4.0 DETECTION OF UXO AND BURIED MUNITIONS

4.1 Introduction

Geophysical detection technologies are deployed in a nonintrusive manner to locate surface and subsurface anomalies that may be UXO or buried munitions. (For purposes of brevity, discussions of UXO and buried munitions will be referred to as UXO throughout this chapter.) Proper selection and use of these technologies is an important part of the site investigation, which often takes place on ranges or parts of ranges that cover many acres. Since excavating all the land to depth is usually not practical, UXO detection technologies are used to locate anomalies that are subsequently verified as UXO or non-UXO. Given the high cost of UXO excavation (due to both range size and safety considerations), the challenge of most UXO investigations is the accurate and appropriate deployment of nonintrusive geophysical detection technologies to maximize probability of detection and minimize false alarms.

Since the early 1990s, existing geophysical survey technologies have improved in their capabilities to efficiently and cost-effectively detect UXO. Much of the improvement is the result of greater understanding of operational requirements for the use of detection technologies. However, the primary challenge in UXO detection today is the achievement of high levels of subsurface detection in a consistent, reproducible manner with a high level of quality assurance. Distinguishing ordnance from fragments and other nonordnance materials based solely on the geophysical signature, called target discrimination, is also a major challenge in UXO detection and the focus of research and development activities. This problem is known as a **false alarm**, as described in the text box below. Poor discrimination results in lower probability of detection, higher costs, longer time frames for cleanups, and potentially greater risks following cleanup actions.

False Alarms

The term *false alarm* is used when a declared UXO detection location does not correspond to an actual UXO location based upon the groundtruth data. **False positives** are anomalous items incorrectly identified as ordnance. False positives can result in incorrect estimations of UXO density and often lead to expensive or unnecessary excavation of an anomaly if it is not UXO. Depending on the site-specific conditions, as few as 1 percent of anomalies may actually be UXO items. Because of the difficulty, danger, and time required to excavate UXO, high costs per acre are exacerbated by a high false positive rate. **False negatives** occur when ordnance items are not detected by the geophysical instrument used or are misidentified in post-processing, resulting in potential risks remaining following UXO investigations.

It should be noted that a particular technology or combination of technologies will never have the highest effectiveness, best implementability, and lowest cost at every site. In other words, there is no "silver bullet" detection technology. It is also important to note that no existing technology or combination of existing technologies can guarantee that a site is completely UXO-free. As discussed in Section 4.2 below and in Chapter 7, a combination of information from a variety of sources (including historical data, results of previous environmental data collection, and knowledge of field and terrain conditions) will be used to make decisions about the detection system to be used, including the particular sensor(s), the platform on which it is deployed, and data acquisition and processing techniques. Detailed fact sheets on each of the detection sensors currently in use are found at the end of this chapter.

Experts in the UXO research and development community have indicated that currently available detection technologies will improve with time and that no revolutionary new systems are likely to be developed that uniformly improve all UXO detection. Much of the performance improvement of current detection technologies has come from a better understanding of how to use the technologies and from the use of combinations of technologies at a site to improve anomaly detection rates. Improvements in detection systems generally focus on distinguishing ordnance from nonordnance. Emerging processing and numerical modeling programs will enhance the target discrimination capabilities of detection systems. In general, these programs rely on identifying UXO and clutter based on their "signatures" (e.g., spatial pattern of magnetic signal).

Geophysical sensors have specific capabilities and limitations that must be evaluated when selecting a detection system for a site. The primary types of sensors in use today are:

- **Magnetometry** – a passive sensor that measures a magnetic field. Subsurface ferrous items create irregularities in the Earth's magnetic field and may contain remnant magnetic fields of their own that are detected by magnetometers.
- **Electromagnetic Induction (EMI)** – an active sensor that induces electrical currents beneath the earth's surface. Conductivity readings of the secondary magnetic field created by the electrical currents are used to detect both ferrous and nonferrous ordnance items.

In addition, under specific and limited conditions, ground-penetrating radar (GPR) has been successfully used to detect UXO. This sensor is mainly helpful when the location of larger munitions burial sites is known and boundaries must be identified. Magnetometers, EMI sensors, and GPR sensors are discussed in detail in Section 4.2 and in the fact sheets at the end of the chapter. The results of investigations using any sensor can vary dramatically depending not only on the site conditions, but also on the components of the detection system, the skill of the operator, and the processing method used to interpret the data.

Detection systems that will be available in the near future include advanced electromagnetic systems and airborne magnetometers. Long-term research endeavors include a GPR that can identify UXO at discrete locations, and an airborne EMI sensor. An overview of emerging detection technologies, as well as data processing and modeling for target discrimination, is presented in Sections 4.3 and 4.4.

In response to the stagnancy of detection technology development at the beginning of the Base Realignment and Closure (BRAC) Program, the U.S. Congress established the Jefferson Proving Ground Technology Demonstration (JPGTD) program in Madison, Indiana. The JPGTD program was established to demonstrate and promote advanced and innovative UXO systems that are more cost-efficient, effective, and safer. The JPGTD as well as other demonstration programs, such as the Environmental Security Technology Certification Program UXO Technology Standardized Demonstration Sites and the Fort Ord Ordnance Detection and Discrimination Study (ODDS) are discussed in Section 4.5.

4.2 Selection of the Geophysical Detection System

Many factors should be considered when identifying the detection system appropriate to your site. First, information about the detection sensors currently available, and the factors that contribute to their successful application, should be evaluated. Next, basic site conditions should be evaluated, such as expected targets (size, location, density, depths), terrain, vegetation, and electromagnetic fields. Finally, the role of each system component and how it affects overall performance should be examined to ensure maximum effectiveness.

