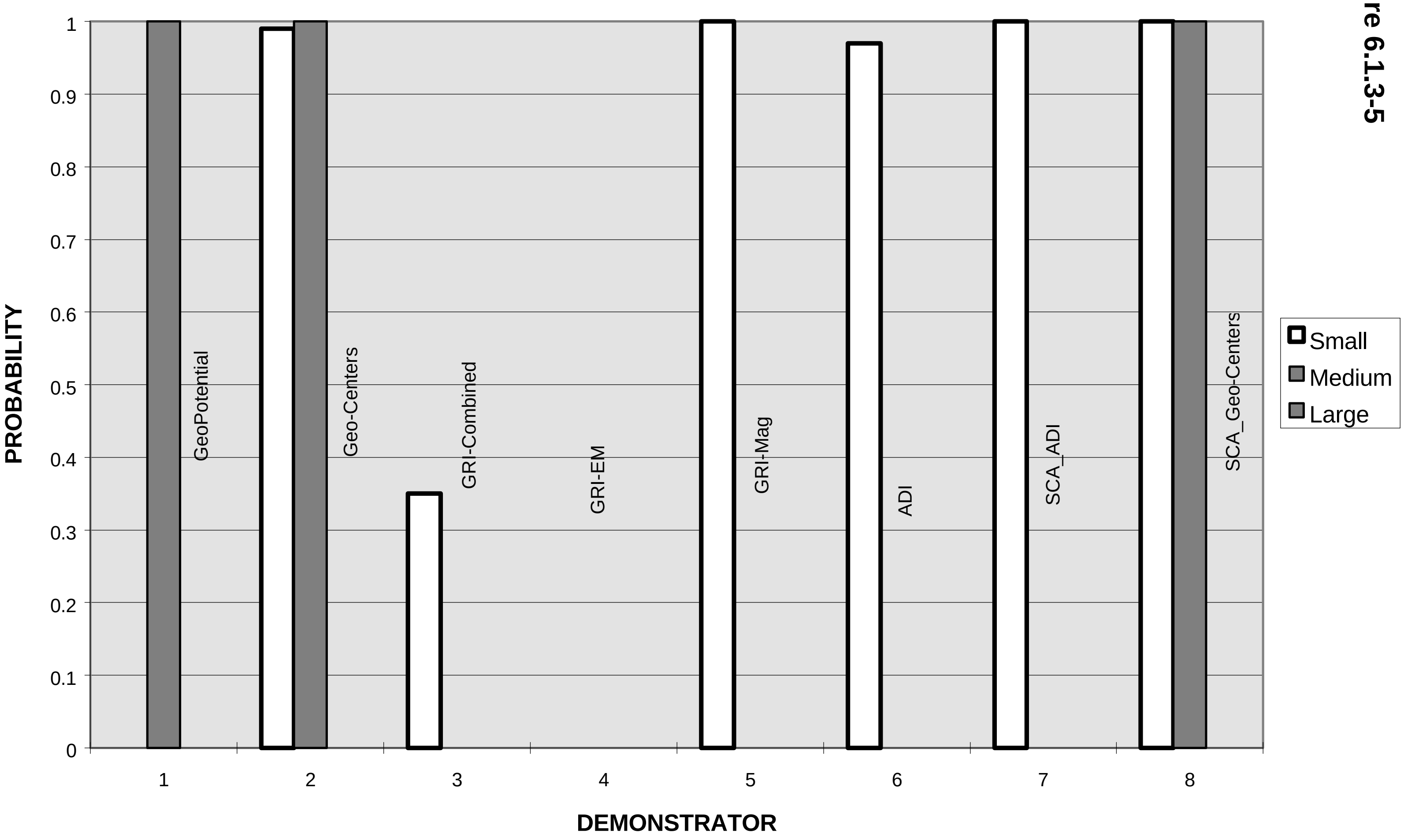


Figure 6.1.3-5

6.1.4 Scenario 4, Interrogation and Burial Area

Seven demonstrators participated in the Scenario 4 characterization demonstrations. The targets they were expected to classify included 17 ordnance items (4 bombs, 10 projectiles and 3 mortars) and 3 nonordnance items. Demonstrators were informed that there were no targets deeper than 2 meters. Since demonstrators were provided the geodetic position of the targets, no summary of their localization statistics is provided. Some demonstrators provided the position data and the error statistics are provided in the individual performance charts of **Section 5.4**. (Note in this section that Geometrics provided only 13 target positions in their target report that matched their assigned 20 target interrogation set. SC&A used Geometrics data and reported all 20 positions correctly. Demonstrators needed to provide a position within two meters of each marked target for their target report data to be considered for evaluation). **Table 6.1.4-1** summarizes the performance of demonstrators grouped by technology in estimating the depth of ordnance targets, typing ordnance and nonordnance, and estimating the size of ordnance targets and class. The numbers of targets is this scenario is small, so that the data is statistically weak. The brief discussion that follows is drawn upon the point estimates of the performance data, primarily because this scenario allowed demonstrators to focus their resources on characterization of marked targets.

ENSCO, with ground penetrating radar, gradiometer, and metal detector had the best performance in estimating depth (0.36 meters), but their performance in this scenario was no different from their performance on the Aerial Gunnery Range (0.35 meters) . No demonstrator correctly typed any of the 3 nonordnance targets, thus again showing the inability of demonstrators to distinguish ordnance and nonordnance baseline targets. Geometrics had the best overall performance in estimating the size and class of the ordnance, but they performed as well on the Artillery and Mortar Range. SC&A improved significantly upon ADI’s sizing performance for medium and large targets.

In summary, the value received out of this scenario was limited. No demonstrations of innovative target interrogation (vice “search”) technologies were conducted. The characterization performance of the demonstrators was comparable to what was achieved in the other scenarios. However, a “characterization” range does allow a variety of target sizes and depths to be emplaced. This variety can be used to assess demonstrator capabilities without the influence that a scenario might have on decisions.

TABLE 6.1.4 - 1

DEMONSTRATOR CHARACTERIZATION CAPABILITIES BY SENSOR TECHNOLOGY

INTERROGATION AND BURIAL AREA

			TYPING		SIZING			CLASSIFYING		
Sensor Type	**Demonstrator**	**Depth Error (meters)**	**Est. Ord.**	**Est. Nonord.**	**Est. Size Small**	**Est. Size Med.**	**Est. Size Large**	**Est. Class Bomb**	**Est. class Projectile**	**Est. Class Mortar**
Gradiometer (Grad)	Foerster	0.81	0.00	0.00	1.00	0.67	0.00	0.00	0.00	0.00
Magnetometer	Battelle	0.92	0.00	0.00	0.00	0.00	NA	0.00	0.00	NA
EM & Mag	ADI	0.42	1.00	0.00	1.00	0.29	0.00	1.00	0.00	0.50
	Geometrics	0.48	1.00	0.00	0.67	0.67	1.00	1.00	0.67	0.50
	SCA_ADI	0.42	1.00	0.00	0.40	0.57	1.00	0.50	0.22	0.00
	SCA_Geometrics	0.50	0.94	0.00	0.40	0.67	1.00	0.75	0.38	0.20
Ground Penetrating Radar & EM & Grad	ENSCO	0.36	0.82	0.00	0.40	0.29	0.80	0.00	0.00	0.00
	Average:	0.56			0.55	0.45	0.63	0.46	0.18	0.20

6.2 OVERALL DEMONSTRATOR SEARCH PERFORMANCE

A secondary objective for JPG Phase III is to continue the characterization of UXO technologies established in the earlier phases. The analysis of overall demonstrator search performance is based on the combined statistics (Scenarios 1, 2, and 3) of **Appendix B**, Demonstrator Summary Reports**.** The scenario numbers that demonstrators participated in are annotated to their names in charts and plots. The performance of survey demonstrators is based on their abilities to detect, localize and characterize an emplaced set of baseline targets. The small survey areas limit the value of distinguishing performance based on the platform used (see Section 4, or Appendix B for the demonstrators' platform technologies).

6.2.1 Detection Performance

The overall ordnance detection performance of demonstrators at JPG Phase III, as grouped by their sensor technology, is summarized in **Table 6.2.1-1.** Three of the demonstrators who had participated in at least two search scenarios, Geo-Centers, NAEVA, and GRI (Combined), scored above 90 percent. All three used the combination of sensor technology that was most successful in Phase II, magnetometer and electromagnetic induction. NAEVA is further distinguished because not only did they achieve the highest P_D, but also their false alarm rate, 24.8 false alarms per hectare, is relatively low among all demonstrators. Geo-Centers' false alarm rate is over three times that of NAEVA's, and GRI (Combined)'s is ten times NAEVA's. In examining the false alarm ratio, a measure of the ordnance likelihood in target excavations, over one-third of NAEVA's target excavations would have resulted in ordnance. This rate is twice that of Geo-Centers' 16 percent rate and more than 5 times GRI's 6 percent rate. (It should be noted that GRI (Combined) has a high false alarm because they elected to report over 1200 nonordnance targets that were counted as "false alarms". If GRI (Combined) had chosen not to report nonordnance targets, they would have reduced their false alarm rates by almost 40 percent while dropping their ordnance detection by only 6 percent). The relationship of P_D to false alarm rate and false alarm ratio is shown for all demonstrators in **figures 6.2.1-1 and 6.2.1-2**. These ordnance detection statistics are a marked improvement over Phase II where the best performing demonstrator (Parsons) achieved

85 percent ordnance detection. Over 40 percent (6 of 14) of the demonstrations in Phase III exceeded Parson's performance in Phase II.

The trends in detection performance and false alarm rates for Phases I, II and III are shown in **figure 6.2.1-3.** There is a tendency for the later Phases to move up on the plot; that is, the probability of detection has been generally improving since Phase I. However, there has been no movement to the left of the chart that would show false alarms decreasing. (The value of conducting trials at JPG is that the performance trend in false alarm rates can be compared to a baseline, since false alarm rates are site-specific). Looking at just the statistics for ground-based demonstrations *that detected at least 50 percent* of the baseline ordnance, the following trends are established for the three JPG Phases:

TABLE 6.2.1-2. Ordnance Detection by JPG Phase

	# Ground-Based Demonstrators	**Average P_D**	**Average False Alarm Rate**
Phase I	1 of 20	0.62	149
Phase II	9 of 12	0.68	60
Phase III	14 of 16	0.77	77

The data also shows the percentage of ground-based demonstrators detecting more than 50 percent of the baseline ordnance has increased since Phase I.

One issue is whether the improvements in ordnance detection seen in Phase III are real, since Phase I and II demonstrators had to look for deeper ordnance. The depth and size of the baseline ordnance influence how well ordnance can be detected. There is evidence that the improvement in detection is not dependent on the maximum depth (2 meters) of the Phase III baseline ordnance set. The Phase II detection results were recalculated with only those ordnance baseline targets that were shallower than 2 meters. The recalculated results showed only minor changes in the Phase II demonstrator performance, and the average P_D for the 9 Phase II demonstrators who scored at least 50 percent, actually deceased from 68 percent to 67 percent.

The change in the average ordnance depth from 0.9 meter in Phase II to 0.4 meter could have a significant bearing on the improvement in performance that was seen in Phase III, but its influence is not so easily determined. Detection usually follows a power relationship proportional to the distance a sensor is from a target, and that makes nearby targets much easier to detect. For example, a total field magnetometer has a cubed distance relationship: a magnetometer 0.5 meter off the ground would see a 370 percent increase [$(1.4/0.9)^3$] in target strength for a steel target at 0.4 meters depth than the target strength for the same target at 0.9 meters depth. This average increase in target strength must be discounted, because while Phase III ordnance was shallower, it was also smaller than the Phase II ordnance. Small targets represented 75 percent (155/208) of the Phase III baseline ordnance but only 44 percent (69/158) of the Phase II baseline ordnance (on the "16A" site). Small targets are more difficult to detect, and not just because there is less mass. Target volume also affects detection. A 55 gallon oil drum has a much stronger magnetic "signature" than a comparable mass of metal collapsed into a sphere. An additional consideration in the Phase II - III differences in detection performance is the dispersal of ordnance in Phase III (no ordnance within 2 meters of other ordnance) relative to Phase II (37 percent of the ordnance to within 2 meters of other ordnance). Demonstrators could take advantage of the target strength of "grouped" ordnance in Phase II, while Phase III demonstrators could not.

The general improvement in demonstrator detection performance may be due to the scenario aspect of the ATD. Demonstrators could apply their technology to scenarios that were within their capabilities. Detection of ordnance under the conditions of the scenarios was adequately demonstrated.

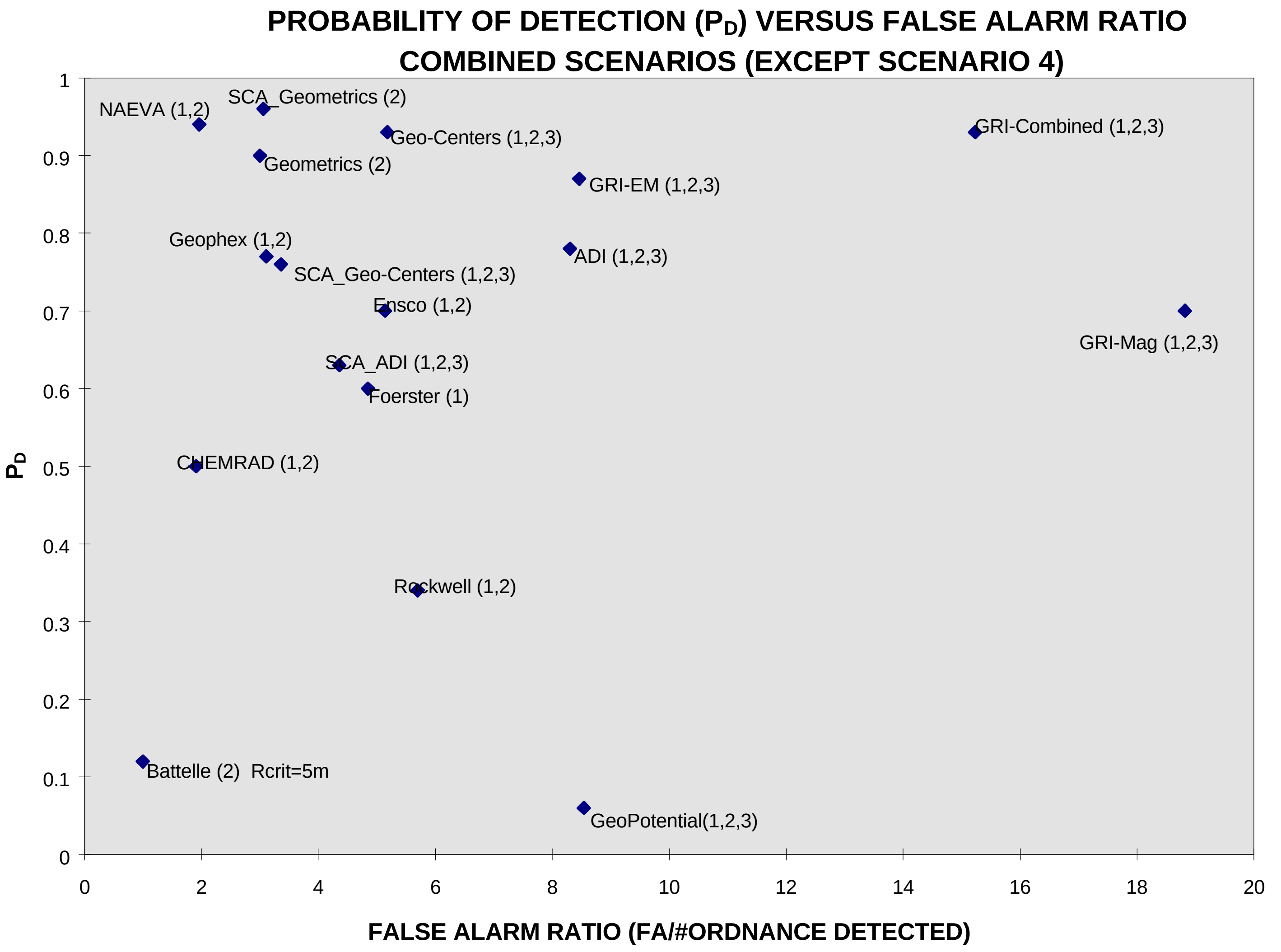

PROBABILITY OF DETECTION (P_D) VERSUS FALSE ALARM RATIO
COMBINED SCENARIOS (EXCEPT SCENARIO 4)
P_D
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
2
4
6
8
10
12
14
16
18
20
FALSE ALARM RATIO (FA/#ORDNANCE DETECTED)
NAEVA (1,2)
SCA_Geometrics (2)
Geo-Centers (1,2,3)
GRI-Combined (1,2,3)
Geometrics (2)
GRI-EM (1,2,3)
Geophex (1,2)
ADI (1,2,3)
SCA_Geo-Centers (1,2,3)
Ensco (1,2)
GRI-Mag (1,2,3)
SCA_ADI (1,2,3)
Foerster (1)
CHEMRAD (1,2)
Rockwell (1,2)
Battelle (2) Rcrit=5m
GeoPotential(1,2,3)

Figure 6.2.1-2

P_D VERSUS FALSE ALARM RATE COMPARISON
(Phase I, Phase II, Phase III)

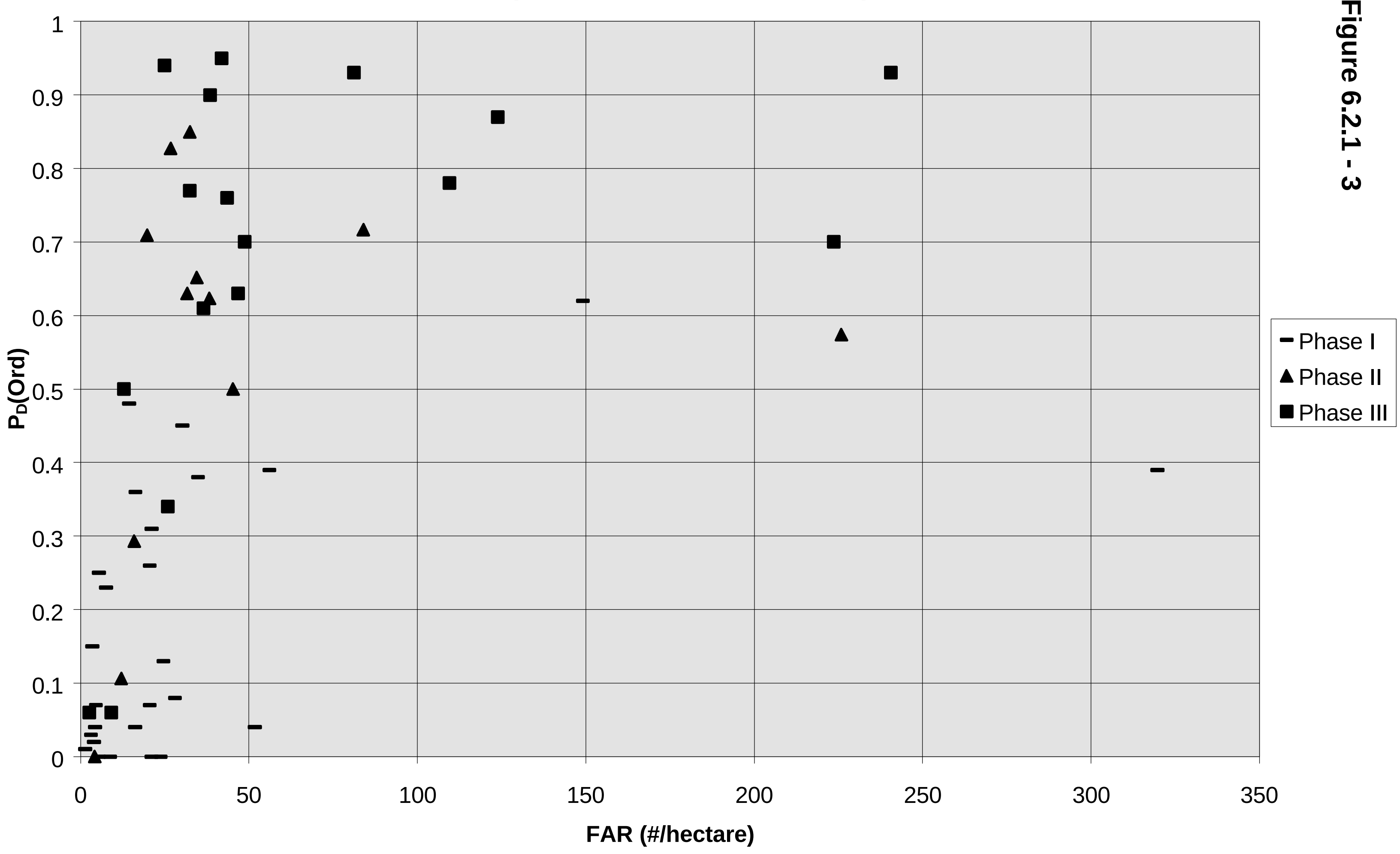


Figure 6.2.1 - 3

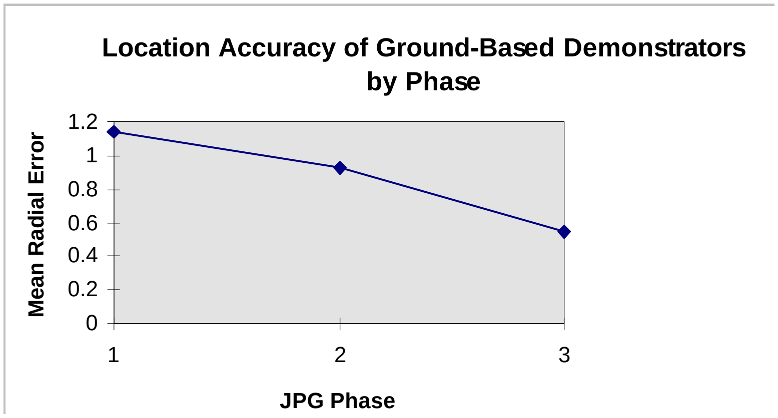
6.2.2 Localization Performance

The performance of all demonstrators is summarized in **figure 6.2.2-1**. GRI (EM and Combined) was one of the better overall performers in locating ordnance in two or more survey scenarios, as they had a mean radial error of 39 centimeters. The choice of navigation technology will determine how well a demonstrator can precisely locate ordnance in the horizontal plane.

Navigation technology was divided into two principal categories. Differential Global Positioning System (DGPS) technology is capable of providing decimeter geodetic positioning real time. NAVSTAR satellite visibility is essential; that is, the DGPS antenna needs line-of-sight to the horizon to take advantage of all satellites in view. Obstructions such as trees and tall buildings can cause problems. Local grid reference systems are relative navigation systems using chains, strings, or odometers. Local grid systems are relatively inexpensive, effective, and reliable, but they can be labor intensive. Demonstrators using local grid reference technology generally took advantage of the 30.5 meter grid already established at JPG.

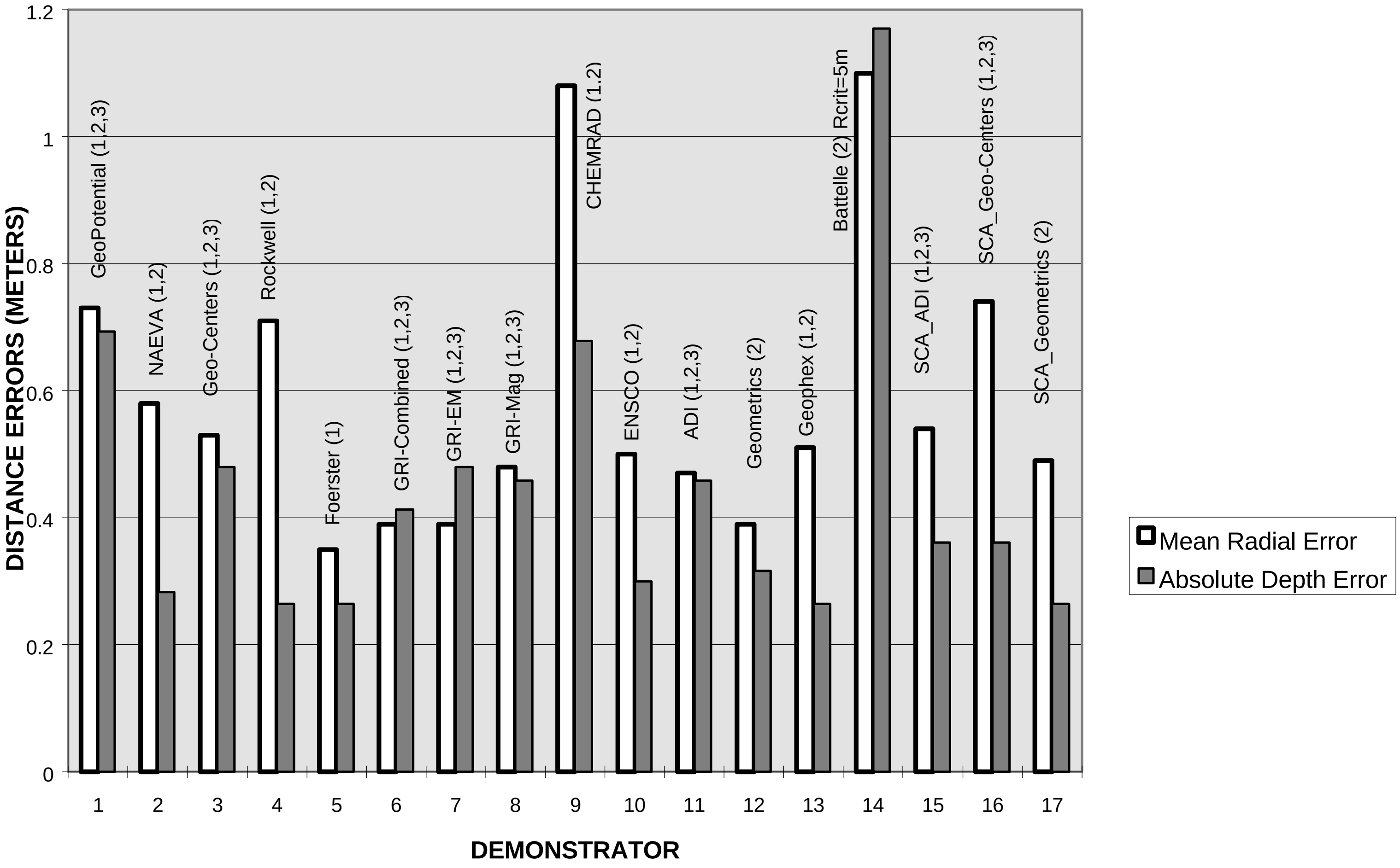
The performance data in **Table 6.2.2-1** was averaged for Phase III ground-based demonstrators (Battelle used an airborne platform) and shows that demonstrators who used a local grid reference outperformed DGPS users, 0.47 meters vice 0.69 meters radial error. The results for both groups appear to be satisfactory for the relocation of ordnance (average: 0.55 meters). The radial error performance of ground-based demonstrators has improved since Phase I, as shown in **figure 6.2.2-2.**

Figure 6.2.2-2 Radial Error by JPG Phase



The mean radial error has decreased on average by more than 50 percent since the initial Phase I, reducing the uncertainty in target location. However, the improvement in location in Phase III may also be due to the shallower and dispersed baseline ordnance, as these targets may be easier to fix in horizontal space than the deeper and grouped Phase I and II targets.

The depth positioning of targets is dependent on sensor technology. The three ground-based demonstrators who used only electromagnetic induction sensors [CHEMRAD, GeoPotential, and GRI (EM)], had the poorest depth performance. The average depth performance of all ground based Phase III demonstrators (0.40 meters) improved significantly upon the depth performance of the Phase II ground-based demonstrators (0.82 meters). Again, the shallower and more dispersed baseline ordnance of Phase III may account for the improvement seen.



DEMONSTRATOR LOCALIZATION PERFORMANCE, COMBINED SCENARIOS (EXCEPT SCENARIO 4)

Figure 6.2.2-1

TABLE 6.2.2-1

DEMONSTRATOR POSITIONING PERFORMANCE BY NAVIGATION TECHNOLOGY, COMBINED SCENARIOS (1, 2, AND/OR 3)

Navigation System	Demonstrator (Scenario #)	Mean Radial Error	Absolute Depth Error
Differential GPS	Battelle (2)	3.37	1.06
	CHEMRAD (1,2)	1.08	0.68
	Foerster (1)	0.35	0.26
	Geo-Centers (1,2,3)	0.53	0.48
	GeoPotential (1,2,3)	0.73	0.69
	Rockwell (1,2)	0.71	0.26
	SCA_Geo-Centers (1,2,3)	0.74	0.36
	Average w/o Battelle	0.69	0.46
Local Grid Reference	ADI (1,2,3)	0.47	0.46
	ENSCO (1,2)	0.50	0.30
	Geometrics (2)	0.39	0.32
	Geophex (1,2)	0.51	0.26
	GRI (1,2,3)	0.39	0.41
	GRI (EM) (1,2,3)	0.39	0.48
	GRI (Mag) (1,2,3)	0.48	0.46
	NAEVA (1,2)	0.58	0.28
	SCA_ADI (1,2,3)	0.54	0.36
	SCA_Geometrics (2)	0.41	0.26
	Average	0.47	0.36

6.2.3 Target Characterization Performance

Characterization performance is determined by a demonstrators ability to type, size and classify detected ordnance.

6.2.3.1 Typing Performance

The overall performance of demonstrators in Phase III in typing targets as ordnance and nonordnance is shown in **figure 6.2.3.1-1.** This figure shows the conditional probability of typing targets correctly. Data is not shown for Rockwell, Foerster, CHEMRAD, ENSCO, or Battelle because these demonstrators typed their ordnance targets as "unknown". In general, demonstrators lack a capability to distinguish ordnance and the emplanted nonordnance, as they did in Phase I and Phase II. While GRI (combined)was able to classify the highest percentage of emplanted nonordnance correctly at 11 percent, they mistyped a significant 6 percent of their ordnance detections as nonordnance. What is not apparent from **figure 6.2.3.1-1** is the typing performances of Geo-Centers, Geometrics and NAEVA, who reported few or no nonordnance targets. It is necessary to look at their baseline nonordnance detection performance to ascertain their capabilities.

Table 6.2.3.1-1 Combined Scenario Detection (TMA *Closest*)

	P_D, Ordnance	P_D, Nonordnance
Geo-Centers	0.93	0.80
Geometrics	0.90	0.84
NAEVA	0.94	0.85

It is apparent in the table that all three demonstrators reported an appreciable percentage of the baseline nonordnance targets as evidenced by their high P_Ds for nonordnance. (Because the baseline nonordnance target set includes nonmetalic debris, nonordnance detection probabilities should be somewhat smaller that ordnance detection probabilities). If these companies had a discrimination capability and had chosen not to report nonordnance targets, their nonordnance detection probabilities should be significantly lower than their ordnance detection probabilities. Although there is some evidence of discrimination, they do not have a statistically significant capability to distinguish ordnance and nonordnance.

The data in **Figure 6.2.3.1-2** shows demonstrators ranked success in typing targets as ordnance for those demonstrators that attempted to do so. NAEVA performed best by being correct 37 percent of the time in declaring a target as ordnance. The value of SC&A's data processing is also evident in that they were able to improve on ADI's and GeoCenter's abilities in determining targets as ordnance.

Scenario 4, the Interrogation/Burial Area, was established to identify demonstrators with a discrimination capability. There has been an emphasis on trying to develop better technology or processing schemes that can recognize ordnance as such in situ. Such technology would be advantageous for land characterization studies, where the goal may be minimal statistical sampling to determine the extent of hazard.   A sampling plan can statistically account for a survey technology that has an adequate probability of detection and no target discrimination capability by "digging a few more holes". However, the impact of demonstrators' inability to distinguish ordnance and nonordnance targets is likely to be severe on remediation efforts. Excavators will have to commit significant resources that will be wasted on false alarms. Better ordnance recognition technology would not help if it does not also improve the rejection of false alarms. Given high false alarm rates, technology that can better recognize detected targets as nonordnance may be more economically useful. Even in a relatively benign environment like JPG (no shrapnel other than what was emplaced), there are typically 3 to 20 times more false alarms than ordnance.

An analysis of errors that are acceptable for ordnance and nonordnance decisions would require economic assumptions beyond the scope of this report. Such an analysis is needed to set realistic standards or guidelines for technology developers and users.

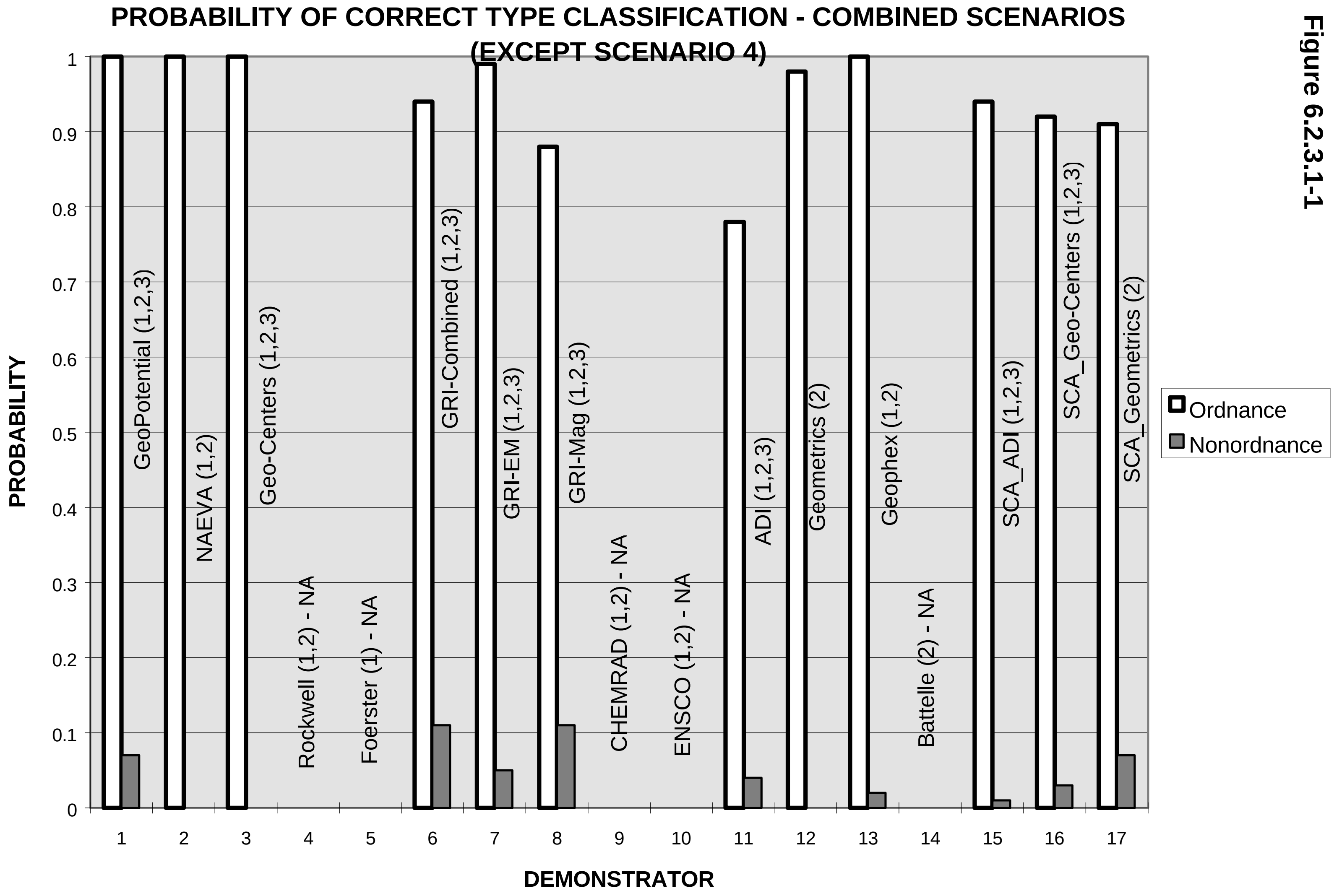
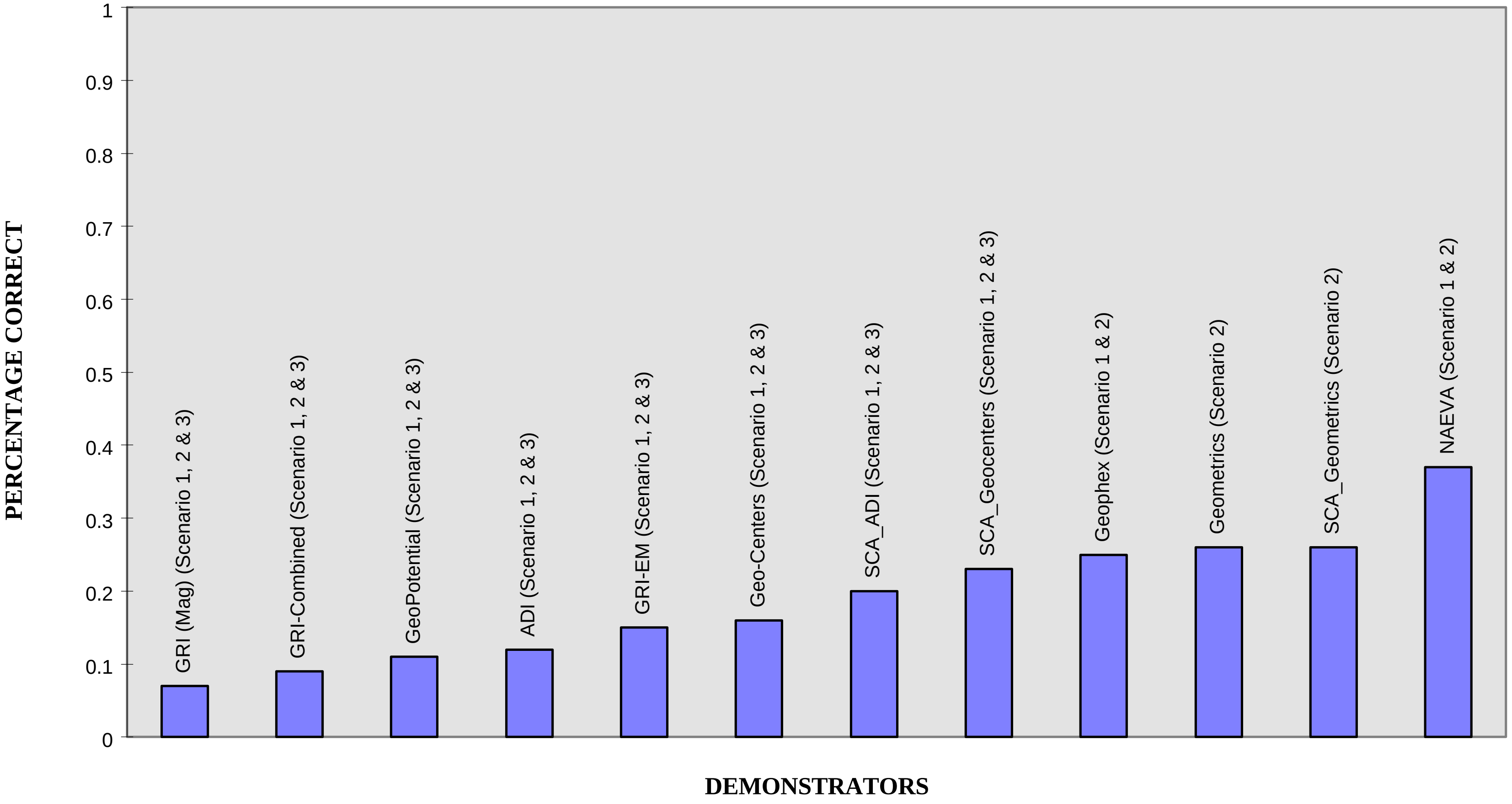

