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13. ABSTRACT ***(Maximum 200 Words)***
This interim annual report addresses FY97 accomplishments in the following areas: test site development, radar upgrade and evaluation, modeling and algorithm development, data collection, and published reports and technical papers. During the reporting period, ARL established a ground truthed/characterized UXO test site containing over 500 inert UXO items (including bombs, mortars, artillery, mines, rockets and submunitions) at Yuma Proving Ground, Arizona. This test site is a national asset available to other researchers and technology developers. In addition, many advancements were made in the areas of radar development, image formation, electro-magnetic modeling, and target detection algorithm development.

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ARMY RESEARCH LABORATORY

Project CU-1070:

Low-Frequency Ultra-Wideband Synthetic Aperture Radar for Remote Detection of UXO

FY97 INTERIM ANNUAL REPORT
(Covering the period Jan - Sep 1997)

submitted to

Strategic
Environmental
Research and
Development
Program

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Strategic Environmental Research and Development Program
Improving Mission Readiness Through Environmental Research

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EXECUTIVE SUMMARY

In January 1997, the U.S. Army Research Laboratory (ARL) began executing project CU-1070: Low-Frequency Ultra-Wideband (UWB) Synthetic Aperture Radar (SAR) for Detecting Unexploded Ordnance (UXO). The objective of this four-year project is to determine and enhance the capability of low-frequency UWB SAR for detecting and discriminating surface and subsurface UXO, in various soils and foliage coverage.

The UXO problem in the U.S. is quite extensive. Estimates indicate that over 11 million acres of land at active DoD sites, Department of Interior sites, and BRAC sites are potentially contaminated with UXO. Using current technologies, the cost of identifying and disposing of UXO in the U.S. is estimated to range up to $500 billion. Current UXO detection techniques are plagued by excessive false alarm rates. Some sites will have more than 100 subsurface non-ordnance items (clutter) flagged and excavated for each actual ordnance item found.

Preliminary investigations using ARL's low-frequency UWB (50 MHz - 1200 MHz) SAR indicate the technology offers potential for providing reliable detection of subsurface UXO, with low false alarm rates. Under this SERDP project, ARL researchers will collect high-quality, high-resolution target and clutter data at two calibrated/characterized UXO test sites to support phenomenological investigations of electromagnetic wave propagation through varying media, which will in turn support the development of algorithms for automated target detection. The ultimate goal is to develop innovative automatic target detection algorithms that provide a high probability of detection with low false-alarm rates under varying environmental conditions and operational scenarios.

This interim annual report addresses FY97 accomplishments in the following areas: test site development, radar upgrade and evaluation, modeling and algorithm development, data collection, and published reports and technical papers. During the reporting period, ARL established a ground truthed/characterized UXO test site containing over 500 inert UXO items (including bombs, mortars, artillery, mines, rockets and submunitions) at Yuma Proving Ground (YPG), Arizona. This test site is a national asset available to other researchers and technology developers. In addition, many advancements were made in the areas of radar development, image formation, electro-magnetic modeling, and target detection algorithm development.

The September 1997 data collection was plagued by Tropical Storm Nora and several smaller storms that produced heavy rains—amounting to over five times the expected monthly precipitation at YPG—and raised the average moisture content at the time of the data collection to over 7% moisture by weight. After the data from two data runs was processed, it became obvious that the soil attenuation was too great to overcome, as we were able to detect the surface items, and only a few of the shallow buried items. Further data collection was delayed until FY98.

A technical report, journal article, and two technical papers describing related work are contained in a separate appendix.

1.0 BACKGROUND

1.1 Unexploded Ordnance (UXO) Clearance

The UXO problem in the U.S. is quite extensive. Estimates indicate that over 11 million acres of land at active DoD sites, Department of Interior sites, and BRAC sites are potentially contaminated with UXO. Using current technologies, the cost of identifying and disposing of UXO in the U.S. is estimated to range up to $500 billion. The technologies currently used for subsurface UXO remediation requires walking with metal detection devices, placing a flag at each location of a detection and manually digging up detected objects. These techniques are plagued by excessive false alarm rates. Some sites will have more than 100 subsurface non-ordnance items (clutter) flagged and excavated for each actual ordnance item found and removed. UXO remediation costs are typically as high as $20,000 per acre.

1.2 Project Description

In January 1997, the U.S. Army Research Laboratory began executing SERDP project CU-1070: Low-Frequency Ultra-Wideband (UWB) Synthetic Aperture Radar (SAR) for Remote Detection of UXO. The objective of this four-year project is to determine and enhance the capability of low-frequency UWB SAR for detecting and discriminating surface and subsurface UXO, in various soils and foliage coverage. Under this project, ARL's UWB SAR (BoomSAR) will be used to collect high-quality precision data to support phenomenological investigations of electromagnetic wave propagation through dielectric media. These investigations, in turn, will support the development of target detection algorithms. Electromagnetic models will be refined and validated and available for extrapolating UWB SAR performance to other environmental conditions (soils).

1.3 BoomSAR Description

ARL has designed, developed, and constructed a world-class UWB radar for the purposes of ascertaining radar capability boundaries (in terms of frequency span, for example), given the device state of the art; evaluating critical enabling components and subassemblies (such as high-sample-rate A/D converters and high-power, wideband transmitters); and finally, gathering instrumentation-grade data for phenomenology evaluations and algorithm development.

The radar is mounted atop a 150-ft telescoping boom lift that is driven forward while erect. Typically, the antennas look to one side of the vehicle path to form the synthetic aperture. Boom height and antenna depression angle may be varied to provide different "looks" at the target area. This allows the system to emulate the imaging geometries of airborne radars at a fraction of the cost. Further, it provides a high degree of control in the design and execution of test scenarios. A photo of the radar system operating at Yuma Proving Ground and an illustration of the BoomSAR mode of operation are shown in Figures 1 and 2.

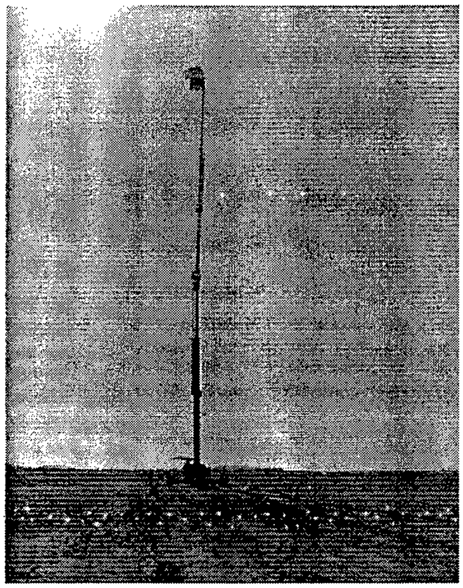


Figure 1. BoomSAR system.

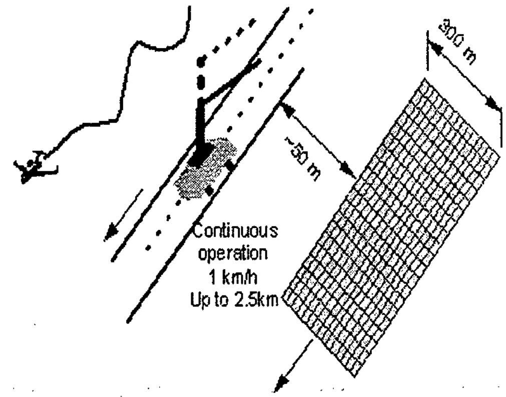


Figure 2. BoomSAR mode of operation.

As the radar proceeds along the aperture the one of the two impulse transmitters is fired so that transmit polarization alternates between horizontal and vertical, while simultaneously receiving on both the horizontal and vertical antennas. These antennas feed high-speed analog-to-digital converters (ADC) that act as base-band receivers.

In each channel, high-speed array processors operate on the ADC data to perform data interleaving, integration, filtering, and resampling to produce 8 gigasample/s equivalent data records. Interleaved output along with the associated position data from a robotic theodolite is typically sent to six 1.3-GB Magneto-Optic (M-O) CD drives, three for each channel. When operating with a 300-m wide range swath, approximately 2.5 km of aperture can be recorded on one side of these six disks.

At the completion of a run, the M-O disks are removed and examined with a graphical data quality tool in the data van. Radar status, position data, data statistics, histograms, and a spectrogram are available for examining the whole of the run, while individual records, or the averages of groups of records, can be plotted against either time or frequency.

Data is further processed in the field, or at the laboratory, to provide motion compensation, self interference rejection(SIR - to compensate for signals generated within the radar or in the supporting structure), Radio Frequency Interference (RFI) rejection to eliminate the signals generated by nearby broadcast and two-way radio, TV, and cellular phones, and range correction. The data is then backprojected to produce the bipolar image plane data used for signature analysis and from that, with application of a Hilbert transform, envelope data (which is then converted into decibels) is created to form SAR imagery. Data can be processed to provide sub-aperture or frequency sub-banded outputs to examine the utility of lower bandwidth systems or spotlight operations. The output data is stored using a flexible tagged file protocol (based upon the open standards of the Tagged Interchange File Format (TIFF) specification). This facilitates easy exchange of data, algorithms, and feature files among researchers, and permits ARL to compile all results in a central repository.

Pertinent operating parameters are provided in Table 1.

Table 1. ARL BoomSAR parameters.

Antenna	4xTEM Horn
Frequency Coverage	50-1200+ MHz
PRF	up to 1 KHz
Polarization	HH, VV, HV, VH (Quasi Monostatic)
Average Power	1 W (up to 5-10 W)
Waveform	Impulse
Receive Processing	Baseband Sampling; 8 Bit Resolution Interleaved RFI "Sniff"
Receiver Noise Figure/Loss	~2 dB/ ~2 dB
Receiver AGC	Computer Control
Processed Range Gates	Scaleable: 2040 and up (currently 4086)
Data Archiving	16K RG's in Presum Mode
Noise Equivalent $Sigma_0$	<-50 dB
3D Capability	Yes, by Altering Boom Height
MOCOMP	Embedded in Data Stream (1 cm @ 1 km)
Platform collection Speed	1 km/hr

1.4 Leveraged Projects

This project leverages annual investments of over $2M in ARL's UWB radar measurements and analysis program and Federated Laboratory Advanced Sensors Consortium on UWB radar. The investment--in radar development and testing, image formation theory and practice, phenomenology and electro-magnetic modeling, and detection theory and practice--directly relate to the needs of the SERDP project for detecting UXO. In addition, this project leverages the Steel Crater Test Site that ARL established at Yuma Proving Ground, Arizona to support work performed under the Defense Intelligence Agency (DIA) Steel Crater program. We were able to directly benefit from the infrastructure (e.g., Boom road, trailer, etc.), planning documentation (e.g, environmental assessment, frequency allocation, etc.) and site characterization information (e.g., soil analysis, etc.) created under the Steel Crater project.

