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Demonstration Design for Unexploded Ordnance Detection Technology: The Needs of the User and Technical Communities

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PREFACE

This paper was prepared for the Deputy Under Secretary of Defense (Environmental Security), under a task entitled "Assessment of Traditional and Emerging Approaches to the Detection and Identification of Surface and Buried Unexploded Ordnance." Earlier work under a task for the Director, Test Systems Engineering and Evaluation, has been incorporated as well.

We greatly appreciate the comments of Dr. Regina Dugan, Ms. Christine Jordan, and Mr. Joseph Stahl. Their efforts greatly improved the quality of the paper.

ACKNOWLEDGMENTS

Much of the information in this report is derived from conversations with a variety of Explosive Ordnance Disposal (EOD) experts from all Services. These include conversations at Naval Ordnance Station, Indian Head, Maryland, and the Mandatory Center of Excellence, Huntsville, Alabama, expressly for this paper. In addition, we have benefited from conversations with EOD, Range Management, and Foreign Material Exploitation experts and tours at Aberdeen, Maryland; Jefferson Proving Ground, Indiana; Yuma Proving Grounds, Arizona; and Fort Benning, Georgia. We have benefited tremendously from the experience and information shared with us. We observe that the experiences of EOD personnel vary a great deal and, as a result, so do their opinions about various aspects of cleanups. The perspectives presented here may not be representative in a statistical sense, but are certainly noteworthy. The authors thankfully acknowledge the assistance of all interviewees. However, any inaccuracies, misunderstandings, or other errors of omission or commission are solely the responsibility of the authors.

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I. INTRODUCTION

Unexploded ordnance (UXO)[1] contamination is a worldwide phenomenon. Much of the contamination is a legacy of wars in Europe, Asia, and the Middle East. In these regions, unexploded ordnance includes bombs, rockets, artillery shells, landmines, naval ordnance, incendiary munitions, and pyrotechnic devices used by all combatants. Within the continental United States (CONUS), however, UXO contamination problems are the result of research, development, testing, manufacturing, stockpiling, and training activities. UXO consists primarily of ordnance items of domestic manufacture. Even within CONUS, the problem is large: current estimates indicate more than 11,000,000 acres of land may be contaminated with UXO (see Table 1).

Table 1. Amount of Potentially UXO-Contaminated Land

Government Lands	Number of Acres Potentially Contaminated with UXO*
Active DoD	6,098,019
Department of Interior	5,111,521
Base Realignment and Closure (BRAC) Sites	84,106
Total	11,293,546

* Does not include Air Force.[2]

Before the mid 1980's, UXO contamination within CONUS was not a major issue of high-level concern. Most of the contamination was confined to DoD-controlled military ranges or stockpile areas on DoD bases. Only military personnel or contractors were likely to come into contact with UXO. It was assumed that all such persons would have some level of training sufficient to help them avoid obvious UXO hazards and seek help upon their discovery.

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1 For purposes of this paper, unexploded ordnance (UXO) is defined to be as follows:

> Explosive ordnance which has been primed, fuzed, armed, or otherwise prepared for action, and which has been launched, placed, fired, or released in such a manner as to constitute a hazard to friendly operations, installations, personnel, or materiel and remains unexploded either through malfunction or design or for any other cause.

2 "Statement of Research Need," Strategic Environment Research and Development Program, 1996, downloaded from the Internet, copy on file with IDA.

With the drawdown of U.S. military forces beginning in 1985 and the transfer of surplus military facilities to other governmental agencies, educational institutions, or their outright sale, the potential for civilian contact with UXO rose dramatically.[3] As a result of The BRAC process and recent amendments to statute dealing with community redevelopment and the transfer of formerly used Defense sites (FUDS), there is even greater emphasis on speedy conversion of DoD facilities to alternative uses under the control of non-DoD government agencies or even private owners. The net effect of these efforts is to increase the possibility of allowing untrained civilians access to lands potentially contaminated with UXO.[4]

DoD is concerned about the health and safety of its civilian and military employees as well as its contractors. Peacetime clearance of UXO from active, reserve, and inactive weapons ranges poses significant safety challenges for DoD and contractor personnel. Clearance of UXO from DoD facilities slated for transfer to non-DoD organizations raises even more demanding safety challenges than UXO clearance from ranges or DoD installation rehabilitation/environmental remediation. UXO clearance at facilities scheduled for conversion is especially demanding because of the possibility of post-transfer incidents involving detonation of hitherto unknown UXO resulting in injury and damage to non-DoD personnel and materiel. The possibility of such incidents requires further UXO clearance efforts by DoD personnel at FUDS. They also represent both the greatest safety challenge to DoD personnel and greatest financial liabilities to DoD. The extraordinary safety problems arise after transfer of DoD lands to others because of multiple uses of land and the commingling of civilians and non-DoD government personnel with no knowledge or concern for munitions safety. The high financial liability to DoD results from (1) the high costs of UXO clearance after land transfer has occurred and (2) the statutory liability of DoD to pay damages to victims of UXO incidents which occur after DoD has certified that its facilities or lands are cleared of UXO or hazardous ordnance waste.[5]

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3 The Defense Authorization Amendments and Base Closure and Realignment Act of 1988 (BCRA 88, Title II of Pub. L. 100-526, 10 U.S.C. §2687 note), and the Defense Base Closure and Realignment Act of 1990 (DBCRA 90, Part A of Title XXIX of Pub. L. 101-510, 10 U.S.C. §2687 note), establish the basic requirements for identifying and implementing domestic military base closures and realignments.

4 See Army and Air Force Regulations on the Management of Real Property; see also *Base Closure Manual* which discusses implementation of statutes intended to give the public greater access to DoD-owned lands, even if DoD determines that lands must be retained in "reserve" status. See also the Proposed Rule for transfer of closed DoD ordnance ranges. All of these items were downloaded from the Internet and are on file at IDA.

5 Resource Conservation and Recovery Act (RCRA), 42 U.S.C. §6901 *et seq.*; 40 CFR Parts 240–281.

As DoD has gained more knowledge and has begun to comply fully with the law, the costs of facilities cleanup and remediating environmental damage have soared. A 1995 Congressional Budget Office study summarized the financial projections and impact of UXO and other environmental cleanup efforts within DoD in the following terms:

> Changes in DoD's cost estimates and budget plans continue to reveal the high degree of uncertainty that characterizes the cleanup program. In 1985 DoD estimated that completing the cleanup program would cost between $6.9 billion and $13.7 billion (1995 dollars). DoD recently estimated that the program could cost about $30 billion. Annual budget requests have also risen. In 1989, the department estimated that it would need between $900 million and $1.2 billion to fund cleanup requirements in 1994; the Congress authorized about twice the higher estimate. Similar trends in cost growth have occurred at individual military bases.
>
> The Inspector General of DoD found that average cleanup costs for defense facilities scheduled to be closed were about 60 percent higher than initial estimates.[6]

The focus of DoD's research, development, test, and evaluation (RDT&E) efforts in UXO detection, classification, identification, and remediation has shifted in response to changes in the program's technical, economic, and political environment. Improving personal safety for individuals involved in environmental remediation efforts at DoD facilities has become a major research and development (R&D) need. The need to be confident in the ability to clear UXO from lands to be released by DoD for other purposes as a result of the drawdown of DoD infrastructure has also driven UXO remediation R&D requirements. The high current and potential long-term costs of UXO clearance and liability for post-transfer incidents has increased emphasis on development of technologies and methods for rapid, reliable, and accurate UXO detection, classification, identification, and removal, especially for buried UXO.

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6 *Cleaning Up Defense Installations: Issues And Options*, Congressional Budget Office, Washington, D.C., January 1995).

There has been an increase in high-level attention within the Department of Defense[7] and also by the General Accounting Office[8] (GAO) and the Congressional Budget Office,[9] which has also helped to refocus RDT&E efforts.

The Department of Defense has developed the Environmental Security Technology Certification Program (ESTCP). The ESTCP seeks to identify those technologies which would provide substantial return on investment through cost savings and improved efficiency. ESTCP seeks to move aggressively from field trials to acquisition, where demonstrations provide evidence of cost-effective performance and market potential.[10] This program demonstrates and validates the most promising innovative technologies that address DoD's most urgent environmental needs and are projected to pay back the investment within 5 years through cost savings and improved efficiencies. The ESTCP is sponsoring a series of demonstrations of UXO detection systems as part of its broad technology demonstration program.

A 1995 review of the Defense Environmental Program Management found that current UXO detection technology was very costly and could not meet DoD requirements because of an inability to detect ordnance buried below 3 feet. The potential for migration of deep buried ordnance to the surface is a major problem. DoD is committed to cleaning up active bases, FUDS, and bases subject to realignment and closure in a manner that allows maximum public use and conversion to other governmental or private use. Unless such ordnance can be detected and cleared prior to DoD release of lands for other purposes, DoD retains long-term clearance responsibility and potential financial liability.

GAO reported three significant barriers to the use of new technology for containing and cleaning up contamination at DoD facilities:

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7 See, for example, Report of the Defense Science Board Task Force on Environmental Security dated 22 April 1995, downloaded from the Internet, copy on file at IDA.

8 See for example, the following GAO Reports to Congress:
Environmental Cleanup: Inconsistent Sharing Arrangements May Increase Defense Costs (Washington, D.C.: GAO/NSIAD-94-231, July 1994); *Military Bases: Environmental Impact at Closing Installations* (Washington, DC: GAO/NSIAD-95-70, February 1995); *Environmental Protection: Status of Defense Initiatives for Cleanup, Compliance and Technology* (Washington, D.C.: GAO/NSIAD-96-155, August 1996).

9 Congressional Budget Office, *Cleaning Up Defense Installations: Issues and Options* (Washington, D.C.: CBO, January 1995).

10 See "[DoD] Environmental Security Technology Certification Program Description," downloaded from the Internet, 30 September 1996, copy on file with IDA. Available: http://estcp.xservices.com/geninfo/docs/guide-11.doc.

