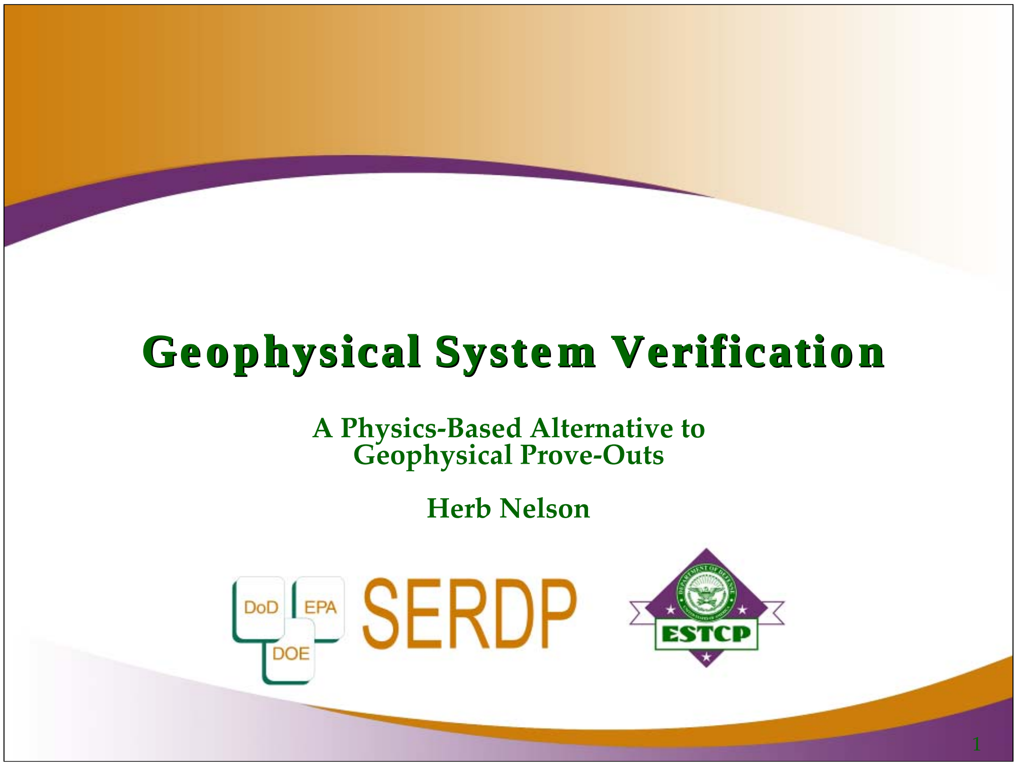

The evaluation and cleanup of current and former military sites contaminated with buried munitions relies on two well-understood geophysical technologies to detect the munitions: magnetometry and electromagnetic (EM) induction. As these technologies were introduced in munitions response projects, the Geophysical Prove Out (GPO) was developed to determine whether the geophysical data collected would meet project objectives. Over the last 15 years, numerous GPOs have been performed on a variety of site conditions, and a significant body of knowledge has accumulated documenting the performance of these technologies. This accumulated understanding, along with the recognition that magnetic and EM responses of munitions may be predicted reliably using physical models, presents the opportunity for both streamlining and enhancing the GPO with a more rigorous physics-based approach.

A Geophysical System Verification (GSV) process is envisioned in which the resources traditionally devoted to a GPO are reallocated to support simplified, but more rigorous, verification that a geophysical system is operating properly, as well as ongoing monitoring of production work. Two main elements are considered in this course:

Instrument Verification Strip and Blind Seeding Program.

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Outline

- Introduction
  - Jim Austreng, California Department of Toxic Substance Control
- Physics basis
  - Tom Bell, SAIC
- Instrument verification strip and blind seeding
  - Jeff Swanson, Colorado Department of Public Health and Environment
- Example site application
  - Andrew Schwartz, U.S. Army Corps of Engineers, Huntsville

Introduction

Jim Austreng

DoD EPA DOE SERDP

ESTCP

3

Analog Sweeps

Introduction 4

Historically, clean ups were addressed using analog sensors such as shown in the slide. Explosive Ordnance Disposal (EOD) technicians would walk side by side scanning the ground and listen for tone changes to identify ferrous items. Many problems were identified using this technique such as no record of what was picked as a target, what areas were and were not covered during the sweep, and other aspects that leave great uncertainty.

Early MR Projects

- No quantitative measure of what is detected and how deep
- Inconsistent results from site-to-site with the same equipment
- Inconsistent results on a given site with different teams

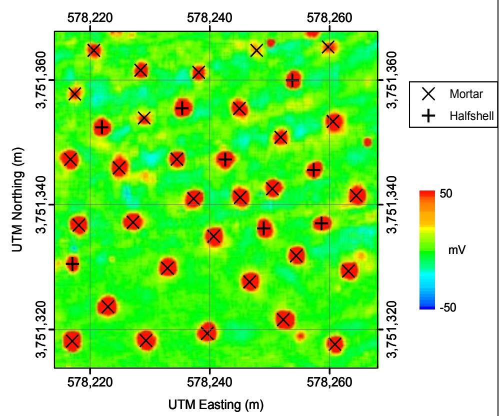
Introduction 5

During early attempts to use detection technologies in munitions response projects, it became obvious that much remained to be learned. The first projects often began with a “test off” of multiple sensor types for each site. Detection technologies that worked well in one place seemed not to work at all at another. Results achieved by one detection team at a given location could not always be duplicated by another detection team at the same location, using the same equipment. Most importantly, there was little information regarding what these first munitions responses were actually achieving: No one could say with much certainty how deeply or effectively the instruments were detecting munitions, nor what was being left behind. In other words, there was no measured, quantitative method of describing the results of a munitions response.

As a result, DoD managers and State and Federal Regulators providing oversight to projects began looking for ways to quantitatively understand, measure, and describe the effectiveness of technologies used at UXO sites.

Early GPO

- Objective:
  - Test off to select technologies
  - Site-specific capabilities and limitations
- Method: Empirical
  - Bury items at known location, depth and orientation
  - Score on how many are detected
- Outcome: Understanding of common sensors



Introduction 6

Munitions response projects began to use GPOs in an attempt to determine the capabilities and limitations of geophysical systems under controlled conditions near the work site. In a GPO, a known number of inert munitions, surrogates, and other objects are buried at precisely known locations and depths, and then the site is mapped with one or more geophysical instruments. The data are processed and targets selected based on some predetermined criteria, and the resulting geophysical map is used to display “anomalies” that represent potential munitions. Performance on the GPO is scored primarily based on the fraction of the emplaced targets that are associated with geophysical detections, often accompanied by many other secondary metrics. Over the years, the accumulation of empirical results from GPOs resulted in an understanding and documentation of sensor capabilities.

GPO Limitations

- No information on quality of field work
  - Limited representativeness
  - Up-front evaluation only
  - Small area allows for more careful work to "pass"
  - 'A team' versus the 'C team'
- Statistical uncertainties
- Cost and time

Introduction 7

Although useful, GPOs have a number of limitations:

Representativeness: An inherent assumption regarding GPOs is that conclusions drawn from performance in the GPO are applicable to work on the "live" production site. This requires that the population of targets and clutter placed in a GPO is representative of the actual target and clutter population that will be encountered in the field and the geophysical systems and processes employed at a GPO sufficiently resemble the geophysical systems and processes employed in the field.

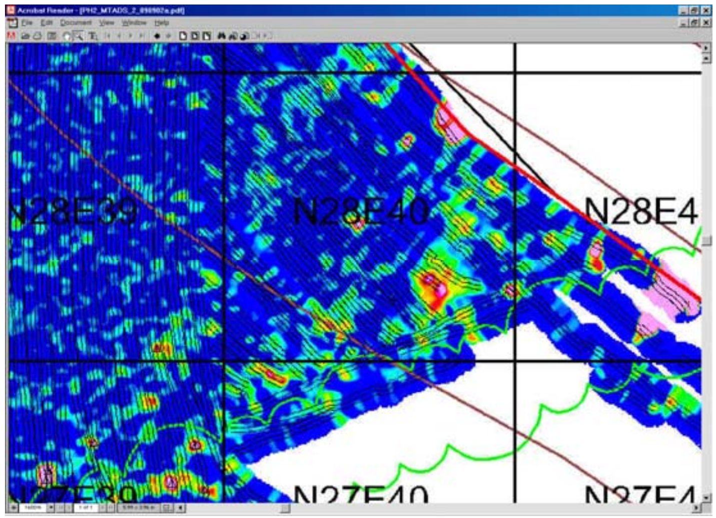
In fact, the true distribution of targets and depths is unknown at the time the GPO is constructed and the resources available typically constrain the size of the GPO and number of targets that are emplaced. Many live sites are vastly heterogeneous across a wide range of variables, including target density, clutter environment, geology and other noise sources. In practice, there is almost always significant discrepancy between the GPO and the live site it models.

In addition, the GPO survey likely represents ideal performance in many applications. There are two common themes in the concerns have been raised over the years about how well performance on the GPO represents performance throughout the production work. First, often projects employ multiple crews with multiple instruments in production work and it is rare for all teams and equipment to qualify each day. If one team passes the GPO at the beginning of the project, no information is available on how that team performs weeks or months into the project, nor on how other teams perform. Second, the GPO is a small area where it is possible that the crew, motivated to "pass" the GPO, can be more careful than they might be throughout the site. Over time the GPO will become familiar to the crews, so any blind testing aspect is lost. Overall, the GPO provides little information on performance of the system or the crew while collecting production data.

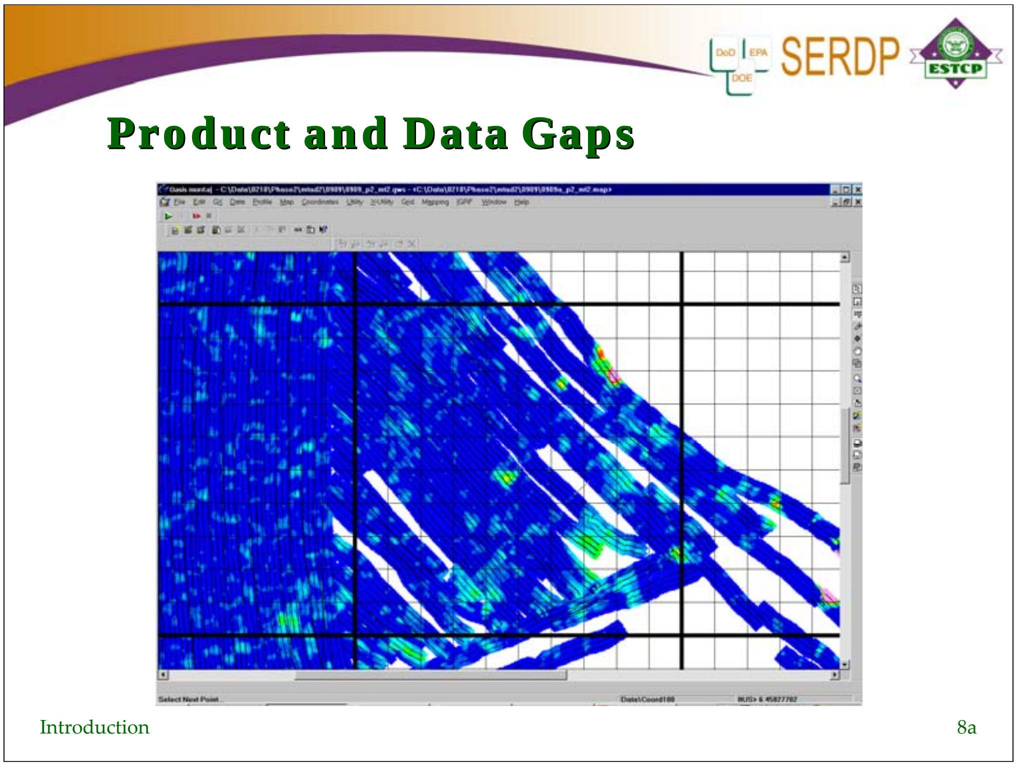
Statistical Uncertainties: the primary measure of success for most GPOs has been the fraction of targets detected, which was treated as a surrogate for the probability of detection that a system would achieve on the site. In fact, few if any, GPOs contained a sufficient number of targets to calculate statistical metrics with the desired uncertainties.

Cost: GPOs have ranged in size and complexity, from a few targets to hundreds of targets. The construction and performance of the GPO have been substantial costs on many sites. Cost factors include identifying and clearing a GPO site, acquiring and seeding targets, data acquisition, processing and report writing. In many cases, the GPO has required a separate deployment in order to obtain approval to proceed.

Product and Data Gaps



While the use of digital technologies brought great enhancements to the munitions response program, data could easily be provided that often left an inaccurate impression of the quality of the work. This chart shows data as gridded and presented by the contractor. The map indicates project requirements were met and appears to be complete and of high quality. When the actual survey data tracks are added and processed according to the project requirements, it is evident that several large data gaps were obscured in the data presentation. The separate function of performing GPOs and then moving into production work created what some have commented as providing an opportunity to have the "A" team do the test, i.e., the GPO and then letting the "C" team to the work.



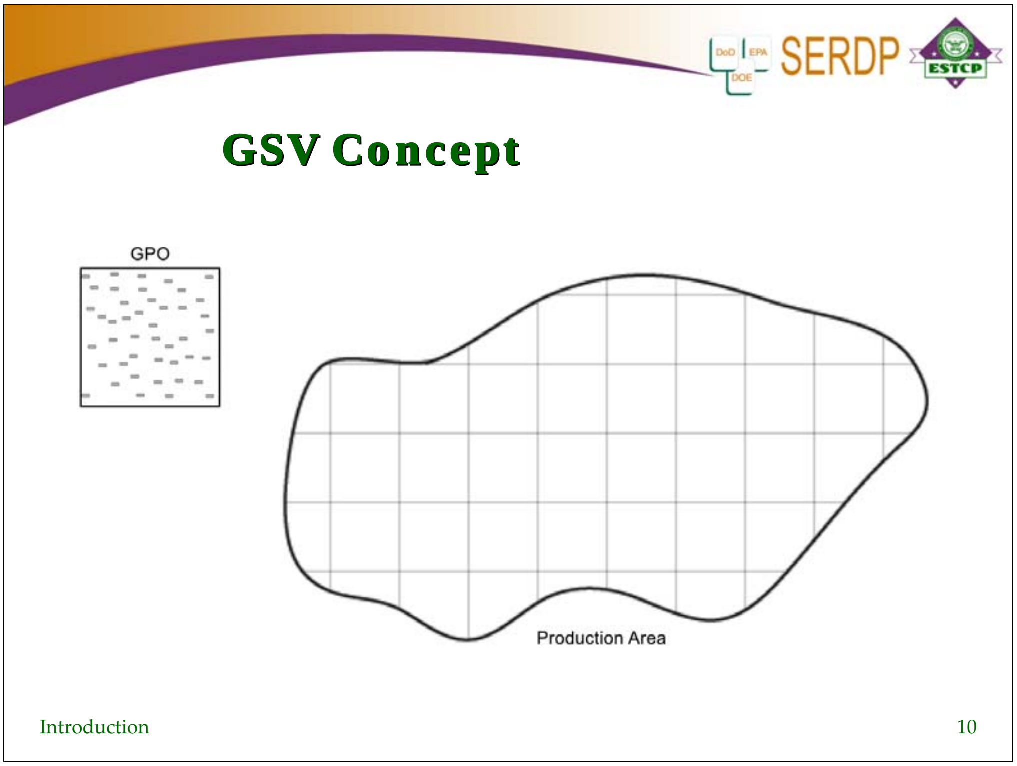
When the actual survey data tracks are added and processed according to the project requirements, it is evident that several large data gaps were obscured in the data presentation. The separate function of performing GPOs and then moving into production work created what some have commented as providing an opportunity to have the "A" team do the test, i.e., the GPO and then letting the "D " team to the work.

Why change?

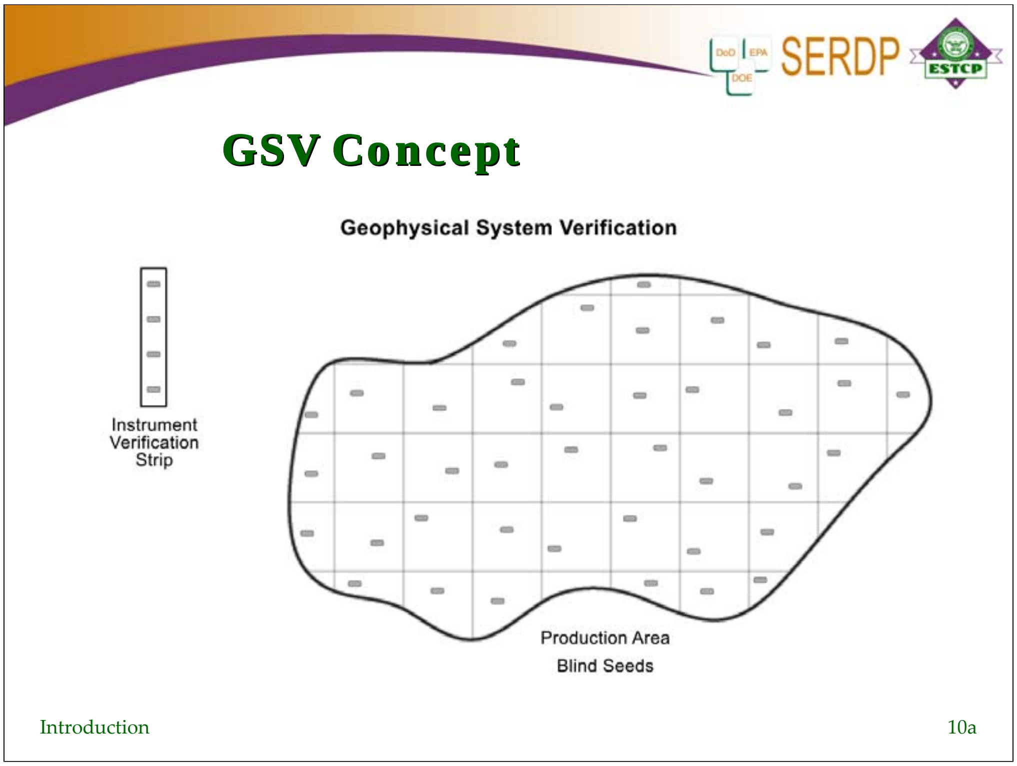
- Continuum of information throughout project
- Rigorous, physics-based, quantitative
- Standard, repeatable, comparable
- Better use of resources

Introduction 9

The GPO has served its purpose. There now have been tests of many geophysical systems at multiple sites over a period of about 15 years, resulting in a vast increase in the understanding of the capabilities and limitations of common geophysical detection systems. This understanding, coupled with reliable models for the signals expected from common sensors, presents and opportunity to move beyond the empirical GPO to a more physics-based verification of sensor performance.



A Geophysical System Verification (GSV) process is envisioned in which the resources traditionally devoted to a GPO are reallocated to support simplified, but more rigorous, verification that a geophysical system is operating properly, as well as ongoing monitoring of production work. The GSV will add to existing QC and QA processes and is not intended to replace current quality practices.



Two main elements are considered in this course:

Instrument Verification Strip (IVS): The traditional GPO, which consists of several tens to a hundred or more targets, would be replaced by an IVS containing a handful of targets. The objective of the IVS would be to verify that the geophysical detection system is operating properly.

Blind Seeding Program: The production site would be seeded with targets at surveyed locations that are blind to the data collection and processing teams. The objective of the seed program would be to provide ongoing monitoring of the quality of the geophysical data collection and target selection process as it is performed in the production survey throughout the project.

Physics Basis for Geophysical System Verification (GSV)

Tom Bell

Outline

- Basis of Geophysical System Verification (GSV)
- Geophysical Sensors
- Electromagnetic sensors (EM61)
  - Electromagnetic induction (EMI) fundamentals
  - Signal response curves
  - Industry Standard Objects
  - Noise and signal detectability
  - Measurement uncertainty and error bars
- Magnetometers
- Summary

Basis of GSV

- Well characterized sensor with predictable response
  - Standard magnetometer and EM61
  - Emerging EM sensors to be documented
- Well characterized target
  - Common munitions
  - Industry Standard Object

Physics Basis 3

Well-characterized sensor: The premise of this approach is that the basic physics of the sensor system is well characterized and documented. Magnetic signatures of items do not vary from one sensor to another, although how the magnetic field is measured differs. Prediction of EM signatures requires knowledge of salient features of the sensors, such as the transmit moment, coil geometry, receive time gates, and so forth, which are well documented for the commonly used EM61-MK2. The GSV may, in principle, be applied to any variation on EM technology that is transparent and documented.

GSV will not be applicable to so-called "black boxes." This will include proprietary devices for which sensor details are not divulged and any other system whose operation, in terms of both hardware and processing, is not well-documented. Nor will it be appropriate for technologies based on completely different physical phenomena, where a GPO may be required.

Well characterized test objects: EM and magnetic signals are site invariant and any well characterized object may be used for GSV. Test objects may include the munitions of interest, but that is not essential for confirming that the system is operating properly. As an alternative, we introduce the concept of an "industry standard object (ISO)." We have selected three sizes of commonly available pipe sections that can be readily obtained from any plumbing or hardware supplier. While munitions may vary by make and model number (i.e., there are many different types of 60-mm mortars), ISOs have the advantage that they will be made to the same specification regardless of where they are obtained. Together, the three sizes should meet the objectives of most MR projects in that the physics characteristics of one or more of the ISOs will be sufficiently similar to the targets of interest that they can be used to verify that the system is operating properly and can be expected to detect the targets of interest.

The ISOs have been modeled and measured so that they can serve as well-characterized test strip targets. (Ref. 3) Similar data are provided for commonly encountered munitions. (Ref. 4) The data are included in the CD that accompanies the course materials to allow application to single-sensor EM61-MK2 systems. A simple windows application is provided that can be used to produce sensor responses for any array arrangement of an EM61.

Geophysical Sensors

The workings of modern geophysical sensors for munitions response applications follow well defined physical principles and their performance can be quantitatively characterized with a high degree of accuracy & precision

- Electromagnetic induction (EMI)
- Total field magnetics

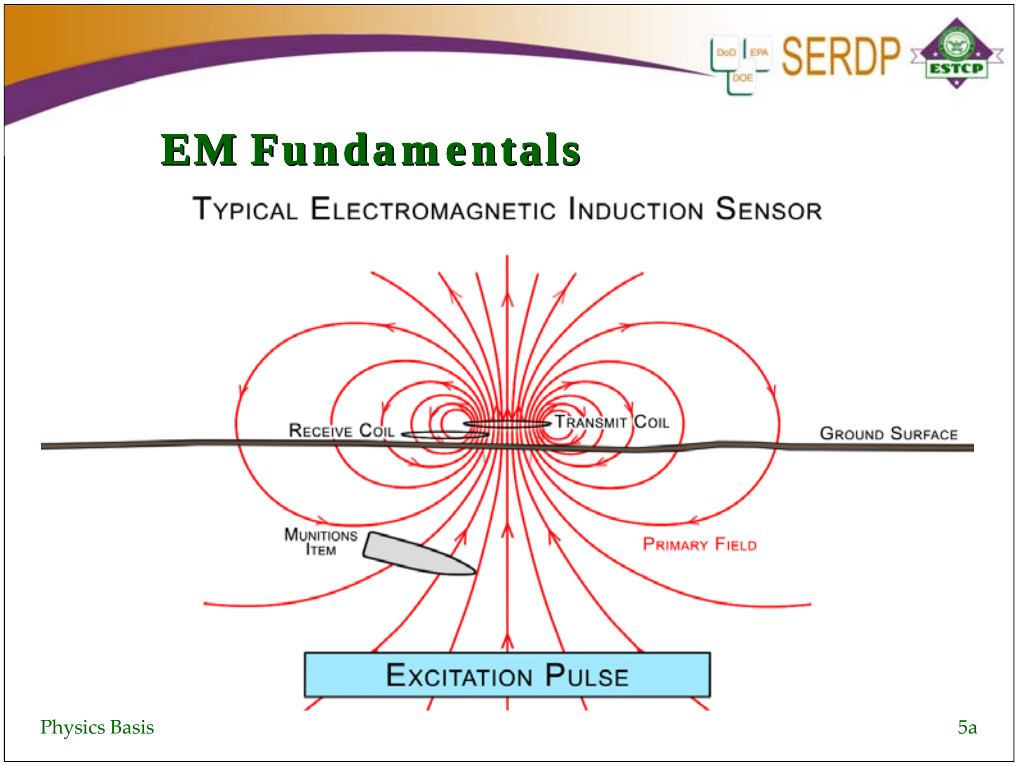
Physics Basis 4

There are two basic types of geophysical sensors used in munitions response work: electromagnetic induction (EMI) sensors such as the EM61, shown here in the standard man-portable configuration (left) and in a towed array configuration (center), and total field magnetometers (right). A physics-based approach to geophysical system verification is possible because these sensors obey well-defined basic physical principles, and their performance can be quantitatively characterized with a high degree of accuracy and precision.

