Classification of Unexploded Ordnance using Geophysics - A Practical Reality

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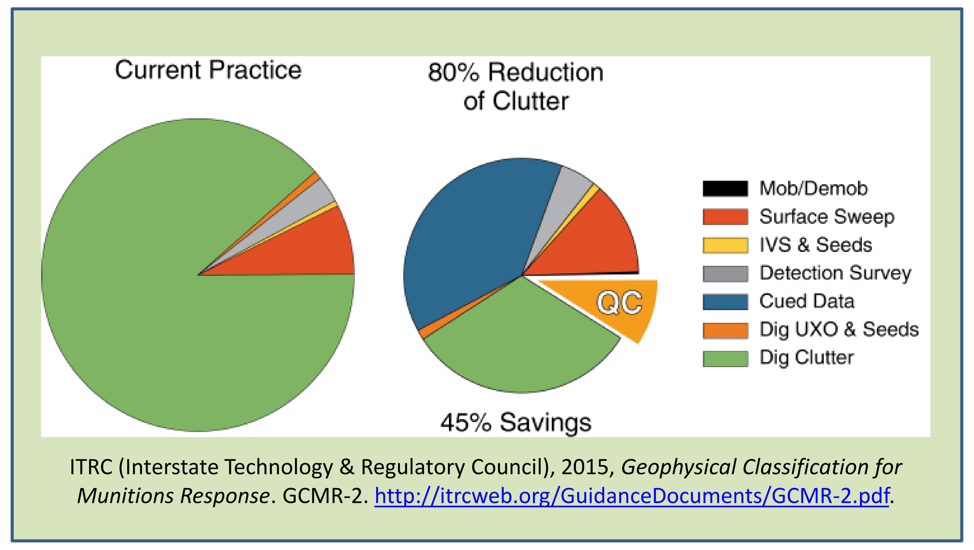
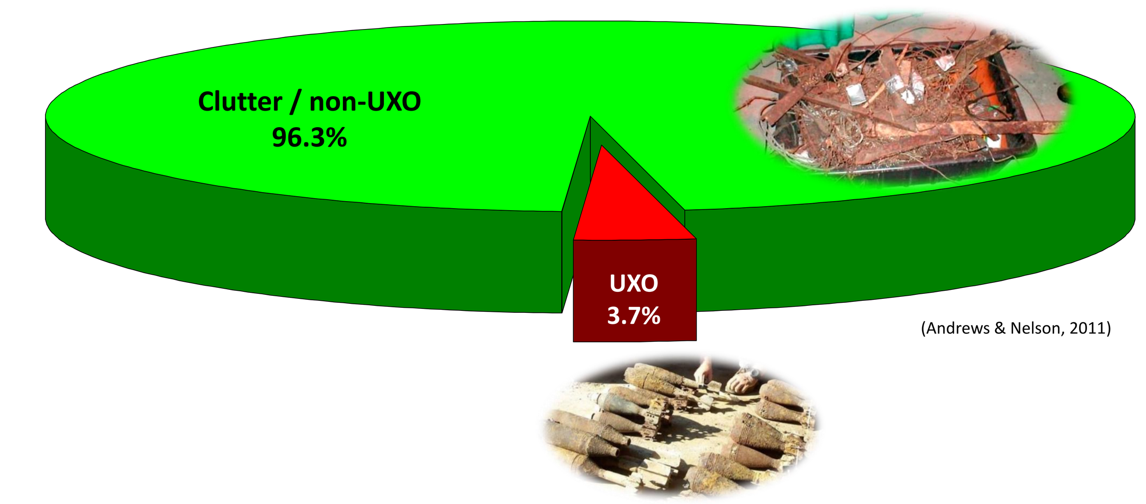


ITRC (Interstate Technology & Regulatory Council), 2015, *Geophysical Classification for Munitions Response*. GCMR-2. http://itrcweb.org/GuidanceDocuments/GCMR-2.pdf.