4.2.1 Geophysical Sensors in Use Today

Magnetometry and electromagnetic induction are the most frequently used sensors for detecting UXO. Both sensors are commercially available and are employed on a variety of systems using various operational platforms, data processing techniques, and geolocation devices.

4.2.1.1 *Electromagnetic Induction (EMI)*

EMI sensors are perhaps the most widely used systems for detecting UXO. The electromagnetic induction system is based on physical principles of inducing and detecting electrical current flow within nearby conducting objects. EMI surveys work by inducing time-varying magnetic fields in the ground from a transmitter coil. The resulting secondary electromagnetic field set up by ground conductors is then measured at a receiver coil. EMI systems can detect all conductive materials but are at times limited by interference from surface or near-surface metallic objects. In general, the EMI response will be stronger the closer the detector head is to the buried target, but close proximity to the ground surface may subject the sensor to interference from shallow fragments. In areas of heavy vegetation, the distance between the detector head and the earth's surface is increased, potentially decreasing signal strength and decreasing the probability of detection. Soil type also plays a role in EMI system detection. EMI systems may have difficulty detecting small items in conductive soils, such as those containing magnetite, or in soils with cultural interferences, such as buildings, metal fences, vehicles, cables, and electrical wires. Because the difficulties with detecting small items in conductive soils are also present for magnetometry, this issue is usually not a limiting factor in selection of an EMI system.

EMI systems operate in time or frequency domains. Time-domain electromagnetic (TDEM) systems operate by transmitting a magnetic pulse that induces currents in and near conducting objects. These currents produce secondary magnetic fields that are measured by the sensor after the transmitter pulse has ended. The sensor integrates the induced voltage over a fixed time gate and averages over the number of pulses. When TDEM detectors are handheld or smaller they may have less penetration depth than the more commonly used EMI.

EMI and Electronic Fuzes

EMI is an active system for which there has been concern about increasing the risk of initiating OE with electronic fuzing. However, there is no evidence that the current generation of EMI based systems (e.g., EM61) generate enough power to cause this effect. This may be an issue to watch in the future, however, if more powerful systems are developed.

Frequency-domain electromagnetic (FDEM) instruments operate by transmitting continuous electronic signals for a single frequency and measuring the resulting eddy currents. FDEM instruments are able to detect deeply buried munitions that are grouped together. In addition, some types of FDEM instruments are capable of detecting very small individual UXO items that are buried just beneath the ground surface, such as metal firing pins in plastic land mines. When detecting individual, deeply buried munitions, FDEM instruments should not be used because of the sensor's decreased resolution, as well as difficulty in measuring the amplitude of return of individual targets.

4.2.1.2 *Magnetometry*

Magnetometers are passive systems that use the Earth's magnetic field as the source of the signal. Magnetometers detect distortions in the magnetic field caused by ferrous objects. The magnetometer has the ability to detect ferrous items to a greater depth than can be achieved by other systems. Magnetometers can identify small anomalies because of the instrument's high levels of sensitivity. However, magnetometers are also sensitive to many iron-bearing minerals and "hot rocks" (rocks with high iron content), which affects the detection probability by creating false positives and masking signals from real ordnance.

The two most common magnetometry systems used to detect buried munitions are cesium vapor or fluxgate. Cesium vapor magnetometers measure the magnitude of a magnetic field. These systems produce digital system output. The fluxgate systems also measure the direction and magnitude of a magnetic field. These systems are inexpensive, reliable, and rugged and have low energy consumption.

4.2.1.3 *Multisensor Systems*

Multisensor systems combine two or more sensor technologies in order to improve UXO detection performance. The technologies that have proved to be most effective in multisensor systems are arrays of full-field cesium vapor magnetometers and time-domain EMI pulsed sensors. Multisensor systems can enhance detector performance by providing complementary data sets that can be used to confirm the presence of UXO.

Multisensor systems are available both as man-portable configurations and as linear arrays on low-signature platforms that are towed over survey sites by all-terrain vehicles.

4.2.1.4 *Ground Penetrating Radar*

GPR is another sensor technology that is currently commercially available, although it is not used as frequently as EMI and magnetometry and is generally not as reliable. GPR systems use high-frequency (approximately 10-1,000 MHz) electromagnetic waves to excite the conducting object, thus producing currents. The currents flow around the object, producing electromagnetic fields that radiate from the target. The signals are received by the GPR antenna and stored for further processing. Most commercial systems measure total energy return and select potential targets based on contrast from background. More advanced processing uses the radar information to produce two-or three-dimensional images of the subsurface or to estimate features of the target, such as length or a spectra. Such processing systems are not generally in use at this time.

The GPR system is more accurate when used in areas of dry soil. Water in the soil absorbs the energy from the GPR, thus interfering with UXO detection. GPR may be used to find the boundaries of large caches of buried munitions.

4.2.2 Selection of the Geophysical Detection System

The selection of a detection system is a site-specific decision. Some of the factors that should be considered in selecting a detection system include, but are not limited to:

- Site size
- Soil type, vegetation, and terrain
- Subsurface lithology
- Depth, size, shape, composition, and type of UXO
- Geological and cultural noise (e.g., ferrous rocks and soils, electromagnetic fields from power lines)
- Non-UXO clutter on-site
- Historical land use
- Reasonably anticipated future land use
- UXO density

Each of the above factors should be considered against the decision goals of the investigation in order to select the most appropriate detection system. Table 4-1 highlights the effects of each factor on the investigation process. This list of considerations is not all-inclusive.