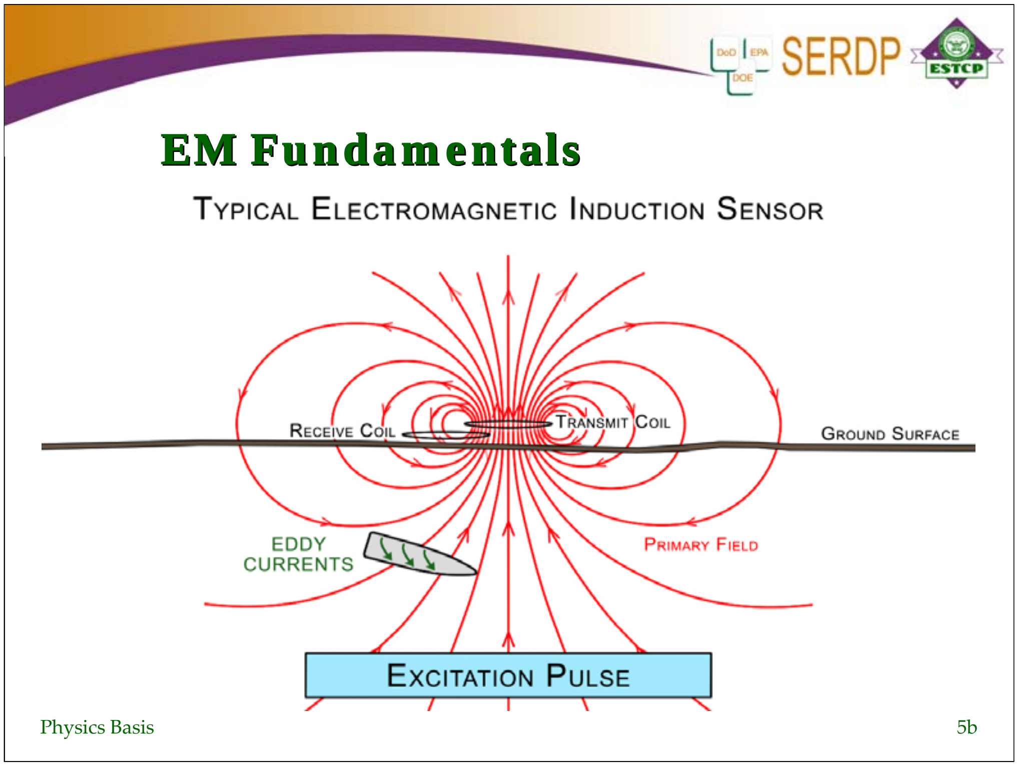
EMI Physics

Physics Basis 5

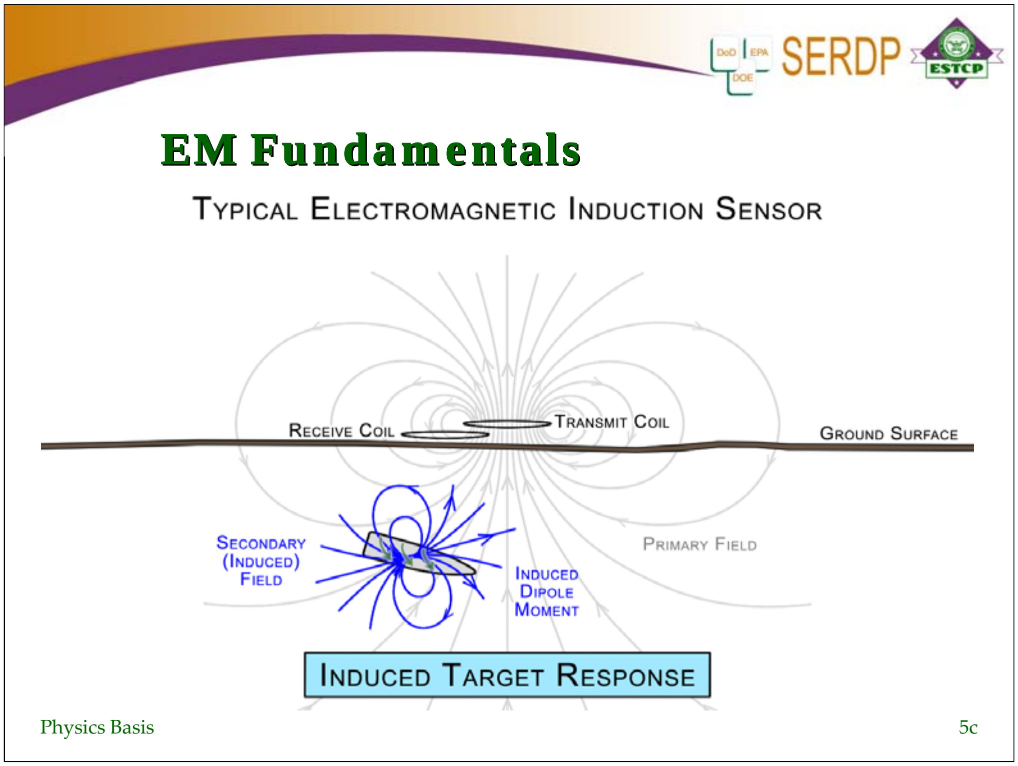
This sequence of slides shows the fundamental concepts involved in EM measurements, starting with a picture of a typical EM sensor being pulled across a field.



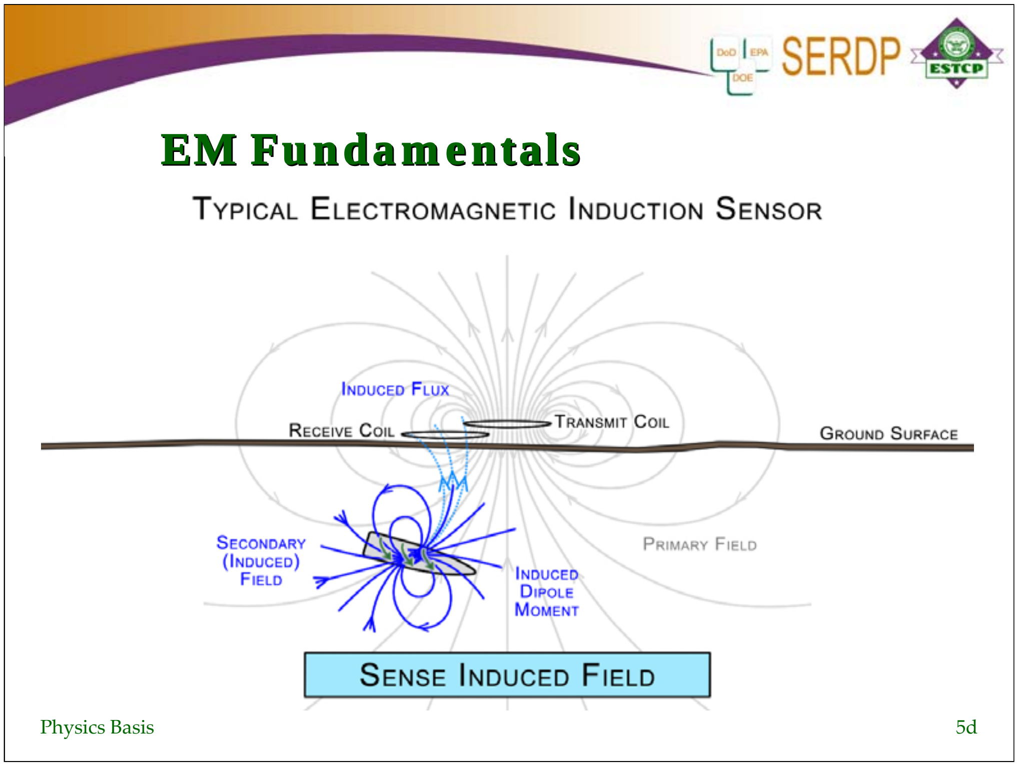
The basic elements of an EM sensor are a transmit coil and a receive coil shown by the loops above the ground surface. A current pulse running through the transmit coil creates the primary EM field, illustrated by the arrows flowing along field lines shown in red. This pulse excites the munitions item under the sensor.



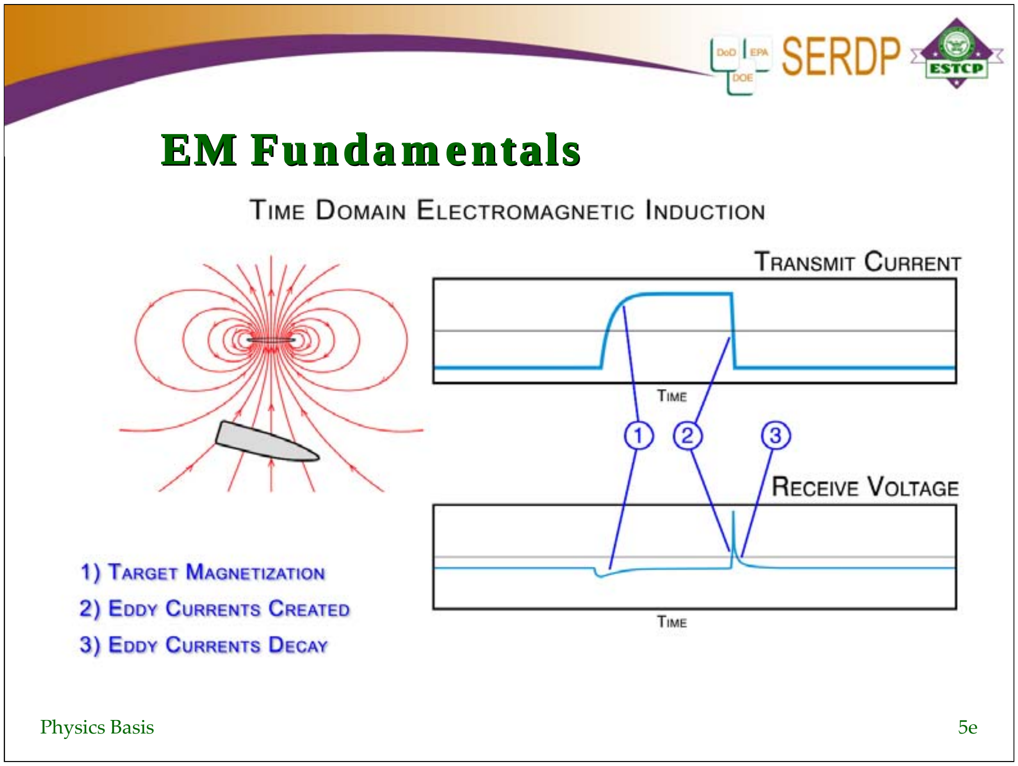
Changes in the primary field set up eddy currents in the object, shown schematically by the green arrows seeming to flow around the buried munitions item.



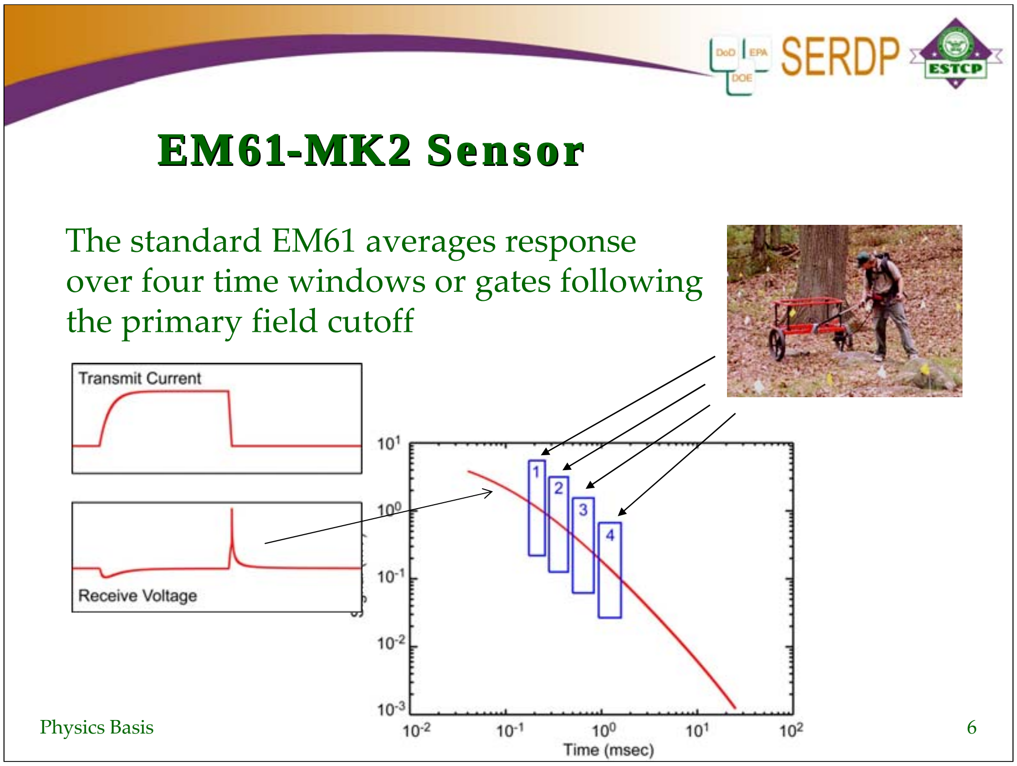
The eddy currents produce a secondary or induced EM field emanating from the object. This field can be represented by an induced dipole at the object's location. The strength and orientation of the dipole moment are determined by the primary field at the object and physical properties of the object such as its size and shape, as well as its orientation.



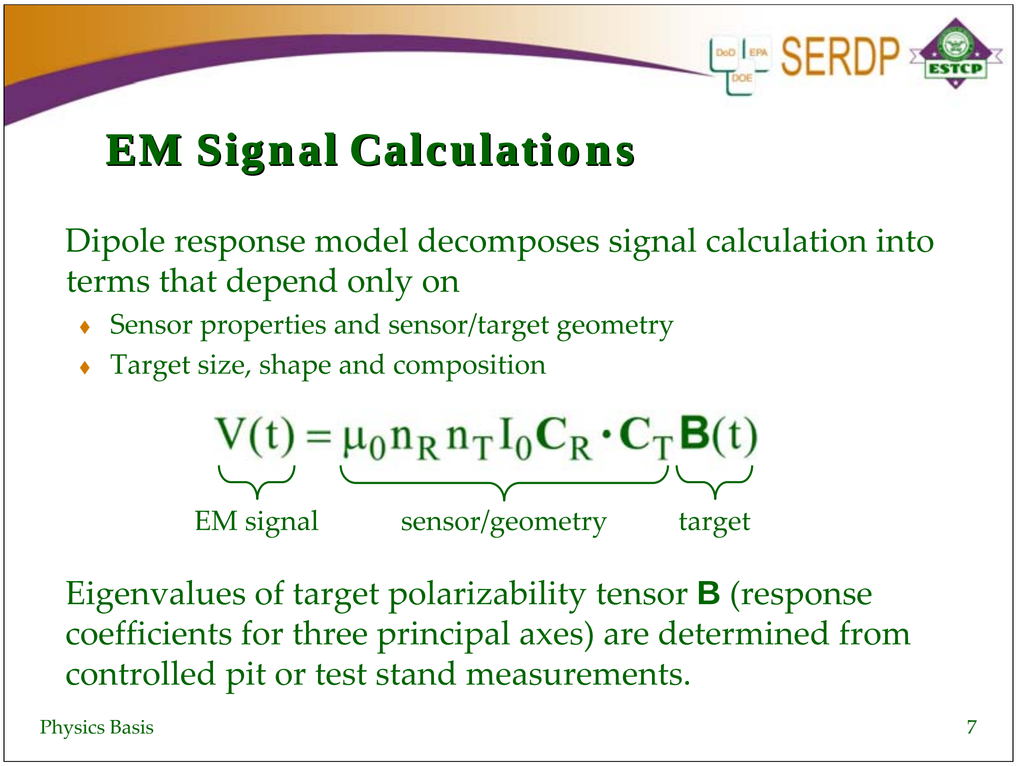
The induced field is measured by the receive coil, the output signal being proportional to the rate of change of the EM flux through the receive coil.



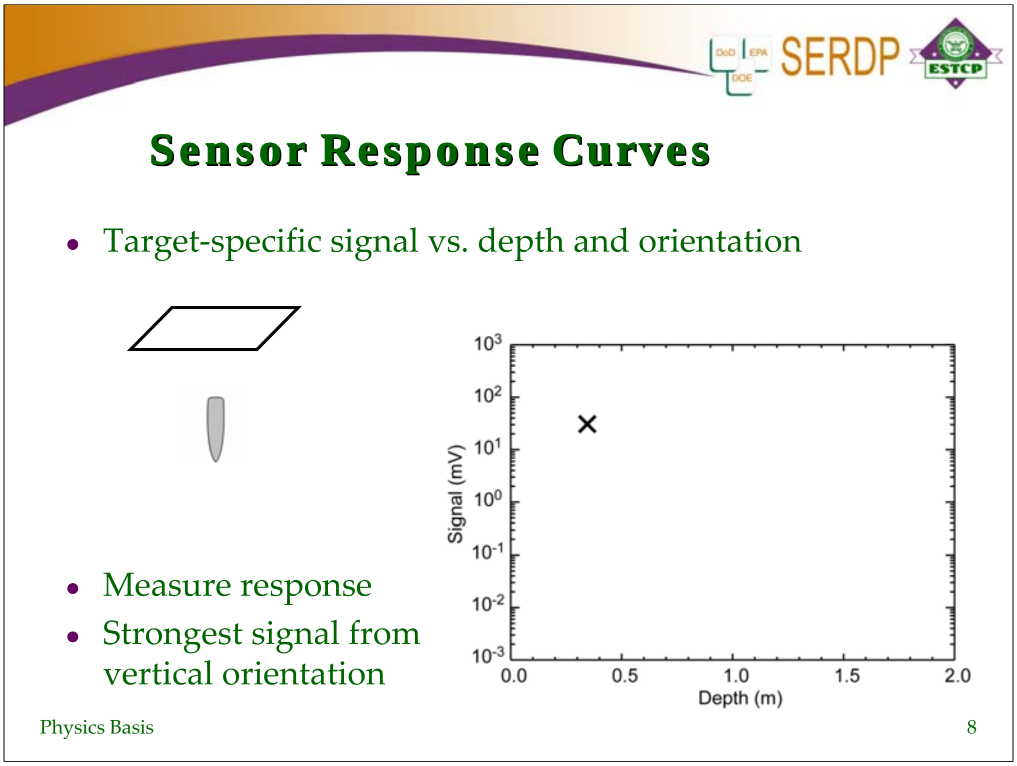
There are two basic types of EM sensor: continuous wave (frequency domain), and pulsed wave (time domain). Frequency domain sensors transmit a continuous waveform, while time domain sensors transmit a sequence of EM pulses. The pulsed sensor is the most commonly used configuration because it allows the eddy current response to be measured when the primary field is not changing and is no longer overwhelming the signal due to the induced field. The two plots show typical transmit and receive waveforms for a pulsed EM sensor and identify the three stages of the EM measurement process. (1) The object is magnetized only during the transmit pulse. (2) The eddy currents are excited in the target when the pulse abruptly ends. (3) The EM response is measured during the eddy current decay after the primary field pulse ends. This measured decay contains the information that is used to classify the target.



We will focus on the standard EM61-MK2 sensor, which is shown in the field in the inset picture. The EM61-MK2 samples the eddy current decay over four windows or time gates following the primary field cutoff. Measurements can be taken at a rate of about ten times per second, corresponding to a spacing along a survey line of about 10-12 cm at normal walking speeds.

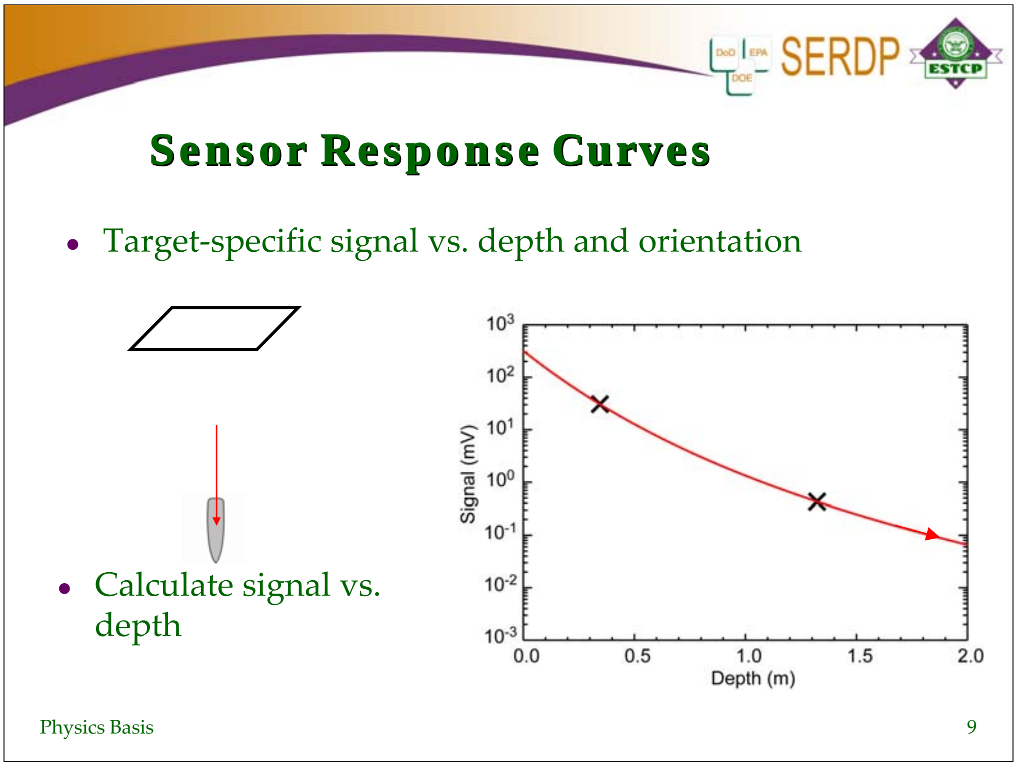


We can use rather simple mathematical formulae to represent the response of the EMI sensor to a buried munitions or clutter item. When the distance between the sensor and the object is somewhat larger than the size of the object we can use a simple "far field" approximation referred to as the dipole response model. This model splits the response into products of terms that depend on properties of the sensor and the sensor/target geometry and terms that depend on basic properties of the target such as its size, shape and material composition. We refer to the sensor and configuration dependent factors as extrinsic factors because they are external to the target, and the basic properties of the target as intrinsic factors because they are inherent to the target. The effect of the extrinsic factors on the sensor response is the same for all targets, while the contribution of the intrinsic factors to the response depends only on what the target is, not where it is or how the sensor is being used. Once we have determined the intrinsic response terms for an object (e.g. a 60mm mortar), we can easily calculate what the sensor response will be for any target depth, orientation, or location relative to a survey line.