PROBABILITY OF CORRECT TYPE CLASSIFICATION - COMBINED SCENARIOS (EXCEPT SCENARIO 4)

Figure 6.2.3.1-1

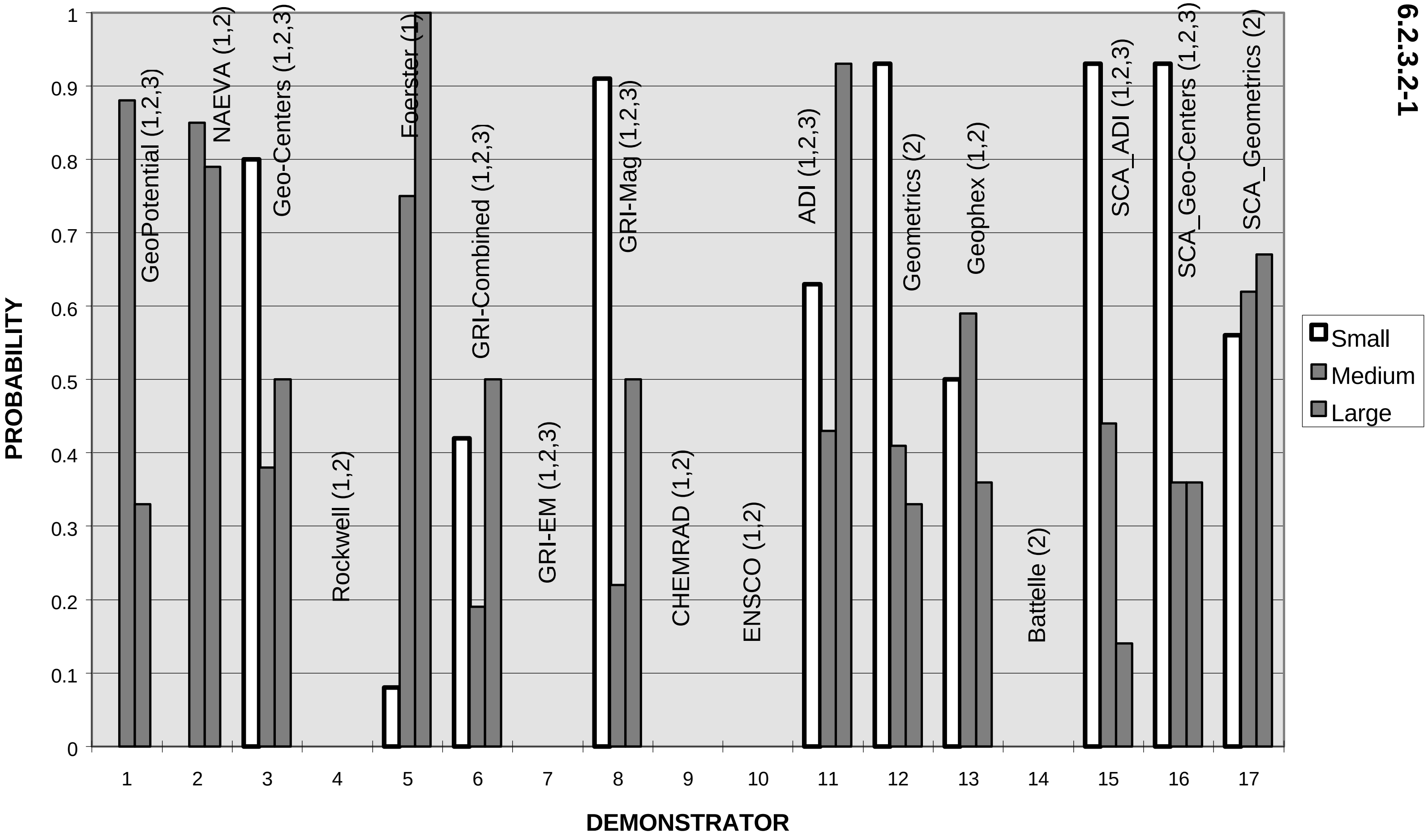
FIGURE 6.2.3.1-2

SUCCESS AT DECLARING TARGETS AS ORDNANCE
(Among Demonstrators Who Tried)



6.2.3.2 Sizing Performance

The overall performance of demonstrators in sizing the small, medium and large ordnance is shown in **figure 6.2.3.2-1**. Sizing ability may be useful in that it provides a alternative means to characterize ordnance and nonordnance targets. (For example, on some sites small targets could likely represent shrapnel and large targets ordnance. Therefore a premium would be placed on a demonstrator who could detect and recognize large targets as such). The combined statistics show that some demonstrators are better estimating certain classes of ordnance. However, these statistics are biased because of the scenario aspect of the demonstration. That is, a demonstrator on Scenario 3 may logically declare all targets small, regardless whether they have a true ability to distinguish this target size or not. The results of Phase III sizing performance are not significantly different from Phase II. In Phase III, demonstrators were correct estimating target size 54 percent of the time; in Phase II, demonstrators were correct 56 percent of the time.



PROBABILITY OF CORRECT SIZE CLASSIFICATION - COMBINED SCENARIOS
(EXCEPT SCENARIO 4)

Figure 6.2.3.2-1

6.2.3.3 Classification Performance

The analysis of overall classification performance, the capability to distinguish ordnance as mortar, bomb, etc. is not provided, as the merit of this statistic is questionable in light of the demonstrators inability to distinguish ordnance and nonordnance.

6.3 EXCAVATION RESULTS AND ANALYSIS

6.3.1 Two excavation systems were demonstrated at JPG for Phase III of the UXO ATD program. Lockheed Martin Advanced Environmental Systems demonstrated a Caterpillar 320L Low Ground Pressure (LGP) excavator with a single remote operator control station (OCS). OAO Corporation (OAO) demonstrated the Teleoperated Ordnance Disposal System (TODS).

6.3.2 LOCKHEED MARTIN ADVANCED ENVIRONMENTAL SYSTEMS (LMAES)

6.3.2.1 The Caterpillar 320L Low Ground Pressure excavator with remote operator control station was demonstrated at the JPG 16-hectare demonstration site from November 20 to 22, 1996. Lockheed Martin was a first time participant in the UXO ATD program.

6.3.2.2 Demonstrated Performance

LMAES excavated 11 targets in the 24 hours allotted for its demonstration. **Table 6.3.2.2** provides details of the demonstration results. Several parameters are of interest including average travel rate to the targets (1.17 kilometers per hour), average burial depth of targets (1.24 meters) and average excavation time (0.55 hours per hole). Note also that most of the targets were large objects.

It was observed by on-site EOD personnel that Lockheed should excavate targets larger than 152 millimeters in diameter. For the second day, EMI personnel made additional target selections and observed that Lockheed was more adept at excavating larger items. Results are comparable to Phase II demonstrators as shown in **Table 6.3.5**.

TABLE 6.3.2.2

Lockheed Excavation Data

Target	Type of Target	Date	Distance to Target (m)	# of min.	Travel Rate (km/hr)	Depth (meters)	Excavation Time (hr)	Comments
1253	152mm projectile	11/19/96	N/A	N/A	N/A	N/A	N/A	Not found(1)
1219	4.2" mortar	11/19/96	10	0.5	1.20	0.38	1.17	Recovered(2)
1258	8" projectile	11/20/96	97.5	4.0	1.46	1.37	0.67	Recovered(2)
1215	175mm projectile	11/20/96	56.7	5.0	0.68	1.31	0.35	Recovered
1253	152mm projectile	11/20/96	123.4	6.0	1.23	0.58	0.98	Recovered(1)(2)
1263	500-lb bomb	11/20/96	157.5	16.0	0.59	0.98	0.05	Recovered
1272	250-lb bomb	11/20/96	41.8	6.0	0.42	1.82	0.43	Recovered
1577	5" rocket	11/20/96	36.6	4.0	0.55	0.42	0.40	Recovered
1269	500-lb bomb	11/21/96	45.7	0.9	3.05	1.44	0.28	Recovered
1229	500-lb bomb	11/21/96	158.6	14.0	0.68	1.07	0.45	Recovered
231	500-lb MK-82	11/21/96	25	1.0	1.50	3.11	0.97	Recovered
1235	750-lb bomb	11/21/96	50	2.0	1.50	1.17	0.30	Recovered
1264	N/A	11/21/96	N/A	N/A	N/A	N/A	N/A	navigation(3)
1266	N/A	11/21/96	N/A	N/A	N/A	N/A	N/A	navigation(3)
AVERAGES			72.98	5.4	1.17	1.24	0.55	

(1) On November 19, 1996, Lockheed Martin Advanced Environmental Systems navigated to a position about 75 feet west of target #1253. Lockheed later reported incorrect coordinate input and was probably about 1 longitudinal degree in error the error was later found and corrected. Target #1253 was successfully excavated on November 20, 1996.

(2) Because Lockheed could not identify the ordnance item from the command vehicle, the target was visually located using a Schoenstadt metal detector.

(3)Lockheed's staked positions at locations 1264 and 1266 were within 30 and 2 centimeters of the actual position respectively.

6.3.3 OAO CORPORATION

6.3.3.1 OAO demonstrated TODS from November 13 through 17, 1996 at the 16-hectare area at JPG. OAO was a first time participant in the UXO ATD program.

6.3.3.2 Demonstrated Performance

TODS excavated 24 targets over the course of the 40 hour demonstration period. **Table 6.3.3.2** provides details of the demonstration results. Pertinent parameters include average travel rate to the targets (1.39 kilometers per hour), average burial depth of targets (0.31 meters) and average excavation time (0.38 hours per hole). Note that most targets are small.

TABLE 6.3.3.2

OAO Excavation Data							
Target	**Type of Target**	**Distance to Target (m)**	**# of min.**	**Travel Rate (km/hr)**	**Depth (meters)**	**Excavation Time (hr)**	**Comments**
1664	MK118 (Rockeye)	30	2	0.90	0.15	0.28	Recovered
1644	M42 Heat	62	2	1.86	0.12	0.22	Recovered
1600	M38 bomblet	83	7	0.71	0.13	0.17	Recovered
1754	M42 Heat	141	4	2.12	0.12	0.25	Recovered
238	90 mm projectile	99	2	2.97	1.27	N/A	Not found(1)
1768	M42 Heat	79	8	0.59	0.18	0.03	Recovered
1610	M38 bomblet	96	2	2.88	0.16	0.12	Recovered
1228	4.2" mortar	179	8	1.34	0.4	1.28	Recovered
1239	60mm mortar	25	1	1.50	0.28	0.32	Recovered
1217	105mm projectile	76	2	2.28	0.23	0.38	Recovered
1254	76mm projectile	60	3	1.20	0.53	0.17	Recovered
314	30mm projectile (4)	104	4	1.56	0.28	N/A	Not found(2)
1196	76mm projectile	243	4	3.65	0.4	N/A	Recovered(4)
272	60mm mortar	53	2	1.59	0.08	N/A	Not found(3)
1449	81mm Illumination	114	28	0.24	0.12	N/A	Recovered
1441	60mm fins	95	14	0.41	0.17	N/A	Recovered
1172	60mm mortar	135	8	1.01	0.24	0.90	Recovered(4)
1344	105 mm projectile (illumination candle)	103	12	0.52	0.23	0.30	Recovered(4)
1852	2.75" rocket	359	16	1.35	0.65	0.75	Recovered
1289	25lb practice bomb	75	4	1.13	0.41	0.87	Recovered
1282	25lb practice bomb	103	5	1.24	0.35	0.20	Recovered
1288	25lb practice bomb	103	5	1.24	0.27	0.23	Recovered
1284	25lb practice bomb	50	6	0.50	0.33	0.23	Recovered
1850	2.75" rocket	150	17	0.53	0.35	0.10	Recovered
	AVERAGES	109.04	6.92	1.39	0.31	0.38	

(1,2,3) Targets Nos. 238, 314, and 272 are designated as "anomalies" from Phase III emplacement. During emplacement, EMI was unable to locate these anomalies. OAO unsuccessfully attempted to locate these anomalies.

(4) As part of their original proposal, OAO performed remote navigation exercises. At these target locations, OAO was given only target coordinates for navigation purposes. In all three attempts, OAO was successful at navigating and excavating the correct targets.

N/A - not available

TODS performance in reducing excavation time is a function of its design. The system is most effective when excavation targets are (1) less than 100 kilograms, (2) less than 1.2 meters below the ground surface, and (3) less than 45 centimeters in length.

6.3.4 Discussion

Travel rate, target depth, excavation time and removal time all factor into total excavation time. Travel rate depends upon terrain, foliage, weather conditions, and obstacles. Target size and depth will dictate the type of equipment used, in turn, affecting excavation time and travel rate because excavation options are reduced. A large, deep target can limit the excavation options to a single piece of equipment.

Small shallow targets are sometimes harder to excavate than deep, larger targets. For example, the small target gets lost in the bucket and ends up in the overburden pile because the operator couldn't "see" it or "feel" it with his equipment. In turn, safety of personnel is compromised because the overburden pile must be swept for targets. For remote operated systems this is especially true.

Ultimately, the excavation rate or "cleanup rate" is linked to accurate information about the target. Is it ordnance? Is it 2.3 meters deep at this location? What kind of ordnance item is it? What is the orientation of the ordnance item in the ground so that excavation is performed safely. JPG provides a data point to help quantify these questions.

6.3.5 Excavation Demonstration Conclusions

Table 6.3.5 shows comparisons of performance between Phase II and Phase III. An attempt has been made to compare excavation demonstrators to each other in a quantifiable way, however, the choice of an excavation system depends upon size and depth of buried UXO as well as environmental conditions. Realizing that there is a "scenario" dependency, there are no significant changes in performance between Phases II and III. Excavation tools that can substantially reduce time and cost of remediation have not appeared.

TABLE 6.3.5

Comparison of Phase II and Phase III Excavation Performance Averages

	Demonstrator:	**Concept Engineering**	**Wright Labs**	**Lockheed**	**OAO**
	Phase:	**II**	**II**	**III**	**III**
Travel Rate (km/hr)		1.24	2.83	1.17	1.39
Target Depth (m)		1.00	1.53	1.24	0.31
Excavation Time (hr)		0.75	0.57	0.55	0.38

6.4 CONCLUSIONS AND RECOMMENDATIONS

JPG Phase III focused on developing relevant performance data of technologies used to search, detect, and characterize or excavate UXO. Search and target recognition has never been a trivial task, whether one is seeking Spanish galleons, Scud missiles, or anti-personnel land mines. The JPG Phase III results showed that state of the art technology exists that is capable of detecting a substantial portion of the ordnance emplaced for the ATD scenarios. In particular, the combination of electromagnetic induction and magnetometer/gradiometer sensors proved to be an effective combination in all three survey scenarios. The top demonstrators used this sensor technology with different platforms and different navigation systems to detect over 90 percent of the emplaced ordnance. The ability ground-based demonstrators to precisely locate the ordnance was also established with an overall mean radial error of 0.55 meters. Demonstrators' abilities to size targets need improvement as their size estimates were correct only a little more than half the time. The definitions or criteria for target size may need to be reconsidered so that the capabilities of demonstrators are better determined.

No demonstrator proved even a modest capability to discriminate ordnance and nonordnance, where one could believe that their declarations were correct. The problem with discrimination of ordnance and nonordnance targets continues as it has since Phase I. This deficiency in technology may not affect UXO site characterization efforts, but it should be a major cost driver in any UXO remediation efforts, since excavations will be slow and likely be unproductive. The demand for remediation of closed Department of Defense properties and formerly used defense sites is high, but the resources available to meet the demand are limited. Resources wasted on unproductive excavations will limit the amount of land that gets remediated to the highest priority properties and UXO situations (such as Spring Valley in Washington DC).

The solution to target discrimination may not be simple. There may be no magnetometer technology that can determine if a piece of steel has explosives attached to it. However, existing technologies, including advanced data processing such as SC&A's efforts, need to be further developed so false alarms can be reduced, without adversely affecting ordnance detection performance. SC&A's efforts are applauded, and their recommendation for the establishment of standards for raw sensor data is endorsed. Furthermore, standard sensor data sets need to be publicly available to encourage the development of advanced processing algorithms without the expense and burden of data gathering. Target discrimination standards or guidance should also be provided to developers. How many false alarms, not excavated, are worth a missed ordnance excavation? Are any missed ordnance detections ever acceptable? These are fair but unanswered questions that discrimination technology developers need to consider.

The performance of two demonstrators showed that remote excavation is feasible, but their results indicate that demonstrators can find targets much faster than they can be excavated using remote technology. The performance of excavators has not substantially changed from Phase I. Each survey demonstrator reported hundreds of targets in their demonstration periods, while the excavators only unearthed a few dozen targets. No cost comparison is offered on the cost to detect an UXO item vice the cost to excavate it, but it is apparent that the two functions are being optimized in isolation from the each other. Disregarding the false alarm issues, it may be necessary for surveyors to consider efforts that would improve excavation productivity, such as centimeter accuracy in target depth positioning.

JPG Phase III allowed technologies to be defined on the basis of their strengths. However, current UXO technologies may be adequate to do little more than be able to characterize the extent of UXO on properties . The cost per hectare surveyed and the cost per UXO remediated are figures of merit that could be used to define better the technology gaps that remain. There is a need to continue the ATD efforts as it provides a means to separate the hyperbole and the performance as new ideas and capabilities are developed. The JPG controlled test site is a unique national resource for assessing UXO technologies. Consideration should be given to setting aside an area for technology developers to use as they wish. Should additional demonstrations be planned at JPG, the following recommendations are offered:

- Incorporate other UXO scenarios as advisable.
- Encourage system approaches to UXO detection and excavation.
- Set a consistent standard for reporting nonordnance so that demonstrators’ false alarm metrics and discrimination (typing) capabilities are better determined.
- Re-examine the ordnance size standards to determine if they should changed, or if another measure, such as target volume, might be more useful.
- Eliminate the need for demonstrators to classify ordnance as mortar, bomb, etc., until such time as their ordnance typing capabilities have developed.

- Characterize “noise sources” (e.g. shrapnel) on live ranges so that debris conditions are more realistic.

APPENDIX A

GEOTECHNICAL AND HISTORICAL DESCRIPTION OF JEFFERSON PROVING GROUND

(Excerted from the JPG Phase II Report)

1.0 TOPOGRAPHIC, PHYSIOGRAPHIC, AND GEOLOGIC PROPERTIES

Topographic relief in Jefferson County is influenced by the Ohio and Muscatatuck River watersheds. The Ohio River watershed, located in the eastern third of Jefferson County, is very dissected and is characterized by narrow, sloping ridges and steep hillsides with terraces. The Muscatatuck River watershed, located in the western two-thirds of Jefferson County, in characterized by broad, nearly level ridges and moderately sloping hillsides. The major tributary of the Ohio River in Jefferson County is Indian-Kentuck Creek, which drains the eastern third of the county (USDA 1985b).

Physiographically, the demonstration areas are nearly level with a slightly undulating surface, marked by minor erosional features from surface water runoff. Both areas are well-vegetated with grasses, shrubs, and trees. No tributaries to the Ohio or Muscatatuck Rivers dissect the demonstration areas.

The demonstration areas are located on the uplands, in areas of sparse forestation. Both areas are located adjacent to access roads along the east side of the facility. Drainage at the 16A-hectare area is to the west into Big Creek. Drainage at the 32-hectare area is to the east into West Fork Creek.

Surficial soils are situated on a flat plain known as the Illinoisan till plain (Indiana Department of Natural Resources [IDNR] no date). The plain consists of glacial till deposited during Illinoisan glaciation. The glacial deposits are underlain by Silurian-aged Laurel Dolomite bedrock. The Laurel Dolomite is about 14 meters (45 feet) thick, gray, and cherty. Below the bedrock, Silurian- and Ordovician-aged interbedded limestone and shale extends from 91 to 121 meters (300 to 400 feet). Depth to bedrock at the demonstration areas ranges from 1.5 to 9 meters (5 to 30 feet) below ground surface (PRC 1994).

Native soils at the 16-hectare and the 32-hectare areas consist mainly of Avonburg and Cobbsfork silt loams. Avonburg soils are nearly level, deep, and somewhat poorly drained soils situated on smooth uplands. Areas of this soil type are broad and irregular in shape and cover 8 to 80 hectares (20 to 200 acres) (USDA 1985b). Cobbsfork soils are nearly level, deep, and poorly-drained soils situated on tabular divides in uplands; Cobbsfork soils are prone to ponding. Areas of this soil type are broad and irregularly shaped, ranging from 16 to 810 hectares (40 to 2,000 acres) in size (USDA 1985a).

Cobbsfork soils have a very high available water capacity and very slow permeability. Avonburg soils have a moderate available water capacity and very slow permeability. In both soil types, the water table is typically perched at or near the surface during most of the year. Both the Avonburg and Cobbsfork soils are low in organic matter, and they are acidic, friable, and best suited for grass and tree development (USDA 1985a and 1985b).

2.0 ECOLOGIC CHARACTERISTICS

JPG consists primarily of poorly drained flats in various stages of succession from open fields to regrowth forested flatwoods. Flatwoods are forested areas that occur on level or nearly level soils that are poorly drained and have a shallow perched water table. Some wooded stream valleys with better drainage are also present at JPG. Vegetative community types that have been inventoried by the IDNR Division of Nature Preserves include bottomland forests, upland forests, and cliffs along these major drainages (IDNR no date).

JPG lies within the Bluegrass Natural Region, as identified by IDNR. This natural region is identified and named for its similarities in physiography and natural communities to the Bluegrass Region of Kentucky. Most of the natural region was originally forested, although a few glade, cliff, and barren remnants are known, as well as nonforested aquatic communities. The areas used for the UXO demonstrations can be classified as Bluegrass Till Plain Flatwoods. These natural communities are forested areas on level or nearly level soils that are poorly drained and acidic, with a shallow perched water table (IDNR no date).

3.0 CLIMATIC PATTERNS

Climate in Jefferson, Ripley, and Jennings Counties is cold in winter and hot in summer. Winter precipitation consists mainly of snow, which aids in soil moisture accumulation and minimizes drought conditions in summer months. In winter, the average temperature is about 2 C (35 F); the average daily minimum temperature is about -4 C (25 F). In summer, the average temperature is about 24 C (75 F); the average daily maximum temperature is about 30 C (85 F).

The total annual precipitation is about 107 centimeters (42 inches), with about 55 centimeters (22 inches) falling from April through September. Thunderstorms occur about 50 days per year; tornados and severe weather also occur occasionally. These types of storms are usually local and short in duration and can cause severe damage locally (USDA 1985a, 1985b).

The average seasonal snowfall is about 33 centimeters (13 inches). The average relative humidity in midafternoon is about 60 percent. Humidity is higher at night, and the average at dawn is about 80 percent. The sun shines 70 percent of the time in summer and 40 percent in winter. Prevailing winds are from the south. Average wind speed is highest in spring at 16 kilometers (10 miles) per hour (USDA 1985a, 1985b).

4.0 HISTORIC SITE USE

An extensive survey of historical data related to the site indicates that farming was the predominant land use. The land was typified by relatively small, dispersed farmsteads and communities. Both woodland and agricultural tracts occurred in the two controlled site areas. In 1940, the federal government acquired the land; the first round of ammunition was tested at JPG on May 10, 1941 (USAEC 1995).

As part of the background investigation for the Phase I UXO ATD program, an archaeological investigation was performed in November 1993. This study revealed that both areas were used for agricultural purposes before the federal government acquired the land. One site identified at the 32-hectare area was believed to be a historic farmstead that was abandoned in 1941. The farmhouse was moved from the JPG property to the east, along Highway 421. Two other sites identified in the study were of indeterminate historic affiliation. None of the sites identified were eligible for listing on the National Register of Historic Places (Anslinger 1993).

Geophysical and geotechnical surveys were conducted in 1994 to establish area conditions and identify hazardous conditions. These surveys were conducted as part of the preparation for Phase I of the UXO ATD program. The survey results identified no hazardous conditions to preclude the use of these areas as controlled demonstration areas. However, given the nature and mission of JPG, a considerable amount of the total base area has undoubtably been affected by munition testing and related activities.

Until September 1995, JPG served as a munitions testing facility of the Test and Evaluation Command, U.S. Army Material Development and Readiness Command. During the period of operation, JPG’s mission was to check, investigate, and evaluate various test items to determine whether they conformed to specifications (JPG 1980). Between 1942 and 1995, JPG conducted a variety of munitions tests throughout the base. Although neither of the areas used for the controlled site are specifically located where these tests took place, they may be within the “fan” area of several of the impact fields.

The controlled site areas are believed to have been only minimally affected by historical activities conducted at JPG.

1.0 ADI[13]

ADI demonstrated from October 15 through 17, 1996 at the 16-hectare area at JPG. ADI also participated in Phases I and II of the UXO ATD program.

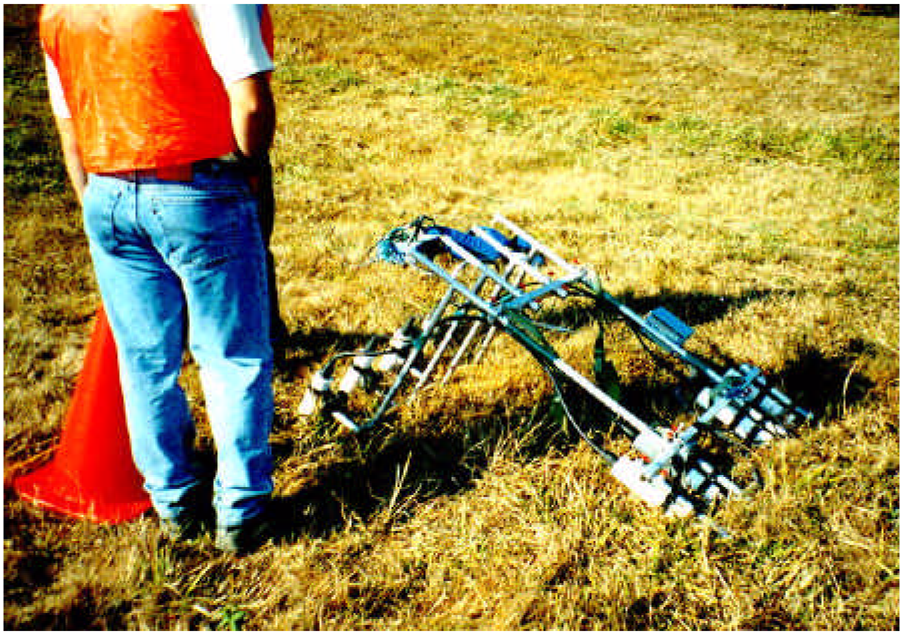
1.1 TECHNOLOGY DESCRIPTION

1.1.1 Sensor System and Transport Mode

1.1.1.1 Magnetometer System

The TM-4 is a complete data acquisition, processing, interpretation and documentation system designed to detect and position ferrous contamination sources. The operating software not only controls and monitors the data acquisition but also generates an audio tone at selected frequency ranges and filters interference from mains' electricity. Field notes can also be recorded within the data. Magnetic field profiles can be viewed on the console during the survey.

The magnetometer is capable of reading the total magnetic field from up to four sensors to a sensitivity of 0.01 nT. at a rate of 100 times per second. Data is collected along the line at predetermined intervals and stored in solid state memory for later transfer to the processing computer.



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[13] ADI, JPG Phase III Technology Demonstration Jefferson Proving Ground, Indiana, Final Report - 1996

A proton precession type magnetometer was used as a magnetic base-station. Data were recorded at 5 second intervals (synchronised with the TM-4) to a resolution of 0.1 nT.

1.1.1.2 EM-61 Time Domain EM System

The EM-61 is a high powered, extremely sensitive Time-Domain Electromagnetic System manufactured by Geonics Limited of Mississauga, Ontario, Canada.

The EM-61 can collect data at one time window after the transmission coil is turned off. The ADI EM-61 was modified to provide an earlier time window than the standard system

The two receiver coil configuration of the EM-61 enables the suppression of near surface metallic targets that can mask or complicate the detection of deeper targets. This suppression is accomplished by taking the difference between the responses of the two receiver coils.

1.1.2 Recommended Applications and Technology Limitations

1.1.2.1 Recommended Applications

Magnetometer

The TM-4 is ideally suited for the detection of ferrous items in all terrains that are accessible on foot. Multiple sensor configurations are available for areas in which the vegetation density does not restrict sensor frame access. Large open areas can be surveyed by a vehicle and trailer mounted system with position recorded by GPS.

Electro-magnetic

The EM-61 is suited for the detection of both ferrous and non ferrous items in fairly open areas. It can be operated in close proximity to electrical power lines, electrified train tracks and metallic structures.

1.1.2.2 Technology Limitations

Magnetometer

The TM-4's main limitations are that it should not be operated in areas close to large metallic structures (buildings, fences, etc.) or in proximity to electrified train tracks.

Magnetic soils can also be a problem in that they create noise that limits the minimum size of detectable items.

Electro-magnetic

The EM-61 has several shortcomings. The size and weight of the coils restrict its operation to a towed or two person carried system that is suited to open flat terrain. Horizontal operation of the towed instrument cannot be achieved in hummocky terrain. The EM-61 has only one time window for data collection. This window is optimum for items of a specific depth/size. Certain items are therefore not adequately sampled.

1.1.3 Logistic Requirements

1.1.3.1 Magnetometer

The portable TM-4 magnetometer comes in two carrying cases, one weighing 43 kilograms and the other weighing 20 kilograms. These cases are transportable as personal baggage on airlines and are easily carried to the site in a sedan.

At JPG, the survey was conducted by two, two person teams. Within each team, one person carries a frame on which were attached the sensors (weighing 2 kilograms each) and the positioning odometer, while second operator carried~~s~~ the data acquisition equipment and battery pack (totalling 10 kilograms in weight) the two sets of components being connected via a 5 meter long cable.

Ideally, the site should be surveyed and marked with non metallic grid pegs positioned every 100 metres or less. Control lines should be positioned perpendicular to the survey direction. Bright orange traffic cones used for heading positioning should be visible from the previous control line.

Data downloading can easily be conducted to a laptop PC in the field. Data processing and interpretation are also carried out on the same PC.

1.1.3.2 Electro-magnetic

The EM-61 is shipped in two aluminium carrying cases. One ~~cubic~~ case weighing 55 kilograms, the second, 45 kilograms. These cases are usually shipped via a commercial carrier. The equipment can be transported on site in a van or small pickup truck.

Grid surveying, power and processing requirements are the same as for the TM-4 magnetometer. The ground surface, however, should be relatively smooth, with grasses and small bushes mowed to a height of 30 cm or less. At JPG, the EM-61 coils were mounted on wheels and towed by one operator.

1.1.4 Data Acquisition

1.1.4.1 Grid Co-ordinates

In each of the two areas surveyed, data were acquired in local grid co-ordinates. Positions were measured along survey traverses using an integrated odometer system for the TM-4 and wheel odometer for the EM-61. Survey pegs provided~~,~~ were used to define control points from which continuous odometer calibrations were performed.

1.1.4.2 Equipment Configuration and Survey Specification

Both the TM-4 and EM-61 were used over all or part of JPG Phase III. Table 1 describes the equipment configurations and survey specifications for each Scenario.

1.1.5 Data Processing and Interpretation

1.1.5.1 Magnetic Data Processing

The position of the TM-4 data were corrected using the control line information. The temporal magnetic disturbances recorded on the base station magnetometer were reviewed to confirm that there have been no large variations in the field that would have an impact on the data collection. These data were then stored as a raw positioned data file in an XYZ format.

The data were then heading corrected for sensor orientation and high pass filtered to remove interference from geological sources below 10 meters.

The raw, positioned data collected in a local co-ordinate system was converted to the UTM Zone 16 co-ordinate system as required by the client. This data is supplied to the client in digital format on CD-ROM as requested.

The data was then post processed using commercially available and proprietary software in order to determine item location, depth and mass. Further processing using a proprietary ordnance library enabled these items to be classified according to type, class, size and azimuth and declination of the item roll axis.

1.1.5.2 Electromagnetic Data Processing

The position of the EM-61 data was corrected by using the control line information. These data were then stored as a raw positioned data file. The raw, positioned data collected in a local co-ordinate system were converted to the UTM Zone 16 co-ordinate system as required by the client and supplied in the digital format requested on CD-ROM.

The top and bottom coil data were then leveled in order to minimise instrument and temporal variations. Both data sets were post processed using both proprietary and commercial software in order to determine the location and depth of the items detected.

1.1.6 Data Interpretation

Data interpretation consisted of integrating both the EM and magnetic outputs. For each target identified, position, depth, weight, size, type class, confidence, azimuth, and declination was interpreted and provided in the Target Database along with comments relevent to the targets.

1.1.7 Quality Assurance

The measures taken to ensure the credibility and quality of –both magnetic and EM data include the following:

Field acquisition and data processing procedures were undertaken under ADI’s accredited ISO 9001 (License No: 5696) work practices.

These work practices include:

- Monitoring of the data during collection;
- Keeping non-target metallic objects far from the sensors;
- Viewing raw data during the survey and prior to processing.

1.2 DEMONSTRATION RESULTS

1.2.1 Assumptions

It has been assumed in the results that all dipoles recorded, above a 2 nT. threshold, on the magnetics dataset, are caused by ordnance or non-ordnance items.

1.2.2 Problems Encountered

1.2.2.1 Grid Surveying

ADI encountered discrepancies with the surveyed grid, in particular the south and west of the grid where there were errors of up to 2 meters in the positions of the pegs. A local grid had been made using line “O” as the base line for Scenario 3. This line was out by approximately 1.5 meters at the point ’O8’ and 0.5 meters out at ’O15’.

Sites set up for demonstrations in which results are judged for positional accuracy should have properly surveyed grids. Errors in grid peg positions are not acceptable. These grid errors should be taken into account during the determination of the results.

1.2.3 Description of Configuration, Survey Specifications and Results

TABLE 1 - Description of Configuration, Survey Specifications and Results

Description		**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**
Magnetics					
Total Area Surveyed		3.46 hectares	4.68 hectares	4.15 hectares	0.31 hectares
Sensor	Top	0.8 metres	N/A	N/A	0.8 metres
Elevation	Bottom	0.2 metres	0.2 metres	0.2 metres	0.2 metres
Line Spacing		0.5 metres	0.25 metres	0.25 metres	0.5 metres
Total Data Points		0.794 million	1.85 million	1.85 million	0.12 million
Measurement Resolution		0.01 nT.	0.01 nT.	0.01 nT.	0.01 nT.
System Noise		0.2 nT.	0.2 nT.	0.2 nT.	0.2 nT.
Electro-magnetics					
Total Area Surveyed		Not Undertaken	Not Undertaken	4.35 hectares	0.31 hectares
Sensor	Top Coil			0.45 metres	0.45 metres
Elevation	Bottom Coil	N/A	N/A	0.25 metres	0.25 metres
Line Spacing		N/A	N/A	0.5 metres	1.0 metres
Total Data Points		N/A	N/A	0.415 million	3,000
Measurement Resolution		N/A	N/A	0.1 mV.	0.1 mV.
System Noise		N/A	N/A	2.0 mV.	2.0 mV.
Total Ferrous Interpretations		**395**	**420**	**395**	**20**
Number Exceeding 75 kg		22	11	2	2
Number between 10 & 75 kg		42	52	14	6
Number below 10 kg		331	357	379	12
Total non-ferrous items interpreted		**N/A**	**N/A**	**308**	**N/A**

1.2.4 DIGITAL DATA

ADI has provided the following digital data to PRC Environmental Management, Inc., as set out in the Request for Quotation:

Raw Data

ADI have provided the raw data in an XYZ format with line numbers included. Each line is broken at the control lines used in the survey and a new line number is used for the next portion of the line. This data is located with the origin of the block being the south western corner of the block.

1.2.4.1 Processed Data

ADI has provided a copy of the processed gridded data for each of the four scenarios in a TIFF Image format.

1.2.5 Conclusions

- A total number of 1,230 ferrous targets were detected and interpreted by interactive computer-aided modelling. This analysis provided a measure of position, depth, mass, size and orientation for each target. A database in the client’s required format was provided containing this information.
- The raw magnetic data (approximately 4.61 million positioned measurements) were provided to the client in digital format.
- A total of approx. 13 hectares was mapped with the two TM-4 crews at 0.25 and 0.5 metres line spacing and a total of approx. 4.5 hectares was mapped at 0.5 meter line spacing using two EM-61 detectors, all within the permitted 40 hour period.
- A total of 308 targets interpreted as having a non-ferrous metal source were detected and interpreted into the combined TM-4 / EM-61 target database.

1.2.6. REFERENCES

The references cited below were used in the undertaking of the survey.

ADI Limited, 1994, **Work Instructions for TM-4 Imaging magnetometer Data Acquisition**.

ADI Limited, 1994, **Work Instruction for Data Processing and Interpretation of Imaging Magnetometer Data**.