Table 4-1. Examples of Site-Specific Factors To Be Considered in Selecting a Detection System

Site Factors	Considerations
Site size	Different operational platforms cover areas at different speeds. If a large area needs to be surveyed, operational platforms such as towed-array or airborne may be considered, if appropriate.
Soil properties	Potential for high conductivity levels to interfere with target signals; potentially reduced detection capabilities using magnetometers in ferrous soils.
Vegetation	Heavy vegetation obstructs view of OE items on surface and may interfere with sensor's ability to detect subsurface anomalies, as well as access to the site and operation of the sensor.
Terrain	Easily accessible areas can accommodate any operational platform; difficult terrain may require man-portable platform.
Subsurface lithology	Soil and rock layers and configurations beneath the ground surface will influence the depth of the UXO and the ability of the sensor to "see" anomalies.
Target size and orientation	Capability of detector to find objects of various sizes and at various orientations.

Table 4-1. Examples of Site-Specific Factors To Be Considered in Selecting a Detection System (continued)

Site Factors	Considerations
Target penetration depth	Capability of detector to find targets at depths. Potential for decreased signal when detecting deeply buried targets.
Composition of UXO	Shell and fuze composition may dictate sensor selection. Magnetometers detect only ferrous materials, while EMI systems detect all metals.
Noise	Both geological noise (e.g., hot rocks or high ferrous content in soil) and cultural noise (e.g., buried cables, overhead utilities) potentially increase false alarms and mask ordnance signals.
Non-UXO clutter	Potential difficulty discriminating between small objects and metallic scrap, resulting in high numbers of false alarms.
Historical land use	Information about expected target location, types, and density.
Future land use	Enables setting of realistic decision goals for investigation.
UXO density	Enables sensor strengths (e.g., ability to see individual items as opposed to large caches of targets) to be maximized.

DoD/EPA Management Principles on Detection Technologies

EPA and DoD identified the critical metrics for evaluating the performance of a detection technology as the **probabilities of detection and false alarms**. Specifically, they call for the performance evaluation of detection technologies to consider the following factors:

- Types of munitions
- Size of munitions
- Depth distribution of munitions
- Extent of clutter
- Environmental factors (e.g., soil, terrain, temperature, and vegetation)

"The performance of a technology cannot be properly defined by its probability of detection without identifying the corresponding probability of false alarms. Identifying solely one of these measures yields an ill-defined capability. Of the two, probability of detection is a paramount consideration in selecting a UXO detection technology."

4.2.3 UXO Detection System Components

Table 4-2 identifies the various elements of a detection system and highlights how each element may affect the overall system performance. For example, the three operational platforms — man-held, towed-array, and airborne — directly affect the sensor's distance from the target, which, in turn, affects the sensor's ability to detect targets. The ability of all sensors to "see" targets decreases as distance from the target increases. However, the rate at which the performance drops off with distance varies by individual sensor. An additional consideration when selecting the operational platform includes what is expected to be found beneath the surface. Large caches of ordnance buried deep beneath the surface may remain detectable from large distances, whereas smaller ordnance items may be more easily missed by the sensor at a distance.

Table 4-2. System Element Influences on Detection System Performance

System Element	Factors To Be Considered
Geophysical sensor	Site-specific conditions and the results of the geophysical prove-out are used to determine the sensor and system configuration best suited to achieve the goals of the investigation.
Positioning System	Accuracy and precision in positioning and navigation are needed to locate targets in relation to coordinate systems. Tree cover, terrain, and need for line of sight may restrict choices.
Geophysical prove-out	The accuracy with which geophysical prove-out represents field conditions and sampling methods helps to ensure the development of data with a known level of certainty in field operations.
Operator capability	The selection and use of detection systems is complex and requires individuals with appropriate qualifications and experience. Qualification of the geophysical team to meet prove-out performance is a recommended QA/QC measure.
Operational platform	Size and depth of ordnance, sensor sensitivity to height above target, and potential for interference with sensor operation by platform components, and terrain and vegetation restriction need to be taken into account when selecting a platform.
Data acquisition	Digital versus analog data, reliability of data points, and ability to merge geophysical signals with a positioning system (e.g., GPS) data affect potential for human error.
Data analysis	Experienced and qualified analysts and appropriate procedures help to ensure reliability of results.

Operational Platforms for UXO Detection Systems

- **Man-Portable** – Man-portable systems can be used in areas that cannot be accessed by other platforms, such as those with heavy vegetation or rough terrain. The use of man-portable systems generally requires extensive man-hours, as the maximum speed with which the system can be operated is that at which an operator can walk the sampling area.
- **Towed Array** – These systems are generally used in flat treeless areas and can cover a larger area using fewer man-hours. Limitations include the inability to use towed-array systems in heavily wooded areas, other areas inaccessible to vehicles, or urban areas with tall buildings.
- **Airborne** – These systems are used to survey large, flat, treeless areas in a short period of time, using current magnetometry sensors requiring minimal standoff. The disadvantage of airborne detection is the high cost of the hardware and potential difficulty of penetrating deep enough below the ground surface, which is a function of both the altitude at which aircraft must fly, as well as of the sensor used. However, airborne systems can be highly cost-effective on large ranges because of the amount of acreage that can be covered and the resulting low cost per acre. In limited use today, airborne platforms are not as widely used as the other platforms.

4.2.3.1 *Positioning Systems*

Positioning systems are used to determine and record where a geophysical sensor is in relation to a known point such as, how it is oriented, and the pathway of its travel as it is collecting data. Knowing the location of the sensor will allow the geophysical analyst to estimate the location of subsurface anomalies that may be UXO. The accuracy of the positioning system will directly affect the ability of field teams to successfully relocate and excavate subsurface anomalies. The performance of the positioning system used on your project should be assessed at the same time that the performance of the geophysical sensor is assessed.