This sequence of slides shows how sensor response curves are created. Signal vs. depth response curves for least favorable (aligned perpendicular to the primary field) and most favorable (aligned parallel to the primary field) target orientations can be scaled to a few measurements. The curves bound the range of signals that the target can produce.

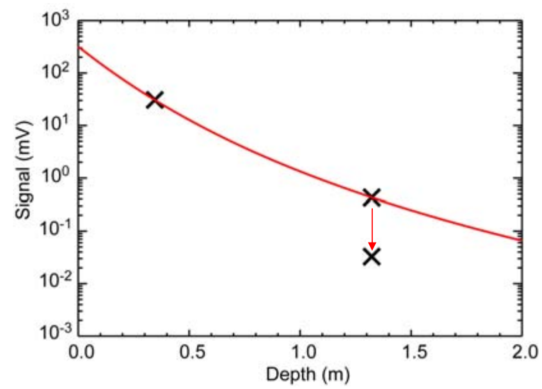
First, the response is measured for some target depth. In this case the target is aligned vertically, which produces the strongest signal and is the most favorable orientation for detection.



We then calculate how the response varies with depth using simple physics equations.

Sensor Response Curves

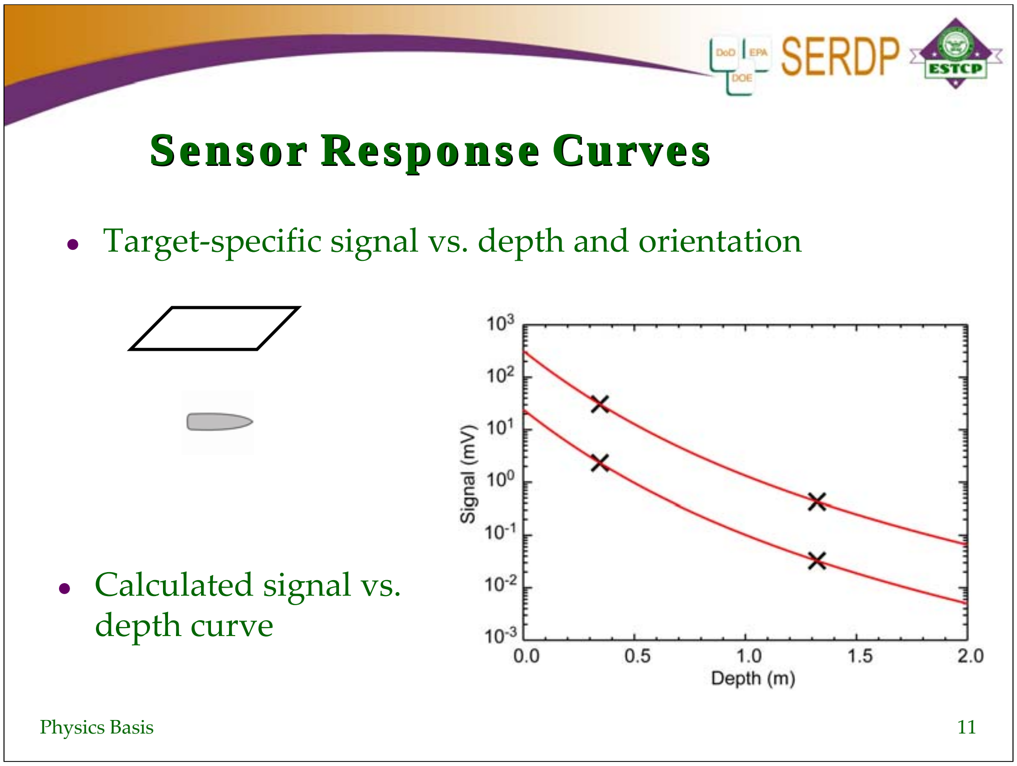
- Target-specific signal vs. depth and orientation



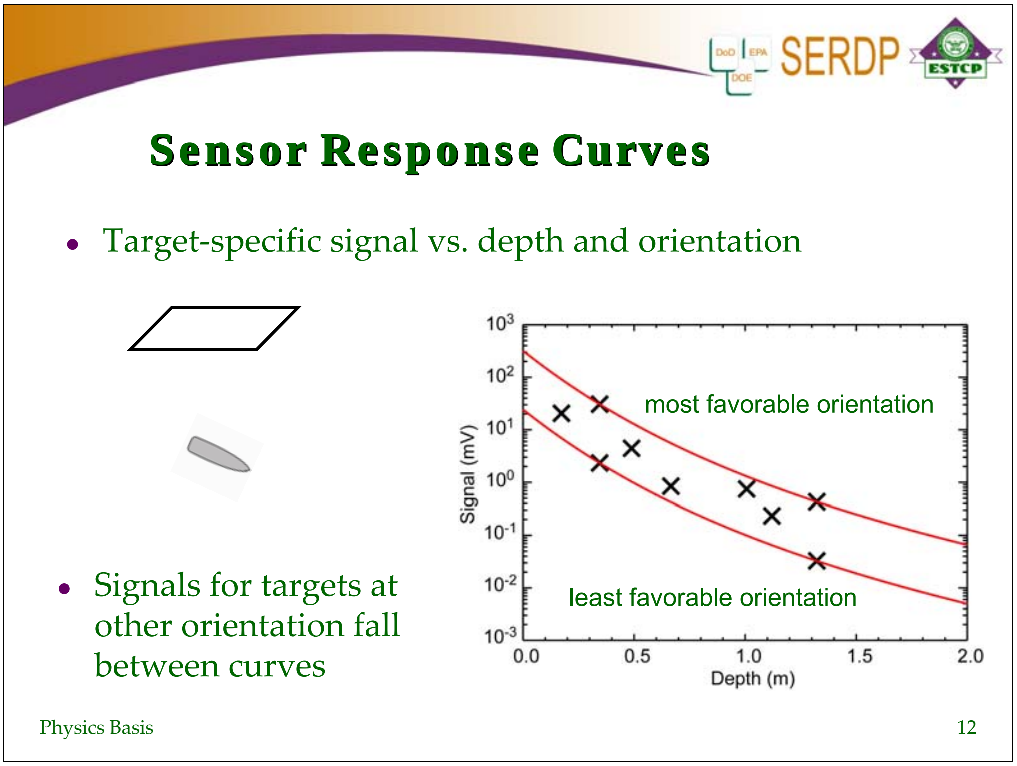
- Weakest signal for horizontal orientation

Physics Basis 10

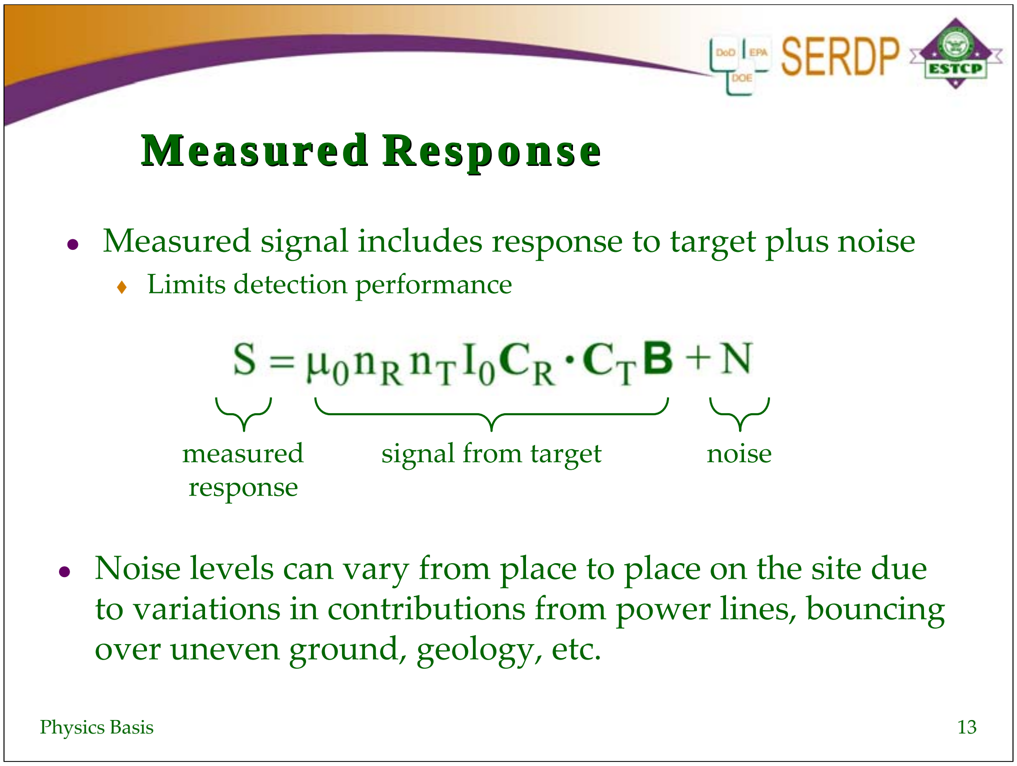
If the target is oriented horizontally, the signal is weaker. This is the least favorable orientation for detection.



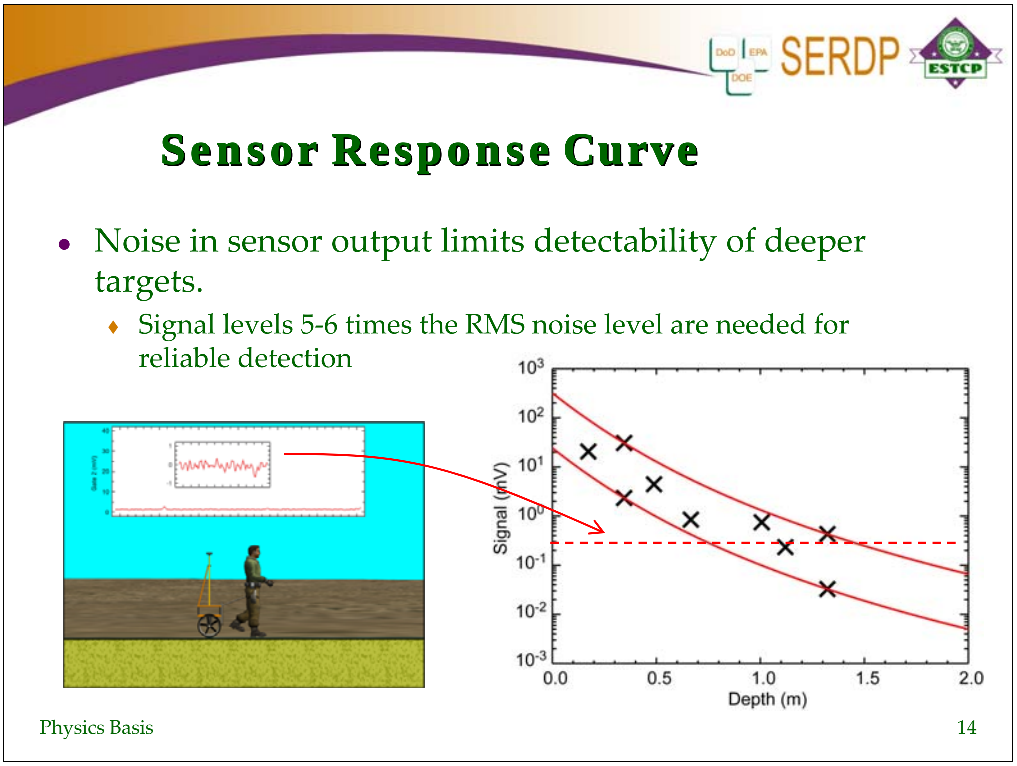
The variation of the minimum signal vs. depth is calculated using the same equations.



Signals for targets at other orientations are bounded by the least favorable and most favorable curves.



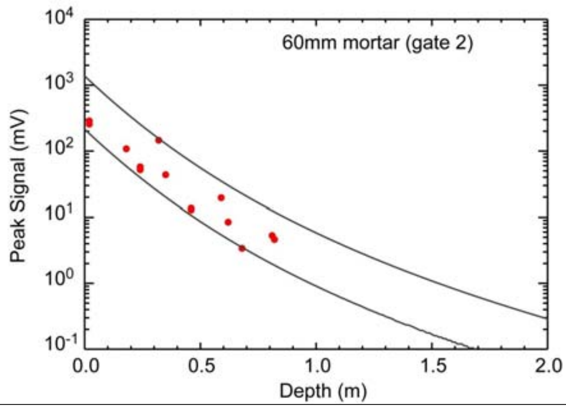
Any fluctuations in the sensor output that are not due to munitions targets or comparable clutter items represent noise that ultimately limits the performance of the geophysical system. Noise arises from a variety of sources, including the sensor electronics, improper or careless operation of the sensor, bouncing and jolting over uneven ground, nearby power lines, geology, etc. Some of these factors can vary from place to place over the site and cause significant variations in the noise level. For example, a part of the site where the ground is rougher will generally have higher survey noise because of increased bouncing and heaving of the sensor. Other factors that can introduce noise variability from place to place include power lines running through the site, variations in the underlying geology, varying levels of small shrapnel fragments, etc.



Whether or not a given object will be detected depends not only on how strong a signal it creates, but also on the level of noise in the measurements. Reliable detection requires a peak signal that is 5-6 times the RMS noise level. In this slide the survey noise level is shown by the dashed line on the response curve plot from before. Targets with signal levels below a few tenths of a millivolt will likely be obscured by the noise.

Response Curve Scaling

Response curves for different munitions items all have the same shape but are scaled by the specific item's response coefficients β_L and β_T



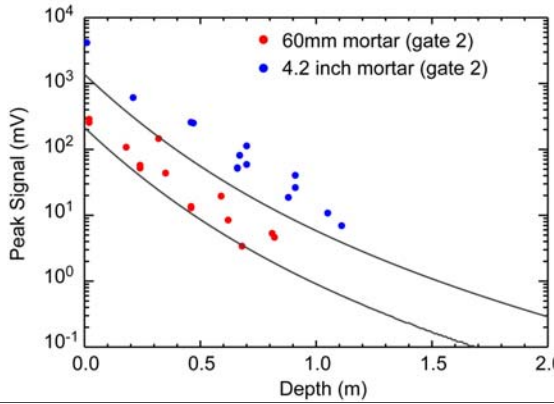
Physics Basis 15

The response curves for different munitions items have the same shape but are scaled by the specific item's response coefficients (β_L, β_T).In this sequence, we start off with the response curves for a 60-mm mortar.

The red dots show measurements of the EM61 (gate 2) signal from a 60-mm mortar at various depths and orientations. The lines show the calculated minimum (least favorable orientation) and maximum (most favorable) signal-vs.-depth response curves.

Response Curve Scaling

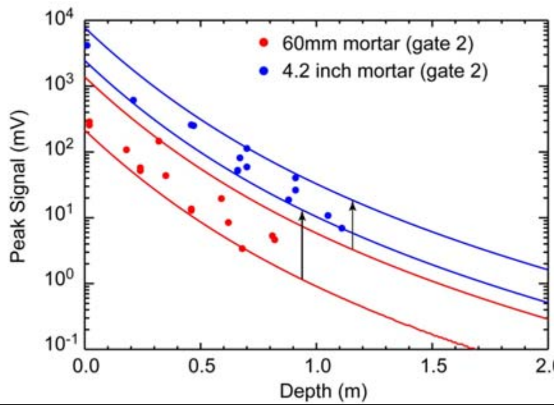
Response curves for different munitions items all have the same shape but are scaled by the specific item's response coefficients β_L and β_T



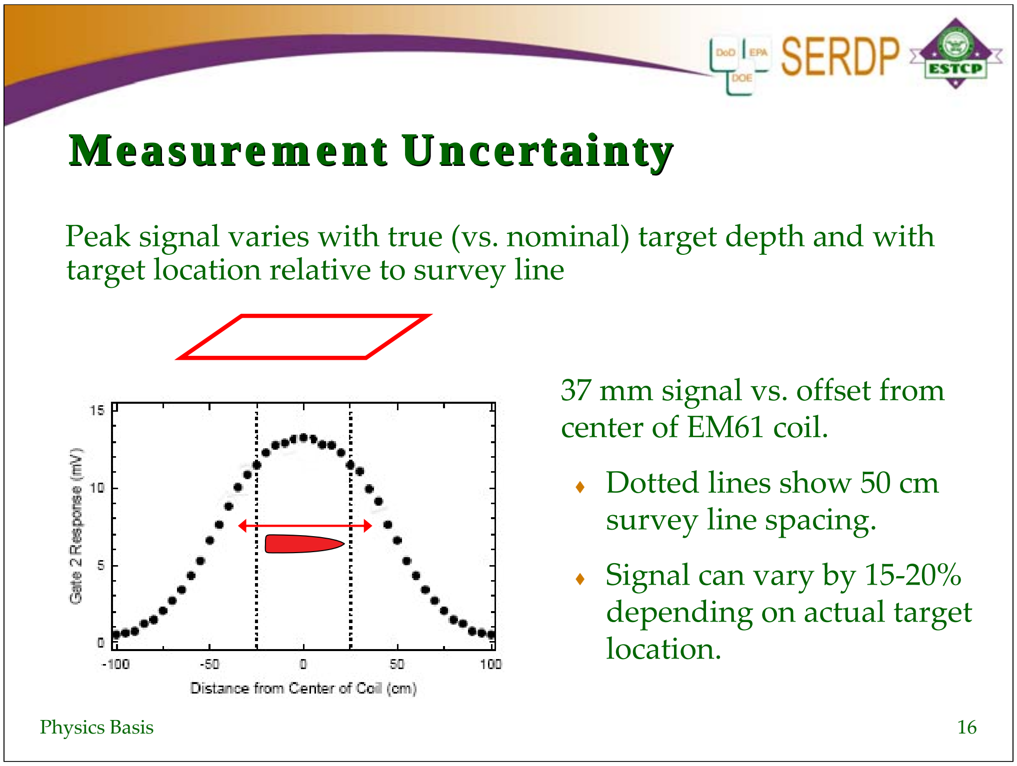
Next we include measured signals for a 4.2-inch mortar (blue dots)

Response Curve Scaling

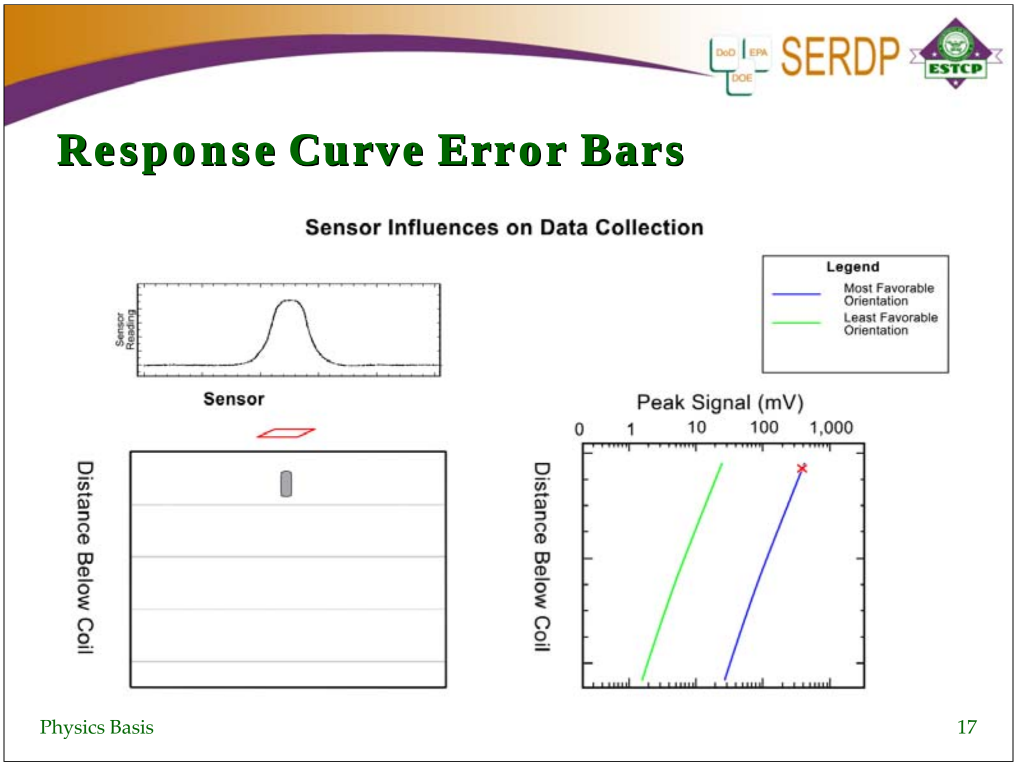
Response curves for different munitions items all have the same shape but are scaled by the specific item's response coefficients β_L and β_T



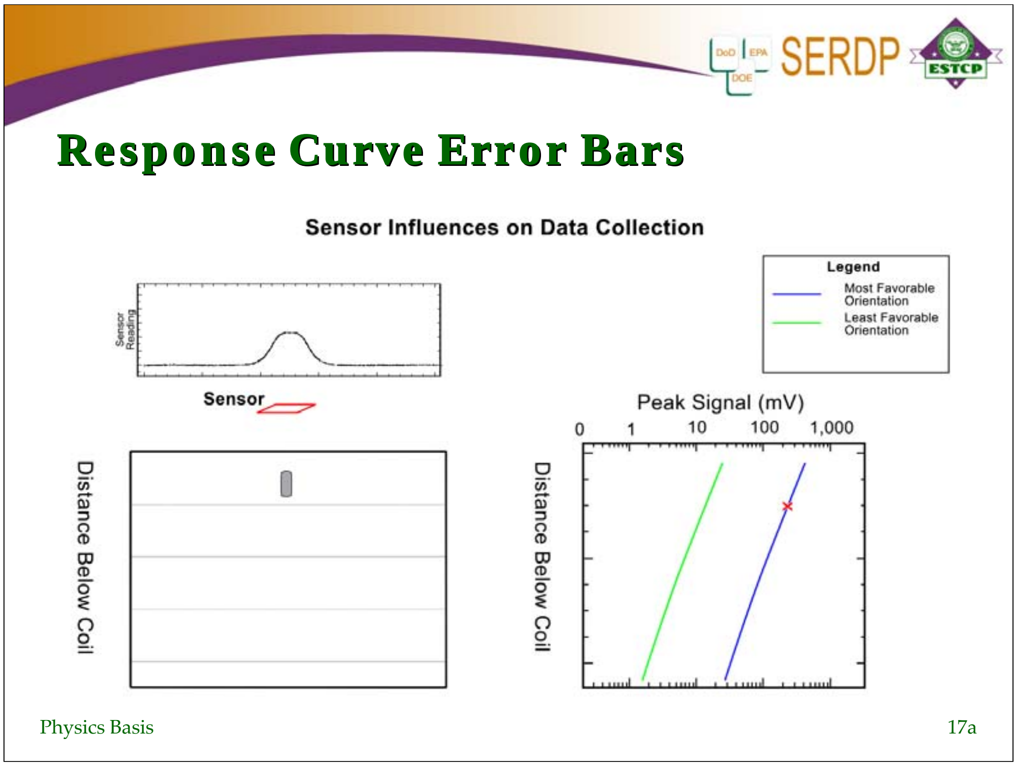
The response curves simply shift up or down to bound the new object's response.



