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**Live-Site UXO Classification Demonstrations:
A Retrospective Summary (Poster)**

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About This Publication

This work was conducted by the Institute for Defense Analyses (IDA) under contract HQ0034-14-D-0001, Project AM-2-1528, "Assessment of Traditional and Emerging Approaches to the Detection and Classification of Surface and Buried Unexploded Ordnance (UXO)," for the Director, Environmental Security Technology Certification Program (ESTCP) and Strategic Environmental Research and Development Program (SERDP), under the Deputy Under Secretary of Defense, Installations and Environment. The views, opinions, and findings should not be construed as representing the official position of either the Department of Defense or the sponsoring organization.

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UXO Live Site Classification Demonstrations: A Retrospective Summary

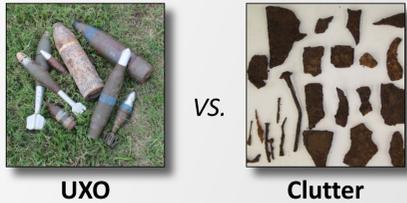
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Introduction

- Unexploded Ordnance (UXO) may contaminate 1400 sites in over 10M acres in the United States*:
 - UXO can bury in the ground and become difficult to distinguish from metallic clutter using traditional detection methods
 - As recently as the early 2000s, 75% of remediation costs were spent on false alarms – excavating objects that turned out to be clutter

* Defense Science Board (DSB), Report of the Defense Science Board Task Force of Unexploded Ordnance, December 2003

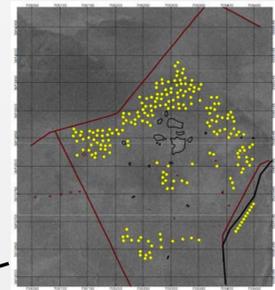


- The Environmental Security Technology Certification Program (ESTCP) has sponsored the development of advanced geophysical instruments and software to rank the likelihood that a buried object is UXO:
 - Objects with a low UXO likelihood can be classified as clutter and left unexcavated, reducing remediation costs
 - Remediation resources can then be directed towards excavating all other objects, allowing more land to be cleared for the same price
- ESTCP has sponsored a series of demonstrations to assess the capability of advanced geophysical classification technologies for safely remediating land of UXO while reducing remediation costs

Methods

For each demonstration:

- ESTCP emplaced inert and surrogate UXO in the ground to increase the number of **Targets of Interest (TOI)**:
 - TOI = UXO, inert and surrogate munitions, seeds, and any other objects for which the site team agrees that removal is required
- Thousands of clutter objects were already native to the site



TOI emplacement plan for the Camp San Luis Obispo (SLO) demonstration:

- Site Boundary
- Road or Rocks
- TOI emplacement



Collecting data with the Time-domain ElectroMagnetic Towed Array Detection System (TENTADS)

Ranked Anomaly List

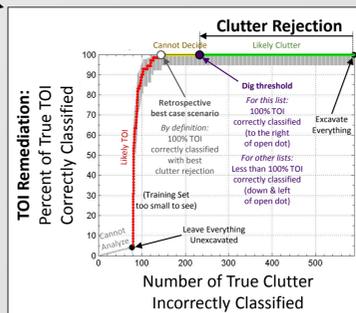
Target ID	Category	Dig Decision
XX-2003	Cannot Analyze	Excavate
XX-2033	Cannot Analyze	Excavate
XX-2030	Cannot Analyze	Excavate
...
XX-2323	Training Set	Excavate
XX-2338	Training Set	Excavate
...
XX-2414	Likely TOI	Excavate
XX-2504	Likely TOI	Excavate
XX-2665	Likely TOI	Excavate
XX-2503	Likely TOI	Excavate
XX-2278	Likely TOI	Excavate
...
XX-2677	Cannot Decide	Excavate
XX-2364	Cannot Decide	Excavate
XX-2616	Cannot Decide	Excavate
...
XX-2674	Likely Clutter	Leave Unexcavated
XX-2058	Likely Clutter	Leave Unexcavated
XX-2274	Likely Clutter	Leave Unexcavated
XX-2054	Likely Clutter	Leave Unexcavated
XX-2541	Likely Clutter	Leave Unexcavated
...

