Report of the

Defense Science Board Task Force

on

Unexploded Ordnance

November 2003

Office of the Under Secretary of Defense
For Acquisition, Technology, and Logistics
Washington, D.C. 20301-3140

OFFICE OF THE SECRETARY OF DEFENSE
3140 DEFENSE PENTAGON
WASHINGTON, DC 20301-3140

DEFENSE SCIENCE BOARD

October 24, 2003

MEMORANDUM FOR THE ACTING UNDER SECRETARY OF DEFENSE (ACQUISITION, TECHNOLOGY & LOGISTICS)

SUBJECT: Final Report of the Defense Science Board Task Force on Unexploded Ordnance

I am pleased to forward the Final Report of the Task Force on Unexploded Ordnance which was chaired by Mr. Bill Delaney and Dr. Delores Etter. The Task Force investigated the application of advanced technology to two dominant DoD problems with unexploded ordnance: can we reduce the cost of current cleanup, and can we minimize the environmental impact of future live-fire training of our forces?

The Task Force found that technology can be of dramatic help in each problem area. The current cleanup problem is massive in scale but there is a clear opportunity to save tens of billions of dollars in the total cleanup process by the use of more modern technology.

With regard to future training, the Task Force believes that we can develop environmentally-friendly munitions, simulation techniques, and training range protocols that will permit the appropriate live-fire training of our forces.

I concur with the Task Force's findings, and I recommend you forward the report for distribution and comment.

William Schneider, Jr

William Schneider, Jr
Chairman

OFFICE OF THE SECRETARY OF DEFENSE
3140 DEFENSE PENTAGON
WASHINGTON, DC 20301-3140

DEFENSE SCIENCE BOARD

October 24, 2003

MEMORANDUM FOR THE CHAIRMAN, DEFENSE SCIENCE BOARD

SUBJECT: Final Report of the Defense Science Board Task Force on Unexploded Ordnance

Attached is the report of the Defense Science Board Task Force on Unexploded Ordnance (UXO). The Task Force investigated two principal issues: (1) can technology help reduce today's high cost of UXO cleanup, and (2) can technology help reduce the environmental impact of future live-fire training? The Task Force concluded that technology can help in both situations, but changes are needed in the current cleanup process and in future live-fire practices.

The UXO cleanup problem is a very large-scale undertaking involving 10 million acres of land at some 1400 sites. Estimated clean-up cost of current UXOs is tens of billions of dollars. The application of modern technology can yield a dramatic reduction in this cost.

The first problem in current UXO cleanup is the lack of a reliable data set on past munitions use of these millions of acres. Munition usage at some sites goes back close to 90 years to the World War I era. Reliable data is the start of any logical and efficient cleanup process, and the Task Force recommends an aggressive plan to address this shortfall.

The second problem is that instruments that can detect the buried UXOs also detect numerous scrap metal objects and other artifacts, which leads to an enormous amount of expensive digging. Typically 100 holes may be dug before a real UXO is unearthed! The Task Force assessment is that much of this wasteful digging can be eliminated by the use of more advanced technology instruments that exploit modern digital processing and advanced multi-mode sensors to achieve an improved level of discrimination of scrap from UXOs. Unfortunately current contracting encourages the employment of small firms that cannot afford to capitalize the purchase of these new technology instruments. Larger firms that can capitalize these kind of expenditures need to be more involved. The total cost avoidance possible in UXO cleanup is enormous – tens of billions of dollars!

The Task Force believes that our continued live-firing of munitions for training purposes will come under increasing environmental pressure. The recent recognition of possibly toxic chemical constituents of UXOs leaching into ground water is an emerging volatile issue that has already shut down one munition training site. The DoD's "green munitions" program is developing munitions that will produce minimum environmental upsets. The Task Force sees this approach as the dominant long-term solution. Advanced simulation techniques which have the potential to reduce the need for live munitions in training can be a help in the near term. The migration to precision-guided munitions where one round does the job of 10 to 100 non-precision rounds will also be of help.

Full implementation of the Task Force recommendations would approximately double the current DoD spending of $200 million per year on the UXO problem. We recommend this increase for two reasons: the downstream savings are great – tens of billions of dollars, and; at the current level of cleanup the DoD may begin to lose control of its own destiny in the continued use of training ranges because of political pressures, the imposition of legal restrictions and the mandated actions of outside agencies.

The Task Force membership is willing to assist the various DoD components who would implement our recommendations in prioritization of the various tasks to be accomplished and in adjusting to less than full funding of our recommendations if that is necessary.

WMDelaney Delores M. Etter

William P. Delaney Delores Etter
Task Force Co-Chairs

This page intentionally left blank

Table of Contents

This page intentionally left blank

Executive Summary

The Defense Science Board Task Force on Unexploded Ordnance, UXO, met from September 2002 to May 2003. The Task Force's charter contained two principal questions: (1) can advanced technology help reduce the very high cost of UXO cleanup at former and current test and training sites and (2) can advanced technology help minimize the environmental impact of future live-fire munitions training? The Task Force's answer to both these questions is a qualified "yes".

Today's UXO cleanup problem is massive in scale with some 10 million acres of land involved. Estimated cleanup costs are uncertain but are clearly tens of billions of dollars. This cost is driven by the digging of holes in which no UXOs are present. The instruments used to detect UXOs (generally located underground) produce many false alarms, – i.e., detections from scrap metal or other foreign or natural objects -, for every detection of a real unexploded munition found. Because each of these false alarms could potentially be a UXO, a careful excavation is required, leading to very high costs. The Task Force believes that modern technology can substantially reduce such false alarms leading to a dramatic reduction in overall cleanup cost. Some substantial changes in cleanup management structure are needed to foster the deployment of such technology.

Much of the aforementioned 10 million acres is free of UXOs and this land could be returned to public use relatively quickly. The Task Force recommends an aggressive five-year program to accomplish this release.

The Task Force concluded that technology can also help with future environmental problems associated with live-fire testing. The DoD uses over two million rounds of high explosive munitions per year for training purposes. Thus we are continuing to produce UXOs at a substantial rate. The Task Force believes that the future problem can be controlled by a variety of measures. First, we should carefully examine this extensive use of live munitions in training. Simulation techniques and inert rounds can reduce the number of live rounds actually used. Second, environmentally friendly "green" munitions are being developed. These green munitions combined with a significant improvement in fuze reliability, especially for medium caliber rounds, offer our best solution for the longer term.

There is an emerging problem of chemical constituents of UXOs leaching into the ground water and possibly contaminating public water supplies. This is a volatile issue, an issue which has already closed down one major test facility. It deserves careful attention by the DoD.

The Task Force recommendations, if implemented, can save tens of billions of dollars in future cleanup costs and can preserve the ability of the DoD to control its own destiny and to conduct live-fire testing into the distant future. The funding impact of the Task Force recommendations is not great considering the dollars to be saved downstream. Current DoD spending on the UXO problem is about $200 million per year. The implementation of the Task Force recommendations would require a rough doubling of this yearly funding.

This page intentionally left blank

I. INTRODUCTION

This is the final report of the Defense Science Board Task Force on Unexploded Ordnance (UXO). The Task Force began its deliberations in September 2002 and concluded them in May 2003. The Terms of Reference for the Task Force are contained in Appendix A. The essence of these Terms of Reference is captured by the following two excerpts:

> **"Can modern technology be exploited . . . . . to reduce the extremely high cost of UXO clean-up?"**
>
> **"Can the science and technology be developed to minimize the environmental impact of continued live-fire training and testing of munitions at ranges across the U.S.?"**

The Task Force's answer to these two questions is "yes, but . . . . " with a substantial part of this final report devoted to the "but".

Appendix B contains the Task Force Membership. The Task Force met for nine two-day sessions over its nine-month duration and heard close to 70 briefings on a wide variety of aspects of the UXO problem. Appendix C lists these briefings.

This was not the first DSB Task Force on the UXO issue. An earlier Task Force started in September of 1996 and issued its final report[1] in April 1998. The Chairman of that Task Force, Dr. John Foster, served on this Task Force and was a valuable connection to the earlier work. Its charter was quite similar to ours, and the findings of both groups have substantial overlap and no disagreements. This does not mean that nothing has happened since 1996. A lot has and one can clearly see the impact of the earlier Task Force in the UXO community today. Progress may appear slow, but that is in large part because the UXO problem is a huge problem, as we will illustrate. Near the end of this report, under the heading "Related Topics", we will comment on the two Task Forces and their recommendations.

The remainder of this report is organized into six major sections:

II. Big Picture of the UXO Problem

III. Existing Cleanup – Can Technology Help?

IV. Future Training – Can Technology Help?

V. Related Topics

VI. Recommendations

Supporting Appendices

---

[1] Report of the Defense Science Board Task Force on Unexploded Ordnance (UXO) Clearance, Active Range UXO Clearance, and Explosive Ordnance Disposal (EOD) Programs, April 1998, Office of the Under Secretary of Defense for Acquisition & Technology, Washington, DC.

We begin by establishing a “Big Picture” view of the UXO problem, to convey why resolution of the UXO problem will require a substantial, carefully orchestrated national effort.

II. THE UXO PROBLEM – THE BIG PICTURE

This section provides a broad view of the UXO problem highlighting the massive scale of the problem, its complexity, the wide-variability from site to site, the challenges involved and the reasons for a heightened concern about the problem.

Some Definitions

The term unexploded ordnance or UXO refers to explosive, propellant or chemical-containing munitions that were armed, fired and remain unexploded through malfunction. It does not refer to the military missions of countermine operations or battlefield explosive ordnance disposal. However, some UXO clearance processes may have common techniques or technologies with those used in these military operations.

Most UXO in the United States is the result of weapons systems testing and troop training activities conducted by the DoD. Property containing UXO includes active military sites, land already transferred to private ownership, such as Formerly Used Defense Sites (FUDS), and land which is no longer being used for military purposes but is still under the ownership of the US Government, such as Base Realignment and Closure (BRAC) sites.

As defined in this report, UXO remediation focuses on efforts to clean FUDS and BRAC sites so they are suitable for private use and to maintain the long-term viability of active ranges. Remediation efforts also include the development of tools and techniques designed to reduce the number of future UXO.

The Scale of the UXO Problem

The UXO community uses the word “munitions response site” to delineate a contiguous area in which munitions have been used and UXO may exist. Thus, a military facility such as a training range may contain more than one site. Originally some 2300 sites in the U.S. and overseas U.S. facilities were identified as possible UXO sites. The ongoing process of investigation has narrowed this number to some 1400 sites suspected of containing unexploded munitions. The total land area involved is some 10 million acres[2]. This is, by any measure, a problem of massive scale in land area.

The cost to remedy this UXO problem is quite uncertain because of many unknown factors in the situation at most of these sites. But while the actual figure is uncertain, there is no doubt that overall the total cost is very high – tens of billions of dollars. At this stage of the nation’s knowledge, there is no point in arguing details of cost estimates or trying to achieve specificity of two or three significant figures. We

[2] This total land area is the size of the combined states of Massachusetts, Connecticut, Rhode Island, and Delaware.

believe that today's estimates, on an absolute basis, are probably not good to even one significant digit. However, relative estimates do have value and in the next section of this report we will develop some first-order cost comparisons to illustrate the value of introducing high-technology instruments into the process.

During our deliberations, we heard a number of cost estimates for remediation of today's known UXO sites. The lowest was in the $12 to $14 billion range. One can easily "roll-up" costs of $50 billion as we will illustrate. Although we cannot reliably estimate a definitive cost now, we know it will be high, with about $20 billion being our low-side estimate. However, despite this uncertainty in absolute cost, in the next section we will establish with some confidence that technology can be a major cost reducer.

Currently, the U.S. spends about $0.2 billion per year on the UXO problem. This is a very small expenditure against this problem. At our low-side cost of $20B, this represents an annual expenditure of only one percent of the eventual total cost. One briefer likened it to just paying the interest on your credit card debt, although one percent interest is a very good deal! The problem, of course, is that the job never gets done. In addition, there are a growing number of forces and pressures, such as a perception of hazard, the economic value of the land and an increasing nationwide environmental awareness, that will probably not allow this low expenditure rate to continue indefinitely. We will discuss such pressures later in this section.

One favorable aspect of the UXO situation is that fatalities or injuries from civilian encounters with UXO are very low – a rough count indicates one or two fatalities per ten years. But despite the low occurrence, any such event receives a great deal of publicity if it involves a "civilian" (versus a UXO clearance worker or military range personnel) and can quickly bring a great deal of political pressure to bear on the DoD.

Looking to the future we note that we use enormous amounts of explosive munitions in training – more than 2 million rounds per year. We are adding more UXOs per year than we currently clean up at our $0.2 billion level of effort, but hopefully the UXOs we add are contained in well-defined, well-documented, and well-managed areas. However, potential UXO detonations are not the only, and perhaps not even the most important concern. A new related problem is beginning to emerge, and many in the munitions and environmental communities see it as a very serious threat to the continued use of operational ranges. This is the so-called "munitions constituents" problem -- chemicals associated with the munitions use, production and demilitarization that can, over time, leach into the ground water and thus migrate substantial distances off the ranges and possibly contaminate public water supplies. We will discuss this in the section on technology to support future training.

In summary, the UXO problem we have inherited from past events and practices over many decades is today daunting in its scale and the problem will continue to grow into the future.