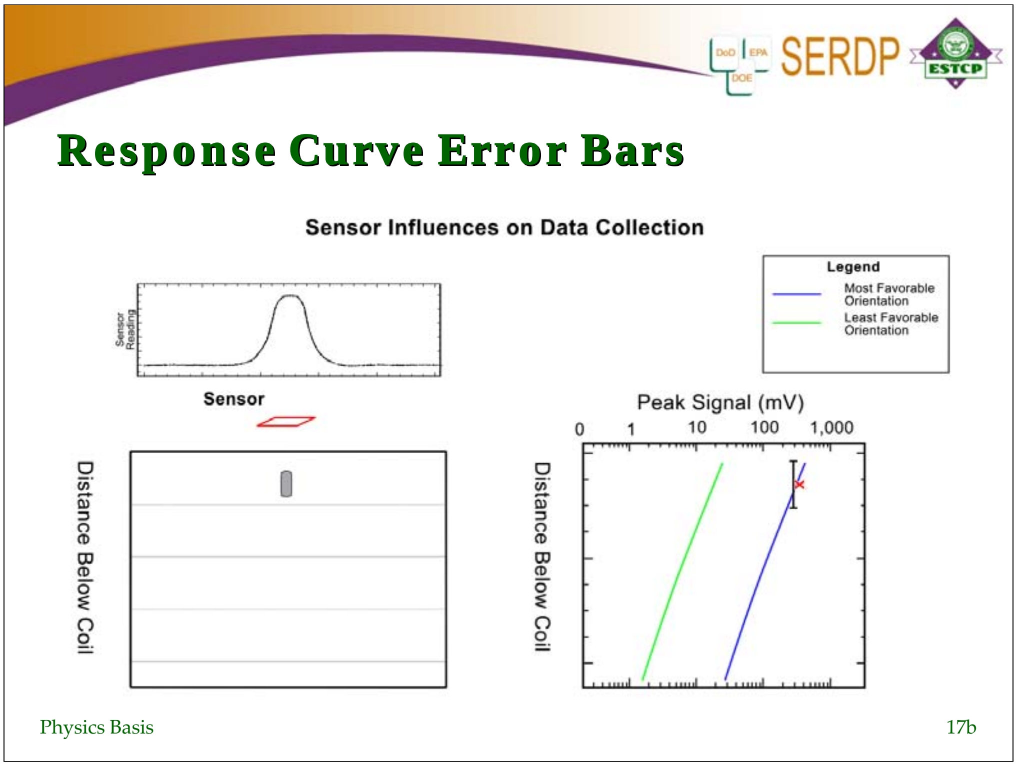
Signal strength depends very strongly on the distance between the target and the sensor. The peak signal strength measured along a survey line over a target will vary depending on the actual vertical distance between the sensor and the target (as opposed to the nominal sensor height and target depth), and any target offset relative to the survey line. For a target that is nominally 20 cm deep, ±5 cm vertical offset due to sloppy target burial or sensor bounce can produce ±20% variation in the measured signal strength. The plot shows the measured EM61 signal for a 37-mm projectile as it moves across the sensor at fixed vertical separation. The EM61 is 1 m wide, and the signal strength drops to about ½ its peak value at the edges of the coil (±50 cm from the center). Imagine that the 37-mm projectile is in a grid that is being surveyed at 50-cm line spacing. One of the survey lines will have to fall somewhere between the dotted lines at ±25 cm, and the signal from the 37-mm projectile could vary by ~15% depending on where.



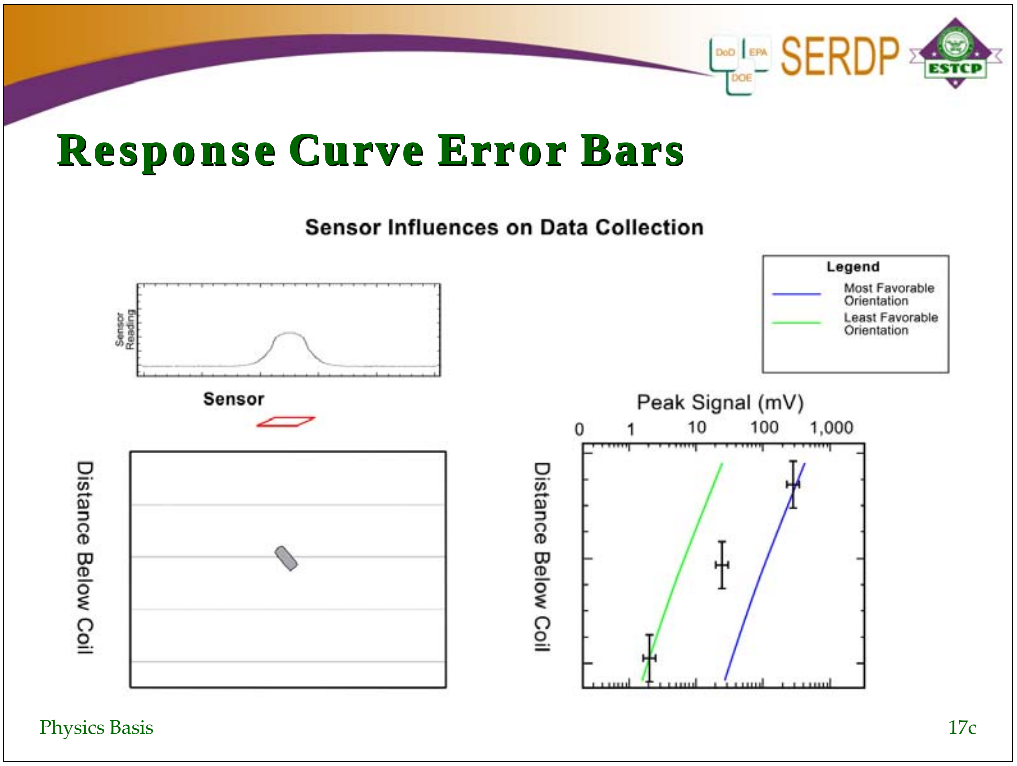
This series of slides illustrates how measurement uncertainty creeps in. As noted in the previous slide, slight variations in the vertical and horizontal offsets between the sensor and the target can produce significant signal variations. Here, the sensor is relatively low to the ground (and thus close to the target) and the signal is relatively high.



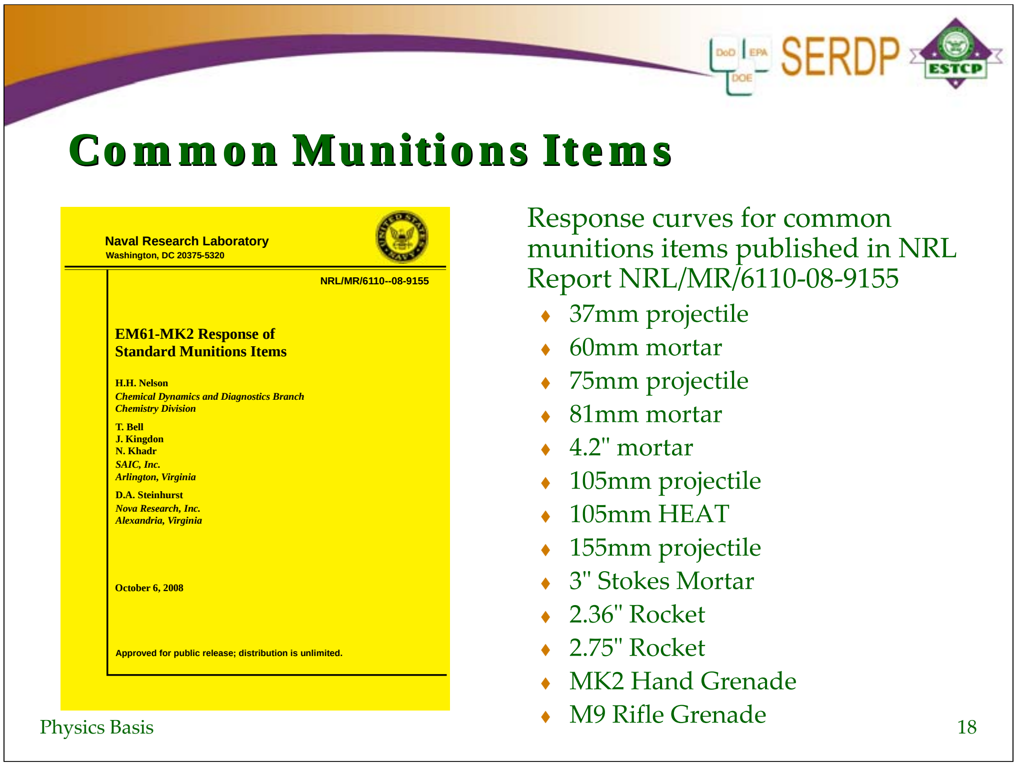
Here the sensor is higher above the ground so the signal is relatively low.



We represent the signal uncertainty that arises because of these sensor height variations (or equivalently target burial depth uncertainty) by error bars on the response curves.



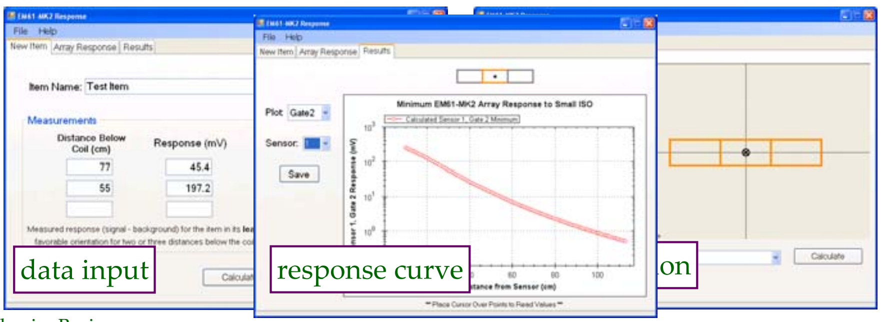
For each of the three target positions, there is an error bar representing sensor height uncertainty and one representing measurement noise.



Response curves for common munitions have been published by the Naval Research Laboratory in report NRL/MR/6110-08-9155. This document is available in the SERDP/ESTCP on-line library, which may be accessed at www.serdp.org or www.estcp.org.

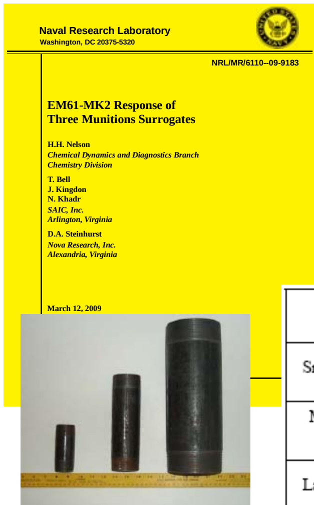
Response Curve Calculator

- EM61 array response curves for common munitions
- Single sensor response curves for new munitions items
  - Requires controlled measurements at several depths for scaling
- Distributed with GSV Report



A simple stand-alone computer program for calculating response curves for arrays of EM61 sensors for any of the common munitions items listed on the previous slide, or calculating single-sensor EM61 response curves for other munitions items is available with the Geophysical System Verification (GSV) report. For new single-sensor response curves, the program must be supplied with controlled pit or test stand measurements of the response at several sensor-to-target ranges.

Industry Standard Objects


Naval Research Laboratory
Washington, DC 20375-5320

NRL/MR/6110--09-9183

EM61-MK2 Response of Three Munitions Surrogates

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Chemical Dynamics and Diagnostics Branch
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March 12, 2009

- Readily available, similar in size and shape to common munitions items
- Documented response curves
- Repeatable, consistent EM signals for calibration and performance validation

Item	Nominal Pipe Size	Outside Diameter	Length	Part Number[1]	ASTM Specification
Small ISO	1"	1.315" (33 mm)	4" (102 mm)	44615K466	A53/A773
Medium ISO	2"	2.375" (60 mm)	8" (204 mm)	44615K529	A53/A773
Large ISO	4"	4.500" (115 mm)	12" (306 mm)	44615K137	A53/A773

1. Part number from the McMaster-Carr catalog.

Physics Basis

20

You don't need to measure the responses from munitions items to verify geophysical sensor performance. Using this physics-based approach, pretty much anything will do. We recommend test items that are readily available, inexpensive, and similar in size and shape to common munitions items, and have identified a set of Industry Standard Objects (ISOs) with documented response curves which can be used to provide repeatable, consistent EM signals for sensor calibration and performance validation. The ISOs, shown in the inset picture, are standard size steel pipe nipples as described in the table. The small ISO is roughly the size of a 37-mm projectile, the medium size ISO is comparable to a 60-mm mortar, and the large ISO is roughly the comparable to a larger munitions item like 105-mm projectile or 4.2-inch mortar. They will produce signals that are similar to those of the corresponding munitions items.

Magnetics

- Signal representation for total field magnetometers is similar to EMI
  - Performance can be accurately calculated using basic EM theory
- EMI GSV apparatus carries over directly to magnetics
  - Uncertainty increased by effects of remnant magnetization

magnetic anomaly

induced dipole moment

$$\mathbf{H} = -\frac{1}{4\pi r^3}\left\{\mathbf{m} - \frac{3(\mathbf{m}\cdot\mathbf{r})\mathbf{r}}{r^2}\right\}$$

Physics Basis 21

Total field magnetometers are also used in munitions response work. They are kind of similar to EMI sensors, but simpler. Most importantly, these sensors also obey well-defined basic physical principles, and their performance can be quantitatively characterized with a high degree of accuracy and precision. The signal representation for magnetics is similar to, but much simpler than for EMI. We still use a far field, dipole representation. Munitions items and comparable clutter are magnetized by the earth's field, and this is expressed by an induced magnetic dipole moment. The strength of the dipole moment is directly related to the size of the object. As with the EMI sensors, signal vs. depth response curves for magnetometers can be calculated using basic electromagnetic theory. The major difference is that the uncertainty (as expressed by error bars) is increased due to the effects of remnant magnetization.

Summary

- Modern geophysical sensors (mag and EM) produce repeatable, site invariant signals which can be accurately modeled using basic electromagnetic theory
- Signal strength vs. depth response curves can be constructed for any munitions item of interest
  - Combined with knowledge of on-site noise levels, response curves can be used to set anomaly selection criteria or evaluate expected performance
- Responses from simple standard objects (ISOs) can be used as surrogates for munitions items for instrument calibration and performance verification

Physics Basis 22

Modern geophysical sensors (magnetometers and EMI sensors) produce repeatable, calibrated signals which can be accurately modeled using basic electromagnetic theory. Consequently, signal strength vs. depth response curves can be constructed for any munitions item of interest. Combined with measurements of the on-site noise levels, the response curves can be used to set anomaly selection criteria or evaluate expected performance. Because the responses of different targets scale in a well-defined, calculable way, the responses from simple standardized objects (ISOs) can be used as surrogates for munitions items for purposes of instrument calibration and performance verification.

Geophysical System Verification

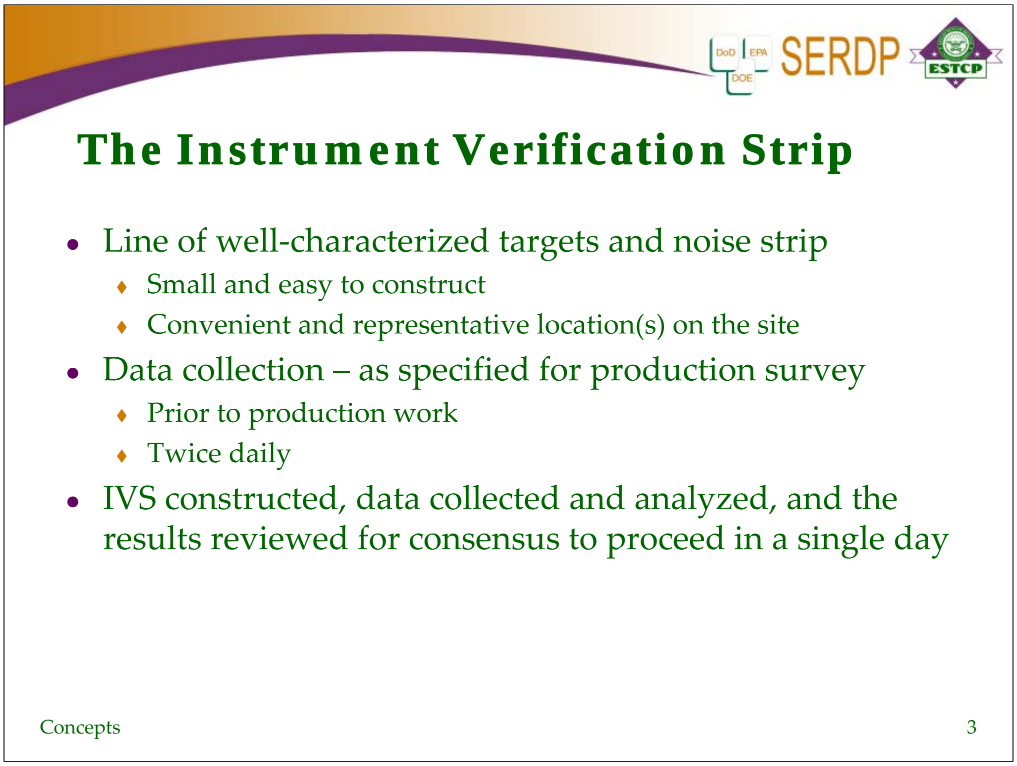
Jeff Swanson

Geophysical System Verification

- Instrument Verification Strip
  - Verify that the equipment is working properly
  - Measure site noise from which the target signal must be extracted
- Production Blind Seeding
  - Ongoing monitoring of production geophysics

The IVS is intended to:

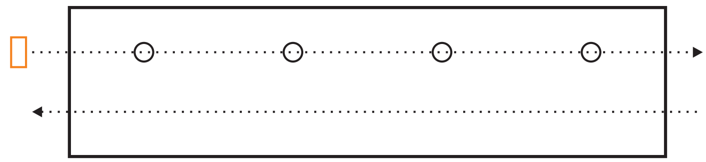
- verify that the equipment is working properly and
- measure site noise from which the target signal must be extracted.



The IVS envisioned consists of a line of well characterized objects, preferably ISOs, buried in an area representative of the local site conditions. Data would be collected prior to beginning production work using the same protocols specified for the field data collection. The first day's IVS survey would verify that DQOs set prior to project initiation are met and that they are sufficient to meet project objectives.

Then, the IVS would be visited twice daily, at the start and finish of the field work, to verify proper sensor operation. Noise will be measured in a convenient adjacent area. It is envisioned that the IVS could be constructed, data collected and analyzed, and the results reviewed for consensus to proceed in a single day.

IVS Specification



- Targets
  - Handful of objects in a line
  - Industry Standard Objects (ISOs) recommended
  - Locations known to sensor operator
- Noise strip
  - Representative of site conditions
  - Sufficiently far from objects

Concepts 4

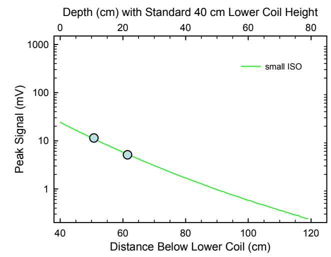
The contents of the IVS can in principle consist of any well characterized objects. Our preference is to use the ISOs, for which sensor response curves have been produced. Strictly speaking only one item would be sufficient to provide the data required for physics based confirmation of performance, that is to ensure that the sensor system is recording the expected signal at the correct location. Multiple items may be desired to provide a range of signals. To that, a project team could add inert versions of the targets of interest. The IVS outlined here is centered around a modest number of the ISOs.

The items will be buried in a straight row and are not intended to be blind to the sensor operator. To the contrary, the lane to be surveyed should be well marked, so that the sensor will pass directly over the targets, providing an accurate measure of the peak signal. The distance between the items should be sufficient so that the sensor signal level returns to the noise level between the test strip items.

Noise measurements will be made on an adjacent strip containing no discrete anomalies or non-representative terrain or geology that will affect the instrument. To be most convenient, the background noise measurements should be made adjacent to or within the IVS. However, noise measurements should made be far enough from the buried targets so that their signals do not contaminate the measured noise background.

Object Burial Depth

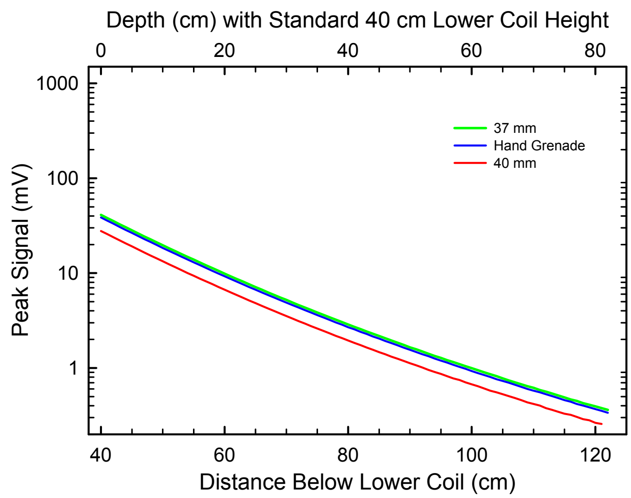
- Objective is to quantitatively verify that sensor is measuring correct signal- not to measure detection depth
- Signal can be verified anywhere along the response curve
- Requires that your measurement is primarily signal and not noise
  - Deeper targets with low SNR difficult to use for verification



Concepts 5

The objective of the IVS is to verify correct operation of the sensor, not to test its maximum performance, which we can calculate. The IVS is intended to provide quantitative confirmation that the sensor is achieving the performance predicted from the sensor response curves. A few measurements at any point along the curve are sufficient for this purpose, and high SNR measurements are preferred for quantitative comparisons. Thus, items buried in the IVS should be at depths that provide signals well above the sensor noise level so that measurements of sensor signal level will not be contaminated by significant noise. However, because of the way expected signals are calculated, the targets should be sufficiently far from the sensor that the dipole approximation is valid. Both the conditions of sufficient signal and dipole response can be met for burial depths of 3 to 7 times the target's diameter. For example, a one-inch ISO buried 7 times its diameter in the least favorable orientation provides a 4.8 mV signal for a channel 2 of an EM61-MK2, which would provide sufficient signal for accurate quantitative measurements in background the of 0.3 mV RMS (or 2 mV peak-to-peak) noise.

Why are ISOs OK?