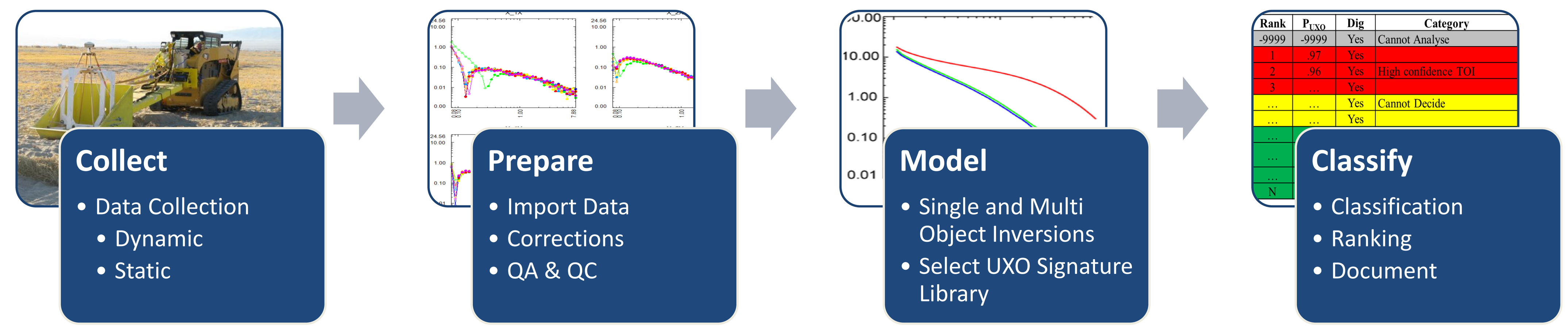
Why Do Classification?

During an unexploded ordnance (UXO) or munition clean-up project, most of the items excavated are not UXO, but are harmless scrap metal (also called 'clutter'). In 2003 it was estimated that there are approximately 10 million acres (4 million hectares) in the United States impacted by UXO. If 75% of the metallic targets found were not UXO, US$52 billion could be spent just to dig up scrap metal (Delaney & Etter, 2003).

If targets can be determined to be non-hazardous without digging, they can be left unexcavated, or can be excavated in a less costly way (i.e. not requiring the same safety precautions). *Classification* is the process of analysing data to decide whether each target is a hazard or not, and in some cases, even deciding which specific type of munition may be present. Such classification, centred on a physics-based analysis that is transparent and reproducible, will enable significant savings to be realized. This in turn will allow limited clean-up funds to effectively clear a greater area.



A Typical Classification Project Workflow



Advanced EM Data Collection Technology

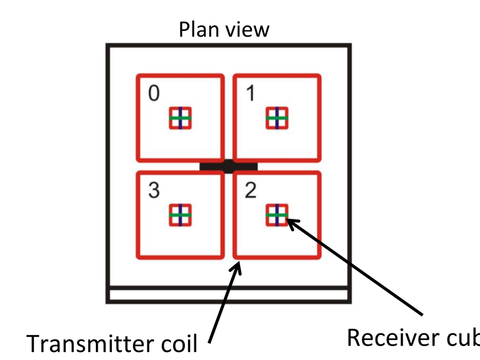
Advanced electromagnetic (EM) sensors have been developed to facilitate the classification of UXO. Development began in the late 1990s with the support of two US Department of Defence (DoD) agencies, the Strategic Environmental Research and Development Program (SERDP) and the Environmental Security Technology Certification Program (ESTCP). Through these projects, several new advanced electromagnetic sensors were developed and tested in live-site demonstrations. Two are now being regularly used for surveys. Both are time-domain electromagnetic (TEM) systems: the MetalMapper and the new XTEM TADS 2x2 system. The XTEM TADS 2x2 is being commercialized by Geometrics based on the former TEMTADS 2x2 system developed by Naval Research Laboratory (NRL).

These new sensors have three key differences from previous EM sensors typically used in UXO surveys:

- multiple transmitter and receiver coils in various orientations to measure multiple components at a single point in space;
- finer sampling of the time decay curve; and
- sample longer periods in time.

