JEFFERSON PROVING GROUND TECHNOLOGY DEMONSTRATION PROGRAM SUMMARY

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This report summarizes the results, conclusions and recommendations for the UXO technology Phases I-IV demonstrations conducted at Jefferson Proving Grounds (JPG) and other Live sites during the period 1994-1999. These demonstrations examined the current capability of commercial and military equipment to detect, classify, and remove Unexploded Ordnance. No performance baseline existed for UXO systems prior to the JPG technology demonstrations.

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EXECUTIVE SUMMARY

This report summarizes the Jefferson Proving Ground (JPG) Technology Demonstrations (TD) Program conducted between 1994 and 1999. These demonstrations examined the current capability of commercial and military equipment to detect, classify, and remove Unexploded Ordnance (UXO). No baseline performance standards existed for UXO systems prior to the JPG-TD.

Phase I was conducted in 1994. The objectives were to evaluate existing and promising technologies for detecting and remediating UXO. Phase I results showed less than expected detection and localization capability and no capacity to discriminate between ordnance and non-ordnance. The average probability of detection (P_D) was 0.62. Airborne systems were unable to detect more than 8% of the UXO. Remediation vendors excavated 4 to 11 targets per 40 hours on site. At the completion of the Phase I testing at JPG, Congress requested a demonstration of the most applicable technologies at five "Live Site" locations to allow collection of comparison data in a variety of vegetative and geologic conditions. The average P_D for the Live Sites demonstration was 0.44.

The Phase II effort in 1995 provided an opportunity to demonstrate capabilities based on lessons learned in Phase I. Phase II showed a significant improvement in P_D from 0.62 to 0.68. The better performers in Phase II detected over 80 percent of the ordnance, but they also reported four to twenty times more targets as ordnance (false alarms).

Phase III was conducted in 1996. This phase provided a more homogeneous set of buried UXO by simulating typical range scenarios, i.e. aerial gunnery range, an artillery and mortar range, a grenade and submunition range, and an interrogation and burial area. JPG Phase III results showed that state of the art technology exists that is capable of detecting a substantial portion of the ordnance. To date, no vendor demonstrated the capability to discriminate ordnance and non-ordnance, although average probabilities of detection increased during successive phases from 62% to 77%. However, the false alarm rate increased.

Phase IV was conducted in 1998. The purpose was to demonstrate the capabilities of technology to discriminate between UXO and non-UXO. Results of Phase IV show there is a developing capability to distinguish between ordnance and non-ordnance. Five of the ten demonstrators showed a capability to discriminate ordnance and non-ordnance over 50% of the time. During the history of the JPG Technology Demonstrations, 76 characterization and remediation technologies were demonstrated. These efforts provided Government and Industry with a unique method of learning and applying knowledge about UXO Clearance in a controlled field environment. Phases I through III demonstrated the capabilities of current technology as it applies to the detection of ordnance while Phase IV demonstrated the state-of-the-art for current UXO discrimination capabilities. The ability to detect and discriminate decreases <u>both</u> the risk and cost of UXO site remediation. It is strongly recommended that these technology demonstrations be continued. There is a need to document the capabilities and limitations of sensor systems as they are developed. Consideration should be given to designating other DOD areas for technology demonstrations to provide geological and vegetative variation.

As a performance test, the JPG demonstrations have shown the strengths of some sensors, the weaknesses of others, and provided insights into the complicated issues surrounding UXO detection and cleanup. Continued support of UXO technology demonstrations will significantly reduce site remediation costs in the future.

INTRODUCTION

This report documents the Jefferson Proving Ground (JPG) Technology Demonstrations (TD) Program conducted between 1994 and 1999. These demonstrations examined the current capability of commercial and military equipment to detect, classify, and remove Unexploded Ordnance (UXO) placed in various underground locations simulating typical UXO Clearance environments. This program was sponsored by the Army Environmental Center (AEC) and executed by the Naval Explosive Ordnance Technology Division (NAVEODTECHDIV) as part of the Army Environmental Technology program under congressional direction.

At the start of the JPG TD Program, UXO site characterization efforts were typically conducted by retired military Explosive Ordnance Disposal Technicians using “Mag and Flag” operations conducted UXO Clearance operations. “Mag and Flag” operations consist of an operator using a hand held magnetometer or an electro-magnetic inductance device to detect an underground anomaly. They then place a flag in the ground corresponding to the center of the anomalous signal. The training and proficiency of the operator directly influenced the percentage of buried UXO detected and the number of anomalies detected that were not UXO. On average, for every UXO item that was detected and excavated, 100 non-UXO items were detected and excavated. “Mag and Flag” is still the most commonly used detection system. The U.S. Army Corps of Engineers calculated that 75% of the cost of UXO Clearance operations are incurred excavating non-UXO items.

As the number of acres of Closed, Transferred, Transferring, Active and Inactive Ranges found to have UXO increased, the interest in reducing the cost of UXO Clearance operations also increased. Sensor manufacturers, university and government researchers proposed a number of different methods for detecting and classifying buried UXO. While many claims were made about the effectiveness of magnetometers, gradiometers, time domain inductance, frequency domain inductance, ground penetrating radar, synthetic aperture radar, hyperspectral imaging, thermal imaging, seismic detectors and chemical detectors based on their performance in detecting other buried objects (everything from mines to pipelines to mineral deposits), there was little documented evidence to assist the UXO Clearance community in selecting methods other than “Mag and Flag”.

The purpose of the JPG TD Program was to establish a comparative performance base for current technologies and systems. The program was not intended to compare the performance of one specific magnetometer with another but instead to answer whether a technology approach, for example magnetometry was currently more mature than ground penetrating radar.

The program was performed in four phases that built on the knowledge and understanding of sensor performance, post processing capability and suitable field simulation experience gained from the previous phase.

Phase I: Evaluate existing and promising UXO technologies with emphasis on detection and removal of UXO.

Phase IA: Evaluation of best performing technologies from Phase I at five geologically diverse live sites containing UXO.

Phase II: Provide industry the opportunity to demonstrate their capabilities based on the lessons learned from Phase I.

Phase III: Provide a more homogeneous set of buried UXO targets based on Phase II results using four different range scenarios.

Phase IV: Investigate capabilities to discriminate between ordnance and non-ordnance and to provide more information about target size, type, shape, depth, and orientation.