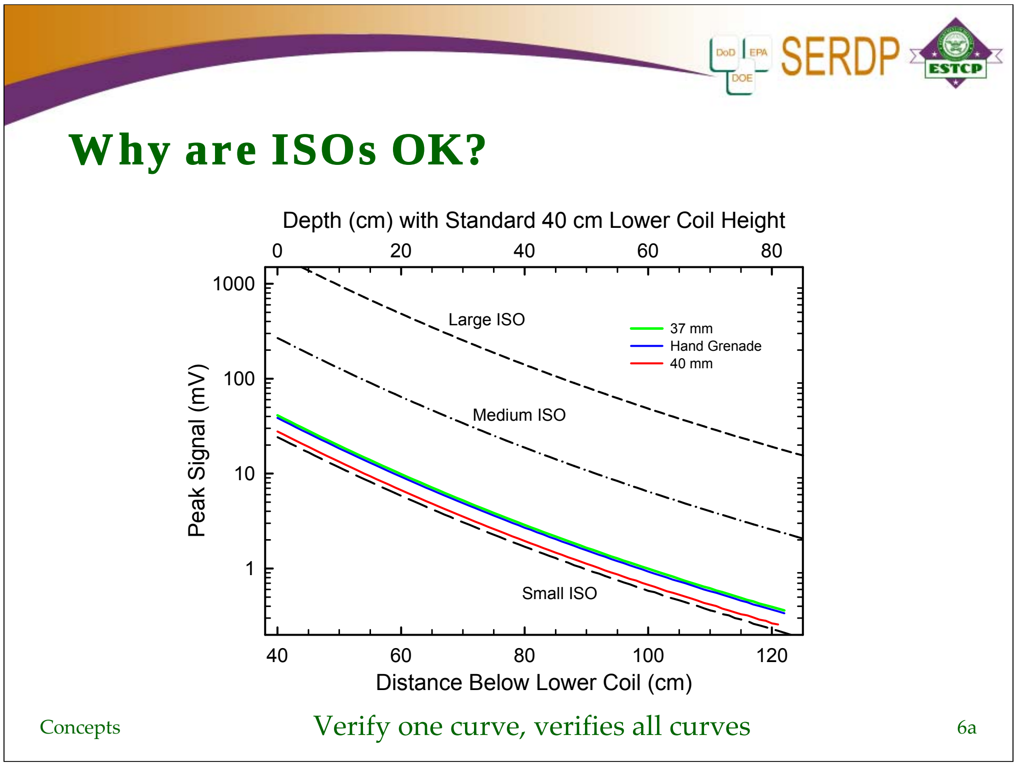


Concepts

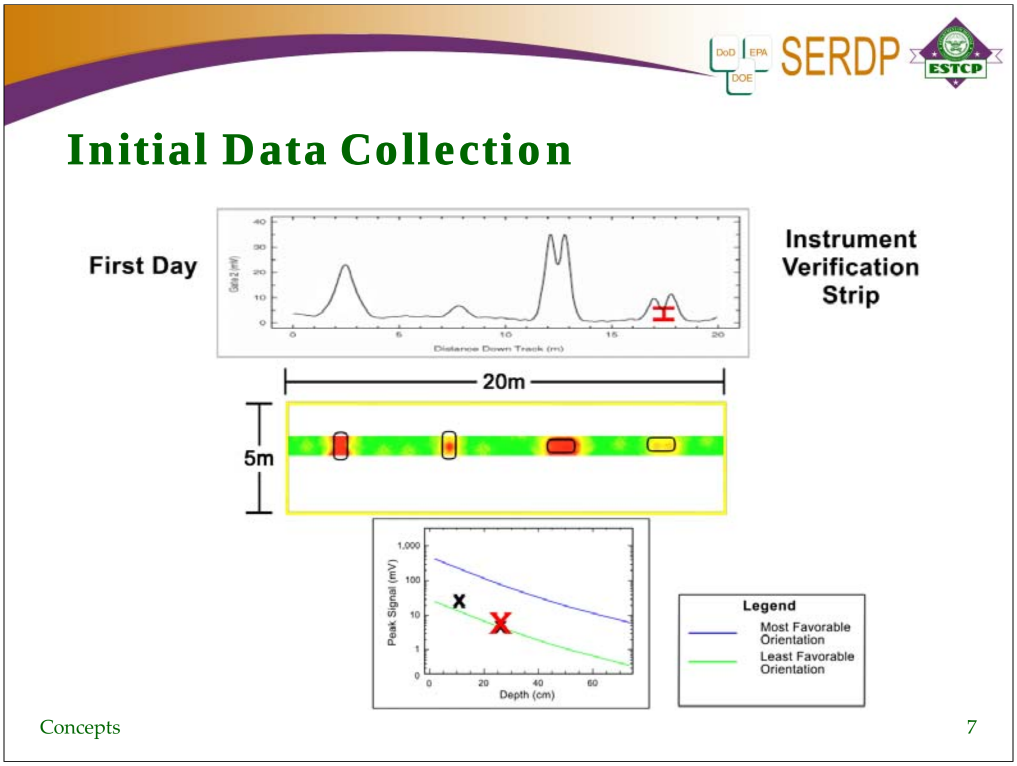
Verify one curve, verifies all curves

6

Any well-characterized target can be used to confirm sensor response is consistent with predictions. There is no need to verify each curve separately. Here are example sensor response curves for three small munitions.



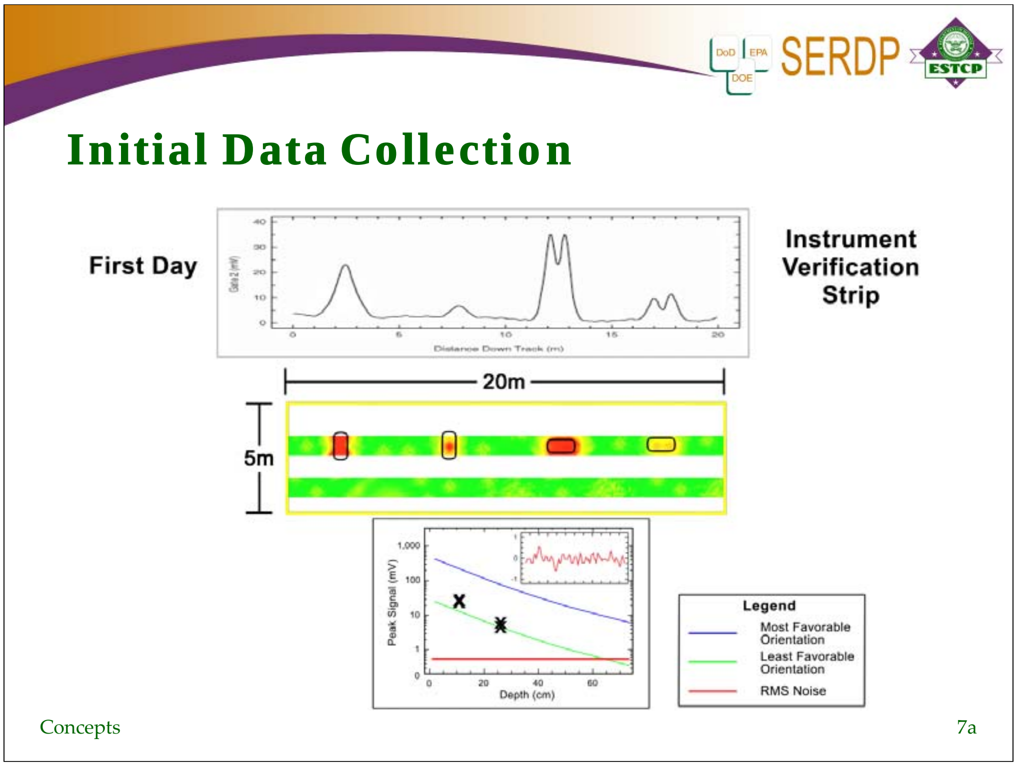
The small ISO can verify performance in the region relevant to similarly sized munitions.



The IVS is meant to be a dynamic test. Data should be collected and processed in the same way that production field data collection will be done. For the IVS data to be representative, adjustable parameters such as height above ground and survey speed must be replicated, but just as importantly the data processing steps should also be the same.

The data collected prior to initiation of field work will be somewhat more extensive than what would be collected daily. At a minimum, one line of data would be collected with the sensor passing directly over top of the items. This will provide the peak signal measurements to confirm sensor operation.

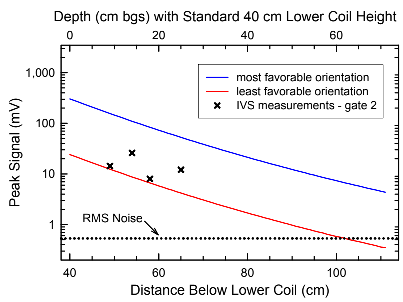
For each item in the IVS, the peak signal strength from the initial day's data should be compared to the expected signal for consistency. In all cases, the signal should be no lower than the predicted signal for the least favorable orientation, and only the signals for objects in that orientation should approach the lower line. The location accuracy should be verified by comparing the picked signal locations to the known locations of the buried objects.

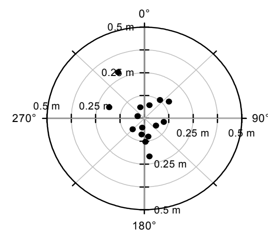


A second pass is made offset from the targets to measure site survey noise. The noise measured here has been plotted on the sensor response curve.

Consensus to Proceed

- Confirm design specifications will meet project objectives
  - All responses as predicted
  - Site noise allows detection of targets of interest
  - Geolocation is within specification
- Consensus to proceed to production work

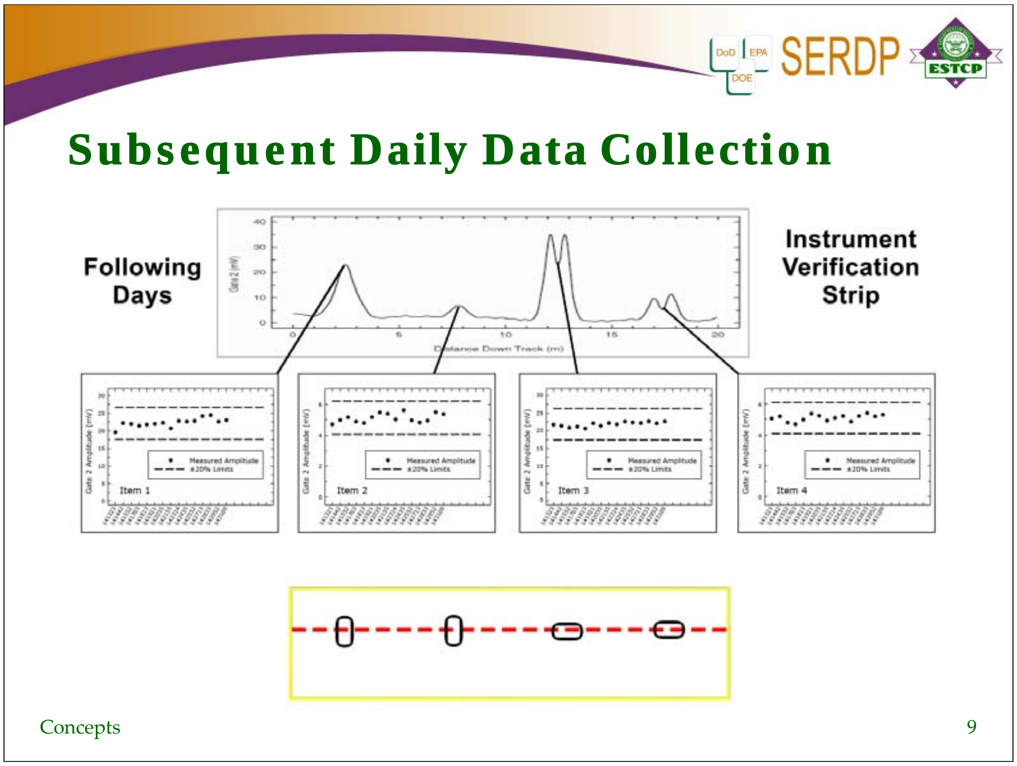




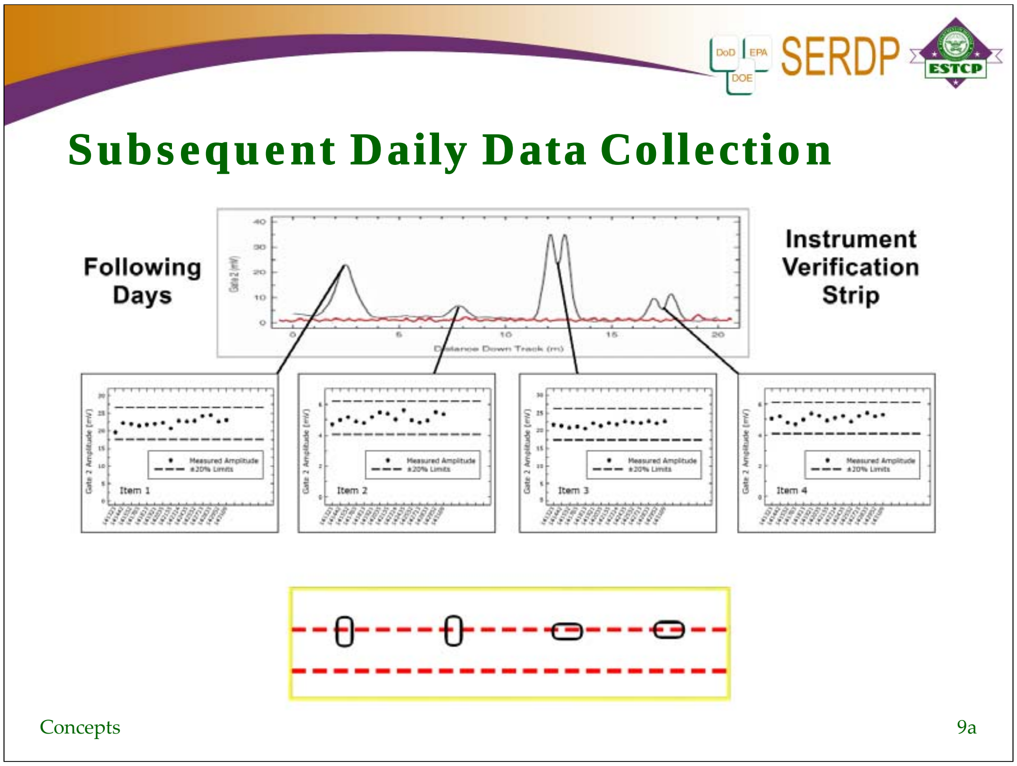
Concepts 8

Requirements for consensus to proceed from the first day on the IVS to field work would be set in advance and consistent with the data quality objectives. The intent of the first day is to confirm that the design specifications are met and that they are appropriate to meet overall project objectives.

All signals should fall within the two bounding sensor response curves and geolocation accuracy within specification. Only items buried at their least favorable orientations should approach the lower line. The RMS noise should be measured and compared to the expected signal values. Together the signal strength and the noise levels will either verify that the targets of interest can be detected to their depth of interest or inform the project team that the planned data collection will not meet project objectives.



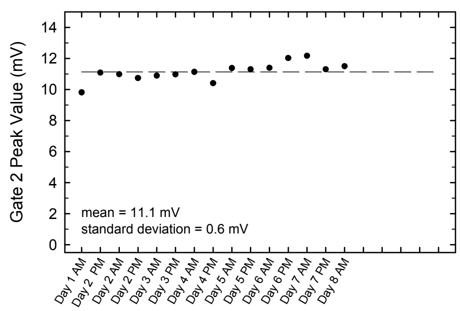
For daily instrument checks, data would be collected in one direction down the center of the target strip. The main objective of the daily run is to check that peak signal levels remain consistently as predicted and that the system noise levels have not changed, which would indicate an equipment malfunction. The single pass will measure geolocation accuracy only in one direction, which will still be sufficient to identify a failure.

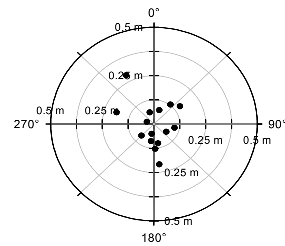


A pass is also collected over the noise strip to ensure the system noise is consistent from day to day.

Daily Confirmation of System Performance

- Monitor system performance for duration of project
  - Consistent response to IVS targets
  - System noise remains within specification
  - Geolocation remains within specification

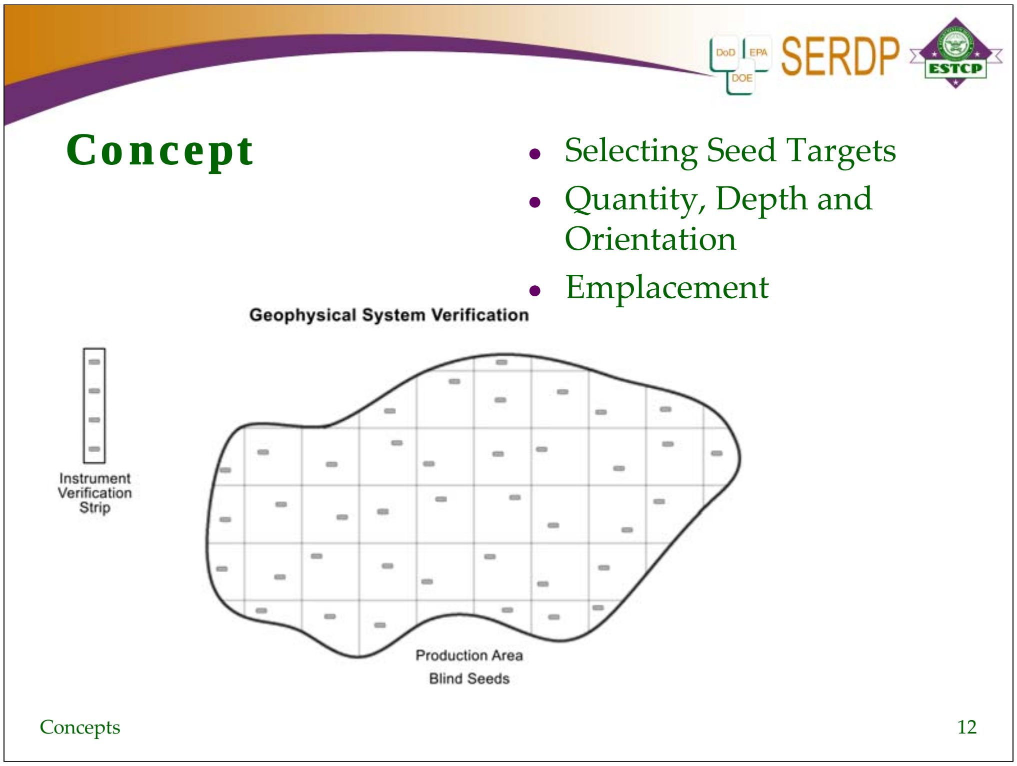




Peak signal amplitudes for each item should be reproducible from day to day. Appropriate acceptable bounds should be set, considering the data quality objectives, as well as the contributions of various error sources. Geolocation accuracy should be within specification.

Geophysical System Verification

- Instrument Verification Strip
  - Verify that the equipment is working properly
  - Measure site noise from which the target signal must be extracted
- Production Blind Seeding
  - Ongoing monitoring of production geophysics



The seeding program envisioned calls for the placement of known objects at surveyed locations that are blind to the survey and data processing teams at sufficient frequency that they are useful for daily quality checks. At a minimum, the seed items should include one or more of the three industry standard objects (ISOs). The main purpose of the seeds is to provide ongoing verification that known objects produce signals that are expected. As such, they need not mimic the munitions of interest in every detail. The ISO that is selected should have a signature that would meet the anomaly selection criteria; that is, you should expect that the seeds would be selected and placed on the dig list. Although not required by the GSV, the project team may also want to include inert versions of the munitions expected at the site in order to support public acceptance.

Selecting Seed Targets

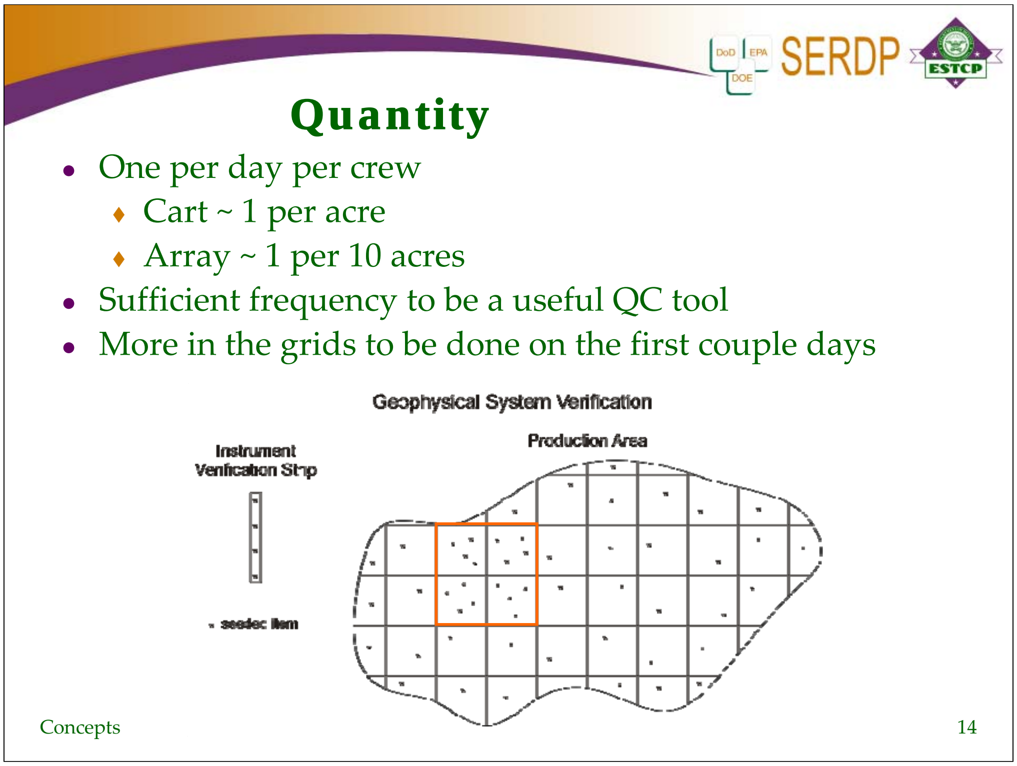
- ISO appropriate to munitions of interest
  - Meet anomaly selection criteria
- Based on most stressing munition on the site
- May supplement with inert munitions
- Corner stakes, etc. may be useful as well, but do not qualify as blind seeds

Concepts 13

The seed program should be built around the ISO that is appropriate to the munitions of interest on the site. In most cases, the ISO should meet the anomaly selection criteria and have a signature with a magnitude and spatial extent that is close to the object of interest. On most sites, there will be more than one munition type of interest. In this case, the ISO should be selected based upon the most stressing target. For example, the site team might pick the object of interest with the smallest spatial signature, as this object is likely to drive the DQO on lane spacing.

ISOs may be supplemented with inert munitions. Although this is not required for the main objective of the seeding, that is to prove that the detection system is working and that the targets of interest will be detected as expected from prior tests, the use of some inert munitions may be necessary to satisfy the public or aid in communication.

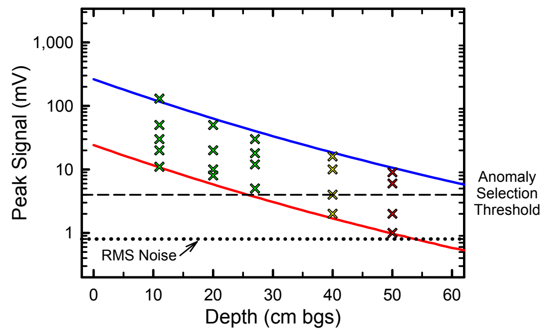
Other common field procedures maybe exploited to augment a blind seed program. Corner stakes at known locations can be used to verify location accuracy, latency, consistency of response, and other data quality measures. Because they are at locations known to the survey and data processing teams and they appear in a regular pattern, they would not be regarded as acceptable blind seeds.



