Geophysical Classification for Munitions Response

Introductory Fact Sheet | October 2012

This fact sheet was developed by the Interstate Technology & Regulatory Council (ITRC) Geophysical Classification for Munitions Response Team. It is the first of three fact sheets designed to provide basic information about geophysical classification for munitions response. For more information about this ITRC team, please visit the ITRC website at http://www.itrcweb.org/Team/Public?teamID=9.

Background

For decades, the Department of Defense (DoD) has produced and used military munitions for live-fire testing and training to prepare the United States military for combat operations. As a result, unexploded ordnance (UXO) and discarded military munitions (DMM) may be encountered on former ranges and former munitions operating facilities (such as production and disposal areas). DoD has identified over 4,400 sites in the United States that require a munitions response.

Limits of Existing Technology

To detect munitions for removal at these sites, DoD and its contractors have historically used various types of detection instruments that are similar to metal detectors used by the public to detect coins on beaches. Much like the metal detectors used by the public, these instruments simply detect a buried metallic object—they cannot identify the type of object present. Consequently, on munitions response sites most detected metallic items must be uncovered to determine whether they are military munitions or nonhazardous metallic items. Typically, highly-trained UXO technicians excavate hundreds of nonhazardous metallic items for each military munition recovered. Given the costs associated with this inefficiency, only limited acreage can be addressed with existing resources and budgets.

The time required for unnecessary excavations not only prolongs munitions response, but can be disruptive to communities or recreational areas because the public is prohibited from entering sites while digging is taking place. This practice can result in extended area closures and evacuations. Additionally, digging unnecessary holes can disturb the landscape and vegetation at these sites, whether they are recreational areas, habitat, farmland, or private backyards.

Advances in Technology-Geophysical Classification

DoD and its research partners in academia and private industry have developed a new approach to improve the efficiency of munitions response using geophysical classification. As before, geophysicists use electromagnetic sensors to detect metallic items beneath the ground surface. However, the use of advanced electromagnetic sensors to collect additional data allows geophysical analysts to estimate the depth, size, density, wall thickness, and shape of each buried item. For example, the photos below show the types of items typically found at munitions response sites:

Munition

Suspected Munition

Munition Fragment

Debris

If the geophysical analysis shows that a metallic item is a cylindrical object with properties indicative of a possible munition, UXO technicians will remove it. If the data show that the item is flat or irregular, which indicates that it is not a munition, the item may be left in the ground. If the data are inconclusive, UXO technicians will excavate the item. In the photos above, the first item on the left would be identified as a munition and excavated, the second item would be excavated for identification, the third item would be identified as a munition fragment and left in the ground, and the horseshoe on the far right would be identified as cultural debris and left in the ground as well. This technique can accelerate munitions response efforts by focusing resources on the investigation of those metallic items identified as possible munitions or where the data are inconclusive. Other metallic items would be left in place without investigation, unless selected for quality control or assurance.

Ongoing Demonstrations

At a series of technology demonstrations at munitions response sites throughout the United States, DoD's Environmental Security Technology Certification Program (ESTCP) has shown that this method, when properly applied, will greatly reduce the number of metallic items investigated, while protecting the public and reducing the impact of munitions responses on both affected communities and the environment. For example, at the Camp Beale demonstration site, geophysical classification would have reduced the estimated number of nonhazardous debris items excavated from 1,310 to 285.

Under ESTCP, the success of the geophysical classification technology continues to be demonstrated at sites across the country. As shown in the figure below, the advanced sensors used for geophysical classification may be either hand held (left) or deployed using all-terrain vehicles (ATVs, center) or wheeled carts (right), depending upon site conditions. For further information, please see the ESTCP website at http://serdp-estcp.org/Tools-and-Training/Munitions-Response/Classification-in-Munitions-Response

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Hand-held Unit

Sled-mounted Unit

Cart-mounted Unit

The ITRC Geophysical Classification for Munitions Response Team is reviewing the results of the ESTCP technology demonstrations as part of the process for developing supplementary fact sheets, guidance, and training on geophysical classification. The guidance will document when and where the use of the geophysical classification method is appropriate, as well as the geophysical expertise and experience necessary for the successful use of geophysical classification technologies, and recommendations for appropriate quality control and quality assurance procedures.

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Geophysical Classification for Munitions Response

Technical Fact Sheet | June 2013

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Introduction

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To identify munitions for removal at these sites, DOD and its contractors have historically used various types of detection instruments to simply detect buried metal items. Consequently, on munitions response sites, most detected items must be uncovered and examined to determine whether they are military munitions. Typically, highly-trained UXO-qualified personnel excavate hundreds of metal items for each munition recovered. Given the costs associated with this inefficiency, only limited acreage can be addressed with existing resources and budgets.

DOD's Environmental Security Technology Certification Program (ESTCP) and its research partners in academia and industry have developed and demonstrated a new approach, using a process called *geophysical classification,* to improve the efficiency of munitions response. As before, geophysicists use electromagnetic sensors to detect metal items beneath the ground surface. Then, using advanced sensors to collect additional data, geophysical analysts can estimate the depth, size, wall thickness, and shape of each buried item. Geophysical classification is the process of using these data to make a principled decision as to whether a buried metal item is potentially hazardous or can be left in the ground. This technique can focus a munitions response on investigating only those anomalies identified as being potentially due to munitions, with required quality assurance investigations of other anomalies, resulting in a more rigorous, better understood, and better documented product. For example, at the former Camp Beale demonstration site, geophysical classification would have reduced the estimated number of debris items excavated by 78%, from 1,310 to 285.

This fact sheet provides an overview of the geophysical classification technology and process, the types of terrestrial sites where this technology may be applicable, and data quality considerations. This fact sheet benefits scientists, engineers, and other environmental professionals who are familiar with or have experience executing or managing munitions responses. This target audience may include, but is not limited to, state and federal environmental regulators as well as munitions response managers and technical staff.