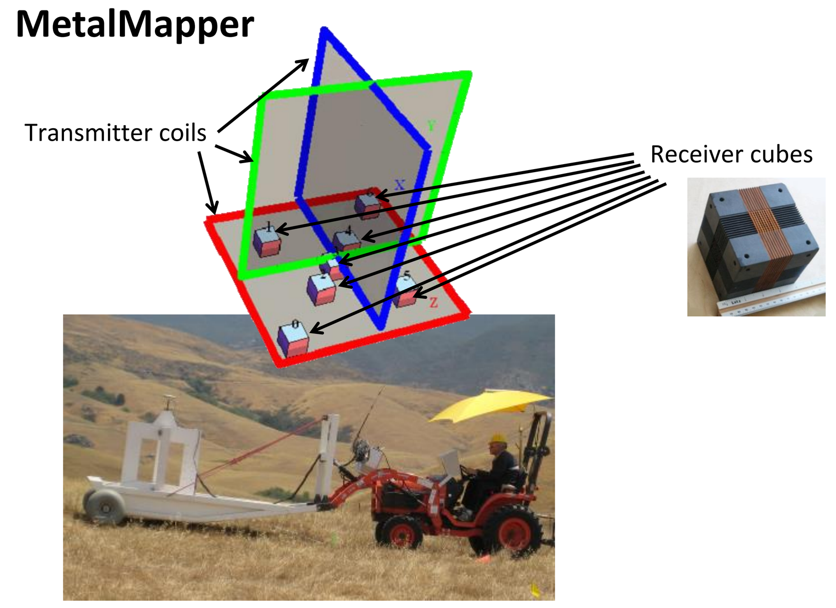
These differences permit 'full illumination' of a target through use of greater data completeness.

TEMTADS 2x2

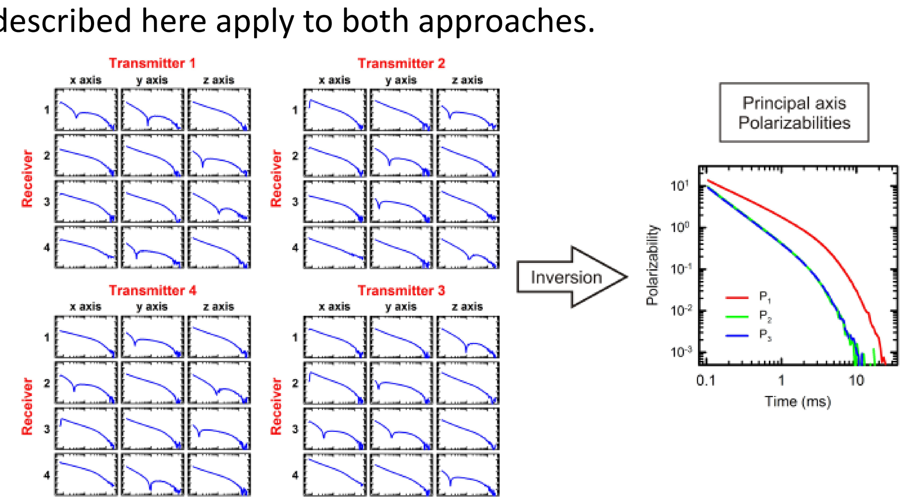


The MetalMapper consists of three orthogonal transmitter loops that are 1m x 1m in size, and seven 3-component receiver coils mounted within the horizontal transmitter coil. The XTEM TADS 2x2 system has four horizontal transmitter loops (~0.5 x 0.5m) with a 3-component receiver coil within each transmitter. This results in 48 datasets, with recording of the decay curve up to 9ms after transmitter turn-off.