On average, at least one seed should be encountered per day per crew. For a field crew using a cart-based EM-61, the daily production rate might be 1 acre. One seed per acre would be appropriate. For a towed array system, the production rate may be 5-10 acres per day. It may be advantageous to place a higher density of seeds in the lots to be surveyed in the first few days of production.

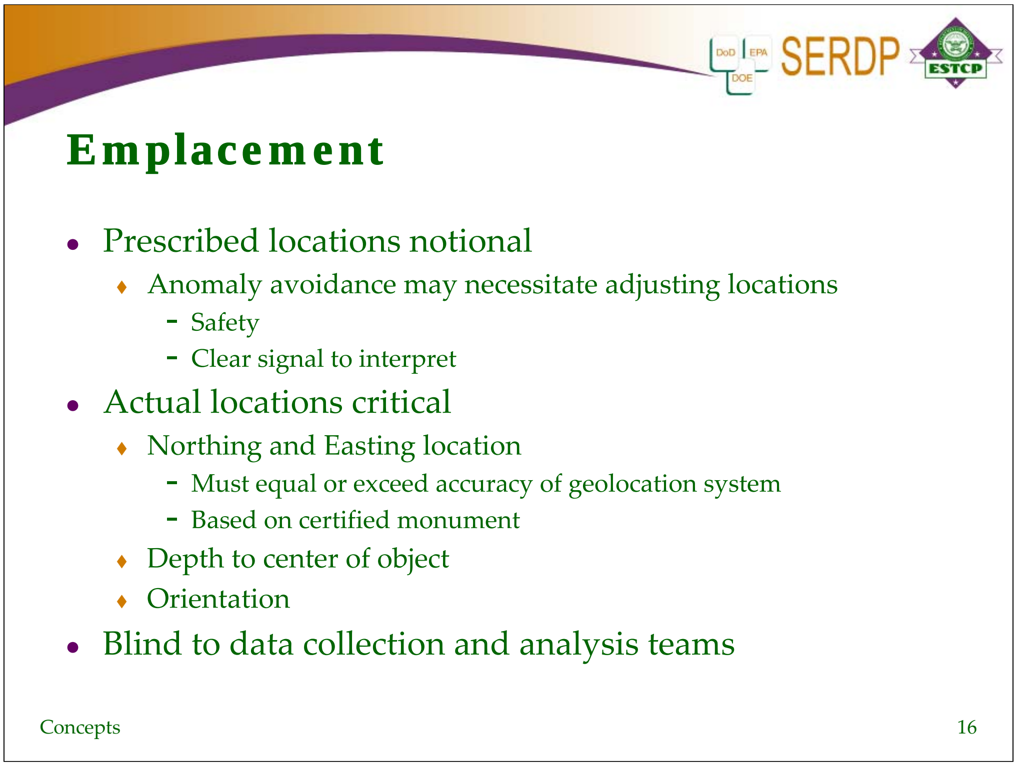
Depth and Orientation

- Depth
  - Depth where items are expected to be detected
  - Can't evaluate non-detect if <100% detection expected
- Orientation
  - May be buried in variety of orientations
  - Horizontal will be most stressing



Concepts 15

Seeds should be buried at depths where they are expected to be detected. It would be difficult to interpret a failure if items were buried at their most stressing depths such that their expected probability of detection was not 100%. Seeds may be buried in any variety of orientations. Quantitative evaluation will be most straightforward for seeds buried in the horizontal (least favorable) orientation, for which the sensor response curves are calculated.

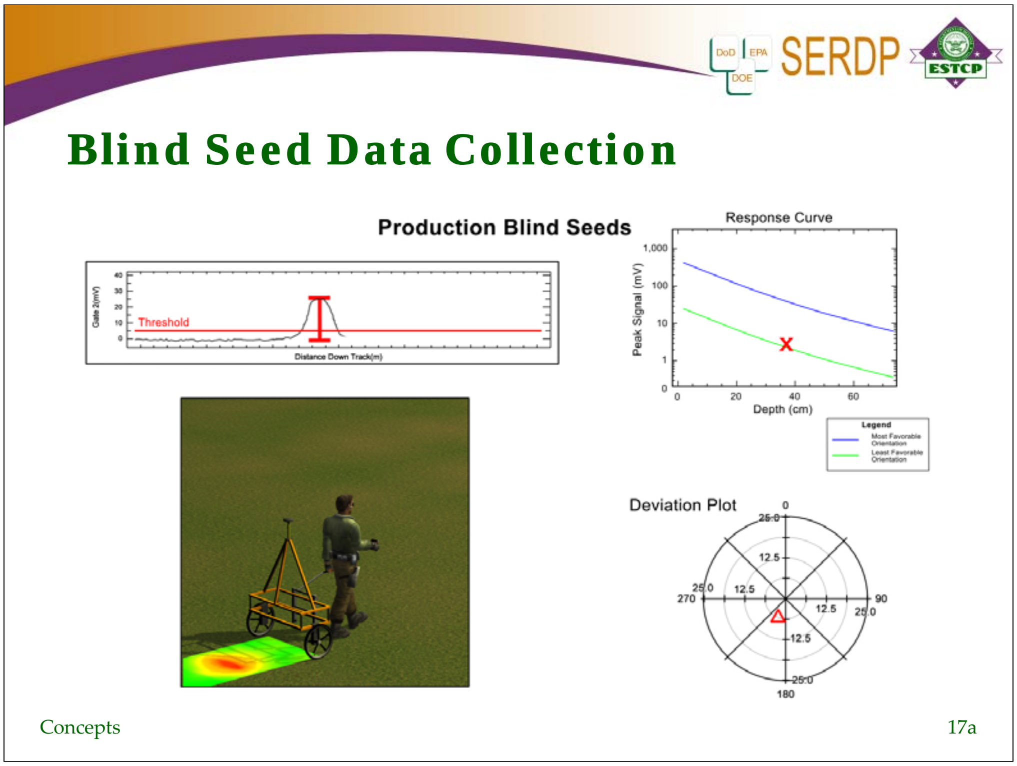


Seeds will be buried in the production site, where UXO is expected to be present. The seed plan will specify planned locations or frequency with which the seeds will be encountered. The planned locations for seeds must be flexible so that they may be emplaced safely. Anomaly avoidance should be practiced in the burying of seeds and all procedures should be in compliance with relevant safety guidelines. As long as the actual buried location is accurately recorded, nothing is lost by moving a planned seed by a few meters.

Seed locations should be surveyed to an accuracy that equals or exceeds the expected accuracy of the positioning system. Locations should be based on a certified monument that will be used for the surveying. Depth to a specified point should be recorded. All of the depths in this report and in Refs. 3 and 4 are to the center of the object. For non-spherical objects, such as pipes or inert munitions, the orientation of the object in the ground should be recorded.

Evaluation of the blind seeds could in principle be done by the QCc arm of the performer, customer or an independent third party. What is important is to maintain the integrity of the blind seeds. This requires that the truth information be segregated from the people collecting and processing the data, as well as those performing the target picking.

Production blind seeds will be encountered by the survey crew in each grid they survey.



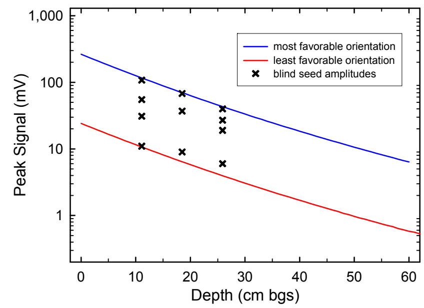
The data required from the data analyst include information that is commonly found in target lists. For each anomaly that meets the target selection criteria, the analyst should report at a minimum the peak signal strength and other required parameters and the X,Y location.

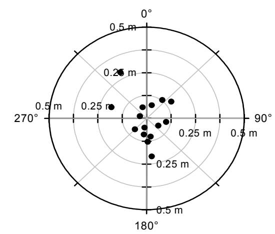
Signal Strength. A plot of the signal strength of seed targets would be updated as the seeds are encountered. The expected values for this example target at its most and least favorable orientations are shown in the dashed lines and the individual measurements are represented by the dots. The seeds in this example are buried at a variety of depths and orientations.

Location accuracy: A polar plot of the location accuracy for seeds depicts the offset of each seed location if the target were centered at (0,0). This also would be updated daily as the seeds are encountered.

Production Blind Seed Evaluation

- Ongoing monitoring of data collection, processing and target selection in the production work
  - All seeds found
  - Peak responses within the expect range
  - Location within tolerance





Concep... 18

All signals should fall within the two bounding sensor response curves. Only items buried at their least favorable orientations should approach the lower line. In this example, the seeds were buried at three depths and a variety of orientations. The RMS noise should be measured and compared to the expected signal values. Together the signal strength and the noise levels will either verify that the targets of interest can be detected to their depth of interest or inform the project team that the planned data collection will not meet project objectives.

Application to an Example Site

Andy Schwartz

Example Site

- 100-hectare (250-acre) site
  - Part of a former bombing and gunnery range
  - Slated for residential development
- A variety of munitions were used on the site
  - Primary concern is 37-mm projectiles
- EM61-MK2 chosen as the geophysical sensor
  - targets of interest are relatively small
  - not expected to be more than one foot deep
  - survey lane spacing of 0.6 m
- Open field with good sky view throughout
  - GPS system is the choice for sensor location

Application to an Example Site 2

The example site to be considered is a 100-hectare (250-acre) site that is part of a former bombing and gunnery range. After remediation, the site is slated for residential development. The historical records indicate a variety of munitions were used on the site but the primary concern is 37-mm projectiles. Since the targets of interest are relatively small and are not expected to be more than one foot deep, the site team has chosen the EM61-MK2 as the geophysical survey instrument to be used at this site with a survey lane spacing of 0.6 m. The site is an open field with good sky view throughout so a GPS system is the choice for sensor location.

Summary of Project Data Objectives

Parameter	Objective at this Site
Geophysical Instrument	EM61-MK2 on standard wheels
Geolocation System	RTK GPS (cm-level)
Depth of Interest	30 cm (1 foot)
Survey Lane Spacing	60 cm
Gate for Primary Data Analysis	Gate 2
IVS Anomaly Amplitude Reproducibility	± 20%
IVS Item Position Reproducibility	± 25 cm
Location Accuracy of Seed Picks	± 50 cm

Application to an Example Site 3

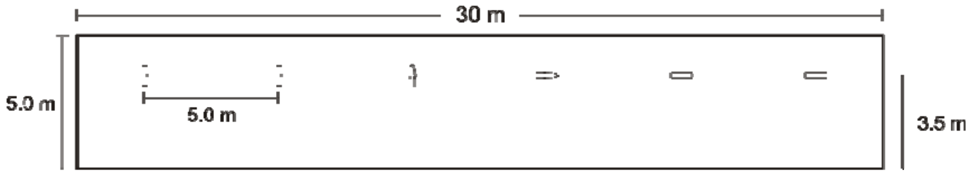
This table summarize the decisions made by the site team. Notice that position reproducibility specification is tighter for the IVS items than for the seeds. The survey team should be able to center the sensor directly over the line of IVS items so the position reproducibility should be high.

Establishing the IVS

- Choose an area on the site that contains representative terrain, geology, and vegetation
- Make sure the area chosen is free of anomalies
- Bury the IVS items, recording the location and depth to a precision of ± 2cm

The expected time line for the first use of the strip involves the geophysical contractor arriving on the site the first day of operations, identifying a location for the test strip in conjunction with the program manager, conducting a background survey to identify a site suitable for a test strip, and emplacing the test items according to the specification in the previous slide. If the test strip location is not very cluttered, this may still leave time for an initial survey on the first day at the site; if not, the test strip can be surveyed at the beginning of the second day on site.

Instrument Verification Strip



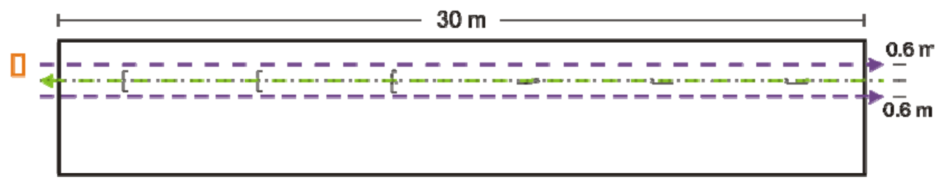
Item	ID	Position (m)	Depth to Center	Orientation	Predicted Response
1	Small ISO	2.5	11 cm (3X)	Horiz. across track	11.6 mV
2	Small ISO	7.5	26 cm (7X)	Horiz. across track	4.8 mV
3	37-mm Proj.	12.5	11 cm	Horiz. across track	18.3 mV
4	37-mm Proj.	17.5	26 cm	Horiz. along track	6.7 mV
5	Small ISO	22.5	11 cm	Horiz. along track	11.6 mV
6	Small ISO	27.5	26 cm	Horiz. along track	4.8 mV

Application to an Example Site 5

The first task in planning the instrument verification strip is to decide what items will be emplaced. The site team at this site decided that since the smallest, most difficult to detect, item of interest is a 37-mm projectile, the test strip would contain two inert 37-mm projectiles and four small Industry Standard Objects (ISOs) to serve as surrogates during the seed program. They will be placed in the IVS at two depths (3X and 7X their diameter) and two orientations. Note that the deepest depth chosen is close to the maximum depth of interest at this site but that was not the reason for the choice. The goal of the IVS is to verify twice each day that the geophysical system is working correctly. To accomplish that with reasonable precision requires a high SNR on the sensor measurements. The two depths were chosen to ensure the required SNR is achieved.

The items to be emplaced are relatively small so the spatial extent of their signatures will not be large but an ancillary purpose of the test strip is to get a measure of site-specific survey noise. With this in mind, the site team decided to emplace the test strip items with spacing of 5 meters, leaving 2.5 meters clear on each end of the strip. This results in a test strip approximately 100 feet long.

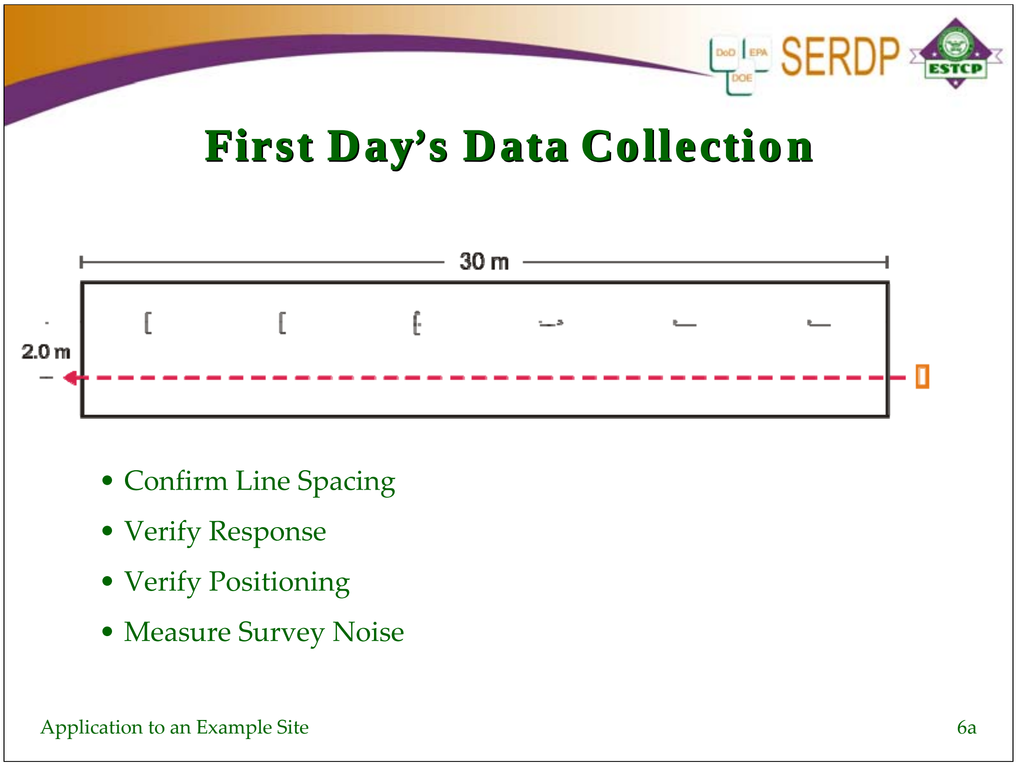
First Day's Data Collection



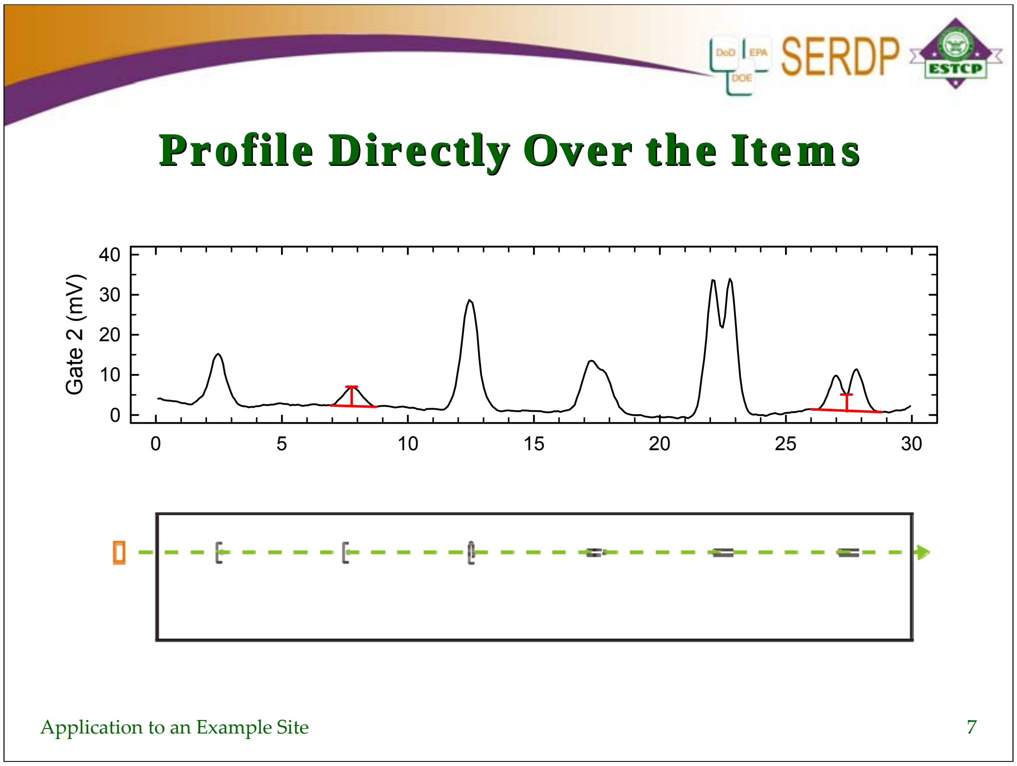
- Confirm Line Spacing
- Verify Response
- Verify Positioning

Application to an Example Site 6

The protocol for the first day's survey of the IVS. The first pass of the 1-m wide by ½ m EM61-MK2 is made with the sensor 0.6 m offset from the test item burial line. The site team has determined a line spacing of 0.6 m is appropriate to ensure detection of the 37-mm projectiles. The next pass is directly over the test items. This will allow the data analyst to determine the maximum signal expected from each item. The third pass is at an offset of 0.6 meter on the other side of the line of items.

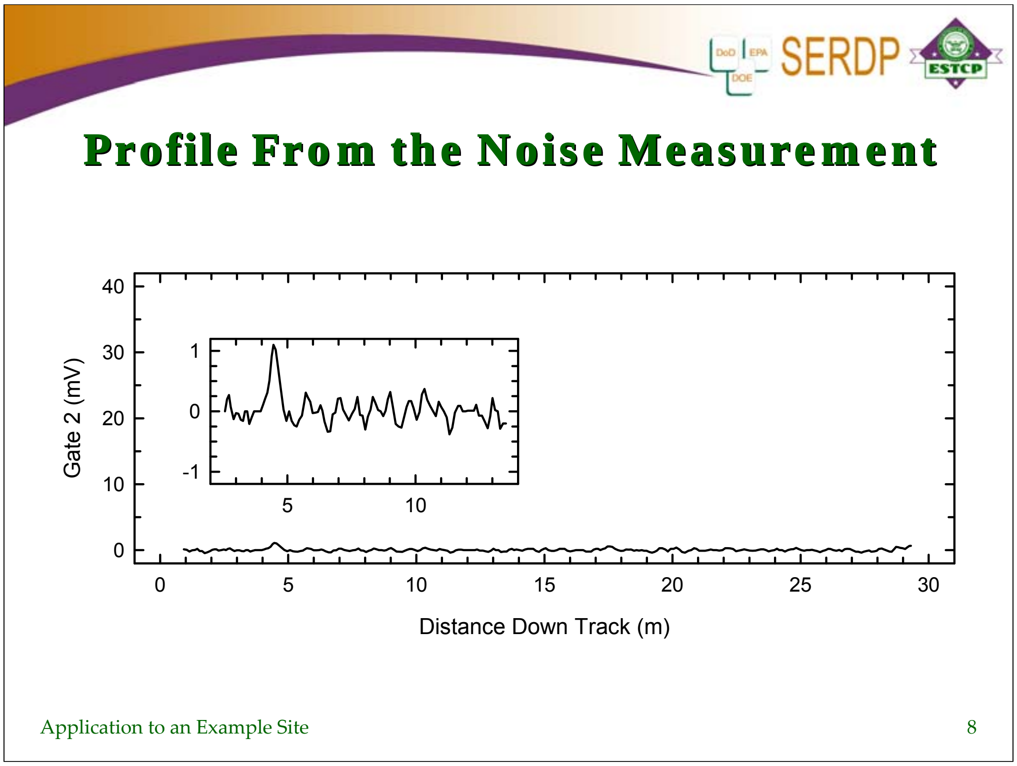


The protocol for the first day's survey of the IVS. The final pass is two meters offset from the line of targets to make a measurement of survey noise at this location.

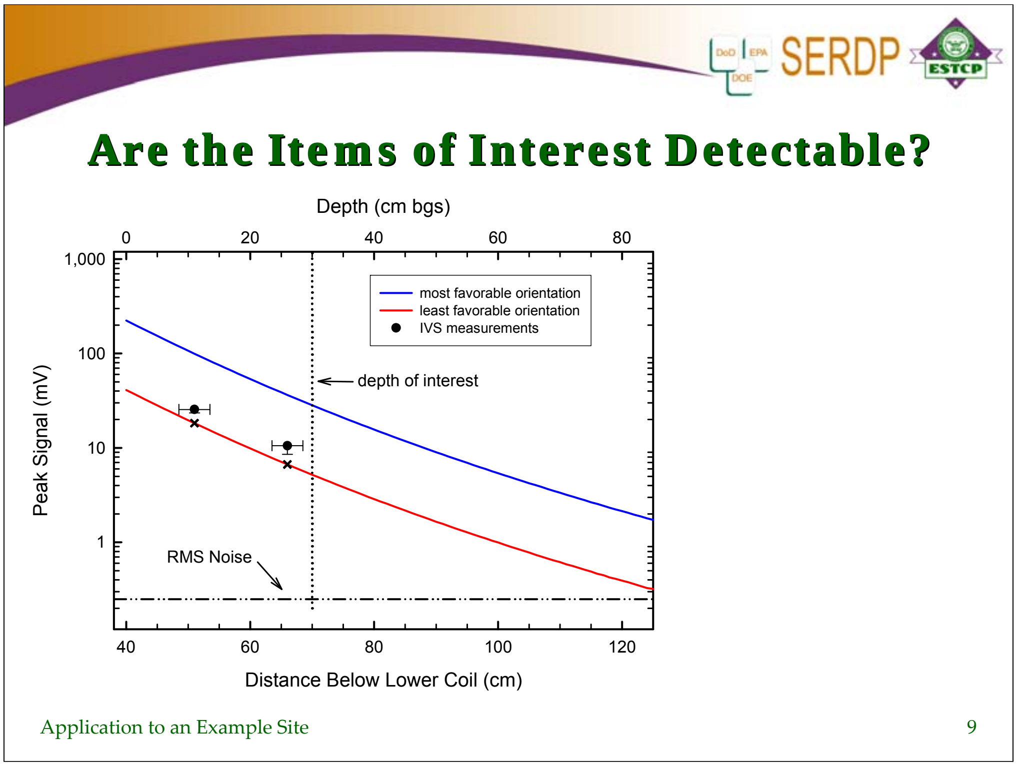


A trace of the measured data from the line directly over the targets. As in all cases in this example, these are actual field data measured over an IVS constructed as specified above.