SUMMARY OF TECHNOLOGY DEMONSTRATIONS

No baseline performance standards existed for UXO detection, discrimination, and removal capabilities of contractor or government systems prior to the Jefferson Proving Ground Technology Demonstrations (JPG-TD). There was no verified data that allowed an installation manager to determine what type of technology was most useful for their UXO Clearance needs. A proposal by the Army Environmental Center (AEC) and the Naval Explosive Ordnance Technology Division (NAVEODTECHDIV) was funded by Congress to determine the current “State of Technology” as it pertained to the UXO removal problem. To accomplish this, a Base Realignment and Closure (BRAC) facility was chosen (JPG) to provide a “blind test site”.

Two parcels of property, 80 and 40 acres respectively, were seeded with inert ordnance and non-ordnance targets at depths and penetration angles of typical bombs, projectiles, mortars, and rockets.[1] The goal of the demonstration was to document the capability of diverse technologies to detect, identify and remediate UXO. These demonstrations were not designed to provide rigorous scientific comparison of each sensor, algorithm or excavator. The information gathered provides evidence of the applicability of one class of technology versus another. The data also provided a guide for future basic and applied research efforts.

PHASE I

Phase I Demonstration Design

Phase I of the JPG-TD was conducted in 1994. The objective of Phase I was to evaluate existing and promising technologies for detecting and remediating UXO. Targets were buried (the Government protected the data on type, number, and locations) singly and in groups. A wide

[1] Conventional Weapons Effects Program (CONWEP), a computer program that can predict projectile penetration depths. It is available to U.S. government agencies from the U.S. Army Waterways Experiment Station, ATTN: CEWES-SS-R, 3909 Halls Ferry Road, Vicksburg, Mississippi 39180, commercial (601) 634-3668.

range of burial depths for each class of ordnance was used, never exceeding the maximum theoretical penetration depth of any ordnance item[1]Refer to Graph 1 and Table 2.Twenty-six technologies representing magnetometry, electromagnetic inductance, ground penetrating radar, synthetic aperture radar and infrared sensors were flown, driven and dragged over the test areas. Twenty different vehicle mounted and man portable technology demonstrators were required to operate on the 40-acre site (16 hectare site: 1 hectare = 2.47 acres), and six airborne systems were required to operate on the 80-acre site (32 hectare). Demonstrators were to provide x,y location in Universal Transverse Mercator coordinates (UTM), estimated depth of the detected anomaly, type of anomaly, and the attitude (azimuth and inclination) of the anomaly.

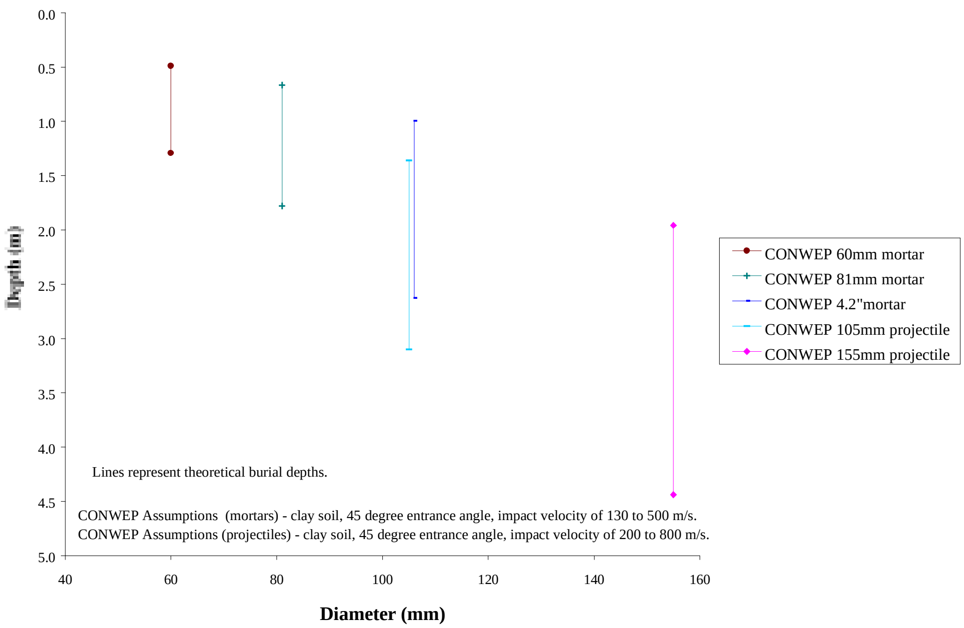
The 26 demonstrated technologies were evaluated according to the probability of detection (P_D= ordnance detected/ordnance buried), false alarm rate (FAR=declarations not matched to baseline targets/area surveyed), target location error (average radial distance between demonstrator declaration and baseline target location), discrimination between ordnance and non-ordnance (R_{ord} and R_{nonord}), and various production rates (time to excavate target, volume of earth removed etc). Some targets were buried next to each other in order to test the resolution capabilities of various sensors. Three remediation demonstrators were required to navigate and dig up buried targets. In addition, they were evaluated on production rate and accuracy.

Results of Phase I

Results from Phase I showed less than expected detection and localization capability for all technologies. The probability of detection for the single demonstrator that detected over 50% of the baseline (buried) ordnance was 62%. The average false alarm rate (false alarms per hectare) was 149 or approximately 60 false alarms per acre. This high false alarm rate was not expected since the area had been searched with hand held magnetometers and most of the shrapnel, range targets, and other ordnance debris normally found were removed.

No capacity to discriminate between ordnance and non-ordnance was reported by participants. In addition, there was no capability to resolve targets buried close to each other or to determine azimuth and inclination/declination headings. Electromagnetic sensors such as magnetometers, gradiometers, and electromagnetic induction coils proved to be the most effective tools in detecting UXO. Ground penetrating radar (GPR), infrared imaging (IR), acoustics, and other imaging technologies were unsuccessful in this phase. Airborne systems, regardless of sensors used, were unable to detect more than 8% of the buried ordnance.

GRAPH 1 Theoretical Ordnance Penetration Into Soil [1]



Poor detection performance during Phase I signaled a physics limitation of current sensor technology in relation to ordnance burial depth. Future phases attempted to decrease the sensor to ordnance distance to facilitate detection performance at depths that were more representative of current UXO Clearance goals.