ADI Limited, 1995, **Work Instructions for EM-61 Deep Metal Detector Data Acquis**

ADI Limited, 1995, **Work Instruction for Data Processing and Interpretation of EM-61 Deep Metal Detector Data.**

ADI - Combined Statistics: Scenarios 1,2,3

Detection Statistics (TMA[a] *Group*)

	# Baseline	# Detected	Pd[b]	P_{random}
Ordnance	208	162	0.78	0.143
Nonordnance	166	133	0.80	
Total	374	295		
Number False Alarms	1345			
False Alarm Rate (#/Hectare)	109.48			
False Alarm Ratio (#/Ord.)	8.30			
Probability False Alarms	0.138			

Localization Statistics (TMA *Closest*) (in meters)

	Mean	Std Deviation
Position (x,y)		
dx - easting error	-0.01	0.36
dy - northing error	0.16	0.44
Radial error	0.47	0.37
Depth (z)		
dz - averaged depth error	0.26	0.38
|dz|[c] - absolute depth error	0.46	

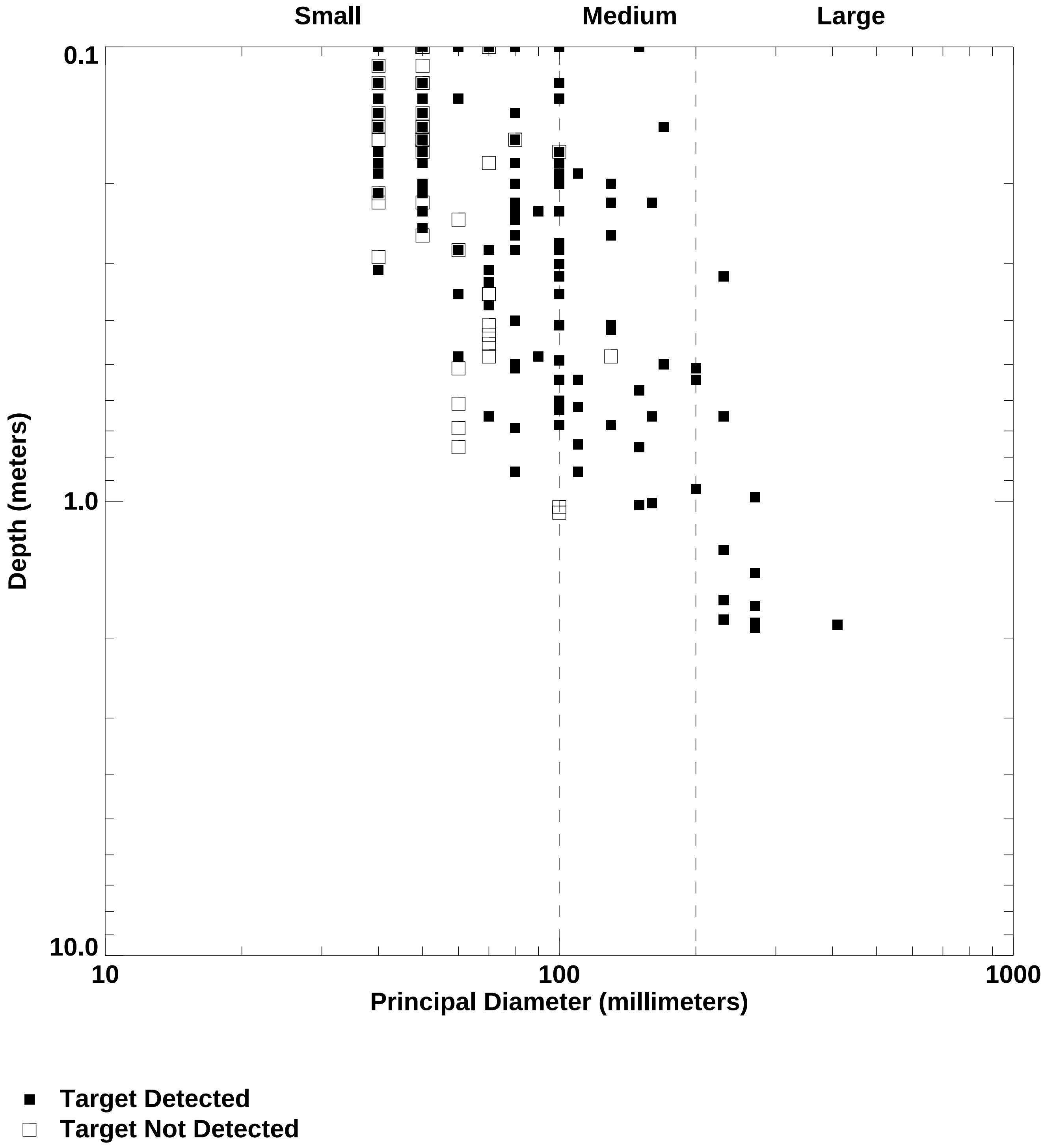
Characterization Statistics (TMA *Closest*)

	# Baseline	# Detected	P_D[b]	# Correct	P_C[d]
Ability to Type					
Ordnance	208	162	0.78	127	0.78
Nonordnance[e]	167	133	0.80	5	0.04
Ability to Size					
Large	14	14	1.00	13	0.93
Medium	39	35	0.90	15	0.43
Small	155	113	0.73	71	0.63
Ability to Classify					
Bomb	21	21	1.00	13	0.62
Projectile	42	39	0.93	0	0.00
Mortar	26	19	0.73	7	0.37
Submunition	97	70	0.72	64	0.91
Rocket	22	13	0.59	2	0.15

Notes:

[a] Target Matching Algorithm
[b] Probability of detection
[c] Square root of the mean square depth error
[d] Probability of correct characterization
[e] TMA affects how nonordnance baseline targets are counted
NA - not applicable

JPG Controlled Site: Phase III
Combined Statistics: All Surveyed Area (Excluding Scen. 4)
Critical Radius: 2 meters
Demonstrator: ADI



2.0 BATTELLE, PACIFIC NORTHWEST LABORATORIES[12]

The Sikorsky Cypher Unmanned Aerial Vehicle (UAV) was demonstrated as a platform for UXO detection at the JPG 16-hectare demonstration site from October 29 through November 4, 1996. Battelle PNL was a first time participant in the UXO ATD program.

2.1 TECHNOLOGY DESCRIPTION

The system that was demonstrated consisted of the Cypher UAV with three total-field magnetometers mounted on it, a GPS-based navigation system, a telemetry subsystem for aircraft control and data transmission, and a control vehicle (base station).

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[12] Battelle, Pacific Northwest Laboratories, UXO Detection at the Jefferson Proving Ground Using the Sikorsky Cypher UAV, January 1997

2.1.1 Aircraft

The Cypher is a unique, doughnut-shaped, rotary-wing, unmanned aircraft (Figure 1- not shown). It is approximately 6.5 ft in diameter and weighs approximately 235 lb. The sensors and associated components that were installed on the aircraft for this survey weighed 22.6 lbs. The current aircraft is a technology demonstrator which does not yet exhibit the performance characteristics that will be provided by later operational versions of the aircraft. Nevertheless, the performance features and mechanical characteristics that have been built into the current aircraft make it capable of performing low-altitude surveys with geophysical sensors such as magnetometers, ground-penetrating radar, and electromagnetic induction devices. These characteristics include the following:

- It performs vertical takeoffs and landings.
- It can hover or fly horizontally or vertically.
- It uses two coaxial counter-rotating blades that are shrouded to protect ground personnel.
- Computer control permits automated surveys and provides a high degree of stability.

2.1.2 Magnetometers

Three Geometrics G822A total-field cesium magnetometers were mounted on short booms that extended radially outward from the aircraft as shown in Figure 1. These measured the magnetic field simultaneously at a rate of 20 samples/s (each sensor). The magnetometers were located at angles of 106 , 180 , and 257 (clockwise looking down) relative to a point defined as the front of the aircraft. The spacing between the right and left magnetometers was 3.0 m. The magnetic data, together with aircraft attitude information, aircraft coordinates, and other flight parameters, were transmitted to the base station where they were recorded on the hard disk of a portable computer (data acquisition and display unit).

2.1.4 Navigation

Two GPS receivers were installed on the Cypher. The first was a Trimble unit that was an integral part of the Cypher's Integrated Flight Management Unit (IFMU). The second, a NovAtel RT2 dual-frequency unit, was installed specifically for this demonstration and provided superior accuracy (approximately 2 cm). The aircraft position coordinates recorded during the survey were provided by the NovAtel unit. A matching RT2 receiver was mounted at known locations to provide differential corrections. The reference locations used during the survey were Monuments 1 and 2 and stake O-1.

2.1.4 Flight Control

The aircraft is designed to be controlled by digital signals produced by its IFMU and by telemetered signals provided by a flight control computer in the base station vehicle. The latter controls the flight path and altitude and provides an automated (programmed) survey mode. The height of the aircraft above the ground is measured by a radar altimeter mounted on the bottom of the fuselage. Fiber-optic gyros provide pitch, roll, and heading data.

2.1.5 Data Recording

All of the data telemetered from the aircraft during flight is recorded by Sikorsky's data acquisition system. This includes a large amount of data that is unrelated to the geophysical measurements. The magnetic data, GPS coordinates, GPS time, and aircraft attitude data are recorded separately by Battelle's data acquisition computer. This unit also displays the sensor data and the track of the aircraft in real time on a color monitor. The ability to observe the data as it is being recorded permits the operator to periodically confirm that the system is operating properly. The data files are stored on a removable hard disk for later processing in the laboratory.

2.1.6 Data Analysis

The magnetic components of the Cypher's engine, gearbox, and electrical generator produce local induced magnetic field variations at each magnetometer as the aircraft pitches, rolls, and changes heading. The errors associated with these attitude-related variations are large compared to UXO signatures and must be removed. This was done by constructing a 3-dimensional lookup table of magnetic correction terms for each magnetometer. These provided the necessary corrections for each combination of pitch, roll, and heading that occurred during the survey. High-frequency magnetic noise produced by the Cypher's electrical generator and ignition system was effectively removed by a low-pass Fourier filter. The pitch, roll, and heading angles were used together with the coordinates of the Cypher's GPS antenna and the radar altimeter readings to calculate the XYZ coordinates of each sensor at the instant of each measurement. The corrected data were then gridded and displayed as color-coded contour maps using the Surfer (Golden Software, Inc.) contouring/mapping program. Numerical estimates of target locations and sizes were then obtained by applying the Geometrics/AETC magnetic anomaly identification and detection program, MagAID.

2.1.7 SURVEY PROCEDURES

The areas (scenarios) to be covered in this demonstration survey were:

- Artillery and Mortar Range, 3.9 hectares (Scenario 2)
- Interrogation and Burial Sites, 3.9 hectares (Scenario 4)
- Aerial Gunnery Range, 3.9 hectares (Scenario 1)

The approach was to fly preprogrammed search patterns along sets of roughly parallel lines spaced approximately 3 m apart. Data were collected at the rate of 20 samples/s per channel. At a flight speed of 3 m/s, this yielded approximate data densities of 6.6 data/m along the flight lines and .7 datum/m in the direction perpendicular to the flight lines. The aircraft was flown as low as possible, usually at a height of less than 3 m, to maximize target detectability. For a variety of reasons, it was not always possible to utilize automated flying. In those cases, the aircraft was manually controlled.

A proton precession magnetometer was used to recorded the diurnal variations in the ambient magnetic field. This sensor was placed at the same fixed location during each survey day and recorded data at 30-sec intervals. The variations were subtracted from the Cypher-measured data.

2.2 RESULTS

2.2.1 Summary

During the 5-day demonstration period, a total of 3.0 hectares in Scenarios 2 and 4 were surveyed in 4.6 hr of flight time. When the aircraft was functioning properly, it efficiently surveyed large open areas at a rate of approximately .5 hectare per 20-minute flight.

Thirty-one targets are reported as detections (Figure 2). These are distributed more or less uniformly over the surveyed areas and are assumed to be targets that are relatively large and/or buried at shallow depths.

2.2.2 Problems Experienced

1) Mechanical and electrical. During the test period, the aircraft experienced several unusual problems that limited the flight time available for data acquisition. Unfortunately, troubleshooting of the aircraft took up the majority of the time available for the survey. The aircraft experienced engine electronics problems as well as problems with high drifts in the velocities provided by the inertial navigation system. Strong winds from unfavorable directions and the number of trees on the demonstration site resulted in inefficient search patterns.

2) Altitude control. The radar altimeter currently used on the Cypher is not accurate at altitudes of less than 3 m, whereas high-sensitivity UXO detection requires sensor heights of less than 2 m. The known limitation of the altimeter and a lack of terrain-following software made the Sikorsky personnel reluctant to fly at altitudes low enough to achieve good target detectability.

3) Automated flight manager. The software that was available for automated survey patterns was limited to rectangular areas. This resulted in inefficient operation and incomplete coverage where the presence of trees required odd-shaped areas. There was also a lack of confidence in the ability of the computer and the flight control system to fly close to the trees even though we used a mobile NovAtel GPS unit to establish accurate tree boundaries.

4) Magnetic noise. It was not possible to correct for all of the magnetic noise associated with changes in the attitude of the aircraft. Rapid changes in heading seemed to produce transients that were difficult to correct. The residual average noise level was only a few nT, but noise spikes of 20 nT or more produced fragmented anomalies and resulted in spurious anomalies that had amplitudes comparable to those expected to be associated with real targets.

2.2.3 Discussion

The performance of the system in terms of both operations and target detection was substantially less than anticipated and was disappointing. On the other hand, the deficiencies in the still-evolving system were clearly illuminated and were found to be of a type that can be remedied by engineering. No assaults on the fundamental principles of physics appear to be needed to achieve improved performance. The needed improvements follow directly from the problems enumerated above. Continued development of the aircraft will enhance its reliability and its controllability in windy conditions. A more significant issue is the ability to fly lower, or at least to ensure that the sensors can be flown closer to the ground surface. This will require an improved low-altitude altimeter and terrain-following software and will be closely tied to an overall improvement in the automated flight manager. A further reduction of magnetic noise can be achieved by reducing the mass of ferrous components in the aircraft and by improved measurement and handling of aircraft attitude effects. The necessary effort seems worthwhile in view of the safety and efficiency benefits to be gained by using this type of sensor platform in large-scale UXO surveys.

Battelle - Combined Statistics: Scenario 2 only

Detection Statistics (TMA[a] *Group*, 5m critical radius)

	# Baseline	# Detected	Pd[b]	P_{random}
Ordnance	67	8	0.12	0.026
Nonordnance	50	5	0.10	
Total	117	13		
Number False Alarms	8			
False Alarm Rate (#/Hectare)	1.71			
False Alarm Ratio (#/Ord.)	1.00			
Probability False Alarms	0.013			

Localization Statistics (TMA *Closest*, 5m critical radius) (in meters)

	Mean	Std Deviation
Position (x,y)		
dx - easting error	-1.45	2.24
dy - northing error	0.64	2.39
Radial error	3.37	1.07
Depth (z)		
dz - averaged depth error	0.57	0.83
|dz|[c] - absolute depth error	0.98	

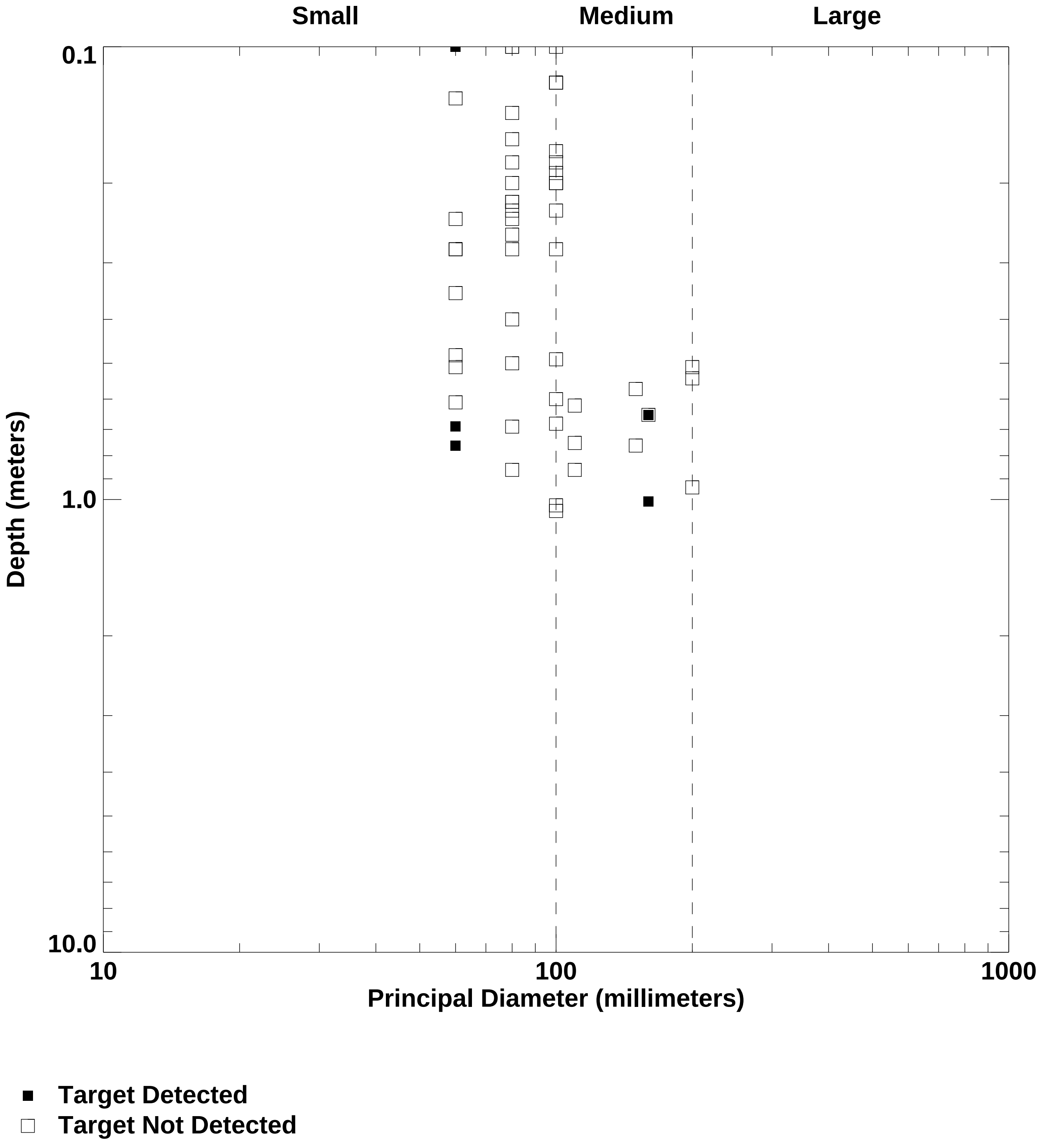
Characterization Statistics (TMA *Closest*, 5m critical radius)

	# Baseline	# Detected	P_D[b]	# Correct	P_C[d]
Ability to Type					
Ordnance	67	8	0.12	0	0.00
Nonordnance	50	5	0.10	0	0.00
Ability to Size					
Large	3	0	0.00	0	NA
Medium	31	4	0.13	0	0.00
Small	33	4	0.12	0	0.00
Ability to Classify					
Bomb	0	0	NA	0	NA
Projectile	41	4	0.10	0	0.00
Mortar	26	4	0.15	0	0.00
Submunition	0	0	NA	0	NA
Rocket	0	0	NA	0	NA

Notes:

[a] Target Matching Algorithm
[b] Probability of detection
[c] Square root of the mean square depth error
[d] Probability of correct characterization
NA - not applicable

JPG Controlled Site: Phase III
Combined Statistics: All Surveyed Area (Excluding Scen. 4)
Critical Radius: 5 meters
Demonstrator: Battelle



3.0 CHEMRAD [7]

Chemrad demonstrated from October 9 through 13, 1996 at the 16-hectare area at JPG. Chemrad also participated in Phase I of the UXO ATD program.

3.1 TECHNOLOGY DESCRIPTION

3.1.1 Sensor System and Transport Mode

The Survey system used for the JPG III tests comprised of 3 major Subsystems
1. The Geonics EM61
2. The Geonics EM61-3D (3-component time domain EM system)
3. the USRADS 2200+ for ultrasonic and/or DGPS positioning as desired

The Geonics EM61 is a high sensitivity high resolution time-domain metal detector. It consists of a transmitter that generates a pulsed primary magnetic field, which induces eddy currents in nearby metallic objects. The decay of the currents is measured by two receiver coils mounted on the coil assembly and output as two separate channels of data.

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[7] CHEMRAD, Final Report for the Advanced Technology Program, Phase III - 14 November 1996

The EM61-3D also consists of a powerful transmitter that generates a pulsed primary magnetic field which induces eddy current in nearby metallic objects. The time delay of these currents is accurately measured over a wide dynamic range of time, *in three orthogonal space components*. The output of each sensor is measured and recorded by the main console at 20 geometrically spaced gates, covering a time range from 320 microseconds to 32 milliseconds. The EM61-3D was developed to provide an improved method to locate and characterize UXO.

The USRADS 2200+ ties the systems together by providing location information and matting this spatial information with the continuously recorded data from the sensors and in the case of the EM61, transmits the data via RF to the USRADS 2200+ Control Center at 1 Hz. The USRADS 2200+ Control Center will display color track maps showing the real-time position and sensor output to aid in survey navigation and support immediate re-acquisition of suspect findings. The USRADS 2200+ has both DGPS and ultrasonic positioning capabilities built into it's design to assure all terrain survey coverage. Since the JPG site had very sparse tree cover, the DGPS capability was used exclusively for this survey.

The USRADS 2200 has been repeatedly man-carried by back-pack using a three person team into extremely rugged terrain and successfully operated for up to 8 hours per day. The EM61-3D and supporting electronics/battery pack can be carried by back-pack with at least a two person team. The EM61 and EM61-3D are both man towable surveying platforms.

3.1.2 Recommended Applications and Technology Limitations

The primary problem facing the UXO detection arena today is the discrimination of UXO targets from non-UXO targets. Pulsed EM Induction (PEMI) techniques have been demonstrated to provide significant discrimination ability via the use of high power EM transmission and the resultant strong eddy currents induced in the targets. The subsequent reflected EM signal from a metallic target is generally much greater than that resulting from the ground and thereby easily detected. Even weak signals can be discriminated since the ground response can easily be modeled as a stable term. More recently, time gating of the reflected signal's induced current in the receiving sensor has been demonstrated to be characteristic of the size and shape of the UXO target (McNeill and Bosnar, 1996, and Kaczkowski and Gill, 1996).

The limitations of the EM61 systems are that they are have a maximum depth penetration of approximately 3 meters and since the EM61-3D is a prototype unit, actual target data for evaluating the effectiveness of the system has not existed before this survey. Another associated limitation because the system is a prototype is that processing software is unavailable or very limited in capability.

3.1.3 Logistical System Requirements

The USRADS 2200+ and the EM61 are man-portable and are both designed to operate at remote sites in rugged terrain for up to 8 hours per day. Hardware components require overnight recharging with 115V AC. The system Control Center is routinely operated from a 4 wheel drive vehicle. Field manpower requirements include 2 surveyors and 1 operator per team.

3.1.4 Data Acquisition, Processing, and Interpretation

The data acquisition was performed in two parts. A standard EM61 interfaced to the USRADS 2200+ System was used to survey the grid at a survey rate of 1m per second on parallel lanes separated by 1.5m. This corresponds to a preliminary survey rate of approximately 0.4 hectares (1 acre) per hour including field QA/QC. These anomalous target findings were identified with the real-time data presentation system and suspect area's were resurveyed with the EM61-3D. The EM61 was used to scan the survey grid to determine the targets "X-Y" location and depth information. The EM61-3D system was then used to attempt determination of the targets shape characteristics, alignment and classification. The EM61 data was processed using CHEMRADS "ANALYZE®" Program. The EM61-3D data was downloaded and processed using a modified Protem processing package supplied by Geonics Limited. All data Acquisition, and processing were performed on 486 or Pentium-based computers running standard Windows 3.1 Software.

The Demonstrator Reference Area (DRA) was processed first and provided a high degree of confidence for the EM61 data interpretation. The data collected with the EM61-3D contained multiple noise spikes and so far, a high degree of data uncertainty when attempting to use the transform response for determining ordnance classification. A review of the current data is still in process as is the writing of new computer codes to more efficiently filter and process the 3D data.

3.2 DEMONSTRATION RESULTS

3.2.1 Assumptions and Problems Encountered

1. *Assumption:* CHEMRADS survey would occur from October 23 to October 29, 1996. Actual: Unfortunately, CHEMRAD discovered that Geonics Limited had concurrently rented the one EM61-3D prototype system to another company that was scheduled on the JPG grid during the exact same time period as CHEMRADs' Survey slot. To alleviate this situation, CHEMRAD accelerated it's project plan to perform the survey in the only other time slot available, which advanced the timeline by two weeks. This schedule acceleration adversely affected the following items:

As soon as the 3D system was built, it was shipped to CHEMRAD for use on the JPG Project. There was very little testing of the equipment electronics and equipment operation prior to it’s first actual field use at JPG. A one week trip by CHEMRAD to Geonics and Geosoft to test, and modify the system for proper field operation and software program performance had to be canceled since it conflicted with the new survey dates. Collection and processing of 3D data for signature analysis from other test sites in the Eastern US were canceled due to schedule acceleration.

As with most prototypes, several complications were discovered just prior to receipt of the 3D system, but with the shortening of the available schedule, there was no time to improve the system prior to the JPG survey. The following are examples of ways in which the 3D system can be or was improved following our JPG project.

The 3D system did not have an active data output port which would enable telemetry of the data to a Personal Computer (PC) for real time data processing and analysis. This would remove the painfully slow data downloads currently required by the equipment and improve Quality Control (QC) of the collected data. There was also no way to review or look at the data without downloading to a computer. This prohibited the surveyor from efficiently modifying gains, stacking data, or determining if the equipment was operating properly.

After collecting data with the 3D system for 1.5 hours, data had to be downloaded (which would take 1 hour) before proceeding with further data collection. Geonics has reduced the download time considerably since CHEMRADs JPG survey, unfortunately the software and EPROMS to upgrade the system arrived the day after CHEMRAD completed surveying the JPG grid. Ability to externally trigger the 3D system and to easily synchronize the location system with the 3D data. A time based system was instituted to resolve this problem.

The weight and bulk of the 3D system needs reduced so that it weighs a lot less than it’s current 60+ lbs to reduce worker fatigue. The 3D system has an intermittent problem that corrupted large amounts of data but would then appear to collect good data for a few targets and then return to collecting sections of unusable data. Originally, it was believed that we were seeing interference from another demonstrator nearby who was using a high powered EM transmitter system but there are area’s of the grid where the second demonstrator would have been at least 400 feet away from the 3D system and the data collected is unusable. Potential sources for the problem range from an intermittent electronic failure to interference from nearby high-powered transmitters or jammers used by the military during the practice bombing runs to coupling with the Receiver coils or interference with the electronics carried in the backpack.

3.2.2 Technology Conclusions

The USRADS+ DGPS System and the standard EM61 were very dependable and provided an excellent method of quickly scanning the combined 20 acres of Scenario’s 1 and 2 to determine where area’s of interest exist. It was at this point that the EM61-3D system was to be used to discriminate between buried ordnance and non-ordnance items.

Theoretical and small scale tests (McNeill, J.D. and M. Bosnar 1996) have shown that the EM61-3D system can delineate between the following ordnance items:

40 mm shell
60 mm M2 mortar
81 mm mortar
105 mm M14 shell
155 mm M107 shell

Unfortunately, at the time of the Phase III Advanced Technology Demonstration, the system appears not to be either durable enough for field use or have proper shielding to provide consistent performance. Additional improvements required are:

- providing an active data output port similar to the EM61
- Reducing the bulk of the instrument package
- Improving basic software available for processing so that the data profiles larger than 3 minutes worth of data collection can be handled more efficiently.

Once these improvements are made, the EM61-3D system should provide the needed discrimination capability to improve the accuracy of UXO Surveys.

CHEMRAD - Combined Statistics: Scenarios 1,2

Detection Statistics (TMA[a] *Group*)

	# Baseline	# Detected	Pd[b]	P_{random}
Ordnance	110	55	0.50	0.024
Nonordnance	127	50	0.39	
Total	237	105		
Number False Alarms	105			
False Alarm Rate (#/Hectare)	12.90			
False Alarm Ratio (#/Ord.)	1.91			
Probability False Alarms	0.016			

Localization Statistics (TMA *Closest*) (in meters)

	Mean	Std Deviation
Position (x,y)		
dx - easting error	0.33	0.83
dy - northing error	0.02	0.79
Radial error	1.08	0.50
Depth (z)		
dz - averaged depth error	0.52	0.43
|dz|[c] - absolute depth error	0.68	

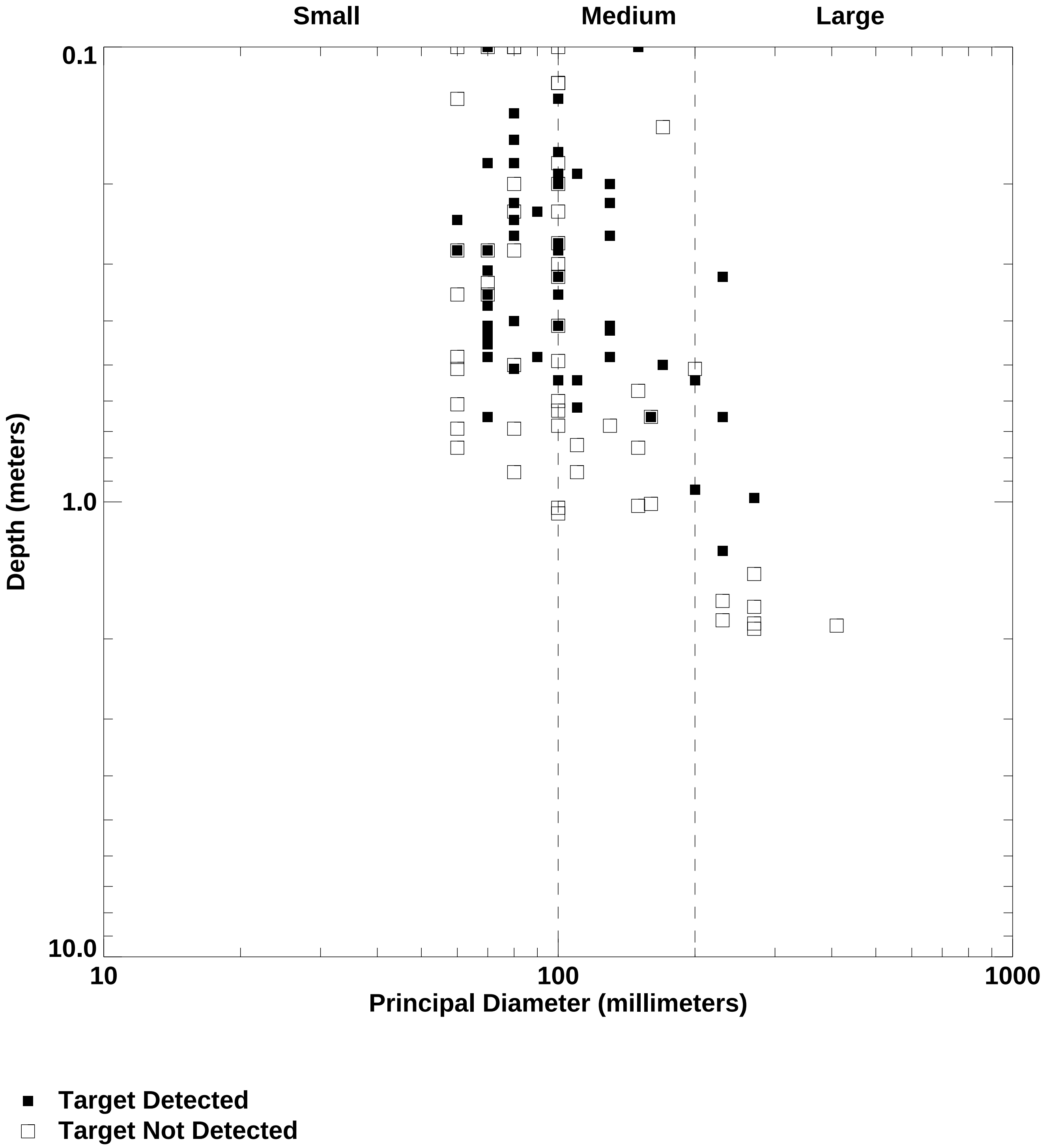
Characterization Statistics (TMA *Closest)*

	# Baseline	# Detected	P_D[b]	# Correct	P_C[d]
Ability to Type					
Ordnance	110	55	0.50	0	0.00
Nonordnance[e]	128	50	0.39	0	0.00
Ability to Size					
Large	14	6	0.43	0	0.00
Medium	38	18	0.47	0	0.00
Small	58	31	0.53	0	0.00
Ability to Classify					
Bomb	21	9	0.43	0	0.00
Projectile	41	20	0.49	0	0.00
Mortar	26	9	0.35	0	0.00
Submunition	0	0	NA	0	NA
Rocket	22	17	0.77	0	0.00

Notes:

[a] Target Matching Algorithm
[b] Probability of detection
[c] Square root of the mean square depth error
[d] Probability of correct characterization
[e] TMA affects how nonordnance baseline targets are counted
NA - not applicable

JPG Controlled Site: Phase III
Combined Statistics: All Surveyed Area (Excluding Scen. 4)
Critical Radius: 2 meters
Demonstrator: CHEMRAD



4.0 ENSCO [6]

Ensco demonstrated from October 15 through 17, 1996 at the 16-hectare area at JPG. Ensco also participated in Phase I of the UXO ATD program.

4.1 TECHNOLOGY DESCRIPTION

ENSCO demonstrated three technologies: i) the *MagnaLog* magnetic sensing system, ii) a Sensors & Software pulseEKKO 1000 GPR system, and iii) a White Spectrum XLT metal detector. Each will be discussed in turn in the following sections.

4.1.1 Sensor System and Transport Mode

MagnaLog. MagnaLog is a hand-held, digital vertical magnetic gradient sensor array and data acquisition system developed by ENSCO. Employing two Schonstedt GA-72-CD sensors and an on-board microcontroller, MagnaLog allows a single operator to survey an acre in 35-45 minutes at a 3-ft sensor separation. The data collection rate along profile lines is user selectable, but we typically use between ¼ and ½ ft/sample (5-10 samples/sec). The operator wears the system comfortably from the shoulders. The microcontroller has a 12-button keypad to setup data collection parameters. During data collection, the operator only has to use a single push-button to interact with the system by marking start and end points of lines, to pause, or to mark an item of interest. Position data is acquired by walking profile lines, typically 200-ft in length, with a marker at the mid-point of the line. The *MagnaLoc* processing software interpolates data positions based on a constant walking speed, start and end positions of the profile, and gaps in the data due to obstructions (trees, etc.).

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[6] ENSCO, Inc., Demonstration of Capability to Detect Unexploded Ordnance at the Jefferson Proving Grounds Phase III, Advanced Technology Demonstration, November 21, 1996

<u>pulseEKKO 1000</u>. The pulseEKKO 1000 is a portable, digital ground-penetrating radar system manufactured and marketed by Sensors & Software, Inc. The pulseEKKO 1000 can be operated by a single user who carries the electronics in a specially configured backpack. For this effort, we transported the system in a garden wheel-barrow to locations where we would collect data. Then, data are acquired by dragging the antenna pair along the ground.

<u>Spectrum XLT</u>. The Spectrum XLT is an off-the-shelf, hand-held metal detector. It is operated by sweeping the ground over suspected targets and listening for a "squawk" that indicates a conductive target. The operator notes the position of the sensor when he hears the "squawk".

4.1.2 Recommended Applications and Technology Limitations

<u>MagnaLog</u>. MagnaLog is designed for rapid, inexpensive magnetic gradient surveying. It is particulary effective for detection of shallow (< 5 m) ferrous objects. As a magnetometer system, *MagnaLog* will not detect non-ferrous objects. *MagnaLog* can operate in most any climatic conditions.

<u>pulseEKKO 1000</u>. As a GPR system, the pulseEKKO 1000 is used for characterizing of subsurface conditions. GPR is most effective in resistive soils. Conductive soils contribute to signal attenuation. GPR can be unusable in highly conductive soils. For UXO, GPR is most effective for validating and/or characterizing previously detected anomalies. The pulseEKKO 1000 has not been ruggedized for use in rain or freezing temperatures.

<u>Spectrum XLT</u>. Designed for use primarily as a "coin finder" or "treasure hunter", the Spectrum XLT is widely used in the EOD industry for detecting shallow metallic

objects. The depth of investigation of the Spectrum XLT is approximately 1-ft. It detects both ferrous and nonferrous objects. It operates only in analog audio mode; no digital data is acquired.

4.1.3 Logistics Requirements

MagnaLog. *MagnaLog* is hand-carried by a single operator and runs on battery power.

pulseEKKO 1000. The pulseEKKO 1000 can be operated by a single user in a backpack mode. We chose to place the system in a portable wheel barrow. The system is battery powered. It can be operated by either one or two people.

Spectrum XLT. The Spectrum XLT is a single user, hand-held system. It is battery powered.

4.1.4 Data Acquisition

MagnaLog. *MagnaLog* acquires digital data continuously while the operator walks a profile line. Data are downloaded periodically to a portable computer.

pulseEKKO 1000. The pulseEKKO 1000 allows data collection in profile lines. We used the system to acquire data only over specific targets.

Spectrum XLT. The Spectrum XLT provides only audio data.

4.1.5 Data Processing and Interpretation

MagnaLog. *MagnaLog* data is processed using the *MagnaLog* data processing package and the LocPlot plotting routine. We prepare 2-D contour plots of magnetic anomalies. We also display each profile line of collected data (amplitude versus position). The data are then jointly interpreted from these two displays, though the profile plots are the primary interpretation tool. When azimuths are estimated, they are based on the spatial orientation of the anomaly field.

pulseEKKO 1000. The pulseEKKO 1000 data are plotted as profile lines. Display signal processing includes gain application, removal of ensemble averages, etc. Interpretation is subjective depending on the displayed data.

Spectrum XLT. No data is processed. The operator interprets results in real-time based on the audio data.

4.1.6 Quality Assurance

MagnaLog. *MagnaLog* operating condition is verified at the beginning and end of each data. In addition we download and validate data approximately every hour in the field.

pulseEKKO 1000. Quality assurance of GPR data is maintained by subjective interpretation of collected data, in much the same manner as the target data is interpreted subjectively.

Spectrum XLT. The Spectrum XLT is validated by operating it over surface metallic objects.

4.2 DEMONSTRATION RESULTS

ENSCO conducted a demonstration in three areas: 1) Scenario 1. Aerial Gunnery Range, 2) Scenario 2. Artillery and Mortar Range, and 3) Scenario 4. Interrogation and Burial Area. Each of these three scenarios will be discussed in turn.