Challenges of the UXO Problem

The challenges in solving today's and tomorrow's UXO problems are many. We outline the major ones in this subsection.

- **Lack of Data:** A major frustration is the lack of reliable data on the approximately 1400 munitions response sites discussed above, including what munitions were used, how many different types were fired and where they impacted. Some munitions use goes back 90 years to the World War I era. Records and archives have been lost, and some munitions tests were never documented. In the course of our investigation, the Service functional experts rarely could give a specific numerical answer to any question involving these sites. The fact that they have few answers is not totally their fault; they have inherited a messy, ill-defined situation. Unfortunately, this difficulty frustrates any attempt to develop an orderly plan or a sensible cleanup prioritization scheme. Recognizing that this is a reality and that it stands in the way of approaching the problem in a systematic manner, the Task Force is recommending a substantial near term DoD effort to remedy this situation.
- **Large Number of Sites:** The challenge involved in dealing with the very large number of sites becomes apparent when one "crunches" some numbers on how many surveys are required, the number of holes that have to be dug, etc. In the next section we will examine some of these numbers (e.g., 200 million holes!). Another complication is that we are dealing with the infinite variety of the earth's surface, and every site is somewhat or very different. We will illustrate this problem with a "travelogue" through a dozen or so munitions response sites.
- **Difficulty of "Seeing" Underground:** Being able to sense what lies under the ground is the principal scientific, technological, phenomenological challenge in the UXO problem. Sensors that can penetrate the earth do not see underground with adequate resolution to allow a quick identification or "discrimination" of an object as metal scrap or an intact, unexploded ordnance. One of the ways in which we "inspect" the underground is by sending signals through it to bounce off objects below its surface. But unfortunately, the underground is notoriously "hostile" to inspection – it reflects signals at the surface, it attenuates signals that make it through the surface, and because it is inhomogeneous, it causes many kinds of back-scattered signals (false alarms) from natural discontinuities, rock, etc., that may resemble signals from buried metal objects. What is needed is instrumentation with a high probability of detecting munition-sized objects without generating too many false alarms. As we will show, high-technology instruments available today do better than the low-technology instruments that are in common use for UXO detection, but getting the better instruments to be widely used is a problem because of non-technical procedural issues.
- **Cost of Digging:** The cost of digging up suspected UXOs is high because of the potential explosive hazard that has to be assumed in every case. The whole process of surveying, digging, removal and disposal is done carefully and rigorously. One does not plunge a shovel into the ground to directly unearth a suspected UXO. One digs around it carefully, slowly working inward to try to see some part of the object. If it looks like a UXO, the level of

care increases tenfold. It helps if one knows the UXOs at this particular place are, for instance, 81-mm mortar rounds, but one does not often have that degree of knowledge. We were told that the “small stuff”, 40-mm round, etc., is the biggest challenge, because there are many of them and many other things look like them; a 500-pound bomb, even though it is potentially more dangerous, is actually easier to deal with because it is easier to identify.

- **The Constituents Problem:** There is an ongoing debate as to the level of toxicity of munitions constituent chemicals. For many of the constituents, there is no accepted standard of concentration level that represents a clear health hazard and must not be exceeded. Thus, it is a challenge to plan a constituent monitoring or cleanup process. Too low a level can lead to excessive cleanup costs, and too high a level will not mitigate the health hazard and will be open to both public and regulatory challenge.
- **Wide Assortment of People Involved:** Interactions on UXO issues involve a variety of local citizenry, tribal representatives (many of the sites are on Native American reservations), state regulators, federal regulators, federal agencies, the military, and politicians at all levels. Interactions are complicated, lengthy, not guided by any established protocol, and often predominantly at the local level. The UXO community must deal with this complexity on a case-by-case basis; there are few standards that can be applied, and learning is not easily transferred from one situation or set of stakeholders to another.

Is There Anything in Our Favor?

Despite the preceding litany of challenges, there are a few important favorable factors:

First, a dedicated DoD-wide cadre of environmental and operational people is already working hard on this problem. They understand what has to be done, they are making progress, and their tasks will likely get somewhat easier as they gain experience with the technical problems and the procedural challenges.

Another salutary situation is that the DoD essentially “owns” or can readily access all parts of the problem. In many, if not most, other DoD problems, the timetable of events is not fully under our control and we can’t fully access the “threat” (e.g. the submarine force of a worrisome nation). In the UXO case, the “threat” is our munitions. We can study them carefully, we can bury samples of them, we can perform well-controlled tests on detection and false alarms, and we can do it all at low cost! Thus, we can develop a realistic and demonstrable assessment of the performance of our instruments, we can compare and test different instruments in different geologic conditions – again at low cost ($50 thousand goes a long way here) – and we can pick what we choose to use in each area to find particular buried munitions.

In summary we have convenient options to confidently assess just how much technology can help reduce the cost of the UXO problem and which technology is most promising in each situation. We can demonstrate performance to the stakeholders and we can "back-check" ourselves by repeat measurements in selected areas.

Why the DoD Should be Concerned

The current DoD funding commitment to this problem is quite limited in view of the scale of the problem. A $200 million per year funding applied to a tens of billions of dollars problem implies that the DoD gives this issue low priority and clearly doesn't care if it takes 100 years to solve. That low priority was evident to the Task Force throughout the study. It is also evident to many of the "stakeholders" in the UXO issue (the local citizens, the state regulators, environmental groups), who justifiably see the DoD's total effort on UXO cleanup as unresponsive.

The UXO issue deserves a higher degree of DoD attention and priority. We foresee increasing political and/or regulatory pressure on the DoD to do much more, much sooner, perhaps to the degree that the DoD loses control of its own destiny in this matter, which in turn could have serious implications on weapons testing, troop training, and overall readiness.

One pressure is the growing economic value of the land. Much of the land with UXOs was truly in the "boondocks" when many of these sites were activated in the World War II era or earlier. That is no longer the case, and the states want to capitalize on the potential economics of these often valuable parcels of land.

A second pressure is just the growing national awareness and concern about the environment and in particular anything that appears as environmental degradation. The national expectations for "fixing" up the mess from the past are high – particularly if the Federal government is the agent both for creating the problem as well as remediating it.

A third and worrisome pressure comes from the emerging munition constituents problem. We will discuss constituents in detail later, but the Task Force sees this as a politically volatile issue that could curtail the DoD's freedom to operate and manage our essential operational ranges and training facilities. It takes little imagination to see a public outcry in response to the contamination of the drinking water of citizens living miles from closed training ranges, because of munitions used there years ago by the military. Many who briefed the Task Force had this munition constituents issue as their principal concern, since it could impact critical operating training and test facilities.

The Task Force believes that the public's perception of DoD's management of its facilities is critically important. The DoD must be seen as, and indeed must be, a willing and responsible steward of its land. Failure to do so could threaten the DoD's ability to continue live-fire training on operational ranges.

Travelogue of Munitions Response Sites

The following photo-collage will help round-out the UXO Big Picture and give some physical feel for typical munitions response sites. The wide variety of terrain and terrain cover illustrated by these 13 sites underscores the observation of many workers in the UXO field that "every site is different".

Ft. Bragg, NC 4 feet by 4 feet

Badlands, SD 360,000 acres

Figure 1a. All Sizes

Honey Lake, CA

Figure 1b. Flat Terrain

Ft. Ord, CA

Figure 1c. Rugged Terrain

Sparse - Lowry, CO

None - Bethany Beach, DE

Figure 1d. Sparse Vegetation

Uplands - Camp Bonneville, WA

Wetlands - Camp Claiborne, LA

Figure 1e. Thick Vegetation

Amchitka, AK

Figure 1f. Remote Location

Boise Barracks, ID
1 UXO in 1,000 acres

Ft. McClellan, AL
1000 UXO in 1 acre

Figure 1g. UXO Density

Geologic Noise at Kaho'olawe, HI

Metallic Fragments at Southwest Proving Ground – Hope, AR

Figure 1h. Clutter

III. EXISTING CLEANUP – CAN TECHNOLOGY HELP?

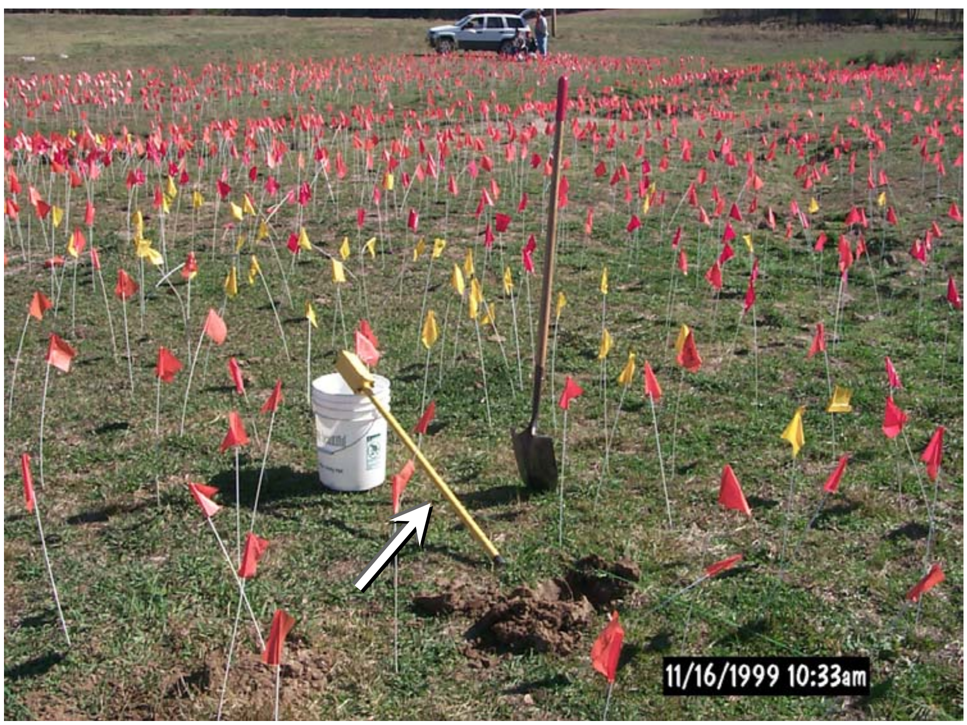
Technology can substantially reduce the high cost of today's cleanup efforts, if we can find a way to deploy this new technology in the cleanup process. This section provides the Task Force's analysis and assessment of the role of technology in reducing costs. We start by comparing the performance, and in particular the false-alarm rate, of existing instrumentation used in the cleanup process with newer, higher technology instrumentation. We then delineate the entire cleanup process, highlighting how false-alarm rate is a major cost driver. This delineation also points to the critical need to remedy today's deficit of data on the totality of the National UXO problem. We then present a case study of the potential cost difference between a low-technology approach versus a high-technology approach to UXO cleanup. The clear and dramatic cost saving in the high-technology approach will be evident, but unfortunately our current cleanup contracting practices do not encourage the introduction of this cost-saving, high-technology instrumentation. We conclude this section with a discussion of possible approaches to improve this situation.

Instrumentation for UXO Detection – A Review

The guiding measure of an instrument's usefulness for UXO detection and discrimination is the instrument's probability of detection, P_D, and probability of false alarm, P_{FA}. P_D is defined as the probability that an instrument will signal a detection of a UXO, given that a UXO is actually there (the desired indication), and P_{FA} is defined as the probability that detection of a UXO will be signaled when no UXO is present (an undesirable indication, typically from a piece of scrap metal). P_D and P_{FA} are unfortunately coupled for the particular level of technology implemented in the instrument. One can raise detection probability to a desirable level, but the false-alarm level will also rise. Conversely, the false alarm level can be reduced to a low level, but then one will be "stuck" with a low probability of detection. The higher the technology employed, the more favorable a relationship between P_D and P_{FA} can be achieved. Appendix D provides more detail on instrument performance and techniques for improved performance. Appendix J presents a brief commentary on why the Task Force believes that we can reduce false alarms with modern technology. In this section, we will illustrate some typical instruments, comment on their performance and then show how a better instrument performance that provides good probability of UXO detection with a substantially lower false-alarm rate can produce a dramatic cost reduction in UXO cleanup.

Figure 2a shows a basic magnetic detection instrument, and Figure 2b shows it in the field amid an array of flags which mark detection of suspected UXOs – an illustration of the so called "mag and flag" approach. This analog instrument is widely used today and detects suspected UXOs by sensing changes in the earth's magnetic field due to ferrous metal objects. Its advantages are low-cost ($800) and excellent portability that allows it to be used in all terrains. Its disadvantages are a high false-alarm rate, a slow survey rate and the lack of a digital record of the details of the detection (how strong was the signal, did it fall off quickly, etc.) or the location of the detection (where on the ground did the detection occur). The only record is the presence of a “flag” sticking out of the ground, put there by the person using the instrument.

Figure 2a. Schonstedt Passive Magnetic Instrument



Schonstedt Instrument

Figure 2b. “Mag and Flag” Approach

Modern technology instruments combine passive and/or active sensors with digital processing and recording. Figure 3a illustrates one such advanced instrument, the EM-61 handheld sensor. It is an active sensor in that it radiates an intermittent low frequency signal. When this signal impinges on a piece of metal, it induces electrical currents to flow in the metal (called "eddy currents") that continue to flow for a short period of time after the impinging EM-61 signal stops. A sensor in the EM-61 detects and analyzes some of the details of these eddy currents, and these details help to differentiate true UXO detections from false alarms. This mode of operation combined with advanced digital processing techniques can provide an improved detection and false-alarm capability over the less sophisticated analog instruments. The EM-61 is usable in all terrains, and it provides a digital record of detections and their locations. It is more expensive than the analog instrument ($20,000 vs. $800) and requires a higher operator skill level because it is more complex to use.