Geophysical Classification Overview

The geophysical classification process normally consists of three steps:

1. Measure the response of a buried metal object to an electromagnetic field using an advanced geophysical sensor.
2. Analyze the measured response to determine target parameters such as depth, size, aspect ratio, and wall thickness.
3. Use these parameters as inputs to a classifier to help decide whether the detected item is most likely a munition that must be investigated to determine whether it is potentially hazardous.

Classification data are collected using electromagnetic induction (EMI) sensors. These sensors produce a magnetic field in the earth's near surface by running a pulse of current through a transmit coil deployed just above the ground. When this induced field is rapidly turned off, eddy currents are created in nearby metal objects that are then sensed in a receiver coil (Figure 1). The amplitude and decay properties of these eddy currents are determined by the size, shape, material composition, and wall thickness of the buried item as well as its location and orientation relative to the sensor. Advanced EMI sensors use sets of transmit and receive coils oriented as two-dimensional and three-dimensional arrays that completely measure the response of the buried item.

The measured EMI decays depend both on parameters that can help classify the target (such as size, aspect ratio, and wall thickness) and parameters related to the target's location and orientation relative to the sensor. The contribution of each parameter is determined individually by fitting the observed EMI decays to a physics-based model. The process results in an estimation of the objects' intrinsic EMI response (also known as the EMI response along the object's principal axes, or "EMI fingerprint"), the location, and the orientation of the object.

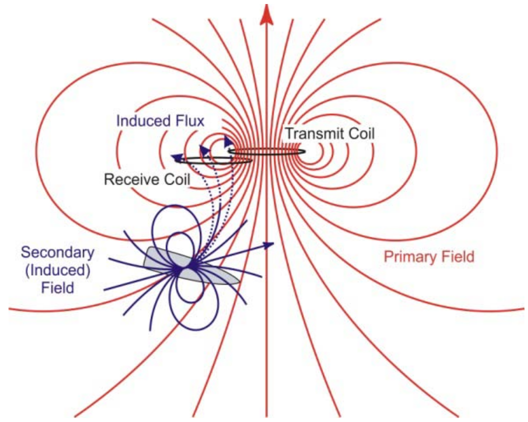

Figure 1. Diagram of a typical electromagnetic induction sensor.

These EMI responses are used as the input data for the classification decision (Figure 2). Once the parameters, or features, of the buried item are determined, the classification decision is made in one of two ways. The most straightforward method is to compare the EMI responses of the unknown item to a library of known munition responses. If the unknown item shows the same EMI characteristics as a munition in the library, then it is classified as a munition. The other method is to use a statistical classifier. In this method, machine-learning techniques are used to train the classifier to recognize EMI responses that indicate a possible munition. Both of these approaches are based on matching the EMI responses, or EMI fingerprint. In the first case, the match is to a pre-existing library of EMI responses of munitions, while the statistical classifier creates its own library from training data. The process of building a standard classification library is ongoing, with EMI responses from munitions continually being added to Oasis Montaj, the software most commonly used by the UXO industry to classify anomalies.

In Figure 2, the overall amplitude of the response (A) is related to the volume of the object; the projectile on the left is larger than the fragment on the right and the responses are about twice as large. The projectile is cylindrical, which results in one large response corresponding to the long axis and two smaller, but equal, responses corresponding to the other two axes (B). The fragment is not symmetric and exhibits three distinct responses. The decay of the curves is related to the wall thickness of the object. The responses of the thick-walled projectile persists (C) for a longer time than the fragment.

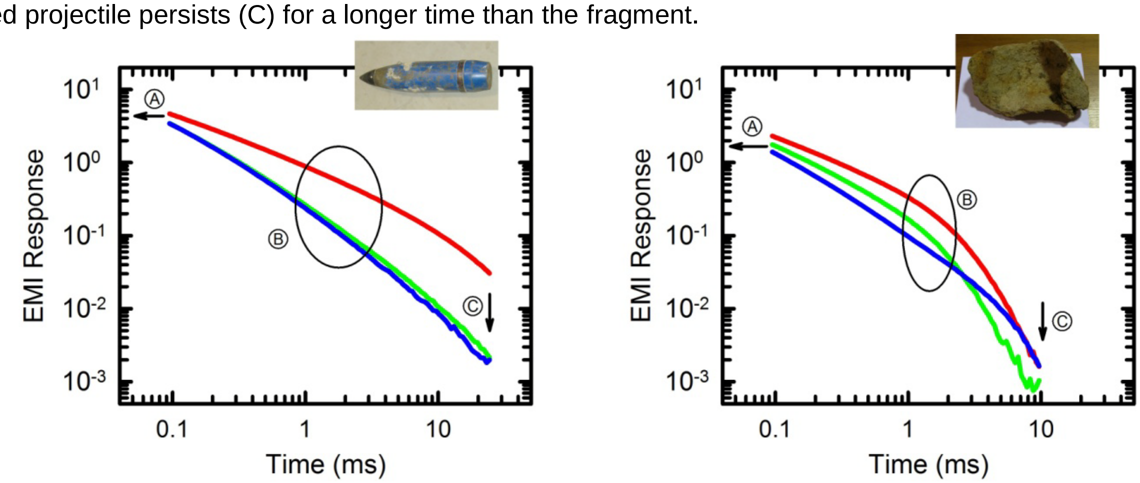

Figure 2. Comparison of the EMI responses for two metal objects.

Appropriate Applications

Geophysical classification can generally be used at any terrestrial site where high-quality geophysical EMI data can be collected. It has been used successfully at a variety of sites across the country in different types of terrain and in areas of varying vegetation. Typically, if the sensors can be towed or pushed across the site, or hand-held equipment can be walked in a grid, then geophysical classification can be used.