All positioning systems rely on determining the location of the geophysical sensor in relation to a known point or points. They also all provide a method for correlating the positional data with the geophysical sensor data. Commonly used positioning systems are shown in the table below.

Table 4-3. Description of Positioning Systems

Positioning System	Description
Differential Global Positioning System (DGPS)	· Triangulates the position of the DGPS receiver with respect to several satellites and terrestrial base stations. · Can yield accuracy on the order of 20 cm. · DGPS signal can be blocked by heavy overhead tree canopy, satellite availability will also strongly influence accuracy. · DGPS receiver must be in close proximity to the geophysical sensor; ideally, the antenna should be located directly over the sensor.

Table 4-3. Description of Positioning Systems (continued)

Positioning System	Description
Acoustic Ranging and Total Station Electronic Distance Meter (EDM)	· Calculates the distance between the receiver and a known point based on return time for either an acoustic or optical (infrared, laser) signal. · Accuracy depends on atmospheric and other conditions that may distort acoustic or optical signal. · Methods require a line of sight between receiver and known points.
Digital Thread	· Hybrid technology uses odometer wheel turned by survey thread; optical switch embeds position mark every 4-5 cm. · Works well in rugged, forested terrain. · Assumes geophysical sensor is traveling in a straight line; uncertainty is introduced when deviations around trees or rocks are required.
"Dead Reckoning" Techniques	· Locations determined by measurements from known points using survey tapes and trigonometry. · Highly dependent on the competence of the operator. · Assumes geophysical sensor has traveled in a straight line from a known point to the point of measurement.

4.2.3.2 *Anomaly Identification*

The geophysical sensor and positional data collected during the survey are analyzed to identify geophysical "anomalies," that is, readings that are different from the surrounding background. There are two steps to the anomaly identification process; data processing and data analysis. The quality of the anomaly identification process is critical to the performance of the geophysical detection system.

In general, data processing consists of the merging of the geophysical sensor and the positional data, and the creation of a map of the geophysical data. The output from this step should include the aforementioned map showing the locations of the sensor readings, a text narrative or a table describing the data acquisition parameters (e.g., sensor and positioning devices used, adjacent lane overlap for grids), and a narrative describing the data processing details (e.g., method used to synchronize geophysical and positional data, any signal filtering or background leveling applied). Digital outputs should include all raw data, field acquisition and data processing notes, and the merged database.

The primary objective of the data analysis step is to determine if a given geophysical anomaly meets the minimum threshold selection criteria of subsurface ordnance. The determination of these selection criteria will be based on the geophysical sensor, the survey pattern, and the type of ordnance under investigation, as well as the geological conditions and the analyst's experience. The output from this step should include a clear description of the selection criteria and the rationale for that criteria, a prioritized dig list with a unique identifier for each anomaly, the spatial location (the "x" and "y" coordinates) of each anomaly, and the metric attributes of each anomally (e.g., the magnitude of the reading above background).

4.2.4 Costs of UXO Detection Systems

The factors influencing the costs of deploying UXO detection systems are complex, and much broader the simple rental or purchase of a detector or sensor. The entire **life cycle** of the response process and the nature of the detection system must be considered. Life-cycle issues include:

- Costs of capital equipment
- Acreage that can be covered by your detection system over a specific period of time
- Rate of false positives, and costs of unnecessary excavation
- Costs of rework if it is later proven that the system deployed resulted in a number of false negatives
- Required clearance of vegetation
- Costs of cleanup
- Costs of operator salaries, based on the complexity and sophistication of the detection system (including training and certification of operators)

Evaluation of the factors may lead to site-specific decisions related to certain cost tradeoffs, for example:

- That high capital expenditures (e.g., airborne platforms) will result in reduced costs when large acreage is involved.
- Extensive use of expensive target discrimination equipment may be more worthwhile at a transferring base where land uses are uncertain, and transfer will not occur until the property is "cleaned" for the particular use.
- For small acreage, equipment producing a high rate of false positives may be acceptable if excavation is less costly than extensive data processing.
- Investments in systems with sensitive detectors and extensive data processing may be considered worthwhile when the potential of rework, and lack of acceptance of cleanup decisions is considered.

4.2.5 Quality Assurance/Quality Control

As discussed in Chapter 8, a comprehensive quality assurance/quality control (QA/QC) process that addresses every aspect of the selection and use of geophysical detection equipment, as well as evaluation of findings, is absolutely essential. Specifically, data acquisition quality is a function of appropriate data management, including acquisition of data in the field, data processing, data entry, and more. In addition, field observation of data acquisition, reacquisition, and excavation procedures will help to ensure that proper procedures that directly affect data quality are followed. General practices that help to ensure quality include monitoring the functionality of all instruments on a daily basis and ensuring that the full site was surveyed and ensuring that there are no data gaps.

Finally, qualification of geophysical operators is critical to ensuring that those operating the equipment can repeat the anticipated performance of the detection system. Chapter 8 describes qualification of geophysical operators in more detail.

4.3 Emerging UXO Detection Systems

The detection systems discussed in the following sections are in various stages of development and implementation. Some are still being researched and tested, while others will be available for operational use in the near future. All of the systems discussed are advanced versions of EMI and magnetometry technologies. The EMI systems discussed below collect vast quantities of data at each position that is used for identification and discrimination purposes, while the magnetometry systems are modifications to accommodate additional operational platforms.

4.3.1 Advanced EMI Systems

There is a whole class of advanced EMI in research and development in DoD.