- Conflicting priorities prevent the approval of innovative approaches for cleanup.
- Field officials may associate the newer technologies with unacceptable levels of risk.
- On-site contractors may favor particular technologies on the basis of their own experience and investments.[11]

The ESTCP asked IDA to assist the program by assessing measures of effectiveness (MOEs) and UXO-detection performance descriptions that would be useful to DoD managers responsible for ordnance test and training range clearing operations as well as UXO contamination cleanup at Installation Restoration Program, BRAC, and FUDS locations. This report describes in general terms the current procedures used for peacetime clearing of UXO from CONUS DoD test and training ranges, Installation Restoration Program sites, BRAC facilities, and FUDS. This report has two goals: (1) to present a set of MOEs for UXO technology demonstration, and (2) to describe the methods of data collection and analysis necessary and sufficient to determine whether the technologies included in the UXO demonstration/validation program offer sufficient promise to warrant further investment. The report relies upon the written record of past UXO technology development efforts, DoD regulations and administrative practices, as well as interviews with Explosive Ordnance Disposal (EOD) personnel to capture as much information as possible to meet the needs of ESTCP managers in developing and implementing realistic demonstration/validation experiments.

Recent DoD UXO R&D efforts have focused on improving sensors for use in the detection of UXO during initial site surveys and in discrimination of UXO from other subsurface objects found during detailed site investigation. Improving performance in these areas offers an opportunity to use more efficiently limited UXO remediation resources, including UXO qualified military personnel (EOD) specialists and civilian munitions destroyers.

Tests of sensors can be designed to produce data that either investigate the phenomenology of the system or that determine the utility of the system in real-world conditions. In either case, data must be taken in such a way as to support clearly articulated

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[11] David R. Warren, "Environmental Protection: Challenges in Defense Environmental Program Management," Testimony before the Subcommittee on Military Readiness and Military Installations and Facilities, Committee on National Security, House of Representatives (Washington, D.C.: GAO/T-NSIAD-95-121, March 24, 1995), pp. 9–10.

measures of performance. Definitions, standard scoring, and report protocols are necessary to make the results of the demonstration easily understood by the entire community. In this same vein, the data must demonstrate convincingly to the user that the technology is worthwhile. EOD-qualified personnel and the users of any system that is ultimately developed (EOD-qualified DoD and contractor personnel) must feel comfortable with the safety and reliability of a system if it is to see widespread use. A technology should not require a drastic departure from current UXO clearance protocols, which are designed to protect the safety of personnel, without good reason.

This report focuses on sensor technologies. We will attempt to inject our knowledge and understanding of UXO detection technology, current procedures for remediation of UXO, the views and concerns of EOD personnel, and lessons learned from past technology demonstrations to guide commentary on the development of techniques to record, analyze, and archive data to support both the UXO technology development and operational communities. It is our hope that this analysis contribute to the reduction of barriers to the adoption of new technology noted by GAO.

II. UXO REMEDIATION: PROCESSES AND BEHAVIORS

A. OVERVIEW

The Department of Defense is responsible for the remediation of health, safety, and actual or potential adverse environmental effects of UXO located on Military Ranges, DoD facilities being disposed of as a result of BRAC Commission actions or service excess property disposal processes, and FUDS[1] on which UXO has been discovered. Remediation efforts must be carried out in accordance with processes mandated by statute and amplified by Code of Federal Regulations, DoD Issuances, Service guidance, and facility-specific guidance. Remediation efforts may also be described in behavioral terms—what actually happens on the ground. In this chapter, we summarize the processes mandated by law and regulations, describe the personnel qualifications and training of individuals who actually clear UXO from the field, and report on the "real-world" processes as described to us by participants in UXO clearing operations.

B. RANGE CLEARANCE PROCESSES

The Department of Defense maintains a number of Military Ranges defined as "any land mass, or water body that is or was used for the purpose of training, research, development, testing, or evaluation of Military Munitions."[2] Ranges fall into five categories, as follows:

1. Active (used for training, research, development, testing, or evaluation of military munitions).
2. Inactive (range not currently in use but still considered to be a potential range area).

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1 According to the U.S. Army Corps of Engineers, a FUDS is "a Site that has been owned by, leased to, possessed by, or otherwise under the jurisdiction of DoD. The FUDS program does not apply to those sites outside the U.S. jurisdiction." For further information see the FUDS page at the Defense Environmental Restoration Program World Wide Web Site, available: http://dogbert.ncr.usace.army.mil/military/derp/fuds/fuds.htm.

2 See Paragraph IV.B.2, "Military Range," in "Section by Section Analysis, Proposed Range Rule," found at Note #78, DENIX Data Manager, 12:24 p.m., September 27, 1996, available: http://denix.cecer.armyu.mil/denix/Webnotes; copy on file at IDA.

3. Transferred (a military range that has been released from military control, i.e., FUDS).

4. Transferring (a military range that has been identified for closure and transfer as part of the BRAC process or has been declared surplus real property by a military Service pursuant to its own processes for disposition of unneeded real property)

5. Closed (range taken out of service by the military and put to new uses incompatible with further use as a range but still under the control of the Department of Defense).

Significant opportunities exist for UXO contamination in each type of military range called out above. DoD is committed to reducing safety risks associated with exposure of the public and clearance personnel to military munitions. The approach to clearing UXO from the ranges varies somewhat with the type of range and intent for future use.

Active ranges are usually cleared of UXO by either active duty UXO-qualified military personnel (EOD specialists) assigned to the range or UXO-qualified civilian contractors (munitions destroyers)[3] under contract to the facility or to RDT&E programs utilizing the range. Clearance activities are part of the day-to-day operation of the range. The frequency of clearance operations is based on guidance issued by the facility commander in conjunction with broad direction from the DoD Explosives Safety Board.[4]

Clearance of UXO may also be undertaken in conjunction with Installation Restoration Programs (IRP) designed to mitigate past practices at DoD sites which may have contributed to the release of pollutants into the environment. IRP efforts are conducted in accordance with rules and procedures established by DoD under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) as amended by

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3 "Section 3.d. UXO Qualified Personnel," in "Safety Concepts and Basic Considerations for Unexploded Ordnance (UXO) Operations: Interim Guidance," Ordnance and Explosives Center of Excellence, U.S. Army Corps of Engineers, Huntsville Division, Revised 16 February 1996, available: http://w2.hnd.usace.army.mil/oew/policy/safecon1.htm, and on file at IDA, defines UXO Qualified Personnel as follows:

> ...U.S. citizens who have graduated from the U.S. Army Bomb Disposal School, Aberdeen, Maryland, or the U.S. Naval Explosive Ordnance Disposal (EOD) School, Indian Head, MD. Graduates of the EOD Assistant Course, Redstone Arsenal, AL, or Eglin AFB, FL, with more than 3 years combined active duty military EOD and contractor UXO experience shall also be UXO qualified.

4 See "Paragraph F. Functions," in DoD Directive 6055.9, The DoD Explosives Safety Board, 25 November 1983, downloaded from DefenseLink Publications, DoD Issuances, available: http://www.dtic.mil/defenslink; on file at IDA.

Superfund Amendments and Reauthorization Act (SARA) requirements and Resource Conservation Recovery Act (RCRA) as outlined below.

It is important to bear in mind that Military Ranges are usually used for multiple RDT&E and training purposes. Ranges are separated by function, not ordnance type. Although RDT&E ranges are usually separate from training and maneuver ranges, multiple types of munitions within a family of ordnance (e.g., artillery) are expended on each range. Furthermore, oftentimes multiple families of ordnance have been expended at any given range. It is not uncommon to find UXO remnants from artillery, surface-to-surface rockets, air-to-surface rockets and missiles, mortars, and bombs scattered on the same range. Range clearance (for all types of ranges) implies mixed-ordnance contamination.

C. STATUTORY ENVIRONMENTAL RESTORATION PROGRAMS

Several different statutes compel the DoD to undertake significant environmental restoration activities in which discovery, rendering safe, and disposal of UXO figure prominently. Key statutory processes or specific laws are the following: [5]

- Defense BRAC processes which are established by several statutes. BRAC requires DoD compliance with National Environmental Policy Act and other environmental laws identified below.
- National Environmental Policy Act (NEPA), 42 U.S.C. §4321 et seq. NEPA requires that DoD Components analyze potential environmental impacts of proposed actions and alternatives for base disposal decisions. Implementing regulations (40 CFR Parts 1500-1508) describe in detail the specific parameters which DoD managers must include in their analyses of potential environmental impacts as well as processes by which such parameters are evaluated. Executive Order 11514 as amended by Executive Order 11991 provides additional guidance to DoD.

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[5] The BRAC process is set forth in a dynamic set of statutes which include but are not necessarily limited to the following:

- Defense Authorization Amendments and Base Closure and Realignment Act of 1988 (BRCA 88) Pub. L. 100-526, 10 U.S.C. §2687 note, 24 October 1988
- Defense Base Closure and Realignment Act of 1990 (DBRCA90), Pub. L. 101-510, 10 U.S.C. §2687 note, 5 November 1990
- National Defense Authorization Act for Fiscal Years 1992 and 1993 (NDAA 92/93), Pub. L. 102-190, §§334(a), 2821, 2827, 5 December 1991
- National Defense Authorization Act for Fiscal Year 1993 (NDAA 93), Pub L. 102-484, 23 October 1992

See Appendices A, B, and C to *DoD Base Reuse Implementation Manual* (Washington, DC: Department of Defense, July 1995), available: http://www.acq.osd.mil/iai/reinvest/manual/manual.html and on file at IDA.

- Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), 42 U.S.C. §9601 et seq. CERCLA requires DoD to undertake any needed response action to clean up contamination found at sites formerly used by DoD activities. Such response measures must address risks to human health and to the environment posed by past releases of hazardous substances. Section 120(h) of this act amended by the Community Environmental Response Facilitation Act (CERFA) governs the identification of uncontaminated parcels and covenant requirements for deed transfers of contaminated parcels. 40 CFR Parts 300-311 provide additional guidance with respect to both process and content of DoD environmental restoration activities to address contamination resulting from past actions.
- Resource Conservation and Recovery Act (RCRA), 42 U.S.C. §6901 et seq. RCRA requires DoD to establish a management system for hazardous waste and provides corrective action authority for cleanup of solid waste management units. 40 CFR Parts 240-281 provide further implementing direction.
- Department of Defense Environmental Restoration Program (DERP), 10 U.S.C. §2701–2708 and 2810 (enacted as section 211 of Superfund Amendments and Reauthorization Act of 1986). DERP provides authority for DoD to remediate environmental hazards emanating from active DoD sites which may be posing potential risk to the health, safety, and environment of surrounding communities. Further implementing guidance is contained within DoD Instruction 4715.7, "Environmental Restoration Program," dated April 22, 1996.