EM-61 Handheld

Figure 3a. Modern Electromagnetic Instrument

A towed-vehicle mechanization of this type of digital sensor, called the Multiple Towed Array Detection System (MTADS), is shown in Figure 3b. This implementation provides a high survey rate in addition to favorable detection and false-alarm performance and digital recording of detection events. Its primary disadvantages are that it cannot be used in rough or vegetated terrain, and its cost is relatively high ($500,000).

This type of instrumentation can also be used from a low-flying airborne platform, as show in Figure 3c. The sensor arrays (similar to the type employed on MTADS) are kit-mounted on a helicopter which flies over the ground at 1 to 2 meters altitude. This provides a very high area search rate in addition to the other advantages of the active instruments.

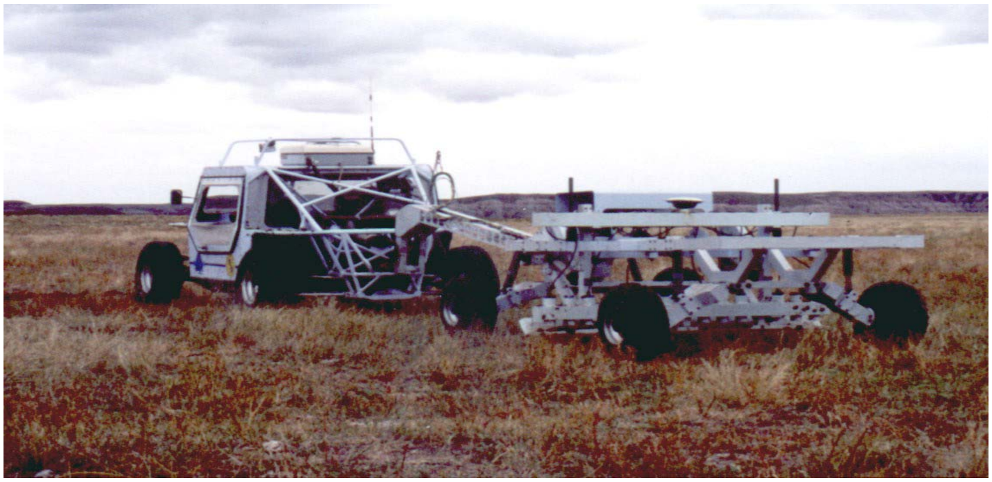


Figure 3b. Multiple Towed Array Detection System (MTADS)

Figure 3c. MTADS Kit on Helicopter

The primary disadvantage of the helicopter sensor approach (outside of cost) is that it is only usable in relatively flat terrains. Also, it is generally not as sensitive as the ground instruments. The sensor kit cost is high ($400,000), but it is designed to fit a variety of general-purpose helicopters. The Task Force sees this approach as most useful for initial, large-scale, wide-area assessments of UXO sites to determine in a quick survey fashion where there are metallic objects in the ground and where there are not. We do not see it as the final instrument in the UXO detection-discrimination process. We see this initial assessment, discussed in more detail in the following section, as a critical step in the DoD's ability to "get ahead" of the UXO problem.

As discussed earlier, an important differentiator among these instruments is their detection and false-alarm performance. Since a high false-alarm rate means high costs in digging "dry" holes (i.e., holes where no UXO is present), a short discussion of the prospects for reducing false alarms is in order. Appendices D and J contain more elaborate discussions.

The performance of all sensors, such as those used in radar, IR, sonar, or UXO detection, is dominated by false-alarm issues. Today's generic (and very successful) approach to reducing false alarms in applications such as radar is to analyze the fine-grain details of the signals reflected from targets using modern digital signal and data processing techniques combined with multi-dimensional sensing technologies to determine the real targets in a sea of false targets. This digital approach exploits the continuing dramatic gains in processing power. So the formula is "go digital, go multi-mode sensing". This formula is now just being applied to UXO instruments and should produce substantial improvements in false-alarm performance. Although there are no guarantees, the potential cost savings from reducing the number of dry holes that are dug are so great that the Task Force recommends the incorporation of this new technology as rapidly as possible. Let us examine what these potential cost savings might be.

The analog instrument, Figure 2a, used in the "mag and flag" technique might typically have 100 false alarms for every real UXO. The more expensive, higher technology (digital) instrument of Figure 3a has the prospect of doing much better: 30:1 today and 10:1[3] with additional development. The false alarm difference between 100:1 and 10:1 can produce a dramatic difference in clean-up cost as we will illustrate in our case study, but first we need to delineate the entire clean-up process, to make clear where the various component costs originate.

Typical Cleanup Process

The typical cleanup process naturally divides into six component steps:

1. Initial Area Assessment – This involves archival searches of existing records, visual site inspections, and possibly some sampling with sensors to determine in gross terms if UXOs are present, and if so, what areas they are in and where they are not.
2. Survey to Delineate UXO Areas – This is a formal field survey of each of the suspected areas to delineate boundaries, establish reference points, and map and mark the areas potentially containing UXOs.
3. Vegetation Removal – Some sites require removal of vegetation. (Our sample cases that follow assume 50% of the sites require vegetation removal.)

[3] Actual observed false-alarm rates vary widely from site to site for all classes of instruments. Our proposed typical false-alarm numbers are the broad average of what would be expected over a wide range of sites.

4. UXO Search and Location – The previously described types of instruments are used to detect and locate suspected UXOs. If Mag and Flag techniques are used, flags are planted to mark suspected UXOs. If modern instruments are used, digital records are established.
5. Digging-up Suspected UXOs – This involves the excavation of suspected UXOs. It involves a careful digging procedure until it is clearly established whether or not a UXO is present. If it is, the UXO is detonated in place or removed to a safe storage area.
6. Supporting Administrative Functions – This cleanup work carries with it a substantial supporting burden of administration, security, safety, and transportation.

The most expensive task in this delineation is Step 5 – the digging task. Anything that can be done to reduce the number of holes being dug will pay substantial dividends, and this is where the higher technology instrumentation is the key prospect.

The Task Force observed many times during its review that this cleanup is done in a highly distributed, piecemeal process – lots of small jobs proceeding simultaneously on many small areas using different contractors who are independent from one another. One observer likened it to a "retail" operation rather than a "wholesale" one. All six steps of the cleanup process just discussed proceed in this fashion, and this situation discourages any logical attempt to improve the process. There are many reasons to change this protocol – the most commanding reason is that "wholesale is always a much lower cost than retail."

<u>A Critical First Step</u>

Today, Step 1 of the process, the "Initial Area Assessment," is done in a piecemeal fashion, focusing on a small number of sites each year without any attempt to achieve an economy of scale. The Task Force sees compelling reasons to attack this initial assessment process much more vigorously. First, it is estimated that of the 10 million acres of UXO concern, only 2 million acres are likely to contain UXOs. Since the area assessment is one of the lowest-cost components of the total process, these eight million acres could be "freed-up" quickly and relatively inexpensively. Why wouldn't anyone want to do so?[4]

The Task Force envisions an intensive five-year campaign to assess all 10 million acres with the goal of delineating where the UXOs <u>are</u> and where they <u>are not</u>. This campaign would use the full range of techniques and instruments including the helicopter-borne sensor where applicable. It would cost an estimated $1 billion over the five years ($100/acre). The compelling advantages of this approach are:

1. It would free 8 million acres for $125 per acre ($1 billion total). Whether for development, passive recreation, conservation, or

[4] Clearly a multitude of involved agencies and stakeholders would have to support such a process, but they should be attracted by the payoff of a great amount of land quickly returned for productive use.

government use, $125 per acre for land is a “best buy” by any standard.

2. It would provide the data base for informed planning of the rest of the cleanup process for the 2 million remaining acres. We point many times in this report to the need to plan and execute cleanup in a wholesale versus retail fashion if we are to achieve dramatic cleanup cost reductions. This assessment, data base, and clear delineation of what has to be done is a necessary first step.
3. It would put the DoD “out in front” of the UXO problem: We noted earlier the public’s perception that the DoD gives this problem a low priority. This aggressive approach to freeing land would be a strong, positive indication of a high DoD interest and priority. It would also arm the DoD with the knowledge necessary to make the public comfortable in the fact that the DoD knew where it was headed and had a clear plan to get there.

The next section is a hypothetical case study that clearly shows the value of higher-technology instrumentation. It presumes that we have implemented this aggressive site assessment process and that it is behind us.

“Low Tech” vs. “High Tech” Remediation – A Case Study

The value of a high-technology approach to UXO cleanup can be illustrated by working through the six-step cleanup process and using cost estimates for the individual processes to make a rough order of magnitude cost estimate for the full national UXO cleanup.

The individual process costs used here are approximate and are based on the cleanup experience of the U.S. Army Corps of Engineers. Appendix E provides more discussion on the costs used. However, the “ball park” cost estimates and sensor performance parameters used here are more than adequate to demonstrate how technology has a dramatic impact on the national cleanup cost. Changing the individual costs by a factor of two would not affect the general conclusion.

The block diagram of Figure 4 illustrates a stylized, low-tech remediation process and associated costs. The assumed false-alarm rate here is 100:1. This analysis used one UXO per acre. The costs add up to a staggering $52 billion, with the dominant cost ($30 billion) being the digging up of some 200 million false alarms or “dry holes” at a cost of $150 each. Only $2 billion is used to dig up the real UXOs. The whole cost “roll-up” is dominated by the assumed 100:1 false-alarm ratio of the “mag and flag” technique. It is startling to note that 75% of the $52 billion is used just to dig up scrap![5]

The stylized use of more modern instruments with an assumed 10:1 false-alarm ratio is illustrated in Figure 5. The use of high-technology should reduce the surveying

[5] The figure of 75% is arrived at by amortizing the $15 billion contractor and government indirect costs across the remaining five processes. If this is done, $9 billion of indirect cost is attributable to digging scrap for a total of $39 billion of the $52 billion total cost.

and mapping costs by a factor of two (see Appendix E). The total cost now is $16 billion and 75% of this cost is devoted to the finding and removing of the real UXOs.