GEM-3 (Geophex Ltd.) — The Geophex Ltd. GEM-3 is a multichannel frequency-domain EMI system that collects the EMI data over many audio frequencies. In other words, the GEM-3 collects multiple channels of information at each survey point. Frequency response data are used for the discrimination of UXO targets from clutter (both manmade and natural). This system has performed well in field tests for discrimination and identification of UXO.

EM-63 (Geonics Ltd.) — The EM-63 is a time-domain EM sensor that records multiple channels of time-domain data at each survey point. It is already commercially available.[61] Processing approaches to fully exploit the additional data measured by the EM-63 are currently being researched. NAEVA Geophysics has demonstrated good performance with the EM-63 in field tests. Zonge Engineering has also developed a multitime gate, multiaxis system currently being characterized.

4.3.2 Airborne Detection

Airborne detection platforms have been tested at the Badlands Bombing Range, near Interior, South Dakota. Tests suggest that this platform can be very cost-effective in large expanses of flat, open, and treeless ranges found in the arid and semi-arid climate of the western United States, where aircraft are able to fly close to the ground. Other types of sites where speculation suggests airborne platforms may be appropriate include marshes, swamps, wetlands, and shallow water.

Airborne Magnetometry — Low-altitude airborne magnetometry has proved promising in tests on the Cuny Table at the Badlands Bombing Range, near Pine Ridge, South Dakota. Because of the conditions at Badlands Bombing Range, aircraft are able to fly close to the ground, providing for increased detection capabilities. Originally, the mission envisioned for airborne magnetics was the identification of concentration of ordnance for further investigation by ground-based sensors.

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[61] ERDC/EL TR-01-20, Advanced UXO Detection/Discrimination Technology Demonstration, U.S. Army Jefferson Proving Ground, Madison, Indiana, Ernesto Cespedes, September 2001.

However, performance in initial tests of commercial, off-the-shelf equipment indicated that for large ordnance (210 kg), individual items were detectable at about 50 percent of the rate of ground-based sensors. Research to improve the probability of detection is ongoing. Aircraft-mounted magnetometers may present a viable option for detecting and characterizing UXO at certain ranges, because the relatively low operation time required to characterize a very large range makes the detection time and cost per acre potentially reasonable despite the high setup and equipment costs.[62]

Airborne MTADS — A second major type of airborne detection is the Airborne MTADS, an adapted version of the vehicular MTADS magnetometry technology for deployment on an airborne platform. The array consists of seven full-field cesium vapor magnetometers (a variant of the Geometrics 822 sensor designated as Model 822A) mounted on a model 206L Bell range helicopter. All sensors are interfaced to a data acquisition computer.

The intent of the adaptation was to provide a UXO site characterization capability for extended, large areas that are inappropriate for vehicular surveys. Because the sensors are deployed further from the ground surface than the vehicular systems, it was understood that some detection sensitivity would be lost. The primary goal of the development was to retain as much detection sensitivity as possible for individual UXO targets. The second primary objective was that the final system must have a production rate and costs appropriate for deployment to explore very large sites that would be prohibitively expensive to survey by other techniques.

Demonstrations of Airborne MTADS at Badlands Bombing Range, near Interior, South Dakota, indicate that the system generates high production rates while maintaining reasonable costs when characterizing very large, open areas. Production rates of 300-400 acres/day were demonstrated with Airborne MTADS as compared with 18-24 acres/day with vehicular MTADS. This indicates that the Airborne MTADS rates can be 15 times greater than the vehicular system's. It is expected that the cost per acre is three to five times less with Airborne MTADS than with a vehicular array. These rates have yet to be tested. As expected, the demonstrations indicated that a major disadvantage associated with the use of Airborne MTADS is the systems' inability to detect small classes of UXO buried at significant depth. In addition, using Airborne MTADS doesn't prove's to be as cost-effective on smaller areas compared with vehicular MTADS because of the deployment costs associated with the airborne platform.[63]

Airborne EM — Airborne electromagnetic induction is under research and development for use at ranges with characteristics similar to those discussed above (e.g., vast, open, treeless, and flat areas). However, unlike airborne magnetometry, airborne EMI could be used at sites with ferrous soils. Because EM signals fall off more quickly with increased distances, the challenge of using this technique from an airborne platform will be greater. Initial tests have shown detectability of large items on seeded sites.

Ground Penetrating Radar Identification — Studies of various GPR systems have been

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[62] *Evaluation of Footprint Reduction Methodology at the Cuny Table in the Former Badlands Bombing Range*, Environmental Security Technology Certification Program, July 2000.

[63] J.R. McDonald, D. Wright, N. Khadr, AETC Inc., and H.H. Nelson, Chemical Dynamics and Diagnostics Branch, Naval Research Laboratory, *Airborne MTADS Demonstration on the Impact Area of the Badlands Bombing Range*, September 2001.

conducted. One study, by Ohio State University with the U.S. Army Corps of Engineers Research and Development Center and the Cold Regions Research and Engineering Laboratory, examined the capabilities of an ultra-wideband, fully polarimetric GPR system to provide information about the size and shape of buried objects. This study was based on UXO with known target locations, and focused on both detecting the UXO items and classifying specific ordnance types.[64]

4.4 Use of Processing and Modeling To Discriminate UXO

The development of advanced processing and modeling to reduce the false alarm rates without affecting an even improved Pd ordnance detection performance is evolving. Rather than using a simple amplitude of response in raw physical data exclusively, advanced processing methods organize large quantities of data. In efforts to encourage the development of algorithms for target discrimination without the expense and burden of field data collection, they have made standard sensor data sets for both controlled and live sites publicly available. For example, EM data in the time-frequency or spatial domain to discriminate particular objects of interest. Statistical methods can be used to associate field geophysical data with signatures of ordnance items that have either been measured or calculated using EM modeling tools. Alternatively, good data can be used to calculate the essential parameters of the targets, such as size, shape, and depth, which can be used to infer the nature of the item giving rise to the return.