1.5 Technical Team

The lead organization is the Army Research Laboratory Sensor & Electron Devices Directorate (SEDD). Co-performers in FY97 include the University of Florida, Duke University, Ohio State University, ARL Fed Lab partners, and Yuma Proving Ground (see Table 2). The in-house project team members and primary functions are listed in Table 3.

Table 2. SERDP Project CU-1070 performing organizations.

Organization	POC	Primary Function
Army Research Laboratory	Marc Ressler	Principal Investigator
	Vince Marinelli	Management POC
University of Florida	Dr. Mary Collins	Soil Analysis/Modeling
	Dr. Jim Kurtz	Soil Analysis/Modeling
Duke University	Dr. Larry Carin	Computational Electromagnetics
Ohio State University	Dr. Jon Young	Ground Contact Radar, Antenna Analysis
ARL Federated Lab Consortium	Multiple	Signal Processing Techniques
Yuma Proving Ground	Steve Patane	UXO Test Site Manager

Table 3. SERDP Project CU-1070 ARL project team

Team Member	Primary Responsibilities
Marc Ressler	Principal Investigator, Test Planning, Test Support
Vince Marinelli	Management, Test Planning, Test Support
Karl Kappra	Management
Clyde DeLuca	Test Planning, Test Site Set Up, Test Support
Dr. Barbara Merchant	Model Development
Dr. Ravinder Kapoor	Polarization Analysis, Algorithm Development
Dr. Raju Damarla	Algorithm Development
Lam Nguyen	Data Processing, Test Support, Algorithm Development
David Wong	Data Processing, Test Support, Algorithm Development
Thoai Nguyen	Data Processing, Test Support, Algorithm Development
Tuan Ton	Data Processing, Test Support, Algorithm Development
Darshanpal Gill	Data Processing, Test Support
Steve Vinci	Data Processing, Test Support
Greg Smith	Motion Compensation, Test Support
Steve Post	Test Support

2.0 ESTABLISHING UXO TEST SITE AT YPG

2.1 Coordination with UXO Community

In FY97, ARL worked (under the sponsorship of the Director, Test Systems Engineering and Evaluation) with numerous test and training range personnel to determine technology requirements of the Active Range Clearance (ARC) mission area. ARL also provided representation for ARC in activities of the UXO Integrated Process Team (IPT)-which led to the formation of the UXO Center of Excellence. Cognizant individuals supporting the ARC and the IPT efforts provided valuable assistance in the planning and coordination of the UXO test site.

2.2 Steel Crater Test Area

The Steel Crater Test Area at YPG was selected as the first UXO test site. The area is unique in that half of the area is part of Philips Drop Zone, in which the soil has been turned over to a depth of about 2 ft and is virtually free of vegetation, an almost homogeneous soil layer. This feature permits the investigation of electromagnetic wave propagation studies in a realistic but relatively easily definable soil. Figure 3 shows an aerial view of the Steel Crater Test Area.

Figure 3. Aerial view of Steel Crater Test Area.

Figure 4 shows a layout of the original Steel Crater Site that, with support from YPG and MIT/Lincoln Laboratory, ARL established in July 1995. The original area contained vehicles, mines, boxes, disks/back-filled holes, repeaters, barrels and clones. A Record of Environmental Consideration was completed as an addendum to the existing Steel Crater Environmental Assessment to allow the expansion of the test site to include several hundred inert ordnance items. Figure 5 shows the Steel Crater Site and locations of the UXO that was placed for the SERDP program. The disks/holes area has not been touched, because we want to see if the radar can still distinguish the holes that were back-filled two years ago. A group of 10 mines that were located east of the main group of mines have been removed, and will be placed at a later time in the natural occurring clutter area. The bombs were placed in both the natural occurring clutter area facing Corral Road, and in the cleared area facing Boom Road as shown in figure 6.

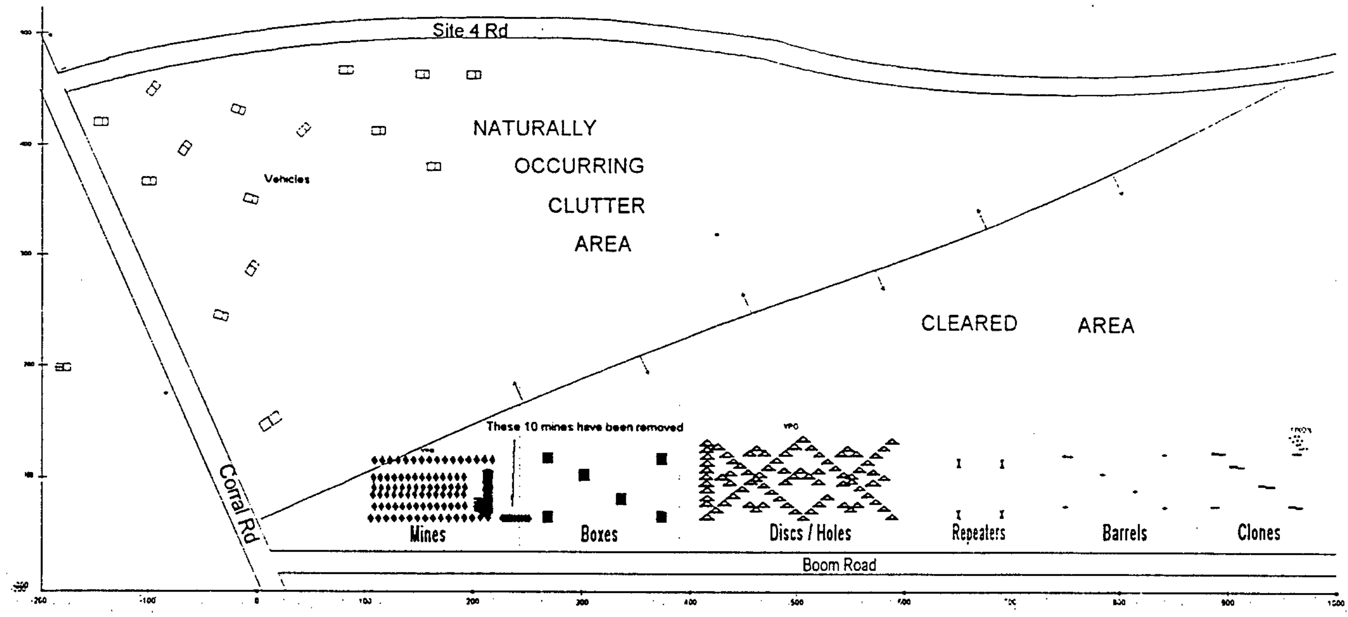


Figure 4. Original Steel Crater Test Area established in 1995.

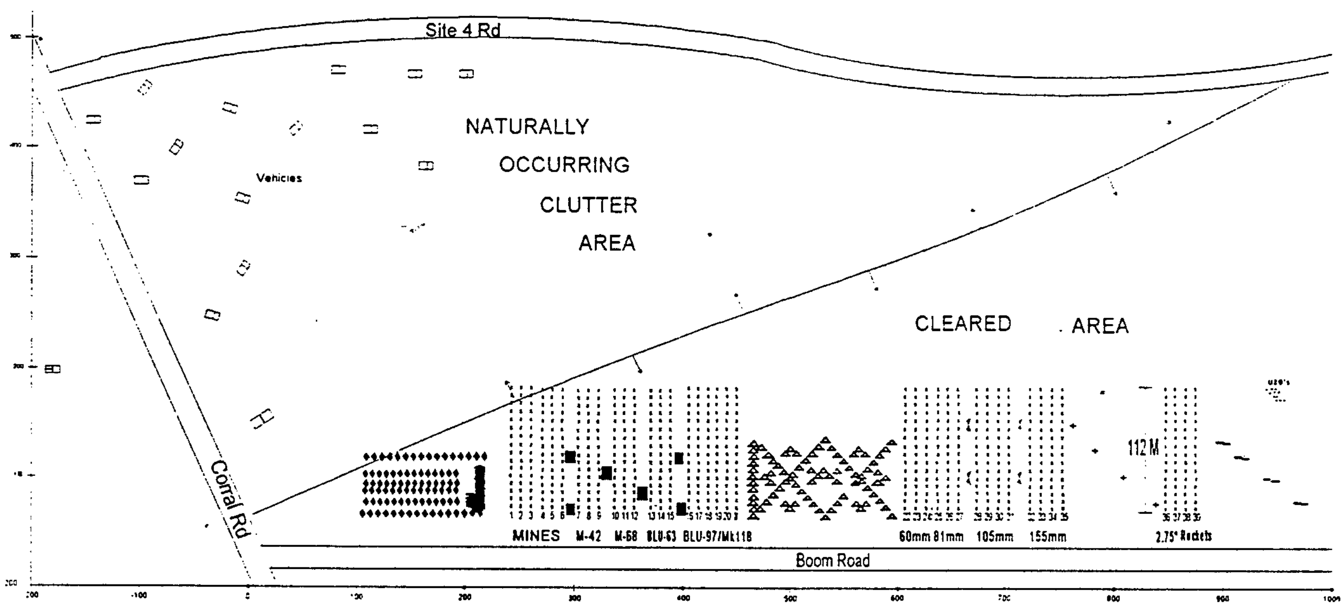


Figure 5. Steel Crater Test Area including UXO placed in 1997.