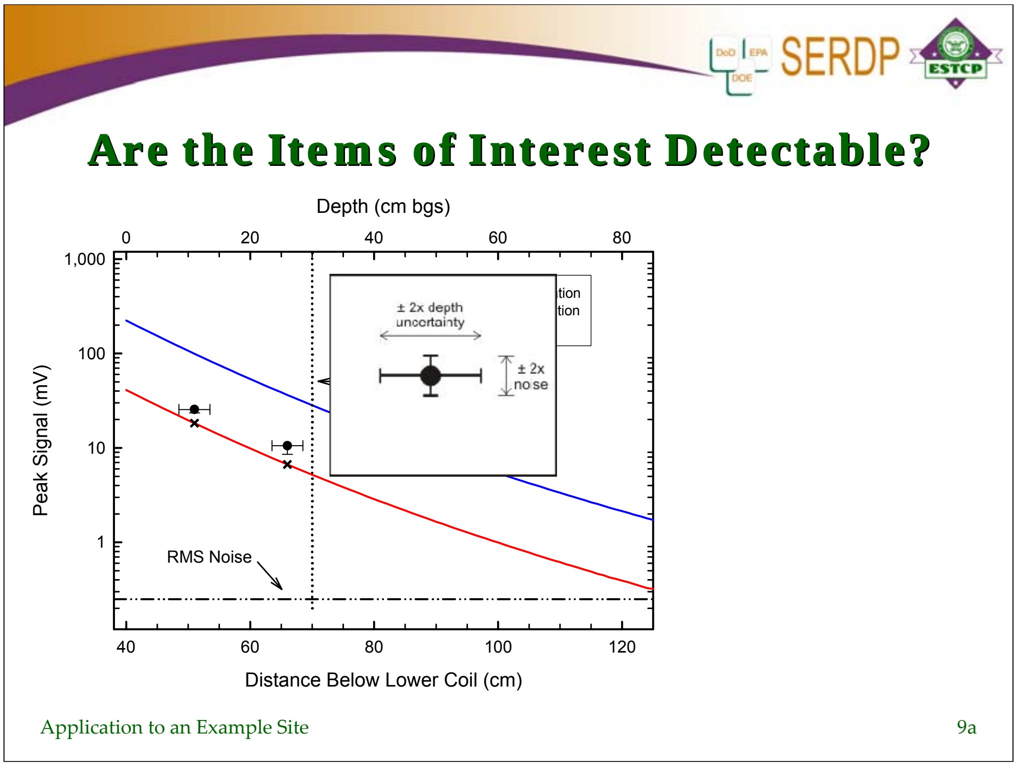
Each of the items is detected with good SNR and the teams' choice of 5 m spacing between the items is confirmed; each anomaly returns to the baseline and there is a good section to measure noise between the anomalies. Notice that items 4, 5, and 6 display the familiar double-humped profile that is the signature of long targets aligned along track. Items 5 and 6 are the symmetric Industry Standard Objects and exhibit a very clean double-peaked profile. Item 4, the 37-mm projectile, is less symmetric (the nose is much smaller than the back of the projectile) with the response from the back larger than that from the nose making it more difficult to establish the location of the center dip.



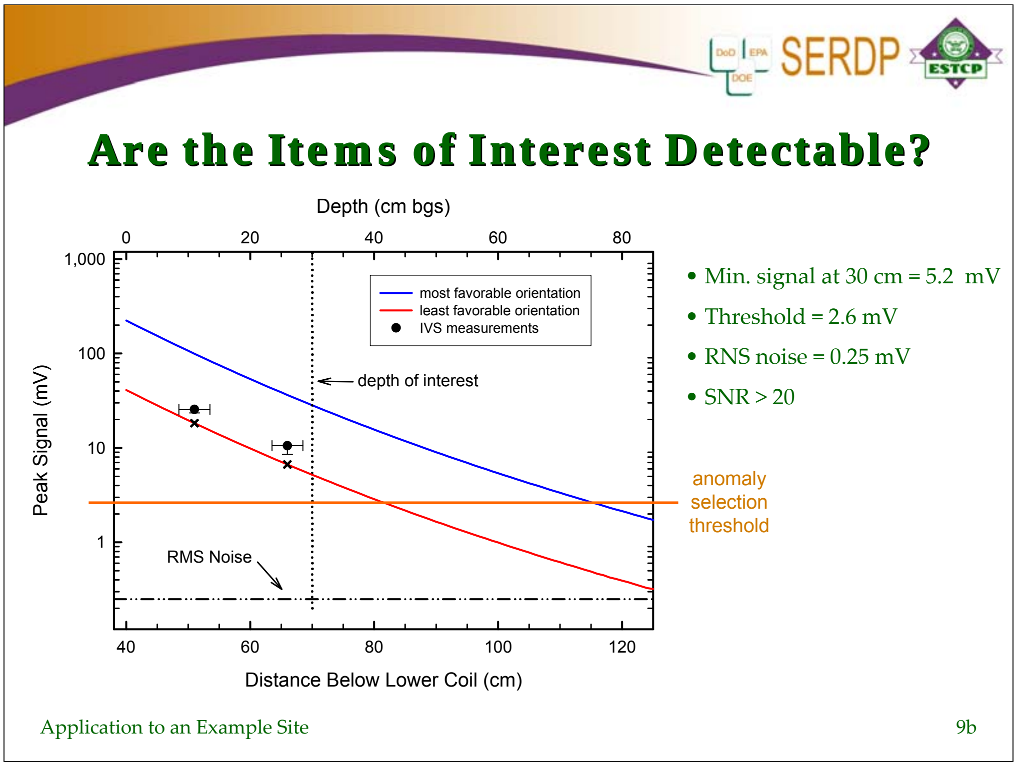
A trace of the measured data from the “noise” line plotted on the same scale as the signal trace with an inset at a higher magnification. There may be a small scrap item remaining about 4.5 m down the line but, otherwise, the contractor team has done a good job identifying a target-free area for the noise measurements. The RMS survey noise in this area is 0.25 mV or about 1.5 mV peak-to-peak.



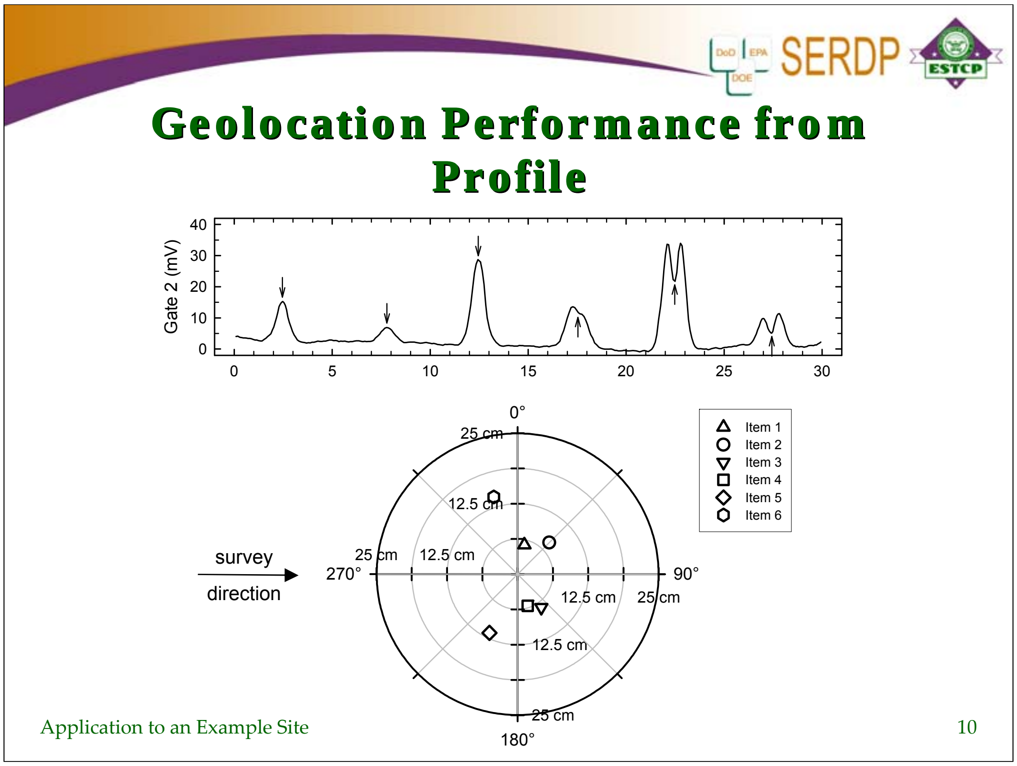
The measured anomaly amplitude in Gate 2 for the two 37-mm projectiles and the RMS noise are compared to the predicted response. The blue curve corresponds to the signal expected when the item is in its most favorable (vertical) orientation and the red curve corresponds to expected signal when the item is in its least favorable (horizontal) orientation. Both of the 37-mm projectiles in the IVS are oriented horizontally so their signals should be close to the solid curve if the sensor is operating normally, which it is in this case.



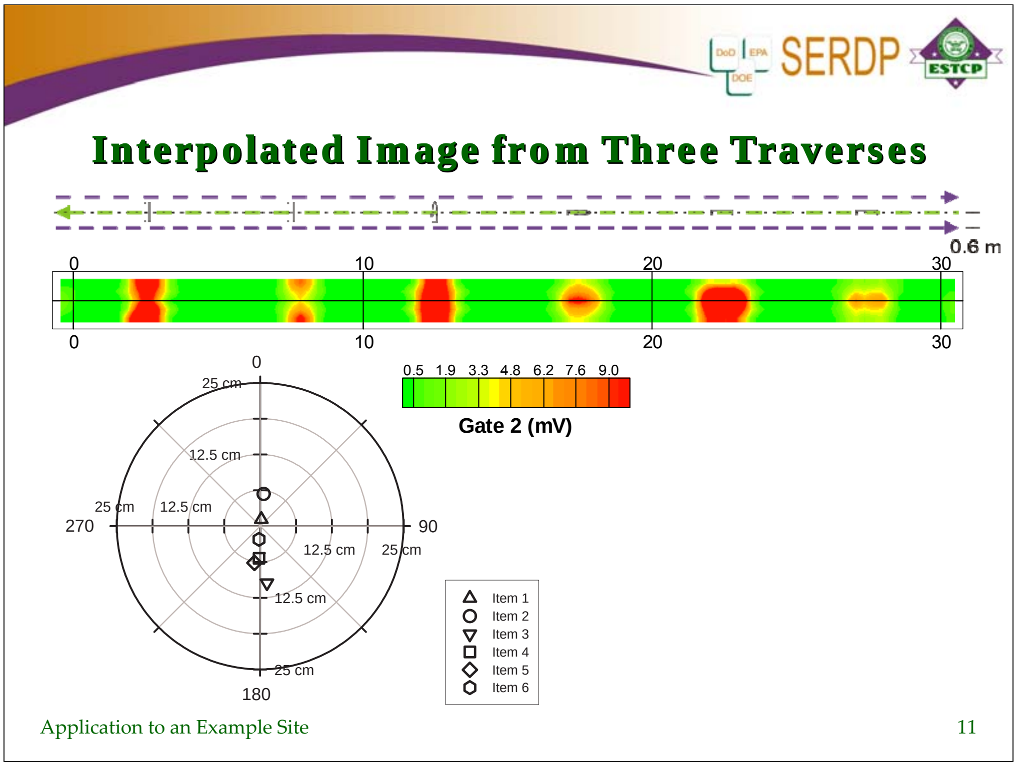
The error bars on the measured points correspond to ± 5 cm depth uncertainty (horizontal) and twice the RMS noise (vertical).



From the site noise data, the site team can confirm that the detection requirements for this item at this site can be met. The depth of interest for the 37-mm is 1 foot or ~30 cm. The minimum signal in gate 2 expected from a 37-mm projectile at this depth is a little over 5 mV. The measured survey noise in this gate at this site is 0.25 mV resulting in a minimum signal-to-noise ratio of almost 20 which is well above the requirements for detection and should lead to few, if any, noise picks.



The second objective to be checked from the first day's data is the performance of the sensor geolocation system. One method to accomplish this is to find the position of the peak signal for each object (or in the case of targets located along track, the center of the double-humped profile) and compare this to the known locations of the targets. Since the GPS system used at this site measures the position of the center of the EM61 coil, this cross-track location accuracy is limited by how carefully the senor operator positions the center of the coil directly over the line of items in the IVS. In this case the operator was very careful, resulting in the measured position deviations shown here in a polar plot. The IVS at this site is laid out E-W so, as expected, the greatest deviations are in the cross-track (N-S) direction. Had any of the deviations been larger than the objective of 25 cm, corrective action would have been required before consensus to proceed was achieved.



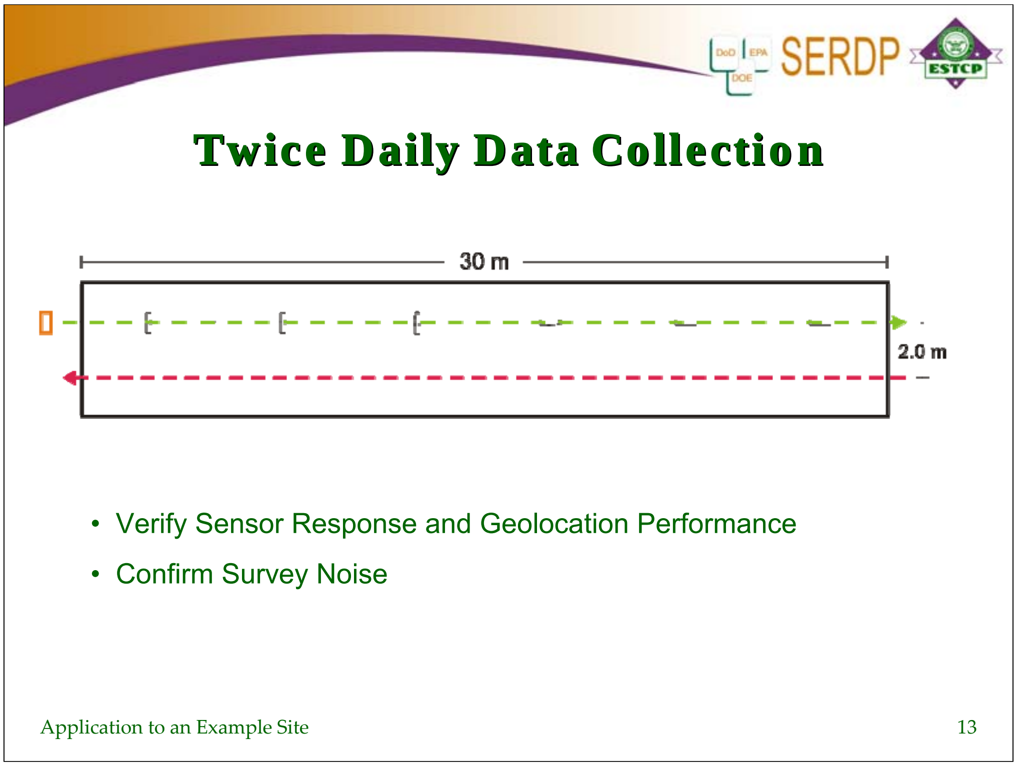
A better method to determine the geolocation performance is to take advantage of the extra survey passes on the first day and invert the geophysical data for the item's position. The data corresponding to the passes at offsets of -60, 0, and 60 cm are presented here. Each anomaly in the data is selected by the data analyst using that contractor's standard methodology and, at a minimum, analyzed for location.

Results of First Day's IVS Survey

- Data collected on the IVS
  - Confirm sensor selection
  - Confirm that targets of interest are detectable to the depth of interest
  - Demonstrate the geophysical sensor and geolocation equipment are operating correctly
- All site team members agree so consensus is achieved to proceed to production work

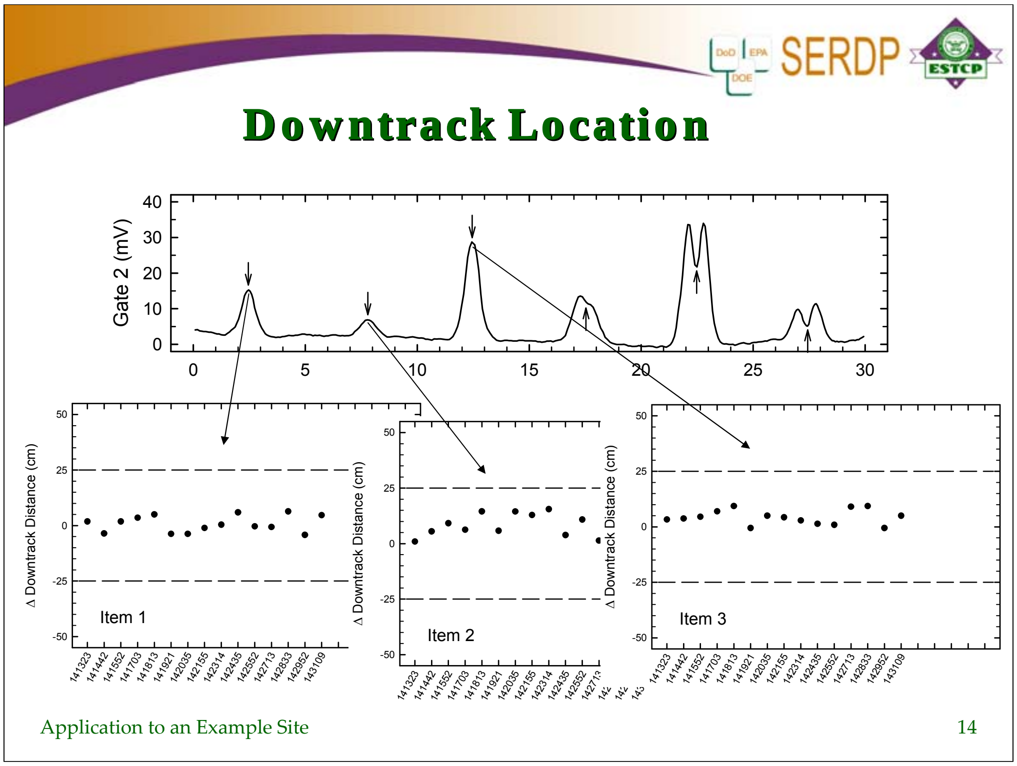
The IVS provides a simple, but rigorous, verification that the geophysical mapping system (sensor plus geolocation equipment) is operating properly. From the data collected on the first day, the site team is able to agree that the correct sensor has been chosen, that the targets of interest are detectable to the depth of interest in the presence of the measured survey noise, and that the data are being collected correctly.

Given these results, achieving consensus to proceed is straightforward.

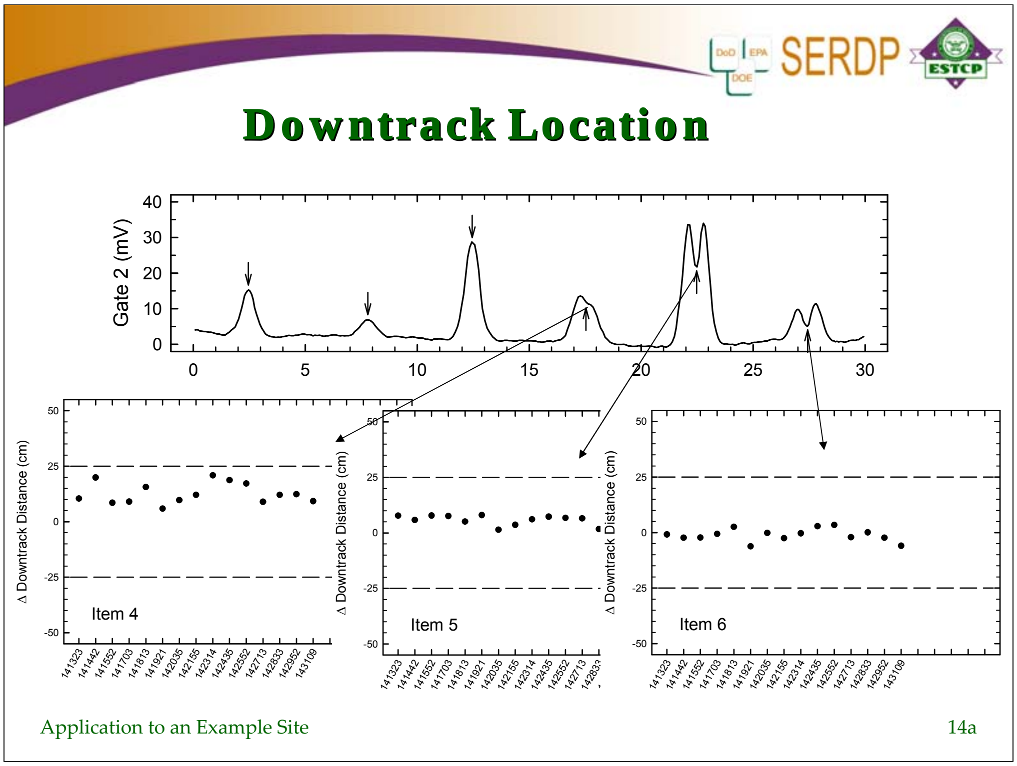


In addition to whatever function tests the contractor performs each day to ensure proper operation of their survey equipment, each survey crew will be required to survey the test strip at the beginning and end of each day. This will be a simplified survey as illustrated here, one pass over the line of emplaced targets to confirm sensor operation and one pass to confirm that the survey noise has not changed. If the sensor performance and system noise are within specifications before and after each day of surveying, it is reasonable to expect that the system was performing within acceptable bounds throughout the day. If the sensor performance is within performance criteria in the morning and not in the evening, the data must be examined to determine if any of it is usable.