Remote remediation or removal tasks were found to occur at a rate of approximately 4 to 11 targets per 40 hours on site. These remediation times included travel from the staging point to the dig point, travel between dig points, and mechanical breakdown times. This compares with 0.1-1.0 hours per target for hand or backhoe excavation (depending on depth).

At the completion of the Phase I testing at JPG, Congress requested a demonstration of the most applicable technologies at five “Live Site” locations. These “Live Sites” allowed collection of comparison data in geological conditions much different from JPG. Some of the sensor technologies were thought to have limited capability in the moist clay soil encountered in Indiana, so some of the less successful technologies at JPG were also included. The “Live Sites” selected were:

Jefferson Proving Grounds, IN
Eglin Air Force Base, FL
Yuma Proving Grounds, AZ
Fort Jackson Military Reservation, SC
McChord Air Force Base, WA

Table 1 summarizes results from the live site demonstrations. Average probability of detection (P_D) for the live sites is 0.44. Randomly selected suspected targets were chosen for excavation and because the validation period lasted only 3 to 4 weeks, a valid statistical sample was not possible. Magnetometry and electromagnetic inductance were by far the top performing technologies. Hand held systems continued to show the best results. Airborne systems continued to perform poorly.

Table 1 Live Sites Probability of Detection

	Vendor	Sensors	JPG	Eglin AFB	YPG	Ft. Jackson	McChord AFB
Ground Platforms:			P_D**	P_D	P_D	P_D	P_D
	ADI	Magnetometer	0.71			0.69	
	Coleman	GPR & EM*	0.54	0.55			
	Chemrad	Magnetometer					0.14
	Geo-Centers	Magnetometer			0.60	0.45	
	Metratek	GPR & EM			0.30		0.61
	Vallon	Magnetometer		0.74			
Aerial Platforms:							
	Aerodat	Magnetometer	0.07				
	SRI	GPR			0.00	0.00	

* GPR-ground penetrating radar, EM-electromagnetic induction
** P_D- probability of detection

Phase II Demonstration Design

Phase II of the JPG-TD was conducted in 1995. The objective of Phase II was a continuation of the work started in Phase I. Phase II provided industry an opportunity to demonstrate their capabilities based on lessons learned in Phase I. Multiple targets that were buried in the same excavation the year before were removed or replaced by single targets. Phase I had shown that no sensors or sensor processing could resolve multiple targets placed close together. For Phase II a new 40-acre subset of the 80 acre site was used to perform demonstrations. Demonstrators that were chosen for Phase II, who had demonstrated during Phase I, were placed on this second site. The same evaluation criteria used for Phase I was used for Phase II.

Results of Phase II

Phase II showed a significant improvement in P_D from 0.62 to 0.68. The better performers in Phase II detected over 80 percent of the ordnance, but they also reported four to twenty times more targets as ordnance (false alarms).[2] Demonstrators who used a combination of electromagnetic induction and magnetometry based sensors provided the best performance. The ability of industry to increase detection rates from Phase I to Phase II was attributed to proper selection of sensors, systems, ordnance declarations, and past experience at the site. This was accomplished by industry with minimal investment by the Government in research and development. The performers at this phase continued to demonstrate an inability to distinguish ordnance from the non-UXO targets. This deficiency translates into a major cost factor in remediating UXO properties. Metrics such as “acres covered per hour” and “target localization error” actually increased and decreased respectively. This meant that the detection contractors were covering more acreage but it may be harder to relocate and excavate the targets.

Remediation demonstrators showed roughly the same production rates as the year before but with better navigational accuracy. Excavation demonstrations of remotely operated systems were demonstrated during both phases. Excavators could unearth ordnance at only a fractional rate (<5%) of how fast demonstrators could detect it.

Phase III Demonstration Design

Phase III of the JPG-ATD was conducted in 1996. Phase III provided a more homogeneous set of buried UXO by simulating four different range scenarios. These scenarios were based on experience gained by the U. S. Army Corps of Engineers in actual UXO Clearance operations. This experience showed that UXO is found in homogenous groups on ranges, rather than diverse groups and burial depths. The past phases may not have demonstrated the full capability of certain technology types to meet specific UXO Clearance needs. To gather data on specific capabilities, an aerial gunnery range, an artillery and mortar range, a grenade and submunition range, and an interrogation and burial area were set up on ten-acre grids. Industry was able to propose work on one or more ranges, depending upon their confidence in finding various classes of ordnance. Targets, other than bombs, deeper than 2 meters were either moved to shallower depths or removed from the site completely.

[2] U.S. Army Environmental Center and the Naval Explosive Ordnance Disposal Technology Division, Report No. SFIM-AEC-ET-CR-97011, *UXO Technology Demonstration Program at Jefferson Proving Ground, Phase III*, April 1997, http://aec-www.apgea.army.mil:8080/

TABLE 2 Phase I-III Buried Ordnance

Buried Ordnance	JPG-ATD Phase	Burial Depth (meters)
20mm & 30mm (aircraft)	I , II	.05 to .30
Mortars (60mm – 4.2”)	I , II	.01 to 1.43
Projectiles (76mm – 8”)	I , II	.22 to 3.66
General Purpose Bombs (250 - 2,000 lb.)	I , II	.15 to 6.1
Rockets (2.75” – 5”)	I , II	.15 to 2.44
Aerial Gunnery Range (2.75” – 2,000 lb.)	III	< 3
Artillery and Mortar Range (60mm – 8”)	III	< 1.2
Grenade and Submunition Range	III	< 0.5
Interrogation and Burial Site (all the above)	III	< 2.0

Results of Phase III

JPG Phase III focused on developing relevant performance data of technologies used in site specific situations to search, detect, characterize, and excavate UXO. The JPG Phase III results showed that state of the art technology exists (still based on magnetometers and electromagnetic induction) that is capable of detecting a substantial portion of the ordnance emplaced for the four scenarios. Results also showed that average probability of detection decreases as a function of ordnance type and size. Table 3 shows this for the three range survey scenarios.

TABLE 3 Probabilities of Detection for Typical Range Scenarios

Survey Scenario	Range of Probabilities of Detection (P_D)	Average
Aerial Gunnery Range	.23 to 1.00	.75
Artillery/Mortar Range	.03 to .97	.69
Grenade & Submunition Range	.01 to .95	.64

Typically, on UXO sites, aerial gunnery range munitions (except 20 & 30mm) are found to be the largest in mass and volume while grenade and submunitions are the smallest. 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 of ground-based demonstrators to precisely locate the ordnance was also established with an overall mean radial error of 0.55 meters while the average depth error improved from 0.82 meters in Phase II to 0.40 meters in Phase III. Demonstrators' size declarations were correct approximately half the time, even with the implicit size bias of the scenario specific ordnance.