These statutes and their implementing Federal Regulations, Presidential Executive Orders, and DoD Issuances form a common procedural framework within which the field work necessary to find, render safe, and dispose UXO takes place. The following process is generally followed whenever a DoD facility is proposed for closure or realignment (BRAC processes), UXO is discovered at a FUDS, or DoD has determined it is necessary to remedy an environmental problem at an active DoD facility or site (IRP).

The discussion of generic DoD environmental remediation process that follows assumes that there is no immediate risk to public health or safety. A different process is used when such risks do arise. Although the form and detailed documentation generated in the process of preparing to remedy UXO contamination at a DoD site depends upon which statutory or regulatory provision governs the effort, the generic process described in Table 2 is quite similar. In many instances, the broader environmental hazard assessments undertaken pursuant to the CERCLA requirements find historical evidence of ordnance activities at a site, which in turn prompts more thorough records and physical inspections. Table 2 lists the major steps and the purpose of each in a site remediation effort.

Table 2. Generic DoD Environmental Remediation Process*

Task	Purpose
Preliminary Assessment	Installation-wide study to determine if sites are present that pose hazards to public health or the environment. Available information is collected on the source, nature, extent, and magnitude of actual and potential hazardous substance releases at sites on the installation.
Site Inspection	Sampling and analysis to determine actual existence of actual site contamination. Information used to evaluate site condition and determine response action needed.
Remedial Investigation	Additional site investigations, sampling, and analytical studies and activities to determine the nature, extent, and significance of contamination; focus is determining risk to the general population posed by contamination.
Feasibility Study	Conducted concurrently with Remedial Investigations; evaluation of remedial action alternatives to determine which alternative would provide the required protection against future hazards.
Remedial Design and/or Removal Design	Detailed plans for chosen remedial/removal actions prepared, including plans for removal and off-site disposal of UXO if in situ destruction is not feasible.
Remedial Action and/or Removal Action	Implementation of remedial/removal plans including in situ destruction of UXO and/or removal of UXO and associated UXO waste.
Interim Remedial and/or Removal Action	Remedial/Removal Action taken at any time during the cleanup process to protect public health and/or to control contaminant releases to the environment.
Remedy in Place; Functioning as Intended	Remedial action is functioning properly and performing as designed. Remediation includes such actions as the operation of pump-and-treat systems that will take decades to complete cleanup.

* This table is modeled after Appendix I in *Military Bases: Environmental Impact at Closing Installations* (Washington, DC: U.S. General Accounting Office, February 1995).

Depending upon the nature of the threat to health, safety, and the environment, the generic process outlined above is subject to specific amendment in accordance with Environmental Protection Agency guidance. Emergency Removal Actions address immediate, unacceptable hazards. Time-Critical Removal Actions respond to releases of contaminants into the environment requiring action in less than 6 months. Non-Time-Critical Removal Actions respond to releases or potential releases of contaminants that can start more than 6 months after a determination that a response is needed. A decision on whether to conduct a Time-Critical Removal Action, a Non-Time-Critical Removal Action, or a combination of both is usually made at the completion of the Preliminary Assessment or the Site Evaluation Phase of the environmental remediation process.[6]

6 See U.S. Army Corps of Engineers, Huntsville Division, "Removal Action Planning for Ordnance and Explosives Sites: Procedural Document," CEHND 1115-3-524, January 1995, Section 7.1.1, available: http://w2.hnd.usace.army.mil/oew/policy/cerctxt2.html and on file at IDA.

D. CLEARING UXO: SAFETY FIRST

DoD has summarized the technical challenge it faces in cleaning up UXO from military ranges and other current or former DoD facilities:

> Military Munitions are designed to injure or kill people, and/or to damage or destroy property. As such, Military Munitions are unlike any other product for which an environmentally based response might be otherwise appropriate. During any response activity, the presence or suspected presence of Military Munitions creates unique explosives safety challenges. Before undertaking any response action...DoD must first consider the explosives safety risks inherent in locating, investigating, evaluating, and responding to...areas where Military Munitions are known or suspected to be present. The explosive safety risk is equally great regardless of whether Military Munitions (including UXO) or Other Constituents are being addressed in the response action. Response personnel, even those specially trained to deal with the explosives safety hazards associated with Military Munitions, must not be exposed to an unreasonable explosive safety risk in order to address less compelling environmental concerns. The potential explosives safety risk to response personnel increases as the density of Military Munitions, e.g., UXO, increases. Additionally, rough terrain and thick vegetation restrict visibility and mobility, thereby substantially increasing the explosives safety hazards associated with response activities. Response activities are made more difficult and dangerous because technology is not yet sophisticated enough to ensure positive detection, identification, and subsequent removal of all Military Munitions in any given area.[7]

The Army Corps of Engineers, on behalf of the Secretary of the Army, is the DoD Executive Agent for the remediation of environmental problems at FUDS and acts as the lead agency in conducting restoration activities at eligible properties on behalf of DoD Components. It also acts as the lead agency in environmental restoration activities at operational installations, closing and realigning installations, and FUDS.[8] The Huntsville District, which hosts the Mandatory Center of Expertise (OECX), observes in its basic guidance that "there is no 'safe' procedure for dealing with UXO, merely procedures which are considered least dangerous."[9]

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7 "IV. Section-by-Section Analysis Paragraph C, Department of Defense Proposed Range Rule," dated 27 September 1996, available: http://denix.cecer.army.mil/denix/Webnotes; copy on file at IDA.

8 DoD Instruction 4715.7, "Environmental Restoration Program," dated 22 April 1996, available: http://www.dtic.mil/defenselink/publications; copy on file at IDA. Each service is responsible for clearing its own active ranges and clearing UXO.

9 U.S. Army Corps of Engineers Huntsville Center, "OE CX: Interim Guidance Safety Concepts and Basic Considerations for Unexploded Ordnance (UXO) Operations," Revised 16 February 1996, available: http://w2.hnd.usace.army.mil/oew/policy/safecon1.html; copy on file at IDA.

E. UXO CLEARANCE: FIELD PRACTICES

UXO is generally cleared by EOD specialists.[10] The following is an abbreviated list of the duties required of EOD technicians:

1. Detect explosive ordnance on the surface and subsurface (land only).
2. Identify explosive ordnance.
3. Render safe unexploded explosive ordnance.
4. Recover explosive ordnance.
5. Evacuate explosive ordnance.
6. Dispose of explosive ordnance.
7. Disassemble and render inert foreign explosive ordnance for technical intelligence.
8. Disseminate technical information on enemy explosive ordnance materials.

Although this list is usually applied to problems in a wartime environment, it forms the core focus of peacetime training. Use of EOD personnel to clear UXO on Military Ranges and to provide a range of emergency and time-critical removal action responses is also viewed as "training." Formally trained active duty and former military EOD specialists form the cadre of UXO-qualified personnel.

Before UXO-qualified personnel begin the process of physically clearing UXO from a site, a great deal of paperwork, study, and analysis is undertaken. The overall process outlined above in generic terms oftentimes begins with the discovery of UXO on or near the land surface. The process goes through a set of formal phases outlined below, culminating in either the destruction of the UXO in place or its removal for subsequent controlled destruction.

1. Phase 0: Discovery of UXO

The discovery of UXO comes about in many different ways. Table 3 summarizes the environments and common methods by which UXO is discovered.

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[10] For additional detailed information see the following documents:

AR 611-105, *Selection, Processing, and Training of Officer Volunteers for Explosive Ordnance Disposal Duty*, 3 September 1985; ARTEP 9-527-30-MTP, *Mission Training Plan for Ordnance Detachment, Explosive Ordnance Disposal*, 2 September 1993; ARTEP 9-527-MTP, *Mission Training Plan for Ordnance Detachment, Explosive Ordnance Disposal Control Team*, 8 September 1993.

Table 3. UXO Discovery and Initial Response (Peacetime Occurrences, CONUS)

Site Type	Discoverer	Jurisdiction	Emergency Response	Long-Term DoD Response
Active Military Range	Active Duty Military, Reserve Military, Contractor, Dependent; Civilian Who Has Made Unlawful Entry Onto Military Range	Military Service Responsible for Range	First Available EOD Unit if Emergency; Parent Service EOD if Not an Emergency	Parent Service
Inactive Military Range; DoD Facility	Active Duty Military, Reserve Military, Contractor, Dependent; Authorized Civilian; Unauthorized Civilian	Military Service Responsible for Range; Facility	First Available EOD Unit if Emergency; Parent Service EOD if Not an Emergency	Parent Service
Transferring Military Range; Transferring Military Facility within CONUS (BRAC)	Active Duty Military, Reserve Military, Contractor, Dependent; Authorized Civilian; Unauthorized Civilian	U.S. Army	Contractor Responsible for Environmental Cleanup; 52nd EOD Group per MOA	Parent Military Service; U.S. Army
Transferred Military Range; Transferred DoD Facility (FUDS)	DoD Contractor; Authorized Civilian; Unauthorized Civilian	Non-DoD Federal Agency or State/Local Civil Emergency Authorities	State or Local Law Enforcement EOD; U.S. Army upon request; First available EOD if an emergency	U.S. Army as Executive Agent for the Department of Defense

The Corps of Engineers, Huntsville Division (CEHND), has established an OECX within the Huntsville District responsible for providing consolidated guidance to all DoD Components on the proper handling of UXO. It is also responsible for coordinating emergency and nonemergency EOD unit responses among military units and civil law enforcement authorities where assistance is requested. Since it is often difficult to determine whether a newly discovered UXO item constitutes an imminent danger to the health and safety of persons or property, discovery is often treated as an emergency.

Figure 1 summarizes common decision routes by which responsibility for emergency response to initial discovery of UXO is allocated among local, state, and DoD authorities.