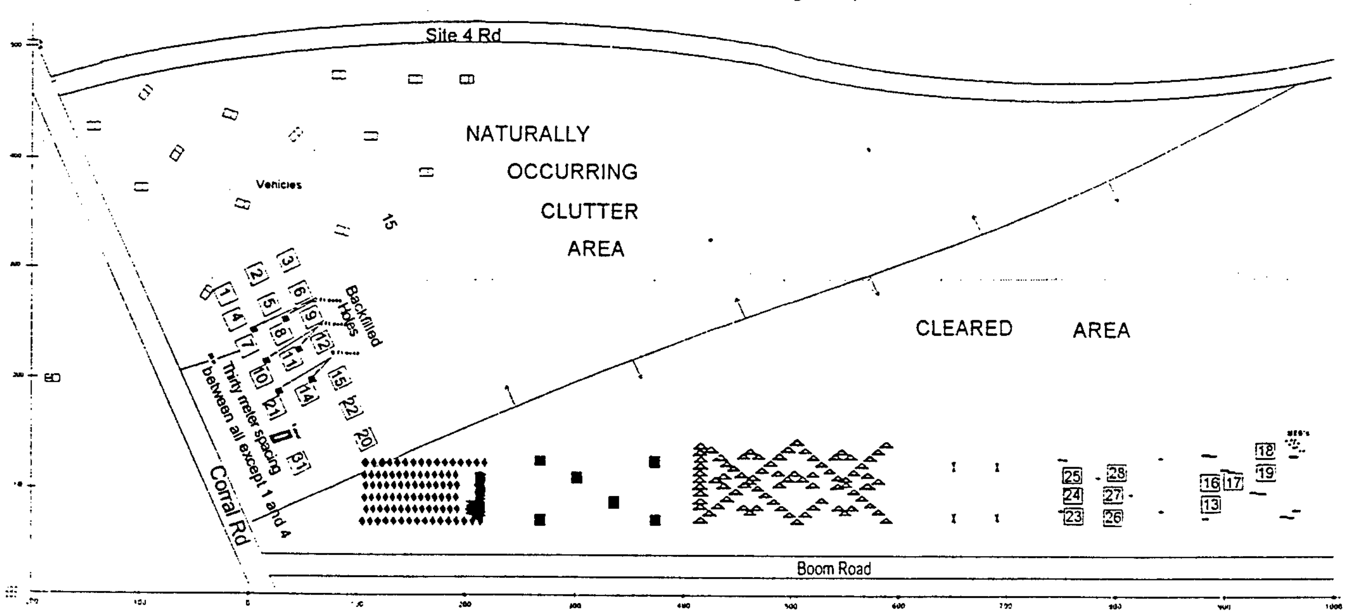


Figure 6. Steel Crater Test Area including bombs placed in 1997.

2.3 UXO Target Set

The Steel Crater Test Area was expanded to include approximately 500 additional pieces of inert UXO (bombs, mortars, artillery shells, rockets, mines, and submunitions) placed in precisely surveyed locations. The types, quantities, and locations (surface-to-tail depth) of UXO items placed in the UXO test site are shown in Table 4. This table does not include items that were already present at the Steel Crater Test Area.

Table 4. List of UXO items at YPG test site

Description	Surface / Part Buried	Buried 0 - 0.5 ft	Buried 0.5 - 1 ft	Buried 1 - 2 ft	Buried 2 - 3 ft	Buried 3 - 6 ft
Shells/Rockets						
60 mm	8	20	12			
81 mm	8	20	12			
105 mm	20	8	12	12		
155 mm	16	20			12	
2.75 in	16	20			12	
Bombs						
250 lb					1	
500 lb				4	2	
750 lb				1	1	1
1000 lb		2		2	6	5
2000 lb					2	1
Submunitions						
M-42	8	40				
M-68	12	20				
BLU-63	12	20				
BLU-97	16	32				
Mk 118	16	32				
Mines						
Gator	8	16				
VS1.6	4	16				
M12		20				
PMN		8				
POM-Z	4					

2.4 Site Layout & Ground Truth

The UXO, segregated by type, were placed in 112-m long rows, each containing 16 pieces spaced 7 m apart. The spacing between the existing targets and the newly placed UXO was also 7 m, except for the 2.75-in. rockets, 105- and 155-mm shells, which were spaced 10 m apart. The UXO was placed from west to east in ascending order of size, starting from the east side of the existing minefield. Given in Appendix A are data sheets illustrating the layout of the UXO test site.

In order to fully understand the results of the BoomSAR data collection and to foster the implementation of new and advanced data processing algorithms, it is critical to know the exact placement of each UXO item. Precise location information (depth, entry angle, and angle with respect to Boom Road and Corral Road (refer to figure 4)) allows us to more accurately evaluate and modify data processing programs and better understand the phenomenology associated with UXO target scattering.

To ensure ground truth accuracy, each UXO item was assigned a number, labeled, photographed, and videotaped, and then placed in its assigned location, which had been previously surveyed by YPG geodetics personnel. Before the UXO was buried, it was photographed and videotaped as it lay on the ground, and each item location was re-surveyed. The UXO was buried at different depths, entry angles, and angles with respect to Boom/Corral Road in an attempt to represent realistic UXO locations and orientations, and to provide us with a wide variation of aspect angles to evaluate algorithm performance. The bombs were placed at depths ranging from surface to 2 m deep, entry angles of 0 to 90 degrees, and angles from 0 to 315 degrees with respect to Boom/Corral Road. Orientation, with respect to Boom/Corral Road, and depth of burial were verified by Yuma Geodetics personnel, and the angle of burial was verified within one degree using a gunner's quadrant.

Figure 7a shows YPG personnel re-surveying a bomb. Figures 7b to 7e show a 250-lb bomb, M42 submunition, BLU-97, and a M118 Rockeye, respectively, each with its relevant information recorded on a placard.

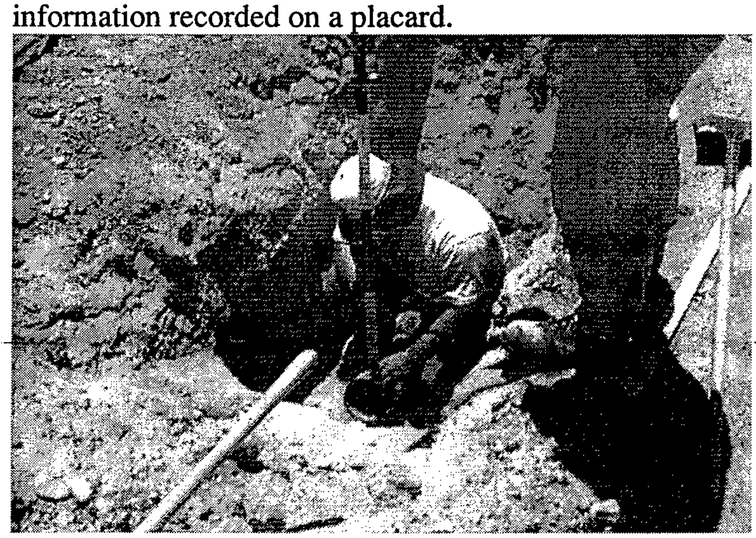


Figure7a. YPG personnel re-surveying bomb.

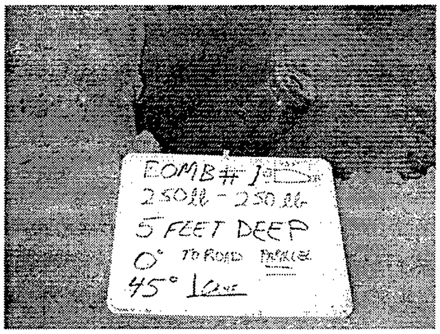


Figure 7b. Bomb #1 information.

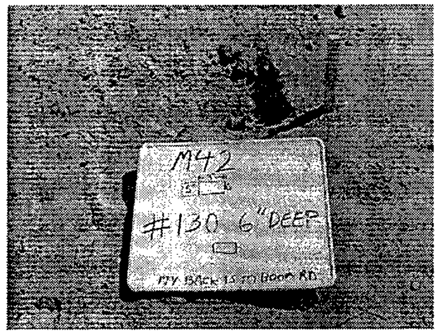


Figure 7c. M42 #130 information.

Figure 7d. BLU-97 #282 information.

Figure 7e. M118 Rockeye #328 information.

A total of 624 locations were surveyed for the placement of the UXO, and 29 locations were surveyed for the placement of the bombs. Of the 624 surveyed locations for UXO placement, 512 pieces have been placed. The remaining UXO will be placed in the test area, in small groups, after each predetermined series of data collections has been completed, to gather data for evaluating change detection algorithms. Of the 29 bombs buried, 18 are located in the natural occurring clutter area of the Steel Crater Test Area, which faces Corral Road, and the remaining 11 were buried facing Boom Road. In addition to burying the 18 bombs in the natural occurring area, six holes were dug and immediately back-filled, to investigate the radar signature of disturbed soil versus an actual target.

2.5 Soil Analysis

The University of Florida conducted extensive soil analyses at the Steel Crater Test Site/UXO Test Site in FY96 (in support of the Steel Crater project) and again in September 1997 (in support of the SERDP project). Details of the September 1997 field and laboratory soil tests, the results of those tests, and results of soil modeling for YPG soils are described in a 65-page report at Appendix B.

Several types of tests were performed on the soils in September 1997, and subsequently in the laboratory, in order to characterize the soil conditions in the areas of interest. Time-domain reflectometer (TDR) tests were made with probes inserted directly into the ground, soil visual inspections and tests were made in the field, and soil samples were collected for further laboratory testing at the University of Florida. The TDR makes a measurement of a pulse waveform input to parallel probes inserted into the soil. From the TDR measurements, the effective velocity of the pulse in the soil is measured and, in turn, the soil dielectric constant (approximately the real dielectric permittivity) and volumetric moisture content can be calculated. The characteristics of the TDR pulse return also allow estimates of low-frequency soil conductivity. Soil samples were collected to make bulk density measurements, gravimetric moisture measurements, soil composition, dc conductivity, and other measurements in the laboratory. Comparisons of field measured moisture to the laboratory measurements were made.

Figure 8. Soil moisture measurements in progress with help of time-domain reflectometer.

Soil model results are presented which show the calculated dielectric permittivity, conductivity, attenuation, and surface reflection loss of representative Yuma soils for different moisture contents ranging from 0 to 10% moisture by dry weight. The model data can be used to estimate several of the major attenuation effects encountered when trying to detect subsurface targets in the types of soils found in this area of Yuma.

3.0 BOOMSAR UPGRADE AND EVALUATION

3.1 Motion Compensation System

An existing Inertial Navigation System (INS) from a previous project was selected for evaluation to determine the value added of an improved update rate for the motion compensation (MOCOMP) system of the BoomSAR. The spare MOCOMP computer and the Inertial Measurement Unit (IMU) and Navigation Computer (NAV) of the INS were mounted in one of the electronics cabinets of the UWB radar and interfaced to the existing Geotronics theodolite data stream. To minimize impact on system operations, the INS system was designed to operate as an independent motion sensor, with common time tagging derived from the geotronics data. A SCSI interface was included to allow the files generated in the INS MOCOMP computer to be off-loaded after testing onto 1.3 GB magneto-optic drives. The intent was that this data would then be merged with the Geotronics data in the MOCOMP processing stage of the UWB post-processing software to produce X,Y,Z position information along with antenna attitude data.