Geophysical classification is not applicable in every situation. Some limitations for this approach involve the technology itself, while others involve site-specific characteristics that impose limitations on access to portions of the site, such as areas of dense vegetation; extremely rough, unstable, or steep terrain; or areas subject to electromagnetic interference. In addition, advanced EMI sensors are not currently used on airborne or underwater platforms.

Technological Limitations – Presently, EMI sensors do not consistently detect deeply buried, smaller munitions or differentiate munitions in high density target areas. While larger towed units have a similar depth range to EM sensors currently used today, current versions of portable/hand-held advanced EMI sensors are lighter weight and less powerful. They are primarily useful for collecting advanced classification data on items in the upper one to two feet of the subsurface, although they can sometimes detect deeper items. Because 80 to 90 percent of clutter is detected in the upper two feet, portable units should be sufficient to either classify an anomaly as due to a TOI (most likely a munition), non-TOI, or to determine it cannot be classified and add it to the dig list with the TOIs.

Although recent ESTCP demonstrations have shown success in classifying multiple overlapping objects, overlapping high density anomalies can be difficult to differentiate. The more knowledge and experience the geophysicist has with the software that analyzes overlapping signatures, the greater the success in classifying targets. Even when target data are clear, a wide range of unknown items or various versions of munitions (such as damaged or bent rounds) must still be added to the classification library of munitions. Additionally, over time a library of EMI responses for non munition items (for instance, horseshoes, mufflers, or gas cylinders) will also be developed. The library of EMI responses from various munitions continues to expand with each survey and has been used to detect a wide range of munitions types, including some in various states of damage (Figure 3).

Figure 3. Damaged munition.

Site Limitations – Commercially available advanced EMI sensors are typically mounted on platforms that can be pushed or pulled across an area. This approach tends to preclude their use in difficult site conditions such as thickly vegetated areas, rocky conditions, extreme terrain, highly muddy conditions, or in areas covered by water. In addition, since location data are typically tied to GPS, areas that cannot receive GPS signals or receive only spotty signals make the process more difficult. Also, as with all EMI sensors, geologic conditions can generate severe interference (for instance, areas with primarily mafic or ultramafic rocks such as basalt). Additionally, sites where electromagnetic interference is an issue (such as sites near electrical substations or transmission equipment), or sites adjacent to large metallic structures either above or below ground are not conducive to current advanced EMI technology.

> ***Cued Interrogation (Data Collection)*** – *Static data collection over an anomaly detected in a separate survey for improved classification performance. Anomalies identified in a dynamic survey are typically used to cue follow-on measurements using a static*

Cost Effectiveness – Geophysical classification is cost effective when the additional costs to perform the cued interrogation are expected to be offset by the reduction in intrusive investigations. Production rates typically vary from 175 to over 300 cued measurements per day. The higher production rates are achieved when the terrain is not difficult and anomalies are of high amplitude and easier to locate. At some sites, however, the use of geophysical classification may not be cost effective. For example, if the site is a high density area that is heavily cluttered with munitions or other metal debris (munitions fragments), then geophysical classification may not be as useful; therefore, it may not significantly reduce the number of excavations and the increased expense of a classification survey would not be offset by cost savings.

Geophysical Classification Process

Typically, metal detectors are used to detect subsurface metallic objects in a time-domain EM survey or a magnetometer survey. Refer to *Survey of Munitions Response Technologies*, June 2006 (ITRC UXO-4) for a comprehensive overview of how these technologies are used during munitions response. High quality detection data with tight survey line spacing, precise geolocation, and low noise result in accurate anomaly locations and few false detections. These data characteristics lead to efficient classification. Each location of a detected anomaly is marked to be revisited with an advanced EMI sensor to collect data needed to classify the source of the anomaly (Figure 4). These data are acquired in a cued mode, which requires the advanced EMI sensor to remain stationary over each anomaly for approximately thirty seconds. During this time thousands of spatial and temporal measurements are recorded from a variety of angles and locations. Field-level quality control checks should be performed at this stage to confirm that adequate signal-to-noise ratios are achieved, the sensor was properly located over the anomaly location, and all geophysical hardware was functioning as designed. All data are recorded and thus may be revisited as needed to verify data quality.

Figure 4. Advanced EMI sensors include hand-held (left), sled-mounted (middle), and cart-mounted (right) units.

Data that meet the quality control (QC) criteria are then passed along to powerful computer software that derives the EMI response for each item interrogated, as described previously. These polarizability decay curves, or EMI fingerprints, are used as input to a classifier. Subsequently, each item identified as a TOI is passed along to an excavation crew for recovery and disposal.

On many sites, especially those similar to previous sites on which classification has been successfully performed, site-specific validation may not be required. On these sites, the classifier and thresholds from earlier work can be used directly. At some sites, in addition to the use of a standard instrument verification strip (IVS) during the survey, a small pilot study to demonstrate the applicability of classification to the site conditions is performed as a component of the feasibility study or prior to beginning a response (removal or remedial) action. This pilot study is generally conducted on a small portion of the site with a significant number of blind seeds to ensure confidence in the results. Detection and classification are performed within the study area with all anomalies intrusively investigated. The classification process is judged by its success in detecting and correctly classifying the QC seed items and other TOI encountered and by the reduction in the number of anomalies selected for investigation that are not munitions. Once validated, the classification method should be able to be confidently applied to the remainder of the site.