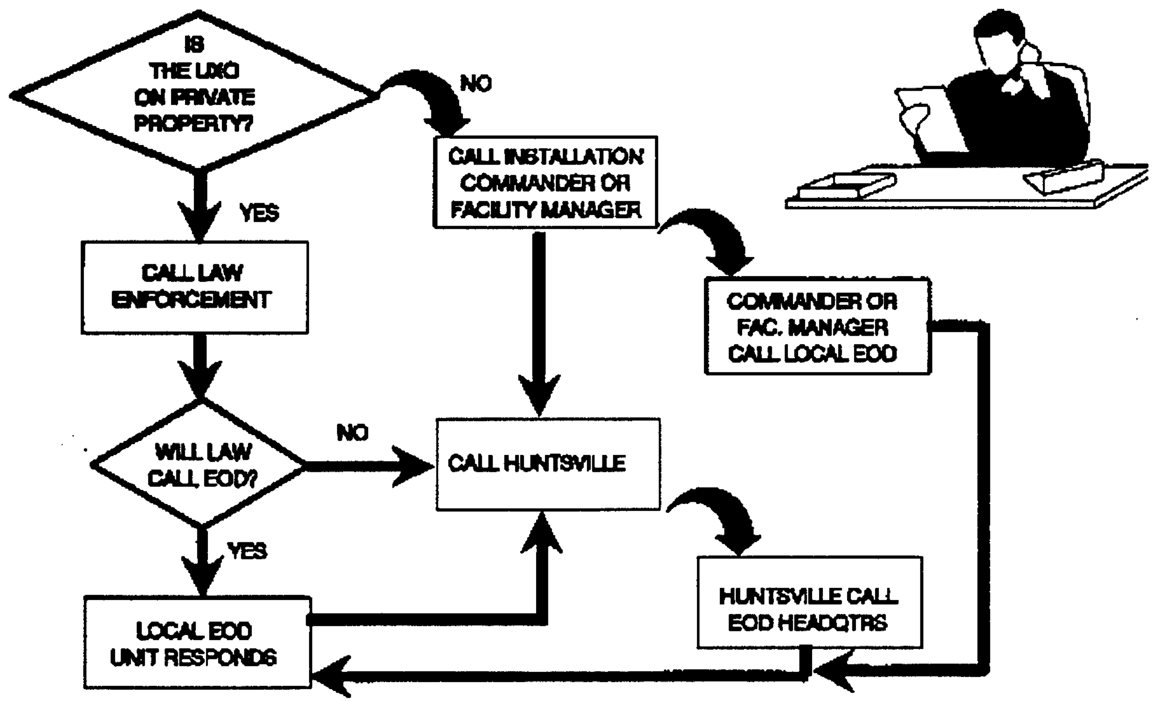

Figure 1. EOD Response Coordination[11]

Calls to the CEHND/OECX are essential, because it is able to help local authorities determine the specific identity of the UXO and whether an emergency rendering safe procedure (RSP) or removal of UXO is required. If an emergency situation exists, Huntsville Division will assist in coordinating the activities of military EOD units and securing necessary resources to protect health and safety. If there is no emergency, OECX will provide initial guidance on methods to secure the UXO site, prevent the development of an emergency situation, and initiate appropriate next steps. Those next steps depend upon the jurisdiction in which the UXO has been discovered but generally follow the generic outline above. The major differences in specific steps result from a determination that a Time-Critical or Non-Time-Critical Removal Action is required. In the case of a Time-Critical Removal Action, periods for public comment and lengthy public participation in the decision making process are abbreviated.

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[11] Extracted from "Ordnance and Explosive Waste (OEW) Mandatory Center of Expertise (MCX) Interim Guidance Regarding Coordination with Explosive Ordnance Disposal (EOD) Organization, Enclosure 1," CEHND-PM-0MC (385-16b), dated 14 December 1994, available: http://w2.hnd.usace.army.mil/oew/policy/coorencl.html; copy on file at IDA.

2. Phase 1: Preliminary Assessment

At some point in the life cycle of a present or former DoD facility, it becomes appropriate to examine continuing need for the facility. At that time, an assessment is often begun for the purpose of understanding what activities may have taken place over the life of the facility and the impact of such activities on the health, safety, and environment of the surrounding area. If the facility had previously been associated with ordnance, explosives, or explosive waste as the result of RDT&E, manufacturing, or stockpiling activities, there is a strong possibility that environmental remediation and/or restoration activities will be required. Such requirements might arise under the IRP (the DoD "Superfund" program intended to bring DoD pollution of its neighboring territories under control) or from realignment or conversion of the DoD facilities.

During the Preliminary Assessment Phase, a rigorous search of all known records of an installation is undertaken.[12] A records search is conducted to gain as much information as possible about the types, quantities, and distribution of ordnance that can be expected on the site. The methods used and the reliability of these record searches vary greatly depending on the circumstances. Searches can take only a few days or up to 6 months. Some sites have complete and accurate records that go back several decades, whereas others have more haphazard records.[13] In some cases, records are practically nonexistent and information must be obtained from indirect sources, such as interviews with personnel that once worked on a particular site. The accuracy of the records also varies a great deal.

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12 See http://dogbert.ncr.usace.army.mil/ceteam/asr.htm [Online] for an excellent overview of the Archive Search Report process, including an abbreviated discussion of the principles and benefits.

13 See, for example, *Ordnance and Explosive Waste Archives Search Report for Assateague Island, Worcester County, Maryland, and Accomack County, Virginia,* by the U.S. Army Corps of Engineers, Rock Island District, and the U.S. Army Defense Ammunition Center and School, dated June 1994. See also *Ordnance and Explosive Waste Archives Search Report for the Former Bluebonnet Ordnance Plant, McGregor, Texas,* by the U.S. Army Corps of Engineers, Rock Island District, and the U.S. Army Defense Ammunition Center and School, dated April 1994. This document is accessible from the U.S. Army Corps of Engineers server maintained as part of the Corps of Engineer's efforts to support the Defense Environmental Remediation Program (DREP).

In the case of active ranges, records generally have been kept for about the last 20 years. Ordnance that was fired before that time is often not recorded.[14] Current procedures require a unit to supply paperwork describing the quantities and types of ordnance that will be fired on each range prior to use. However, this was not always the case. Furthermore, the quality of records varies widely, even among ranges with similar missions. Army Corps of Engineer records of Ordnance and Explosive remediation efforts[15] and EOD personnel identified the following general trends in record keeping:

- The least busy ranges generally have the best records.
- Chemical weapons testing has always been well documented, even for ordnance that was fired before current requirements mandating ordnance records were in place.[16]
- Records are usually more accurate for routine maintenance cleanup, since a Military Range or base generally has accurate information about what has been fired in the approximately 1-year time span between subsequent sweeps. Records from more than about 20 years ago can be sparse, inaccurate, or both.
- Test and evaluation ranges tend to have fairly complete records. Records are generally very good for developmental tests of small numbers of items. For example, EOD personnel identified White Sands as an example of a base having records that are detailed and complete. Such records generally give the EOD personnel the information they require in a short time frame, usually only a few days.
- Record keeping associated with historic ordnance waste disposal on base is frequently incomplete, inaccurate, or nonexistent. In years past, ammunition

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14 See, for example, the discussion of the 1991 Preliminary Assessment of Assateague Island in U.S. Army Corps of Engineers Rock Island District, and U.S. Army Defense Ammunition Center and School, *Ordnance and Explosive Waste Archives Search Report for Assateague Island, Worcester County, Maryland, and Accomack County, Virginia* (Project Number C03MD093001, June 1994), Section 2, available: http://dogbert.ncr.usace.army.mil/military/derp/fuds/projects/ASSATEAG/oew /asr/ findings/dp09toc.htm#sec1 ; copy on file at IDA.

15 See, for example, records of selected Army Corps of Engineers ordnance and explosive waste remediation archive record searches for the following facilities: Assateague Island, Maryland, and Virginia (cited above); Bluebonnet Ordnance Plant, McGregor, Texas, available: http://dogbert.ncr.usace.army.mil/military/derp/fuds/projects/bluebone/bluebone.htm); Camp Croft, Spartanburg, South Carolina, (available: http://dogbert.ncr.usace.army.mil/military/derp/fuds/projects/cmpcroft/cmpcroft.htm); Camp Greene, Charlotte, North Carolina (available: http://dogbert.ncr.usace.army.mil/military/derp/fuds/projects/cmpgreen/cmpgreen.htm); and Culebra Island National Wildlife Refuge, Culebra, Puerto Rico (available: http://dogbert.ncr.usace.army.mil/military/derp/fuds/projects/culebra/culebra.htm).

16 See, for example, Volume I, Archives Search Report and Appendices A–F, Supplemental Archives Search Report, Preliminary Assessment of Chemical Warfare materials at the Former Black Hills Army Depot, South Dakota (available: http://dogbert.ncr.usace.army.mil/military/derp/fuds/projects/black_hi/black_hi.htm).

was often disposed in burial pits, the locations of which were not accurately recorded or records of which were not preserved. Current regulations prohibit these practices, but locating and cleaning up the residue from the past is a challenge DoD must meet.

- Sometimes ordnance inadvertently landed outside the desired impact area without being observed or, if observed, without having been recorded.

The EOD personnel with whom we spoke stressed that immaculate records do not necessarily correspond to conditions found in the field. There can be uncertainties in what, where, and how much ordnance is found, even on ranges with "good" records. Other problems with documentation may arise under special circumstances. For example, allied troops conducting training on American ranges with foreign-made ammunition may not record their activities with the same degree of rigor and accuracy as U.S. forces. Testing of special ordnance that is not yet in the inventory and firing foreign ordnance for technology exploitation may also result in incomplete range use documentation. Intelligence and special operations activities may leave incomplete records of range use, consistent with the requirements of operations security associated with their activities. These situations can often leave UXO-qualified personnel without complete information about what to expect when entering a range or other DoD facility for the purpose of clearing UXO.

The development of new information processing technology and techniques holds out the promise of making record searches in support of UXO clearance and other environmental remediation efforts much more efficient and effective. The Corps of Engineers is integrating a Geographic Information System (GIS) image processing system and database as part of its Ordnance and Explosive Waste (OEW) clearance program. The information system is part of the Corps FUDS program. This approach integrates information from a variety of historical sources and records searches. For example, maps from the National Archives and the U.S. Geological Survey (USGS) can be used to catalog past uses of a DoD facility. Present maps, showing current structures and geographical features, can be overlaid on these historical maps. Engineers can compare and contrast current structures and activities with past uses of the installation. This reduces the area to be subjected to a detailed site survey by focusing efforts on areas with a high probability of ordnance contamination. Projects at Fort Monroe and Camp Simms have demonstrated the use of this approach with good results.