To date, no vendor demonstrated the capability to discriminate ordnance and non-ordnance. This deficiency in technology would be expected to adversely affect UXO site characterization efforts. In addition, it would be a major cost factor in any UXO remediation effort, since excavations will be more numerous due to the need to dig up both ordnance and non-ordnance objects.

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 versus the cost to excavate but it is apparent that the two functions are being optimized in isolation from 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.

Remote excavation is feasible, but results indicate that demonstrators can find targets much faster than they can be excavated using remote technology. JPG Phase III allowed technologies to be defined on the basis of their strengths. However, current UXO technologies can do little more than characterize the extent of UXO on properties.

ORDNANCE DETECTION RATE INCREASES IN JPG PHASE I, II AND III

Table 4 and Graph 2 show detection performance and false alarm rate for the first three phases of JPG. These trends only represent the better ground-based sensor systems that detected at least 50 percent of the baseline ordnance targets at each of the phases. The general trend of ordnance detection for succeeding phases is positive. More industry participants, as a percentage of overall demonstrators, are detecting 50% or more ordnance under the defined conditions. Average probabilities of detection increased during successive phases from 62% to 77%. However, the false alarm rate increased from Phase II to Phase III after a significant decrease between Phases I and II. Further work needs to be done to address the issue of discrimination and false alarms.

Table 4 Ground Based Technology Performance

	# of Ground –Based Technologies*	P_D	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 first number is the number of ground based demonstrators that detected over 50% of the targets while the second number is the total number of demonstrators for that phase.

Graph 2 Probability of Ordnance Detection (PD) versus False Alarm Rate

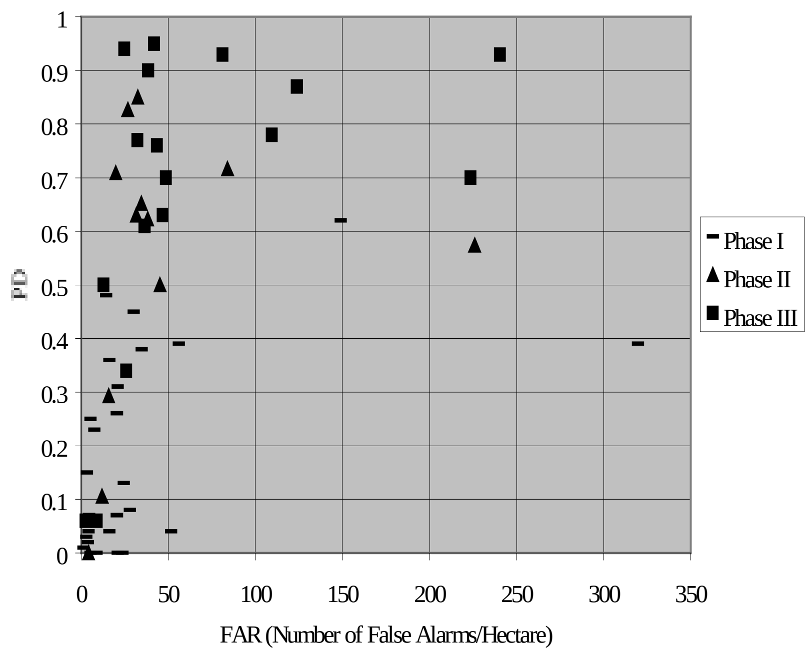


Table 5 List of Top Detection Performers by JPG Phase

Phase I	Phase II	Phase III
Vallon – P_D of 0.65	Geometrics - P_D of 0.83	NAEVA - P_D of 0.94
ADI - P_D of 0.48	Parsons - P_D of 0.85	SC&A/Geometrics - P_D of 0.96
Geo-Centers - P_D of 0.43	Geophex - P_D of 0.71	Geometrics - P_D of 0.90
Foerster - P_D of 0.41	ADI - P_D of 0.63	Geophex - P_D of 0.77
UXB - P_D of 0.37	Geo-Centers - P_D of 0.72	SC&A/Geo-Centers - P_D of 0.76

This is a subjective list of the top five performers from each phase. Although probability of detection was the main focus, false alarm rates are also important and are not included for brevity. When evaluating Phase III results, the reader should keep in mind that the statistics make no distinction between demonstrators who chose to survey 1, 2 or all 3 of the range scenarios.

THE DISCRIMINATION PROBLEM

Phases I, II and III demonstrated that existing magnetometers and electro-magnetic inductance sensors have the capability to detect a large percentage of buried objects, including UXO. This can increase the installation commanders' or clearance managers' confidence that risk can be reduced to an acceptable level. However the cost of achieving an acceptable level of risk was still high. The fact that excavation of false alarms due to system or environmentally induced noise or non-UXO clutter was still the driving costs upward. The solution to discriminating between UXO, non-UXO clutter and noise is not simple. Debate still continues as to what defines a false alarm. Is a false alarm any non-ordnance item? The most useful discrimination ability would be between ordnance items, ordnance-related debris, and non-ordnance items. Looking at the larger picture, cleanup of UXO is actually a sub-set of the overall Department of Defense goal to reduce risk, irrespective of the nature of that risk. Providing the installation commander or clearance manager with the ability to understand the composition of all buried targets provides them an increased ability to understand their risk.

Prior to Phase IV, technologies such as advanced data processing and new sensors types were under development to reduce false alarms without adversely affecting ordnance or risk detection performance. Furthermore, standard sensor data sets were becoming publicly available through the Defense Advanced Research Project Agency (DARPA) and the Joint Unexploded Ordnance Coordination Office (JUXOCO) to encourage the development of algorithms without the expense and burden of on site data gathering.[4] In addition, the JUXOCO has facilitated workshops to develop target discrimination standards and general guidance so that developers could exchange and compare results. The Department of Defense and industry had made major investments in the ability to discriminate UXO from clutter and noise by the start of JPG-AD Phase IV.