A test plan was developed to gather INS data in the parking lot of the ARL Adelphi facility. Data analysis after the test showed a large drift component in the output of the INS as compared to that of the existing MOCOMP system. Tests in the lab showed that the north-seeking gyro functions and attitude outputs were working properly, but that integrated accelerometer outputs were not being corrected to the reference location provided by the theodolite system, and thus the INS believed it was moving, even when stationary. An examination of the INS control program revealed some errors that were corrected, and operation for periods of an hour or more while stationary did not produce a change in INS reported position. Further data recording was done with the modified software when the radar was operated at Yuma in September 1997. Post-test analysis showed that there is still drift term in the INS position output. Further experimentation and processing of the INS data is required to determine the effectiveness of this MOCOMP system.

3.2 Post-Processing Enhancements

Increased Sensitivity of Radar -- Improvements were incorporated into the data processing to increase its sensitivity to see smaller targets. The embedded motion compensation was enhanced by post-processing calibration target data to minimize errors across the aperture by making corrections to acquisition delay, antenna phase rotation center, and applying these as lever arm corrections to generate a new effective motion compensation record.

Evaluation of Aperture Effects -- Analyzed the effect of processing data with varying image aperture size and squint direction to determine effects on resolution and to quantify advantages of spatial diversity in improving target detection,

3.3 Antenna Testing

Developed an antenna test plan for use at ARL Adelphi, MD, to evaluate the antenna pattern of the complete array of four UHF antennas, or two VHF antennas, in the presence of the surrounding metal support of the boomlift. Developed a plan to evaluate the effect of antenna pattern, target orientation, and target height above ground on the return from calibration targets. The antenna test plan was redesigned to take advantage of an existing EA, and hardware was constructed at ARL's rooftop radar facility. Calibration target testing was added as a task for field testing at YPG. We completed the requisite planning documents including a Record of Environmental Consideration as an addendum to the previously existing Environmental Assessments at ARL, Adelphi, but access and safety considerations made testing during normal working hours impossible. Two series of antenna tests (and the INS test) were conducted on weekends to meet schedule requirements.

4.0 MODELING AND ALGORITHM DEVELOPMENT

We ported the Vitebeskiy (Duke University) designed body of revolution (BoR) numerical code to ARL computers to analyze cylindrically symmetric targets and their natural frequencies and to compare them to field data gathered with the UWB radar. We also ported the Duke finite difference, time domain (FDTD) model to ARL computers to be able to model simple target shapes (two dimensional) in the time domain. These models support the effects of nearby flat or rough dielectric half-spaces (the ground). We have applied the FDTD code to model the response of a simple two-dimensional calibration target at various heights and rotations above a dielectric half-space. Verification of these models is planned with a series of tests to be conducted later at Yuma Proving ground. We beta tested the initial graphical user interface (GUI) versions of this code intended to be run on personal computers, and have provided a continuing feedback and product improvement path for this software. The simulations run with these codes have provided insight into anomalous responses from the radar as well as characteristics that may have promise in classifying target types.

The automatic target detection (ATD) graphical user interface (GUI) designed with the University of Florida was modified to support the needs of subterranean target detection. Detection modules are divided into two broad categories: those which generate "points of interest" (POIs) by canvassing large image areas (i.e., a prescreening function) and those which focus their attention on specified POIs (i.e., a discrimination function). A set of flexible TIFF file formats is used for radar aperture data, focused data, and feature data. Because the open standards specifying TIFF allow user-defined tags, new information can be added (by defining new tags) without compromising the ability of older versions of the reader program to access the originally defined data fields. Ground truth data and summary information about the composite TIFF file set are stored in relational database tables for ease of search and retrieval.

As part of ARL's mission-funded efforts, initial target/clutter discrimination features have been developed. After reviewing the phenomenological characteristics of the data collected in 1996 and the results from models, ARL has developed an initial structure for data prescreening. It utilizes a pruning approach where a set of increasingly more sophisticated tests are applied to locations that have been supplied from the previous stage. To maintain computational efficiency, the simplest tests are applied first. The approach is heavily weighted towards capitalizing on the phenomenological underpinnings. Amplitude and standard deviation texture features are employed to quickly canvas large image areas. These are followed by more stringent texture tests using spatial templates. Anisotropic scattering characteristic can be used to exploit the fact that some target classes are aspect dependent (shallow angle impact targets with a large length to width ratio, such as rockets) while bushes and mines are more isotropic. Finally, frequency dependent scattering features are also exploited. All discriminant features are combined using a quadratic polynomial detector (QPD) in a final decision statistic. Algorithms have been trained and tested using the data gathered in the 1996 test and will be updated as new test data becomes processed.

In our case, using an Ultra-wideband SAR, there exist three types of diversity that may be exploited for detection of targets: they are frequency, angular, and polarimetric diversity. By far the most salient property of our data is the frequency diversity due to the wideband nature of our radar, however, angular and polarimetric properties either by themselves or in combination with the frequency information can be used to improve detection. The idea of using frequency dependent scattering feature is primarily driven by the need to utilize all available features embedded within the wideband data. This feature offers ease of use coupled with improved performance at the prescreener but without substantial changes to the ATD approach.

The GUI also allows quantitative comparison of processing algorithms where probability of detection is plotted against probability of false alarm. These receiver operating characteristic (ROC) curves can be plotted for individual features or groups of features so the analyst can evaluate the final efficiency of the processing approach and the value added by each stage.

Trade-offs in performance and processing efficiency can then be evaluated, as well as any improvement offered by varying the order of processing.

5.0 DATA COLLECTION

The September 1997 data collection was plagued by Tropical Storm Nora and several other rains. Two data runs were made in September, with the hope of collecting useful data. The average moisture content at the time of the data collection was over 7% moisture by dry weight. After the data was processed, it became obvious that the soil attenuation was too great to overcome, as we were able to detect the surface items, and only a few of the shallow buried items. At that point, little meaningful data could be collected, therefore further data collection was delayed until FY98.

Presented in figure 9 is a pictorial representation of data taken from the discs/holes area at the original Steel Crater Test Area in 1996. Presented in figure 10 is a pictorial representation of the data taken from the discs/holes area when the soil moisture content was much higher. Refer to figure 4 to see the general layout of the discs area. The left-most row of discs is located on the surface, while the rest of the discs are buried at varying depths ranging from flush with the ground to 6 in. deep. The boxed areas in figure 9 show the discs (surface and buried) detected in 1995. When soil moisture content was extremely high, only discs that were located on the surface were detected, as shown in figure 10.

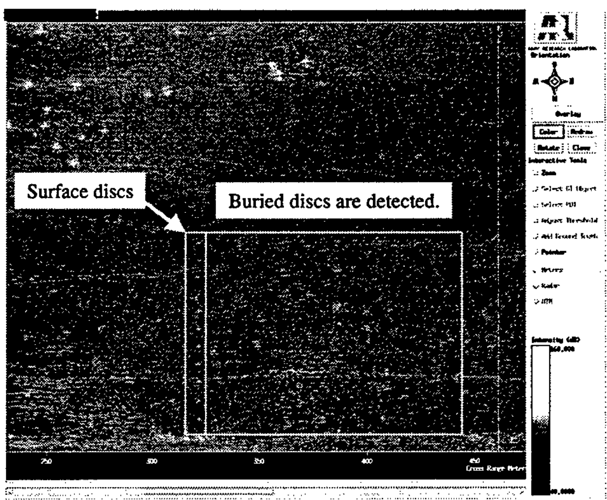


Figure 9. Discs detected in a data collection run from 1996.

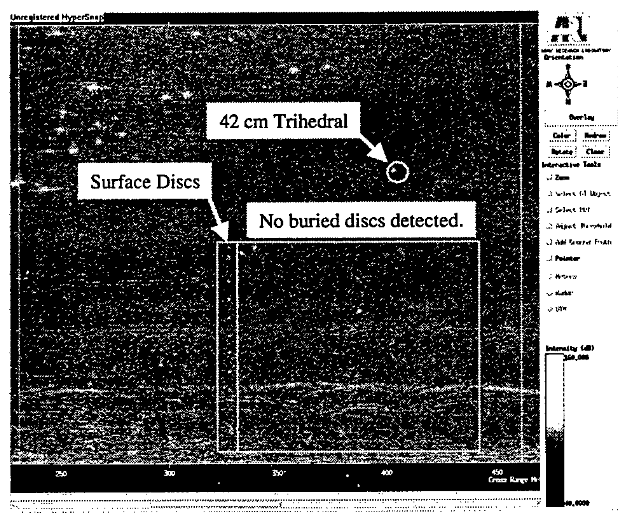


Figure 10. Same area as figure 9, but discs have not been detected due to soil conditions.

In addition to conducting a BoomSAR data collection in FY98, ARL is planning to fund its Federated Laboratory Advanced Sensors Consortium, specifically Ohio State University, to collect GPEN data at YPG. ARL's Fed Lab will be providing $135K to demonstrate a surface scanning ground-penetrating radar and magnetometer survey instrument for the purpose of detecting buried UXO. These sensors, mounted and co-registered on the Air Force Research Laboratory's Active Range Ordnance Mapping System (AROMS), will be used to characterize subsurface UXO at the YPG test site.

6.0 REPORTS AND PRESENTATIONS (Provided as a separate appendix)

6.1 Peer-Reviewed Journals

Ultra-Wideband, Short-Pulse Ground-Penetrating Radar: Simulation and Measurement, S. Vitebskiy, et al., published in IEEE Transactions on Geoscience and Remote Sensing, May 1997.

6.2 Technical Reports

Additional Soil Evaluations of Yuma Proving Ground, M. Collins, et al., December 1997.