About Signatures

The various methodologies deployed to detect UXO produce digital data that is recorded at each survey location. These data are displayed as graphs, charts, and maps that indicate the presence of an anomalous measurement. The graphical reports produce patterns that may be used to estimate the sizes, types, and orientations of UXO. These patterns are called "signatures." Signatures are being used in emerging technologies and rely on databases of electronic signatures to help discriminate between types of UXO, fragments of UXO, naturally occurring metals, and non-OE scrap.

Aided or automatic target recognition, or ATR, is a term used to describe a hardware/ software system that receives sensor data as input and provides target classes, probabilities, and locations in the sensor data as output. ATR is used to design algorithms to improve detection and classification of targets and assist in discriminating system responses from clutter and other noise signals, thereby reducing the false alarm rate.[65] These techniques are under development and are not yet available for use in the field.

AETC, Inc., and Geophex Ltd., under contract to SERDP, have developed a data-base GEM-3 electromagnetic induction data to support identification of UXO and nonordnance items based on their frequency-domain electromagnetic signature. The signature library for a wide variety of UXO and clutter objects were developed at frequencies between 30 Hz and 30 kHz. A database has been

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[64] M. Higgins, C.C. Chen, and K. O'Neill, U.S. Army Corps of Engineers Research and Development Center (ERDC), Cold Regions Research and Engineering Laboratory, ESTCP Project 199902 – *Tyndall AFB Site Demo: Data Processing Results for UXO Classification Using UWB Full-Polarization GPR System*, 1999.

[65] Notes from the Aided Target Recognition Workshop, Unexploded Ordnance Center for Excellence, January 28-29, 1998.

set up to organize and make available results from over 60,000 measurements of different sizes and shapes of UXO and non-UXO objects.[66] In addition, software has been developed to analyze the data and identify a wide variety of anomalies.[67]

The Naval Research Laboratory has developed a technique that uses data fusion to discriminate objects detected in magnetometry and electromagnetic surveys. The laboratory has developed model-based quantitative routines to identify the target's position, depth, shape, and orientation (see Fact Sheet 2 for a full description of MTADS). In addition, location information, including position, size, and depth, is expected to be improved to a small degree.[68] This data fusion method is primarily effective in the discrimination of large UXO items. However, the major contribution of this system and the AETC/Geophex system described above is anticipated to be their ability to differentiate UXO from fragments of ordnance and other clutter.

DoD is funding multiple universities for advanced processing research. Duke University, for example, has engaged in both physics-based modeling and statistical signal processing and has shown performance improvements in many diverse data sets, including EMI, magnetometer, and GPR/SAR.

4.5 UXO Detection Demonstration Programs

Several demonstration programs have been developed to test the effectiveness of various UXO detection sensors and systems in controlled environments. Because of the lack of technologies available to effectively locate UXO on thousands of acres of DoD ranges being closed or realigned under the BRAC program, Congress established the Jefferson Proving Ground Technology Demonstration Program. Since then, other programs such as the former Fort Ord Detection and Discrimination Study and the Environmental Security Technology Certification Program (ESTCP) UXO Technology Standardized Demonstration Sites have been established to further the development of UXO detection technologies.

SERDP and ESTCP

The Department of Defense (DoD) operates two programs designed to develop and move innovative technologies into the field to address DoD's environmental concerns. The **Strategic Environmental Research and Development Program (SERDP)** is DoD's environmental research and development program. Executed in partnership with both the Department of Energy and EPA, the goal of SERDP is to identify, develop, and transition technologies that support the defense mission. The second program is the **Environmental Security Technology Certification Program (ESTCP)**. The goal of the ESTCP is to demonstrate and validate promising innovative technologies. Both organizations have made heavy investments in detection, discrimination, and cleanup technologies for UXO.

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[66] EMI signature database in Microsoft Access available at FTP host: server.hgl.com, log in ID: anonymous, File:/pub/SERDP/GEM3.data.zip.

[67] T. Bell, J. Miller, D. Keiswetter, B. Barrow, I.J. Won, *Processing Techniques for Discrimination Between Buried UXO and Clutter Using Multisensor Array Data*, Partners in Environmental Technology Conference, December 2, 1999.

[68] J.R. McDonald, *Model-Based Data Fusion and Discrimination of UXO in Magnetometry and EM Surveys*, Naval Research Laboratory, May 18, 1999.

4.5.1 Jefferson Proving Ground Technology Demonstration Program

Congress established the JPGTD program in response to the realization that the BRAC process could not take place until thousands of acres of military property littered with UXO were cleaned up. Available technologies were also inefficient and inadequate to address the widespread need to detect and remove UXO on such a large scale. (See Chapter 7; "Mag and Flag" had been in use for several decades with few advances or improvements.)

The JPGTD program was established under the management of the U.S. Army Environmental Center (USAEC) to identify innovative technologies that would provide more effective, economical, and safe methods for detecting and removing ordnance from former DoD testing and training areas. The program also was created to examine the capability of commercial and military equipment to detect, classify, and remove UXO and to develop baseline performance standards for UXO systems. The JPGTD program aimed to (1) establish criteria and metrics to provide a framework for understanding and assessing UXO technology, (2) provide funding for technology demonstrations, (3) document the performance of advanced technologies to give decision makers a better understanding of the capabilities and limitations of the technologies; and (4) improve demonstration methodologies so that the results would be applicable to actual UXO clearance operations and decision making. The objectives and results of each of the demonstration projects are outlined in the next text box.