> ***Blind Seed*** *– Inert munition or munitions surrogate (such as an Industry Standard Object) placed on the site to serve as a process QC check. The location and identities of these seeds should be blind to the data collectors, analysts, and intrusive crew.*

Quality Considerations for Geophysical Classification

Geophysical classification can be divided into subprocesses and tasks that have associated metrics, which can be used to ensure the quality of the work performed. Quality on a munitions response site using geophysical classification is just as important as on a site using standard geophysical sensors, although the differing processes require differing quality procedures. The quality considerations for each step in the process—detection, cued data collection, parameter estimation, and classification—are described below. If all of the geophysical classification processes meet the quality requirements, the project team can have a high degree of confidence in the results from the use of geophysical classification at the site.

To ensure quality in the initial survey to detect buried metal items throughout the site, verify that all equipment checks and geophysical sensor warm-up procedures were performed satisfactorily. The project geophysicist documents these and other quality checks with standardized forms. Equipment check forms include verification of daily static checks within the required metrics (typically +/- 10% of the expected values for the time gates). Another criteria to ensure quality in the initial survey is the measurement of consistent peak signal results from the

IVS surveys. The initial detection survey should also detect all blind seeds in the survey area and place them on the list for cued interrogation.

Quality considerations for the collection of high-fidelity geophysical data at each anomaly also require verification that all equipment checks and warm-up procedures are performed satisfactorily for the advanced geophysical equipment. Because advanced sensors have multiple transmitters and receivers, site personnel must verify that all relevant transmitters and receivers are operating properly in order to have confidence in the model parameters. Figure 5 illustrates a case in which one of the measured decays was spurious. Including these results would have led to the incorrect conclusion to not dig the item. Excluding this spurious channel from the analysis allows the geophysicist to correctly identify the item as a TOI.

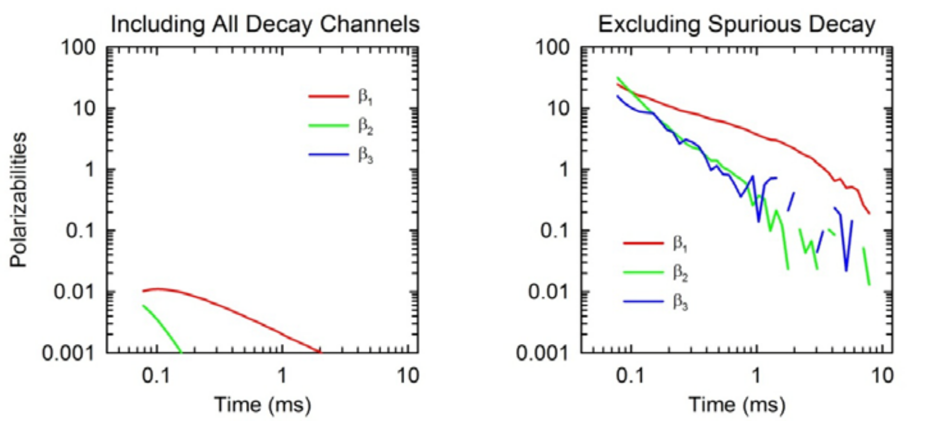

Figure 5. QC plot for a cued measurement for all decay channels including one spurious channel (left) and one in which the spurious decay was removed (right).

To ensure proper placement of the instrument over an identified anomaly, the target depth and size, as well as the physical size of the instrument's transmitters and receivers, must be taken into account. For example, advanced EMI instruments should not be more than 40 cm off-center over a small, shallow anomaly to collect high-fidelity geophysical data. In addition, the signal-to-noise ratio should be high enough to extract parameters from the data. A method that has been used to verify the quality of the work performed using the IVS has been to ensure that the daily generated EMI responses of the items in the strip match the library parameters within 95%.

Rank	Anomaly ID	UTM Easting (m)	UTM Northing (m)	Dig?	Ground Truth
1	PM-1926	470,214.5	4,566,896.5	Y	60mm
2	PM-92	469,990.4	4,566,487.4	Y	60mm - QC Seed
3	PM-272	470,051.2	4,566,548.3	Y	37mm - QC Seed
4	PM-656	470,265.1	4,566,510.6	Y	60mm
5	PM-1029	470,314.8	4,566,613.0	Y	37mm
6	PM-1268	470,260.8	4,566,717.6	Y	ISO - QC Seed
7	PM-2223	470,359.1	4,566,826.4	Y	frag
8	PM-1583	470,336.6	4,566,687.0	Y	60mm
9	PM-1493	470,373.0	4,566,608.6	Y	60mm - QC Seed
10	PM-414	470,081.6	4,566,573.3	Y	60mm - QC Seed
11	PM-947	470,191.0	4,566582.5	Y	57mm
12	PM-567	470,267.6	4,566,486.0	Y	ISO - QC Seed
13	PM-2162	470,335.3	4,566,875.0	Y	60mm - QC Seed
14	PM-1158	470,213.3	4,566,663.3	Y	57mm
15	PM-1821	470,149.3	4,566,909.3	Y	ISO - QC Seed
16	PM-1249	470,291.6	4,566,710.4	Y	60mm
17	PM-606	470,129.5	4,566,493.4	Y	57mm
18	PM-2130	470,318.3	4,566,727.8	Y	37mm - QC Seed
19	PM-766	470,207.4	4,566,541.1	Y	60mm - QC Seed
20	PM-1847	470,166.0	4,566,724.3	Y	ISO - QC Seed
21	PM-689	470,140.1	4,566,522.6	Y	60mm
22	PM-1580	470,349.8	4,566,682.9	Y	60mm - QC Seed
23	PM-91	469,990.3	4,566,495.6	Y	57mm
[illegible]	PM-635	470,289.5	4,566,502.9	Y	60mm

Figure 6. Ranked anomaly list from the ESTCP Pole Mountain demonstration.