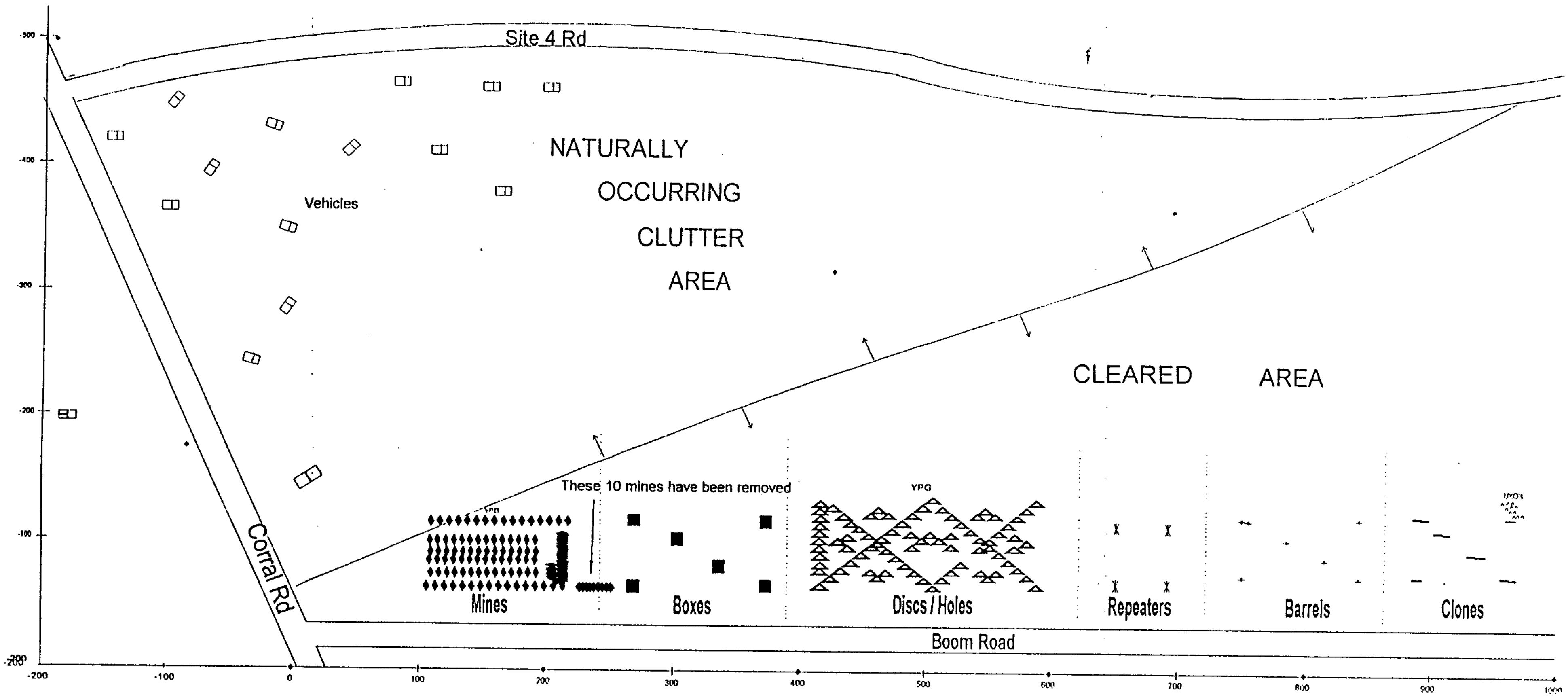
6.3 Symposium Proceedings Papers

Ground-Penetrating Radar Experiments, V. Marinelli, et al., presented at ADPA 23rd Environmental Symposium, April 1997.

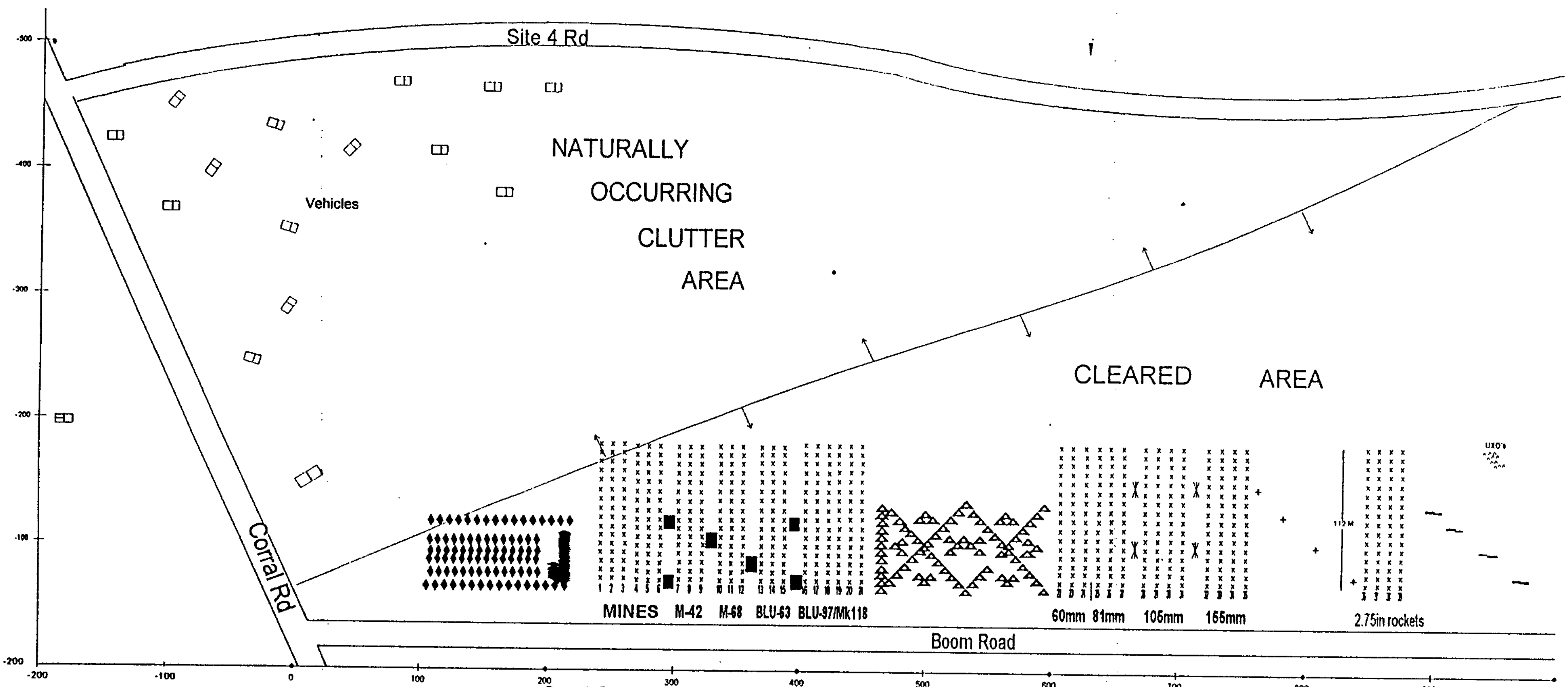
Remote Detection of Unexploded Ordnance Using Ultra-Wideband Synthetic Aperture Radar, K. Kappra, et al., presented at ADPA Night Operations Symposium, September 1997.