4.2.1 Assumptions

Scenario 1. Aerial Gunnery Range. We made no assumptions other than those provided in the Demonstration Work Plan.

Scenario 2. Artillery and Mortar Range. We made no assumptions other than those provided in the Demonstration Work Plan.

Scenario 4. Interrogation and Burial Area. We made no assumptions other than those provided in the Demonstration Work Plan.

4.2.2 Site-Specific Procedures

Scenario 1. Aerial Gunnery Range. We collected *MagnaLog* data in approximately 1-acre segments (61-m by 61-m.) Plastic flagging was used to mark walking profiles. Data were collected in profiles spaced by 6-ft (1.8 m), which, with our 3-ft (0.9 m) sensor separation, allowed data to be acquired on 3-ft (0.9 m) profile spacing. Data were acquired to overlap adjacent grids by at a minimum 5 feet. Data were collected at a rate of 5 samples/sec, which corresponds to an average spatial sampling rate of 0.5 ft (15 cm). Data were acquired moving in a north-south direction. Following data analysis, as many anomalies as time permitted were reoccupied so that their position and character could be validated.

Scenario 2. Artillery and Mortar Range. We collected *MagnaLog* data in approximately 1-acre segments (61-m by 61-m.) Plastic flagging was used to mark walking profiles. Data were collected in profiles spaced by 6-ft (1.8 m), which, with our 3-ft (0.9 m) sensor separation, allowed data to be acquired on 3-ft (0.9 m) profile spacing. Data were acquired to overlap adjacent grids by at a minimum 5 feet. Data were collected at a rate of 5 samples/sec, which corresponds to an average spatial sampling rate of 0.5 ft (15 cm). Following data analysis, as many anomalies as time permitted were reoccupied so that their position and character could be validated.

Scenario 4. Interrogation and Burial Area. For each of the 20 targets we were assigned, we setup a 36-ft by 36-ft grid centered on the marked position. *MagnaLog* data were collected on 1.5-ft (0.46-m) profiles in a north-south direction. The Spectrum XLT was used to investigate whether the target was shallow, and if so, its length and orientation. GPR data were collected along four profiles. Each profile started and stopped at the edge of our 36-ft grid. The profiles were collected in a north-to-south, northwest-to-southeast, northeast-to-southwest, and west-to-east orientation. Each of these four profiles crossed directly over the PRC-provided marked position.

4.2.3 Problems Encountered

No significant problems were encountered. Time on the grid as determined by the PRC EMI representatives was closely controlled and rigidly adhered to. This caused some inefficiencies in data acquisition and prevented some final quality assurance data from being collected.

Scenario 1. Aerial Gunnery Range. Data collection and processing required longer than expected. Therefore, we were only able to reoccupy a limited number of anomalies for validation and relocation. Because of the high quality of the magnetic data, we focused our efforts in the validation stage on improving location estimates, not improving characterization. We relocated 91 anomalies in the validation stage. Some of the (apparent) larger excavations have undergone significant settling, which causes uncertainty in determining where depth is measured from. Apparent remnants of a fence were detected in this scenario. We did not report every piece of the fence as a target, but instead reported the end points of the fence as a target (within the scenario boundaries), and so annotated the comment in the data file.

Scenario 2. Artillery and Mortar Range. Data collection and processing required longer than expected. Therefore, we were only able to reoccupy a limited number of anomalies for validation and relocation. Because of the high quality of the magnetic data, we focused our efforts in the validation stage on improving location estimates, not improving characterization. We relocated 79 anomalies in the validation stage. Apparent remnants of a fence were detected in this scenario. We did not report every piece of the fence as a target, but instead reported the end points of the fence as a target (within the scenario boundaries), and so annotated the comment in the data file. We also detected a large, sheet-like (mat-like) target in this scenario. The approximate mid-point of this object was declared a target and so annotated in the data file.

Scenario 4. Interrogation and Burial Area. No problems were encountered during data collection. Definition of the scenario in the Demonstration Work Plan was not sufficiently complete. The range of targets for this scenario were not adequately defined. The data entry format (the Excel worksheet) had an inadequate range of acceptable entries. For example, there was no means by which to identify a burn or burial site. Also, some of the pin flags marking locations did not seem to be located with sufficient accuracy, which was a “given” for the scenario. (This might have been due to the metal pin flags used to mark locations: each demonstrator had to move the ferrous flags to survey the site.)

4.2.4 Discussion of Results

Scenario 1. Aerial Gunnery Range. We believe the data quality was high and the results very good. The *MagnaLog* system appeared to perform well. We would have like to have had the time to validate more anomalies with GPR, but available time precluded this effort.

Scenario 2. Artillery and Mortar Range. We believe the data quality was high and the results very good. The *MagnaLog* system appeared to perform well. We would have like to have had the time to validate more anomalies with GPR, but available time precluded this effort.

Scenario 4. Interrogation and Burial Area. Detection and location were successful. GPR data was generally of high quality: targets were clearly seen. Only one target was clearly seen with the Spectrum XLT, the other targets being too deep.

4.2.5 Raw Data

Digital raw data are attached on 3.5 inch IBM-format diskettes. Magnetic data are found in the .csv files; GPR data are located in the .dt1 and .hd files. All data files have been compressed using the PKZIP utility. The magnetic data files contain both raw and processed data. Raw data is found in column 3.

4.2.6 Processed Data

Processed magnetic data are included in the magnetic data files along with the raw data. Processing includes attachment of X and Y coordinates, computation of slowly varying biases and trends in the data, and extraction of a residual signal. GPR data are only processed for display and hence are not included here.

4.2.7 Conclusions

We make the following conclusions from our demonstration:

MagnaLog is an effective tool for detecting and locating UXO. It is efficient, inexpensive, and accurate.

MagnaLog position data could be improved. Our analysis indicates the majority of our position error is in the direction we walked the instrument (N-S), with minimal error in the E-W direction.

GPR can be an effective tool for validating previously detected anomalies and contributing to the characterization of anomalies. Even for the well-known poor quality soils at JPG, our GPR data was quite good. Many previous demonstrators at JPG have shown that GPR is ineffective at UXO detection at JPG. We believe the proper role for GPR is not for detection, but instead to validate previously detected anomalies and contribute to the classification of the target.

ENSCO - Combined Statistics: Scenarios 1,2

Detection Statistics (TMA[a] *Group*)

	# Baseline	**# Detected**	**Pd[b]**	**P_{random}**
Ordnance	110	77	0.70	0.071
Nonordnance	127	82	0.65	
Total	237	159		
Number False Alarms	396			
False Alarm Rate (#/Hectare)	48.66			
False Alarm Ratio (#/Ord.)	5.14			
Probability False Alarms	0.061			

Localization Statistics (TMA *Closest*) (in meters)

	Mean	**Std Deviation**
Position (x,y)		
dx - easting error	-0.12	0.32
dy - northing error	0.05	0.56
Radial error	0.50	0.43
Depth (z)		
dz - averaged depth error	-0.06	0.29
|dz|[c] - absolute depth error	0.30	

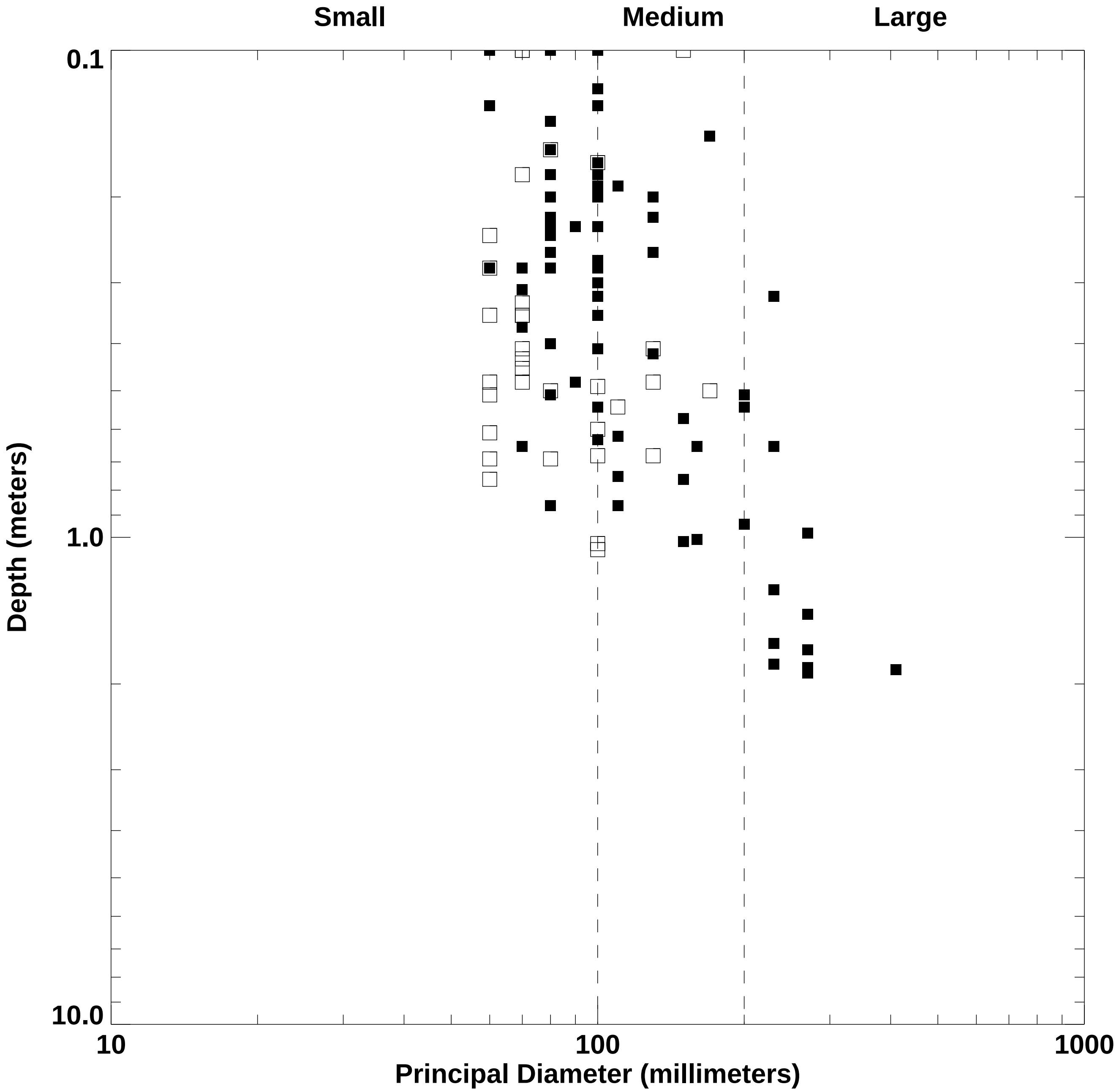
Characterization Statistics (TMA *Closest)*

	# Baseline	**# Detected**	**P_D[b]**	**# Correct**	**P_C[d]**
Ability to Type					
Ordnance	110	77	0.70	0	0.00
Nonordnance[e]	128	82	0.64	0	0.00
Ability to Size					
Large	14	14	1.00	0	0.00
Medium	38	26	0.68	0	0.00
Small	58	37	0.64	0	0.00
Ability to Classify					
Bomb	21	21	1.00	0	0.00
Projectile	41	33	0.80	0	0.00
Mortar	26	14	0.54	0	0.00
Submunition	0	0	NA	0	NA
Rocket	22	9	0.41	0	0.00

Notes:

[a] **Target Matching Algorithm**
[b] **Probability of detection**
[c] **Square root of the mean square depth error**
[d] **Probability of correct characterization**
[e] **TMA affects how nonordnance baseline targets are counted**
NA - not applicable

JPG Controlled Site: Phase III
Combined Statistics: All Surveyed Area (Excluding Scen. 4)
Critical Radius: 2 meters
Demonstrator: ENSCO



■ **Target Detected**
□ **Target Not Detected**

5.0 FOERSTER[5]

Foerster demonstrated from October 2 through 5, 1996 at the 16-hectare area at JPG. Foerster also participated in Phase I of the UXO ATD program.

5.1 TECHNOLOGY DESCRIPTION

5.1.1 Sensor System and Transport Mode

The FÖRSTER MULTI-CAT is a towed vehicle array, utilizing the best in fluxgate magnetometer technology. The system uses up to 9 new patented FÖRSTER Sensors, developed and based on the current FEREX sensor which is in service in the US Military and known as the Mark 26 Ordnance Locator. The gradient magnetometer sensor principle of the FEREX is widely known. It is most suitable for the detection and exact location of unexploded bombs, pipes, cables, ferromagnetic containers, etc. Each sensor assembly contains two FÖRSTER Probes which are optimized for the detection of ferrous objects located below the ground surface. Depending on the size and position of the ferromagnetic objects, the advanced updated FEREX-sensors detect ordnance down to a depth of approximately six (6) meters. The new developed patented FEREX sensors are light weight and aligned for life. They do not need re-calibration as with the MK 26 sensors. Their detection sensitivity is improved by approximately 20 %. The MULTI-CAT is constructed of entirely advanced composites. No metal is used in its manufacture. The MULTI-CAT's unique probe array assembly coupled with FÖRSTER's MAGNETO software, provides users with an advanced and accurate ordnance location system.

[5] **Foerster, Demonstration Summary Report, 30 October 1996**

Global Positioning System (GPS)

The vehicle mounted GPS-system consists of the GPS antenna, the stationary and mobile receiver and a laptop type computer with an additional landscape software program. The landscape software enables the presentation of a map of the whole search area with specific markings such as corner or grid points. It can also provide for a grid system adapted to the intended tracks of the vehicle; or , for example; it can adapt its grid systems to the areas designated for the demonstration as indicated in the request for proposal.

The GPS and landscape software system enables the graphical presentation of “excluded” areas such as obstacles which then are specifically marked, and will be searched by the conventional handheld datalogging method with the FEREX (MK 26), for later integration into the vehicle mounted search system results.

Since the used DGPS system is a so called differential system, there is (separate from the mobile GPS receiver on the vehicle) a stationary reference receiver station which is linked by UHF transmission with the mobile station. The geographical position of this reference station placed nearby to the starting point of the search must be exactly measured and conventionally described.

5.1.2 Recommended Applications and Technology Limitations

Regarding the difficulties of detecting and classifying buried unexploded ordnance, in general, the gradiometer principle cannot differentiate between ferrous ordnance and non-ordnance items. This is due to the physical fact that the signatures of such items can be more or less the same, depending on composition, type, shape, depth, history, and configuration. Only in areas where the ground has not been contaminated by non-ordnance items, the presence of ordnance can be determined with near accuracy. Our data reports indicate that we are unable to classify targets by type and class. This is a major limitation of this type of technology.

5.1.3 Logistics Requirements

The MULTI-CAT system can be transported on a trailer or in a van to all areas of interest. The system, itself, is self maintained with sufficient spare electric power requirements. The MULTI-CAT uses off the shelf parts for its sensors. Due to Foerster’s patented tension-band probe arrangement, the sensors used in the MULTI-CAT, never need adjusting. No special maintenance of the system is required. The MULTI-CAT is a self contained unit with no internal moving parts, except the wheels. It is well suited for a variety of operational conditions, such as remote areas and in rugged terrain. It can be used both on land and underwater. The MULTI-CAT can also be configured with deep search sensors, enabling the MULTI-CAT to perform even deeper search detection operations. The MULTI-CAT is easily assembled in the testing area, requiring no longer than 60 minutes to assemble. The MAGNETO software, uses a standard 486 based microcomputer, that is easily obtainable and configured.

The MULTI-CAT can be towed by any vehicle that is suited to the terrain of the survey involved. Depending on terrain conditions, a scanning rate of 2 meters per second is considered well within the capabilities of the platform in non-forested areas. In addition, the vehicle that is used to tow the MULTI-CAT is used as a platform for the MAGNETO Magnetometer Survey Software. Also, the GPS antenna, transmitter, and receiver package is mounted on the MULTI-CAT and the towing vehicle to serve for the accuracy needed in determining the location of buried munitions.

5.1.4 Data Acquisition

During the data collection survey phase, the measurement data of each individual sensor was digitized with extreme resolution and transferred via a multiplex station to a personal computer (PC) system mounted in the towing vehicle. By the use of the MAGNETO software, the magnetic anomalies in the ground are presented on the towing vehicle PC screen in real time and automatically stored for later interactive interpretation and calculation as individual objects or object configurations on another PC station.

5.1.5 Data Processing and Interpretation

The MAGNETO Software can be run on any 486 Class Personal Computer or Laptop. The recommended system requirements are: 486DX266 or higher processor, 16 Mb RAM, with at least 30-40 megabytes of free hard disk space. Interpretation and calculation of columns in the target data are as follows

Target

The objects in the lists have a sequential number. These two numbers are combined to the target-demomination for the final evaluation in the worksheets. Except for Scenario 4, in which target numbers were given.

Northing/easting

For the local field coordinate system in the MAGNETO software “Monument 3” has been used as the reference point (zero point). They have been transformed into UTM-coordinates by shifting and rotating the object coordinates.

Depth & Weight

Is equivalent to the MAGNETO software for calculation of the object depth. The mass has been calculated using the specific density of iron and the volume. The mass serves as a decision criteria for the three different weight classes.

Size

The three different size classes have been determined according to the object diameter.

Azimuth

This value represents the declination in the MAGNETO software. The range had to be recalculated from “-180º to +180º” into “0º to 360º”.

Declination

Is the same as MAGNETO software inclination field values.

5.1.6 Quality Assurance

Quality assurance on-site was maintained throughout the demonstration by performing a daily reference calibration comparison on the reference training grid provided by PRC and a daily check of the DGPS coordinate system used given the reference points of the testing grid. Daily backups of the data were performed to ensure data integrity.

5.2 DEMONSTRATION RESULTS

5.2.1 Assumptions

Our team came prepared to handle any difficulties that could be encountered during our demonstration period. Of major concern was the coordinate information given to us by PRC personnel. The accuracy of our software is almost fully dependent on the accuracy of the coordinates used for reference and positioning. Many inquiries to on-site and off-site PRC personnel assisted us in ensuring that the coordinates given were indeed accurate.

5.2.2 Site-Specific Procedures

Each day of data collection on the Jefferson Proving Ground site was started with a systems check of the MULTI-CAT, and DGPS. The vehicle system consists of a combination of a towing vehicle and the MULTI-CAT. The vehicle is equipped with a differential mode Global Positioning System (DGPS) consisting of an antenna, mobile, and a stationary receiver.

Depending on the surface conditions of the search area, the towing vehicle was driven up and down with a speed of approximately one to two (1-2) meters per second (m/sec) along straight and parallel lines. In some cases rectangular search fields/driving path was used as a result of this search procedure. Such fields, however, were joined together by the MAGNETO software. In the south east corner of Scenario 1, Aerial Gunnery Range, the terrain prevented the MULTI-CAT from being able to survey due to the proximity of the trees. The survey of this area was performed manually with a standard FEREX 4.021

(MK 26) modified with a datalogger for use with our single channel MAGNETO version. The data collected by manual survey was then transferred and combined for evaluation with the MULTI-CAT's multi-channel MAGNETO system software.

5.2.3 Problems Encountered

The only equipment related problem encountered during the data collection phase of the demonstration occurred on the first day. A failure of the radio data modem was discovered. Within approximately 10 minutes, the problem was corrected and no further data collection problems were identified for the duration of the demonstration.

5.2.4 Discussion of Results

In Scenario 1, Aerial Gunnery Range, a total of 167 targets were identified by the MAGNETO software in approximately 2.2 hectares of surveyed terrain. In Scenario 4, Interrogation and Burial Sites, all twenty targets locations were given to us by PRC personnel. In four occasions, multiple targets were identified for a given target number. Again, the state of the technology used prevents us from accurately determining type and class of the objects detected. These two scenarios were completed within twenty hours. On-site PRC personnel allowed us to continue our survey in Scenario 2, Artillery and Mortar Range, to fill our allotted twenty-four on-grid time frame. We successfully surveyed an additional 1.85 hectares, and identified 172 targets within that survey. Please refer to the attached target data.

5.2.5 Conclusions

Foerster Instruments Incorporated, together with our teaming partners, was completely convinced that our approach afforded us the ability to complete the stated objective listed in the statement of work. The approach of interfacing GPS with the search signals, allowed us to maneuver without ground measurement within the site area, except the true position of the corner points and other reference markings which were provided. In parallel, areas which are not accessible with the towed vehicle array (dense trees, etc.) were searched with hand-held conventional MK 26 MAGNETO equipment. Our total system provides for the integration of all data obtained.

Foerster was contracted to perform a nonintrusive detection demonstration using a combination of the FOERSTER MULTI-CAT Towed Vehicle Array , and magnetometer sensors for a minimum survey of a 2 hectare Aerial Gunnery Range, and a minimum 2 hectare Interrogation and Burial Area for a variety of buried ordnance in 24 working hours, depending upon the terrain selected for demonstration. The FOERSTER MULTI-CAT exceeded this requirement. We were able to successfully complete the above survey well within the time limits set. In addition, we were able to survey an additional 1.85 hectares of Scenario 2, Artillery and Mortar Range, and have included our results as part of the data.

Foerster - Combined Statistics: Scenario 1 only

Detection Statistics (TMA[a] *Group*)

	# Baseline	# Detected	Pd[b]	P_{random}
Ordnance	43	26	0.60	0.054
Nonordnance	77	49	0.64	
Total	120	75		
Number False Alarms	126			
False Alarm Rate (#/Hectare)	36.46			
False Alarm Ratio (#/Ord.)	4.85			
Probability False Alarms	0.458			

Localization Statistics (TMA *Closest*) (in meters)

	Mean	Std Deviation
Position (x,y)		
dx - easting error	-0.05	0.35
dy - northing error	-0.04	0.3
Radial error	0.35	0.31
Depth (z)		
dz - averaged depth error	0.15	0.22
|dz|[c] - absolute depth error	0.26	

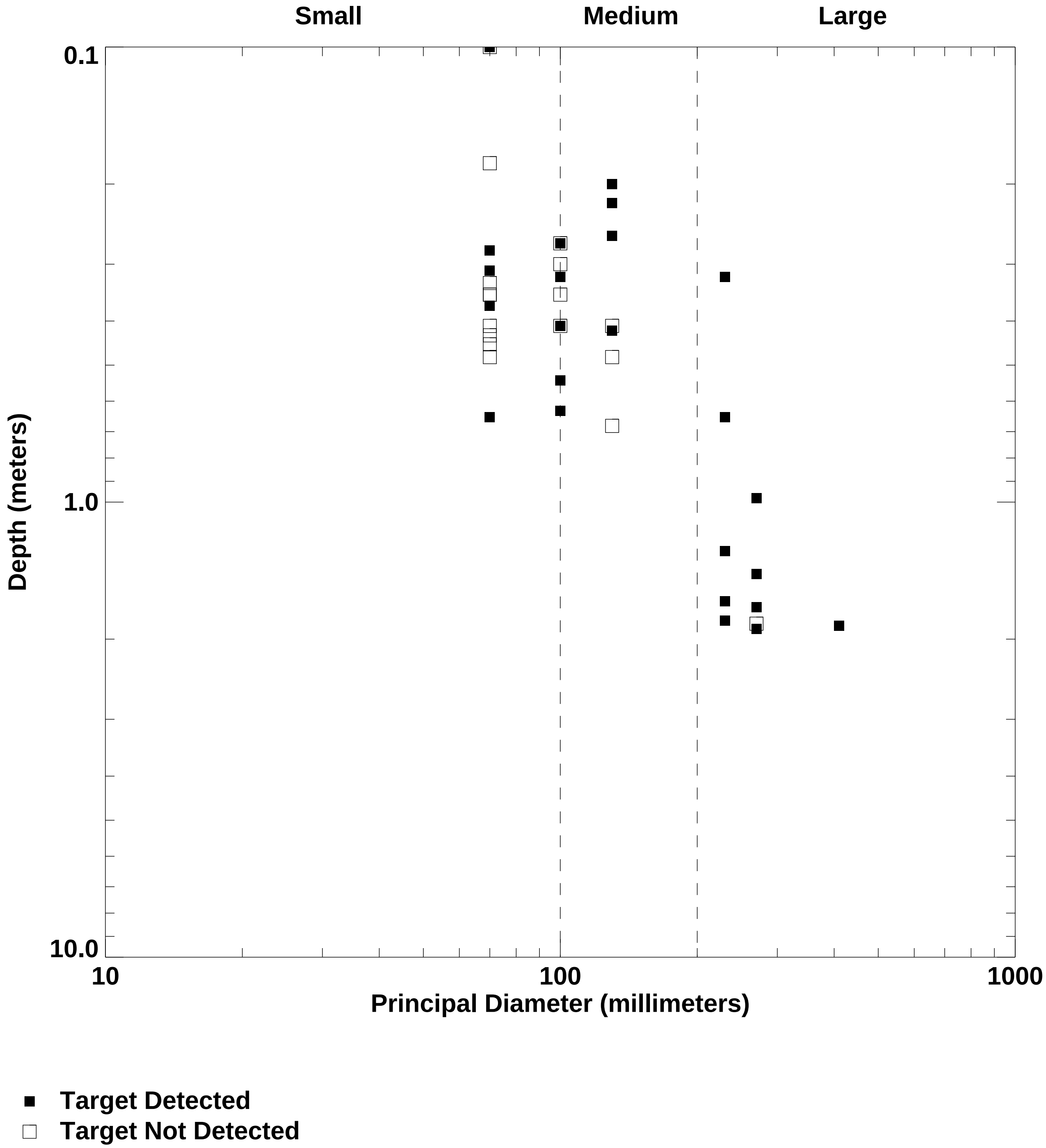
Characterization Statistics (TMA *Closest)*

	# Baseline	# Detected	P_D[b]	# Correct	P_C[d]
Ability to Type					
Ordnance	43	26	0.60	0	0.00
Nonordnance[e]	78	49	0.63	0	0.00
Ability to Size					
Large	11	10	0.91	10	1.00
Medium	7	4	0.57	3	0.75
Small	25	12	0.48	1	0.08
Ability to Classify					
Bomb	21	16	0.76	0	0.00
Projectile	0	0	NA	0	NA
Mortar	0	0	NA	0	NA
Submunition	0	0	NA	0	NA
Rocket	22	10	0.45	0	0.00

Notes:

[a] **Target Matching Algorithm**
[b] **Probability of detection**
[c] **Square root of the mean square depth error**
[d] **Probability of correct characterization**
[e] **TMA affects how nonordnance baseline targets are counted**
NA - not applicable

JPG Controlled Site: Phase III
Combined Statistics: All Surveyed Area (Excluding Scen. 4)
Critical Radius: 2 meters
Demonstrator: Foerster



6.0 GEO-CENTERS, INC.[3]

Geo-Centers demonstrated from September 24 through 28, 1996 at the 16-hectare area at JPG. Geo-Centers also participated in Phases I and II of the UXO ATD program.

6.1 DEMONSTRATED TECHNOLOGIES

6.1.1 Sensor System and Transport Mode:

STOLS® is the only GPS-integrated simultaneous magnetometer, gradiometer, and EM61 survey system in the world. It effectively performs three distinct geophysical surveys for the price of one, and does so with the highest data density presently offered in the industry. Features include:

- Vehicular, surface towed, concurrent, multisensor capability
- Total field/gradiometer magnetometer array (8 Geometrics 822A cesium vapor magnetometers with 0.5 meter spacing updating at 20 Hz, arrayed four over four with a 15" vertical separation, on a towed platform)
- Electromagnetic pulsed induction sensor array (3 Geonics EM61, half-meter coils, upper and lower, updating at 10 Hz, on front-mounted platform)
- Tow vehicle and sensor platforms designed for low magnetic and pulsed induction self-signatures
- Electronics optimized for low magnetic and electromagnetic noise
- Trimble differential GPS with Real Time Kinematic (RTK) for real-time 3 to 5 cm precision data processing center
- Same-day production of images of magnetic and EM data

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[3] **GEO-CENTERS, New Vehicular Multisensor Array Technology for UXO Detection (Phase III) at Jefferson Proving Ground, Madison, Indiana - Final Survey Report - October 1996**

6.1.2 Recommended Applications and Technology

With its vehicular-based simultaneous acquisition of GPS-integrated total field magnetometer, gradiometer, and EM61 data, STOLS® is absolutely unique in its ability to rapidly traverse large amounts of area and provide very high density, high resolution geophysical imagery in a cost-effective manner. STOLS® has been successfully deployed on over 50 commercial surveys spanning UXO, HTRW, landfill, underground storage tanks, archeological, and utility mapping applications. Magnetometers are not optimally fielded in areas where there are high concentrations of magnetic rock or other local high-frequency magnetic gradients; however, magnetometers augmented with the electromagnetic pulsed induction sensor array alleviate this situation. STOLS® has proven performance in a wide variety of topography and conditions. It can negotiate 30 degree inclines, and with 14 inch vehicle ground clearance it has been deployed in wet conditions including foot deep swamp water. Open terrains are easily traversed at 5 to 10 mph. Average speeds of 20 mph have been sustained over smooth topography. The system has been deployed in a full range of outdoor temperature conditions from below 30 F to over 120 F. Even with its front-mounted pulsed EM coils and towed magnetometer platform, the system is quite maneuverable. The differential GPS can be freely deployed worldwide, limited only by surface features blocking satellite visibility.

6.1.3 Logistics Requirements

STOLS® is a self-contained survey system with no external requirements beyond adequate parking for the tractor-trailer. The system arrives on-site complete with generators, spares, computers, and all necessary tools for field maintenance, repairs, and data processing.

6.1.4 DATA ACQUISITION

STOLS® technology is a trilogy of total field magnetometer, total field gradiometer, and electromagnetic (EM) induction sensors. The data acquisition equipment for the magnetometers includes:

- Mil-spec 486 computer with 16 megabytes RAM
- Proprietary Windows®-based data acquisition software
- Geometrics 822A cesium vapor total field magnetometers deployed in total field and gradiometer configuration
- Proprietary magnetometer interface acquiring 8 channels at 20 Hz

1 Hz DGPS input for precise positioning of magnetometer data (GPS antenna located over center magnetometer)

- Time-synchronized diurnal variation data concurrently recorded on separate reference magnetometer station

Data acquisition equipment for the electromagnetic sensors includes:

- Rugged 486 computer with 4 megabytes RAM
- Proprietary data acquisition software
- Three half-meter Geonics EM61 coils, upper and lower
- Six channels of serial data acquired at 10 Hz
- 1 Hz DGPS input for precise EM61 positioning (GPS antenna located over center coil)

6.1.5 Data Processing and Interpretation

On-site data processing uses a Silicon Graphics Unix workstation with 100 megabytes of memory and proprietary X/Motif software to combine the sensor data with the DGPS data and create spatially registered data images of the surveyed area. Data processing involves time-correlating and subtracting the reference magnetometer data from the vehicular magnetometer data, correcting for errors in the navigation and heading data, individually calibrating the sensors, and interpolating the sensor data onto a 10 cm grid for visual display. Observable surface features are surveyed with the DGPS to create a file of GPS locations that can be overlaid on a data image to correlate anomalies with trees, buildings, manholes, wells, and other cultural objects. Data are exported at several raw, preprocessed, and processed stages in a variety of file formats compatible with standard GIS, signal processing, and image processing software packages.

Magnetic data analysis includes visually identifying anomalous areas of interest in the total field data, and using a three-dimensional nonlinear least squares curve fit to a model of a magnetic dipole to extract location, size, depth, and angular parameters. The gradient data and a gradient model is then examined to further refine and resolve compound objects. In the case of electromagnetic (EM61) data, depth estimates are made using data from the lower and upper coils. Target picks from the magnetometer and EM data are spatially correlated to produce a final list.

6.1.6 Quality Assurance

STOLS® is a field hardened, ruggedized, all terrain, multisensor survey system. With over 4 years of deployment experience and over 50 commercial surveys under its belt, major design reliability issues have been addressed. The system is fielded with a set of spares, including tools and sheltered work area for affecting necessary repairs. System status indicators are provided to the operator during operations. Data are downloaded several times per day during survey operations and immediately displayed and pre-processed to validate system performance and to document coverage to date. Once validated, routine data processing is initiated on-site. Any suspect data is reacquired, if necessary. Daily coverage maps are provided so that progress can be assessed, monitored and documented. The control monuments and grid locations are overlaid on sensor image data to visually confirm that the DPGS is correctly set up and reporting locations in true latitude and longitude.

6.2 Demonstration Results

6.2.1 Assumptions

The main assumption in data analysis is that the unexploded ordnance and their depths are commensurate with the descriptions for each scenario.

6.2.2 Site-Specific Procedures

GEO-CENTERS surveyed scenarios 1, 2 and 3 with a single mob/demob. Each scenario consisted of 10 acres for a total of 30 acres. The specific scenarios surveyed are “Serial Gunnery Range,” “Artillery and Mortar Range,” and “Grenades and Submunitions Range.” These scenarios were chosen to evaluate the multisensor technology separately for specific ranges by ordnance type. All three scenarios were surveyed with the sensors at a 6" height. Scenarios 1 and 3 were surveyed first with east-west traverse lines to maximize coverage. Scenario 2 was surveyed last with north-south traverse lines.

6.2.3 Problems Encountered

A magnetometer sent out for repair did not arrive when expected, necessitating starting the survey using a spare magnetometer which was functionally equivalent but housed in a larger tube which needed to be secured to the sensor platform. The correct, repaired sensor arrived on the second day. The sensor platform experienced one flat tire. Rainy weather slowed progress on the third day but did not cause any shutdowns. Several of the heavily treed sections indicated on the topographic map were impenetrable by the vehicle and went unsurveyed.

6.2.4 Discussion of Results

As required, results are provided in a Microsoft Excel spreadsheet called *geocen3.xls* based on the Excel workbook *data_ent.xls* distributed with the statement of work. For analysis, the survey area was broken up into three separate sites reflecting scenarios 1-3. During analysis, the operator recorded a confidence flag based on the visual strength of signals in the magnetometer and EM data. These confidence flags are written into the spreadsheet under the comment field. Targets are commented “high confidence” if they had very strong mag or EM signals, or if a discernable signal was present on both the mag and EM sensors. Targets that were high confidence and also close enough to another target to be considered “compound” objects were commented as such. Targets were commented “medium confidence” if a nominal visually identifiable signal was present on either sensor. Targets were commented “low confidence” if there were some signal that might be geology or noise. A fence line runs north-south through scenarios 2 and 3, and east-west through part of scenario 3, and targets within approximately 15 meters of the visual center of these lines were commented “within 15 meters of probable fence line.” Scenario 2 contained an additional anomaly -- a very strong magnetic “streak” coincident with a gully-like geologic formation. This is probably an extended run of barbed wire lying in a gully. The endpoints of this anomaly were logged as “along the probable fence,” but several objects along this streak were individually discernable, particularly with the gradiometers and EM61 sensors, and these were logged as high-confidence targets. Other faint effects of geology can be seen in the magnetometer data. If a scenario included large objects which could have anomalies similar to geology, large signals which probably are geologic were commented “low confidence.” If the scenario precluded large objects, spatially large anomalies that were possibly geologic were not logged as targets.

It should be stressed that STOLS® is a very high resolution, very low noise, multisensor survey system, and will detect very small amounts of ferrous and non-ferrous metal left over from prior use of the survey area.

	Scenario 1	Scenario 2	Scenario 3
High Confidence	194	168	195
Medium Confidence	86	149	132
Low Confidence	39	52	68
Along Probable Fence	none	72	53

6.2.5 Raw Data

The raw data enclosed are from the STOLS® main control computer on the vehicle. Files with the extension “.mag” are sensor data files containing vehicular GPS and sensor data. These files are in a binary, compressed GEO-CENTERS format. “.mag” files whose names begin with “jpg3" contain eight channels of magnetometer data at 20 Hz and GPS data from the antenna over the center magnetometer. “.mag” files whose names begin with “0004" contain six channels of EM61 data at 10 Hz and GPS data from the antenna over the center EM coil. Files with the extension “.ref” are reference magnetometer files from the diurnal variation station. These raw data files occupy approximately 22 megabytes.

6.2.6 Processed Data

Due to the binary, compressed nature of raw STOLS® data files, a second set of processed files is provided in ASCII format. Files with the extension “.dat” are ASCII, whitespace delimited files containing latitude, longitude, and sensor values of the STOLS® data files before interpolation. Latitude and longitude are in decimal degrees. All appropriate navigation, heading, reference magnetometer, and sensor calibration corrections have been applied to the sensor data. Files on Unix machines can have longer names than files on PCs, so the names of the “.dat” files have been shortened to archive them on PC-compatible media. “.dat” files whose names begin with “m" are from the magnetometer array. ”.dat” files whose names begin with “e" are from the EM61 array. These preprocessed data files occupy approximately 113 megabytes.