Phase IV

Phase IV Demonstration Design

Phase IV of the JPG Technology Demonstration (TD) was conducted in 1998. Ten detection technology demonstrators and one remediation demonstrator participated. The purpose of Phase IV was to:

- Demonstrate the capabilities of technology to discriminate between UXO and non-UXO
- Establish discrimination performance baselines for sensors and systems.
- Make raw sensor data available to the public.
- Establish state-of-the-art for predicting “type” of ordnance.
- Direct future R&D efforts.

Phase IV also investigated the capabilities of various technologies to provide information about specific targets’ size, shape, depth, and orientation underground (previous phases concentrated on detection).

Both the 40-acre and the 80-acre sites were seeded with samples of the same ordnance and non-ordnance targets both with a ratio of 1:2.2 respectively (see Table 6). Target locations

[4] http://www.denix.osd.mil/Public/News/UXOCOE

were marked with flags to emphasize vendor discrimination capabilities rather than to use the allotted time locating targets. Demonstrators who proposed new data analysis techniques and wanted more ground-truthed field data were given access to the 80-acre site and all pertinent information was provided on the seeded targets. This option allowed demonstrators to calibrate or train their systems' response to known targets. All demonstrators, even those who were not directly funded to participate in the 80 acre site, were provided samples of applicable ordnance and non-ordnance targets during the 40 acre site demonstration.

Table 6 Typical Ordnance Burial Depths

Diameter	**Type**	**Depth (meters)**
20mm	projectile	.026 to .112
57mm	projectile	.314 to .503
60mm	mortar	.214 to .524
76mm	projectile	.172 to .559
81mm	mortar	.092 to .549
90mm	projectile	.326 to .543
105mm	projectile	.364 to .711
4.2"	mortar	.325 to .747
152mm	projectile	.579 to 1.680
155mm	projectile	.680 to .999

Arbitrary discrimination performance metrics for JPG Phase IV were established based on government and industry input during the UXO Forum held in 1998. At that time desired goals for the program were a 95% true positive rate with a 75% true negative rate. True positives (TP) are demonstrator declared ordnance targets that are indeed ordnance. True negatives (TN) are demonstrator declared non-ordnance that is truly non-ordnance. False positives (FP) are demonstrator declared ordnance that is actually non-ordnance, resulting in an added cost burden to investigate or remove. False negatives (FN) are demonstrator declared non-ordnance that is actually ordnance, resulting in a continuing level of risk.

Demonstrators were asked to not only "classify" targets as ordnance and non-ordnance but to provide the government with the actual ordnance "type" designations (e.g. 60mm mortar or 105mm projectile). If specific information could not be provided, "unknown" was an acceptable demonstrator response for target type.

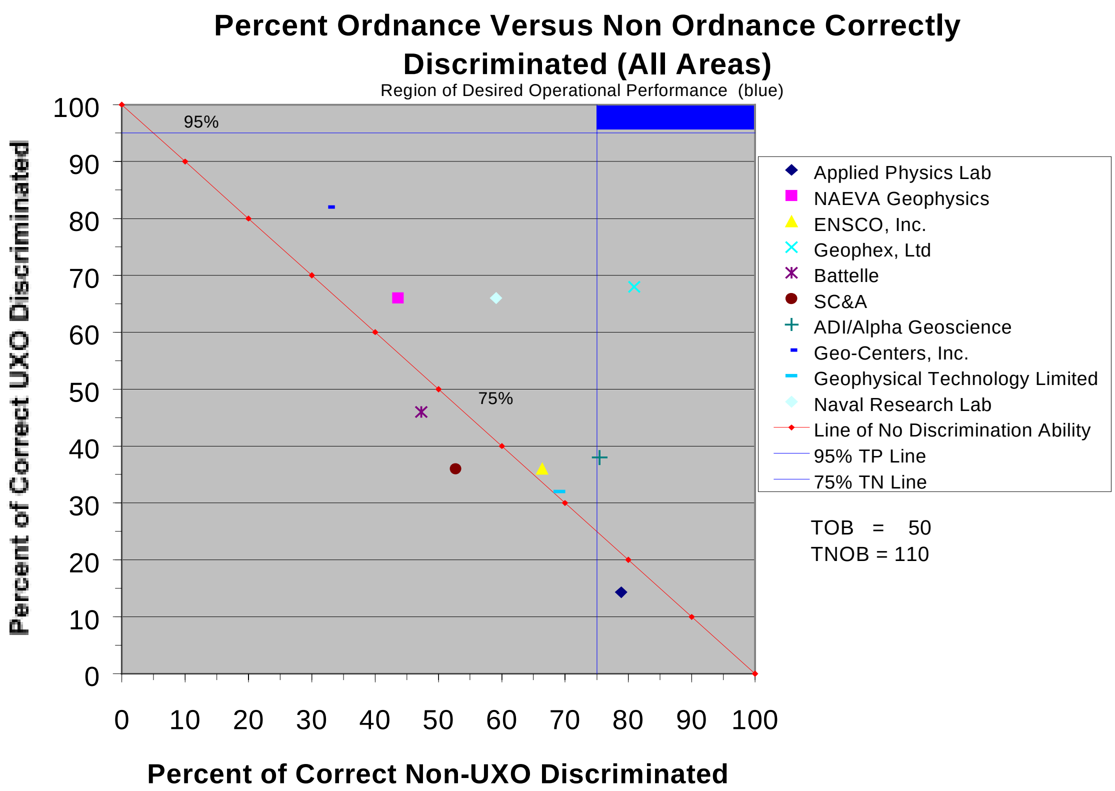
Results of Phase IV

Results of Phase IV show there is a developing capability to distinguish between ordnance and non-ordnance. Five of the ten demonstrators showed a capability to discriminate ordnance and non-ordnance that was better than the chance probability of 50%. One demonstrator showed a better than 75% ability to discriminate non-ordnance from ordnance while maintaining a relatively high TP rate. The data generated from Phase IV was gathered in a standard format and is available, along with the ground truth, to Aided Target Recognition

(ATR) researchers through the UXOCOE web site.[3] It is through ATR that the ability to discriminate will be provided for UXO Clearance.