Blind seeding can also assess the quality of the identified parameters. The blind seeds' size and shape can be compared to the estimated targets' size and shape to ensure the reliability of these estimates. For instance, 37-mm blind seeds should have similar extracted parameters that are distinct from 75-mm blind seeds.

Blind seeding can build confidence in the development and quality of the classifier and can verify work in production areas. Typically, at least one blind seed should be encountered on a daily basis. The seeds used should reflect the types of munitions expected to be encountered at the site (i.e. site TOI). To assess an anomaly's classification (i.e. remove or leave in place), verify that all blind seeds are properly classified and that other items dug fit the expected shapes and sizes from the classifier. This process can include digging an agreed upon number of anomalies that have not been classified as due to a munition to confirm proper classification. Figure 6 is a ranking of anomalies from a submitted dig list. This figure illustrates that all QC seeds must be properly classified and the individual QC seeds must be located on the submitted dig list. All of the blind seeds (highlighted in the table) were correctly classified as items that must be dug. Additionally, the seeds were interspersed with the existing munitions on the ranked list indicating they were no easier or harder to classify than the existing munitions at the site.

Future Technological Advances

Geophysical classification is continually improving and the conditions under which geophysical technologies and processes are applicable are expanding. For example, emerging advanced sensors have been designed on smaller and more portable platforms deployed to address difficult site conditions. Research studies are currently being conducted for geophysical classification on underwater sites and in areas exhibiting a high density of anomalies. Additionally, studies on the use of non-GPS technology for location positioning are also underway. As innovative applications of this technology are developed and brought to market, the detection survey and cued survey may be combined. In this scheme, detection and some level of classification will be accomplished using dynamic survey data collected by an advanced sensor. Prototypes of such systems are now in development and testing.

Summary

Geophysical classification technologies and processes have been successfully demonstrated and have transitioned to production-level surveys. The use of geophysical classification and processes have proven, based on a number of demonstrations, capable of improving the efficiency of munitions responses on a variety of sites. As with all technologies, their use has some limitations and should be considered on a site-by-site basis. The successful use of geophysical classification requires that the initial detection survey provides quality data and that additional quality measures have been implemented specific to the classification process, such as those related to cued data collection, feature extraction, and classification. In addition, experienced geophysicists must participate in designing the investigation, operating the equipment, and processing and interpreting the data for successful classification.

For More Information

ESTCP has completed a number of technology demonstrations at munitions response sites across the country and is currently conducting additional demonstrations. For further information, please see the ESTCP website at http://serdp-estcp.org/Tools-and-Training/Munitions-Response/Classification-in-Munitions-Response.

The ITRC Geophysical Classification for Munitions Response Team is reviewing the results of the ESTCP technology demonstrations as part of the process for developing supplementary fact sheets, guidance, and training on geophysical classification. The guidance will document when and where the use of the geophysical classification method is appropriate, as well as the geophysical expertise and experience necessary for the successful use of geophysical classification technologies and recommendations for appropriate quality control and quality assurance procedures.

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To identify munitions for removal at these sites, DOD and its contractors have historically used various types of detection instruments to simply detect buried metal items. Consequently, on munitions response sites, most detected items must be uncovered and examined to determine whether they are military munitions. Typically, highly-trained, UXO-qualified personnel excavate hundreds of metal items for each munition recovered. Given the costs associated with this inefficiency, only limited acreage can be addressed with existing resources and budgets.

Geophysical Classification Process Overview

DOD's Environmental Security Technology Certification Program (ESTCP) and its research partners in academia and industry have developed and demonstrated a new approach, using a process called *geophysical classification,* to improve the efficiency of munitions response. As before, geophysicists use electromagnetic induction (EMI) sensors during an initial survey to detect metal items beneath the ground surface. Then, advanced EMI sensors specifically designed to support geophysical classification are used to collect additional data, which geophysical analysts can use to estimate the depth, size, wall thickness, and shape of each buried item. Geophysical classification is the process of using these data to make a principled decision as to whether a buried metal item is a potentially hazardous munition, called a target of interest (TOI), or metal clutter, debris, or geology (non-TOI) that can be left in the ground. Use of the geophysical classification process can focus a munitions response on excavating only those geophysical anomalies identified as potential munitions. The use of this process, in combination with quality assurance (QA) investigations of other anomalies, results in a more efficient, more rigorous, better understood, and better documented munitions response.

This fact sheet provides regulators responsible for munitions response sites with a source of information about geophysical classification that clearly explains what geophysical classification is, its benefits and limitations, and, most importantly, the information and data that regulators need to monitor and evaluate its use. This fact sheet also emphasizes using a systematic planning process to develop upfront data acquisition and decision strategies. Systematic approaches include the U.S. Environmental Protection Agency's (USEPA's) Data Quality Objectives (DQO) process and the Uniform Federal Policy for Quality Assurance Project Plans (UFP-QAPP).

Benefits of Geophysical Classification

Geophysical classification can focus a munitions response on excavating only those geophysical anomalies identified as potential TOI and those anomalies for which a classification determination cannot be made. By minimizing unnecessary excavations, the limited resources available for cleanup can be applied to address more land quickly, thus freeing up land sooner for appropriate use. The time required for unnecessary excavations not only prolongs munitions response, but also can be disruptive to communities or recreational areas because the public is prohibited from entering sites while excavations are taking place. This practice can result in extended area closures and evacuations. Additionally, digging unnecessary holes can disturb the landscape, vegetation, and cultural resources at these sites, whether they are recreational areas, habitat, farmland, or private backyards.

Using a simple but realistic cost model, if 75% of the detected anomalies can be confidently classified as non-TOI and left in the ground, then the area that can be remediated for a fixed budget roughly doubles. For example, at the former Camp Beale, California demonstration site, properly performed geophysical classification would have reduced the number of non-TOI items excavated by 78%, from 1,310 to 285.