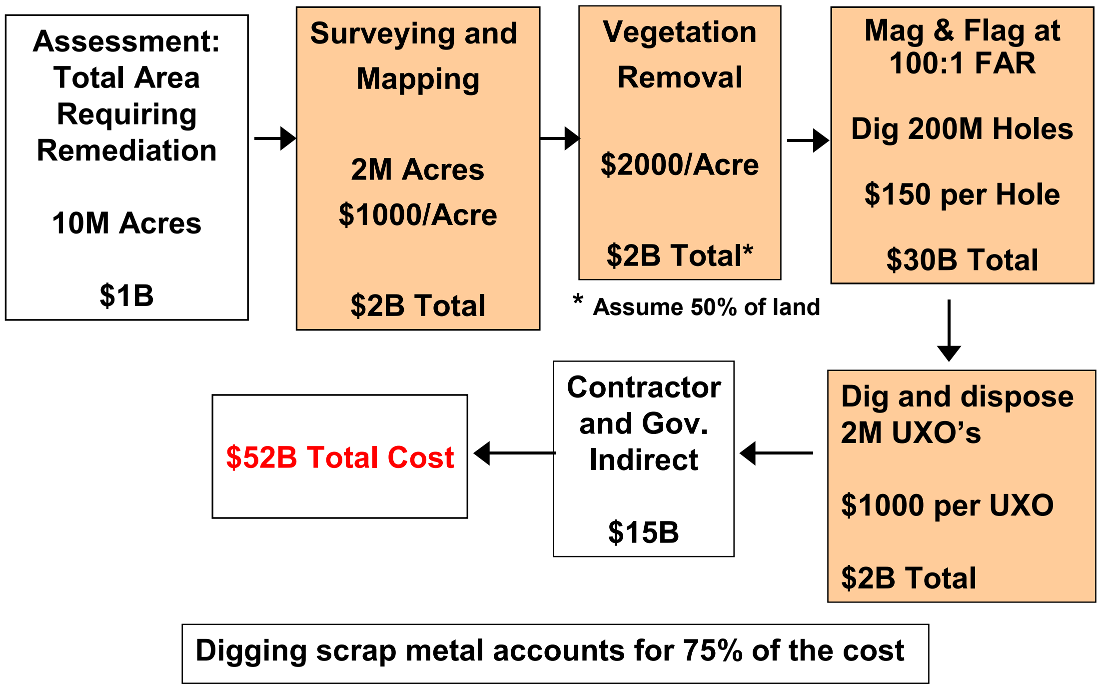


Figure 4. Low Tech Remediation

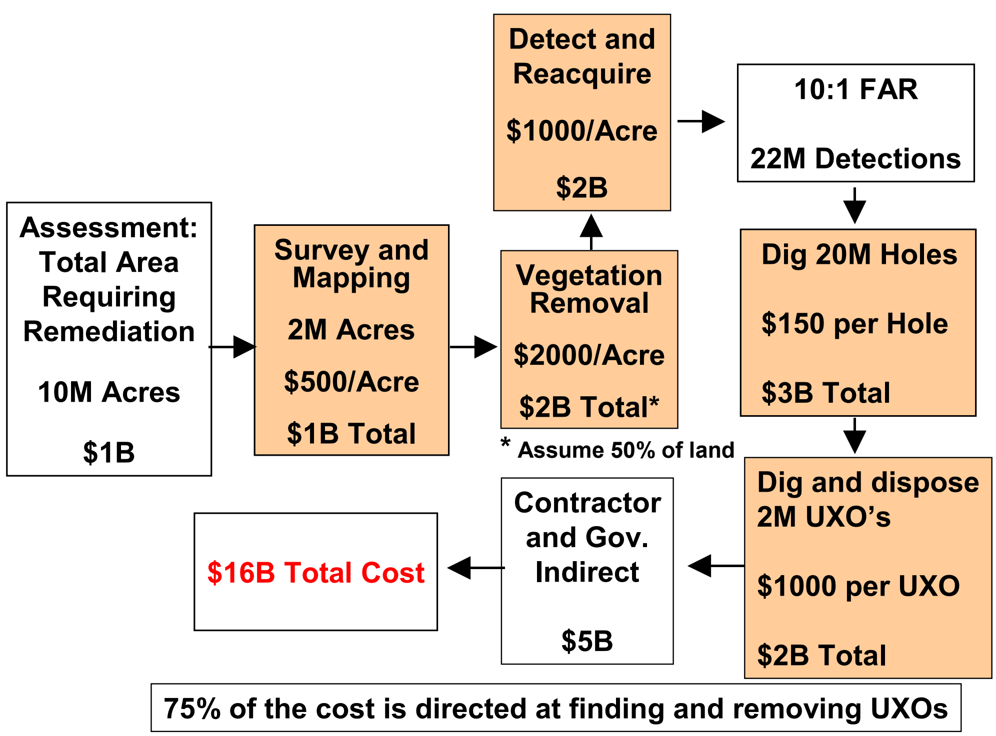


Figure 5. High Tech Remediation

One can illustrate the same point in a different form with the bar charts of Figure 6 and Figure 7, which show graphically the component costs for each of the stylized processes. Notice how the cost of digging scrap metal dominates the costs in Figure 6, while the use of high-technology to achieve low false-alarm rate in Figure 7 brings the cost of removing scrap metal more or less in line with all the other costs.

The whole process swings on whatever false-alarm rate is achievable, so a natural question is why not push even harder on reducing false alarms? Figure 8, which plots the total cost per acre of UXO removal as a function of false-alarm rate, shows that a false-alarm rate of about 10:1 is at the knee of the curve; there is not much benefit for trying for better. We are not there now (50:1 is one informal estimate[6]), but the Task Force is convinced that a modest increase in R&D funding over the next five years for the science and technology of UXO detection will allow us to reach this desired 10:1 false-alarm rate in the not-too-distant future. Appendices D and J provide more detail on potential false-alarm reduction.

Figures 4 through 7 and the curve of Figure 8 make a clear and incontrovertible case for deploying higher-technology instruments in the UXO process. There is no question that we should proceed in that direction, because the cost advantage achieved through the higher technology approach is enormous – tens of billions of dollars. However, today's piecemeal UXO cleanup process will not encourage or support the deployment of these higher-technology instruments. That problem is discussed next.

[6] Once again, the actual false-alarm rate can vary wildly from site to site. Our 100:1, 50:1, 10:1 numbers here are a broad average of what one might experience across a wide range of sites.

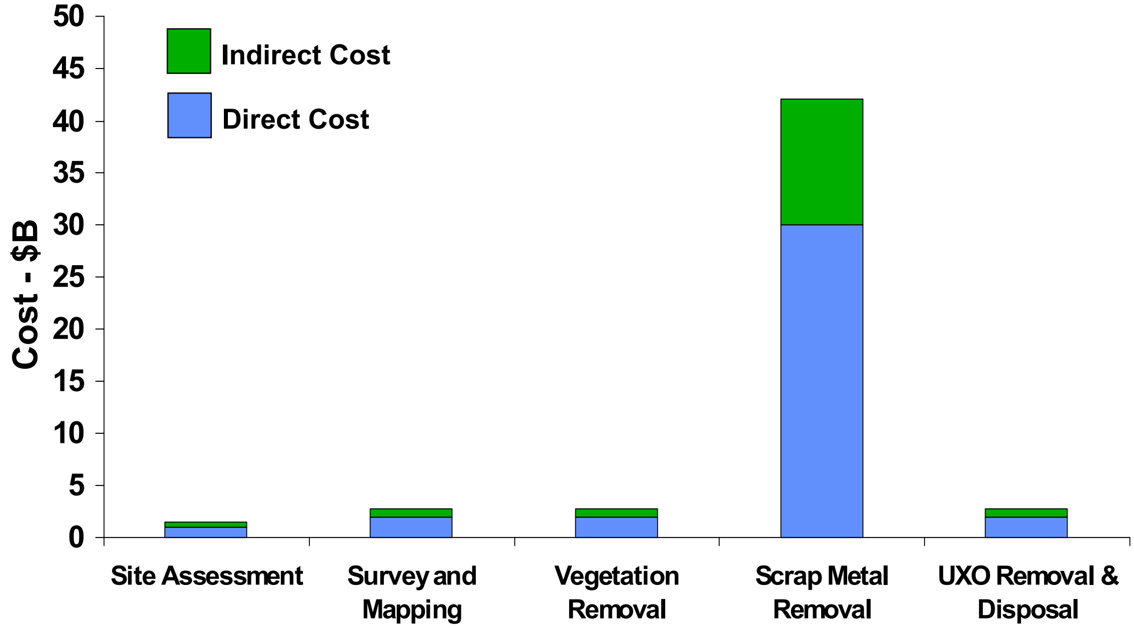


Figure 6. Low Tech Remediation - $52B

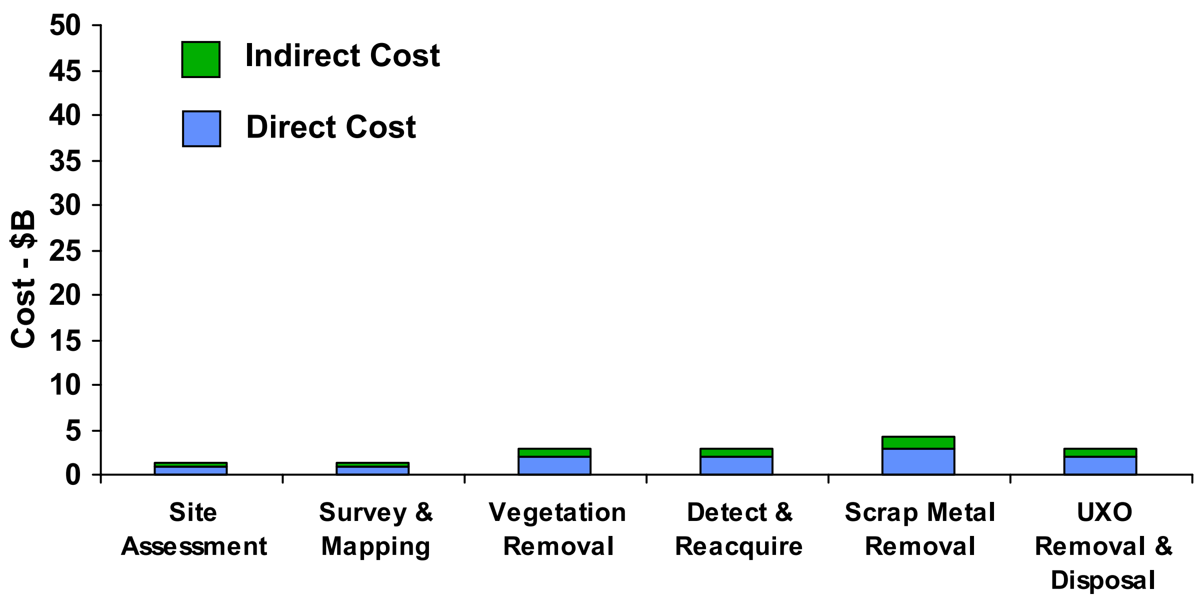


Figure 7. High Tech Remediation - $16B

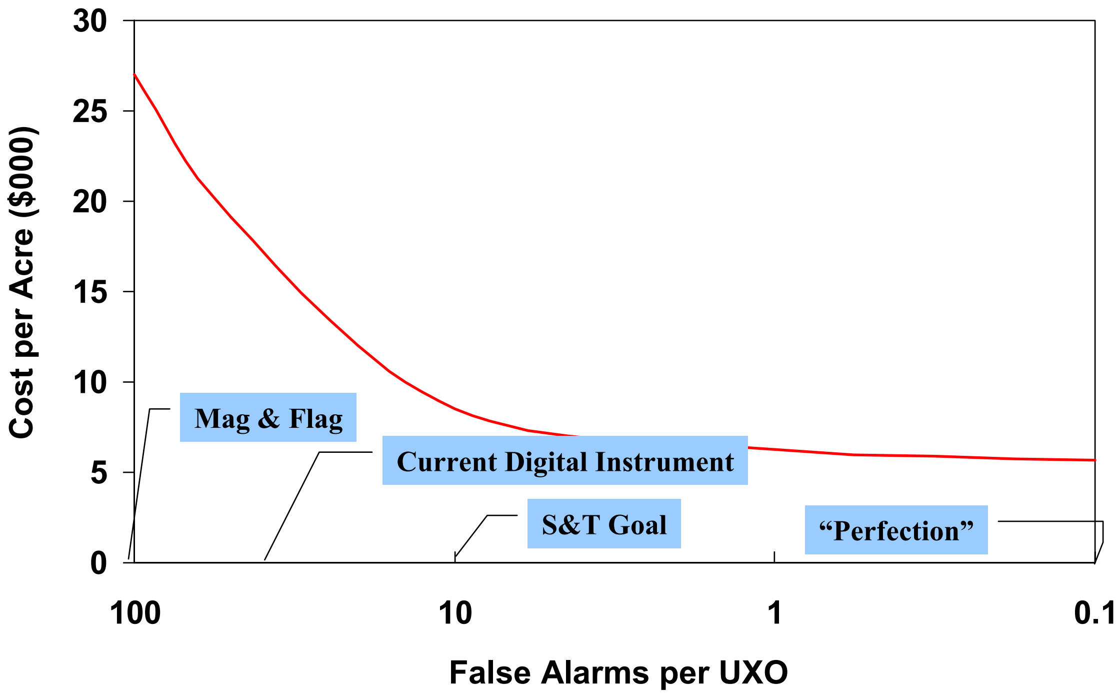


Figure 8. Cost to Remediate for "Nominal" Site

<u>Deploying New Technology Instrumentation – A Problem</u>

Today's DoD policies for UXO cleanup encourage a highly distributed process dominated by small business firms. We referred to this above as a "retail" model of operation. The Task Force believes that these piecemeal efforts are inefficient; fixed costs are substantial, and "lessons-learned" may not be transferred from small project to small project.

However, the most worrisome aspect of the retail mode is that the small business firms do not have the capital resources to acquire and use the latest-technology instruments, which are substantially more expensive to purchase than the old-fashioned "mag and flag" equipment. Thus, under this mode of operation we may never be able to reap the enormous cost benefits achievable in the higher-technology approach, because no contractor will be willing to purchase it.

This situation can be remedied by migrating the cleanup process to a few larger industrial performers, who will have adequate resources, a larger-scale cleanup contracting base, and sufficient backlog to capitalize new-technology instrumentation. These larger performers would presumably subcontract to the smaller firms who have the trained people and are now doing the cleanup in the field. (We understand that there is a somewhat fixed cadre of UXO field workers available, and they will find their way to the next UXO cleanup job, so individual employment concerns and small business goals can continue to be satisfied.)

The larger firms told us that the current government yearly spending level of about $200 million, even if spread over fewer cleanup contracts, is too low to provide adequate technology investment incentives for them. A yearly level of $400 to $500 million would provide sufficient incentive and would be of great interest to them. The Task Force recommends an increased funding to this level in its Recommendations (Section VI) for a number of reasons, only one of which is the ability to attract larger industrial performers to the UXO cleanup process.

Another approach to deploying higher-technology instrumentation to UXO cleanup would be for the DoD to supply the new instrumentation to firms as government furnished equipment. The Task Force views this as a less workable solution than the migration to larger industrial performers, because of the problems of scheduling equipment use, making it consistent with the phasing of work each contractor was engaged in, maintaining the equipment, etc. The Task Force felt that this was not a desirable role for the DoD and that private industry was far more suitable.

We recognize that moving to a centrally-planned and implemented "wholesale" approach will require the support of a large number of constituencies, most importantly, the U.S. Congress. The DoD must convince Congress of the necessity of that approach, so that Congress will support the funds necessary to implement it.

Summary

Can Technology Help Reduce the Cost of UXO Cleanup?

The answer is clearly "yes". The Task Force believes the path is obvious: the DoD needs to take a larger-scale, more aggressive approach to this multi-billion dollar problem, rather than nibble at it at a rate of $200 million per year. We believe the DoD will face increasing pressure for UXO cleanup, and we urge the Department to "get out in front" of the problem to preserve its ability to continue live-fire testing on our operational ranges and maintain the high degree of readiness we now enjoy.