Demonstrator Evaluation Criteria

Detection capability
False negative rate
False positive rate
Target position and accuracy
Target classification capability
Survey rate (used in Phase I only)
Survey costs (used in Phase I only)

UXO detection technologies such as magnetometry, electromagnetic induction, ground penetrating radar, and multisensor systems were tested and analyzed using a variety of platforms and data processing systems at the JPGTD. The platforms analyzed for the detection technologies included airborne, man-portable, vehicle-towed, and combination man-portable and vehicle-towed. Systems were analyzed using evaluation criteria such as probability of detection, false alarm rate, and other parameters, as described in the adjacent text box. Certain local and regional conditions and soil characteristics (e.g., soil type, moisture, resistivity) may impact the effectiveness of detection systems. Specifically, detector performance may differ significantly at sites with conditions different from those at Jefferson Proving Ground (e.g., ranges in the western U.S. with different soil resistivity/conductivity).

Each of the four phases of JPGTD provided useful data about UXO detection and remediation technologies. In Phase I, conducted in 1994, 26 demonstrators, representing magnetometry, electromagnetic induction (EMI), ground penetrating radar (GPR), synthetic aperture radar (SAR), and infrared (IR) sensors, performed using 20 vehicle-mounted and man-towed platforms and six airborne platforms. Only one demonstrator achieved over a 50 percent detection rate and the false alarm rate was high, an especially disappointing rate considering most of the clutter had been removed prior to the demonstration. Electromagnetic induction, magnetometry, and gradiometry proved to be the most effective sensors, while GPR, IR, and other imaging technologies were not effective. Airborne systems performed the worst of all the platforms, detecting less than

8 percent of buried ordnance, while hand-held systems had the best performance. At the conclusion of Phase I it was suggested that the geological conditions at the Jefferson Proving Ground may reduce the capabilities of certain sensors.

Therefore, live test sites at five other installations were used to compare the detection data obtained in different geological conditions. Results from the live test sites showed that magnetometry and EMI continued to be the best performers. The average probability of detection at the live test sites was 0.44, and there was a continued inability to distinguish between ordnance and nonordnance.

In Phase II, conducted in 1995, demonstrators had better detection performance, with some sensors detecting over 80 percent of buried ordnance. However, the false alarm rates increased as overall anomaly detection increased. The best performing sensors in Phase II were multisensor systems combining EMI and magnetometry.

In Phase III, conducted in 1996, four different range scenarios were used in Phase III to facilitate the development of performance data for technologies used in specific site conditions. Over 40 percent of demonstrators had greater than 85 percent detection, and combination magnetometry and EMI systems repeatedly detected close to 100 percent of buried ordnance. In addition, the multisensor system, which consisted of electromagnetic induction and either magnetometry or gradiometry, had a slightly lower than average false alarm rate. However, no sensor or combination of sensors demonstrated an ability to distinguish baseline ordnance from nonordnance, and no system performed better than chance in this area.

Phase IV, conducted in 1998, was aimed at improving the ability to distinguish ordnance and nonordnance. Fifty percent of the demonstrators showed a better than chance probability of discriminating UXO from clutter, with one demonstrator correctly identifying 75 percent of ordnance and nonordnance items. While advanced data processing has greatly improved target discrimination capabilities in pilot testing, these methods need to be further developed and tested. In order to make advanced processing techniques widely used and to develop a market for constantly improving systems, they need to be made commercially available. With reliable and readily available target discrimination technologies, false alarm rates could be greatly reduced, thereby significantly improving the efficiency and reducing the costs of UXO detection and remediation.

Synopsis of Objectives and Results of Jefferson Proving Ground Technology Demonstration Program, Phases I through IV

Phase I, 1994
Objective: Evaluate existing and promising technologies for detecting and remediating UXO.
Results: Limited detection and localization capabilities and inability to discriminate between ordnance and nonordnance. Average false alarm rate was 149 per hectare. Airborne platforms and ground penetrating radar sensors performed poorly; combination electromagnetic induction and magnetometry sensors were the best performers, but also had modest probabilities of detection and very high false alarm rates.

Phase II, 1995
Objective: Evaluate technologies effective for detecting, identifying, and remediating UXO, and measuring these results against the Phase I baseline.
Results: Significant improvement in detection capabilities with commensurate increases in false alarms among better performing technologies. Continued inability to distinguish ordnance from nonordnance. Again, airborne platforms and ground penetrating radar sensors performed poorly; combination electromagnetic induction and magnetometry sensors were the better performers, but continued to have very high false alarm rates.

Phase III, 1996
Objective: Develop relevant performance data of technologies used in site-specific situations to search, detect, characterize, and excavate UXO. Four different range scenarios were used, which had typical groups of UXO.
Results: Improvement in detection, but continued inability to distinguish ordnance from nonordnance. Localization performance for ground-based systems improved. Probability of detection is partially dependent on target size. False alarm rates ranged from 2 to 241 per hectare.

Phase IV, 1998
Objectives: 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 ordnance "type"; direct future R&D efforts.
Results: Capability to distinguish between ordnance and nonordnance is developing. Five demonstrators showed a better than chance probability of successful discrimination.

4.5.2 Former Fort Ord Ordnance Detection and Discrimination Study (ODDS)

A phased geophysical study of ordnance detection and discrimination specific to the former Fort Ord, California, environment has been in existence since 1994. In November 1998, the U.S. Army evaluated OE at Fort Ord in an Ordnance and Explosives Remedial Investigation/Feasibility Study (OE RI/FS) concurrently with removal actions. The RI/FS evaluated long-term response alternatives for cleanup and risk management at Fort Ord. The technologies considered for use during the Fort Ord study were demonstrated during the Jefferson Proving Ground study. The text box below describes the four phases of the Fort Ord study.