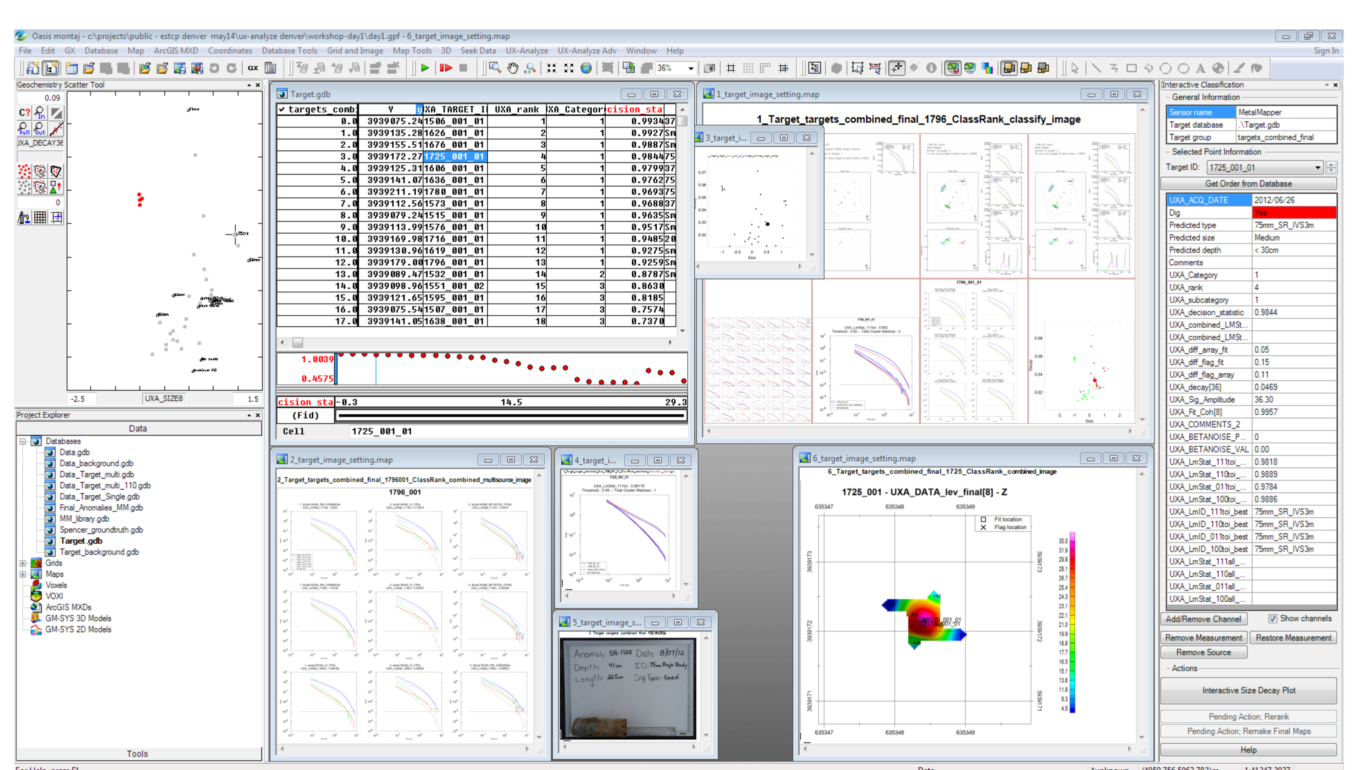
MetalMapper



Surveys can be carried out in either static (cued) mode or dynamic mode. In static mode survey data is collected while the platform is stationary over a suspected target location, as identified by a previous dynamic mode survey or a previous, simpler target detection survey (such as a Geonics EM61). Dynamic survey mode data is collected from a moving platform, and carries out a full spatial survey using the advanced EM sensor to both locate and classify targets. There are differences in field processes, but the classification principles described here apply to both approaches.

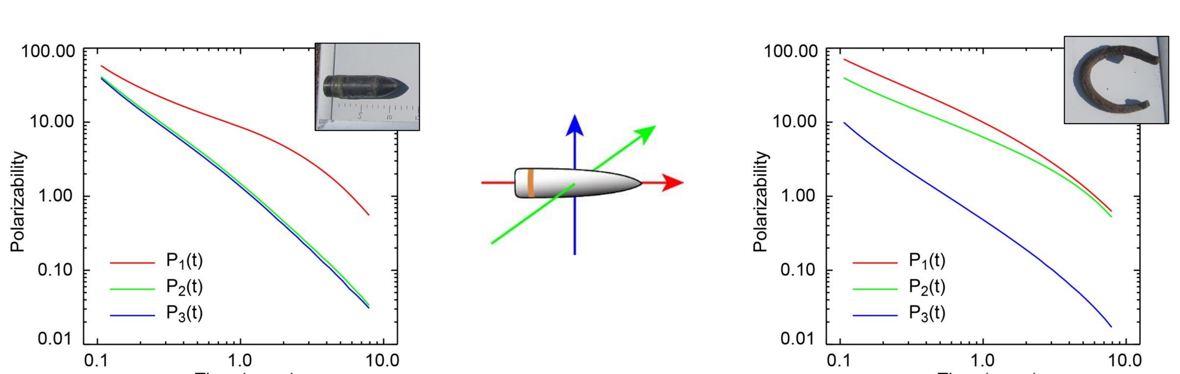


EM Response Curves, from a single TEMTADS 2x2 reading, and the resulting polarizabilities after inversion (ITRC, 2015)



Data Processing

Classification depends on calculating model parameters (polarizabilities and decays) that relate to intrinsic physical features of the target objects, rather than external features such as location and orientation of the target. After checking data quality and preliminary processing, these polarizabilities are determined through forward modelling and inversion of the measured survey data. This inversion process also yields a more accurate location and depth of the buried object.