IV. CAN SCIENCE AND TECHNOLOGY HELP FUTURE LIVE-FIRE TESTING AND TRAINING?

Once again the answer is "yes, but." Science and technology can produce "green" munitions (those that reduce or eliminate hazardous materials) to help mitigate future UXO and constituents problems. But in addition, we need to take another look at our use of munitions during our live-fire testing and training, and we need to develop a full life-cycle-cost view of munitions (including their eventual use or disposal). We believe that DoD's continued use of live munitions will come under increasing pressure, and we see three courses of action as necessary to mitigate these pressures: a migration to "green munitions", a better quantitative understanding of the munitions constituents problem, and a more disciplined approach to live munitions use. A new analysis of the need for, and use of, munitions in training is required. These will be discussed in turn, but we will begin by reviewing the rationale for, and the impact of, live munition use in training and testing.

Rationale for Live Munition Use in Training

The Task Force received briefings from Army, Air Force, Navy, and Marine Corps officers on the continued necessity for live-munitions use in training. They were uniformly emphatic about the need and referred many times to the theme: "practice the way you intend to fight". They felt it was most important to have trainees experience the effect and the feel of nearby munitions explosions. They stressed how critically important it was for trainees to get used to handling and firing live munitions. They were emphatic, to say the least, and didn't consider this a debatable topic!

The Task Force accepts that live munitions use in training is important and needs to continue, but we also think this use needs careful scrutiny on a case-by-case basis. We observe that the predominant training with U.S. Army tank direct-fire main guns is with realistic simulators, and these weapons have been a resounding success in recent combat. Similarly, modern medium caliber and large munitions will increasingly migrate to precision guidance, because one precision munition does the job of 10 or 100 non-precision ones, and collateral damage effects are much more controlled. At $25,000 or higher per round, the number of precision rounds used in training is likely to be reduced significantly.

In summary, there are many trends and forces in addition to the UXO problem and the associated munitions constituents problem that argue for a full reexamination of when, where, and how much live munitions should be used in training.

Typical Live-Munitions Use in Training

The numbers here are surprisingly large. Table 1, supplied by munitions specialists in the Office of the Secretary of Defense, shows the Fiscal Year 2003 munitions procurement and the expected munitions use in training.

Table 1. Typical Munitions Yearly "Buys" (FY03 Total Cost ~ $1.6 B)

	Buy	**Use in Training**
Small arms (5.56 mm – 12.5 mm)	**780 million rounds**	**500 million rounds**
Medium caliber (20 – 80 mm)	**21 million**	**14 million**
Large caliber (105 – 155 mm)	**850 thousand**	**650 thousand**
Grenades	**4 million**	**1 million**
Bombs	**50 thousand**	**90 thousand**

All of the small-caliber (50 caliber and below) and most of the medium-caliber (20mm to 81mm) ammunition is non-explosive. We estimate about 300 thousand rounds of the medium caliber is explosive, e.g., 40-mm HE rounds.

Thus, we fire about 2 million live-munition explosive rounds per year. This number can now be used to perform a rough calculation of the rate at which we will produce future UXOs.

Table 2 summarizes information provided by fuze experts from the Army's ARDEC facility on typical fuze "dud" rates, i.e., the percentage of live munitions that will not explode when fired because of fuze malfunctions.

Table 2. Typical Fuze Dud Rates

Latest Fuze Technology:	1-2 percent
Today's Typical Fuzes:	3-8 percent
20 Year or Older Munitions:	8-10 percent

If, as an example, we take a dud rate of five percent and apply it to the two million explosive training rounds, we would be producing 100,000 UXOs per year. This is far more than our current UXO remediation program removes in a year, and thus one could argue that we are not gaining on the UXO problem but losing ground! This is probably a pessimistic view of the problem, because, although the raw numbers support this view, most of these new 100,000 UXOs are contained in well-known, highly restricted, and well-controlled areas. However, on the pessimistic side, the munitions constituents associated with the use of munitions are not constrained and can migrate out of these well-controlled areas. The Task Force believes these problems need attention, particularly the munitions constituent problem, which is likely to become the foremost limitation on live-munition use in training. We discuss the constituent problem next.

<u>Munitons Constituents</u>

We understand that the greatest part of the munitions constituent problem comes from sources (e.g., munitions manufacturing, demilitarization) other than from UXOs. In this report, we are concerned with constituents that may originate from UXOs. However, regardless of source, munitions constituents are a growing concern. Of particular concern are perchlorates normally found in propellants or special-purpose payloads such as flares or smoke rounds that can leach into the ground water beneath test and training ranges.

Munitions constituents that result from use can impact the ground water that can migrate off the test range and find its way into domestic water supplies. The toxicity of these constituents is still open to debate, but the Task Force observes that the specific toxicity levels don't matter in terms of public pressure; if a potentially toxic constituent is detectable in people's wells or the public water supply, it becomes a most sensitive and politically volatile issue. In extremis, the finding of munitions constituents can shut-down testing on a major facility.

The Massachusetts Military Reservation is the first major example of munitions constituents shutting down a range, and more sites could follow. In late April 2003, the national press carried articles on traces of perchlorate found in samples of California supermarket lettuce (see Appendix H for the text of an article from the Boston Globe on April 28, 2003). Again, the source here apparently is not UXOs, nonetheless, the Task Force believes this issue can intensify and can bring increasing pressure on continued live fire testing at operational ranges. Many Service functional experts who briefed this Task Force felt that this constituents issue is their most worrisome problem, because it could lead to curtailment of important live-fire testing at operational ranges. The difficulty in dealing with it is compounded by the fact that emotion plays a much bigger role in driving events than either science or logic, particularly if the science is not well understood.

Controlling the Future

The Task Force sees a four-part approach to controlling future problems so we can continue acceptable live-munitions training on operational ranges:

- Increase the emphasis on "green munitions" technology
- Increase the use of simulation techniques in munitions training
- Improve the scientific understanding of munitions constituents regardless of source, phenomenology and human health effects
- Develop modified training and range management protocols

We discuss each of these next.

- **"Green Munitions" Technology**

The DoD has supported a "green munitions" program, as part of its environmental R&D effort, since 1991, and it is currently funded at about $25 million per year in the Science and Technology budget. The main focus of the program is the reduction or elimination of hazardous materials in munitions and in their manufacture, such as development of substitutes for the perchlorates of the munitions constituents problem. (Appendix F provides more detail on the overall program.) A prominent example of the green munitions effort is the development and substitution of a tungsten bullet for the lead bullet in the 5.56-mm military small arms cartridge. The non-toxic tungsten round costs a bit more than the lead round (35 cents versus 25 cents), but it avoids the necessity for the eventual removal of the lead round from the ground. Therefore the total life-cycle cost of the tungsten round is lower, since the lead recovery process can be expensive – far more per round than the 10 cent procurement differential!

Another easily achievable green munitions effort is the development of more reliable fuzes and fuzing processes. Fuze failure is the principal cause of UXOs, and a few more dollars spent on the fuze will pay handsome dividends. For example, the total cost of a UXO is surprisingly high: it costs roughly $1000 to dig up and dispose of the UXO, but the search for that UXO will turn up 10 to 100 false alarms that need to be dug up at a cost of some $150 each. Thus, a single UXO may carry a cost-to-remedy of anywhere between $2500 and $16,000, exclusive of finding it. Additional modest dollars applied to the fuze to reduce the dud rate from five percent to one or two percent can make economic sense. Fuze experts told us that one- to two-percent dud rates are achievable. One possibility is the use of a timer that works in parallel with the contact fuze and detonates the ordnance at a prescribed time after launch. This approach looks particularly attractive for the 40-mm grenades which have a high fuze failure rate.

Another attractive green munition approach, which is applicable to larger caliber munitions, is an instrumented band or tag on the munitions. This band carries a passive chip which can reply with an identification code when interrogated by a special instrument that would function much like a hand-held detection instrument. If the munition is intact (a UXO) the band survives and identifies the UXO. This technique is in early development, and the Task Force recommends accelerated development.

The Task Force recommends a strengthening and acceleration of the entire green munitions effort. As we take a long term view of the UXO problem, we see precious few fixes, and green munitions will be the backbone of our future munitions training. Again, in this UXO area, it is trivially easy to show handsome payback for dollars invested in the technology of green munitions.

- **Increased Use of Simulation**

Appendix G makes the case for an increased use of modern simulation techniques to replace some of DoD's live-fire exercises. Simulation is lower-cost, it is always "green", and it allows many more "firing" events per trainee. Today's simulations are quite realistic and capture close to the full sense of the firing event for even the case of small-arms weapons.

- **Improved Understanding of Munition Constituents**

The munitions constituent problem is relatively new to the DoD, and a wide range of efforts are needed to better understand the problem and its potential solutions. The development of management options to monitor, contain, and remediate munitions constituents on our operational ranges will require a better understanding of sources of contamination, their behavior over time, the transport mechanisms, and human and ecological toxicology.

The munitions constituents issue can become a volatile public controversy, and we can foresee a potentially endless chain of political actions and litigations that could threaten the DoD's long-term ability to use munitions in testing and training on operational ranges. A factually enlightened Department of Defense, with a vigorous program in this area, is the appropriate action.

- **Develop Modified Training and Range Management Protocols**

Achieving a full inventory of green munitions will take decades, and in the meantime we will continue to use a large number of munitions in training. We believe that the Services should be tasked to re-examine the use of live munitions on their ranges and ask to what extent live fire exercises can be reduced without significantly jeopardizing troop proficiency and readiness. They also should examine an increased use of modern simulation techniques which can offer frequent, lost-cost, and realistic training.

The DoD does have range clearance and maintenance activities. Because of our heightened concern about the munitions constituents problem, we recommend that range managers assess the environmental impact of the munitions use as a means of preventing a release or substantial threat of a release of munitions constituents from operational ranges to off-range areas. This seems to us to be just common sense. On operational ranges, the knowledge of where UXOs are is at its highest, the ground has not been "grown over" or settled significantly, and most important, leaching of constituents which takes time to occur has not begun.

The Task Force recommends that the DoD develop and promulgate a life-cycle cost view of munitions used in training. This cost would include the expected cost to deal with the munition as a UXO, which as we have seen is non-trivial because of the cost of digging the explosive UXO and the cost of digging a large number of false-alarm holes. These costs now occur in different accounts, and we are concerned that there is little financial incentive for managers to aggressively try to reduce UXO on their ranges. Our example above of how a slightly more expensive fuze has the potential to save, or at least cost avoid, many hundreds of million dollars per year, will fall on deaf ears, because the acquisition community has no stake in the cleanup cost. All a more expensive fuze will mean to the range users is an additional budget issue, with no compelling war-fighting advantage, that will have to be offset somewhere else in the acquisition budget. A life cycle view of the cost of munitions might at least help deal with this very real issue.

The Task Force asked if the ready availability of aging munitions led to more live-firing than was necessary. Range representatives were firm that this was not the case. They argued that no one wants to fire aged munitions; they want to train with the latest munitions; the ones they would fight with. We agree that all aged munitions should be "demilitarized" and not live-fired. Firing would not be a cheap way to dispose of aged munitions as is pointed out in a simple calculation in Appendix I involving 155-mm rounds. Our bottom line is: every live-fire event should involve a thoughtful awareness of the future cleanup cost.

V. RELATED TOPICS

The Terms of Reference for the Task Force asked for an assessment of underwater munitions clearance and an update of the previous Defense Science Board Task Force on UXOs findings. These two items will be briefly discussed in this section, along with a third topic that emerged in the course of our Task Force: the possibility of leveraging the relative economics of remediation and development.

Underwater Munition Clearance

This area has not yet received much attention. The Navy has conducted some simple experiments in relatively shallow water (typically 10-meter depth or less). The experimental results would be applicable to beach-like environments. An encouraging result is that waterproof versions of conventional detection sensors do work underwater, and they do detect metallic objects located on the bottom or located under the silt of bottom cover. There are many unresolved issues concerning boat platforms to carry the instrumentation, platform motion due to waves and surf, etc. Our assessment is that this is a relatively new field with much to be learned. The Navy seems to have made a good start with their current modest program. The Task Force is not aware of any assessment of the total extent of this underwater UXO problem, and one is needed to fill out the full picture of the national UXO problem. The Navy experiments in this area should be encouraged and expanded, and the Navy should develop a first-order estimate of the total underwater UXO problem. Appendix K discusses the underwater problem in more detail.

Update of the 1998 DSB Task Force on UXOs

The words of the 1998 Task Force[1] read much like the words of this report: there is strong agreement and correlation between our two reports and no outstanding disagreements. We note that the 1998 DSB Task Force called for larger industrial entities to do the UXO clearance, thereby permitting the introduction of more-sophisticated instrumentations and a more “wholesale” approach to the problem.

This is not to suggest that nothing has happened since 1998, nor that the 1998 recommendations were ignored. A number of DoD organizational changes took place that provided a more direct, clear focus and reporting chain for the UXO clearance problem. A number of coordinating groups across various DoD components were established, likely in response to the 1998 Task Force recommendations. Appendix L provides additional detail on the impact of the 1998 DSB Task Force.