Appendix A

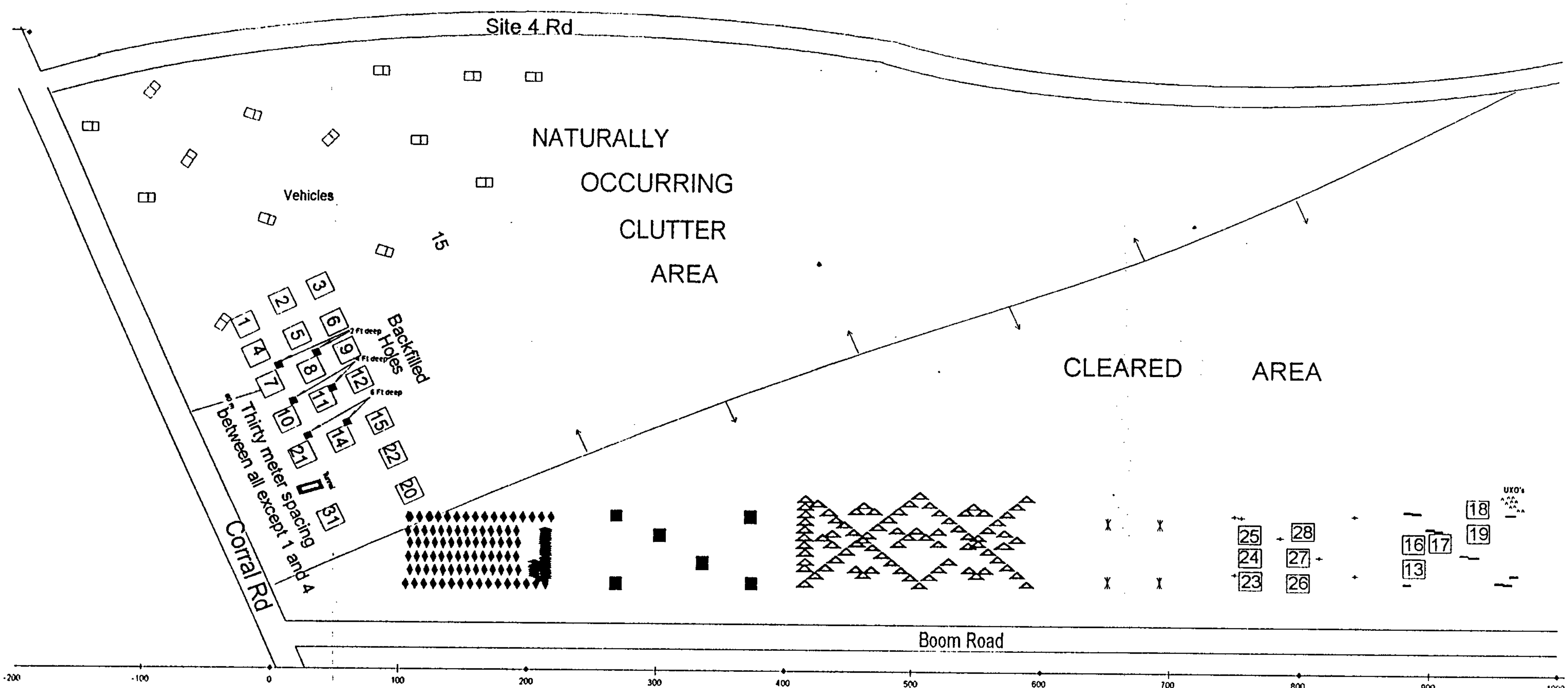
UXO TEST SITE LAYOUT DATA SHEETS



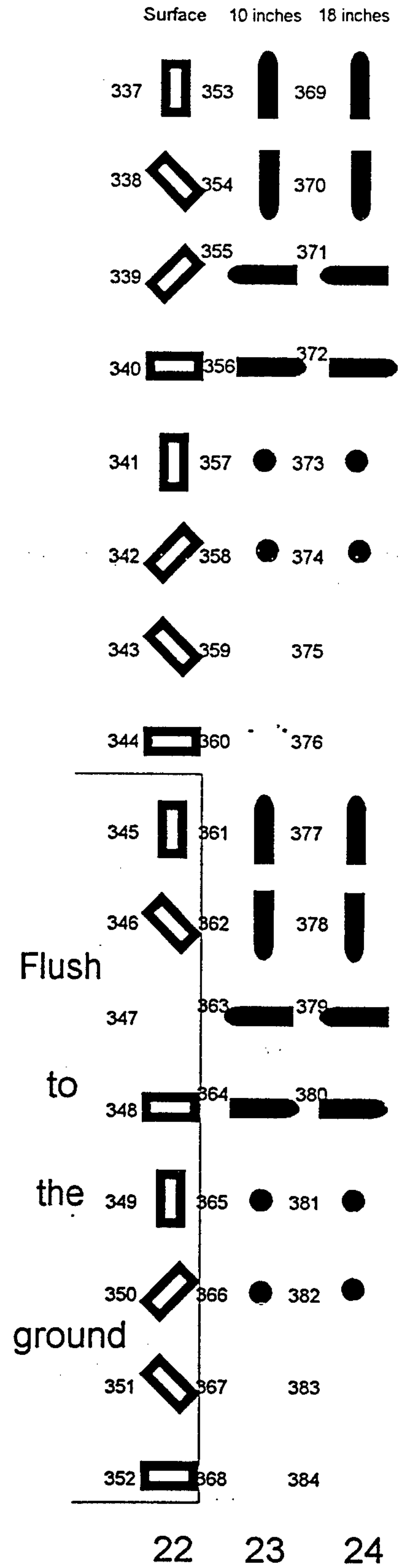
Original Steel Crater Test Area established in 1995.



Steel Crater Test Area including UXO placed in 1997.



Steel Crater Test Area including bombs placed in 1997.

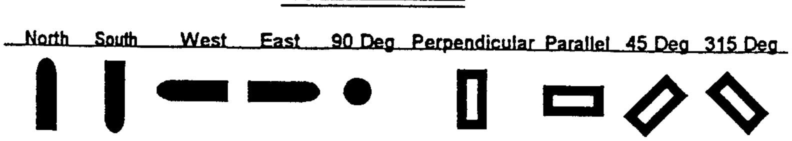


N

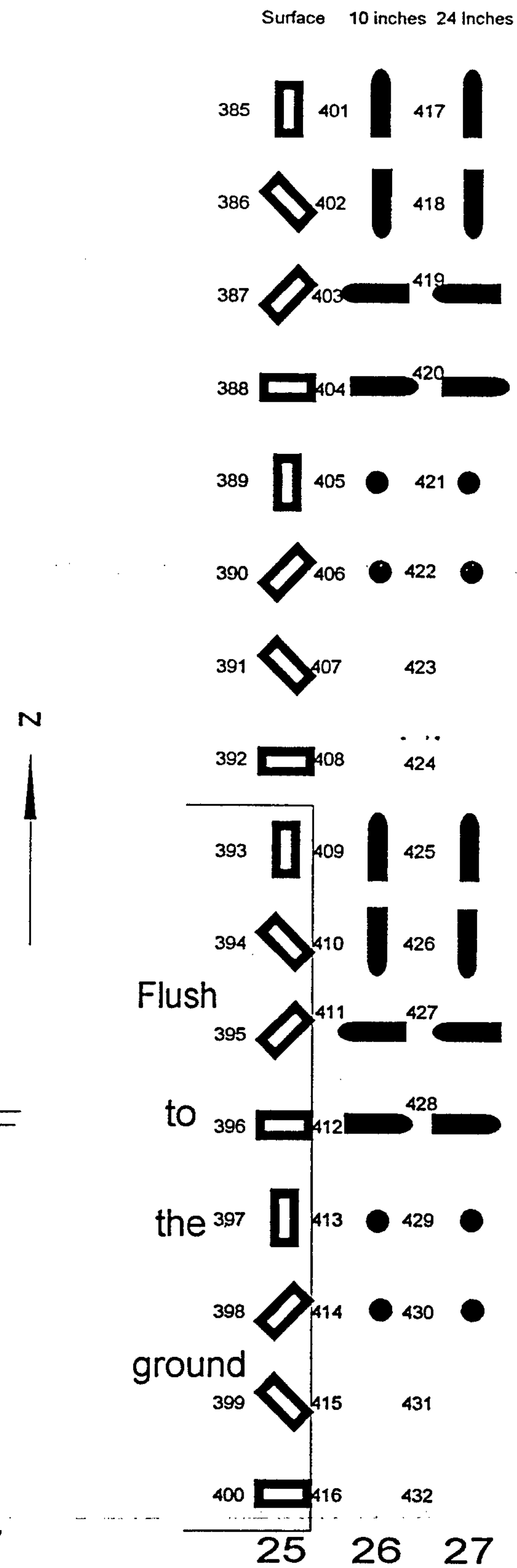
60 MM Mortar

1. 3 rows
2. 16 per row
3. Horizontal spacing = 7M
4. Vertical spacing = 7M
5. 60M between Boom Rd and first row of ordnance.
6. Empty spaces reserved for future tests.
7. Angle of entry on row 23 and 24 approximately 60 Deg.

Orientation



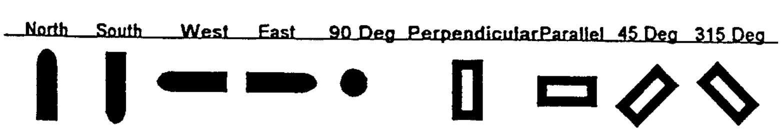
Boom Rd



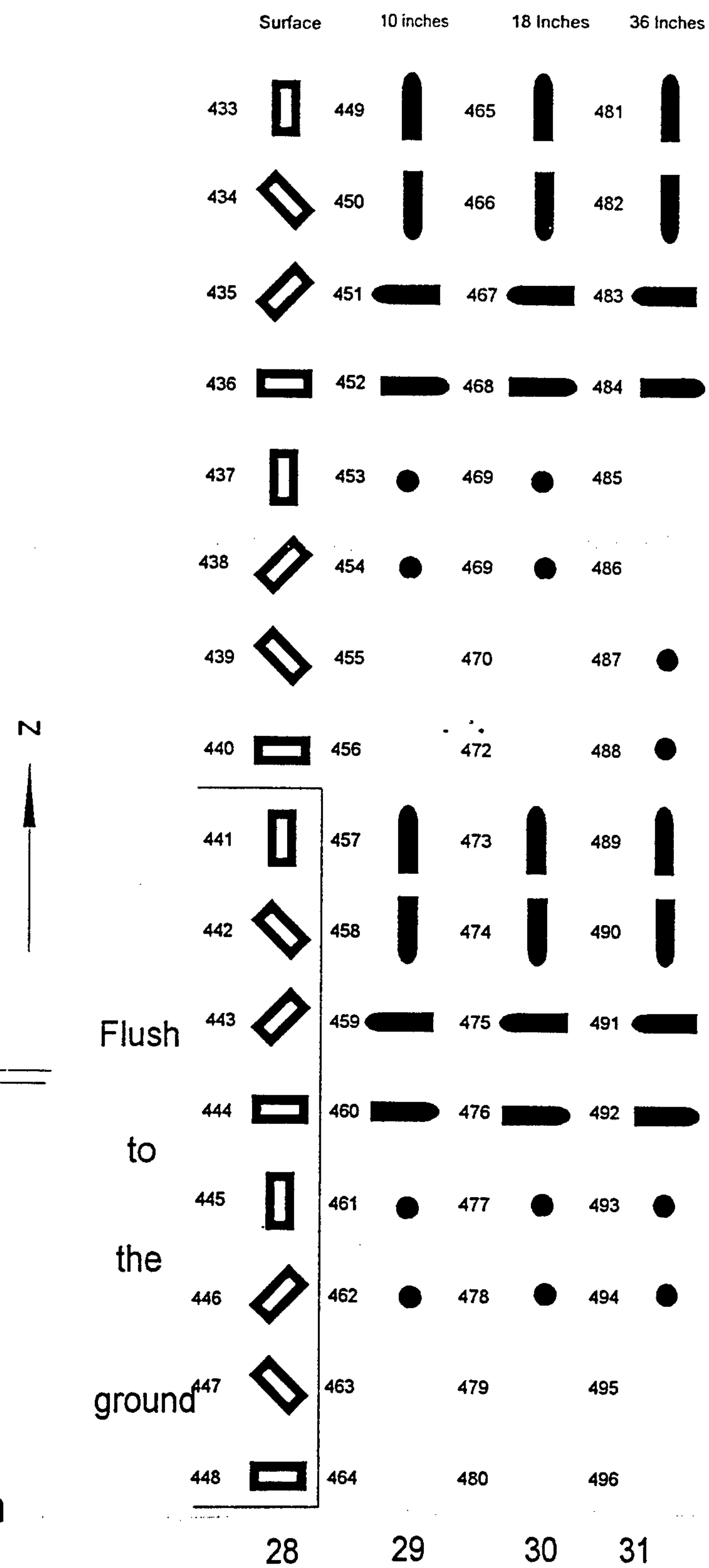
81 MM Mortar

1. 3 rows
2. 16 per row
3. Horizontal spacing = 7M
4. Vertical spacing = 7M
5. 60M between Boom Rd and first row of ordnance.
6. Empty spaces reserved for future tests.
7. Angle of entry on row 26 and 27 approximately 60 Deg.

Orientation



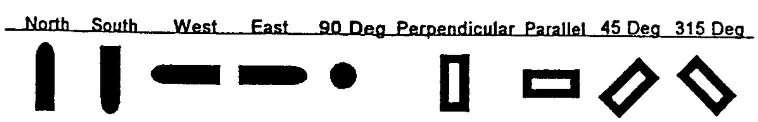
Boom Rd



105 MM

1. 4 rows
2. 16 per row
3. Horizontal spacing = 10M
4. Vertical spacing = 7M
5. 60M between Boom Rd and first row of ordnance.
6. Empty spaces reserved for future tests.
7. N, S, E, W indicates the direction with relation to the BOOMSAR.
8. Angle of entry on row 29, 30 and 31 approximately 60 Deg.