Analysis of Phase IV data is still underway and has provided for lively debate inside the UXO Clearance community. The goal of the JPG-TD program is not to give an absolute answer but to show trends and to indicate the current state-of-the-art. To help understand the results of Phase IV, Graph 3 shows the relationship between correct declarations of UXO (TP) and correct declarations of non-UXO (TN). The line that runs diagonally from the top left to the lower right is the 50% chance line, or simply guessing about the target type. The area below this line is incorrect discrimination. The top left point on the line is where a demonstrator may declare all targets to be ordnance. Although the demonstrator will reduce the risk to zero by not missing any detectable targets he will have a larger number of false declarations that significantly increase the cost of remediation. The lower right point indicates where a demonstrator may declare all the targets to be non-ordnance. If a demonstrator felt that the vast majority of target detections were non-ordnance, he could declare them as such. This scenario would represent a significantly higher level of potential risk. Drawing a straight line between these two points represents the line of “no discrimination ability”. For true discrimination to take place a demonstrator must declare a combination UXO and non-UXO above this chance line.

Graph 3 Summary of JPG IV Results

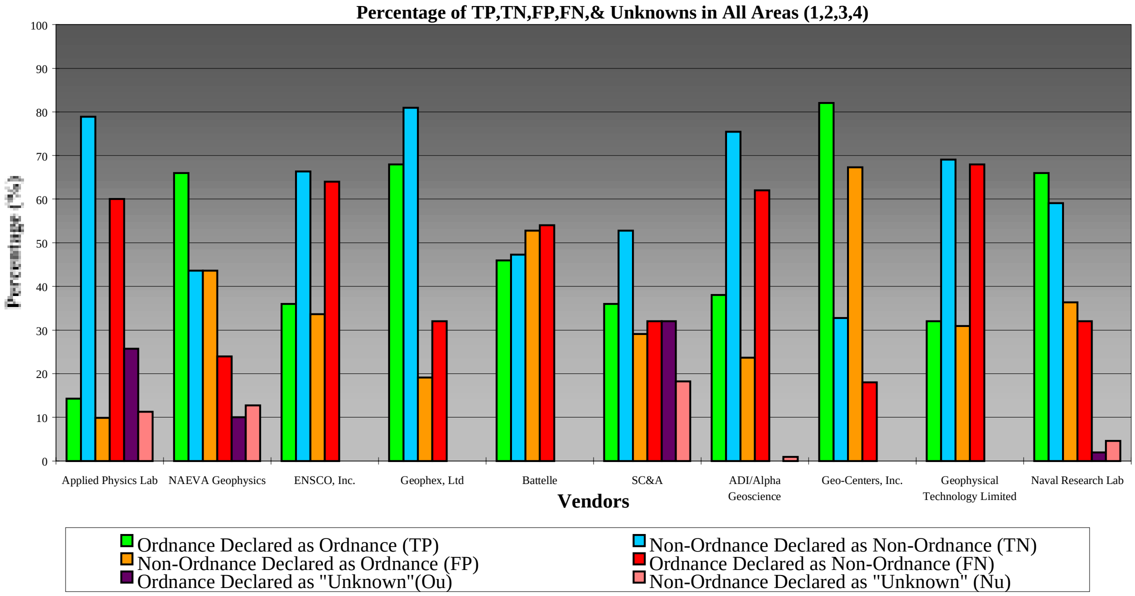


The most promising trend in this data is the success of vendors using electro-magnetic inductance equipment. While considered mature sensor technology, there is a wealth of information in the frequency and time domain signals that provide discrimination capability. This information is normally lost when normal UXO Clearance operators use the equipment. However, analysis of this information in digital form, along with very precise location information allows the use of ATR algorithms to identify signals normally ignored by the operator.

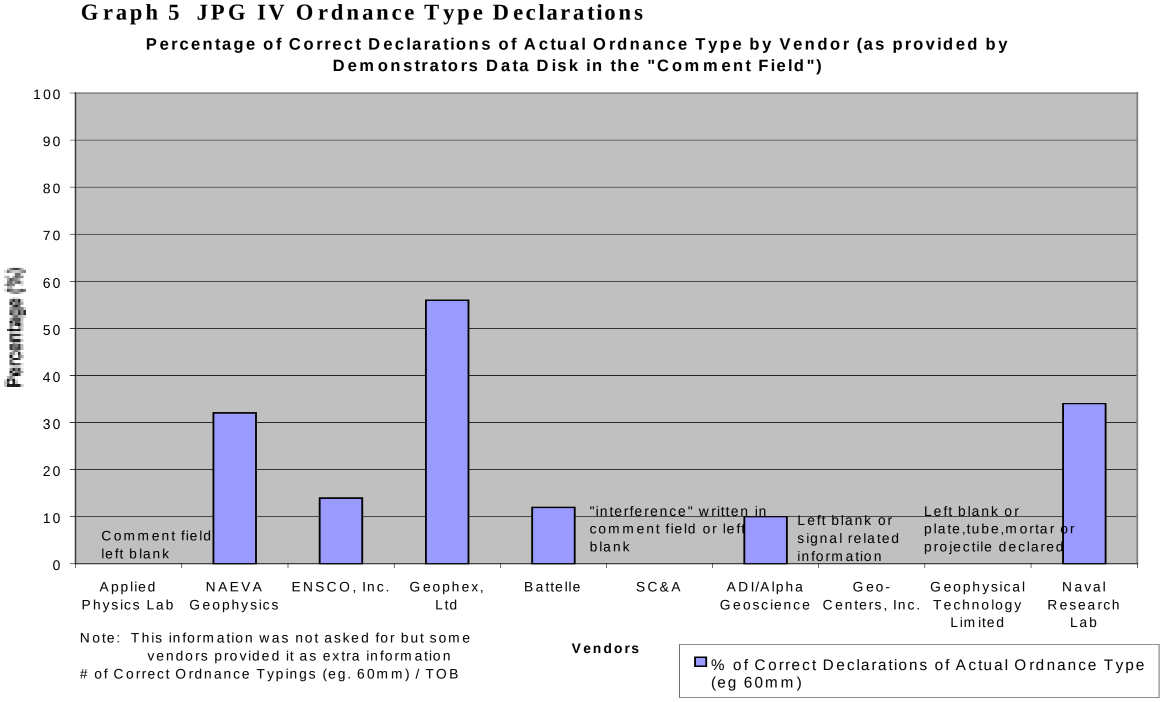
To further analyze the data a comparison of TP, TN, FP, FN and unknown results is needed. Graph 4 provides this information for each vendor. The graph portrays the fact that while some vendors performed well in identifying ordnance or non-ordnance, combinations of sensor technology or ATR are still possible that would move our discrimination capability further from the chance line. The strength of one vendor's approach in ordnance detection could be married with a vendor strong at non-ordnance to provide a superior product.