A perception that “not much has happened since 1998” can be caused by the sheer magnitude of the UXO clearance problem and the relatively paltry government yearly funding devoted to this problem. The recommendations of this 2003 Task Force, contained in the section which follows, call for more DoD funding of the UXO problem, so that it is in consonance with the magnitude of the problem. But we have tempered these recommendations so they are affordable and in no way “break the bank”.

Leveraging Development Interest and Remediation Costs

During the course of our Task Force, the topic of funding remediation efforts by land developers or state development agencies was discussed a number of times. We see here a “win-win” strategy where the future land value is used to fund the UXO remediation of the land.

The value of the land after remediation and subsequent development can be high. We offer as an example the former Lowry Bombing Range near Denver, Colorado. The cost to remediate the 1000 areas of UXO area at Lowry is $7.5 million. The value of the planned housing development and associated amenities is $1 billion to $2 billion. The local property tax gain on such a development will be $6 million to $12 million per year. Thus, even using 10% of the newly created tax revenue stream for 10 years could pay for the remediation necessary to get the project off the ground to begin with. A host of other methods exist as well, including developer profit incentives. The bottom line is that in those cases in which a sharp increase in land value will be created by removing UXOs, that future value should be tapped. HUD has a large amount of expertise in this area, having done similar up front financial seeding of projects to create downstream value. The Task Force recommends that some effort be devoted to exploring this way to cover the cost of remediation in selected cases where the land value is or will be great. We note that substantial UXO land has become high-valued property due to the great urban spread in the United States over the past 50 years.

VI. RECOMMENDATIONS

This section summarizes the Task Force recommendations along with a suggestion as to which part of the DoD should pursue the implementation of the recommendations. The funding impact of the recommendations are summarized in Table 3.

1. Institute a national area assessment of the identified 10 million acres (Action: Deputy Under Secretary of Defense for Installations and Environment)

A major benefit of this recommendation is the freeing up of about eight million acres of land for public use in a relatively short time at the low-cost of $125 per acre.

Another major benefit of this five-year intense assessment program is it will provide the data for detailed planning of a wholesale approach. The Task Force sees little hope of reducing UXO cleanup costs if we continue to adhere to a “retail model” of operations.

The cost of this five-year effort is estimated at $1 billion, or $200 million per year, which will necessitate a substantial increase in the current DoD program which now runs at a total of about $200 million per year. We believe the DoD will be impelled by many forces to increase funding of UXO cleanup. Our view is the DoD should get ahead of these forces and plan a sensible, coherent program. This national assessment provides the information base for that informed, coherent plan.

2. Increase the R&D effort on UXO instrument technology, green munitions, and munition constituents phenomenology to a level of $80 million per year (Action: Director, Defense Research & Engineering)

These three R&D activities are now funded at about $40 million per year. They are all high-payoff technologies with the promise of saving tens of billions of dollars in UXO costs over the mid to far term.

UXO Instrument R&D: The simple cost analysis in this report points clearly to reducing the false-alarm rate in these instruments as the dominant factor in reducing the future national UXO cleanup cost by <u>tens of billions</u> of dollars. The technology goal should be a false-alarm rate of 10:1 or lower, to be achieved in five years. With today's modern sensing and digital processing capability, this capability is well within our grasp. If the DoD is committed to UXO cleanup cost reduction, this should be the definitive first step in technology.

Green Munitions: Green munitions fix the UXO problem where it starts – the munition design itself. They are our long-term solution to the UXO problem, and they should be pursued aggressively. The goals here are much better fuzes, particularly for low-cost medium caliber munitions (40-60 mm) which have proven to be the least reliable and are consumed in the largest quantities, the elimination of toxic materials in the munitions, and tags that can identify an expended munition that has become a UXO. The green munitions effort is the way to engineer ourselves around future UXO problems. The payoff is high because UXO remediation cost is high.

Constituents Phenomenology: Munitions constituents are an emerging, volatile issue which can become a "show-stopper" (e.g., the Congress or the courts shutting down munitions training on an operational range). The DoD needs a better understanding of this phenomenology so it can implement a definitive set of measures to sense, control, and remediate them. The Task Force is concerned that the DoD could find itself "litigated to death" here, and we urge the DoD to "get out in front" of this problem. Understanding the munitions constituent phenomenology is the start.

3. Institute a management and contractual structure that can capitalize new technology instruments (Action: Deputy Under Secretary of Defense for Installations and Environment)

The deployment and use of new-technology instruments is key to the saving of billions, and perhaps tens of billions, of dollars in potential UXO cleanup costs. These savings were easily identified by the Task Force in a straightforward fashion and were exemplified above in this report.

In today's world it is impossible to justify digging 100 holes in the ground to find one real UXO. Modern sensor and processing technology can do much better. We also need larger industrial firms involved in the UXO cleanup to migrate it fully to a "wholesale" model of operation. The DoD needs to take the necessary management steps to encourage the participation of larger industrial firms.

4. Conduct an assessment of live-fire practices on ranges with the goal of reducing the UXO and the related munition constituents problems (Action: Service Chiefs)

The Task Force recognizes the need for live fire training but we are not fully convinced that the large amount of such firing on our ranges (some two million explosive rounds per year) is in consonance with the growing UXO problem and the emerging munition constituents problem. We can foresee more use of realistic simulators and inert rounds to help the situation. This assessment, by those who set training standards, is a start on controlling the future UXO problem.

5. Establish a full life cycle cost protocol for munitions that includes cleanup and demilitarization (Action: Under Secretary of Defense for Acquisition, Technology, & Logistics)

The eventual disposal of a munition is a real part of its ownership cost, but in the current DoD structure the communities that procure and fire the munition, thereby creating UXOs, are widely separated from the community that eventually has to clean up the UXOs. The Task Force sees a need to raise the consciousness of the acquisition and firing communities to the UXO cleanup problem. We don’t see an easy way to charge the procurer or the user for eventual cleanup as is done by the five-cent deposit on beverage cans; but we should not have them oblivious to that cleanup cost. We want to encourage green munition acceptance and use, and a true understanding of cleanup cost will help do that. We recommend that the munitions specialists in OSD search for ways to do this.

<u>Cost Implications of Recommendations</u>

The DoD is facing UXO problems that will cost tens of billions of dollars to remedy. The Task Force described an approach that was relatively modest in scale -- one that would not “break the bank.” We foresee many pressures on the DoD to increase its funding on the UXO problems; a reasonable step in that direction would be a rough doubling of the current $200 million per year. Table 3 lays out this current funding and our suggestions for increased funding over the next five years and the out years. Our goal was to be ready to execute a full-wholesale approach to UXO cleanup starting five years from now. The large-scale cost savings (tens of billions) accrue in those out years.

Table 3. Funding Impact of Recommendations

Activity	Current Funding	Recommended Funding Next Five Years	Recommended Funding Out Years
Area Assessment	$25 M/yr	$200 M/yr	--
UXO Cleanup	$125 M/yr	$150 M/yr	$350 M/yr (wholesale model)
Instrumentation R&D	$20 M/yr	$40 M/yr (high tech instruments in five years)	--
Munitions Improvements - Green and Constituents	$20 M/yr	$40 M/yr (add human health component)	$40 M/yr
Total	**~$200 M/yr**	**~$450 M/yr**	**~$400 M/yr**

VII. SUMMARY

The some 70 briefings to the Task Force by UXO specialists and our own wide ranging discussions paint a clear picture that the UXO problem is a tough and important challenge for the nation. The problem is huge, complex, diverse and growing. We see increasing public pressure on the DoD as inevitable. We see no low-cost, short-term "silver bullet" way out of the problem.

While the challenge is great, we believe the DoD can get "out in front" of this problem. Technological help and management changes can dramatically reduce cost and schedule. We should be able to quickly free eight million acres of the total ten million acres of concern.

Some level of funding increase is needed to accomplish this "get-out-in-front" strategy and avoid tens of billions of dollars in downstream UXO cleanup costs. We estimate an increase to $450 million per year from today's $200 million per year can put us on this track.

Electronic technology and astute management clearly have great payoff here as we move over the longer term to a truly green munitions era.

Appendix A

Terms of Reference

This page intentionally left blank

THE UNDER SECRETARY OF DEFENSE

3010 DEFENSE PENTAGON
WASHINGTON, DC 20301-3010

ACQUISITION, TECHNOLOGY AND LOGISTICS

SEP 26 2002

MEMORANDUM FOR CHAIRMAN, DEFENSE SCIENCE BOARD

SUBJECT: Terms of Reference - Defense Science Board Task Force on Unexploded Ordnance

You are requested to form a Defense Science Board (DSB) Task Force on Unexploded Ordnance (UXO). Decades of military training and testing have resulted in the presence of UXO at many of our current and former test and training ranges. These are munitions that have not fully functioned or fully detonated. The processes of closing these ranges and transferring them from Department of Defense control has resulted in a major challenge and a major cost burden on the Department to locate and remove this potentially dangerous ordnance. The March 2001 UXO Report to Congress cited the DoD FY 2000 Financial Statements as placing the cost of clean up at ranges that are closed or to be closed and/or transferred at some $14 billion dollars. In addition, the potential environmental consequences associated with continued use of military munitions on operational ranges recently has raised many questions about the continued full use of these assets for live-fire training and testing of weapon systems.

The issues to be addressed by this Task Force are twofold:

1) Can modern technology be exploited or developed to reduce the extremely high cost of UXO clean up and improve its effectiveness for UXO-contaminated land and water ranges and help accomplish the job in a reasonable time?

2) Can the science and technologies be developed to minimize the environmental impact of continued live fire training and testing of munitions at ranges across the United States?

A Defense Science Board Task Force on Unexploded Ordnance Clearance operated from 1996 to 1998 with a final report[1] in April 1998. That Task Force made a number of organizational and science and technology recommendations. Today, there is a focused activity in the Department of Defense under the direction of the Deputy Under Secretary of Defense (Installations and Environment). The Deputy Under Secretary's Report to Congress in March of 2002 cited some 28 installations that may need UXO clearance efforts involving close to 90,000 acres of possible UXO-contaminated land.

---

[1] Report of the Defense Science Board Task Force on Unexploded Ordnance (UXO) Clearance, Active Range UXO Clearance, and Explosive Ordnance Disposal (EOD) Programs, April 1998 (Unclassified).

The challenges facing the Department in answering the questions posed by the Congress are extensive and complex. The extent of the munitions contamination on the Department's current and former ranges and maneuver areas is not readily identifiable. The ability effectively to narrow the area of investigation is extremely difficult, but also directly affects the Department's credibility to properly scope the challenge and provide the necessary explosive safety protection.

The reliable location and identification of unexploded ordnance that may be located well beneath the surface is a most challenging task. Sensors that are sensitive enough to see 10 to 20 feet down are frustrated by numerous false alarms from rocks, scrap metal, and other anomalies. The removal process employed today is tedious, labor intensive, and leaves behind--at best-- an uncertain level of residual explosives safety and environmental risk. Scrap residue disposal and the cleanup of munitions constituents are also hampered by a deficiency in knowledge – from basic science to demilitarization techniques.

The Task Force should:

1 Review and update the recommendations of the 1998 DSB Task Force.

2. Review and comment on the existing methods of location, discrimination, and clearance and the science and technology initiatives that are underway in the Department of Defense. Suggest additional science and technology initiatives that could improve our capability and reduce clearance costs.

3. Conduct an initial investigation of technology possibilities for clearing underwater range environments and recommend avenues for further investigation.

4. Review the various simulation and modeling activities that attempt to model the range clearance process and couple this with cost models to estimate range clearance costs. An initial assessment of the validity of these models and simulations should be made if enough information is available to do so.

5. Review and comment on the potential environmental impacts due to the use of live munitions in testing and training activities. Suggest additional science and technology initiatives that could aid in predicting the environmental impact from live- fire activities and effectively manage or mitigate potential risks.

6. Review the munitions life cycle working backwards from the unexploded ordnance issue to range practices to the actual manufacture of the munitions to suggest ways to significantly reduce the unexploded ordnance problem in the future.

7. Review and comment on the current cost- to- complete methodologies for non-operational munitions sites. Review and comment on possible methods to use cost data to focus development of new technology.

The Task Force should provide its final report by July 2003, but an interim briefing should be prepared for presentation in January 2003 to inform the Department's UXO technology development report to Congress in April 2003.

The Task Force will be co-sponsored by me as the Under Secretary of Defense (Acquisition Technology and Logistics) (USD(AT&L)) and the Deputy Under Secretary of Defense (Installations and Environment). Dr. Delores Etter and Mr. William Delaney will co-chair the Task Force. Col John Selstrom, USAF, of the ODUSD(I&E) will serve as the Executive Secretary and provide connectivity to the operational range, munitions response, and explosives safety communities. LTC Carla Kendrick will serve as the Defense Science Board Secretariat representative. Dr. Jeffrey Marqusee of OUSD(AT&L) will serve as the representative of the Environmental Security Technology Certification Program (ESTCP) and the Strategic Environmental Research and Development Program (SERDP).

The Task Force will operate in accordance with the provisions of the "Federal Advisory Committee Act," 5 U.S.C. Appx. 2, secs. 1-15, and DoD Directive 5105.4, the "DoD Federal Advisory Committee Management Program." It is not anticipated that this Task Force will need to go into any "particular matters" within the meaning of Section 208 of Title 18, U.S. Code, nor will it cause any member to be placed in the position of acting as a procurement official.