6.2.7 Conclusions

STOLS® functioned nearly flawlessly, acquiring roughly 30 acres of data over scenarios 1 through 3 in roughly 24 survey hours. The only system of its kind in the world, STOLS® simultaneously high-resolution, GPS-integrated acquires total field magnetometer, gradiometer, and EM61data**.**

6.2.8 References - None.

Geo-Centers - Combined Statistics: Scenarios 1,2,3

Detection Statistics (TMA[a] *Group*)

	# Baseline	# Detected	P_D[b]	P_{random}
Ordnance	208	194	0.93	0.116
Nonordnance	166	133	0.80	
Total	374	327		
Number False Alarms	1005			
False Alarm Rate (#/Hectare)	81.80			
False Alarm Ratio (#/Ord.)	5.18			
Probability False Alarms	0.103			

Localization Statistics (TMA *Closest*) (in meters)

	Mean	Std Deviation
Position (x,y)		
dx - easting error	-0.18	0.37
dy - northing error	0.24	0.37
Radial error	0.53	0.30
Depth (z)		
dz - averaged depth error	0.38	0.3
|dz|[c] - absolute depth error	0.48	

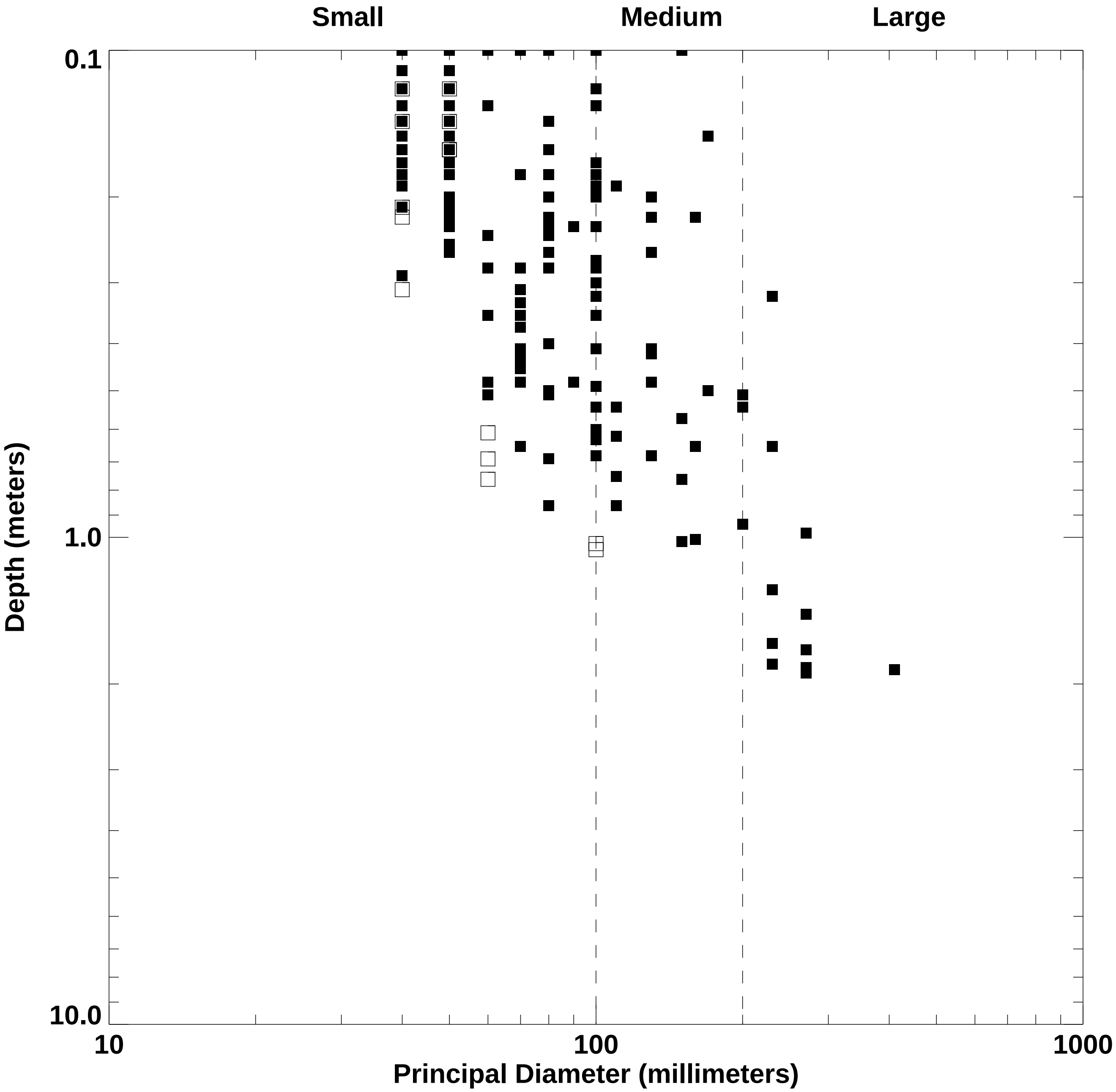
Characterization Statistics (TMA *Closest)*

	# Baseline	# Detected	P_D[b]	# Correct	P_C[d]
Ability to Type					
Ordnance	208	194	0.93	194	1.00
Nonordnance[e]	167	133	0.80	0	0.00
Ability to Size					
Large	14	14	1.00	7	0.50
Medium	39	37	0.95	14	0.38
Small	155	143	0.92	115	0.80
Ability to Classify					
Bomb	21	21	1.00	21	1.00
Projectile	42	40	0.95	39	0.98
Mortar	26	23	0.88	0	0.00
Submunition	97	88	0.91	88	1.00
Rocket	22	22	1.00	0	0.00

Notes:

[a] Target Matching Algorithm
[b] Probability of detection
[c] Square root of the mean square depth error
[d] Probability of correct characterization
[e] TMA affects how nonordnance baseline targets are counted
NA - not applicable

JPG Controlled Site: Phase III
Combined Statistics: All Surveyed Area (Excluding Scen. 4)
Critical Radius: 2 meters
Demonstrator: GEO-CENTERS



■ **Target Detected**
□ **Target Not Detected**

7.0 BLACKHAWK GEOMETRICS[9]

Blackhawk Geometrics demonstrated from October 23 through 29, 1996 at the 16-hectare area at JPG. Blackhawk Geometrics also participated in Phases I and II of the UXO ATD program.

7.1 TECHNOLOGY DESCRIPTION

The Geometrics team used a ground-based multi-sensor approach (magnetics and time-domain electromagnetics) for the JPG Phase III demonstration. These two methods showed the highest probability of detection (P_{D}) of UXO in the JPG Phase II demonstration. We believe that additional improvements in the P_{D} and a reduction in the false alarm rate (FAR) will result by combining the two methods.

The geophysical equipment used in the Phase III demonstration were:

The Geometrics G-858 MagMapper Magnetometer.
The Geonics EM61 (TDEM) Metal Detector.

A The Geonics EM61-3D (TDEM) System.

The Geometrics G-858 MagMapper$^{\text{TM}}$ portable magnetometer/Gradiometer was developed to be a rapid, efficient in-field data collection and map processing unit. It was designed for a variety of detection applications such as buried drums, tanks, etc. Geometrics and AETC have also developed maximum-likelihood dipole pattern-matching software (MagAID$^{\text{TM}}$) that allows the user to analyze magnetic data quickly and interactively. Blackhawk Geometrics has independently developed a genetic-algorithm approach to magnetic-target estimation based on the field of a uniformly magnetized rectangular prism.

[9] **Demonstartion Summary Report, Phase III UXO Detection, Identification, & Remediation, Advanced Technology Demonstration, Jefferson Proving Ground, Madison, Indiana**

The Geonics EM61 (TDEM Metal Detector) was developed to detect buried metal such as drums, storage fuel tanks, utility lines and a variety of metal objects buried in trenches and/or landfills. The system was specifically designed to mitigate the influence of variations in soil properties and ambient EM noise. The system has been used for numerous UXO surveys; however, the design is not optimized for detection of small metallic targets, such as submunitions. The prototype Geonics EM61-3D was designed for UXO detection by incorporating a more powerful transmitter and by measuring three orthogonal components of the induced magnetic field in twenty time channels (the standard EM-61 records the vertical component only at a single time gate). The EM61-3D can be operated to record a continuous data stream (dynamic mode) or at discrete locations (static mode) analogous to standard EM exploration procedure. In contrast to other demonstrators who used the dynamic mode, we operated the EM61-3D almost exclusively in the static mode in order to ensure high signal to noise ratio.

7.1.1 FIELD METHODS

7.1.1.1 SCENARIO 2 (10-Acre Artillery & Mortar Range)

Data for Scenario 2 were acquired with a hand-pulled dual array of cesium-vapor magnetometers and two hand-pulled EM61 TDEM metal detectors

The magnetometers were mounted on a rigid-wheeled cart with a horizontal sensor separation of 18 inches and sensor height of 18 inches above the ground. The array was operated by a single person. Magnetic data were taken with the array on lines three feet apart at a sample rate of 10 samples per second, resulting in a magnetic reading about every six inches along lines spaced by 18 inches. A base station magnetometer was used to remove diurnal variations from the magnetic field data.

The two EM61s were operated in the standard wheel-cart mode. Data were taken on 3 ft line spacing using an optical wheel encoder to trigger the measurements. The result is an EM61 measurement about every 7 inches along lines spaced by 36 inches.

Survey lines for all instruments ran site north to site south, parallel to survey stakes established by PRC. The field coordinate system therefore used an x-axis to site west and y-axis to site south. The x-position is therefore the line number and the y-position the station number. Line/station coordinates were converted to UTM using known site monuments.

Survey control was established by taping and spray-painting the 3-ft survey lines at 100-ft along-line intervals established by the survey stakes. Fluorescent traffic cones at these 100-ft intervals provided instrument operators a clear position of the survey line and fiducial checks were performed at each 100-ft mark. The accuracy of surveys positioned this way is expected to be ±1 ft and yet provides comparatively rapid coverage even in rough or tree-covered areas. Data acquisition rates for both EM61s and magnetometers were each better than two acres per day per unit. In typical field conditions, average productivity with magnetometers tend to be higher than with the EM61. Real-time quality assurance for the magnetics survey was achieved by monitoring the MagMapper control unit which contains a field-data display unit. For the EM61 surveys, data quality assurance was monitored by repeat test segments off the grid. For both magnetics and EM61 surveys, the data were partially processed in the field to verify data quality and to monitor total coverage on a daily basis.

There are no specific weather limitations for the use of the G-858 MagMapper^{TM} dual-sensor magnetic detection system or the EM61 metal detector. Geological limitations for magnetic measurements can occur in volcanic areas. The limitation is not in the ability to measure the magnetic anomalies but in the ability to separate geologic noise from targets of interest. There are minimal cultural limitations since both sensors are not affected by power lines or strong RF signals. The magnetic method is only effective for ferrous UXO, so that non-ferrous UXO will not be found with the magnetometer. TDEM is effective for non-ferrous and ferrous UXO and can be used in geologic environments that have volcanic materials. The biggest limitation for existing TDEM systems is their limited detection range (less than three meters depth). TDEM systems and magnetometer systems are complimentary. They each measure different physical parameters of the UXO. Together they have the potential to better locate, discriminate, and characterize.

7.1.1.2 SCENARIO 4 (20-Target Interrogation & Burial Area)

Data for Scenario 4 were acquired with magnetometers, EM61s, and the EM61-3D. The magnetometer cart was modified to include two additional sensors in a second rack 18" above the original two sensors; the resulting quad-sensor configuration can then produce both horizontal- and vertical-gradient data. The EM61-3D was operated in station-by-station, or static, mode. EM61 procedures were identical to those in Scenario 2.

Twenty red-flagged targets in Scenario 4 were assigned to Geometrics. In order to improve visual contrast with the orange group of flags, the red flags were replaced with blue ones (with the approval of PRC personnel). The flag locations were surveyed by taping their positions from the marked grid corners. The modeled target locations have small corrections to the flagged positions of order tens of centimeters; the final target locations were then converted to UTM coordinates.

A 30' x 30' grid was tape-surveyed around each target flag using local coordinate systems with the same orientation as the field coordinate system used for Scenario 2.

Magnetometer and EM-61 line and station spacings also follow Scenario 2. Station spacing for the EM-61-3D was 1 to 3 ft.

5.9.1.2 DATA PROCESSING, INTERPRETATION, AND RESULTS

The magnetic data collected in Phase III were forwarded to AETC for processing. The combined magnetic and TDEM data sets were processed by Blackhawk Geometrics. The final interpretation of the data was made by synthesizing the combined interpretation by AETC and Blackhawk Geometrics.

7.1.2.1 SCENARIO 2 (10 Acre Site, Artillery & Mortar Range)

The magnetics data taken at Scenario 2 were processed and interpreted by a workstation version of MagAid^{TM}. This software corrects for diurnal variations (drift), heading error (orientation of sensor), and performs data quality assurance checks. The graphical, interactive interface allows rapid analysis, which is important for Scenario 2 where a large number of targets are identified. Anomalies are visually selected and outlined; the program then finds the best-fitting magnetic dipole for the selected data and reports goodness-of-fit. The fitted parameters are the three-dimensional location of the target, the dipole angles (inclination and declination), and dipole moment. The target magnetization can be determined from the magnitude of the Earth's field under the assumption that magnetization is induced. The size of a sphere matching the best-fitting dipole then follows from the magnetization and the inferred magnetic moment. Parameters for accepted fits are recorded in a target list; these target lists were used to help prepare the target detection sheets.

EM61 data were used mainly for target identification. However, target depths and sizes can be estimated using programs developed at both AETC and Blackhawk Geometrics incorporating the time-domain response of a ferrous sphere. Due to the large number of targets in Scenario 2, quantitative EM61 interpretation was applied principally at Scenario 4; the methodology is described in that section below. EM61 processing is minimal, involving only a regional bias correction.

The combined data sets (magnetics and TDEM) for Scenario 2 were analyzed in two ways:

1) In a conventional manner in which magnetic anomalies and TDEM anomalies are separately located and characterized by the methods described above. Magnetic and EM anomalies that coincide were evaluated by using histogram equalization analysis to enhance anomaly contrast in a given image. This technique is useful for magnetometer and EM61 data sets since limited contrasts are sometimes observed in these data. This process is conducted on PCs using commercially available software. Color grid maps of the magnetics and EM61 data taken over Scenario 2 are given in Appendix C (Figure 1).

2) By using an advanced sensor fusion technique, Principal Component Analysis, (PCA) to statistically recombine the magnetometer and TDEM data sets into images of decreasing variance to facilitate detection and classification of anomalies. The geophysical anomalies observed in these images can be identified and delineated more robustly compared to the original images. The PCA code is proprietary to Blackhawk Geometrics and is run on a workstation. A color grid map of the second principle component for the data taken over Scenario 2 is given in Appendix C (Figure 2). The PCA clearly outlines the areas of coincident magnetic and EM61 anomalies, and reduces ambiguities caused by noise in the individual data sets. A set of overlays of the targets derived from the PCA for the Scenario 2 area is given in Appendix C (Figure 3a-3d).

In Scenario 2, UXO target locations were picked by several methods:

Manual selection based on magnetics only.
Manual selection based on EM61 only.

A.Automatic selection of combined data sets with Principal Component Analysis (PCA).

When anomalies existed in both magnetic and EM61 data, a comparison of manual selection and automatic selection with PCA showed an accurate correspondence. This comparison gives confidence in PCA for further work. Several other targets which were detected by only one method (i.e., deep targets detected by magnetics, non-ferrous targets detected by EM61) were classified by an operator using method 1 (above). Examples of deep targets detected only with magnetics are target numbers 158, 228, and 239. Examples of non-ferrous targets detected only with the EM61 are target numbers 224-227. Target parameters (type, class, depth, etc.) were mainly derived from the magnetic data, except where the magnetic data were ambiguous or targets were non-ferrous. Non-ferrous targets detected with the EM61 were classified as ordnance, but do not have ferromagnetic mass. Thus, the weight (requested in ferrous material) for these targets was listed as “none.” An additional column “NF Weight” (Non-ferrous weight) was added to the detection sheet to accommodate these targets. Obvious non-ordnance anomalies such as the buried fence line (north-south linear anomaly on west side of site) were not reported in the Detection Sheet. The detection sheet and floppy disk for Scenario 2 are given in Appendix D.

7.1.2.2 SCENARIO 4 (20 Targets, Interrogation & Burial Area)

The magnetics and EM61 data taken in Scenario 4 were also processed in the same manner as in Scenario 2. EM61-3D processing involved only editing of field errors.

The three data sets were interpreted separately and the results weighed qualitatively for the combined interpretation. Magnetic theory is best developed at present and so the magnetometer data carry the greatest weight in our interpretation. Two independent methods were used for magnetic interpretation. The first was AETC’s dipole-fitting program MagAid^{TM}, described above. The second approach, developed at Blackhawk Geometrics, is more general but broadly similar. This technique uses the analytical formulation for the magnetic field from a uniformly magnetized rectangular prism. The method therefore has the potential to accurately model the magnetic field of elongated objects (e.g. UXO) with arbitrary orientations and differing induced and remnant fields. For simplicity and comparison to MagAid^{TM}, however, all targets were modeled as cubes with a single magnetizing field. A second procedural difference is the use of a new class of global optimization methods, genetic algorithms, to solve for the best-fitting model parameters. Both magnetic modeling techniques were employed and compared. In all but five targets (with noisy signatures), there was good agreement. For the five targets, a compromise in target parameters between the two modeling procedures was used.

The time-domain electromagnetic response of a spherical target to the EM61 can also be modeled, and depth can be determined from either the anomaly half-width or the ratio of upper-to-lower receiver coil responses. Given the target depth and the peak voltage on either channel, the target diameter may be estimated. These models consider only vortex currents induced in a conductive target and do not account for the so-called "permeability currents" caused by alignment and relaxation of magnetic domains in a ferromagnetic target. EM61 depth and size modeling was used for comparison, more weight was given to the magnetic modeling.

With the EM61 - 3D a large data set is recorded per station (60 values), and the technology for effective processing is not yet developed. Moreover, the time to develop the processing capability was not available under JPG III. We evaluated several targets and considered visually the discrimination potential contained in the data, such as target orientation. Some of these visual observations have been included on the data sheets. Examples of visual display of EM61 - 3D data are shown in Figures 4 and 5 of Appendix C. Figure 4 is data acquired on the Blackhawk test range for a 25 lbs bomb, showing dependence on target orientation. Figure 5 is data acquired at JPG (Scenario 4, Target 1227) showing the potential for better positioning and orientation information.

For either magnetic or TDEM data, the equivalent (spherical) volume of known ordnance was then compared to the inferred target volume to estimate ordnance type. Three-dimensional position follows directly from the modeling procedures. Target orientation was estimated principally when the computed magnetization directions differed strongly from the natural field, under the assumption that magnetization generally follows the long axis of an elongated body. Secondary estimates of position and orientation were inferred from the EM-61-3D.

The final target parameters were obtained by combining the results from all of the estimating methods. The target detection sheet and floppy disk for Scenario 4 data are given in Appendix D.

CONCLUSIONS

The Geometrics team used a multi-sensor approach (magnetics and EM61) using the two sensors which showed the highest probability of detection (P_D) in previous JPG demonstrations. The survey procedure selected was ground-based (man-carried) using equipment and positioning techniques commonly used in commercial geophysical studies. This procedure is applicable to all terrain types, and resulted in rapid deployment, no breakdowns or lost time due to equipment failures, and nearly 100% coverage of the site.

From the interpretation of both magnetics and EM61, we concluded:

> Greater than 90 percent of the targets show coincident anomalies in both methods.

Deeply buried (greater than three meters) targets were only detected with magnetics.

B.Non-ferrous targets were only detected with the EM61.

In terms of operational capability, we observed:

Magnetic surveys are more portable and can achieve a higher productivity.
Both methods are influenced by non-ordnance metallic structures (buried fence line).

Significant new developments from the data analysis at JPG, Phase III are:

The automatic target detection with principal component analysis (PCA) is accurate when coincident anomalies in magnetic and EM61 data sets occur. PCA requires two data sets and we have already proved that the two channel readings of the EM61 also can be used to perform a PCA.

A large data set is collected with the EM61 - 3D system. There was no time to fully analyze the data set in the time frame allotted. Visual observations of graphical displays of the data indicate a high potential for target discrimination.

Geometrics - Combined Statistics: Scenario 2 only

Detection Statistics (TMA[a] *Group*)

	# Baseline	# Detected	Pd[b]	P_{random}
Ordnance	67	60	0.90	0.063
Nonordnance	50	42	0.84	
Total	117	102		
Number False Alarms	180			
False Alarm Rate (#/Hectare)	38.44			
False Alarm Ratio (#/Ord.)	3.00			
Probability False Alarms	0.048			

Localization Statistics (TMA *Closest*) (in meters)

	Mean	Std Deviation
Position (x,y)		
dx - easting error	-0.01	0.23
dy - northing error	0.21	0.38
Radial error	0.39	0.30
Depth (z)		
dz - averaged depth error	0.12	0.29
|dz|[c] - absolute depth error	0.32	

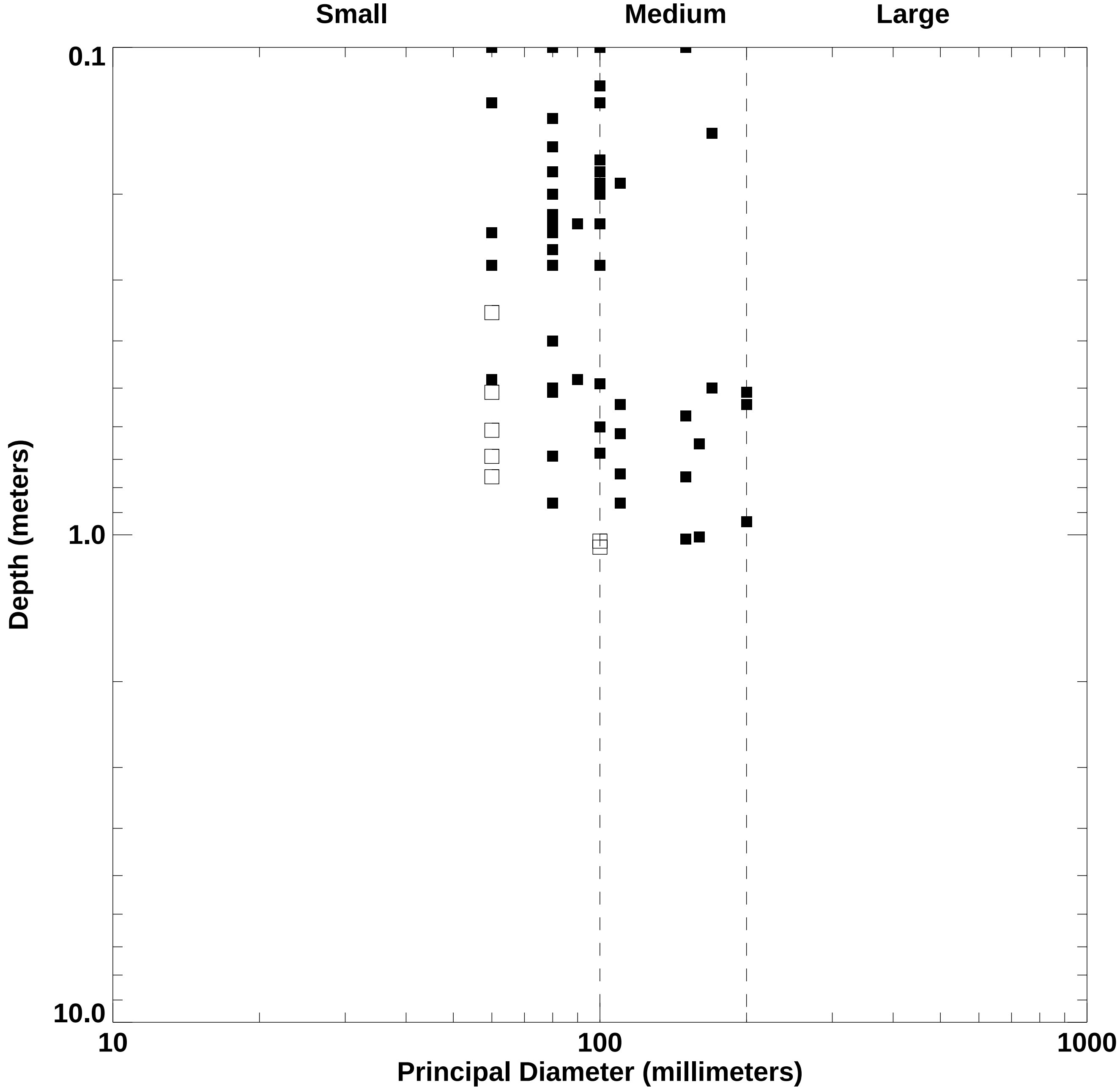
Characterization Statistics (TMA *Closest)*

	# Baseline	# Detected	P_D[b]	# Correct	P_C[d]
Ability to Type					
Ordnance	67	60	0.90	59	0.98
Nonordnance	50	42	0.84	0	0.00
Ability to Size					
Large	3	3	1.00	1	0.33
Medium	31	29	0.94	12	0.41
Small	33	28	0.85	26	0.93
Ability to Classify					
Bomb	0	0	NA	0	NA
Projectile	41	39	0.95	11	0.28
Mortar	26	21	0.81	19	0.90
Submunition	0	0	NA	0	NA
Rocket	0	0	NA	0	NA

Notes:

[a] Target Matching Algorithm
[b] Probability of detection
[c] Square root of the mean square depth error
[d] Probability of correct characterization
NA - not applicable

JPG Controlled Site: Phase III
Combined Statistics: All Surveyed Area (Excluding Scen. 4)
Critical Radius: 2 meters
Demonstrator: Geometrics



■ Target Detected
□ Target Not Detected

8.0 GEOPHEX [8]

Geophex demonstrated from October 23 through 27, 1996 at the 16-hectare area at JPG. Geophex also participated in Phase II of the UXO ATD program.

8.1 TECHNOLOGY DESCRIPTION

During the JPG demonstration we used a combination of the GEM-3 (Geophex ElectroMagnetic instrument, version 3; Figure 1) and a commercially available cesium-vapor magnetic gradiometer. The GEM-3 is a frequency domain, electromagnetic induction sensor developed by Geophex, Ltd. It is a unique, lightweight (total weight of 10 lb.), hand-held instrument. The GEM-3 transmits a primary electromagnetic field that induces a secondary current in electrically conductive targets. It then senses the secondary magnetic field produced by these induced currents. The primary transmitted field is made up of a multi-frequency composite waveform, allowing different penetration depths in the earth, depending on conductivity structure. The GEM-3 consists of a transmitter and receiver coil assembly, a digitally controlled transmitter, a low-noise analog receiver, an analog-to-digital converter, and a custom digital signal processing unit. The magnetometer used was a Geometrics G-858, cesium-vapor magnetic gradiometer. We feel that when combined, the use of magnetic and electromagnetic sensors provides a more effective technique for UXO surveys than either technology alone.

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[8] GEOPHEX, Final Demonstration Report on Geophex's Technology Demonstration, December 1996

8.1.1 Assumptions Made Prior to Demonstration

We assumed that targets of interest in the JPG demonstration could be either magnetic and non-magnetic conductors. For this reason we elected to use total magnetic field, vertical magnetic field gradient, and electromagnetic induction instruments. No other assumptions were made prior to the demonstration.

8.1.2 Procedures Used to Conduct Demonstration

Data were collected in a grid pattern using the grid coordinate system already in place at JPG. Grid lines were laid out and each instrument traversed these lines while collecting data. All instruments used by Geophex personnel were man-portable. Data point locations were determined via a dead reckoning procedure.

8.1.3 Raw Data Obtained

The raw data collected during surveys conducted at JPG consisted of magnetic (total field and vertical gradient) and electromagnetic (GEM-3) readings. Secondary electromagnetic field data were presented as parts per million of the primary transmitted field. The 20 acres included in scenarios 1 and 2 were surveyed with both magnetic and electromagnetic sensors in less than the 40 hours allotted. This time period includes time spent re-acquiring data over areas where preliminary data analyses indicated less than optimal data quality. Additionally, the entire 20 acre site was surveyed twice, with both instruments, once with traverse lines in the east-west direction, and again with lines in a north-south orientation.

8.1.4 Data Processing

The raw data were plotted in contour maps from which we determined the target location and other attributes.

The target data information include the target identification number, spatial coordinates (northing and easting), depth (m), type (ordnance or non-ordnance), weight (light, moderate, or heavy), and size (small, medium, or large).

8.1.5 Technology Capabilities and Limitations

GEM type instruments have been successfully used by Geophex personnel since 1992 to map targets as varied as contaminant plumes, buried landfills, and underground storage tanks. Testing by Geophex staff members has shown the GEM-family of instruments to be effective in locating many different kinds of buried targets and debris. These include tanks, wells, pipelines, barrels, and the site of a former underground nuclear detonation. Since the GEM-3 is a hand-held instrument, a major limitation is the ability and endurance of the operator. As with all geophysical techniques, magnetic and electromagnetic data suffer from non-uniqueness. That is, many different targets are capable of producing the same magnetic or electromagnetic signature. This is probably the major limitation of these technologies.

During the course of the demonstration we did experience some equipment problems with the magnetometer, but this did not materially effect our data acquisition efforts. We experienced no equipment malfunctions with the GEM-3.

Considering the results of our demonstration at JPG II and ancillary experience, we feel the combination of magnetic and GEM-3 electromagnetic sensors yield a powerful combination of data sets for location of UXO targets.

Geophex - Combined Statistics: Scenarios 1,2

Detection Statistics (TMA[a] *Group*)

	# Baseline	# Detected	Pd[b]	P_{random}
Ordnance	110	85	0.77	0.053
Nonordnance	127	89	0.70	
Total	237	174		
Number False Alarms	264			
False Alarm Rate (#/Hectare)	32.44			
False Alarm Ratio (#/Ord.)	3.11			
Probability False Alarms	0.041			

Localization Statistics (TMA *Closest*) (in meters)

	Mean	Std Deviation
Position (x,y)		
dx - easting error	-0.06	0.45
dy - northing error	0.17	0.39
Radial error	0.51	0.34
Depth (z)		
dz - averaged depth error	-0.05	0.27
|dz|[c] - absolute depth error	0.26	

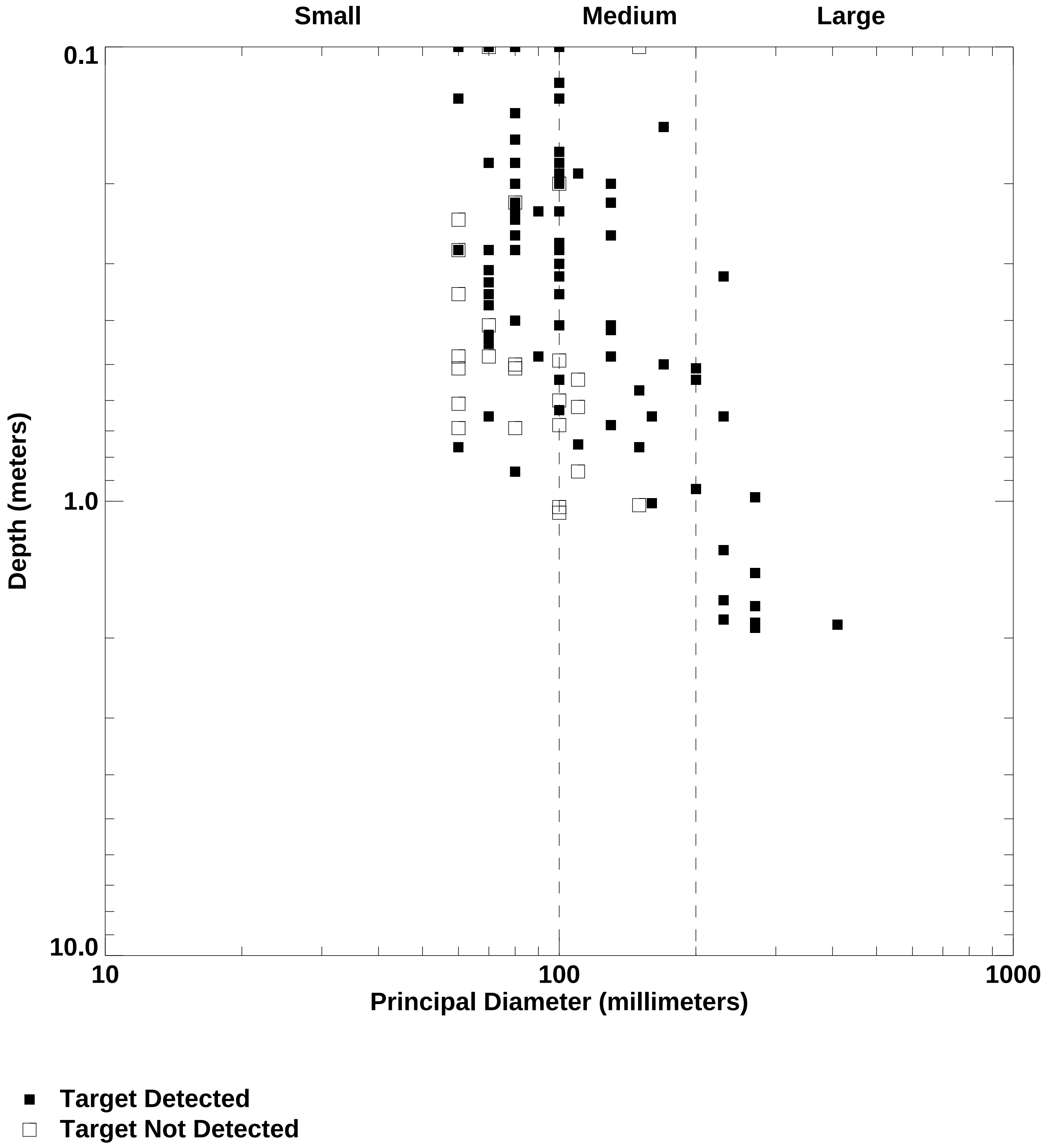
Characterization Statistics (TMA *Closest)*

	# Baseline	# Detected	P_D[b]	# Correct	P_C[d]
Ability to Type					
Ordnance	110	85	0.77	85	1.00
Nonordnance[e]	128	89	0.70	2	0.02
Ability to Size					
Large	14	14	1.00	5	0.36
Medium	38	27	0.71	16	0.59
Small	58	44	0.76	22	0.50
Ability to Classify					
Bomb	21	21	1.00	0	0.00
Projectile	41	30	0.73	0	0.00
Mortar	26	15	0.58	0	0.00
Submunition	0	0	NA	0	NA
Rocket	22	19	0.86	0	0.00

Notes:

[a] Target Matching Algorithm
[b] Probability of detection
[c] Square root of the mean square depth error
[d] Probability of correct characterization
[e] TMA affects how nonordnance baseline targets are counted
NA - not applicable

JPG Controlled Site: Phase III
Combined Statistics: All Surveyed Area (Excluding Scen. 4)
Critical Radius: 2 meters
Demonstrator: Geophex



9.0 GEOPOTENTIAL [1]

GeoPotential demonstrated from September 3 through 6, 1996 at the 16-hectare area at JPG. GeoPotential also participated in Phase II of the UXO ATD program.

9.1 TECHNOLOGY DESCRIPTION

9.1.1 Sensor System and Transport Mode

The AQUA-TRONICS A6 TRACER is manufactured by AQUA-TRONICS in Redmond, Oregon. It is a man-portable elctromagnetic induction instrument operating at 117 kHz. The instrument consists of transmitting and receiving antennas separated by a 1.22 meter handle. Subsurface features such as UXO will cause variations in the shape of the transmitted wave which will be detected as voltage variations by the receiving antenna.

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[1] **(GeoPotential , Phase III Unexploded Ordnance Advanced Technology Demonstration Program - Survey Data Analysis Report - October 5, 1996).**

9.1.2 Recommended Applications

The A6 TRACER was developed over 20 years ago to detect subsurface utilities such as conductive pipes and power cables and is an excellent tool for these applications. GeoPotential has worked with AQUA-TRONICS over the last several years to adapt the A6 TRACER for the applications such as locating buried waste drums, underground storage tanks and other near surface objects and is now used routinely by GeoPotential for these applications.

The A6 TRACER is limited to near surface features. Variations in soil moisture and soil types can cause voltage changes which can create false positive anomalies. Surface features such as overhead power lines, vehicles, buildings, etc. can create interference during a survey.

9.1.3 Logistics Requirements

The A6 TRACER is man portable and can be operated in any areas where the instrument can be carried. It is necessary to maintain a level orientation between the antennas since the instrument is sensitive to tilting.

9.1.4 Data Acquisition

For the UXO PHASE III demonstration two A6 operators used the A6 TRACER in the search mode utilizing the audible output to locate possible UXO. These targets were flagged on the site. Next a 6X6 meter grid was laid out over the target and 5 east-west profiles with a 1 meter profile spacing and 1 north-south profile were recorded with the A6 TRACER in the mapping mode. Data was recorded on a OMNIDATA PRO2000 data logger at a 1 second sampling interval.

The UTM COORDINATES of the targets were measured using a SOKKIA GIR1000 GLOBAL POSITIONING SYSTEM in the differential mode.

9.1.5 Data Processing and Interpretation

A6 data for each target were downloaded to a LAPTOP computer. The 5 east-west profiles were gridded and contoured to form the EM CONTOUR maps provided for each target. In addition the north-south profile was plotted along with the contour map for each target. North-south profiles cross the middle of the grid at meters east = 3.

The contour maps were evaluated to determine the azimuth, declination, depth and size for each target. Anomaly shape and gradient was used to interpret target azimuth and declination. Anomaly amplitude and wavelength was used to inerpret target depth and size. The north-south profile was used to identify linear targets which had a east-west orientation since this sort of target will not produce a significant anomaly along the east-west profiles. This is caused by the fact that a linear target produces a maximum A6

TRACER anomaly when oriented perpendicular to the direction of traverse and a minimum anomaly when oriented parallel to the direction of traverse.

9.1.6 Quality Assurance

Repeats of targets with the GPS system provided repeatability within .4 to .6 meters which was considered of sufficient quality for the statistical requirements of the UXO program.
A6 TRACER quality was tested by repeating several targets to assure repeatability of results.

9.2 DEMONSTRATION RESULTS

9.2.1 Assumptions

Targets which produced EM ANOMALIES which were of the size and shape compatible with UXO were assumed to be caused by UXO.

9.2.2 Problems Encountered

Along some of the A6 TRACER PROFILES and corresponding contour maps dc level shifts and ramps were found as noise in the A6 data. In most cases it was possible to resolve this noise from the target anomaly.

9.2.3 Discussion of Results

The results demonstrated that of the 147 targets detected in the survey; 93 occurred in SCENARIO 1, 22 in SCENARIO 2 and 32 in SCENARIO 3 (GeoPotential did not survey SCENARIO 4). It is most probable the larger targets in SCENARIO 1 made them more receptive to detection with the A6 TRACER. Utilizing the TRACER in the search mode, where the audible output of the TRACER is used for target detection, makes detection of smaller targets difficult.

If the noise encountered in the A6 mapping mode (dc level shifts and ramping) can be diagnosed and eliminated then the A6 TRACER could be used to map large areas and identify smaller target sizes. GeoPotential and AQUA-TRONICS are currently researching the noise problems encountered during mapping mode.

9.2.4 Conclusions

The A6 TRACER is an effective instrument to detect the types of TARGETS in SCENARIO 1 when used in a combination SEARCH and MAPPING modes.

If noise problems encountered in the MAPPING MODE can be solved then the A6 TRACER should be an effective instrument for detecting smaller UXO such as encountered in SCENARIO 2 and SCENARIO 3.