Graph 5 shows that there is more promise in some of the demonstrators' approaches. Not only did vendors show a capability to discriminate UXO from non-UXO, some were able to identify specific types (i.e., 20mm vs. 60mm) of UXO. This capability needs to be further explored and encouraged because it will provide the UXO Clearance community with the greatest information to reduce risk.

Graph 4 JPG IV Vendor Performance



Graph 5 JPG IV Ordnance Type Declarations



JPG TD SUMMARY

During the history of the JPG Technology Demonstrations, 76 characterization and remediation technologies were demonstrated. These efforts provided Government and Industry with a unique method of learning and applying knowledge about UXO Clearance in a controlled field environment. The JPG TD allowed the Government to insert lessons learned from past phases and ongoing UXO Clearance operations to increase the utility of the results for installation commander and clearance managers. Industry was provided an opportunity to both demonstrate their capabilities (UXO Detection and Remediation contractors) and understand the technologies most applicable to current UXO Clearance projects (UXO Clearance contractors). JPG TD Phases I and II were used to determine the emphasis of Phases III and IV. Phases I through III demonstrated the capabilities of current technology as it applies to the detection of ordnance while Phase IV demonstrated the promise of current UXO discrimination capabilities. From these four phases the following observations and recommendations can be made:

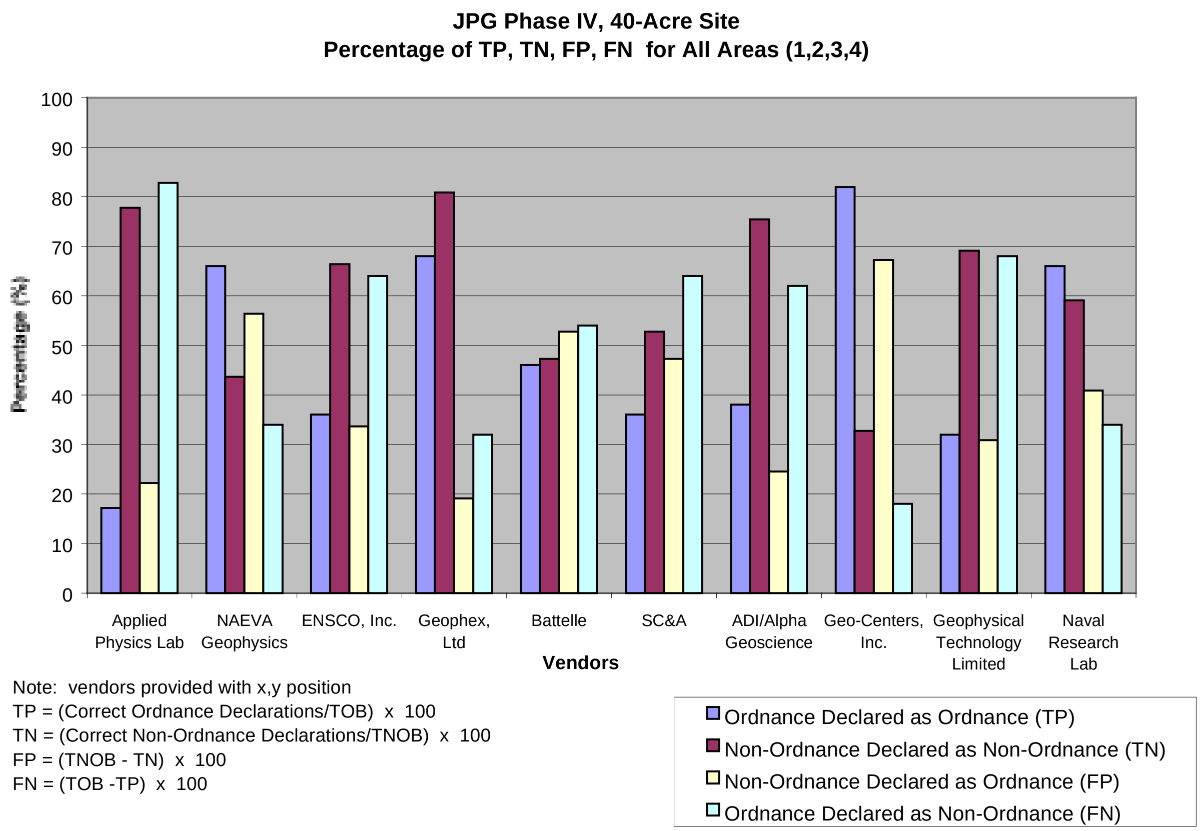
- Technology to detect deeply buried ordnance is currently inadequate. New sensors need to be developed to detect in-ground targets and provide higher resolution.
- Current discrimination capabilities need to be improved.
- Establishment of test site(s) that allow industry to take data from buried ordnance and debris is needed. Documentation should include target type, depth, orientation, size, weight, volume, and type of material. This “ground truth” will help sensor developers focus on the specific problems in ordnance detection along with the environment in which it is found.
- “Blind tests” or “standards testing” should be performed every two to three years to monitor progress of industry capabilities. Funding for promising technologies and novel approaches should be made available.
- Combinations of electromagnetic induction and magnetometer/gradiometer sensors proved to be an effective combination in all surveys and should be developed further.