The use of historical records in defining the characteristics of a site on which UXO contamination may be present is important but should not be overstated. There seems to be a perception in the sensor development community that copious quantities of accurate, reliable, and complete historical information for each site of possible UXO contamination are available. Sensor developers often suggest that their products will work well when tuned to a particular ordnance type, implying that the UXO-qualified personnel engaged in clearing operations will know with precision which type of ordnance to expect or, alternatively, that only ordnance of a particular type will be encountered when clearing a specific range. We spoke with the EOD personnel who had experience in range clearing and UXO clearance at FUDS locations. They confirmed that record searches were usually not entirely accurate in characterizing the UXO actually found during clearing operations.

3. Phase 2: Remedial Investigation/Engineering Evaluation

After the completion of a Preliminary Assessment of a site, including a detailed historical survey, a detailed assessment is undertaken. The Site Survey phase is conducted by UXO-qualified and support personnel for the purpose of trying to locate UXO, characterize its condition, and gain additional, site-specific information necessary to draw up detailed engineering alternatives. Detailed site surveys are intended to fulfill the following purposes:

- Identify most likely areas of anomalies indicating UXO or other contamination.
- Develop specific requirements for equipment, materiel, and specialized additional support personnel.
- Detect the presence of additional hazardous materials, structures, utilities, antiquities, or the remains of other human activity that may not have been adequately described in the archive search reports.
- Develop a detailed health and safety plan, including emergency medical and materiel response plans in the event of accident or contamination.

During the early field investigation phase, several 100 meter by 100 meter plots will be marked and searched to develop an estimate of the total contamination on the site. UXO-related procedures, including the location and marking of subsurface anomalies and the location and marking of suspected surface UXO, will be performed during investigation of these sample plots. These activities may be performed by either UXO-qualified personnel or others who are not UXO qualified. Certain UXO procedures may also be undertaken, including (1) gaining access to (manual excavation) and identifying subsurface anomalies and assessing condition of buried UXO and (2) identifying and assessing the condition of surface UXO. Only UXO-qualified personnel (who may be uniformed military personnel or civilian munitions destroyers) are allowed to perform these UXO procedures.[17]

The Site Survey results in the collection of detailed information which will confirm the findings of the Archive Records Search and Preliminary Assessment, expand upon them (in terms of munitions types, condition of UXO, etc.), and provide additional data needed to accurately gauge the most effective routes to removal of UXO and other contaminants on the site. These alternatives are developed in subsequent phases of the environmental/installation remediation/restoration action.

4. Phase 3: Feasibility Study/Cost Analyses

A second round of studies, analyses, and site surveys may be required to arrive at a set of feasible environment restoration/remediation alternatives which can be examined for cost and schedule implications. Substantial additional site surveys, investigations into the actual condition of UXO, and location and marking of subsurface anomalies may be required. This phase of UXO clearing is almost always undertaken in environmental restoration activities associated with either IRP or BRAC actions. It may also be included in FUDS cleanup where emergency actions are not required.

5. Phase 4: Removal Design (Explosive Safety Submission)

Following completion of the initial phases of UXO clearance, and the selection of an approach to the elimination of UXO contamination, a detailed Removal Design and Safety Plan is prepared and submitted to the Headquarters, Corps of Engineers, and the DoD Explosives Safety Board. Preparation of the Removal Design and Safety Plan may require additional site visits and extensive exploration to further identify types of UXO and constituents present, their overall condition, other hazards or potential hazards commingled with the UXO, and the response capability of the facility and its surrounding environment in the event of an accident or environmental hazard release during UXO contamination removal.[18]

Embedded within the Removal Design and Safety Plan is a detailed Health and Safety Plan. This document outlines the specific proposed measures that will be carried out

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17 See Reference 9, paragraph 3. Definitions.

18 The specific standards for the health and safety plan are set forth in Occupational Health and Safety Administration (OSHA) standards published at 29 CFR 1910.120 and 1926; and U.S. Army Corps of Engineers, EM 385-1-1, *Safety and Health Requirements Manual*.

during the day-to-day process of UXO clearance operations. The broad outline of the Health and Safety Plan is the following:[19]

1. Site Description and Contamination Characterization.
2. Hazard/Risk Analysis.
3. Accident Prevention.
4. Staff Organization, Qualifications, and Responsibilities.
5. Training.
6. Personal Protective Equipment.
7. Medical Surveillance.
8. Exposure Monitoring/Air Sampling Program.
9. Heat/Cold Stress Monitoring.
10. Standard Operating Safety Procedures; Engineering Controls and Work Practices as Appropriate.
11. Site Control Measures.
12. Personal Hygiene and Decontamination.
13. Equipment Decontamination.
14. Emergency Equipment and First Aid Requirements.
15. Emergency Response and Contingency Procedures (On Site and Off Site).
16. Logs, Reports, and Record Keeping.

Much of the work undertaken to perform the Preliminary Assessment and to prepare other Engineering Evaluation, Feasibility, and Cost Estimate documents would be directly applicable to the preparation of the Removal Action and Safety Plan and the subordinate Health and Safety Plan. However, further UXO procedures may be required on the initial sample area to acquire all information needed to prepare the safety and health plan for decontamination of the site.

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[19] This is based on "Appendix B, Safety and Health Elements for HTRW Documents," in U.S. Army Corps of Engineers, Engineer Regulation 385-1-92, Safety and Occupational Health Document Requirements for Hazardous, Toxic, and Radioactive Waste (HTRW) Activities (Washington, D.C., 13 December 1991).

6. Phase 5: Removal Action

Months after the initial discovery of UXO, a detailed plan for the removal of UXO contamination at a site has been prepared and reviewed by government and citizen groups, and resources have been marshaled to restore the environment. The removal actions now proceed with full-blown UXO reconnaissance—detailed survey of the entire site.

During the course of conducting a detailed site survey, special care must be exercised to avoid contact with camouflets, small underground cavities formed when ordnance penetrates the earth to a depth where the force of the explosion is insufficient to rupture the earth's surface. Camouflets are filled with carbon monoxide gas and other end products of ordnance explosion and can be very dangerous to personnel seeking to clear UXO.

Access to the detected UXO is gained by UXO-qualified personnel by excavation using power equipment, powered hand tools, or by hand in accordance with the Removal Action and Safety Plan. The identity of the munition is verified. The type and condition of the fuzing and arming mechanisms, the condition of explosive materials in the munition, and the condition of other materials within the munitions case are evaluated.

The UXO-qualified specialist then examines the surrounding environment to determine whether the safety of the UXO clearance team and other personnel would be endangered from an unsuccessful in-place Render Safe Procedure (RSP). Even though these issues have been addressed in the extensively documented Removal Action and Safety Plan, variations from the expected conditions based on preliminary assessments and site surveys to the specific conditions on hand require constant attention to safety.

The preferred method of UXO clearance is disposal in place by detonation. If this cannot be accomplished, open burning of explosives and smokeless powder, or chemical decomposition of explosives may be allowed, but prior approval of the contracting officer is required. If necessary, UXO may be transported off site for proper disposal. If transportation is required, UXO must be treated as hazardous cargo in accordance with 49 CFR 100-199, DA Pam 385-64, and relevant state and local laws.

F. UXO CLEARANCE: SUMMARY

This chapter summarizes the general processes by which UXO contamination comes to light and is dealt with within CONUS by DoD Components.

Within CONUS, the primary focus of UXO cleanup has been on ferrous and non-ferrous metal munitions and chemical components. A 1995 Congressional Budget Office study observed the following:

> Cleaning up unexploded ordnance and chemical warfare materials is among the most difficult, dangerous, time-consuming, and expensive tasks DoD faces. The U.S. Army Corps of Engineers has identified almost 1,700 sites on which these hazardous materials have been reported.
>
> Current technology to remediate buried ordnance is time consuming and costly. Most ordnance sites are surveyed by operators on foot using hand-held metal-detecting equipment. Bulldozers and specially protected heavy equipment are used to dig up buried ordnance and transport it to facilities where it will be de-armed or exploded.... DoD recently estimated that, using current technology, it costs about $65,000 per acre to survey and remediate a site with unexploded buried ordnance. The Army Crops of Engineers estimates that tens of thousands of acres will require remediation. Cleanup costs for buried ordnance and chemical warfare materials could total several billion dollars.[20]

The key to accelerating the pace of CONUS cleanup and reducing its overall cost to DoD, while accelerating the transfer of surplus DoD facilities to others, may be found in developing new technology which is better able to detect, classify, and identify buried objects as UXO requiring remediation. We turn to a consideration of the technology needs of the UXO remediation community.

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20 See Congressional Budget Office, *Cleaning Up Defense Installations: Issues and Options*, (Washington, D.C., CBO, January 1995), downloaded from the Internet but no longer available, copy on file at IDA.

III. NEEDS OF THE UXO REMOVAL COMMUNITY

In this chapter we report on a set of emerging technical needs that successful UXO detection technology should be able to meet.

It is important to bear in mind that the ESTCP is a DoD demonstration and validation program. It is therefore obliged to consider operational, maintenance, and training requirements or implications of technology included in its demonstration and validation activities. While the potential concepts of operation, training, maintainability, and reliability issues need not be completely resolved during field demonstrations, the impact of these considerations on users has a strong bearing on their receptiveness to participate in a demonstration/validation (dem/val) program and to lobby on behalf of an emerging technology that represents a technical advance. Those technologies which demonstrate promise in narrow technical parameters but do not relieve operational, logistical, or training burdens on operators do not, as a general rule, survive in the acquisition process

IDA staff met several times with DoD EOD Program Managers and trainers because DoD-trained EOD personnel constitute virtually the entire current and near-term pool of UXO-qualified personnel. We wished to better understand the operational needs for and impediments to the adoption of new UXO detection technology for peacetime, CONUS-based UXO clearance from the perspective of the EOD community. Our goal was to assess the ESTCP UXO Technology Demonstration Plan and offer suggestions and recommendations that took concerns of field-level operatives into consideration. We did not address substantive resource management questions in detail because those larger policy and personnel issues are well beyond the scope of this task. Nevertheless, in focusing on the development of technology and testing methods to use existing resources more efficiently, we learned of policy and technology concerns of users that will have an impact on the ultimate acceptance of and insertion of new UXO detection technology into DoD activities. The following discussion summarizes these concerns as well as the technical performance needs of the UXO community.

A. POLICY AND HUMAN RESOURCES

The ability to clear UXO from DoD facilities and FUDS within CONUS is limited, at least in part, by the availability of UXO-qualified personnel. Current DoD policies allow non-UXO-qualified personnel to perform the following functions associated with removal of UXO contamination from active DoD facilities or FUDS:

- Location and marking of subsurface anomalies.
- Location and marking of suspected surface UXO.
- Transportation and storage of recovered UXO.
- Utilizing earth-moving machinery (EMM) to excavate soil to no closer than approximately 12 inches of a subsurface anomaly.