GeoPotential - Combined Statistics: Scenarios 1,2,3

Detection Statistics (TMA[a] *Group*)

	# Baseline	# Detected	Pd[b]	P_{random}
Ordnance	208	13	0.06	0.013
Nonordnance	166	15	0.09	
Total	374	28		
Number False Alarms	111			
False Alarm Rate (#/Hectare)	9.04			
False Alarm Ratio (#/Ord.)	8.54			
Probability False Alarms	0.011			

Localization Statistics (TMA *Closest*) (in meters)

	Mean	Std Deviation
Position (x,y)		
dx - easting error	0.12	0.61
dy - northing error	-0.19	0.6
Radial error	0.73	0.49
Depth (z)		
dz - averaged depth error	0.36	0.6
|dz|[c] - absolute depth error	0.69	

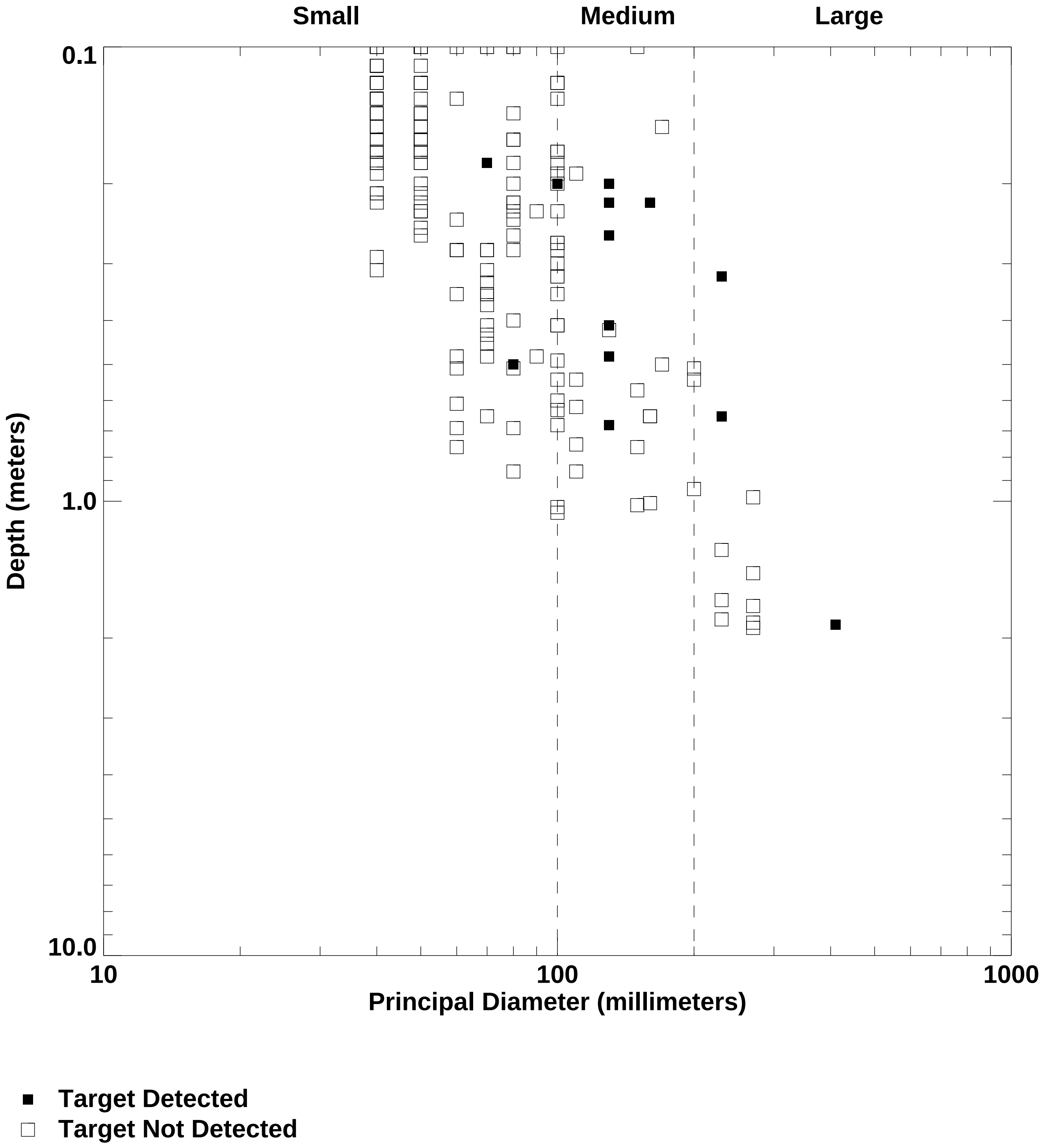
Characterization Statistics (TMA *Closest)*

	# Baseline	# Detected	P_D[b]	# Correct	P_C[d]
Ability to Type					
Ordnance	208	13	0.06	13	1.00
Nonordnance[e]	167	15	0.09	1	0.07
Ability to Size					
Large	14	3	0.21	1	0.33
Medium	39	8	0.21	7	0.88
Small	155	2	0.01	0	0.00
Ability to Classify					
Bomb	21	3	0.14	0	0.00
Projectile	42	2	0.05	0	0.00
Mortar	26	1	0.04	0	0.00
Submunition	97	0	0.00	0	NA
Rocket	22	7	0.32	0	0.00

Notes:

[a] Target Matching Algorithm
[b] Probability of detection
[c] Square root of the mean square depth error
[d] Probability of correct characterization
[e] TMA affects how nonordnance baseline targets are counted
NA - not applicable

JPG Controlled Site: Phase III
Combined Statistics: All Surveyed Area (Excluding Scen. 4)
Critical Radius: 2 meters
Demonstrator: GeoPotential



10.0 GEOPHYSICAL RESEARCH INSTITUTE[10]

The Geophysical Research Institute (GRI) demonstrated from October 9 through 13, 1996 at the 16-hectare area at JPG. GRI was a first time participant in the UXO ATD program.

10.1 TECHNOLOGY DESCRIPTION

The TM-4 & TM-4ε employ the same instrumentation system interfaced with either total field magnetic or multi-period, transient EM sensors respectively.

10.1.1 TM-4 Magnetometer System

The TM-4 magnetometer is a turnkey data acquisition, processing, interpretation and documentation package designed to efficiently detect and locate ferrous items. It was demonstrated as a two-person operation, with four sensors (Geometrics G822AS) recording simultaneously from parallel survey lines. Total field measurements are automatically recorded at 0.1 metre intervals irrespective of traverse speed.

[10] **The Geophysical Research Institute, Final Report for UXO Detection, Identification and Remediation Technology Demonstration -1996, 13 November 1996**

10.1.2 TM-4ε Electromagnetic System

The TM-4ε is a turnkey system designed to efficiently detect and locate both ferrous and non-ferrous metallic sources. It is immune to interference from magnetic minerals in the ground, is able to detect both large and very small (including the detonator of a plastic AP mine) items and able to resolve between items that may be close to each other. The TM-4ε shares the proven TM-4 data acquisition hardware, and data processing, interpretation and documentation software package.The TM-4ε demonstrated used asingle, 18 inch diameter coil sensor (Minelab F1A4). It was operated by one person. Multi-period, transient EM measurements were automatically recorded at regular 0.05 metre intervals regardless of survey speed.

10.1.3 Recommended Applications and Technology Limitations

10.1.3.1 TM-4 Magnetometer System

In EOD applications magnetometers are suitable only for detecting ferrous items. The TM-4 is used to greatest advantage when its survey specification has been optimised for targets deeper than 0.3 metres as a shallow search is most efficiently conducted using the complementary TM-4ε. Multiple magnetic sensors may be used in all terrain conditions that are accessible on foot provided the density of trees is sufficiently sparse as to permit the sensor array to pass through.

10.1.3.2 TM-4ε Multi-period, Time Domain EM System

The TM-4ε is suitable for detecting all metals, ferrous and non-ferrous. It may be hand-held or vehicle-towed. The TM-4ε is particularly suited to locating UXO in geological environments that contain magnetic minerals near the surface. Such situations occur in magnetite rich volcanic basalts and in terrains containing laterite. Ability to detect very small, near surface items and to resolve between close targets makes the TM-4ε an ideal complement to the deep search performance of the TM-4.

10.1.4 Logistics requirements

The TM-4 and TM-4ε systems are designed to be readily transportable and operational with a minimum of logistical support. Both instruments pack into cases permitted for airline travel as personal baggage. Battery charging power requirements can be met from automotive 12 volt supply if mains is not available.

10.1.5 Data Acquisition

The quad sensor TM-4 magnetic data to 0.01 nT resolution were recorded at a sensor elevation of 0.65 metres, with 0.1 metres sample interval along lines and 0.5 metre separation between lines. A base-station (Geometrics G856) magnetometer was used recording to 0.1 nT, each five seconds.

At each controlled site, TM-4ε electromagnetic data were recorded at a mean sensor elevation of 0.1 metres, sample interval of 0.05 metres and survey line spacing of 0.5 metres.

In both the TM-4 and TM-4ε applications, position control along survey lines was determined by cotton thread odometer and control lines of known separation located at grid markers provided by PRC. Across line control was achieved by the use of a line of visual markers located at survey chains laid along the control lines. The use of DGPS is optional with both TM-4 and TM-4ε systems.

10.1.6 Data Processing and Interpretation

Data processing was performed on a standard IBM-compatible PC (minimum 486 with 8 Mb RAM and 100 Mb HDD). In the main, GRI employed Toshiba 410 lap-tops with Pentium 90 processor, 16 Mb RAM, 720 Mb HDD.

10.1.6.1 TM-4 Magnetic Data

The TM-4 positional data was corrected by using the control line information recorded during data acquisition. Compensation was also performed to remove the temporal magnetic disturbances recorded at the base-station magnetometer. This data were stored as a raw, positioned data file. The data were then heading corrected for sensor orientation and high pass filtered to remove interference from geological sources below 10 metres. Next, data validation and QA procedures were performed.

The data interpretation process involved computer-aided, 3-D modelling of each magnetic anomaly and comparison with a UXO knowledgebase. The output of this interpretation process was a database file “GTLMG.XLS” containing position, mass, size, depth and orientation of each target recognised.

10.1.6.2 TM-4ε Electromagnetic Data

The TM-4ε positional data was corrected by using the control line information recorded during data acquisition. This data were then stored as a raw positioned data file. Next, data validation and QA procedures were performed. The data interpretation process involved manual and automatic, computer-aided identification of each electromagnetic anomaly followed by interpretation using a UXO knowledgebase. The output of this interpretation process was a database file “GTLEM.XLS”.

10.1.6.3 Integrated TM-4 and TM-4ε Data

The database files GTLMG.XLS and GTLEM.XLS were then integrated in order to:

- take greatest advantage of the optimised deep detection capability of the TM-4;
- detect non-ferrous as well as ferrous targets;
- discriminate against magnetic false negatives using immunity of the TM-4ε to mineralised soil; and
- utilise the TM-4ε to resolve between small near surface items.

The database file containing the integrated interpretation has been named GTLCB.XLS.

10.1.7 Quality Assurance

Quality assurance procedures were applied to each phase of the operation. These procedures included:

- instrument calibration checks with known response source at each power-up and power-down;
- continuous, in-built, instrumentation self diagnostics with audio and visual alerts;
- routine odometer calibration check during data pre-processing;
- routine cross-correlation positional accuracy check during data processing;
- routine image cross-correlation data validation check during pre-processing;
- routine duplication of interpretation modelling; and
- routine data back-up during all stages.

10.2 Demonstration Results

10.2.1 Assumptions

All electromagnetic responses exceeding the system noise threshold were assumed to have as their source a potentially hazardous item of metallic UXO unless the dimensions of the interpreted source were inconsistent with those of UXO or a burial pit potentially containing UXO.

10.2.2 Site-Specific Procedures

The occurrence of standing and fallen vegetation and erosion gullies dictated that hand-carried operation using the in-built odometer and control lines (rather than the optional DGPS) would be the most efficient and cost-effective procedure at this site.

10.2.3 Problems Encountered

One magnetic sensor incurred minor damage during transit and as a consequence required an abnormal warm-up period before becoming fully functional.

Grid markers at the four corners of the entire demonstration area had been accurately located by surveying prior to the UXO data acquisition survey. However, grid markers between these points were not accurately located. As accurately located survey control lines rather than control points are best used for survey control, reliance on the intermediate markers would give a potential source of uncertainty in data positioning.

10.2.4 Discussion of Results

The attached tables summarize the results at each of the three sites investigated.

TABLE 1
Aerial Gunnery Range

Total area surveyed:	3.45 hectares

Magnetic sensor elevation:	0.65 m
Magnetic sample interval along traverses:	0.1 m
Magnetic sample interval across traverses:	0.5 m
Number of magnetic data measurements:	691,740
Survey duration:	10.5 hours
Magnetic measurement system noise:	0.2 nT
Magnetic interpretation noise threshold:	1 nT
Number of interpreted ferrous items:	880

Electromagnetic sensor elevation:	0.05 m
Electromagnetic sample interval along traverses:	0.05 m
Electromagnetic traverse width:	0.5 m
Number of electromagnetic data measurements:	1,383,480
Survey duration:	11.0 hours
Electromagnetic interpretation noise threshold:	±10 emu
Number of interpreted metallic items:	416

Total number of targets identified:	**828 (combined data set)**

TABLE 2
Artillery and Mortar Range

Total area surveyed (Magnetics):	4.68 hectares
(Electromagnetics):	4.53 hectares
Magnetic sensor elevation:	0.65 m
Magnetic sample interval along traverses:	0.1 m
Magnetic sample interval across traverses:	0.5 m
Number of magnetic data measurements:	827,820
Survey duration:	14 hours
Magnetic interpretation noise threshold:	0.2 nT
Number of interpreted ferrous items:	1,186
Electromagnetic sensor elevation:	0.05 m
Electromagnetic sample interval along traverses:	0.05 m
Electromagnetic traverse width:	0.5 m
Number of electromagnetic data measurements:	1,655,640
Survey duration:	15 hours
Electromagnetic interpretation noise threshold:	±10 emu
Number of interpreted metallic items:	611
Total number of targets identified:	**1,280 (combined data set)**

TABLE 3
Grenades and Sub-munitions Range

Total area surveyed (Magnetics):	4.16 hectares
(Electromagnetics):	4.08 hectares
Magnetic sensor elevation:	0.65 m
Magnetic sample interval along traverses:	0.1 m
Magnetic sample interval across traverses:	0.5 m
Number of magnetic data measurements:	934,690
Survey duration:	13.5 hours
Magnetic interpretation noise threshold:	0.2 nT
Number of interpreted ferrous items:	853
Electromagnetic sensor elevation:	0.05 m
Electromagnetic sample interval along traverses:	0.05 m
Electromagnetic traverse width:	0.5 m
Number of electromagnetic data measurements:	1,869,380
Survey duration:	14 hours
Electromagnetic interpretation noise threshold:	±10 emu
Number of interpreted metallic items:	694
Total number of targets identified:	**1,071 (combined data set)**

10.2.5 Digital Data

10.2.5.1 Raw Data

The raw data were provided in XYZ format, local coordinates. Coordinate translation was used to provide UTM coordinates. The parameters used in this translation are listed in the file ‘readme.txt’.

- The magnetic raw data from the Aerial Gunnery Range is contained in file 1MG.XYZ
- The magnetic raw data from the Artillery and Mortar Range is contained in file 2MG.XYZ
- The magnetic raw data from the Grenades and Sub-munitions Range is contained in file 3MG.XYZ
- The EM raw data from the Aerial Gunnery Range is contained in file 1EM.XYZ
- The EM raw data from the Artillery and Mortar Range is contained in file 2EM.XYZ
- The EM raw data from the Grenades and Sub-munitions Range is contained in file 3EM.XYZ

10.2.5.2 Processed Data

The combined magnetic and electromagnetic interpretation database (GTLCB.XLS) is our primary processed data set. The databases for each individual interpretation has been provided to facilitate a breakdown analysis from which the value of the components and the combination may be assessed.

- The complete magnetic target database is contained in file GTLMG.XLS
- The complete EM target database is contained in file GTLEM.XLS
- The complete combined target database is contained in file GTLCB.XLS

10.2.6 Conclusions

- Four hectares at each of the “Aerial Gunnery Range”, “Artillery and Mortar Range” and “Grenades and Sub-munitions Range” sites were mapped with GTL’s proprietary TM-4, quad sensor magnetometer system and proprietary TM-4ε electromagnetic system.
- The magnetic survey was conducted with a single, two person operated instrument in a total survey time of 38 hours with 2 hours down-time.
- The electromagnetic survey was conducted by three, single-person operated TM-4ε instruments in a total crew time of 120 hours. No down-time was experienced.
- The magnetic survey, optimised for targets occurring deeper than 0.3 m, detected a total of 2,919 magnetic targets on this data alone.
- The EM survey detected a total of 1,721 metallic targets.
- Integrating the magnetic and EM data permitted discrimination against false negative magnetic targets and resulted in a total of 3,179 potential targets being identified.

Integration of the magnetic and electromagnetic data optimised the deep search capability of the TM-4 with the ability of the TM-4ε to detect non-ferrous metals and to discriminate against interference from mineralised soils.

GRI (Combined) - Combined Statistics: Scenarios 1,2,3

Detection Statistics (TMA[a] *Group*)

	# Baseline	# Detected	Pd[b]	P_{random}
Ordnance	208	194	0.93	0.276
Nonordnance	166	147	0.89	
Total	374	341		
Number False Alarms	2955			
False Alarm Rate (#/Hectare)	240.53			
False Alarm Ratio (#/Ord.)	15.23			
Probability False Alarms	0.302			

Localization Statistics (TMA *Closest*) (in meters)

	Mean	Std Deviation
Position (x,y)		
dx - easting error	-0.04	0.3
dy - northing error	0.08	0.35
Radial error	0.39	0.27
Depth (z)		
dz - averaged depth error	0.23	0.34
|dz|[c] - absolute depth error	0.41	

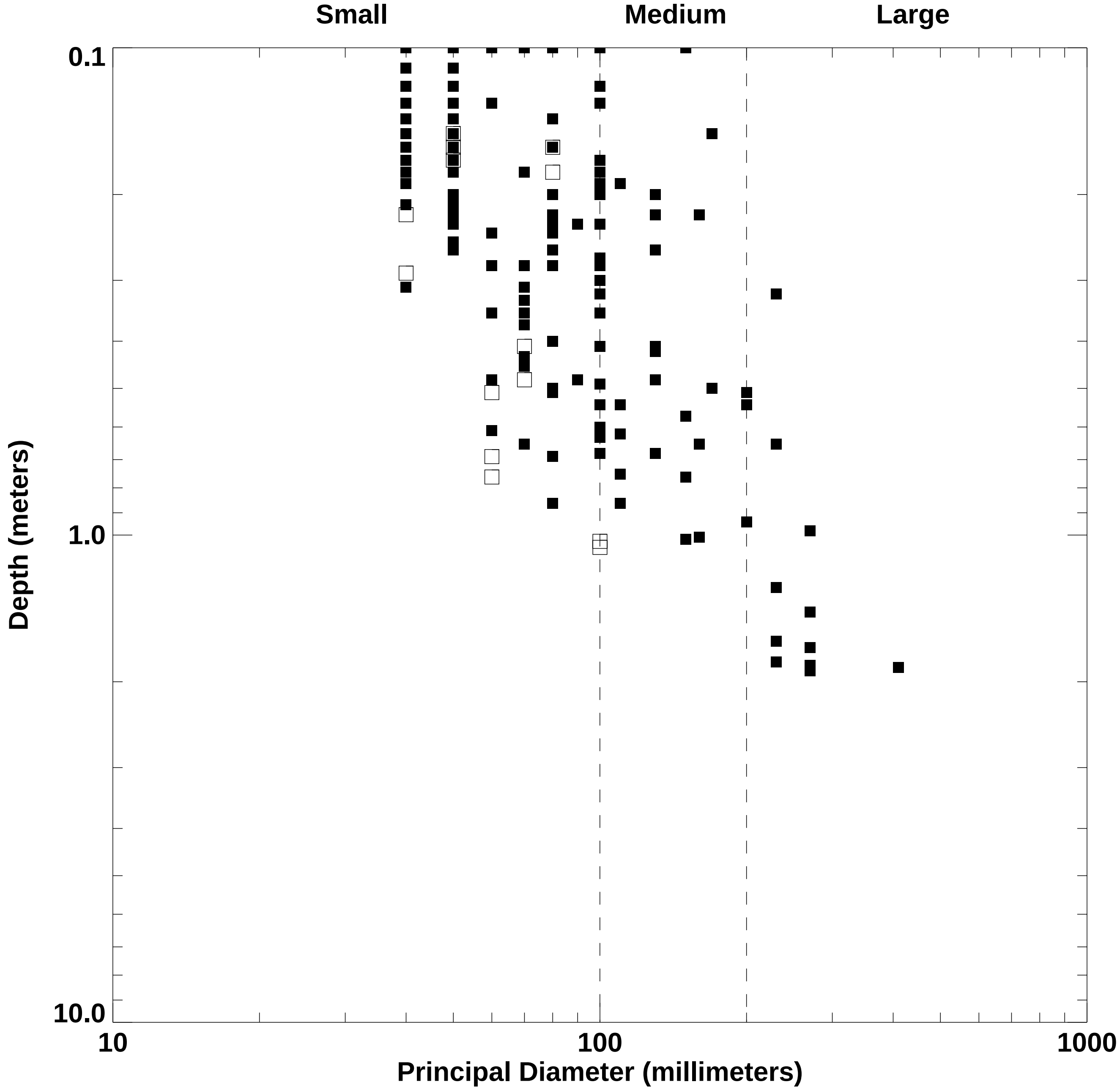
Characterization Statistics (TMA *Closest)*

	# Baseline	# Detected	P_D[b]	# Correct	P_C[d]
Ability to Type					
Ordnance	208	194	0.93	182	0.94
Nonordnance[e]	167	147	0.88	16	0.11
Ability to Size					
Large	14	14	1.00	7	0.50
Medium	39	37	0.95	7	0.19
Small	155	143	0.92	60	0.42
Ability to Classify					
Bomb	21	21	1.00	10	0.48
Projectile	42	39	0.93	11	0.28
Mortar	26	22	0.85	10	0.45
Submunition	97	92	0.95	0	0.00
Rocket	22	20	0.91	10	0.50

Notes:

[a] Target Matching Algorithm
[b] Probability of detection
[c] Square root of the mean square depth error
[d] Probability of correct characterization
[e] TMA affects how nonordnance baseline targets are counted
NA - not applicable

JPG Controlled Site: Phase III
Combined Statistics: All Surveyed Area (Excluding Scen. 4)
Critical Radius: 2 meters
Demonstrator: GRI-Combined



■ Target Detected
□ Target Not Detected

GRI (EM) - Combined Statistics: Scenarios 1,2,3

Detection Statistics (TMA[a] *Group*)

	# Baseline	# Detected	Pd[b]	P_{random}
Ordnance	208	180	0.87	0.16
Nonordnance	166	135	0.81	
Total	374	315		
Number False Alarms	1522			
False Alarm Rate (#/Hectare)	123.89			
False Alarm Ratio (#/Ord.)	8.46			
Probability False Alarms	0.156			

Localization Statistics (TMA *Closest*) (in meters)

	Mean	Std Deviation
Position (x,y)		
dx - easting error	-0.04	0.32
dy - northing error	0.1	0.33
Radial error	0.39	0.28
Depth (z)		
dz - averaged depth error	0.32	0.36
|dz|[c] - absolute depth error	0.48	

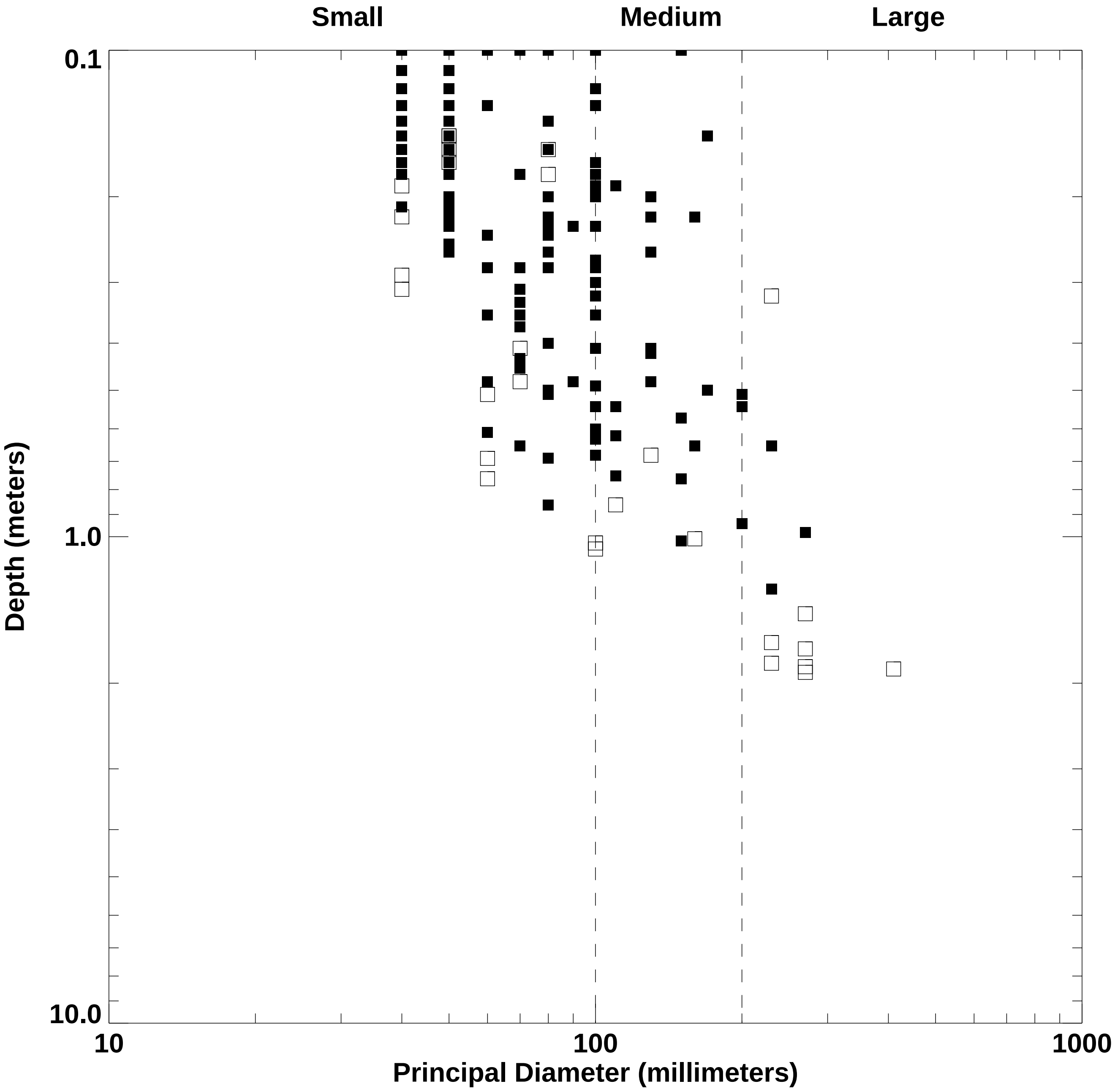
Characterization Statistics (TMA *Closest)*

	# Baseline	# Detected	P_D[b]	# Correct	P_C[d]
Ability to Type					
Ordnance	208	180	0.87	178	0.99
Nonordnance[e]	167	135	0.81	7	0.05
Ability to Size					
Large	14	6	0.43	0	0.00
Medium	39	34	0.87	0	0.00
Small	155	140	0.90	0	0.00
Ability to Classify					
Bomb	21	13	0.62	0	0.00
Projectile	42	37	0.88	0	0.00
Mortar	26	22	0.85	0	0.00
Submunition	97	89	0.92	0	0.00
Rocket	22	19	0.86	0	0.00

Notes:

[a] Target Matching Algorithm
[b] Probability of detection
[c] Square root of the mean square depth error
[d] Probability of correct characterization
[e] TMA affects how nonordnance baseline targets are counted
NA - not applicable

JPG Controlled Site: Phase III
Combined Statistics: All Surveyed Area (Excluding Scen. 4)
Critical Radius: 2 meters
Demonstrator: GRI-EM



■ **Target Detected**
□ **Target Not Detected**

GRI (Mag) - Combined Statistics: Scenarios 1,2,3

Detection Statistics (TMA[a] *Group*)

	# Baseline	# Detected	Pd[b]	P_{random}
Ordnance	208	146	0.70	0.257
Nonordnance	166	140	0.84	
Total	374	286		
Number False Alarms	2748			
False Alarm Rate (#/Hectare)	223.68			
False Alarm Ratio (#/Ord.)	18.82			
Probability False Alarms	0.281			

Localization Statistics (TMA *Closest*) (in meters)

	Mean	Std Deviation
Position (x,y)		
dx - easting error	-0.07	0.37
dy - northing error	0.08	0.46
Radial error	0.48	0.35
Depth (z)		
dz - averaged depth error	0.14	0.44
|dz|[c] - absolute depth error	0.46	

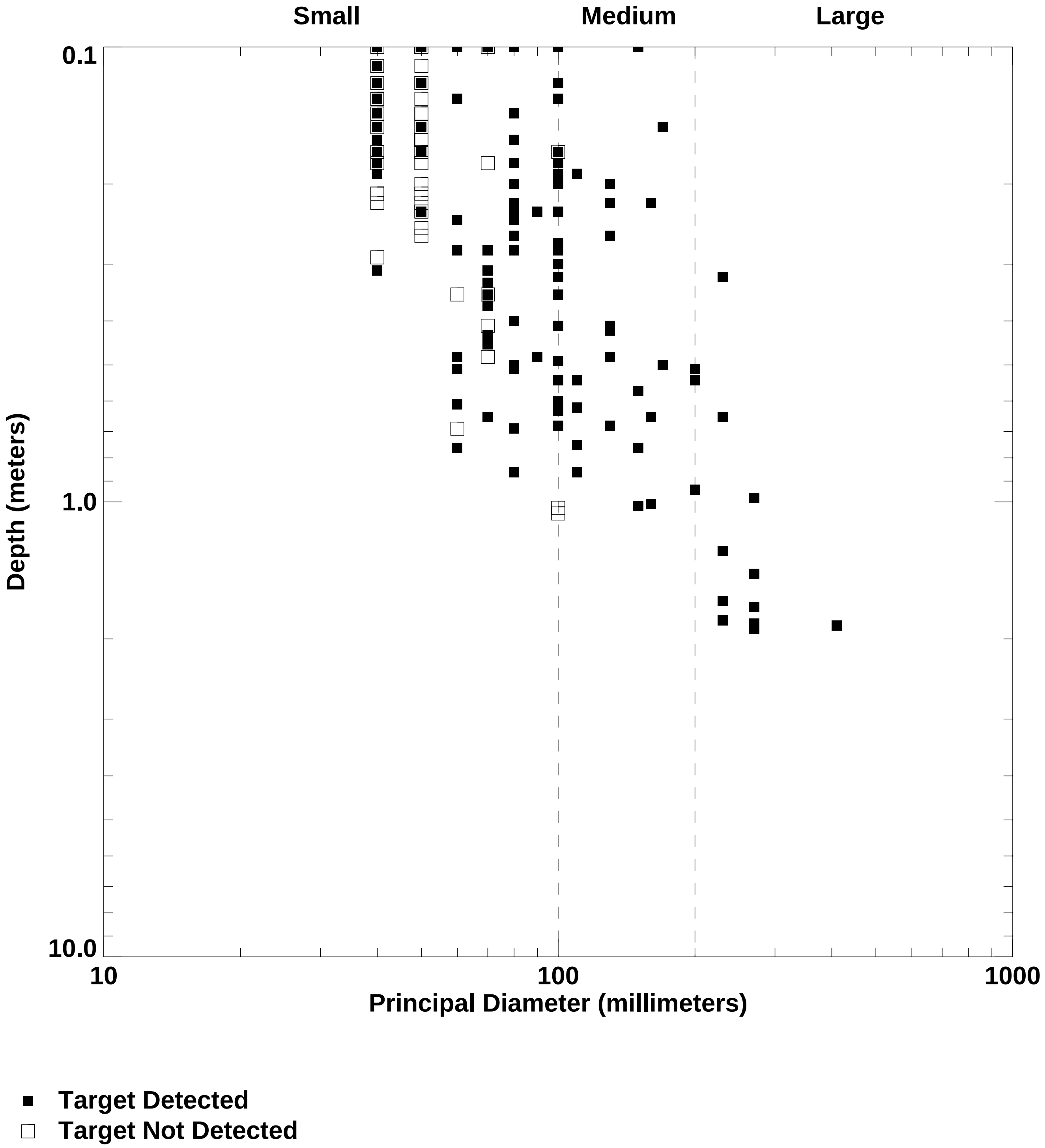
Characterization Statistics (TMA *Closest)*

	# Baseline	# Detected	P_D[b]	# Correct	P_C[d]
Ability to Type					
Ordnance	208	146	0.70	128	0.88
Nonordnance[e]	167	140	0.84	16	0.11
Ability to Size					
Large	14	14	1.00	7	0.50
Medium	39	36	0.92	8	0.22
Small	155	96	0.62	87	0.91
Ability to Classify					
Bomb	21	21	1.00	10	0.48
Projectile	42	39	0.93	14	0.36
Mortar	26	24	0.92	20	0.83
Submunition	97	45	0.46	0	0.00
Rocket	22	17	0.77	12	0.71

Notes:

[a] Target Matching Algorithm
[b] Probability of detection
[c] Square root of the mean square depth error
[d] Probability of correct characterization
[e] TMA affects how nonordnance baseline targets are counted
NA - not applicable

JPG Controlled Site: Phase III
Combined Statistics: All Surveyed Area (Excluding Scen. 4)
Critical Radius: 2 meters
Demonstrator: GRI-Magnetometer



11.0 LOCKHEED MARTIN ADVANCED ENVIRONMENTAL SYSTEMS[14]

The Caterpillar 320L Low Ground Pressure excavator with remote operator control station was demonstrated as a remediation platform at the JPG 16-hectare demonstration site from November 20 to 22, 1996. Lockheed Martin was a first time participant in the UXO ATD program.

11.1 TECHNOLOGY DESCRIPTION

11.1.1 System and Transport Mode

The LMAES system included a Caterpillar 320L Low Ground Pressure (LGP) excavator, and one remote operator control station (OCS) located in a panel van. The 320 was outfitted with a 1.125 cubic yard bucket and hydraulic thumb for excavation and removal of ordnance. The standard 320 had been modified with the LMAES Reconfigurable Remote Control System (R2CS)[1] electronics package to allow tele-operation of the vehicle. The OCS consisted of a chair, operator controls, audio, video and computer displays, and electronics which enabled the operator to remotely control the excavator. The OCS used spread-spectrum radios for command and control of the excavator. A separate RF channel provides the audio and video, while a dedicated narrowband RF signal was used for range safety. For precision navigation, a DGPS system was installed

[14] Lockheed Martin Advanced Environmental Systems, Jefferson Proving Ground Advanced Technology Demonstrations Phase III, Demonstration Summary Report, 19 December, 1996

on the 320. A dedicated computer display at the OCS provides the operator with real-time feedback on vehicle position. A custom antenna mount was developed to align the DGPS antenna with the bucket, so that the bucket could be positioned as accurately as possible over the target.

11.1.2 Recommended Applications and Technology Limitations

LMAES developed the remote excavator for remediation and other hazardous work. The remote excavator has direct application to the numerous DoD cleanup programs at current or former military installations. These cleanup programs include the unearthing, handling and removal of stored and buried ordnance. There are no known limitations to the use of this technology for the given application.

11.1.3 Logistics Required

Very little in the way of logistics is required to support the LMAES remote excavator. As a daily procedure[2], the vehicle should be fueled and daily maintenance performed prior to operations. The vehicle can carry enough fuel to support a full 8 hour work day. The OCS, as packaged, is powered by a 5000 watt generator whose fuel tank is also sufficient to support an 8 hour work day.

11.1.4 Data Acquisition

Performance data for these demonstrations was recorded manually by the test director from the feedback provided to the operator on the various displays. The OCS VCRs were also used to videotape operations.

11.1.5 Data Processing and Interpretation

All data processing, specifically for the DGPS system, was performed manually.

11.1.6 Quality Assurance

To provide Quality Assurance, LMAES provided a certified 320L operator as well as a highly skilled technician for on-site operations. A notebook of all operations was maintained by the test director to document the events which transpired while on-site and a library of videotapes has been made from the vehicle and site video VCRs.

11.2 DEMONSTRATION RESULTS

11.2.1 Assumptions

LMAES assumed that all buried ordnance at the JPG site were inert. Therefore, formal procedures or protocols for handling hazardous materials were not instituted.

11.2.2 Site-Specific Procedures

The basic remediation procedure developed by LMAES, first had the operator navigate the excavator towards the target as displayed on the DGPS display. After the excavator got close to the target, the display was zoomed in, and the bucket oriented so that it was directly over the target. Once the bucket was positioned, the bucket teeth were used to scratch the ground. The excavator was then repositioned for digging depending on the expected depth of the target. The digging sequence was a series of scratching with the teeth to break the dirt loose, and then removing the dirt with the bucket until the target was visible. Once visible, the bucket and thumb were used to extract the ordnance from the hole. The ordnance was separated from any dirt, set on the ground, and the hole filled back in.

11.2.3 Problems Encountered

LMAES encountered three problems during the course of the demo. First, was confusion over the map coordinates supplied as to whether they were in WGS-84 or State Plane projections. Secondly, the operator control van had to be repositioned on day 2 to maintain line-of-sight with the excavator. LOS was necessary for the radio configuration used. Thirdly, an emergency stop occurred on the excavator during day 3 as a result of a tripped circuit breaker. The cause for the breaker tripping was not identified.

11.2.4 Discussion of Results

11.2.5 Remediation History

During the first day of the demonstration, Wednesday November 20th, the command and control station was set up using the temporary monument located behind the trailer on the east perimeter road about one-half mile from the grid. At this location we were limited to remediating targets on the east side of scenario 4, because line of sight communication with the excavator was lost due to elevation drop and tree cover on the grid. On Thursday morning, November 21st, the command and control station was relocated onto the grid and setup using Monument-1. It remained there for the rest of the demonstration.

20-Nov, Num. 1, Target 1219, 4.2in mortar, 0.38m (1.25ft) deep.
Forty-nine minutes into the excavation a metal detector was brought in to determine if the mortar was still in the hole. It was located in the dirt removed from the hole. The operator then sifted through the dirt using the teeth of the bucket. The metal detector was brought in a second time, the mortar was located and marked with a stake. Sixty-nine minutes into the excavation the mortar was located by the operator using the cameras. The operator then successfully picked up the mortar using the bucket and the thumb.

20-Nov, **Num. 2,** Target 1258, 8in projectile, 1.37m (4.49ft) deep.
Thirty-nine minutes into the excavation the projectile was located by the operator using the cameras. The operator then successfully picked up the projectile using the bucket and the thumb.