Geophysical Classification Process

The geophysical classification process generally consists of three steps:

1. Measure the response of a buried metal item to an electromagnetic field using an advanced EMI sensor.
2. Analyze the measured response to determine parameters such as depth, size, wall thickness, and shape.
3. Use these parameters as inputs to a classifier, which is a computer program that sorts detected items as either likely TOI that must be excavated or as non-TOI.

Successful geophysical classification currently depends upon the quality of the initial geophysical survey. This initial survey is designed to detect all buried items to a specific depth using a time-domain EMI sensor or a magnetometer, and 100% site coverage should be achieved. Previous ITRC documents provide more information on technologies and quality considerations associated with geophysical surveys on munitions response projects (see *Survey of Munitions Response Technologies* (UXO-4) and *Quality Considerations for Munitions Response Projects* (UXO-5) at www.itrcweb.org). High-quality detection data with tight survey line spacing, precise geolocation, and low noise result in accurate anomaly locations and fewer false detections. These data characteristics lead to efficient classification.

The location of each item detected during the initial geophysical survey is recorded, to be revisited with an advanced EMI sensor to collect data needed to classify the anomaly. These data are acquired in a cued mode, which requires the advanced EMI sensor to remain stationary over each anomaly for approximately 30 to 90 seconds. During this time, thousands of spatial and temporal measurements are recorded from a variety of angles and locations. Field-level quality control (QC) checks should be performed at this stage to confirm that adequate signal-to-noise ratios are achieved, the sensor was properly located over the anomaly location, and all geophysical hardware was functioning as designed. All data are recorded and thus may be revisited as needed to verify their quality.

> ***Cued Interrogation (Data Collection)—****Static data collection over an anomaly detected in a separate survey for improved classification*

Data that meet the QC criteria are then entered into computer software that derives the EMI response for each anomaly interrogated. These EMI responses are used as inputs to a classifier. Subsequently, each anomaly classified as a TOI and those anomalies that cannot be classified are passed along to an excavation crew for recovery and disposal. See *Technical Fact Sheet: Geophysical Classification for Munitions Response* (GCMR-1) for more information regarding the science and analysis of EMI responses.

As innovative applications of geophysical classification are developed and brought to market, the detection survey and cued survey may eventually be combined. In this scheme, detection and some level of classification will be accomplished using survey data collected with an advanced EMI sensor.

Building and validating the performance of a sensor/classifier are integral components of the geophysical classification process. At some sites, a small pilot study to demonstrate the applicability of geophysical classification to the site conditions is performed as a component of the Feasibility Study (FS) or prior to beginning a munitions response (removal or remedial) action. At other sites, data collected from equivalent sites with similar site conditions can fulfill this purpose. This pilot study is generally conducted on a small portion of a munitions response site with a significant number of blind QC seeds emplaced to ensure confidence in the results. Detection and classification are performed within the study area and all buried items are subsequently excavated. The geophysical classification process is judged by its success in detecting and correctly classifying the QC seed items and TOI, as well as by the reduction in the number of buried items selected for excavation that are non-TOI. Once validated, the classification process can be confidently applied to the remainder of the site.

> ***Blind QC Seed—****Inert munition or munitions surrogate (such as an Industry Standard Object) buried on the site to serve as a process QC check. Surrogates are selected to correspond with munitions of interest on the site. The location and identities of these surrogates should be unknown to the data collectors, analysts, and excavation crew.*

Geophysical Classification Challenges

The geophysical classification process can generally be used at terrestrial sites where high-quality geophysical EMI data sensors can be towed or pushed across the site, or handheld equipment can be walked in a grid. This process has been used successfully at a variety of sites with different types of terrain and varying vegetation.

The geophysical classification process is not applicable in every situation. Site-specific characteristics can impose limitations on its use, such as areas of dense vegetation; extremely rough, unstable or steep terrain; or areas subject to electromagnetic interference. In addition, advanced EMI sensors are not currently used on airborne or underwater platforms. Correctly classifying TOI and non-TOI is easier if the items being classified are consistent, possess unique signatures, are present in lower densities, and are not located in geophysically-noisy environments. To the extent that these conditions are not met, geophysical classification performance suffers.