UXO-qualified personnel must carry out the following functions:

- Gaining access to (manual excavation) and identifying subsurface anomalies, and assessing condition of buried UXO.
- Identifying and assessing condition of surface UXO.
- Recovery and final disposal of all UXO.[1]

Reallocation of responsibilities from UXO-qualified to non-UXO qualified personnel or expanding the number of UXO-qualified personnel through reliance on civilian training programs might have some positive effect on the shortage of personnel trained in UXO clearance. To the extent that UXO clearance is limited only by the availability of UXO-qualified personnel, these policy options might be worth assessing in detail.

However, discussions with UXO technology users led us to conclude that the development of new UXO detection technology will not lead to insertion and acceptance of by the user community unless it offers operational advantages. Users told us that improvements in safety, reliability, ease of maintenance, and ease of use would be important factors in their decisions to accept new technology in fielded UXO detection systems. The impact of new technology on training requirements, maintenance burden, and non-time-critical response might become a salient issue and a barrier to the acceptance of demonstrated UXO detection technology in the future.

Based on our review of existing literature, as well as discussions with EOD personnel at DoD ranges, we believe improvements in UXO clearance efficiency require improvements in two technology areas which translate immediately into improved safety for personnel involved in UXO clearing operations. Increases in detection capability accompanied by improvements in the ability to discriminate hazardous ordnance from other debris will be well received by users. Further, minimization of false alarms of all types

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1 See U.S. Army Corps of Engineers, Huntsville Division, "Interim Guidance Safety Concepts and Basic Considerations for Unexploded Ordnance (UXO) Operations," Revised 16 February 1996

will also be perceived as an operational advantage compared to present technology. Accomplishing these technical objectives will improve the overall efficiency of UXO clearance.

B. SENSORS

The primary sensor used by EOD technicians to detect UXO today is the magnetometer. Active sensors such as induction coils and ground-penetrating radar (GPR) are also used on occasion. EOD personnel expressed concerns that the signals emitted from active devices could trigger electronic fuzes, especially whenever fuzes have been damaged. There appears to be poor understanding of the possible interactions between UXO detector sensors and fuzes among the EOD and the UXO detection communities. The possibility of deliberate or accidental initiation of arming and fuzing actions in UXO as a consequence of active sensor UXO should be addressed during the development of any active sensor system.

The magnetometers most commonly used in UXO work today typically give the technician many targets to evaluate, but the vast majority of these are from debris rather than ordnance. Personnel involved in the detection, marking, and identification of UXO need a sensor that can distinguish the actual hazards from debris, so targets can be evaluated and appropriate courses of action chosen. A sensor that could provide information about the shape of the object, whether it was intact, whether it contained high explosive, and whether the fuzing was active would be nearly ideal.

The development and fielding of such an ideal sensor may be years away. In the near term, incremental improvements in performance for detection and discrimination of targets and debris would be valuable. The Jefferson Proving Ground demonstration established a baseline performance level for a variety of currently available and emerging technologies.[2] The most successful demonstrators achieved probabilities of detection (*Pd*)

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2 PRC, Inc., *Demonstrator Work Plan for UXO Detection, Identification and Remediation Advanced Technology Demonstration at the Jefferson Proving Ground, Indiana* (NAVEODTECHCEN Contract No. N00600-88-D-3717, 1994); U.S. Army Environmental Center, *Unexploded Ordnance Advanced Technology Demonstration at Jefferson Proving Ground (Phase I)* (prepared by PRC, Inc., Report No. SFIM-AEC-ET-CR-94120, December 1994); M. Mulqueen, V. George, A. Andrews, D. Sparrow, and R. Dugan, "Performance Assessment at the Jefferson Proving Ground Demonstration of Systems for the Detection and Identification of Buried Unexploded Ordnance," *SPIE Proceedings*, April 1995; U.S. Army Environmental Center, *Evaluation of Individual Demonstrator Performance at the Unexploded Ordnance Advanced Technology Demonstration Program at Jefferson Proving Ground* (prepared by the Institute for Defense Analyses, Report No. SFIOM-AEC-ET-CR-95033, March 1995); Institute for Defense Analyses, *Demonstrator Performance at the Unexploded Ordnance Advanced Technology Demonstration at Jefferson Proving Ground (Phase I) and Implications for UXO Clearance*, IDA Paper P-3114, 1995.

of about 70 percent and one or more false alarms per ordnance item detected. The EOD technicians with whom we spoke indicated that this capability, although far from ideal, would be useful to them. For example, they specifically indicated that a map of the range with a known and reasonably high *Pd* (70 percent) would direct them to specific locations of anomalies to be investigated—a tool they do not now have.

In general, the EOD technicians with whom we spoke seek a sensor that will let them do their jobs better, faster, or more safely than at present. They do not necessarily want a silver bullet that claims to solve all of their problems at once. Rather, they would find value in sensors directed at specific problems that can do one job well. For example, a sensor that could detect UXO in very rough or heavily vegetated terrain, where UXO reconnaissance is very difficult, even on foot, would be very helpful. For such a developmental sensor to be of value, however, substantial documentation describing the effect of weather, depth of UXO, size of UXO, ambient environmental conditions, etc., on sensor performance would also have to be provided. The total data package would ensure that technicians neither overestimate nor underestimate the effectiveness of the sensor when examining data collected from it.

Of the three goals—"better, faster, more safely"—EOD personnel consider doing their jobs more safely to be the most important. The EOD personnel with whom we spoke indicated that the majority of accidents are caused by human error during the UXO removal phase of response actions.[3] Unfortunately, our interviewees found no common faults which could account for accidents in their personal experiences. There was no single piece of information that could be identified by our interviewees that would have averted accidents had it been provided by a sensor.

New technology incorporated into new tools that can reduce the likelihood of accidents is most likely to be adopted by the EOD community. Since most accidents occur after UXO has been detected, improvements in remote identification of UXO and its in situ characterization are improvements most likely to yield benefits in terms of personnel safety. Knowing the specific munition, the condition of the arming and fuzing mechanisms, the condition of the explosive material contained within the munition and its immediate environs, the nature of the material adjacent to the munition, and the material in the surrounding area would allow UXO-qualified personnel opportunities to minimize

3 It should be stressed that this information was taken from a relatively small number of EOD personnel. It is possible that accidents share more in common than those of this group's experience.

excavation of UXO before having specific render safe/disposal/removal plans for each UXO target in hand.

C. COMMUNITY ACCEPTANCE

The most important question in designing a test of this equipment is, "What information does the user need to establish the utility of this technology?" When we asked this question of EOD technicians, there was substantial agreement that they would first like to see a controlled test done on a live range. Such a test would have some ordnance emplaced with known ground truth so that there is a measure of detection capability. This test should be followed by a demonstration also on a live range in circumstances similar to those under which the technology would ultimately be used.

The EOD community would like to test the equipment in a test and evaluation (T&E) unit made up of EOD personnel. Some of the more important questions that should be addressed are the following:

- What is required to establish and maintain user competency?
- What kind of ancillary support (power, cooling, transportation) is required to sustain the equipment?
- What circumstances are stressing to the equipment?

Finally, EOD personnel are interested in an assessment similar to a Cost and Operational Effectiveness Analysis (COEA) to establish time between failure, cost, servicing requirements, and so on.

The EOD community emphasized the need for controlled data collection and analysis with independent verification and validation of claims regarding successful detection of UXO and discrimination of UXO from other debris. We came away from interviews with the distinct impression that the EOD community felt victimized by developer claims which turned out to be false.

There was also some discussion regarding the desirability of operating UXO detection systems in a manner consistent with current practices and sound safety practices. Much UXO activity undertaken today by EOD personnel is regarded as training for EOD wartime missions. To the extent that such training compels development of man-portable UXO detection systems, the ESTCP technology demonstration does not lend itself to the development of new combat support equipment. However, since UXO clearance for IRP, BRAC facilities, and FUDS does not generally relate directly to wartime EOD missions, the

ESTCP technology demonstration may have only limited immediate relevance to formal EOD technology requirements as promulgated through the JCS/CINC process.

On the other hand, high costs and pressing resource demands for efficient, reliable UXO detection in support of range clearance, installation rehabilitation, closure and transfer of installations as a result of the BRAC process, and clearance of UXO at FUDS are compelling arguments for continued DoD investment in UXO detection technology demonstrations. Furthermore, if a technology can meet the information needs for UXO detection, discrimination, identification, and characterization in the IRP/BRAC/FUDS environment, it may pave the way for the development of similar technology packaged to meet the needs of combat EOD units. Hence, the ESTCP technology demonstration remains an important facet of DoD's ongoing RDT&E efforts to meet current and future combat technology needs.

IV. TEST DESIGN

This chapter incorporates the lessons learned at previous UXO detection technology demonstrations, with the types of information that UXO-qualified personnel find useful in assessing a new technology. It draws heavily upon the UXO detection experiments conducted at the Jefferson Proving Ground, Indiana. This section summarized the user needs that might be addressed with new technology or new systems and outlines the design of technical tests to collect data addressing the MOEs of interest to EOD personnel. We will sketch how the issue of training load vs. system effectiveness can be addressed in these tests. In addition, there are known pitfalls in any demonstration of this type. We will review some of the dangers and their remedies. Finally, no real-world test with constrained resources will suffice to answer all the questions one might ask. Hence, we will close with recommendations for questions that will probably need a parametric study or COEA-type study.

A. QUESTIONS TO BE ADDRESSED

The two most important measures of performance for a detection system are the probability of detection of an object and the probability of detecting a "real" object versus the probability of detecting a "false" target. When a detector reports a target, it is not immediately obvious whether the report is a hit (a real target) or a false alarm. For example, how near must the hit be to a target object to count as a detection?

There is also a question as to the definition of a false alarm. Some believe that detecting a man-made nonordnance object that falls within the sensor detection parameters should be counted as a hit even though exploitation of the data would result in the excavation of a nonordnance, nonhazardous item (and the consumption of scarce human and material resources). Just because a sensor works within design parameters and reports a buried object does not mean that it has detected UXO. Accordingly, we recommend that all nonordnance detections be counted as false alarms.