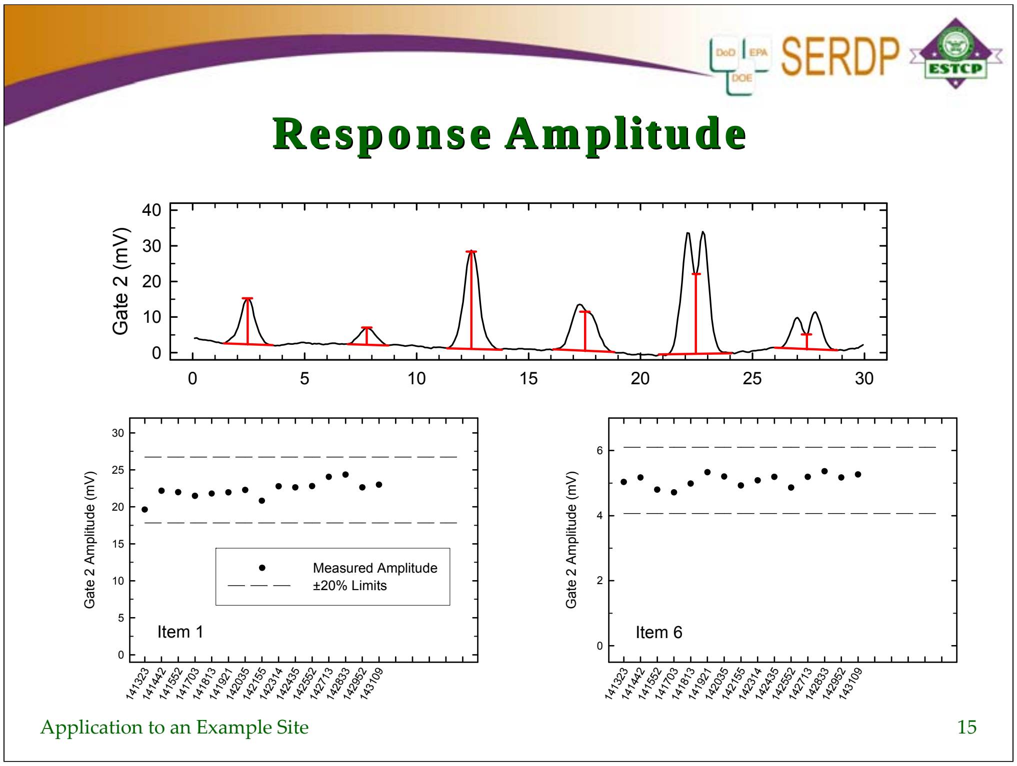
The results of these twice-daily performance confirmation surveys will be reported in a continually-updated set of plots showing the down-track position error and amplitude variation for each target. As with the first day's measurements, any deviations outside of the data objectives will require a detailed failure analysis before survey operations can be resumed.



Plots of the down-track location of the measured anomalies corresponding to the IVS items. The points correspond to the locations determined each morning and evening and the dashed clines correspond to the ± 25 cm specification for this measurement.



Notice in that the measured down-track position of Item 4 appears to have an offset from the known value. This arises from the difficulty in determining the center of the signal for this item and illustrates the advantages of the standard targets for the IVS.



Twice daily variation in the measured anomaly amplitude for two of the IVS items. Similar plots corresponding to all six items are updated daily. The points correspond to the measured anomaly amplitudes and the dashed lines represent ± 20% of the mean for each item.

Production Blind Seeding

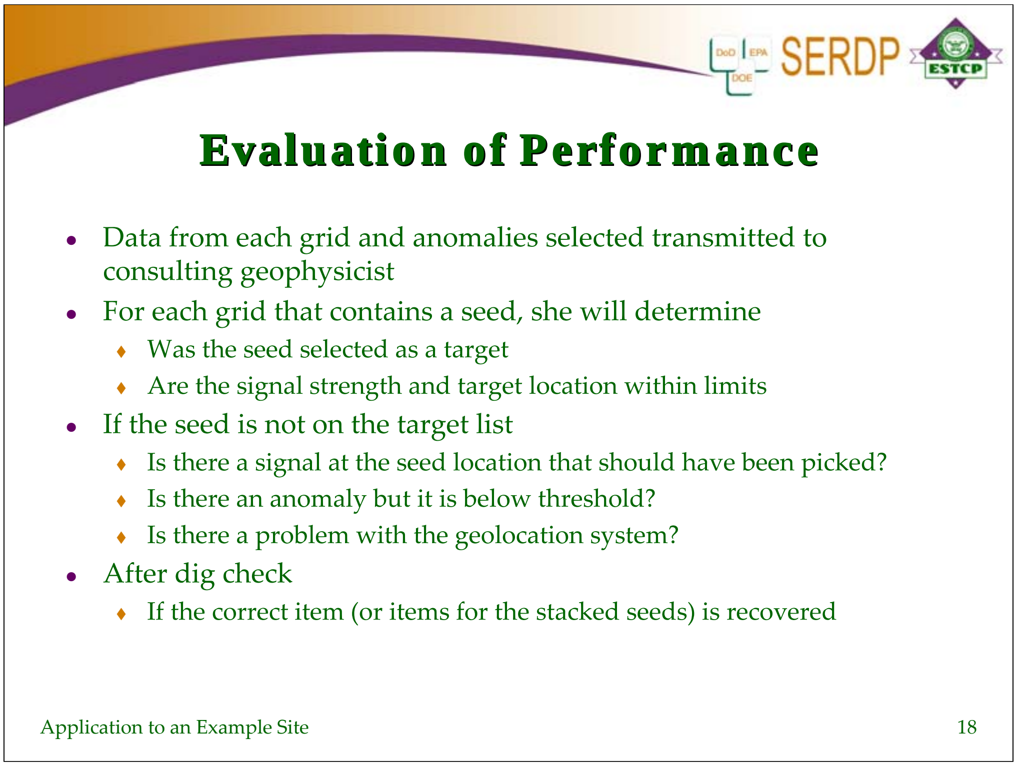
- The site team has hired a third party to design and implement a blind seed program in the production survey areas
- Only one component of QC plan for the site
  - Verifies geolocation, sensor performance, anomaly selection, and anomaly resolution on an on-going basis
- Based on the small ISO
  - Surrogate for 37-mm projectile

Seed Plan

- Site has been divided into 50 m x 50 m grids
  - 400 grids
- Seeds will be emplaced in all the grids
  - 1/3 at 10 cm
  - 1/3 at 20 cm
  - 1/3 at 30 cm
  - Random orientations
- Three seeds in the first grid to be surveyed by each team
- 25 of the shallow seeds will have another seed placed below it

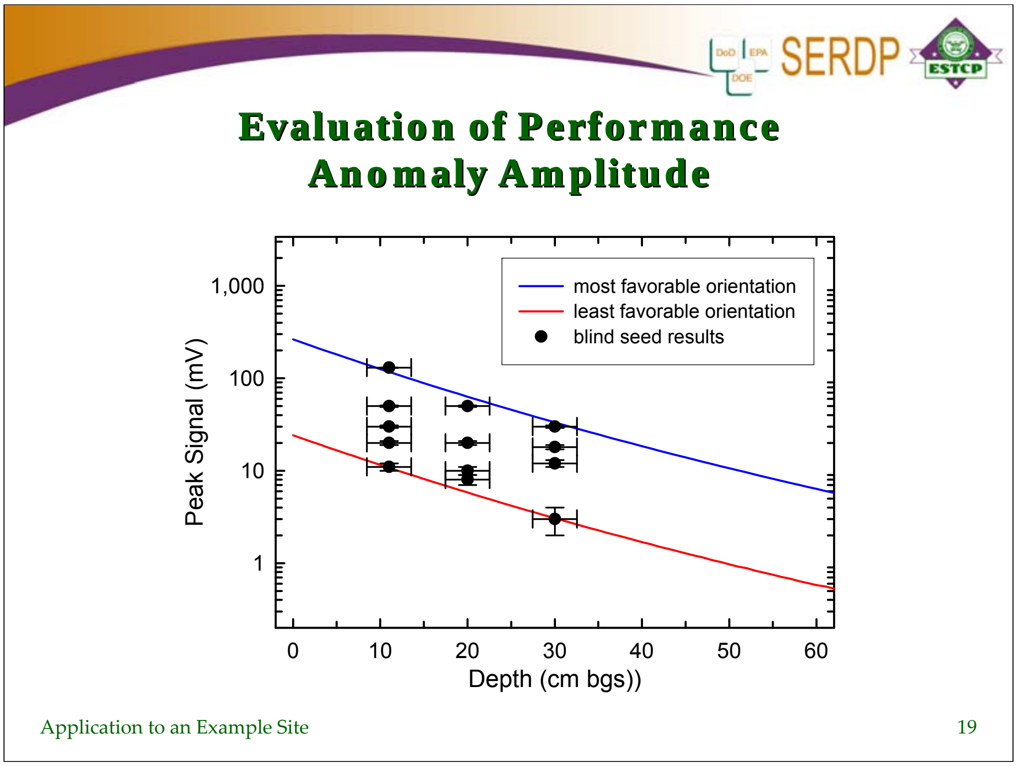
Application to an Example Site 17

The site has been divided into 50 m x 50 m grids. Under the conditions at this site, each survey team covers one grid per day. The site team has determined that to adequately measure the performance of each team, they will require a seed in each of the grids in addition to any seeding the contractor employs for their own quality program. This means ~400 seeds items will be required. One third of the seeds will be placed at 10 cm, one third at 20 cm, and one third at our depth of interest, 30 cm, in random orientations with all measurements corresponding to the center of the item. Twenty five of the shallow seeds will have an additional seed placed under them for the purposes of confirming the anomaly resolution process (stacked seeds). In addition to this, three seeds will be placed in the first grid surveyed by each of our three survey crews.



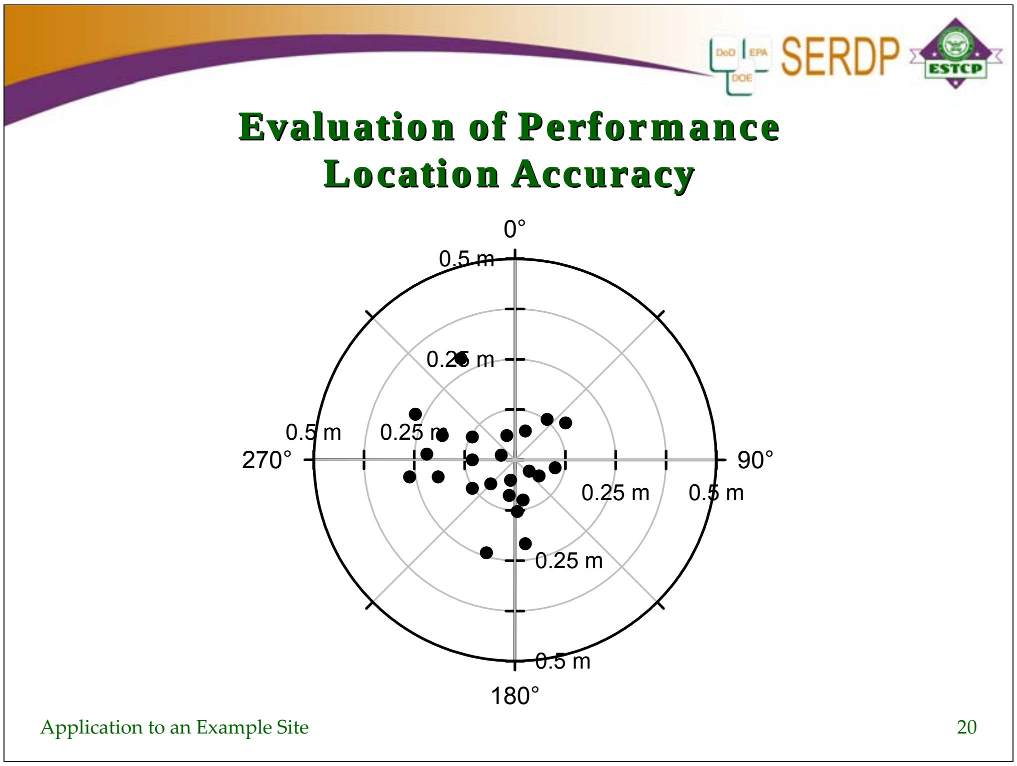
Performance evaluation against the seeds can, in principle, be done by the performer or a third party employed for this purpose. The only requirement is the seeds be blind to the personnel collecting the data, analyzing the data, and selecting targets for the dig list. At this site, a consultant geophysicist has been hired to oversee the blind seeding program and the performer has chosen to plant some additional, non-blind seeds for their own quality program.

As the data from each grid are analyzed and targets selected, this information will be transmitted to the consulting geophysicist. For each grid that contains a seed, she will determine whether the seed(s) made it to the target list. If it did, she will ensure the signal strength and location accuracy are within contract specifications and, after the anomaly has been dug, make sure that the correct item (or items if this was a stacked seed) is recovered. If the seed is not on the target list, she will begin a root cause analysis. Questions to be asked include: is there a geophysical signal at the seed location that should have been picked?; is there an anomaly but is it below the selection threshold?; is there an anomaly remaining that was below a more shallow anomaly (stacked seed)?; and is there a sensor location issue?

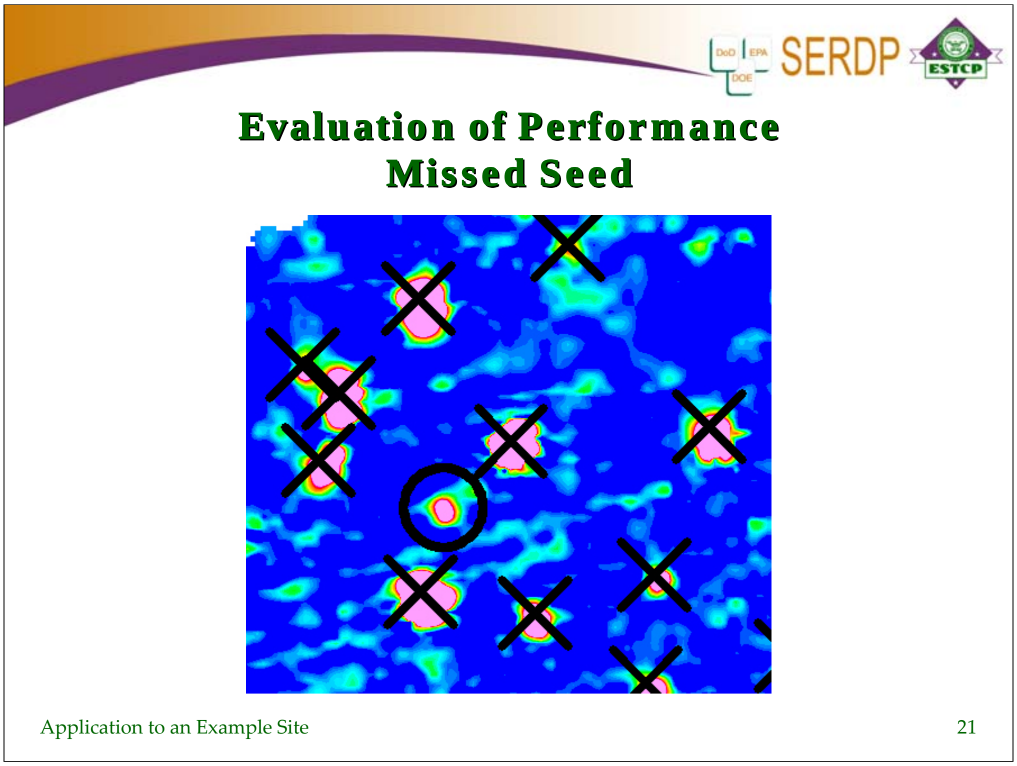


One of the products of the performance analysis is shown here. Just as for the IVS, the geophysicist checks to make sure the anomaly amplitude measured for each seed is within the expected bounds. Since the seeds were buried with random orientations, the measured amplitudes are expected to span the signal between the least- and most-favorable orientations.

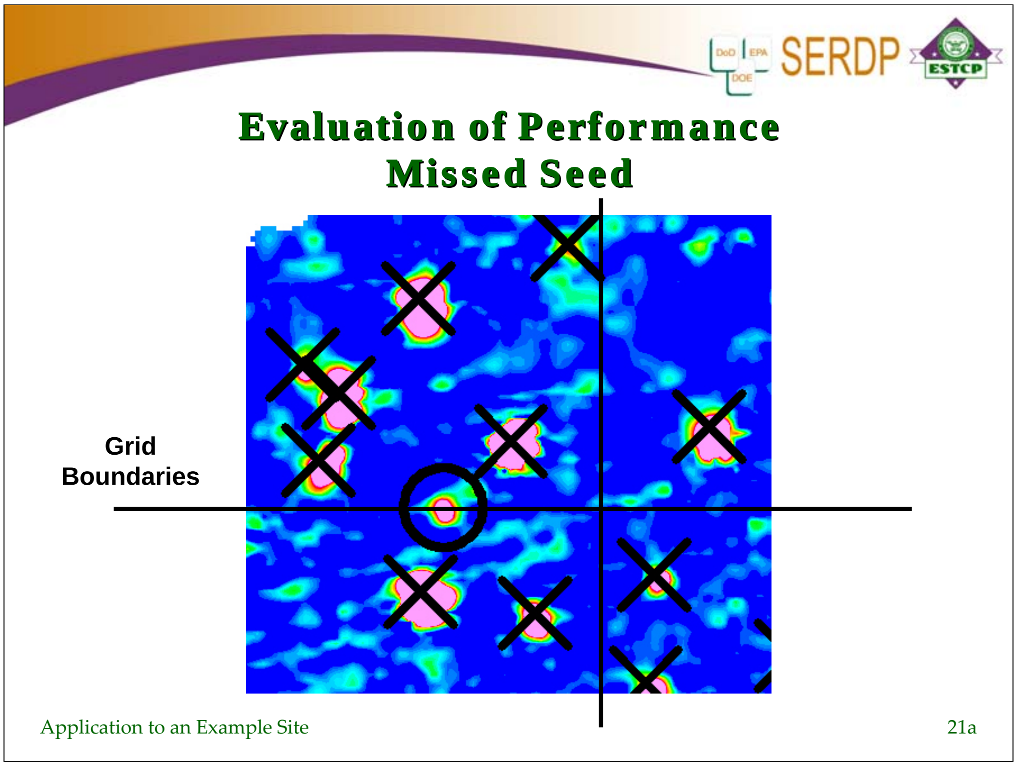
The error bars on the measured amplitudes correspond to ± 2.5 cm in depth and twice the measured site noise.



Analysis of the seed location data shows that a bias to the west is beginning to be evident. Although the performance still meets the DQOs, it would be wise to begin to investigate the cause of this bias.



Geophysical data from an area of the site where a seed was missed. The X's represent targets that appear on the pick list, and the circle denotes the missed seed. In this case, a response is present at the location, but it was not picked in the analysis process. A root cause analysis would be initiated to identify the failure and, if necessary, prescribe a corrective action.



In this case, it was found that the missed seed was right on the boundary of the grids established by the contractor to facilitate their survey but was chosen in neither. A procedure was establish to choose all anomalies on the boundary in both grids and then deal with the redundancy when the final list is compiled.

Project Summary

- IVS constructed and surveyed
  - Consensus to proceed on the same day
- Daily IVS verified continued system performance
- Production blind seeds
  - Detected a flaw in the data processing approach
  - Production results verified design criteria were met
- Coupled with other project QC built a strong and defensible case that if munitions were on our site and we went over them, they were detected and recovered

Wrap Up

Jim Austreng

DoD EPA DOE SERDP

ESTCP

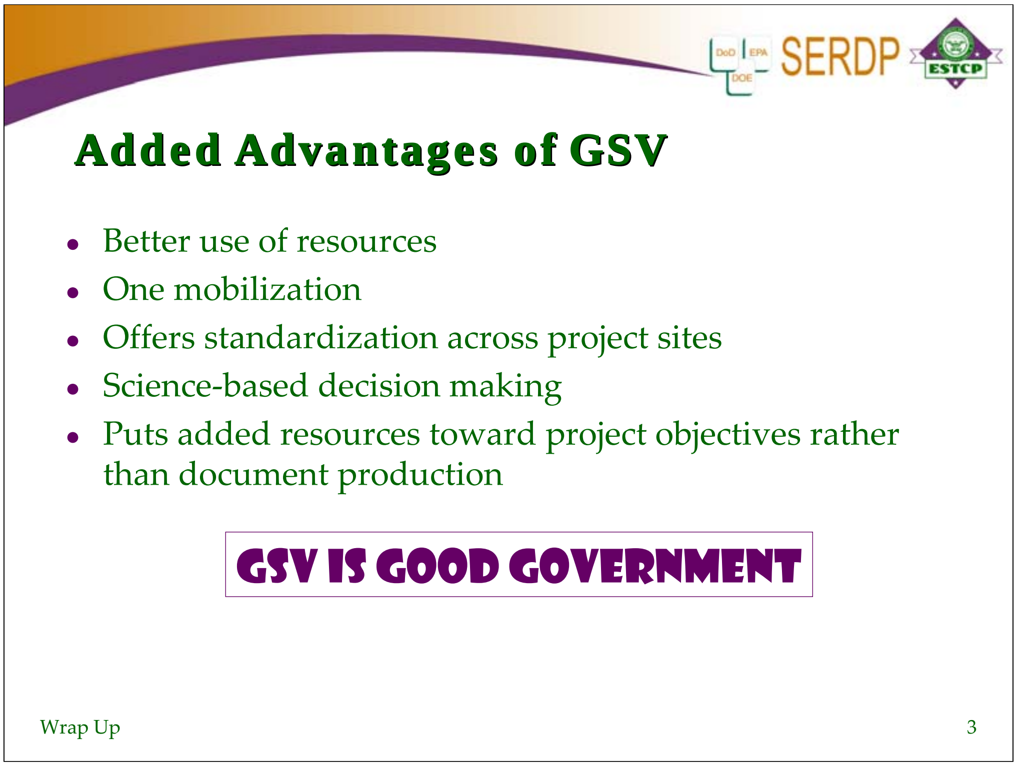
Moving Beyond GPOs

- Original GPO objectives not abandoned
  - "Quantitatively understand, measure and describe the effectiveness of UXO detection technology"
- Geophysical System Verification
  - Builds on a wealth of accumulated understanding
  - Physics-based
  - Provides continual monitoring for the life of the project
- GSV complements existing QA/QC

Wrap Up 2

The GSV process outlined here is both straightforward and rigorous and, combined with other quality measures, meets the historical objectives of the GPO. It redirects resources from a traditional GPO to a quantitative and transparent evaluation of data quality that spans the life of the project.

Daily visits to the IVS before and after the production work will provide quantitative checks on signal and noise consistency in a known location. Blind seeds, emplaced at intervals to provide a minimum of one seed in each day's data collection, provide ongoing evidence that the entire data collection and analysis process is working. Seeds should be detected at correct signal levels and placed on the dig list. Monitoring of noise in production data ensures that either expectations of detection performance will be met or that changes in noise conditions are recognized and appropriate adjustments made. Taken together, these elements of the GSV lead to confidence that data throughout the project is meeting project objectives.



GSV is a more efficient use to limited resources.

One deployment. The current GPO is expensive, in part because it often involves one deployment to construct the GPO and collect the data, followed by an interval in which a formal report is written, reviewed and approved. This is not necessary. With advanced planning based on an understanding of the geophysical equipment, the essential items could be verified on-site in a timely manner to support a single deployment. Conditions must be outlined in detail in advance, including metrics and success criteria. If GSV is completed successfully, approval to proceed could be immediate. If problems are encountered, the information generated in the IVS, noise measurements and evaluation of initial data collection would be useful for failure analysis and corrective action.

Can be standard across sites. GPOs have always varied considerably, in size, number and selection of targets, and evaluation criteria. This has made it difficult to compare data from one GPO to another. Whether the targets were inert munitions or other objects like pipes or spheres, none was ever well characterized and did not support any type of quantitative interpretation. Using the response curves generated for both the proposed ISOs and common munitions, it is now possible to establish a minimum of standardization across sites, while recognizing that individual site teams may want to add to what is presented here.

Science-Based Decision Making. The GSV allows a project team to set quantitative criteria defining acceptable data for a project to proceed. Recognizing how the site-invariant signal of an object of interest and site-specific noise combine to determine detecability of targets sets realistic expectations for meeting project objectives. With proper QC of the production data, the GSV enhances confidence that objectives are met throughout the project.