Synopsis of Objectives and Results of the Former Fort Ord Ordnance Detection and Discrimination Study, Phases I through IV

Phase I
Objective: Evaluate detection technologies "Static" measurements in free air (i.e., in the air above and away from ground influences/effects) given variable OE items, depths, and orientations.
Results: Signal drop-off in the electromagnetic (EM) response is proportional to the depth of the object to the 6th power. For horizontally oriented OE items, the EM signal response was predicted fairly well.

Phase II
Objective: Evaluate the effectiveness of geophysical instruments' ability to detect and locate "seeded" or planted OE items.
Result: Noise levels increased 3 to 35 times from the static to seeded tests. There was a significant degradation of profile signatures between static and field trial tests.

Phase III
Objective: Evaluate geophysical instruments and survey processes at actual uninvestigated OE sites.
Results: The effects of rough terrain and vegetation on detection and discrimination capabilities can be significant. Removal of range residue before the OE investigation began would have reduced time and effort spent on unnecessary excavations.

Phase IV
Objective: Evaluate discrimination capabilities of OE detection systems.
Results: The instruments with the highest detection rate required the most intrusive investigation. Conversely, instruments with lower detection rates required less intrusive investigations. **The ODDS determined that no one instrument provides the single solution to meet the OE detection needs at Fort Ord.**

The first phase of the ODDS found the electromagnetic and magnetometer systems to be effective in the detection and location of buried OE items. Phase II was conducted in a controlled testing environment. The controlled area consisted of five "seeded" plots. Two of the plots consisted of items with known depths and orientations, while the other three areas consisted of "unknown" plots where target information was withheld. The plots were designed to be representative of the terrain of Fort Ord. The seeded tests concluded that the noise levels of the EMI systems increased 3 to 35 times from the static to seeded tests. In Phase III it was concluded that the effects of terrain, vegetation, and range residues can significantly alter detection and discrimination capabilities of the detectors. Phase IV of the study determined that discrimination capability of the instruments tested was minimal. The Phase IV study also determined that both EMI and magnetometer systems performed well in finding the larger and deeper items, whereas only the EMI systems consistently found smaller and shallower items. The results indicated that different systems are required for different types of sites, depending on OE expected and the site-specific environmental/geological conditions.

4.5.3 UXO Technology Standardized Demonstration Sites

The U.S. Army Environmental Center (USAEC) is conducting an ESTCP-funded program to provide UXO technology developers with test sites for the evaluation of UXO detection and discrimination technologies using standardized protocols. The USAEC is developing standardized test methodologies, procedures, and facilities to help ensure accuracy and replicability in measurements of detection capability, false alarms, discrimination, target reacquisition, and system efficiency. Data generated from these standardized sites will be compiled into a technology-screening matrix to assist UXO project managers in selecting the appropriate detection systems for their application.

Standardized test sites will be made up of three areas – the calibration lane, the blind grid, and the open field. The calibration area will contain targets from a standardized target list at six primary orientations and at three depths. The target depth, orientation, type, and location will be provided to demonstrators. The calibration area will allow demonstrators to test their equipment, build a site library, document signal strength, and deal with site-specific variables. In the blind grid area, demonstrators will know possible locations of targets and will be required to report whether or not a UXO target clutter or nothing actually exists. If a UXO target is found, they must report the type of target, classification of target, and target depth and a confidence level. The blind grid allows testing of sensors without ambiguities introduced by the system, site coverage, or other operational concerns. The open field will be a 10 or more acre area with clutter and geolocation targets about which demonstrators will be given no information and will be required to perform as if they were performing at an actual DoD range. Testers will report the location of all anomalies, classify them as clutter or UXO, and provide type, classification, and depth information. The open field conditions will document the performance of the system in an actual range operation mode.

In addition to the construction of test sites available to the UXO community, the primary products of this program will be the creation of a series of protocols to establish procedures necessary for constructing and operating a standardized UXO test site. A standardized target repository will be amassed that can be used by installations, technology developers, and demonstrators.

4.6 Fact Sheets and Case Studies on Detection Technologies and Systems

Three fact sheets on UXO sensors and three case studies describing detection systems are found at the end of this chapter as Attachments 1 through 6. Information on the nature of the technology and its benefits and limitations is provided. Since the performance of the instruments is not solely based upon the sensors deployed, the case studies provide more insights on the operation of the systems. The performance of detection systems is dependent upon platform characteristics, survey methodology and quality, data processing, personnel operation/performance, and appropriate quality control measures that should be taken throughout the investigation.

4.7 Conclusion

The performance of many existing and emerging technologies for UXO detection and discrimination is limited by specific site characteristics such as soil type and composition, topography, terrain, and type and extent of contamination. What works at one site may not work at another. Our ability to find UXO in subsurface locations has improved dramatically. The JPGTD studies have shown that we have gotten much smarter about how to deploy these technologies and how to locate a high percentage of UXO. However, the results of a controlled study such as the JPGTD should not give us unrealistic expectations about the capabilities of these technologies when used in range investigation. Studies at true UXO areas, such as at Fort Ord, provide additional information about the challenges and issues that have to be considered in selecting UXO detection systems. For example, the nature of the targets (e.g., composition, size, and mass), the depth of UXO penetration (a function of the soil and the ordnance item), and expected spatial and depth distribution should be considered along with the geology, terrain, and vegetation. Other factors affecting the results include operator performance and postprocessing techniques. Given the sizes of the ranges and the cost of investigating anomalies, the greatest challenge to improving UXO detection is being able to discriminate UXO from other subsurface anomalies. Although there have been improvements in this area, much developmental work remains.