From an operational point of view, all resources spent recovering nonhazardous items are wasted. It is therefore useful to distinguish man-made, nonordnance items from "natural" false alarms. This information will be important if results are to be extrapolated to predict performance at other locations. The extrapolation will be greatly aided by background data taken on uncontaminated sites. The ability to distinguish man-made, nonordnance items from naturally occurring ferrous materials which generate false alarms will also be helpful in planning further environmental remediation/restoration efforts as may be required, depending upon the future uses of the sites from which UXO is being cleared.

The question of labeling false alarms is of more than academic interest. In a commercial sweep of an area near the Chocolate Mountain Bombing Range, 393 anomalies were detected, 4 of which proved to be ordnance items (bombs). NRL personnel were present for the examination of 116 anomalies, 97 of which had their source identified by excavation and 19 of which did not. Scaling to the full site, there were 4 ordnance items, 325 identified nonordnance anomalies, and 64 mysterious anomalies. This results in 389 detector declarations resulting in excavations without recovering an item of ordnance. This is the number of false alarms according to the definition proposed.[1]

There are a number of operational issues that the technology demonstrations could illuminate to stimulate performance of further analyses, including:

- Quantity and quality of support equipment and infrastructure required to maintain the operability of the sensors in the field.
- The number of support/maintenance personnel required (both DoD and contractor) for sustained operation of the sensors.
- Logistics associated with the movement of the sensors and supporting infrastructure from one CONUS site to another (deployability).
- Training requirements/integration of sensor into existing EOD courses for operators and maintainers.

B. DATA COLLECTION AND MEASURES OF PERFORMANCE

It is important to develop protocols for data collection and reporting that allow appropriate comparisons and contrasts among different demonstrations to be made. In some instances, different demonstrations will seek answers to questions which result in data that cannot be readily compared to data from other demonstrations. In other instances, however, different demonstrations will explore the same phenomena, resulting in data that

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1 McDonald, J.R., and R. Robertson, *Evaluation of the Trimble DGPS Navigation System, Chocolate Mountains Bombing Range: A Magnetometer Survey for a Gas Transmission Line Southern California Gas Company; Project 6902*, Naval Research Laboratory, NRL/PU/6110-94-260, July 8, 1994, pp. 44–46.

lends itself to cross-demonstration comparison and analysis. The following discussion seeks to structure questions and answers so that data can be gathered in ways that are useful to both users and developers whose perspectives on technology demonstrations may be very different.

There are two principal types of tests of a detection system: (1) tests designed to gather data on the *operational characteristics* of the sensor to produce better understanding of its performance, and (2) tests designed to gather data on the *operational performance and techniques of sensor employment* to determine its utility. The information requirements for each type of test are very different.

Tests of operational characteristics (sensor phenomenology) require extensive information about the locations and types of test objects, as well as the local geology and conditions, so that the sensor response can be understood.

Tests of operational performance and techniques of sensor employment require that the operator have no information about the ground truth and that there be no interaction between the demonstrator and the evaluator, so that the utility of the sensor can be evaluated without bias. We will concentrate primarily on a test of the sensor utility.

There are three reasons for emphasizing tests of operational performance and technique:

1. The ESTCP goals emphasize demonstration of field-ready technologies; even if enhanced UXO detection technology is not sufficiently advanced for immediate transition to the field, the program should pull the technology towards this goal by virtue of test design and evaluation.
2. UXO-qualified personnel need performance data and operational information to better judge the utility of a technology or system for their jobs; scientific or engineering data on sensor performance is not immediately useful or relevant to users.
3. Tests focusing on sensor phenomenology often require use of proprietary data or other data closely held by the developers and their government sponsors, which makes widespread analysis and discussion of the test results more difficult.

The most important measures of performance of UXO detection systems are the following:

- Probability of detection.

- Ability to discriminate ordnance and nonordnance items among detected targets.
- False-alarm rates.

A high probability of detection capability is important in the efficacy and efficiency of a UXO cleanup: obviously, locating more ordnance allows one to mitigate more risk. Discrimination ability and false-alarm rates affect the amount of time spent at one site, the number of excavations performed, and the overall cost of a cleanup. To clean a site, resources must be expended to destroy UXO in place or to remove it. Any resources expended removing debris or investigating other false alarms are, in a sense, wasted. The EOD personnel interviewed indicated that good discrimination ability could have a large impact on the efficiency of most cleanups, because well over half of the objects they investigate are not intact ordnance.

There are a number of variables that may affect the detection ability and false-alarm rate of a sensor. Among these variables are the following:

- Size, shape, and condition of UXO.
- Attitude of UXO and depth of burial.
- Geographical and geological conditions surrounding UXO.
- Past and current human activity in the vicinity of UXO.
- Operating conditions at the time UXO reconnaissance is undertaken.

The effects of these variables on sensor operation and technique need to be quantified. For example, some sensors may be better suited to detecting certain types of ordnance than others. Some sensors may perform better on UXO that is oriented closer to the horizontal than the vertical, regardless of the type of UXO in question. Some sensors might work better in certain soil conditions than in others; some sensors might work better than others in areas where there is a great deal of "clutter" comprised of man-made nonordnance items. Some sensors might be better at discriminating among detected items, while others might be better at merely detecting the presence of an object without necessarily being particularly good at discriminating among targets.

To establish the reproducibility of results across many conditions, tests need to be done in a variety of conditions representative of areas where the sensor is proposed for use. Furthermore, the consistency and reliability of the sensor, in general and under various operating conditions, is important. Data about failure mode, time between failure, and the time required for repair should also be collected, preferably while the sensor is being used by UXO-qualified personnel.

The capability of a sensor to classify targets when multiple target types are present is next in importance after probability of detection and false-alarm rate. Although classification is likely to be problematic for all of the systems currently being developed under ESTCP, sensor performance data should be collected and reported in a standard fashion. The analog to *Pd* and false alarm rate (*Pfa*) for target classification is the so-called confusion matrix. As illustrated in Figure 2, the columns indicate the demonstrator's identification of ordnance type. The rows indicate true ordnance type. In the example presented, the demonstrator attempted to distinguish bombs and mortar rounds. Five bombs were detected. Of these, four were identified as bombs and one was identified as a mortar round. Ten mortar rounds were detected. Seven were identified as mortars and three were identified as bombs.

	Called Bomb	Called Mortar Round
Is a Bomb	4 (80%)	1 (20%)*
Is a Mortar Round	3 (30%)	7 (70%)*

* Row entries must sum to 100%.

Figure 2. Illustrative Confusion Matrix for UXO Target Classification

Location and navigation ability will influence the resources that are consumed in investigating each identified UXO item. The ability to accurately locate a target, both in horizontal space and in distance below the surface, may also help in choosing the appropriate tools for excavating, inspecting, and removing the detected item. Further, the ability of a sensor to resolve closely spaced targets is important. UXO-qualified personnel need to know whether the anomaly is a single object or a group of objects; if a group of objects are in the target, knowledge of how many objects are in the target is also important.

C. DATA ANALYSIS

Determining probability of detection and false-alarm rate requires a method of scoring demonstrator declarations (of locations believed to contain ordnance) to separate detections from false alarms. This can be a nontrivial issue if false alarms are dense or if a system, even with good detection capability, suffers from poor navigation.

One can envision several ways of pairing up targets identified by the demonstrator as ordnance with emplaced items. The entire field can be optimized by pattern matching, where the detections and the emplaced items are overlaid to produce the maximum overlap. This is straightforward if false alarms are sparse, but difficult if they are frequent. Furthermore, such pairing ignores a demonstrator's absolute ability to locate targets. Locating targets precisely is very challenging, especially for airborne platforms.

The other option is to choose an absolute requirement of separation distance. Only those declarations that fall within this separation distance from an emplaced item would be counted as a detection. This has a more stringent location requirement, which may be difficult for airborne platforms to meet. Also, it will generally confuse the measure of detection ability with navigation accuracy.

To understand the performance of the sensor over its range of operation, a receiver operating characteristic (ROC) curve is often employed. The ROC curve is determined by measuring probability of detection and false-alarm rate at several thresholds of the sensor's sensitivity. Good sensor performance means large increases in probability of detection for modest increases in false alarms at initial sensor performance threshold. As the sensor sensitivity thresholds are increased, there is a crossover in performance. Small increases in the probability of detection result in increasingly larger false-alarm rates. At some point, even small increases in sensor sensitivity result in only minimal increases in the probability of detection but very large increases in false alarms. With a ROC curve one can compare two sensors over their operational range without worrying about whether the results are dependent on different threshold settings for the two sensors. Furthermore, a ROC curve will be more broadly applicable in assessing utility since different regions of the ROC curve will be important for different clearance activities.

D. RECOMMENDED MEASURES OF PERFORMANCE

In light of the above concerns, we recommend use of the following measures of performance: probability of detection, false-alarm rate, discriminant capability, location accuracy, and system reliability/maintainability. We realize that individual tests may not support all of these measures and that additional measures may also be appropriate for certain tests. However, this core of measures (with terms defined below) will produce data that—although it may not perfectly reflect the performance of a given sensor in a way that is agreeable to all—will be comparable among tests.

- *Probability of Detection:* This measure is needed as a function of ordnance type and size, as a function of depth, and as a function of geology/site characteristics. In all cases the data should be recorded as a function of a calibrated sensor threshold or confidence level for highly processed returns. The scoring needs to be calculated relative to known ground truth (discussed below). Declarations of nonordnance items, be they man-made or natural, should count as false alarms (see below). Finally, if the survey speed is not constrained, then probability of detection (*Pd*) should be evaluated as a function of survey speed. For visual surface sweeps, increasing the survey rate has been shown to result in reduced probability of detection.[2] It would be useful to have similar data for instrument detection of buried ordnance.