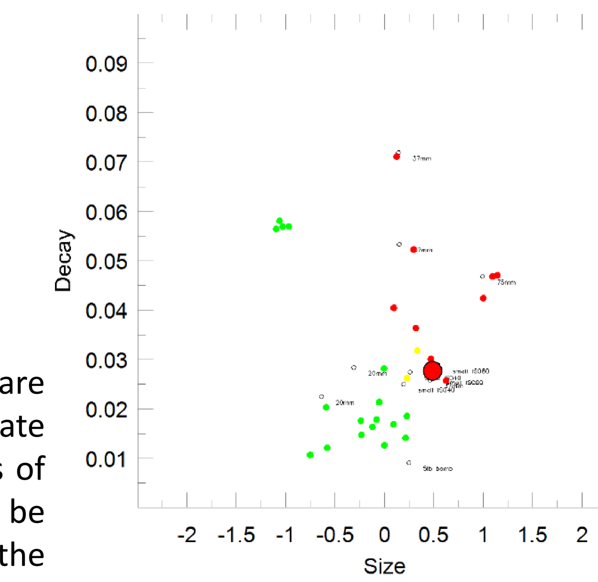
Identifying UXO from Scrap

The polarizabilities (also called Betas) relate to the object size and shape, whereas decay relates to the material properties and wall thickness. UXOs are typically long cylindrical objects; therefore they have one strong or primary polarizability (red, in the diagram at left) and two weaker (secondary/tertiary) but equal polarizabilities (blue and green). This is a distinguishing characteristic of cylindrical objects.

Classification

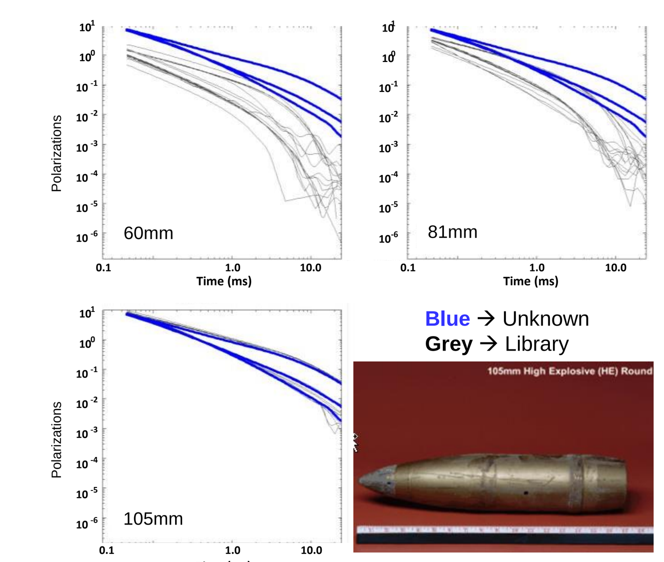
The classification process determines the likelihood that an item is a UXO. There are two main types of classifiers: direct and library matching. Direct classifiers evaluate the calculated model parameter values directly to determine which combinations of feature values make an object look like a UXO. Direct classifiers can easily be visualized through a plot of "feature space"; most commonly relative size of the source dipole polarizabilities vs. decay.

Library matching classifiers match target features to those from a library of polarizability signatures made up of munition types suspected to exist at the site. An unknown object or target that has polarizability curves that are mathematically similar to those of a known library item, can be said to match the library item. This method is very successful in classifying UXO vs. non-hazardous objects, and in some instances being able to distinguish the specific type of UXO.



Scatter plot of "feature space", Size vs. Decay. The colours indicate the classification category, as shown on the table (below).

Example of a target being compared graphically to three library munitions and closely matching the "105 mm" library polarization curves.



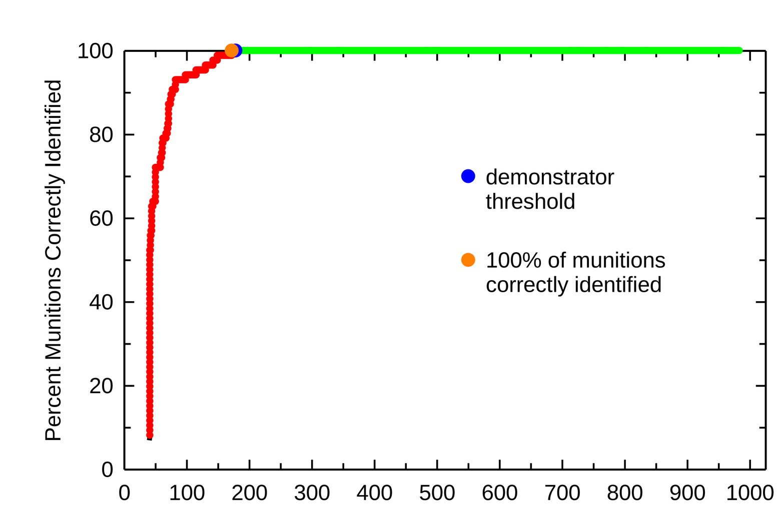
Rank	P_{UXO}	Dig	Category
-9999	-9999	Yes	Cannot Analyse
1	.97	Yes	
2	.96	Yes	High confidence TOI
3	…	Yes	
…	…	Yes	Cannot Decide
…	…	Yes	
…	…	No	
…	…	No	Highly Confidence non-TOI
…	.02	No	
N	.01	No	