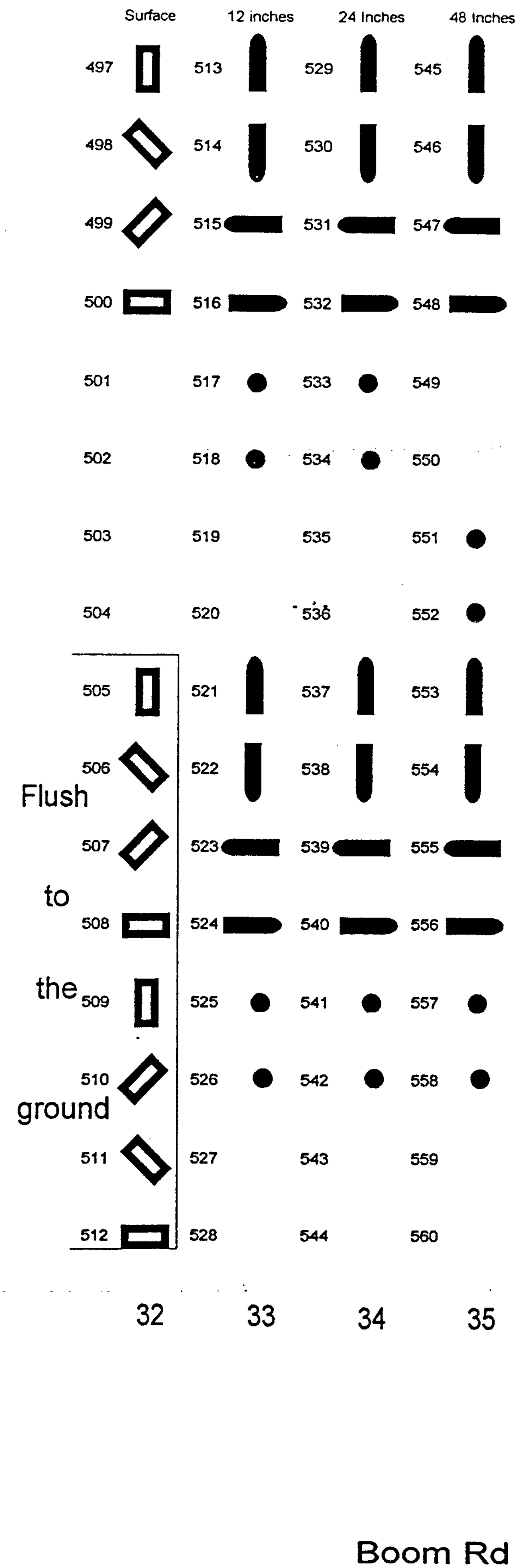
Orientation



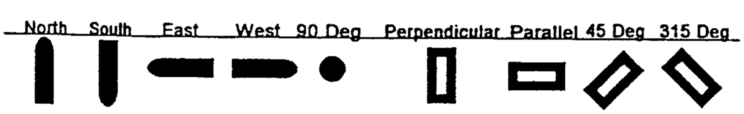
Boom Rd

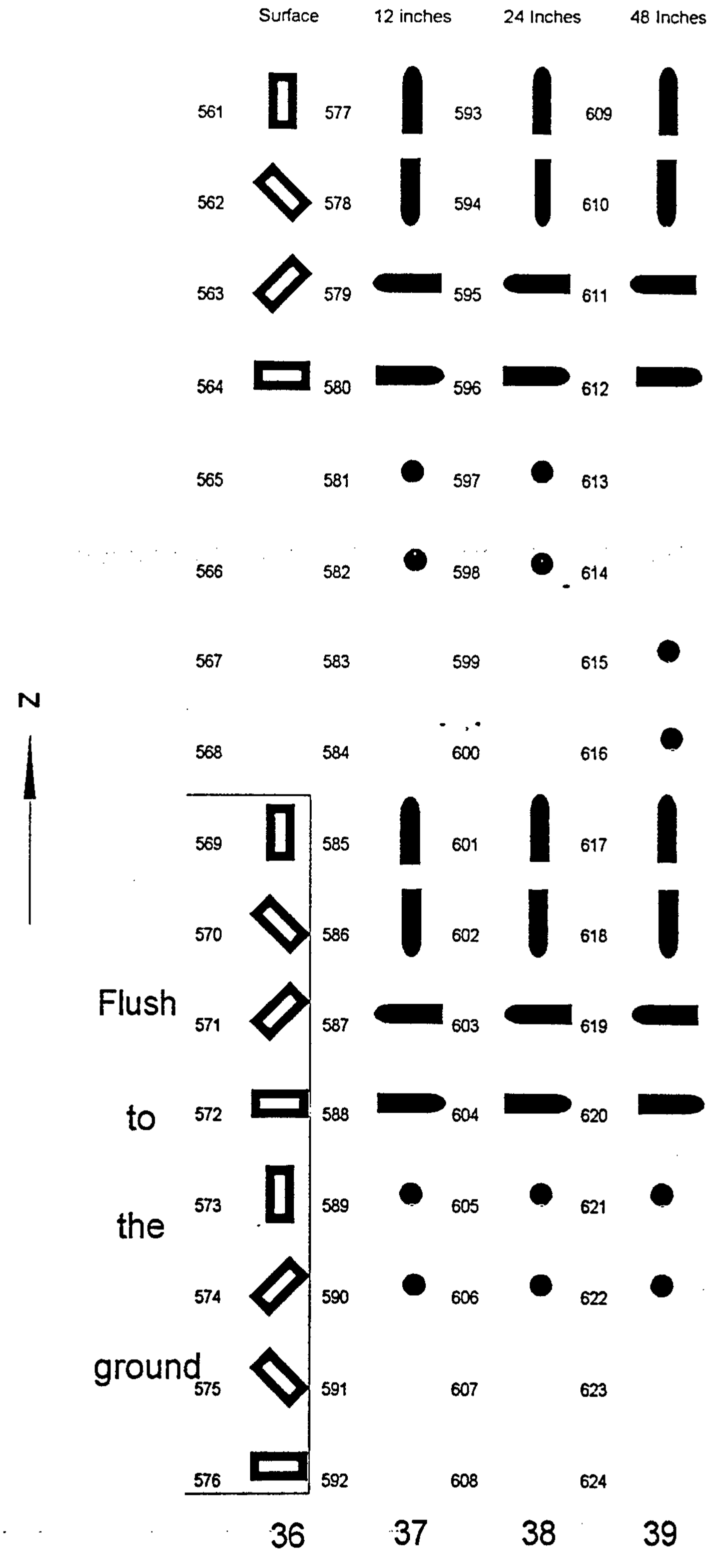
155 MM

1. 4 rows
2. 16 per row
3. Horizontal spacing = 10M
4. Vertical spacing = 7M
5. 60M between Boom Rd and first row of ordnance.
6. Empty spaces reserved for future tests.
7. N, S, E, W indicates the direction with relation to the BOOMSAR.
8. Angle of entry on row 33, 34 and 35 approximately 60 Deg.



Orientation

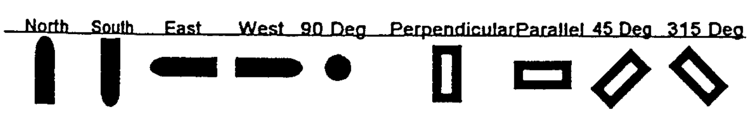




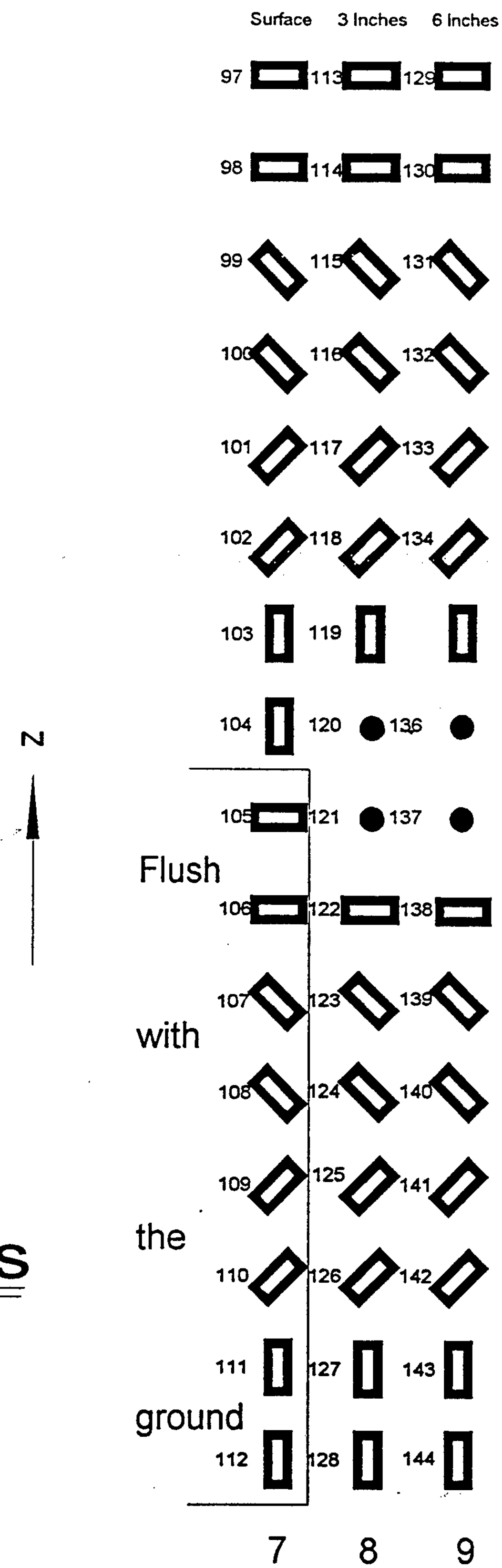
2.75 inch rocket

2. 16 per row
3. Horizontal spacing = 10M
4. Vertical spacing = 7M
5. 60M between Boom Rd and first row of ordnance.
6. Empty spaces reserved for future tests.
7. N, S, E, W indicates the direction with relation to the BOOMSAR.
8. Angle of entry of row 37, 38 and 39 approximately 60 Deg.

Orientation



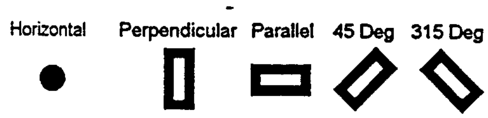
Boom Rd



M42 Submunitions

1. 3 Rows
2. 16 per Row
3. Horizontal Spacing - - 7M
4. Vertical Spacing - - 7M
5. 60 M between Boom Rd and first row of ordnance.