- *False-Alarm Rate:* The primary means of reporting false alarms should be per unit area, FA/km. This data should be taken as a function of all the same parameters as probability of detection. This can, in a model-dependent way, be converted to a probability of false alarm (*Pfa*), where the model is a means of specifying how many opportunities for a false alarm exist per unit area. All nonordnance items should be regarded as false alarms, even if they are man-made objects which could be a priori known to mimic the signature of an ordnance item. The purpose of the exercise is to assess the efficiency of the search, not to check on the laws of physics. However, in order to extrapolate results to other sites, distinguishing man-made objects and naturally occurring objects as sources of false alarms is likely to be useful. In addition, simple calibrated surveys of areas believed to be uncontaminated with ordnance will be valuable in estimating performance at other, uncontrolled sites.
- *Discrimination Capability:* The most useful discrimination capability would be the ability to discriminate hazardous from nonhazardous items. With the possible exception of thermal neutron activation, we are aware of no technical approaches within the ESTCP projects that have any prospect in this area. The next most useful discrimination ability would be between ordnance items, ordnance-related debris, and nonordnance items. Finally, within the category of ordnance, it would be desirable to discriminate one ordnance type from another. This type of discrimination is usually referred to as classification. It is our belief that the only discrimination ability likely to be demonstrated will be related to physical size.
- *Location Accuracy:* For location accuracy, horizontal position and depth are important. In addition, it is important to be able to place detections on an absolute coordinate system or in relation to a fixed landmark as well as relative to the sensor platform. With the proliferation of digital Global Positioning System (DGPS) technologies, this is becoming increasingly straightforward.
- *System Reliability/Maintainability*: Records should be maintained describing the manner in which demonstrated systems fail, the amount of time between

2 NAVEODFAC Technical Report TR-23S, "Study of Search Effectiveness of Surface Clearance Techniques on Kahoolawe Island" (Indian Head, Maryland: November 1980).

failures, and the dollar cost needed to return the system to working order. Cost and mean-time-to repair data on prototype systems should be viewed with great skepticism; failure mode data is especially important to collect. The reliability and maintainability of commercially available components integrated into the technology demonstration is also important to track. The contractors should be required to prepare detailed failure mode analysis of prototype system components and subsystems, relying upon the databases of reliability data maintained by the Reliability Analysis Center, Rome, New York, to illuminate potential system design issues for further consideration.

E. POSTMORTEM ANALYSES

A significant unknown likely to remain so at the end of the demonstration is the source of false alarms. After the demonstration is complete, it will be useful to examine as many false alarms as possible to determine their common features, to identify the source(s) of those with the largest signatures, and to identify the source(s) of the most frequent false alarms. A detailed calibrated map of sensor returns and a calibrated map of ground truth items that allow for matching are very much needed in order to better understand the origin of false alarms across the entire range of demonstrated systems and technologies.

False-alarm data, if archived, will allow for two additional valuable activities. First, other processing schemes can be applied to the data to see if performance can be improved. The value of the demonstration may be greatly increased if the final performance measures are not constrained by processing schemes in place before the first data are taken. Second, if similar background data are taken on a variety of uncontaminated sites, performance can be more widely extrapolated. These two activities are linked. To have credibility, processing schemes developed after ground truth data from a specific site have been revealed to the developer must not be "site-specific," but rather shown to be applicable to sites not used in algorithm adjustment.

V. SUMMARY AND CONCLUSIONS

Tests and demonstrations of developmental equipment largely serve the purpose of confirming that the equipment performs as the developers intended in the scenarios they had envisioned. This is a necessary portion of any successful developmental program.

The ESTCP UXO Detection Demonstration Project seeks to lay the groundwork for future acquisition of UXO detection equipment that goes beyond use of magnetometer technology. As noted by the Defense Science Board, the General Accounting Office, the DoD Inspector General, and even the DoD, UXO detection within CONUS, focused on relatively large, metallic ordnance remains is a very difficult task. The expansion of this effort to include global search and detection capability, especially to support detection, discrimination, and removal of plastic landmines is far beyond the limited scope of the proposed demonstrations. Within the proposed, limited scope, two additional RDT&E purposes can be served with relatively little increased effort at this stage. These are discussed below.

A. EXPANDED UXO DEMONSTRATION PURPOSES

The first of these purposes is aimed primarily at the technical community. Data collection on UXO detection sensor technical performance should allow for common definitions, figures of merit, and analytic approaches across all the demonstrations to facilitate technology comparisons. In addition, data collection on backgrounds in land uncontaminated with UXO would add greatly to the community's ability to extrapolate performance to other sites.

The second expanded RDT&E purpose is aimed primarily at the user and acquisition communities. The sensor technical performance data collected and the system field performance should document detections, false alarms, mean time between failures, mean time to repair, and other data on figures of merit of interest to the user community. In the case of UXO detector technology, this user community is primarily the DoD EOD community and its associated civilian contractors, who provide UXO-qualified personnel to DoD ranges, and other DoD contractors engaged in environmental cleanup activities. The collection and documentation of system performance based on operator techniques as well as sensor performance would inform program managers seeking to make decisions on which technical approaches to pursue or field.

B. ISSUES FOR THE TECHNICAL COMMUNITY

Sensor systems are generally characterized in terms of a ROC, which relates increases in false-alarm rates to increases in the probability of detection as the criteria for declaring a detection are relaxed. Technical tests measuring probability of detection and false-alarm rates inevitably involve the use of surrogate targets. Most UXO detection schemes, including most ESTCP projects, rely on the detection of metals or electrical discontinuities that might be associated with ordnance, rather than trying to detect directly the presence of explosive. Consequently, there is room for debate about how to count different objects as false alarms or true detections in a demonstration that uses intact inert ordnance in place of live ordnance in various stages of damage or decay. The distinction of interest to the EOD technicians is, "Is this an object which presents a possible explosive hazard, and therefore requires EOD examination, or can the object be bypassed for later examination by non-UXO-qualified persons?" This distinction does not truly apply when using explosive simulants for safety reasons.

We believe the most useful approach is to declare as false alarms anything other than ordnance items. From an operational point of view, any resources spent on non-hazardous items are wasted. If possible, it is useful to distinguish man-made nonordnance items from "natural" false alarms because this will relate to extrapolating results to other locations. The extrapolation will be greatly aided by background data taken on uncontaminated sites.

After probability of detection and false-alarm rate, the classification capability of a sensor when there are multiple target types is of interest. We are skeptical of the classification capability of any of the systems currently being developed under ESTCP; nevertheless, we believe the data should be reported in the form of a confusion matrix (see Chapter IV).

Finally, in addition to the above, background clutter maps for regions believed to be free of explosive contamination should be collected, preferably for several varied areas. This information is necessary to determine whether the sensor performance at the test site is characteristic of its performance anywhere or is idiosyncratic.

To satisfy the main needs for the technical community:

- Specify detection capability by full ROC curves, with the calibrated thresholds used for the probability of detection and probability of false alarm points recorded. All nonordnance items declared should be counted as false alarms.
- Characterize effect on ROC curve of ordnance type—include survey rate, location, etc.
- Characterize classification capability by the full confusion matrix, also as a function of threshold.
- Collect calibrated background data on uncontaminated sites to the maximum extent feasible.

C. ISSUES FOR THE USER COMMUNITY

For the users of UXO detectors, the issue of utility extends beyond the sensor systems' technical performance. The ease of operation, reliability of the equipment, and training required to achieve and maintain proficiency are of interest. Furthermore, it must be possible to operate the equipment in a manner consistent with established procedures and sound safety practices. The goal of ESTCP is to meet the broadest DoD environmental monitoring and restoration technology requirements. Therefore, the demonstration should be documented so that those approaches which are most promising can be examined further to determine whether or not the technology can be repackaged for use in combat EOD environments as well as in seeking UXO in the peacetime, CONUS environment. The issues of suitability—training, consistency with current operations, and deployability—could be addressed by having EOD personnel participate in one or more of the demonstrations with the equipment. This might require an additional training effort, but the feedback from user to developer would be invaluable. Estimating costs of production versions of developmental systems is an uncertain practice. The needed information on system complexity, maturity of components, scheduled maintenance, mean time between failure, and so on could be made available by the developer for use in standard estimation techniques. To satisfy the main information and technology evaluation needs for the user community, the demonstration should

- Include active duty EOD technicians in the demonstrations, either operating equipment or interpreting sensor output or both. This will provide insight into the suitability of the equipment, especially as it affects

  — Ease of operation,

  — Training requirements, and

— Consistency with current safety practices.

- Provide system data that will allow independent cost estimation for procurement and operating costs.
- Result in the collection and analysis of data that sheds light on the interaction between UXO detectors and munitions fuzes.

D. RECOMMENDATION

The collection of consistent data on effectiveness, suitability, and cost, as outlined above, should be pursued as part of the ESTCP program. This data will be essential for evaluation and comparison of different technologies. It will also prove essential to decision makers in determining which technologies or systems to pursue further. In addition, the interaction with the user community in this fashion will greatly increase the probability that an effective system is ultimately placed in the user's hands.

GLOSSARY

BRAC	Base Realignment and Closure
CBO	Congressional Budget Office
CEHND/OECX	Corps of Engineers, Huntsville Division/Mandatory Center of Expertise
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CERFA	Community Environmental Response Facilitation Act
CFR	Code of Federal Regulations
COEA	Cost and Operational Effectiveness Analysis
CONUS	continental United States
dem/val	demonstration/validation
DERP	Defense Environmental Restoration Program
DGPS	digital Global Positioning System
DoD	Department of Defense
EMM	earth-moving machinery
EOD	Explosive Ordnance Disposal
ESTCP	Environmental Security Technology Certification Program
FUDS	formerly used Defense sites
GAO	General Accounting Office
GIS	Geographic Information System
GPR	ground-penetrating radar
HTRW	Hazardous, Toxic, and Radioactive Waste
IRP	Installation Restoration Programs
JCS/CINC	Joint Chiefs of Staff/Commander in Chief
MOEs	measures of effectiveness
NEPA	National Environmental Policy Act
NRL	Naval Research Laboratory

OEW	Ordnance and Explosive Waste
OSHA	Occupational Health and Safety Administration
Pd	probability of detection
Pfa	false-alarm rate
R&D	research and development
RCRA	Resource Conservation Recovery Act
RDT&E	research, development, test, and evaluation
ROC	receiver operating characteristic
RSP	rendering safe procedure
SARA	Superfund Amendments and Reauthorization Act
T&E	test and evaluation
USGS	U.S. Geological Survey
UXO	unexploded ordnance

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This report describes the general magnitude of potential contamination of DoD lands by Unexploded Ordnance. It describes the generic procedural and technical processes used by DoD to clear land under its control during peacetime in the United States prior to conversion to alternative uses within DoD or transfer to other government agencies, educational institutions, or the private sector. It identifies technical needs and requirements for improved UXO detection. It outlines a set of test procedures and data analysis criteria that would aid DoD Program Managers in assessing the performance of prototype or technology demonstration UXO detection systems.

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