E. C. Aldridge, Jr.

Appendix B

Task Force Membership

This page intentionally left blank

Task Force Co-Chairs

Mr. William Delaney
MIT Lincoln Laboratory

Dr. Delores Etter
United States Naval Academy

Executive Secretary

Col. John Selstrom
USAF, OSD-ATL

Task Force Members

Mr. John C. Fielding
Raytheon Company

Dr. John S. Foster
Consultant

Mr. Don Fredericksen
Hicks & Associates, Inc.

Mr. Cliff E. McLain
ARES Corporation

Mr. Gerald McNiff
Consultant

Dr. Eliahu Niewood
MIT Lincoln Laboratory

Dr. George Schneiter
Consultant

Mr. Robert Stein
Consultant

Mr. Fritz Steudel
Consultant

Government Advisors

Dr. Jeffrey Marqusee
OUSD (AT&L)

Ms. Sherry McCahill
USN

Dr. John Potter
US Army Corps of Engineers

Defense Science Board Secretariat

LTC Scott Dolgoff
United States Army

Support Staff

Mr. Chester Kurys
MIT Lincoln Laboratory

SAIC Support

Ms. Allison Balzano, SAIC
Ms. Allison Burrey, SAIC

Appendix C

Briefings Received

This page intentionally left blank

Title of Brief	Briefer	Organizational Affiliation	Date
ESTCP/SERDP Technology Overview	Dr. Jeff Marqusee	ESTCP/SERDP	09/26/2002
JUXOCO Briefing	Mr. Jim Hersey	JUXOCO	09/26/2002
Operational Range Strategy	Mr. Bruce Beard	ODUSD	09/26/2002
OEESCM Briefing	Mr. Ken Cornelius	OEESCM	09/26/2002
DAA: Section 311 Prioritization Method	Ms. Patricia Ferrebee	OADUSD	09/27/2002
DAA Section 313 Cost Estimate	Mr. Bob Turkeltaub	OADUSD	09/27/2002
DAA Section 313 Technology	Dr. Jeff Marqusee	ESTCP/SERDP	09/27/2002
DDESB	Capt. Bill Wright	DDESB	09/27/2002
Operational Range Clearance Policy	Mr. Brian Hemlinger		09/27/2002
Community Outreach	Ms. Jan Larkin		09/27/2002
OE Investigations	Dr. Theodore Asch	USA-COE	10/30/2002
Lowry Bombing Range Case Study		Army Corps of Engineers	10/30/2002
Boise Case Study		Army Corps of Engineers	10/30/2002
System Performance	Dr. Ann Andrews	ESTCP/SERDP	10/31/2002
Mag & EMI UXO Phenomenology	Dr. Thomas Bell	AETC Incorporated	10/31/2002
MTADS System	Dr. Herb Nelson	NRL	10/31/2002
UXO Signal Processing	Dr. Leslie Collins	Duke University	10/31/2002
Airborne UXO Technology	Dr. James McDonald	AETC	11/21/2002
Army EQT Program	Dr. John Cullinane	ERDC	11/21/2002
Standardized Test Sites	Mr. George Robitaille	AEC	11/21/2002
Fuze Reliability	Mr. Cliff McClain	ARES Corporation	11/21/2002
Boise Cascade Study	Dr. John Potter	Army Corps of Engineers	11/21/2002
RACER	Mr. Bruce Wagner	EarthTech	11/21/2002
Munitions Action Plan	Mr. Greg Schirf	OEESCM	11/22/2002
Rand Risk Assessment	Ms. Jackie McDonald	Rand	11/22/2002
Air Force Overview Brief	Lt. Col. Jeff Cornell	USAF	12/03/2002
Navy and Marines Overview	Ms. Cindy Turlington	USN	12/03/2002
Army Overview Brief	Mr. JC King	ASA-I&E	12/03/2002
FUDS	Mr. Jim Coppola	HQUSACE, FUDS BRANCH	12/03/2002
Kahoolawe Case Study	Ms. Sherry McCahill	USN	12/03/2002
Community Perspective	Ms. Aimee Houghton		12/03/2002
UXO Clearance Industry	Mr. Jack Norris	NOAC	12/03/2002
Development of Airborne SQUID	Mr. TJ Garney	ORNL	12/04/2002
3D Steerable Magnetic Field Sensor	Mr. C. Nelson	JHU, APL	12/04/2002
Advanced Magnetic Field Sensor	Mr. Y. Dalishaouch	Quantum Magnetics	12/04/2002
Munitions Response Inventory	Mr. Bob Turkeltaub	OADUSD	01/22/2003
Munitions Response Prioritization	Ms. Patricia Ferrebee	OADUSD	01/22/2003
Munitions Response Cost Estimate	Mr. Bob Turkeltaub	OADUSD	01/22/2003
Munitions Response Technology	Dr. Jeff Marqusee	ESTCP/SERDP	01/22/2003
ITRC	Mr. Jeff Swanson	Colorado Dept. of Public Health and Environment	02/12/2003
EPA Ordnance and Explosives Initiatives	Mr. Jim Woolford	EPA-FFRRO	02/12/2003
Scissors Discussion	Col. John Selstrom	USAF	02/12/2003
OSD Readiness	Mr. John Walsh	OSD	02/12/2003
TRI Reporting	Mr. Greg Schirf	OEESCM	02/12/2003
OSD Munitions	Mr. Tony Melita & Mr. Dave Houchins	OSD	02/12/2003
Congressional Staff	Ms. Rebecca Cook (Congressman Blumenauer)	Congress	02/12/2003

Title of Brief	Briefer	Organizational Affiliation	Date
JUXOCO Tech Transfer	Mr. Jim Hersey	JUXOCO	02/13/2003
AF Ranges	Ms. Maureen Koetz	USAF	02/13/2003
Munitions Response Case Study	Mr. Leo Montroy	Tetra Tech Inc.	02/13/2003
Fuze Discussion	Mr. Lee Springer	US Army Fuze Management	02/13/2003
DDESB	Capt. Kiser	USN	02/13/2003
Munitions Constituents (Science)	Dr. Jeff Marqusee	ESTCP/SERDP	02/13/2003
Green Munitions Overview & Underwater Issues	Dr. Jeff Marqusee	ESTCP/SERDP	03/11/2003
Joint Munitions Command on the Perchlorate Issue	Mr. Redding Hobby	Office of the Dep CoS, G-3	03/11/2003
Range Clearance Policy	Mr. Tom Macia	Office of the Dep CoS, G-3	03/11/2003
Army Need for Live Fire	Mr. Tom Macia	Office of the Dep CoS, G-3	03/11/2003
Marines Need for Live Fire	Col. Bob Strahan	USMC	03/11/2003
Navy Need for Live Fire	Capt. Jim Scholl	USN	03/11/2003
Air Force Need for Live Fire	Col. Jim Wilson	USAF	03/11/2003
Ft. Belknap Range	Col. Jim Wilson	USAF	03/11/2003
Industry Perspective	Mr. Bob Menke & Mr. Jack Foley	Shaw Environmental and Infrastructure, Inc.	03/12/2003
Navy Program Mgmt; Contracting Strategy & Tech Transfer	Mr. Brian Harrison & Mr. Richard Mach	Naval Facilities Engineering Command	03/12/2003
Navy Underwater UXO RDT&E Efforts	Mr. Brian Harrison & Mr. Richard Mach	Naval Facilities Engineering Command	03/12/2003
Green Munitions	Mr. John Middleton	ARDEC	03/12/2003
Land Developer Approach to UXO	Mr. Jack McIlrath		04/22/2003
Munitions Background Info	Mr. Redding Hobby	Office of the Dep CoS, G-3	04/22/2003
DERP Report to Congress	Mr. Kurt Kratz	DERP	04/22/2003
Munitions Life Cycle Examples	Mr. Dave Houchins	OSD	04/22/2003
AFCEE Contract Strategy for Airborne Sensors	Mr. Gene Gallogly	USAF	04/22/2003

This page intentionally left blank

Appendix D

UXO Sensors and Sensor Technologies

Gerald McNiff

Eliahu Niewood

Fritz Steudel

This page intentionally left blank

Introduction

This appendix provides an overview of the Unexploded Ordnance (UXO) detection and discrimination process (Section 1), followed by a discussion of current technology and future technology improvements to achieve an order of magnitude reduction in false alarm rates (Section 2). Section 3 provides a discussion in greater detail on the phenomenology of the various sensor technologies.

1. UXO Process

While the problem of unexploded ordnance on current and former military ranges has political, financial, policy, and other considerations, technology is clearly a key aspect of this problem. Any technology allowing faster, cheaper, and/or more accurate cleanup of land potentially containing UXO would greatly help alleviate the UXO problem. This appendix examines the role of technology in improving the UXO cleanup process as well as describing some of the key emerging technologies in this area. In particular, this appendix focuses on the role improved sensing technology could play.

As shown in Figure D-1, there are a number of steps in the UXO cleanup process.

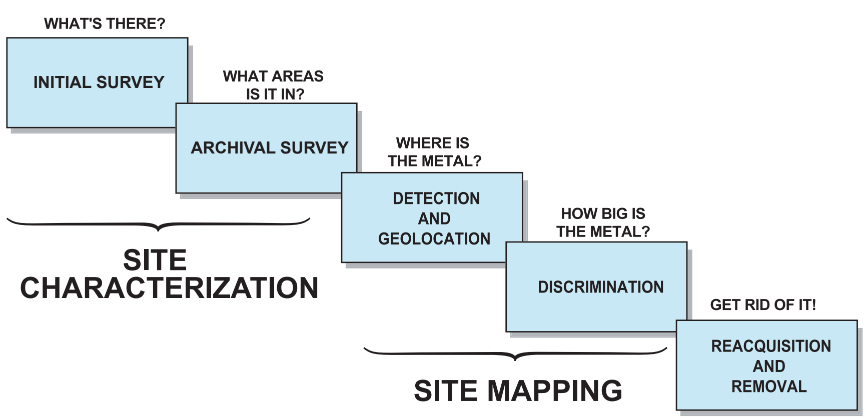


Figure D-1. Elements of the UXO Cleanup Process

However, there are two elements to this process where improved sensing technology could play an important role. The first is to determine which pieces of land may have UXO. This step is described herein as site characterization. The second primary element of the UXO cleanup process is to perform a detailed investigation of those pieces of land identified during the site characterization process. This step is described herein as site mapping. Clearly, a given technology may impact either or both of these processes. However, the challenges, requirements, and impact of a given technology may be different for the different steps.

Site Characterization

Any land that was once used by the Department of Defense (or the organizations which it is made up of) could potentially have a UXO problem. Not counting active military ranges or properties closed as part of the Base Realignment And Closure (BRAC) process, there are approximately 9000 Formerly Used Defense Sites (FUDS) in the United States. As a rough estimate, these 9000 properties contain over 100 million acres of land. Given typical costs to clean an acre of land ranging from $2000 to $20,000, clearly all of this acreage cannot go through the site mapping and cleanup process. Fortunately, past experience shows that the overwhelming majority of this land contains no UXO. In order to know which lands must be cleaned, a site characterization process is used to eliminate acreage that is not likely to pose danger currently or in the future. There are a number of reasons why a given piece of land may not need cleanup. At some sites, the planned usage may be limited enough that only a surface clearance may be required. For example, this was done at Boise Bombing Range, where only 50 acres of a 1000-acre site had subsurface clearance done. The rest of the acreage was surface cleared only.

More commonly however, the characterization process involves determining that there are no UXO at a given site or within a particular area at a given site. The site characterization process typically starts with initial surveys to identify which sites had gunnery or artillery ranges, and where those ranges were. This initial survey is followed by a more detailed archival search, in which historical information about the identified ranges is collected and reviewed. For the FUDS sites, as of FY 2001, nearly all 9000 sites have been reviewed. Approximately 1700 properties were determined to require a preliminary survey. Of these sites, 763 properties with

1450 ranges covering 8 million acres were assessed to require at least some further analysis. As shown in Figure D-2, these initial steps typically eliminate over 95% of the overall acreage at a defense site.