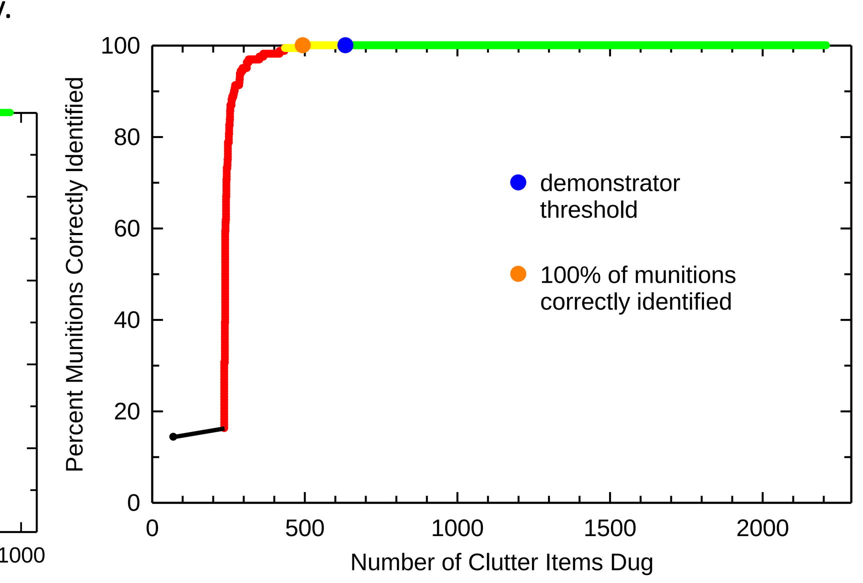
The final product of the data analysis is a dig list, ranking all of the detected targets by the likelihood that they are UXO or 'targets of interest' (TOI). This ranked list is categorized into four groups: Cannot Analyse, Highly Confident TOI, Cannot Decide and Highly Confident non-TOI. These categories are shown in the table on the left and the colour corresponds to the curves below.

The geophysicist/analyst must determine a "stop-digging" threshold in the ranked target list. Typically a detailed review of the data and calculated parameters is required for the small population that were not automatically classified with high-confidence. These "Cannot Decide" items are assessed by the analyst based on factors specific to the site, including anomaly amplitudes, anomaly size and decay rate, and other information. In the process of reviewing the parameters (e.g. Size vs. Decay plots) and comparing curves to other target items, clusters of self-similar items may be identified. These "clusters" may be sampled by digging some of the targets, to determine whether they are TOI and should thus be added to the signature library.

Examples of Classification Success

As part of the live-site demonstrations all the items on the sites were excavated. The results can be plotted (right). The line colours represent the classification categories and give an indication of how successful the classification has been. In future projects a statistical number of non-munitions will be excavated beyond the stop digging point, to ensure full confidence in the classification results.





Conclusion

The inversion and classification tools described here are available as UX-Analyze, a software module provided by Geosoft Inc. (Geosoft, 2015) with ESTCP funding. UX-Analyze is currently available to US government, regulators and contractors for US government projects at no cost, but requires use of Geosoft's commercial Oasis montaj and UX-Detect software as a platform. The package includes tools for data quality control, target picking and analysis with classification, and mapping of basic and advanced geophysical sensor data.

Reliable classification of suspected UXO targets using geophysical survey data is now possible. These technologies and processes have been thoroughly proven in live-site demonstrations. Government program managers and regulators have been included in the demonstrations, and they are now beginning to require the use of UXO classification technologies investigations on their cleanup sites throughout the United States.

References

Available on request.

Poster at NAOC Annual Meeting – Savannah GA, November 2015