Orientation



Boom Rd

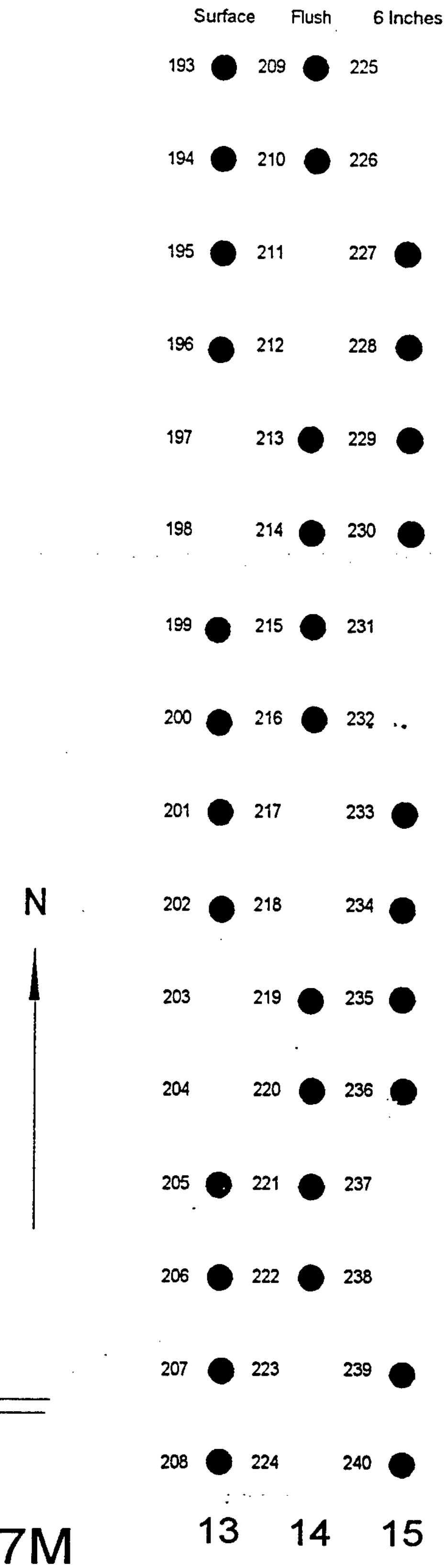
	Surface		Flush		6 Inches
145	●	161	●	177	
146	●	162	●	178	
147	●	163		179	●
148	●	164		180	●
149		165	●	181	●
150		166	●	182	●
151	●	167	●	183	
152	●	168	●	184	
153	●	169		185	●
154	●	170		186	●
155		171	●	187	●
156		172	●	188	●
157	●	173	●	189	
158	●	174	●	190	
159	●	175		191	●
160	●	176		192	●
	10		11		12

N

M-68

1. 3 rows
2. 16 per row
3. Horizontal spacing = 7M
4. Vertical spacing = 7M
5. 60M between Boom Rd and first row of ordnance.
6. Empty spaces reserved for future tests.

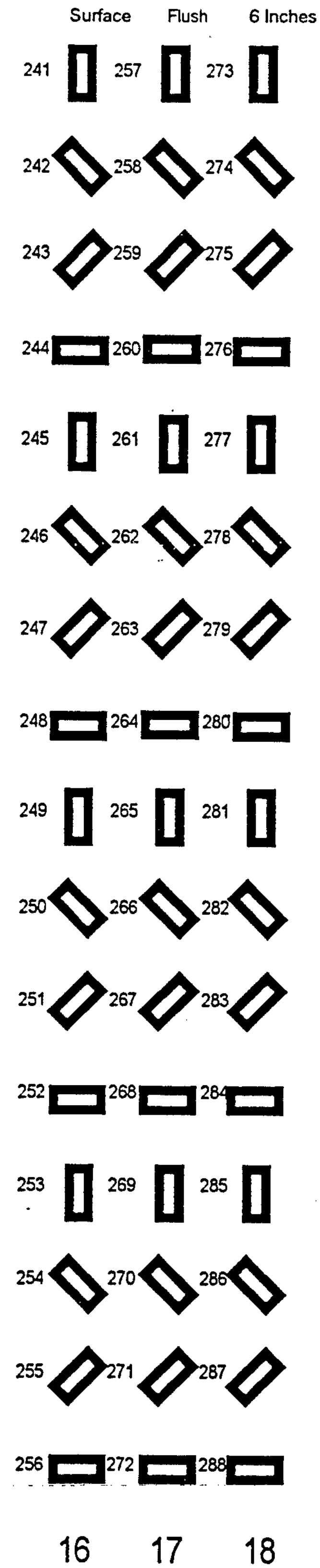
Boom Rd



BLU-63

1. 3 rows
2. 16 per row
3. Horizontal spacing = 7M
4. Vertical spacing = 7M
5. 60M between Boom Rd and first row of ordnance.
6. Empty spaces reserved for future tests.

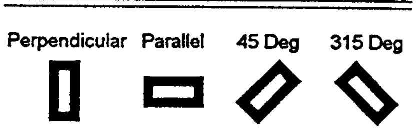
Boom Rd



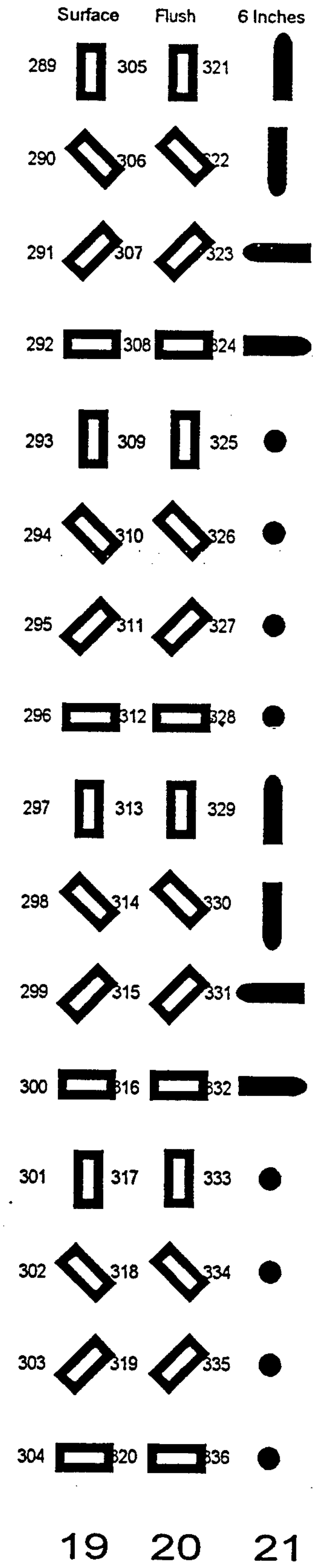
BLU-97

1. 3 rows
2. 16 per row
3. Horizontal spacing = 7M
4. Vertical spacing = 7M
5. 60M between Boom Rd and first row of ordnance.

Orientation



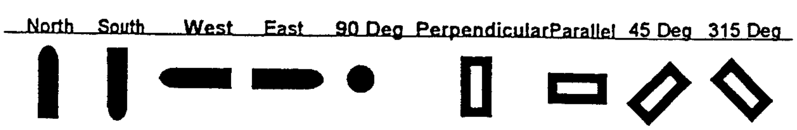
Boom Rd



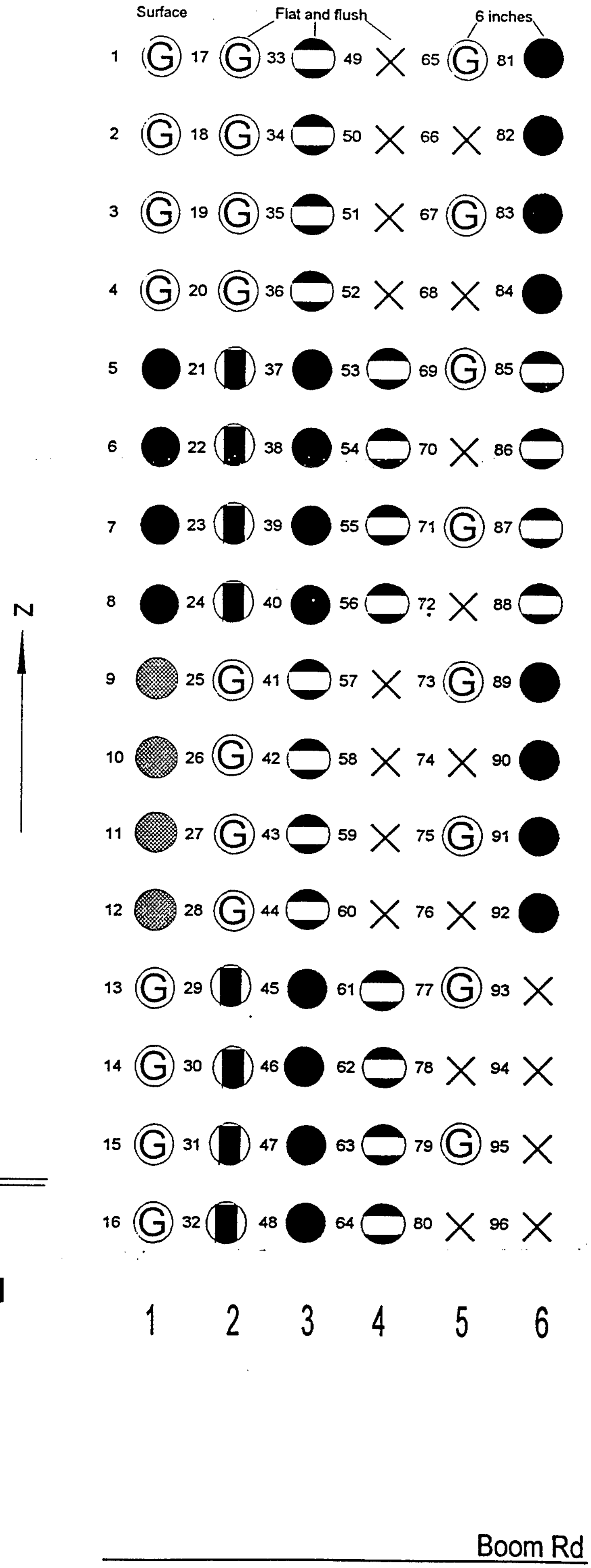
M-118

1. 3 rows
2. 16 per row
3. Horizontal spacing = 7M
4. Vertical spacing = 7M
5. 60M between Boom Rd and first row of ordnance.
7. Angle of entry on row 20 and 21 approximately 60 Deg.

Orientation



Boom Rd



MINES

1. 6 Rows
2. 16 per Row
3. Horizontal Spacing - - 7M
4. Vertical Spacing - - 7M
5. 60 M between Boom Rd and first row of ordnance.

Legend