TOI Likelihood Rank

Dig Threshold

- Demonstrators collected data using advanced instruments and processed the data using advanced software to produce a ranked anomaly list
- Each ranked anomaly list consisted of an ordered set of locations detected at the site, ranked by their likelihood of containing a buried TOI
- Demonstrators selected a **dig threshold** to apply to each ranked anomaly list

ROC Curve



- ESTCP excavated all detected locations to construct **ground truth**
- The Institute for Defense Analyses (IDA) compared each list to ground truth and created a **Receiver-Operating Characteristic (ROC) curve** to score the list's performance

Results

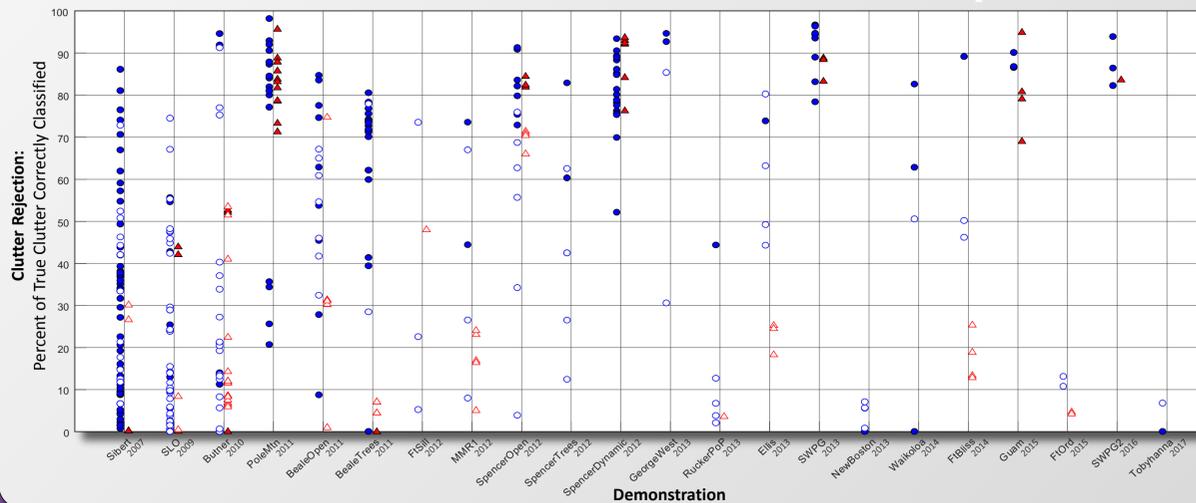
UXO Live Site Demonstrations, FY2007 - FY2017