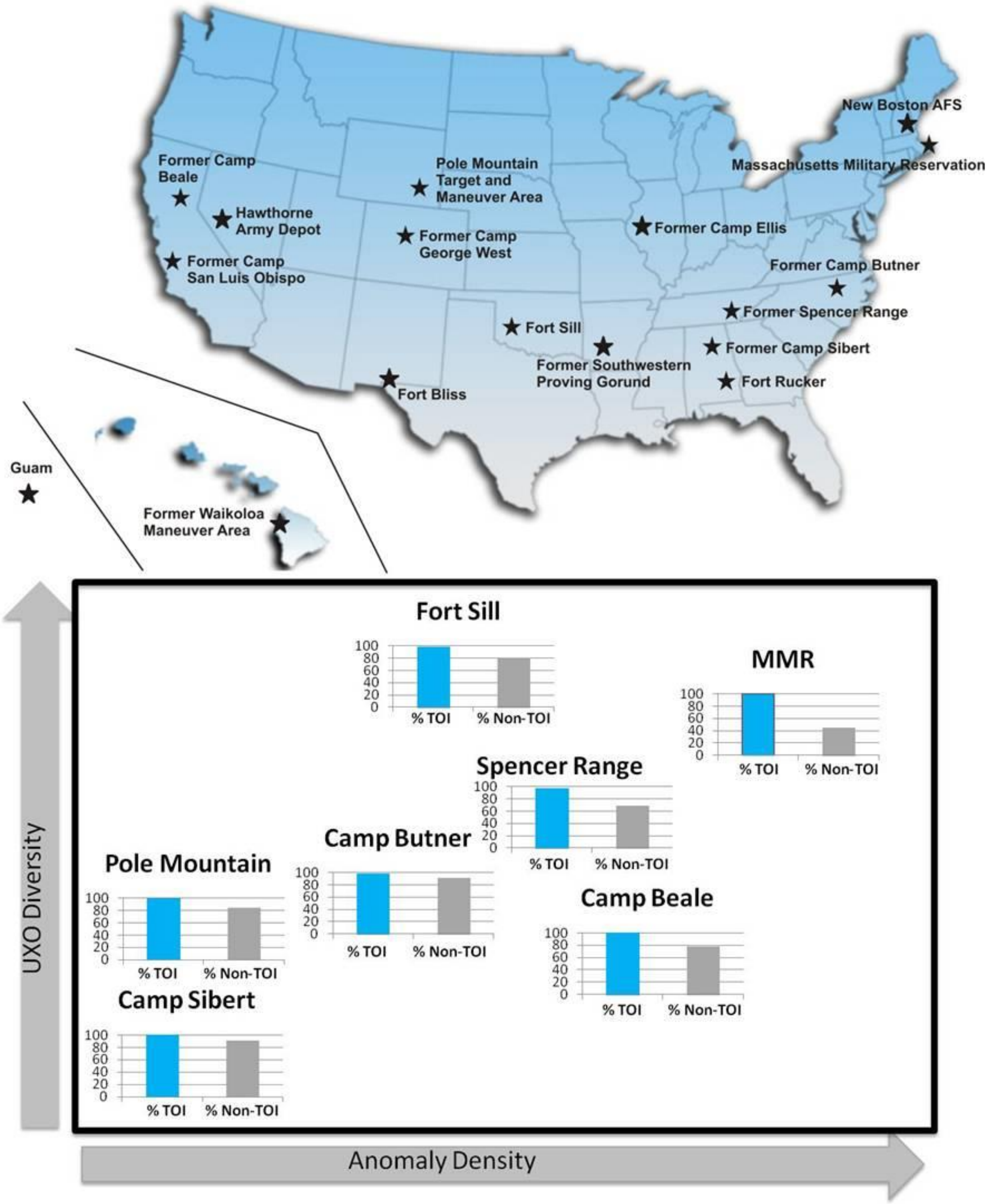
What does this mean in practice? Some common challenges and situations include:

- Anomaly density: If non-TOI is present to the extent that each excavation recovers multiple distinct pieces of metal of similar size to a TOI, then classification performance declines. Additionally, high anomaly densities can limit the opportunity to measure the local soil response and sensor drift, which also degrades classification performance.
- TOI diversity: Classification performance improves when the diversity of TOI is limited and the munitions known or suspected to be present are of different size and character than the non-TOI at the site. Sites with a limited number of munitions types are generally more conducive to correctly identifying TOI than sites with a greater diversity of munitions types.
- TOI density: If the ratio of TOI to non-TOI across the site is much higher than typical, the number of excavations avoided by using geophysical classification may not justify the additional cost of employing the process. This situation was observed on an air-to-ground gunnery range at New Boston Air Force Station, New Hampshire, but is not commonly encountered at most munitions response sites.
- Magnetic geology: Magnetic geology can also affect success of the geophysical classification process, especially at sites where the near-surface geology changes rapidly over short distances. At sites exhibiting extreme magnetic geology, the EMI contribution from the ground response can approach the magnitude of small- to mid-size munitions.
- Terrain: Variable and rough terrain impedes the geophysical classification process when it hinders the survey team's ability to get the sensor close to the buried item during data collection.
- Environmental interference: At some sites, environmental noise and EMI signatures resulting from structures such as power lines or other utilities can saturate the sensor and thereby prevent the use of geophysical classification.

Geophysical Classification Demonstration Results

In 2007, ESTCP initiated a Geophysical Classification Pilot Program to validate the application of a number of recently-developed technologies in a comprehensive approach during a munitions response. The program goals are to (1) demonstrate that classification decisions can be made using an explicit approach, based on physics-based analysis that is transparent and reproducible; (2) gain acceptance of the geophysical classification process by federal and state regulators, the munitions response industry, and the public; and (3) transition the analytical tools and techniques to production use.

During the course of the Geophysical Classification Pilot Program, ESTCP successfully demonstrated use of the geophysical classification process and its benefits at multiple military sites that possessed a variety of geophysical classification challenges (Figure 1). The sites were ordered based on their perceived difficulty, starting with the easiest. The initial site, Camp Sibert, Alabama, was selected because it had favorable terrain, a single munition of concern, and a single dominant non-TOI type. Subsequent sites had between 3 and 21 different munitions types and variable survey conditions, terrain, and anomaly densities. All buried items were excavated and identified to confirm technology performance in these demonstrations. Regardless of the specific objectives, analysts were able to demonstrate successful geophysical classification. In some cases, near-perfect classification results were realized. In others, analysts correctly classified 100% of the TOI and 50-70% of the non-TOI. In the bar charts presented in Figure 1 below, classification performance is plotted as a function of site anomaly density and munition diversity including the percent of correctly classified TOI (blue) and correctly classified non-TOI (gray). TOI classification at these sites was highly successful. At sites with increased munition diversity and anomaly densities, non-TOI was more difficult to confidently identify, and additional non-TOI excavations were required to achieve 100% correct classification of TOI. Non-TOI classification is more successful at sites with lower munition diversity and anomaly densities, resulting in a substantial reduction of non-TOI excavations. The ESTCP Classification Pilot Program website provides further information about the program at http://www.serdp-estcp.org/Featured-Initiatives/Munitions-Response-Initiatives/Classification-Applied-to-Munitions-Response.