21-Nov, **Num. 3,** Target 1215, 175mm projectile, 1.31m (4.30ft) deep.

Thirty-eight minutes into the excavation a metal detector was brought in to determine if the projectile was still in the hole. It was located in the hole. Eighty minutes into the excavation the projectile was located by the operator using the cameras. Three minutes later it was removed from the hole.

21-Nov, Num. 4, Target 1253, 152mm projectile, 0.58m (1.90ft) deep.
Fifty-five minutes into the excavation a visual check was made at the hole to locate the projectile. The projectile was found on the surface behind the dirt pile, out of the operator s view.

21-Nov, Num. 5, Target 1263, 500-lb bomb, 0.98m (3.22ft) deep.
Three minutes into the excavation the operator had the bomb in the bucket. Total number of scoops during the excavation was three.

21-Nov, Num. 6, Target 1272, 250-lb bomb, 1.82m (5.97ft) deep.
Twenty-four minutes into the excavation the bomb was located by the operator using the cameras. The operator dropped the bomb on the first attempt to remove it from the hole. The operator successfully removed the bomb two minutes after locating it in the hole.

21-Nov, Num. 7, Target 1577, 5in rocket, 0.42m (1.38ft) deep.
Eleven minutes into the excavation the operator uncovered a suspect object. Three minutes later EOD personnel determined from visual inspection at the hole that the rocket casing had been sheared into two pieces. Eighteen minutes into the excavation the operator removed the largest piece of the rocket casing.

22-Nov, Num. 8, Target 1269, 500-lb MK-82, 1.44m (4.72ft) deep.
Seventeen minutes into the excavation the bomb was located by the operator using the cameras. Five minutes later the operator had the bomb on the ground out of the hole.

22-Nov, Num. 9, Target 1229, 500-lb bomb, 1.07m (3.51ft) deep.
Twenty minutes into the excavation the operator was informed by EOD personnel that he had been driving the bomb into the near wall of the hole (toward the excavator) since the fourth bucket of dirt was removed. Five minutes later the operator removed the bomb from the hole.

22-Nov, Num. 10, Target 1235, 750-lb bomb, 1.17m (3.84ft) deep.
Fourteen minutes into the excavation the bomb was located by the operator using the cameras. Four minutes later the operator had the bomb on the ground out of the hole.

22-Nov, Num. 11, Target 231, 500-lb MK-82, 3.11m (10.20ft) deep.
Twenty minutes into the excavation the operator began widening the hole to the right and taking another foot off the far wall. Fifty -eight minutes into the excavation the bomb was located by the operator using the cameras. Three minutes later the operator had the bomb on the ground out of the hole. Total excavation time, after subtracting sixteen minutes for an emergency stop delay, was forty-five minutes.

11.2.6 Navigation History

The real-time DGPS system was used to navigate to eleven marked UXO targets and two unmarked UXO targets. Latitude and longitude of the surveyed targets were compared to the latitude and longitude of the DGPS system once positioned over the target. The differences are shown in Table 1. The accuracy of the DGPS system is two to five cm. The remainder of the error is a function of how accurately the operator can place the DGPS antenna, and therefore the bucket, over the target. Navigation to the marked targets was successful eleven out of twelve times. Navigation to the first target failed because the target entered into the DGPS map was in error by one second in latitude. Navigation to the unmarked targets was successful both times. Error for the first unmarked target was less than one inch and for the second target was one foot.

The real-time DGPS system was also used to determine the depth of the deeper holes during excavation.

In hole Number 2 it was used to check the depth of the hole after excavation was complete. EOD personnel estimated the hole to be between five and six feet deep. The DGPS systems elevation delta between the surface and the bottom of the hole was 5.5 feet (904.8 - 899.3). For hole Number 11 the DGPS elevation was used during excavation as an additional feedback to the operator s camera views. The operator estimated, knowing the length of the stick and the size of the bucket, the hole was thirteen feet deep. The elevation delta of the DGPS system was 13.2 feet (915.7 - 902.5).

11.2.7 DGPS Performance

DGPS system performance was excellent. During the four days of testing and demonstrating the system only lost satellite lock once. This could have been due to incomplete initialization (operator error) and/or a brief period of bad satellite geometry. During excavation the antenna s orientation changed an estimated ten to thirty degrees while maintaining satellite lock.

The Geolink DGPS software used for vehicle tracking and navigation worked well. The cursor representing the vehicle was easily visible. A Geolink software utility was used to create graphic scaleable symbols for targets from lat./long. coordinates. The dotted trail generated during travel was used as a heading indicator to easily navigate toward a target.

11.2.8 Excavator Performance

From a reliability standpoint the tele-operated excavator had already proven itself during the past five months of contracted work at Aberdeen Proving Ground (APG) in Maryland. It continued to perform well during the demonstration at JPG. During the three days of operation two minor incidences occurred. A hydraulic leak was discovered at the end of the day on Thursday. The hose was replaced first thing Friday morning. Down time for the excavator was forty-five minutes. Friday afternoon an Emergency Stop occurred shutting down the excavator. During diagnosis of the problem the CPU circuit breaker was reset. This corrected the problem and lead us to believe we had a faulty circuit breaker. Down time for the excavator was sixteen minutes.

From a control standpoint the operator has nearly the same capability remotely as he does in the cab. During tele-operated control the boom, stick, bucket and swing have the same feel as in the cab. The foot pedals have a slightly different feel traveling at slow speeds. The camera views the operator has give him more capability than a man in the cab has while excavating. He uses the pan, tilt and zoom for close-up views inside the bucket and inside the hole. The camera views the operator has while traveling limit his side to side view. This is a limitation the operator has easily adapted to and it has not posed any problems during tele-operated travel.

11.2.9 Excavation Performance

A tele-operated excavation performance study was done to quantify how much dirt can be moved over what period of time. The data used was the time tagged video tape recorded while UXO target Number 11 was being remediated. The target was buried 10.2 feet deep. Data was collected over the first thirteen minutes of the excavation. Elapsed time was recorded for fifteen individual scoops. The duration of a scoop is from when the teeth go below the surface, a bucket full of dirt is removed and dumped on the ground, the bucket is positioned for the next scoop and the teeth go below the surface again. The minimum time for a scoop was thirty-three seconds while the maximum was seventy-one seconds. The average scoop was calculated at 52.7 seconds/scoop or 1.14 scoops/minute.

The amount of dirt in the bucket for each scoop was estimated. Measurement criteria was percent full recorded in ten percent increments. All of the fifteen buckets were overfilled. The percent overfill ranged from ten to one hundred with an average overfill of forty percent. Using a 1.125 cubic yard bucket, a cubic yards per hour rate can be calculated for the amount of dirt being removed from the hole. Two rates were calculated to present a performance range. Using zero percent overfill the rate was 77 cubic yards/hour. Using the estimated forty percent overfill the rate was 108 cubic yards/hour.

11.2.10 Digital Data

Appendix A contains the raw data recorded by LMAES for each scenario. This appendix has additional information not required by the official data reporting sheet. Appendix B contains the formal report data in the specified format for the JPG III database.

11.2.11 Conclusions

We have demonstrated at JPG, and the previous five months at APG, that tele-operated excavation is effective. The first step has been taken in applying this technology for the remediation of buried UXO s. By developing our recommended improvements we will be one step closer to fielding a production level system capable of undertaking large remediation projects.

11.2.12 References

[1] “R2CS - Reconfigurable Remote Control System”, Laura Dussinger and Scott Williams, to be published by the American Nuclear Society, in the Proceedings of the 7th Topical Meeting on Robotics and Remote Systems, May 1997.

[2] “Operation and Maintenance Manual for the 320L Excavator”, LMAES, Document # T01A2002, Rev -, March 1996

12.0 NAEVA GEOPHYSICS INC. [2]

NAEVA Geophysics demonstrated from September 11 through 15, 1996 at the 16-hectare area at JPG. NAEVA Geophysics was a first time participant in the UXO ATD program.

12.1 TECHNOLOGY DESCRIPTION

12.1.1 Sensor System and Transport Mode

NAEVA Geophysics surveyed a 10 acre Aerial Gunnery Range and a 10 acre Artillery and Mortar Range using man-portable Scintrex Smartmag SM-4 total field magnetometers and Geonics EM-61 metal detection instruments.

The Scintrex Smartmag SM-4 system is based upon a very sensitive self-oscillating split-beam cesium vapor magnetometer. It measures the total magnetic field with a sensitivity of ± 0.01 nT (range 15,000 to 100,000 nT) at sample rates from 1 to 10 samples per second. The SM-4 system includes a cesium sensor, associated electronics, carrying harness, ENVI control console, ENVIMAP operating software, and rechargeable batteries. The system is man-portable.

[2] ***NAEVA GEOPHYSICS INC.*****, Phase III UXO Detection, Advanced Technology Demonstration, Jefferson Proving Grounds, Madison Indiana - Survey Data Analysis Report**

The Geonics EM-61 is a time-domain electromagnetic instrument designed to detect shallow metallic objects with good spatial resolution. The system consists of two air-cored coils, each one meter in diameter, batteries and processing electronics, and a digital data recorder. Secondary voltages induced in both coils are measured in millivolts. The coils are arranged so that the larger coil (EM source and receiver) lies 40 cm below a second receiver coil. Two modes of operation are available, 1) trailer mode, in which two wheels support the coils, and 2) harness mode, in which the operator carries the coils on a belt and shoulder harness. Three instruments may be "ganged" and pulse synchronized in order to cover open ground rapidly with one meter line spacings.

12.1.2 Recommended Applications and Technology Limitations

The current system is well suited for ordnance detection on sites where unexploded surface ordnance have been cleared. The EM-61 metal detectors are designed for resolving small shallow features or non-ferrous metallic ordnance, while the magnetometer is preferred for detection of large, deeper ferromagnetic ordnance (beyond the range of reliable EM-61 metal detection). This integrated approach achieved better results than either method standing alone. The EM-61 is more affected by topography than the magnetometer, because it is most commonly operated with wheel-mounted coils. For both systems, surveying in areas of thick vegetation requires prior line clearing. The only geologic limitation imposed on the system is naturally occurring high variation in magnetic background. The EM-61 is virtually unaffected by soil/geologic conditions. Heavy rain may restrict operation of both instruments.

12.1.3 Logistics Requirements

NAEVA Geophysics' geophysical ordnance detection system can be employed with minimal logistical requirements. The instruments can be shipped through standard commercial services world-wide. The crew size is dependant on the area of investigation and can be as small as two persons.

12.1.4 Data Acquisition

The Aerial Gunnery Range (1) and the Artillery and Mortar Range (2) subareas were swept using three Geonics EM-61 metal detectors and a Scintrex Smartmag cesium vapor magnetometer.

The ganged EM-61 instruments swept a 10-foot width with a sensor separation of approximately one meter. The Smartmag collected data at 5-foot line separation. The magnetometer operated in continuous mode. The EM-61 operated in wheel odometer mode, collecting data every 0.63 feet along lines. Data were directly recorded for digital analysis, and gridded to a 1-foot interval. A separate base station magnetometer acquired data for magnetic diurnal drift corrections.

Hand-held FM radios were used for communications by the five person field crew and PRC. The survey lines were controlled by chain on 10-foot spaced north-south survey grid lines with fiducials every 20 feet, in order to assure better than ± one foot accuracy.

12.1.5 Data Processing and Interpretation

The magnetic data were processed and analyzed using the MAGFIT method. MAGFIT has been devised and implemented in computer C++ code for UNIX and DOS operating systems by Dr. G. Hunter Ware and Hunter A. Ware. This unique and proprietary computer program scans the theoretical anomalies of a very large number of magnetic dipole models (all locations, depths, orientations, and dipole moments of interest) over the field data, and identifies the best models using a "best least squares fit" criteria. MAGFIT also yields model fit contours (in 1%) around the best fit location, in plan or cross-section. This technique has only recently become feasible, due to increases in the speed and memory capacity of small computers. MAGFIT was described in greater detail by G.H. Ware and H.A. Ware in a recent paper published in the proceedings of SAGEEP 1996.

MAGFIT is superior to commercially available software for total field magnetic data analysis which use Euler deconvolution, "analytic function" analysis, or interactive modeling. These approaches require the numerical calculation of field derivatives (gradients), which is often inaccurate for sparsely gridded data. It is preferable to select a large number of simple (but appropriate) models such as dipoles, and scan their anomalies over the actual field data, seeking best least-squares fits. MAGFIT avoids the numerical approximations of the analytic methods.

EM-61 profiles were interpreted using Geonics DAT-61 software. Depth and character estimates by MAGFIT and DAT-61 were integrated in order to achieve more accurate final predictions of target location and depth.

12.1.6 Quality Assurance

Data quality was ensured by: 1) experienced field personnel; 2) use of a base station magnetometer to eliminate the effects of diurnal drift; 3) instrument calibration, as required; 4) repetition of selected north-south survey lines and east-west tie lines for data comparison; and 5) daily review of geophysical data profiles and contours.

12.2 Demonstration Results

12.2.1 Assumptions

It was assumed that the 100 by 100 foot control grid previously emplaced is properly located and accurate. It is also assumed that target sizes and maximum depth of burial for each scenario has been accurately described.

12.2.2 Site Specific Procedures

Survey lines were established over designated grid blocks by placing marked ropes east-west, spaced 20 feet apart. Wooden stakes were used to secure the ropes, although an alternative method would be used if live ordnance is suspect. Instruments were run simultaneously in a systematic fashion across the grid blocks. The EM-61's were run as a three ganged unit in open areas and individually in areas of scattered trees.

12.2.3 Problems Encountered

Survey procedures required use of existing grid nodes (marked by PVC tubes and stakes) for grid control. Some minor inaccuracies were noted when directly measuring between nodes. Although minimal, these discrepancies may introduce a source of error in determining location.

A moderate amount of instrument noise was recognized in both EM-61 and magnetics data, necessitating additional post-collection processing.

12.2.4 Discussion of Results

With our integrated magnetic and electromagnetic surveys, we have selected 141 ordnance targets in scenario 1 and 143 in scenario 2.

Field data were measured along grid lines with fiducials placed every 20 feet. The precision of measurement locations is probably ± 1 to 2 feet, due to uncertainties in sensor velocity and fiducial location. These location errors and terrain noise are probably the limiting factors in accurate target location.

12.2.5 Conclusions

We believe the technologies that were demonstrated are appropriate and complimentary. It is possible that we have interpreted some small EM anomalies as ordnance, that are in fact nonordnance or false positives. This is because we do not have actual ordnance with which to calibrate our instrument response. We would appreciate the opportunity to calibrate our measurements and target selections against the site truth table at some future date.

12.2.6 References

Magnetic Interpretation by Scanning Multiple Models for Best Least Squares Fit, Ware, G.H., and Ware, H.A., Proceedings of SAGEEP '96, April 1996.

NAEVA - Combined Statistics: Scenarios 1,2

Detection Statistics (TMA[a] *Group*)

	# Baseline	# Detected	Pd[b]	P_{random}
Ordnance	110	103	0.94	0.046
Nonordnance	127	109	0.86	
Total	237	212		
Number False Alarms	202			
False Alarm Rate (#/Hectare)	24.82			
False Alarm Ratio (#/Ord.)	1.96			
Probability False Alarms	0.031			

Localization Statistics (TMA *Closest*) (in meters)

	Mean	Std Deviation
Position (x,y)		
dx - easting error	-0.28	0.42
dy - northing error	0.08	0.42
Radial error	0.58	0.32
Depth (z)		
dz - averaged depth error	0.16	0.24
|dz|[c] - absolute depth error	0.28	

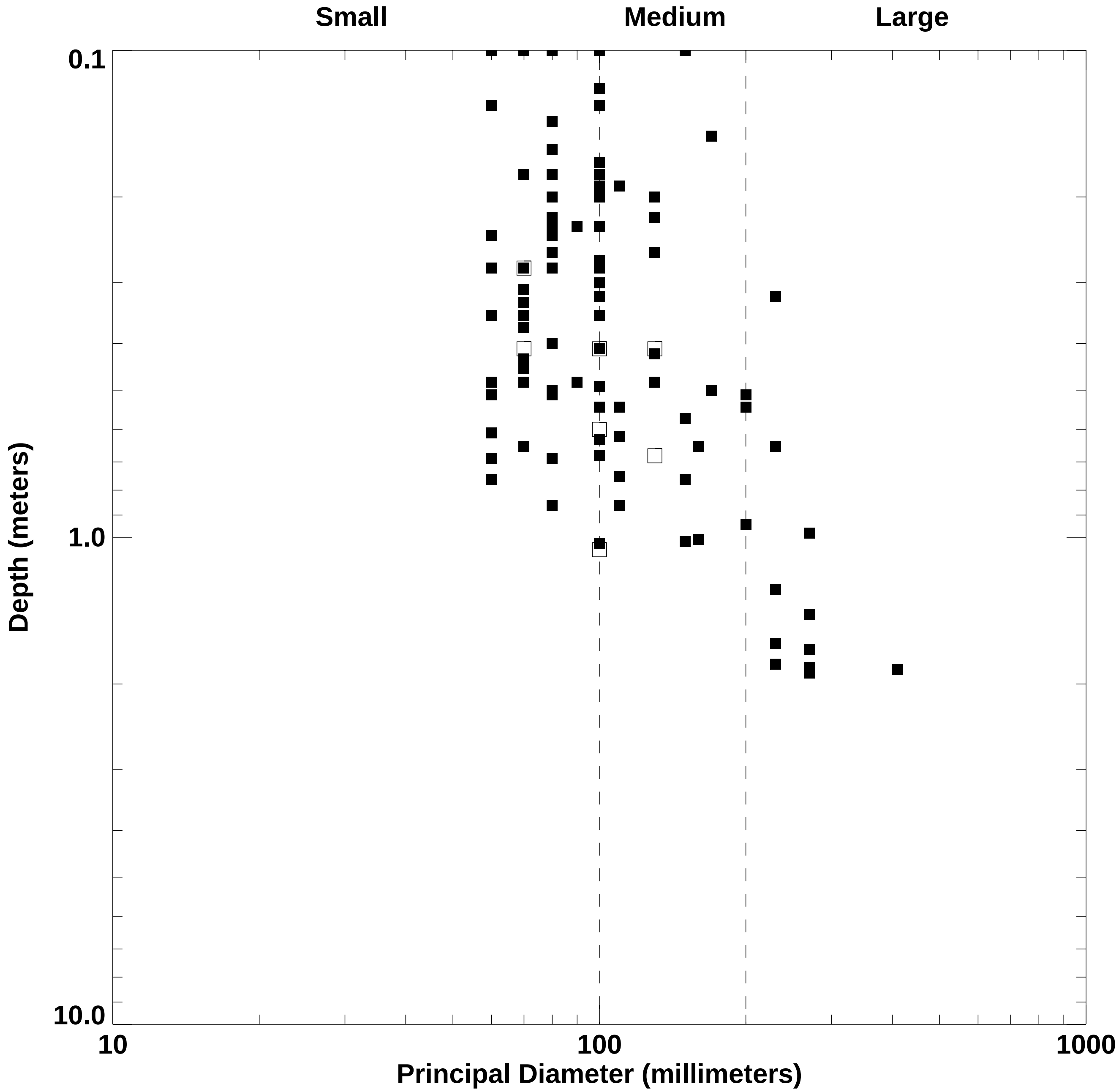
Characterization Statistics (TMA *Closest)*

	# Baseline	# Detected	P_D[b]	# Correct	P_C[d]
Ability to Type					
Ordnance	110	103	0.94	103	1.00
Nonordnance[e]	128	109	0.85	0	0.00
Ability to Size					
Large	14	14	1.00	11	0.79
Medium	38	34	0.89	29	0.85
Small	58	55	0.95	0	0.00
Ability to Classify					
Bomb	21	20	0.95	20	1.00
Projectile	41	39	0.95	39	1.00
Mortar	26	26	1.00	0	0.00
Submunition	0	0	NA	0	NA
Rocket	22	18	0.82	0	0.00

Notes:

[a] **Target Matching Algorithm**
[b] **Probability of detection**
[c] **Square root of the mean square depth error**
[d] **Probability of correct characterization**
[e] **TMA affects how nonordnance baseline targets are counted**
NA - not applicable

JPG Controlled Site: Phase III
Combined Statistics: All Surveyed Area (Excluding Scen. 4)
Critical Radius: 2 meters
Demonstrator: NAEVA



■ Target Detected
□ Target Not Detected

13.0 OAO CORPORATION[15]

OAO demonstrated from November 13 through 17, 1996 at the 16-hectare area at JPG. OAO was a first time participant in the UXO ATD program.

13.1 TECHNOLOGY DESCRIPTION

13.1.1 System Operational Description

The TODS remote control site is set up at known GPS coordinates near to suspect UXO locations. It is assumed the locations are documented and mapped based on previous location methods. The mapping consist of either markers at the suspect location and/or GPS coordinates for the target. Using DGPS, the operator drives the TODS vehicle towards target. The operator then either excavates the target based upon a visual marker or uses the Schiebel mine detector to locate the UXO. The operator would then use the backhoe, Air Knife, and gripper to excavate and remediate the UXO.

[15] **Test Results for the Teleoperated Ordnance Disposal System (TODS), Phase III UXO Detection, Identification, and Remediation Advanced Technology Demonstration, Jefferson Proving Ground, Madison, Indiana - 1996**

OAO demonstrated the TODS for the Phase III UXO Detection, Identification, and Remediation Advanced Technology Demonstration at Jefferson Proving Ground, Madison, Indiana in November 1996. A 40 acre controlled test site was created by emplacing inert ordnance and debris at documented but unpublished locations. The TODS demonstrated five approaches to UXO remediation and support activities. The first and simplest involved excavating a UXO at a known location. This proved that the TODS was an effective EOD tool under remote control teleoperation. The second involved navigating with GPS and excavating a marked UXO. This proved that the GPS could be used to navigate the TODS until visually acquiring the target and then proceed with remediation. The third scenario involved navigating to an unmarked target using GPS, acquiring the target using a metal detector and proceeding with excavation. This proved two principles; first, that GPS was accurate to get within 1 meter of an unmarked target, and second, that the metal detector could be used to pinpoint the metallic target within the GPS error zone. The fourth demonstrated approach was to clear vegetation from an area under teleoperation to allow detection or surveying activities. The fifth was to utilize the gripper attachment to remove exposed UXO from excavated holes and handle UXO for final disposition. Appendix C depicts the TODS performing various tasks during the November testing.

Four ordnance scenarios comprised the test site and are briefly described. The Aerial Gunnery Range represented aircraft aerial delivery of ordnance; it consisted of 2.75 inch rockets to 25 lb. bombs at depths from near surface to 1.2 meters. The Artillery and Mortar Range represented conventional ground ordnance fired at fixed, hardened targets; it consisted of 60-mm mortars to 8-inch projectiles at depths from near surface to 1.2 meters. The Grenades and Submunitions Range represented a conventional impact area delivered by aircraft and field artillery; it contained submunitions and grenades at depths shallower than 0.5 meters. The Interrogation and Burial Area represented a conventional impact area; it contained 2.75 inch rockets to 25 lb. bombs with depths from near surface to 1.2 meters.

13.1.2 Remote Controlled, Teleoperated Excavation

The TODS is based upon a modified New Holland L465 Skid-Steer loader that accommodates a modified Woods Backhoe Arm. The skid loader and backhoe arm hydraulics were reconfigured to allow remote control via the standard OAO remote control electronics. The operator commands the remote vehicle via a portable control panel with switches and joysticks. The vehicle operates as a manual backhoe would, but the operator uses two vehicle mounted cameras to remotely monitor operations. An Air Knife compressed air excavation system assists in non-intrusively removing dirt and mud while excavating and identifying UXO. Two common uses are when seeking first contact with the buried UXO, and searching the over burden pile.

13.1.3 Metal Detection

A Schiebel AN-19/2 Mine Detector was modified to allow its remote operation on TODS. This included an interface to allow the detection to be observed by the operator via video overlay, and an actuator that allows the operator to remotely raise and lower the detection head. The detector was used to acquire unmarked targets, to reacquire targets during the excavations and to locate targets that were excavated into the overburden pile. The detector was also used to establish the UXO's geometry for planning the TODS' approach (backhoe arm perpendicular to the linear axis of the UXO). The detector's sensitivity was manually set prior to a mission when approximate depths were known by holding a metallic object the known distance from the detection head and manually adjusting the Schiebel's sensitivity knob control.

13.1.4 Global Positioning System

The TODS utilized a Differential Global Positioning System (DGPS) to guide the remote controlled vehicle to the predetermined UXO locations with the Base Station antenna at a GPS monument. The DGPS provided the operator the location of the vehicle. The TODS proved to be able to provide positions in real time with a nominal accuracy within 4 meters, and a 10 minute occupancy accuracy near 1 meter.

13.1.5 Vegetation Clearance

To clear vegetation prior to UXO detection or surveying activity, the TODS allows the attachment of a rotary cutter (instead of the backhoe arm). The cutter is COTS with a standard mounting attachment for fast and simple installation and removal. The cutter has a 55 in. diameter cutting capacity and can cut vegetation up to 3 inches in diameter. The operator remotely commands the cutter on/off as well as the height and angle of the cutter via the portable controller. Blade speed is a function of the vehicle throttle.

13.1.6 Manipulation

When grasping, rather than digging is required, the operator can easily reconfigure the arm in the field to, in place of the bucket, attach the one degree of freedom gripper to hold and manipulate UXO. The gripper utilizes a dual piston, self-centering mechanism to grasp objects up to 10 inches in diameter. The gripping force can be manually set prior to the mission from negligible to 1300 lb.

13.2 DEMONSTRATION RESULTS

The TODS successfully excavated 18 targets. 2 targets were used to demonstrate navigation only and were not excavated. Four more targets were known anomalies for a total of twenty-four targets. The average excavation time was 27 minutes. The average travel rate was 2 km/h. 10 targets were successfully remediated from marked locations with no navigational requirement. OAO successfully located 10 targets using GPS navigation, 6 were to marked locations and 4 were to unmarked locations. 8 of the 10 GPS navigations were excavated; 2 of the GPS navigations were to only acquire unmarked target locations. A surveying crew quantified the resultant accuracy. The first target was located within less than 0.5 meters of its actual location and the second was located within 5 cm. Using the metal detector was successful in locating all 4 unmarked targets. Sweeps conducted by the metal detector at unmarked locations encompassed 4 meter squares. The GPS subsystem proved to be accurate within a 2 meter square with a precision of better than 1 meter. The TODS also demonstrated vegetation cutting as is required to place surveyor's marks and demonstrated the gripper operation to assist in grasping some UXO in the excavated holes for final disposition.

13.2.1 Assumptions

It was assumed that all points in the 16 hectare area would be visible from at least one location so that line-of-sight was available for video signal reception. This was found not to be true and the OAO team set up a mobile Base Station utilizing a mini-van and a portable generator for power. Each reconfiguration required that the TODS GPS Base Station was set up on a known GPS monument. It was assumed that target GPS coordinates provided by PRC were within 2 cm in any horizontal direction of the actual target location. Two or more targets were not to be located within 2 meters of each other. It was further assumed that it would be acceptable to transport UXO to their final destination in the bucket as convenient throughout the day. In the event that gripper operations are require, it would be acceptable to excavate numerous UXO, reconfigure with grippers, and return to transport the multiple UXO to their final destination. Due to the physical limitations of the backhoe arm's geometry, it was assumed that no targets would be excavated deeper than 1.2 meters.

13.2.2 Site-Specific Procedures

Procedures specific to JPG included mobile capability of the Base Station, hazardous terrain avoidance and Schiebel detector calibration. Due to the numbers of trees and the rolling terrain, and the required line of sight for video transmission, the Base Station could not be placed at any single location to cover all four ranges. Sufficient, surveyed GPS monuments were available, however, to accommodate range specific Base Station locations. A generator was required to power the mobile Base Station, and refueling was required several times a day. A mini-van was large enough to accommodate the remote control equipment as well as the operator, JPG test observer and data recorder. All antennas and stands were easily assembled and disassembled for each move.

Several times during the test, the Schiebel metal detector's sensitivity was recalibrated based upon provided knowledge of the depth of targets. During the GPS navigations mode, it was often required to move an exact number of meters in the latitude or longitudinal axes. By observing the wheel and counting revolutions, the operator could drive the TODS an exact distance in an axis.

The poor drainage throughout the JPG test site created puddles, mud holes and other slippery conditions causing poor traction. This never caused a mission failure but was more a matter of inconvenience and required additional planning. This was mostly an issue during mine detection sweeps when skid steering tore up the ground cover removing the last vestige of traction. At no time during the test did the vehicle require ancillary power to traverse the test site.

No problems were encountered although enhancements are targeted to improve vehicle and mission efficiency. To reduce the travel time during GPS navigations, quicker vehicle position updates would be required. In addition, a vehicle mounted compass would assist the operator in determining the direction of travel desired. Combining these two enhancements would allow for a more direct route traveled between targets. A calculation by the operator could be performed to quickly determine the distance and direction of the next target. The portable controller will be modified to reflect final configuration. These modifications will include joystick control of the backhoe arm to more closely follow the controls of a manual backhoe. This will human engineer the operator interface and allow the TODS operation similar to manual backhoe operation with minimal training.

A remote adjust capability for the metal detector sensitivity would be desirable to aid in the detection of multiple metal objects at varying burial depths during a single mission. During practical field use it was discovered that the remote operator needs to switch from detection of deeply buried objects to detection of shallow buried objects such as the investigation of excavated overburden piles.

Depth perception for the vision system would greatly enhance the operation. Depth perception will allow the remote operator better visual sensitivity with UXO discovery, identification, and removal. In addition, OAO recommends accompanying the excavator with a smaller, highly visible, remote observing platforms allowing for viewing the excavation progress from many different angles.

13.2.3 Discussion of Results

The 24 missions conducted by OAO personnel with the TODS at Jefferson Proving Ground were over twice in quantity above the proposed 11 missions. 14 excavations at marked targets with no navigational requirements were conducted where 4 were proposed. 10 of these resulted in remediation of the targeted UXO. 4 excavations were conducted at locations predetermined as anomalies where nothing was found. 1 anomaly target was beyond the extent of the system limitations as described in the assumptions and PRC limited the excavation time. 6 GPS navigations to marked UXO locations were conducted where 3 were proposed. Successful excavations and UXO removals were conducted at each target. 4 GPS navigations to unmarked UXO locations were conducted as was proposed. Final determination of each target was pin-pointed by an organized pattern sweep with a metal detector. In the first 2 cases, OAO personnel informed JPG test personnel of the target location as determined by the center of the detectors search head. An on-site surveying crew then compared the actual location to the estimated. In both cases, the TODS was close enough that successful excavations would have resulted had JPG personnel requested them. The last 2 UXO were excavated successfully given only the GPS coordinates, the approximate size and the approximate burial depth.

The average excavation time across all scenarios was 27 minutes. Excavation times can be increased dramatically with operator training and UXO experience, as was evident by the OAO operator improving his dig times as the test progressed. On the final day, excavation times were reduced to 13, 17 and 8 minutes. The last excavation (target 1850), the operator demonstrated the delicacy of the backhoe arm by completely uncovering a 30" rocket before removing it where inexperience resulted in damaging a rocket earlier (target 1852). The removal time for the last target was 24 minutes.

The metal detector was used effectively to both determine initial target locations and also to reinvestigate excavation holes and overburden piles to reacquire targets. OAO successfully located four unmarked targets with the metal detector. Unbeknownst to the OAO operator at the start of the test, there are many schemes that EOD personnel use with the detectors in the determination of UXO type, size, depth and orientation. EOD personnel use learned techniques with the metal detector to facilitate in organizing and expediting an excavation. OAO personnel were given such hints piece-meal as the test progressed.

The average travel rate was 2 km/h. The travel rate will increase with the next phase of improvements to the TODS. Some time was spent avoiding hazardous terrain. Yet, most of the excess time was due to the current GPS subsystem settling time which will be eliminated in the next phase of the TODS.

The vegetation cutter was used to trim grass three feet high with sparse populations of small shrubs. This is beneficial for practical applications where it is not advisable to send in manned mowers.

The grippers were demonstrated to show the ability to retrieve UXO or fragments when using the bucket is not desirable. In one instance, the TODS placed the UXO in the back of a van as the final disposition.

13.2.4. Data

13.2.4.1 Raw Data

The raw data is attached as an Appendix A in both hard and soft copies.

13.2.4.2 Processed Data

Table 1 presents data concerning the TODS JPG test. The supporting derived data is attached as Appendix B.

13.2.5 Conclusions

The TODS proved to be a quick, efficient and cost effective system for the remediation of UXO. The TODS average travel time using GPS was 2 km/hr but in the next phase of TODS, will increase closer to the 10 km/hr system velocity. The average excavation time was 0.45 hours per hole. These statistics along with the 100 percent success rate outperformed previous JPG and Live Site Technology demonstrators. These times will improve based upon enhancements discussed as well as training and the use of EOD-knowledgeable personnel to operate TODS. As was discussed excavation times could be reduced by being more familiar with the use of the detector, excavation planning, and excavation techniques. The TODS proved to be extremely reliable with no breakdowns suffered and the ability to work eight hour days consistently demonstrated. The OAO crew required two people to operate the system; an operator and a GPS navigator. Again, enhancements discussed can eliminate the GPS need and result in a single person to effectively operate the system. The ability to work 8 hour days without tiring results in further efficiencies and can be taken advantage of by trading off EOD operators throughout a working day. In addition, the ability to operate the system from a controlled environment eliminated environmental impacts that typically result in operator fatigue. The TODS worked in the cold and the rain while the operators sat in a warm, dry van. The TODS required minimal setup with a single non-technical person able to accomplish this activity in less than 0.5 hours. The TODS cost is about $200k with many of the components being required to conduct EOD work manually such as the skid loader with backhoe, GPS, and mine detector. This is a minimal investment compared to what would be manually required. The demonstrated efficiencies, speed of remediation, and inherent safety prove the TODS to be a viable EOD tool for UXO remediation.

13.2.6 References

1. PRC Subcontract 50075-96-UXO-13 (including OAO's proposal).
2. The Teleoperated Ordnance Disposal System (TODS) Operator's Manual. OAO Corporation. August, 1996.
3. Test Results for the Teleoperated Ordnance Disposal System (TODS), Phase II. OAO Corporation. August, 1996.
4. Unexploded Ordnance Advanced Technology Demonstration Program at Jefferson Proving Ground (phase II). USAEC. June, 1996.
5. Live site Unexploded Ordnance Advanced Technology Demonstration Program. USAEC. June, 1996.

14.0 ROCKWELL [4]

Rockwell demonstrated from October 2 through 5, 1996 at the 16-hectare area at JPG. Rockwell was a first time participant in the UXO ATD program.

14.1 TECHNOLOGY DESCRIPTION

14.1.1 Sensor System and Transport Mode

The sensor system is a new high-performance magnetic search system design especially for UXO surveys and for surveys having similar requirements. The complete system consists of four main components: a sensor subsystem, a position monitoring subsystem, a data handling subsystem, and a carry assembly.

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[4] ROCKWELL, Jefferson Proving Ground, UXO Technology Demonstration, Demonstration Summary Report - November 4, 1996

The sensor subsystem is a four foot array of 3-axis fluxgate magnetometers arranged in an in-line differential configuration. Magnetic “balance” among the magnetometers is maintained by the rigidity of the housing design and a proprietary imbalance compensation mechanism. The position monitoring subsystem provides accurate three-dimensional position information for all magnetometers in the sensor unit. This is accomplished with a commercially available carrier phase tracking differential GPS system (Trimble model 7400MSi) and a commercially available accelerometer (Applied Physics Systems). The GPS system provides accurate position information and the accelerometer, in conjunction with the magnetometer, provides attitude information. These are combined in post-processing to determine magnetometer positions at each data sample, based on the known geometry of the system. Both the position information and the attitude information are recorded by the data handling subsystem, and are time-keyed to the magnetometer data for proper recovery during post-processing. The data handling system consists of proprietary electronics coupled to a commercially available notebook computer (Gateway 2000 133 MHz Solo with a 1.4 GByte removable hard drive) for control and recording of the data. The carry assembly is a specially designed pair of backpacks. The system is currently configured to be carried by two people in a leader-follower arrangement. The lead unit has a special cradle assembly for the sensor subsystem, and also contains the accelerometer and the GPS antenna. The carry height for the sensors is about 1 m above the ground, yielding an appropriate balance of performance and ergonomics. The back unit contains the power supply, a daylight display, the notebook computer, and much of the electronics. The two units are connected by an electrical umbilical.

This system, along with proprietary data processing algorithms and software, yields a swath width substantially wider than the sensor array itself. This in turn yields higher areal coverage rates and faster more economical surveys. In addition, it provides a stand-off range for detecting and locating otherwise inaccessible targets.

14.1.2 Recommended Applications and Technology Limitations

The system is a very sensitive passive magnetic device and is capable of detecting anomalies in the ambient magnetic field. Most frequently such anomalies are due to concentrations of ferrous material in an otherwise non-ferrous environment. Because of the unique design of the system, it is able to not only detect such anomalies, but it can accurately estimate their locations in three-dimensions and their magnetic strengths. The system can be used to survey any terrain which is traversable by two people carrying moderate weight backpacks. The search strategy for the area can be easily tailored to the specific terrain and conditions of the site. Grid layouts or special paths are not required. In areas where GPS does not perform well because of tree canopy or other obstructions, the system can be augmented by ultrasonic or optical positioning systems. Except for thunderstorms, the system can be used in most weather conditions. For extreme conditions of rain, humidity, blowing dust or sand, the system would be repackaged to protect internal components. In conditions of extreme heat or cold the system may require site-specific calibration procedures, depending on the level of performance desired.

The current system is designed to be man-portable, but could be readily configured for vehicle mounting (towed, pushed, or beam-mounted). It could also be configured for use by low-flying remotely piloted aircraft. In addition, it could be packaged for underwater use, either in a hand-held arrangement or in a towed, pushed, or beam-mounted system.

14.1.3 Logistics Requirements

The system is small enough to be transported in a mini-van or a small truck, and is readily shipped over large distances by a commercial air carrier (as was done for this demonstration). The system is powered by batteries, which must be recharged and replaced on a regular basis. For best performance, an on-site calibration of the system can be performed using a specially designed calibration stand.