Year	Demonstration	Location	Number of Intermediate and Final Lists	TOI types (description or caliber)	Instruments
2007	Sibert	Camp Sibert, AL	42	4.2in	Berkeley UXO Discriminator (BUD), EM61-Mk2 Cart, EM63 (cued), GEM-3 (cued), Multi-Sensor Towed Array Detection System (MTADS) - EM61-Mk2/GEM-3/mag
2009	SLO	Camp San Luis Obispo, CA	59	37mm, 60mm, 81mm, 2.36in, 3in, 4.2in, 5in	BUD, EM61-Mk2 Cart, MTADS - EM61-Mk2/mag, Man-portable Simultaneous magnetometer and ElectroMagnetic System (MSEMS), MetalMapper, Time-domain ElectroMagnetic Towed Array Detection System (TEM-TADS) 5x5
2010	Butner	Camp Butner, NC	54	37mm, M48 fuze, 105mm	EM61-Mk2 Cart, MetalMapper, TEM-TADS 5x5
2011	PoleMtn	Pole Mountain, WY	36	small Industry Standard Object (ISO), 37mm, 57mm, 60mm, 75mm, 3in	EM61-Mk2 Cart, MetalMapper
2011	Beale	Camp Beale, CA	95	small ISO, 37mm, 60mm, 81mm, 105mm	BUD, EM61-Mk2 Cart, MetalMapper, Man Portable Vector (MPV), TEM-TADS 2x2
2012	FSill	Fort Sill, OK	9	signal flare, RA/RP pipe, LAW rocket motor, grenade, rifle grenade, practice grenade, flare canister, small ISO, 37mm, 40mm, 2.36in, 3.5in	MetalMapper
2012	MMR1	Massachusetts Military Reservation, MA	24	parachute flare, illumination round, smoke canister, cartridge, 37mm, medium ISO, 60mm, 2.5in, 75mm, 81mm, 105mm, 4.2in, 155mm, 8in	MetalMapper, TEM-TADS 2x2
2012	Spencer	Camp Spencer, TN	75	small ISO, 37mm, medium ISO, 60mm, 75mm, 3in, 105mm, 155mm	MetalMapper, MPV, TEM-TADS 2x2 and 5x5
2013	GeorgeWest	Camp George West, CO	5	medium ISO, 75mm	MPV
2013	RuckerPop	Fort Rucker, AL	32	small ISO, hand grenade, rifle grenade, 2.36in, 2.36in motor, 3.5in motor, one 2.36in motor & one 3.5in motor, two 2.36in motors, three 2.36in motors, three 2.36in motors & one 3.5in motor, one 2.36in & 118 2.36in motors	MetalMapper, TEM-TADS 2x2 and 5x5
2013	Ellis	Camp Ellis, IL	18	small ISO, grenade, hand grenade, rifle grenade, 2.36in	MetalMapper, TEM-TADS 2x2
2013	SWPG	Southwestern Proving Ground, AR	21	20mm, small ISO, 37mm, 40mm, medium ISO, 75mm, 90mm, 105mm	MetalMapper, TEM-TADS 2x2
2013	NewBoston	New Boston Air Force Station, NH	9	1/2in x 2in pipe, 1/2in x 3in pipe, 20mm, two 20mm, small ISO, scar rocket, 382 practice bomb, M103 bomb nose fuze, 100lb bomb, M1 practice bomb	MPV, TEM-TADS 2x2
2014	Waikoloa	Waikoloa, HI	9	small ISO, 37mm, medium ISO, 60mm, 81mm, TOI frag	MetalMapper, MPV, MPV3D
2014	FtBliss	Castner Range in Fort Bliss, TX	12	25mm, small ISO, 37mm, 105mm	TEM-TADS 2x2
2015	Guam	Andersen Air Force Base, Guam	14	small ISO, 37mm	TEM-TADS 2x2
2015	FtOrd	Fort Ord, CA	4	20mm, 35mm, small ISO, 37mm, 40mm, 57mm, medium ISO, 60mm, 75mm, 81mm, large ISO, 105mm, 4.2in, 155mm	MetalMapper
2016	SWPG2	Southwestern Proving Ground, AR	8	20mm, small ISO, 37mm, 40mm, 57mm, 75mm, 90mm	One-Pass Time-domain ElectroMagnetic Induction Array (OPTEMA), TEM-TADS 2x2
2017	Tobyhanna	Tobyhanna Army Depot, PA	2	small ISO, medium ISO, 75mm	MPV

From FY2007 – FY2017, IDA scored 538 lists created by 22 organizations using 11 instruments in 19 demonstrations

Performance of Every Final List from Every Demonstration, FY2007 - FY2017

- IF 100% of TOI were correctly classified at the **dig threshold**, THEN plot **clutter rejection** at the **dig threshold**, with **filled markers** indicating who created the list:
 - Technology Developer (filled blue circle)
 - Production-Level Remediation Company (filled red triangle)
- ELSE IF less than 100% of TOI were correctly classified at the **dig threshold**, THEN plot **clutter rejection** for the retrospective best case scenario, with **open markers** indicating who created the list:
 - Technology Developer (open blue circle)
 - Production-Level Remediation Company (open red triangle)



Discussion

- By design, later demonstrations typically included smaller TOIs:
 - Rule of thumb: the smaller the TOI, the more difficult the demonstration
- Overall, demonstration results typically improved with chronological order:
 - By 2011, most organizations at most sites could correctly classify 100% TOI while rejecting more than 70% clutter
 - On other sites, advanced geophysical classification demonstrated utility for more directed goals, e.g.:
 - FtOrd: large, shallow munitions could be correctly classified
 - MMR1: large munitions with unexpended explosive material could be correctly classified
- Improvements in classification results over time were likely due to advances in instruments, software, and processes for quality control and quality assurance
- Advanced geophysical classification technology now has the capability to focus remediation efforts on the excavation of explosive hazards while reducing the costly and unnecessary excavation of non-explosive clutter

Sponsored by the Environmental Security Technology Certification Program (ESTCP)

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