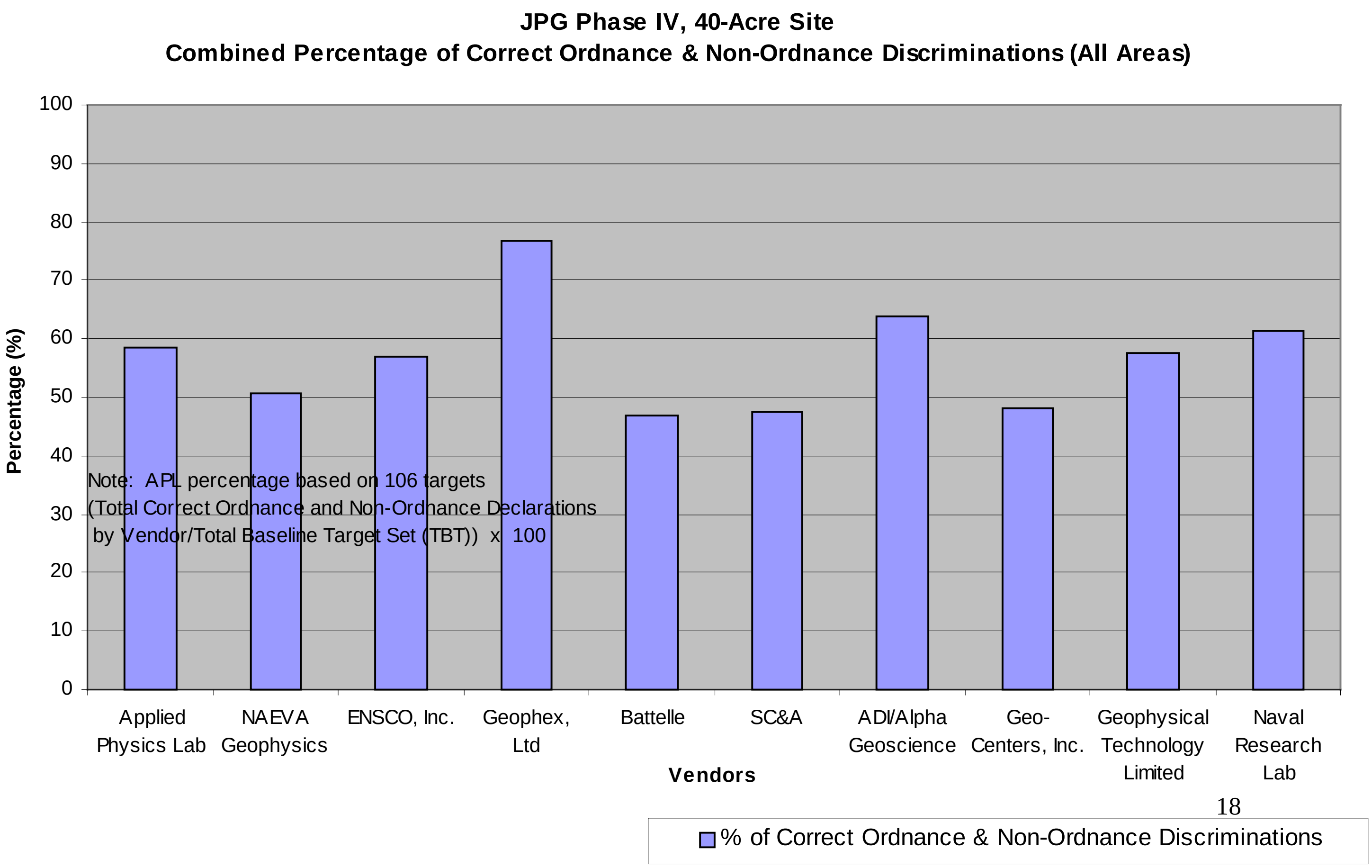
RECOMMENDATIONS

Future efforts should focus on programs to increase the true positive (TP) and true negative (TN) rates and to further characterize “noise” sources on real ranges. True identifications decrease both the risk and cost of UXO site remediation. It is highly desired to obtain technologies that have increased ability to discriminate ordnance from non-ordnance, as well as to tell what type ordnance item is buried. The key to more efficient UXO remediation lies in the products that can come from a partnership between Industry and Government in an aggressive development of cost effective remediation technology to replace currently fielded tools and practices. The four demonstration phases at Jefferson Proving Ground (JPG) document some significant advances in unexploded ordnance (UXO) detection, discrimination, and identification capability that have come from current partnering efforts. The JPG sites originally thought to be simple sites for the UXO technology demonstrations in terms of geologic noise and cultural clutter backgrounds have characteristics in some areas that can make UXO detection difficult. Detection of UXO must be accomplished in the presence of these backgrounds.

There are inherent limitations on the detection capability of geophysical systems caused by the size and depth of burial of UXO (a given UXO may be too small and/or too deep to produce a detectable anomaly signature); these limitations exist regardless of the geological and clutter backgrounds. The geological background further decreases UXO detectability by attenuating signatures, reducing physical property contrasts, and providing sources of localized anomalies. The cultural background or clutter decreases the reliability of UXO detection due to interference signals and false alarm anomalies caused by surface and buried cultural features.

It is strongly recommended that these technology demonstrations be continued. There is a need to continue the technology demonstration effort to document the capabilities and limitations of sensor systems as they are developed. The JPG controlled test site is a unique national resource for assessing UXO technologies. Consideration should be given to designating other DOD areas for technology demonstrations to provide geological and vegetative variation. The Jefferson Proving Ground technology demonstrations also provided a way for current UXO detection systems vendors to assess their probability of detection, false-alarm rates, and ability to discriminate ordnance from non-ordnance. As a performance test, the JPG demonstrations have shown the strengths of some sensors, the weaknesses of others, and provided insights into the complicated issues surrounding UXO detection and cleanup. As noted earlier, 75% of UXO cleanup costs are attributed to the removal of non-ordnance items. Continued support of UXO technology demonstrations will significantly reduce remediation costs in the future.


JPG Phase IV, 40-Acre Site
Percentage of TP, TN, FP, FN for All Areas (1,2,3,4)
Percentage (%)
Applied Physics Lab
NAEVA Geophysics
ENSCO, Inc.
Geophex, Ltd
Battelle
SC&A
ADI/Alpha Geoscience
Geo-Centers, Inc.
Geophysical Technology Limited
Naval Research Lab
Vendors
Note: vendors provided with x,y position
TP = (Correct Ordnance Declarations/TOB) x 100
TN = (Correct Non-Ordnance Declarations/TNOB) x 100
FP = (TNOB - TN) x 100
FN = (TOB -TP) x 100
Ordnance Declared as Ordnance (TP)
Non-Ordnance Declared as Non-Ordnance (TN)
Non-Ordnance Declared as Ordnance (FP)
Ordnance Declared as Non-Ordnance (FN)


JPG Phase IV, 40-Acre Site
Combined Percentage of Correct Ordnance & Non-Ordnance Discriminations (All Areas)
Percentage (%)
Note: APL percentage based on 106 targets
(Total Correct Ordnance and Non-Ordnance Declarations
by Vendor/Total Baseline Target Set (TBT)) x 100
Applied Physics Lab
NAEVA Geophysics
ENSCO, Inc.
Geophex, Ltd
Battelle
SC&A
ADI/Alpha Geoscience
Geo-Centers, Inc.
Geophysical Technology Limited
Naval Research Lab
Vendors
% of Correct Ordnance & Non-Ordnance Discriminations