14.1.4 Data Acquisition

The system collects and stores data at a sample rate that results in oversampling by at least a factor of two for normal walking speeds. The sample rate can be increased for higher speed vehicle mounted searches. The stored data includes magnetometer, differential magnetometer, magnetic imbalance compensation, accelerometer, and GPS data. All data is initially recorded on a removable hard drive in the system's notebook computer. Periodically the data is compressed, and transferred to diskettes for back-up, data quality checks, and for processing.

14.1.5 Data processing and Interpretation

After the survey is completed all data is transferred to a desktop personal computer and decompressed. Rockwell proprietary software is then used to process the data using two desktop computers (133 MHz Pentiums with 32 MBytes RAM and 800 MByte hard drives) with a shared 1 GByte directory on a LAN.

It was originally planned to process the data in three stages as follows. First, a number of corrections are applied to the magnetic sensor data in order to recover accurate values for the differential magnetic field signals. The corrections include electronic gains, sensor calibrations, mismatch and rotational imbalance corrections, and attitude corrections. Second, the corrected data are then processed to recover the sources responsible for producing the observed magnetic field data. This is done in a manner equivalent to a least squares fit to the data. The sources are assumed to belong to three categories: geology, line-like sources, and dipole-like sources. Pertinent parameters are determined for each source. For the dipole-like sources, the parameters are 3-D location, magnetic moment, and moment orientation. Finally, for each dipole-like source a determination is made as to whether or not the source is an object of interest. This is done on the basis of the size of the source's magnetic moment, its orientation, and its depth.

The preceding paragraph describes the data processing that was planned for this demonstration. However, the system experienced an electronic failure during the survey, and during post-processing some other system problems were uncovered (see section 3.3). As a consequence the planned data processing procedure outlined above was amended. Some additional filtering was performed on the data and a less ambitious approach to characterizing the targets was used. The strength estimates were converted to target weight estimates using a simple proportionality between moment strength and weight for typical ferrous objects in the earth's field. This proportionality is usually good to within a factor of 3, but may be off by as much as a factor of 10 in some circumstances. Nevertheless, it provides a mechanism for grouping the targets into small, medium, or large weight categories. The performance level of the fully functioning system would be adequate to permit further interpretation of the data, especially in conjunction with an appropriate target database.

14.1.6 Quality Assurance

During a survey, the quality of the data is checked at regular intervals. To accomplish this, survey data (stored on the hard disk of the system notebook computer) is transferred to another computer. Randomly selected portions of the data are then plotted and examined in order to assess its quality. For best performance the system is also calibrated both before and after the survey, using a special calibration stand. The stand permits controlled orientation of the system within the ambient field. All aspects of the system can be calibrated in this way, except for an overall scale factor for the magnetometers, which must be established in advance by special calibration techniques employing a Helmholtz coil facility at A&MSD's facility in Anaheim, California.

14.2 DEMONSTRATION RESULTS

14.2.1 Assumptions

Only three assumptions were made in planning and executing the survey. First, it was assumed that in the data processing all sources of interest in the survey areas could be represented as magnetic dipoles at depths of 0 to 12 m. In particular, this excludes non-ferrous objects such as aluminum rocket casings in the AGR. (The AGR became the replacement area for A&MSD in lieu of the second artillery and mortar range requested in Rockwell's original proposal). Second, it was assumed that the terrain would permit a walking speed of at least 1 m/s. Third, it was assumed that carrier phase tracking differential GPS would be functional throughout most of the survey areas.

14.2.2 Site-Specific Procedures

The amended proposal called for surveying both the AMR (scenario 2) and the AGR (scenario 1) in 32 hours. A preplanned search strategy was adopted to efficiently cover the two survey areas. The plan called for following straight line paths where terrain and vegetation permitted, and using paths of opportunity otherwise. A 1.5 m path separation was adopted, which resulted in 146 paths for the AMR and 122 paths for the AGR. The swath width of the system for the smallest targets of interest was expected to be about 2.3 m, so that the 1.5 m path separation provided a conservative overlap of nearly 70%.

The system was carried by three two-man teams in rotation. Special path-following software and a simple daylight display permitted the carriers to follow the preplanned paths without the need for grid layouts or other path markers. Except for walking around isolated trees and some deeper standing water areas the survey teams were able to follow the preplanned search strategy over most of both sites. There were three areas, however, where standing and fallen trees, underbrush, and bramble did not permit following the preplanned paths: 1) a small area along the north central boundary of the AMR, 2) a much larger area near the west central boundary of the AMR and a modest sized area in the southeast corner of the AGR. All of these areas were surveyed following paths of opportunities.

At the assumed minimal walking speed of 1 m/s the AMR and the AGR could both be covered in about 25 hours, leaving a safety margin of 7 hours in the allotted 32 hour performance period. The two areas were actually covered at a significantly higher rate, finishing in about 21 hours of total survey time. This left time for a system re-calibration and a rerun over the Demonstration Reference Area (DRA) within the allotted performance time, despite a 24 hour delay due to an electronics part failure (see section 3.3).

14.2.3 Problems Encountered

A battery harness was inadvertently connected backwards early on the morning of the second day (Thursday) causing the harness to burn out. A replacement harness was installed, permitting surveying to continue. A simple change in the battery harness design will prevent a future recurrence of this problem. Later the same day an electronics failure occurred rendering the system inoperable. Cause of the failure is not known, but may have resulted from stress on the electronics due to the earlier battery harness episode. The system was repaired late Friday evening with parts flown in from California. The repair was successful in getting the main sensor channels operable, but left some imbalance compensation channels non-functional. The system was used in this somewhat degraded state to finish the survey on Saturday within the allotted time frame.

Occasional degradation of GPS performance occurred during the surveys, presumably because of satellite blockage by trees. This caused the GPS accuracy level to drop from a few centimeters to a meter (or worse, in a few instances). This in turn tended to degrade overall system performance in the sense of increasing target location and moment errors.

During post-processing of the data it was discovered that there were a few previously unnoticed problems with the system. From a system stand-point these problems are easily corrected and will be done so as a part of the on-going development process. First, there appeared to be magnetic sources internal to the system which were contributing to the noise level. Two such sources were subsequently found. One was a piece of GPS equipment in the front backpack and the other involved some special alignment pins within the sensor subsystem. Second, the imbalance compensation mechanism had apparently failed earlier than previously recognized, so that the full capability of the imbalance compensation was not available throughout most of the survey. Third, it was determined that the front backpack frame is not sufficiently rigid, allowing the sensor unit to sag about 4.5 degrees from its position in the calibration stand. As far as the survey data is concerned, special filtering and re-calibration procedures were implemented to partially compensate for these problems.

14.2.4 Discussion of Results

The noise level for the system in operation on the two sites was 0.73 nT rms per difference channel. This is somewhat higher than expected due to the problems discussed in section 3.3. However, it is still a very respectable operational noise level for a passive magnetic system. With minor improvements and corrections, the system noise level can be readily reduced to the 0.1 nT target level. It was originally planned to use a detection threshold of 15 dB above the noise level. With that detection threshold many individual targets are detected multiple times on adjacent search paths. The original processing plan called for grouping these multiple detections together and processing them as a whole to recover target features. Because of the slightly degraded performance, it was deemed better to increase the threshold to 18 dB and eliminate the weaker (more corrupted) multiple detections of each target. This eliminated 59% of the individual detections, some of which may have been singly detected weak targets. Of the remaining detections about 32% were determined to represent the same targets and were grouped accordingly.

The AMR results exhibit a clear line of magnetic sources roughly parallel to the western boundary and passing about 16 m to the east of monument #3. The line coincides with a slight rise in the southwest corner of the site and passes thorough the wooded and brambly area 2) mentioned in section 3.2. This may be a fence row, a fragmented pipeline, geology, or a collection of interesting targets. The targets seem to be well isolated and hence may, in fact, be targets of interest.

14.2.5 Raw Data

The raw data was compressed and stored on 39 high density diskettes. Total amount of decompressed raw data is nearly 90 MBytes. It consists of magnetometer, differential magnetometer, imbalance compensation, accelerometer, and GPS data.

14.2.6 Processed Data

The total amount of stored data at all stages of processing is in excess of 600 MBytes. It includes data to show the paths actually followed during the survey, system attitude, transformed and filtered signal data, differential field contour maps, threshold statistics, detection groupings, target locations and target strengths. Details of the target features resulting form the data processing are provided in the attached data package using the prescribed data format.

14.2.7 Conclusions

The subcontract agreement called for surveying two 10 acre scenarios in a 32 hour time period: the Artillery and Mortar Range (scenario 2) and the Aerial Gunnery Range (scenario 1). The original proposal called for surveying two distinct artillery and mortar ranges, but because the second such range was not available the aerial gunnery range was substituted in its stead. Both sites were completely surveyed within the allotted time period. In fact, the actual survey time on the "grid" was about 21 hours. Some system electronics problems occurred which slightly degraded system performance, but the level of performance was still very respectable. All data was successfully recorded and processed and the results reported in the attached data package using the prescribed format.

Rockwell - Combined Statistics: Scenarios 1 and 2

Detection Statistics (TMA[a] *Group*)

	# Baseline	# Detected	Pd[b]	P_{random}
Ordnance	110	37	0.34	0.038
Nonordnance	127	35	0.28	
Total	237	72		
Number False Alarms	211			
False Alarm Rate (#/Hectare)	25.93			
False Alarm Ratio (#/Ord.)	5.70			
Probability False Alarms	0.033			

Localization Statistics (TMA *Closest*) (in meters)

	Mean	Std Deviation
Position (x,y)		
dx - easting error	0.02	0.43
dy - northing error	0.06	0.74
Radial error	0.71	0.48
Depth (z)		
dz - averaged depth error	0.04	0.27
|dz|[c] - absolute depth error	0.26	

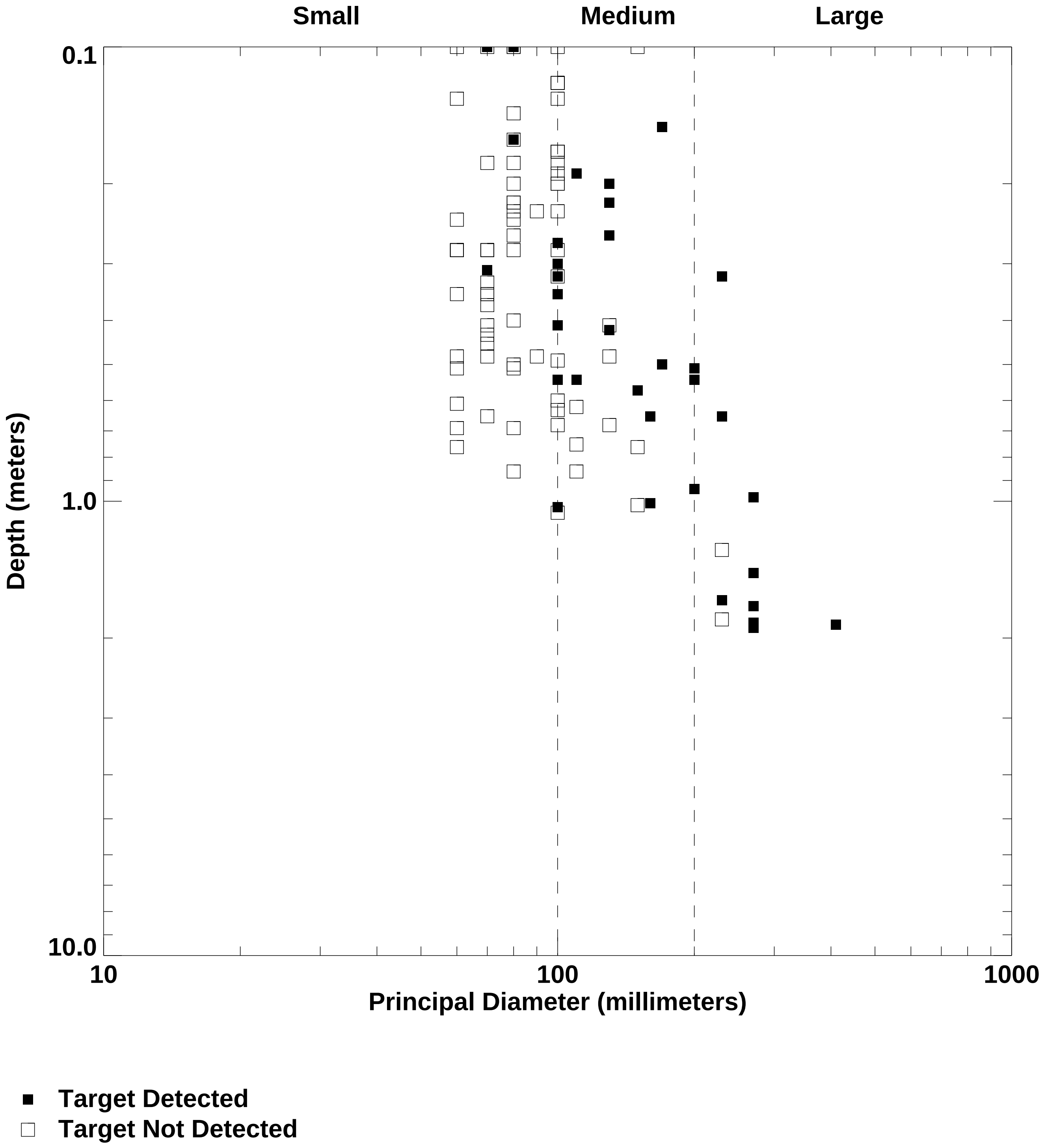
Characterization Statistics (TMA *Closest)*

	# Baseline	# Detected	P_D[b]	# Correct	P_C[d]
Ability to Type					
Ordnance	110	37	0.34	0	0.00
Nonordnance[e]	128	35	0.27	0	0.00
Ability to Size					
Large	14	12	0.86	0	0.00
Medium	38	13	0.34	0	0.00
Small	58	12	0.21	0	0.00
Ability to Classify					
Bomb	21	17	0.81	0	0.00
Projectile	41	12	0.29	0	0.00
Mortar	26	2	0.08	0	0.00
Submunition	0	0	NA	0	NA
Rocket	22	6	0.27	0	0.00

Notes:

[a] **Target Matching Algorithm**
[b] **Probability of detection**
[c] **Square root of the mean square depth error**
[d] **Probability of correct characterization**
[e] **TMA affects how nonordnance baseline targets are counted**
NA - not applicable

JPG Controlled Site: Phase III
Combined Statistics: All Surveyed Area (Excluding Scen. 4)
Critical Radius: 2 meters
Demonstrator: Rockwell



15.0 SANFORD COHEN AND ASSOCIATES (SC&A)[11]

Sanford Cohen and Associates (SC&A) analyzed data collected by three participants in the JPG III Advanced Technology Demonstration using advanced Ordnance and Explosives Knowledgebase (OE-KB) concepts. The participating companies are: ADI Limited, GeoCenters, Inc., and Geometrics. The objectives of this analysis are:

1. Demonstrate the effectiveness of OE-KB techniques when applied to industry standard geophysical data sets as compared to other techniques demonstrated by the data suppliers.
2. Isolate performance differences in geophysical instruments and survey methodology by providing a baseline analysis technique applied identically to three independent data sets.
3. Demonstrate effective coordination between companies in the OE detection and discrimination market.

Information on system transport, sensor type, navigation systems and survey techniques can be found in the sections provided by the participating companies and is not addressed here.

15.1 TECHNOLOGY DESCRIPTION

The OE-KB techniques have been developed by SC&A under the sponsorship of the US Army Corps of Engineers, Engineering and Support Center, Huntsville (CEHND). OE-KB involves two levels of operation : Detection and Discrimination.

15.1.1 Detection Approach

Detection involves locating potential anomalies. This is typically an automatic operation, using algorithms developed specifically for this purpose. Existing automatic techniques were found to be ineffective in some data sets owing to a significant noise component. Using such an automatic method would have resulted in degraded results on some data due, in part, to the picking algorithm. Therefore, anomaly detection was conducted manually at JPG III to ensure consistent and complete results.

To aid in visually separating potential anomalies from the back ground noise several filters were developed. Two types of "Gradient Focusing" were used along with a slightly smoothed raw data representation to identify anomalies. Figure 1 is raw EM-61 data from JPG III. Figure 2 is gradient focused data at the same scale: the improvement in anomaly detectability is dramatic (figures not present in MS Word document - refer to Wordperfect document)

[11] **Sanford Cohen and Associates, JPG III Report**

After these processing steps, anomalies in the magnetic data were picked for each scenario then, if there was an EM-61 data set, EM-61 anomalies were picked. The result is a CAD file with white target cells for magnetic anomalies and yellow target cells for those anomalies not seen with the mag but seen by the EM.

15.1.2 Discrimination Approach

SC&A's approach to discrimination is an attempt to optimize the tradeoff between reducing excavation/project cost and the risk of leaving ordnance in the ground. Based upon prior experience, SC&A has adopted some basic premises to accomplish this optimization:

1. The vast majority of metallic targets at OE sites are smaller than the definition of ordnance at a particular site (less than 1 LB, for example). The number of holes dug can be significantly reduced at minimum risk, if this target population is identified and eliminated from excavation.
2. The limited number of large targets and the risk associated with misidentification of a large target as non-UXO minimizes the cost/benefit of winnowing the target population from this subset of the target population.
3. Noise levels in EM and magnetometer data are commonly sufficient to degrade anomalies produced by targets near the low mass-limit of interest (those outlined in premise 1). Algorithms such as gradient focusing, neural and fuzzy systems etc., tailored to site specific noise conditions, are required to reliably separate targets directly above and below the low mass limit.

15.1.3 Discrimination Implementation

15.1.3.1 Phase I

The process of picking anomalies on multiple data sets, described above, provides a direct discrimination between ferrous and nonferrous-metallic anomalies. This accomplishes an initial subdivision of the anomaly population.

15.1.3.2 Phase II

Slightly smoothed magnetic and EM-61 data sets are displayed side by side on a screen and each anomaly is classified as either ordnance, non-ordnance, or unknown, using the conservative approach described above.

15.1.3.3 Phase III

Due to time restrictions this level of the discrimination system was applied only to scenario 4 data. An adaptive neural fuzzy system is used to estimate mass, based on signal returns from both coils of the EM-61.

15.1.3.4 Phase IV

A data fusion system that uses data from both the EM-61 and the magnetometer could not be applied: unanticipated corrections of data from the participants imposed time limitations that could not be overcome.

15.1.4 Limitations

During previous site remediation actions SC&A was able to establish precise definition of the lower mass limit through an iterative update of the database. This was achieved by associating anomalies with known targets through the progression of site excavations. Such an iterative optimization of the lower mass-limit could not be achieved at JPGIII as no excavations were done. Hence, the inability to precisely distinguish masses on the lower side of the low mass-limit diminishes SC&A's ability to pare false alarms from the JPGIII data.

15.1.5 Methodology

In an effort to prevent cross-contamination of results, each data set was processed and analyzed independently. The order for processing was GeoCenters, ADI and Geometrics. The results for each participant were compiled and sent to PRC before the next data set was started. After each data set was sent to PRC, that participant’s data and results were removed from the computers and stored on a backup device: results from different companies were not compared.

To ensure that each data set was evaluated similarly, a single analyst evaluated all of the data sets. Because of the very large number of anomalies evaluated it was felt that operator bias would not be a factor in anomaly location: this proved to be the case.

15.1.6 Performance Differences

SC&A found differences in data quality between the participants for given types or classes of instruments. These differences impacted the amount of SC&A’s effort required to produce reliable test results. This level of effort will likely not be apparent in the JPG III results.

Different companies elected different instruments or instrument suites on the different scenarios (Table 1). SC&A analyzed the data set(s) provided by each company, for each scenario, as a whole to obtain the best results possible. Data type differences yielded different results. For example: ADI proposed and used a magnetometer for scenario 1 and the results for ADI in scenario 1 reflect this survey approach. GeoCenters proposed and used both a magnetometer and an EM-61. Results for GeoCenters reflect this combination of instruments. Thus, results from individual scenarios for different companies are not related to instrument quality or survey methodology alone, they also reflect the instrument choices made.

Table 1. Instrumentation deployed by each participant for each scenario.

Participant	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**
ADI	MAG	MAG	MAG and EM-61	MAG and EM-61
GeoCenters	MAG and EM-61	MAG and EM-61	MAG and EM-61	None
Geometrics	None	MAG and EM-61	None	MAG and EM-61

15.1.7 Objective 3: Demonstrate effective coordination between companies...

Coordination was required from the beginning in order to accomplish this unique proposal. ADI, GeoCenters and Geometrics agreed to participate with SC&A in the further analysis of their JPGIII data. This multicompany coordination is reminiscent of the way data is collected, processed, and interpreted in the oil industry. Indeed, the OE-KB was designed with this type of service segmentation in mind. In order to facilitate this cooperative model SC&A believes that adoption of a near surface geophysical data standard is necessary. Such a standard would eliminate time consuming effort expended to translate a particular vendor's data into a format compatible with another vendors data, processing, and/or interpretation requirements. In addition to facilitation of data transfer, such a standard would also enable easy reevaluation (processing or otherwise) of old data in light of new data, results, processing methods, and/or interpretation methods.

Efforts aimed at developing specialized expertise and standardization are leading to lower overall costs and more effective operations. SC&A considers this "experiment" to have been a success and looks forward to further coordination in the future.

15.1.8 Data Processing System

15.1.8.1 Hardware

Pentium Class Personal Computers with minimum of 64 Mb Ram were used.

15.1.8.2 Software

The following software was used for various phases of the analysis:

1. Intergraph MGE software suite
2. OE-KB, A CEHND product for analysis of OE geophysical anomalies
3. MATLAB
4. Various programs for manipulating ASCII data series including AWK and MS Excel
5. Custom programs for data manipulation and processing
6. Personnel

15.1.8.3 Personnel

Matthew Gifford - Project manager and data analyst
Jack Foley - Software design and program management
Dave Lieblich - Software design and data pre-processing
Cynthia Saine - Data pre-processing
Brian Coolidge - Data pre-processing

SCA_ADI - Combined Statistics: Scenarios 1,2,3

Detection Statistics (TMA[a] *Group*)

	# Baseline	# Detected	Pd[b]	P_{random}
Ordnance	208	132	0.63	0.07
Nonordnance	166	110	0.66	
Total	374	242		
Number False Alarms	575			
False Alarm Rate (#/Hectare)	46.80			
False Alarm Ratio (#/Ord.)	4.36			
Probability False Alarms	0.059			

Localization Statistics (TMA *Closest*) (in meters)

	Mean	Std Deviation
Position (x,y)		
dx - easting error	0.02	0.45
dy - northing error	-0.08	0.46
Radial error	0.54	0.35
Depth (z)		
dz - averaged depth error	-0.14	0.34
|dz|[c] - absolute depth error	0.36	

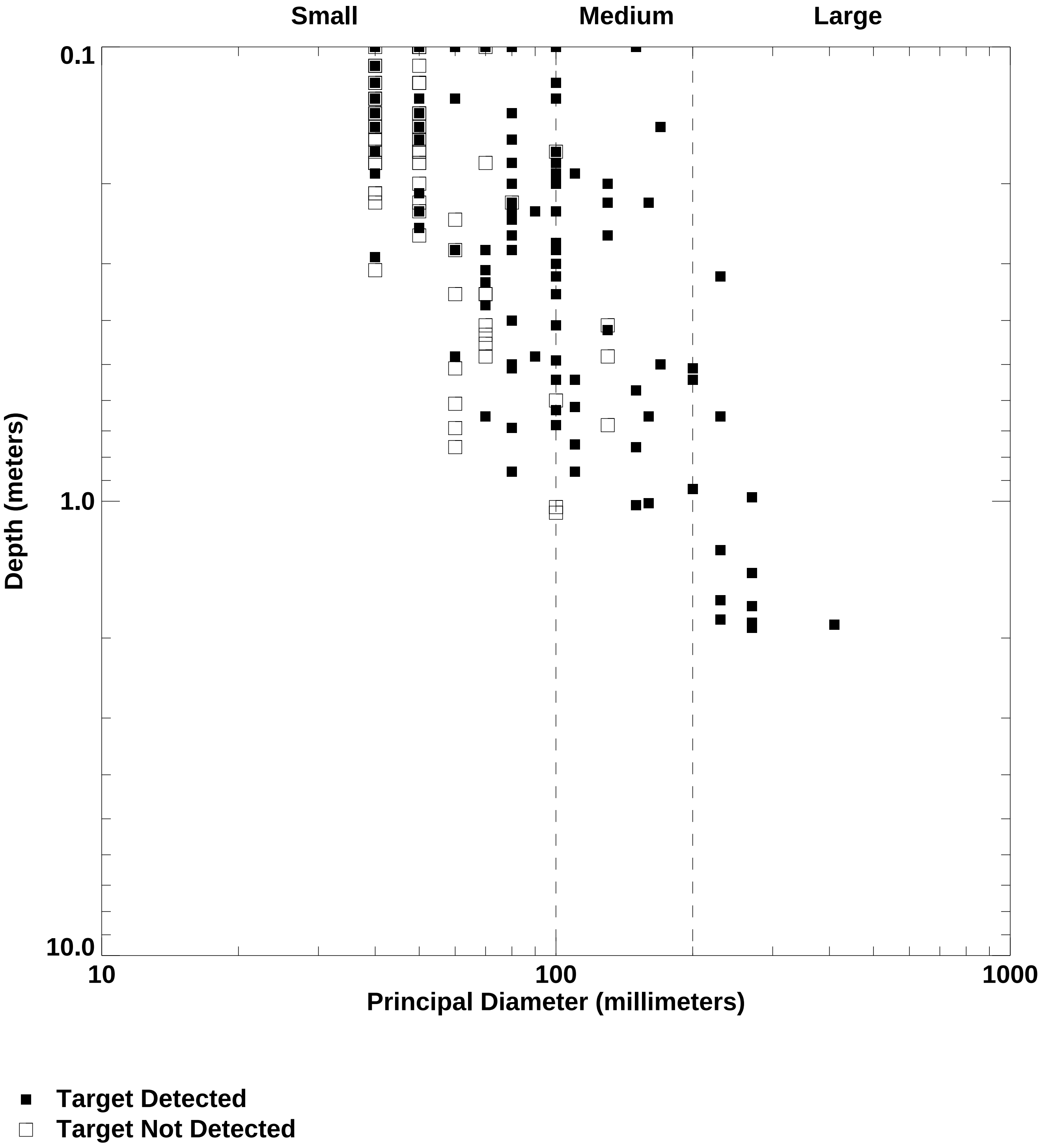
Characterization Statistics (TMA *Closest*)

	# Baseline	# Detected	P_D[b]	# Correct	P_C[d]
Ability to Type					
Ordnance	208	132	0.63	124	0.94
Nonordnance[e]	167	110	0.66	1	0.01
Ability to Size					
Large	14	14	1.00	2	0.14
Medium	39	32	0.82	14	0.44
Small	155	86	0.55	80	0.93
Ability to Classify					
Bomb	21	21	1.00	0	0.00
Projectile	42	38	0.90	0	0.00
Mortar	26	18	0.69	0	0.00
Submunition	97	44	0.45	43	0.98
Rocket	22	11	0.50	0	0.00

Notes:

[a] Target Matching Algorithm
[b] Probability of detection
[c] Square root of the mean square depth error
[d] Probability of correct characterization
[e] TMA affects how nonordnance baseline targets are counted
NA - not applicable

JPG Controlled Site: Phase III
Combined Statistics: All Surveyed Area (Excluding Scen. 4)
Critical Radius: 2 meters
Demonstrator: SCA_ADI



SCA_Geo-Centers - Combined Statistics: Scenarios 1,2,3

Detection Statistics (TMA[a] *Group*)

	# Baseline	# Detected	Pd[b]	P_{random}
Ordnance	208	159	0.76	0.069
Nonordnance	166	112	0.67	
Total	374	271		
Number False Alarms	535			
False Alarm Rate (#/Hectare)	43.55			
False Alarm Ratio (#/Ord.)	3.36			
Probability False Alarms	0.055			

Localization Statistics (TMA *Closest*) (in meters)

	Mean	Std Deviation
Position (x,y)		
dx - easting error	-0.27	0.57
dy - northing error	0.22	0.52
Radial error	0.74	0.41
Depth (z)		
dz - averaged depth error	-0.14	0.34
|dz|[c] - absolute depth error	0.36	

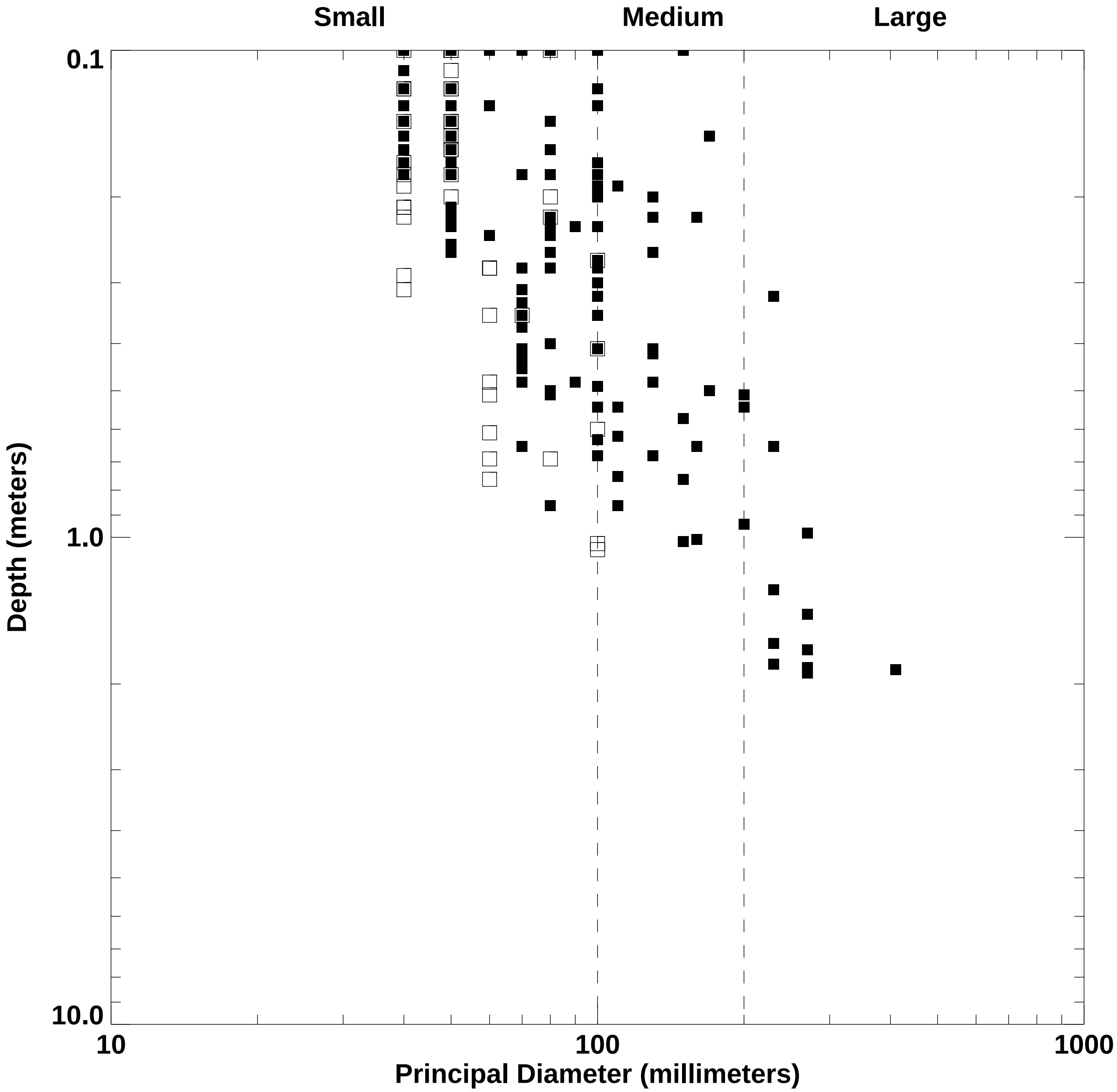
Characterization Statistics (TMA *Closest)*

	# Baseline	# Detected	P_D[b]	# Correct	P_C[d]
Ability to Type					
Ordnance	208	159	0.76	147	0.92
Nonordnance[e]	167	112	0.67	3	0.03
Ability to Size					
Large	14	14	1.00	5	0.36
Medium	39	36	0.92	13	0.36
Small	155	109	0.70	101	0.93
Ability to Classify					
Bomb	21	19	0.90	0	0.00
Projectile	42	37	0.88	0	0.00
Mortar	26	15	0.58	0	0.00
Submunition	97	67	0.69	67	1.00
Rocket	22	21	0.95	0	0.00

Notes:

[a] **Target Matching Algorithm**
[b] **Probability of detection**
[c] **Square root of the mean square depth error**
[d] **Probability of correct characterization**
[e] **TMA affects how nonordnance baseline targets are counted**
NA - not applicable

JPG Controlled Site: Phase III
Combined Statistics: All Surveyed Area (Excluding Scen. 4)
Critical Radius: 2 meters
Demonstrator: SCA_Geocenters



■ Target Detected
□ Target Not Detected

SCA_Geometrics - Combined Statistics: Scenario 2 only

Detection Statistics (TMA[a] *Group*)

	# Baseline	# Detected	Pd[b]	P_{random}
Ordnance	67	64	0.96	0.068
Nonordnance	50	46	0.92	
Total	117	110		
Number False Alarms	196			
False Alarm Rate (#/Hectare)	41.86			
False Alarm Ratio (#/Ord.)	3.06			
Probability False Alarms	0.053			

Localization Statistics (TMA *Closest*) (in meters)

	Mean	Std Deviation
Position (x,y)		
dx - easting error	-0.09	0.35
dy - northing error	0.11	0.45
Radial error	0.49	0.32
Depth (z)		
dz - averaged depth error	-0.04	0.26
$\lvert dz \rvert$[c] - absolute depth error	0.26	

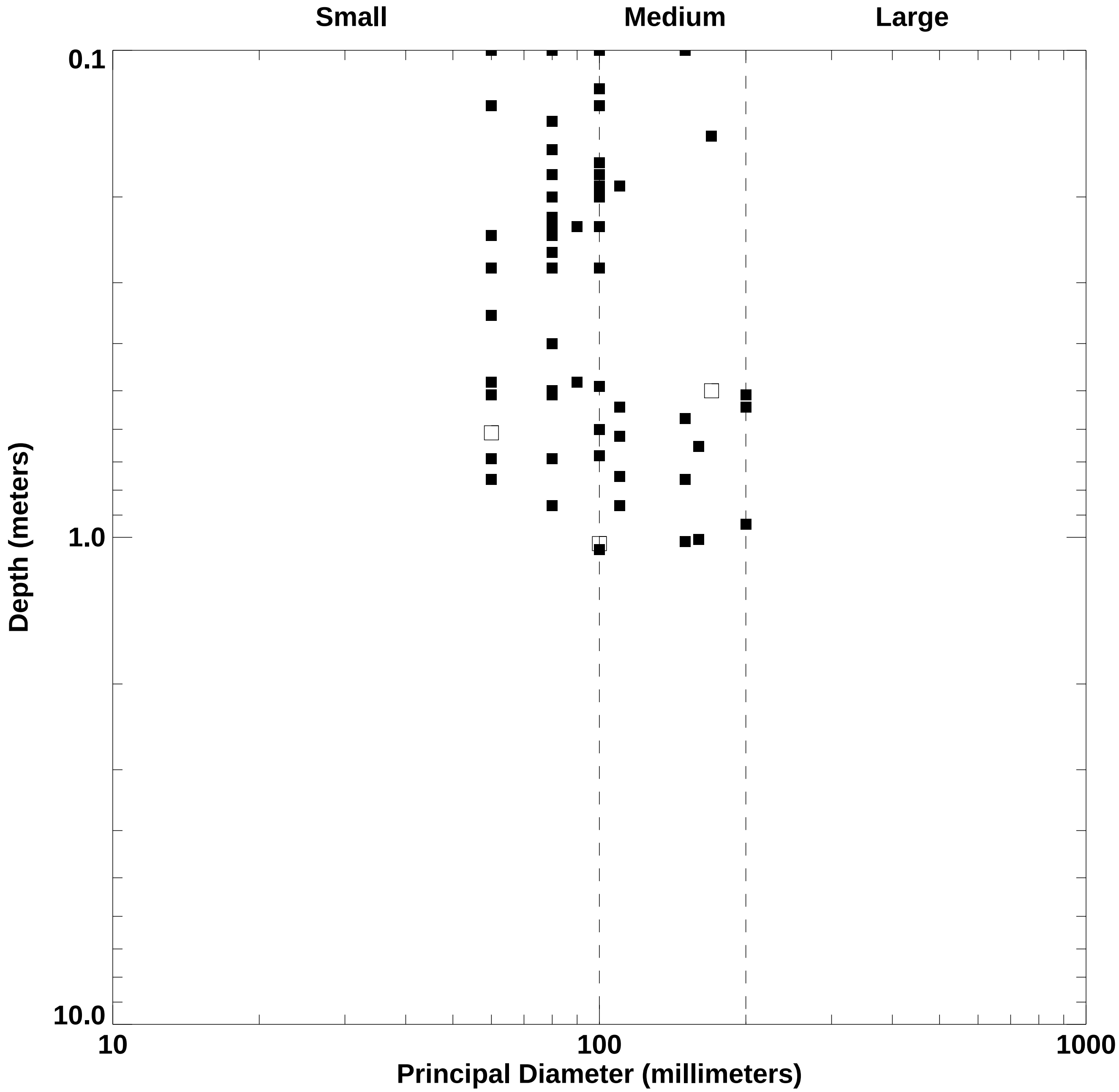
Characterization Statistics (TMA *Closest*)

	# Baseline	# Detected	P_D[b]	# Correct	P_C[d]
Ability to Type					
Ordnance	67	64	0.96	58	0.91
Nonordnance	50	46	0.92	3	0.07
Ability to Size					
Large	3	3	1.00	2	0.67
Medium	31	29	0.94	18	0.62
Small	33	32	0.97	18	0.56
Ability to Classify					
Bomb	0	0	NA	0	NA
Projectile	41	39	0.95	0	0.00
Mortar	26	25	0.96	0	0.00
Submunition	0	0	NA	0	NA
Rocket	0	0	NA	0	NA

Notes:

[a] Target Matching Algorithm
[b] Probability of detection
[c] Square root of the mean square depth error
[d] Probability of correct characterization
NA - not applicable

JPG Controlled Site: Phase III
Combined Statistics: All Surveyed Area (Excluding Scen. 4)
Critical Radius: 2 meters
Demonstrator: SCA_Geometrics



■ Target Detected
□ Target Not Detected