ESTCP classification demonstration site locations (top). Classification performance plotted as a function of site anomaly density and munition diversity (bottom) , percent correctly classified TOI (blue), and percent correctly classified non-TOI (gray). TOI classification is highly successful. At sites with increased munition diversity and anomaly densities, non-TOI is more difficult to confidently identify and additional non-TOI excavations are required to achieve 100% correct classification of TOI. Non-TOI classification is more successful at sites with lower munition diversity and anomaly densities, resulting in a substantial reduction of non-TOI excavations.

Munitions Response Regulatory Framework

Munitions response projects can be performed under the regulatory framework of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) or the Resource Conservation and Recovery Act (RCRA). Most commonly, however, munitions response projects are performed under CERCLA. During the CERCLA process, geophysical classification may be evaluated as part of a remedial option in the FS analysis. A treatability study may be required either in the FS or remedial design phase, if suitable examples similar to the site are not readily available.

Regulators face a unique challenge in providing oversight of the geophysical classification process. Additional regulatory approvals are not required for use of the geophysical classification process. However, early and continuous communication among project teams, which include regulators and stakeholders, is recommended to develop project objectives that may help avoid costly re-work. Project teams must be informed about the geophysical classification process and how it will be implemented at the site. The first in this series of ITRC fact sheets, *Overview Fact Sheet: Geophysical Classification for Munitions Response,* explains the geophysical classification process to stakeholders who may not wish to examine all of the technical details associated with the process (GCMR-1). The second in this series, *Technical Fact Sheet: Geophysical Classification for Munitions Response*, provides an overview of the geophysical classification technology and process, types of applicable terrestrial sites, and data quality considerations for those familiar with executing or managing munitions responses (GCMR-1).

State Regulator Role in the Munitions Response Process

The regulator's responsibility on a munitions response project is to ensure that the project complies with federal and state laws and regulations and meets the requirements for characterization, cleanup, and site closure. Environmental regulators should participate in defining the overall objective of the munitions response project, concur with key processes necessary to realize the objectives, approve process and final product performance requirements, and agree with the QA/QC activities necessary to demonstrate that requirements have been achieved (UXO-5).

Properly implemented, the team-based process approach should generate a QAPP. This document identifies the necessary QA and QC activities to be performed and data requirements that must be met during the munitions response. Standard geophysical classification QC requirements should include repeatability of instrumentation verification strip measurements and sensor function tests; detection and classification of all blind QC seed items; and adequate spatial sampling during data collection. Typical QC steps include problem identification, problem analysis, problem correction, and feedback. In the geophysical classification process, QC tasks would generally be carried out by the project geophysicist. A QA evaluator may be a manager, a client, or even a third-party auditor. QA activities may include verifying the data coverage, noise levels, classifier used, and classification logic, as well as failure analyses, if necessary.

Data quality and integrity are critical to the geophysical classification process. Compliance with QA and QC activities helps to ensure that reliable, high-quality data are generated. Effective QA and QC also provides confidence that the tasks or processes were completed properly, the data meets quality requirements, and the decision making is scientifically defensible. Currently, the Intergovernmental Data Quality Task Force (IDQTF) is developing a geophysical classification QAPP template. This document is expected to be completed in 2015.

Geophysical Classification Participants and their Respective Roles and Experience

Munitions response project planning may include a wide variety of individuals and organizations, including project managers and technical personnel, contractors, customers, suppliers, scientific experts, and stakeholders, who together determine if the project is successful (Uniform Federal Policy for Implementing Environmental Quality Systems).

Geophysical analysts, whether contractors or government staff, are responsible for analyzing the data and making classification decisions. These analysts should have documented experience in every aspect of the geophysical classification process. Performance and supervision of geophysical classification data acquisition and analysis should be carried out by geophysicists with documented experience in successfully applying geophysical classification methods. Organizations should have a process in place to educate and train personnel to implement the quality system and quality requirements of individual projects. Third party technical reviewers can also provide valuable insight regarding the reasonableness and defensibility of the classification decisions offered by the geophysical analysts.

Regulators can enhance their knowledge about geophysical classification and the munitions response process through training sessions offered by the ITRC and by using the ITRC GCMR guidance document, which is expected to be published in 2015. Additional resources will be cited in the guidance document.

The public should be viewed as partners in munitions response projects. To create a constructive partnership, responsible parties and regulators must establish trust with engaged members of affected communities and inform them as to how the geophysical classification process works and how munitions response projects are carried out.

Summary

Geophysical classification technologies and processes have been successfully demonstrated and are transitioning to accepted use on munitions response projects. These demonstrations have shown that using geophysical classification technologies and processes improves the efficiency and effectiveness of munitions response projects on a variety of sites. As with all technologies, the use of geophysical classification has some limitations and should be considered on a site-by-site basis. The successful use of geophysical classification requires that the initial detection survey provides quality data. Additional quality measures must also be implemented, which are specific to the geophysical classification process (such as those related to cued data collection, feature extraction, and classification). In addition, experienced geophysicists must participate in designing the project, operating the equipment, and processing and interpreting the data in order for geophysical classification to be successful.

For More Information

ESTCP has completed a number of geophysical classification demonstrations at munitions response sites across the country and is currently conducting additional demonstrations. For further information, please see the ESTCP website at http://www.serdp-estcp.org/Featured-Initiatives/Munitions-Response-Initiatives/Classification-Applied-to-Munitions-Response.

The ITRC GCMR Team is reviewing the results of the ESTCP demonstrations as part of the process for developing the guidance document and training for geophysical classification. The guidance will describe when and where use of the geophysical classification process is appropriate, the geophysical expertise and experience necessary for the successful use of geophysical classification, and recommendations for appropriate QA/QC procedures.

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