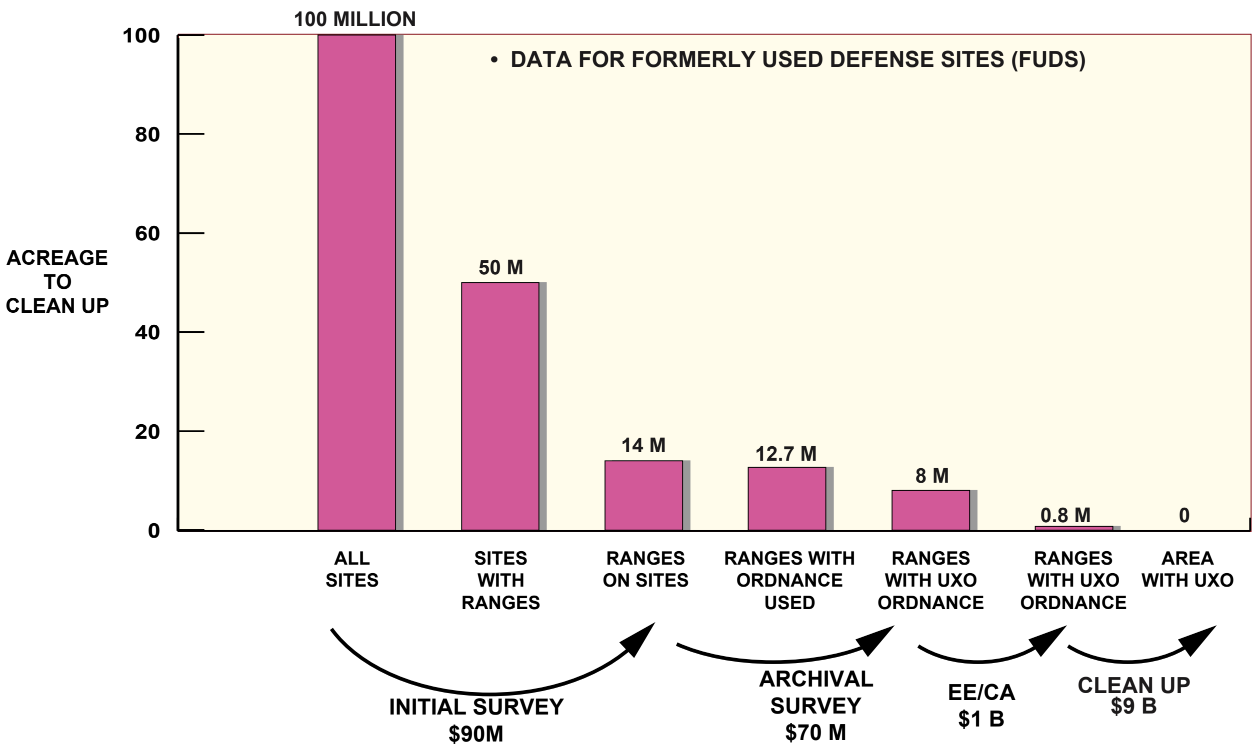


Figure D-2. UXO Site Characterization Process

For the remaining acreage, a detailed Engineering Evaluation and Cost Assessment (EE/CA) study is typically performed. The primary purpose of the EE/CA process is to determine the most appropriate course of action for the site. A detailed description of the EE/CA process is beyond the scope of this appendix. However, it typically involves doing detailed surveys on statistically significant portions of the site in order to determine the location, density and type of UXO present.

As shown in Figure D-2, the addition of the EE/CA results reduces the acreage for which site mapping and cleanup are required to less than 2% of total defense site acreage. However, the accuracy of this characterization process is not well described. Given the extremely low density of UXO at some EE/CA sites, and the lack of specific cleanup standards, it is possible that the characterization process is eliminating sites with UXO that should be slated for cleanup.

It is certain that there are UXO at sites that have been declared clean, even though these UXO may never be found or cause damage to property or people. It is also not well known if all sites that are slated for cleanup after the characterization process are indeed found to contain UXO. Of 19 typical EE/CA and sites for which data is available, no UXO were found at 6 of the sites. The accuracy of the characterization process is one challenge that technology should be able to improve. If new technologies were to include faster, cheaper wide area sensing, this would enable more area to be characterized as part of the EE/CA process. This should lead to reducing the acreage mapped and cleaned unnecessarily. This would directly reduce the cost of doing UXO cleanup. It should also lead to fewer sites with UXO being declared clean when they did actually contain UXO. Although this would cause cleanup costs to rise, it would enable a better job of UXO cleanup to be performed.

<u>Site Mapping Process</u>

The site characterization process described above is only the first step in the UXO process. The more costly step is the actual site mapping and cleanup that follows the characterization process. The site mapping process typically includes using an Electromagnetic Induction (EMI) sensor or magnetometer (or both) and carrying the sensor (by hand, cart, truck, or helicopter) across the site so as to pass within sensor range of every square inch of the site. In the past, the sensors had analog output only, and any detections that were made were flagged so they could be relocated. At a later time, Explosive Ordnance and Demolition (EOD) personnel would reacquire the detection and dig until something was found. Today, digital geophysical mapping (DGM) is used at many of the sites. This process uses digital output from the sensors to discriminate somewhat based on the characteristics of the sensor output. Also, precise locations of the detection are recorded via differential GPS or other means so that the detection can be more easily reacquired.

Currently, the bulk of the cost in UXO cleanup projects is the digging of holes to find UXO at the locations of the sensor detections. On a typical site, as shown in Figure D-3, between 10 and 2000 holes are dug per acre.

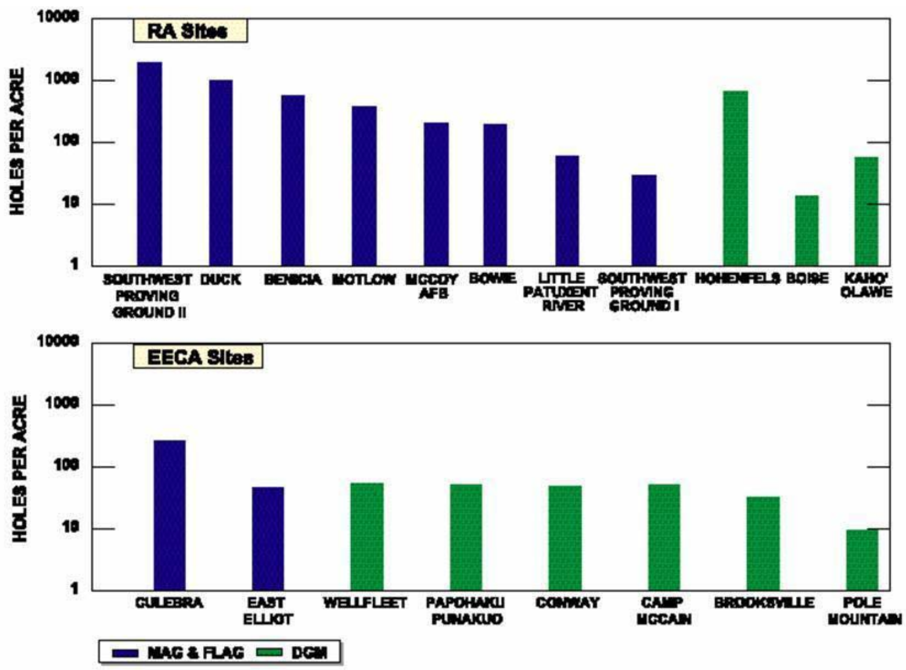


Figure D-3. Number of Holes Dug per Acre

Figure D-3 shows data for two types of sites, Removal Action (RA) sites where a full cleanup has taken place and all of the required acreage has been fully mapped and all UXO found have been excavated and removed, and EE/CA sites where a limited amount of acreage has been mapped and excavated to get an assessment of what steps will be required to fully clean up the site. Note that there is almost a two order of magnitude variation in the number of holes dug per acre from site to site. This large variation has a number of causes. The primary reason is variation in the amount of munitions fragments at the site. Other causes include

1) geology of the site (type of soil, type of rocks, etc.)
2) topology of the site
3) number of ordnance expended at the site
4) size of ordnance expended
5) types of ordnance expended
6) cultural debris

For example, at some sites, ordnance of all sizes was used. Because of this, every detection made at the site must be dug and investigated. This can result in an extremely large number of holes dug per acre. At other sites, only large caliber ordnance was used. This allows fewer detections to be investigated and dug.

Of all of the holes dug at a given site, as shown in Figure D-4, only 1 in every 10 to 1000 actually contain UXO, when there is UXO at a site.

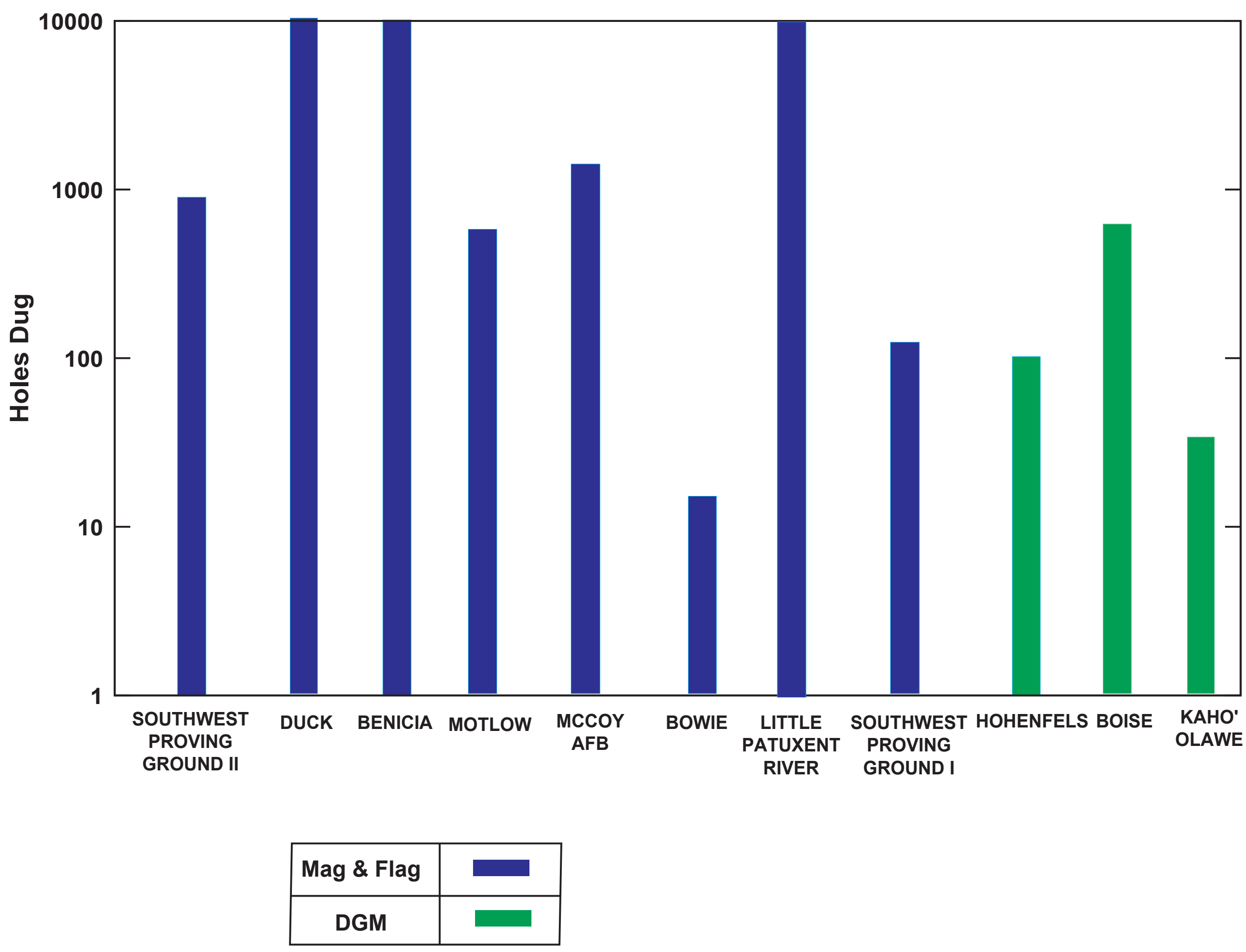


Figure D-4. Number of Holes Dug per UXO Found

Again, as in Figure D-3, there is a large variation from site to site, for the same reasons given above. For those particular sites, there does seem to be a significant improvement in the number of holes dug per UXO using DGM instead of mag and flag. However, given the small number of sites and large variation from site to site, this improvement is difficult to quantify or even substantiate. But, under controlled demonstrations on seeded test sites where ordnance and metallic clutter have been emplaced underground, digital geophysical methods have shown significantly higher probability of detection and lower false alarm rates than "mag and flag." Tests conducted at Jefferson Proving Ground by ESTCP showed an increase in the probability of detection of approximately 30 % and a decrease in false alarms by a factor of 2 to 3 by using advanced digital geophysics. At the Fort Ord FUDS, a number of areas were scanned using both mag and flag and DGM techniques. The number of anomalies detected with DGM were significantly less at these test locations than with mag and flag. Anecdotally, a factor-of-ten improvement is expected from current DGM techniques over old mag and flag approaches. Even with DGM however, Figure D-4 shows a significant number of holes being dug for each UXO.

The holes not containing UXO contain a mix of exploded ordnance of a similar size to UXO, smaller fragments from exploded ordnance, other small metal objects or are due to sensor false alarms. The relative numbers of the various types of objects found in the holes dug varies dramatically from site to site. Numbers for three different areas at the Fort Ord FUDS are shown in Table D-1.

Table D-1. Source of False Alarms at Fort Ord Test Sites

Test Site	Total Holes Dug	No Metal Found	Small Fragments	OE	UXO
FTS1	8579	532	7978	69	0
FTS3	1086	887	194	5	0
FTS6	2375	299	2043	31	2

For over 10,000 holes dug at the three test sites, only 2 UXO were found. However most of the holes contained metal fragments of one kind or another and were not false alarms.

The primary impact improved technology should have would be to further reduce the holes dug with no UXO. Improved discrimination is one focus of current research and development. This discrimination would allow cleanup personnel to determine not only if subsurface metal is present, but an approximate size or perhaps even the shape of the metal detected. Thus, holes would only need to be dug for buried metal similar to UXO.

However, many of the non-UXO holes do contain metal or explosives material of a similar size to the UXO used at the site. These holes will continue to require digging even with improved technology. Data to determine what percentage of the holes dug contain metal similar in size or shape to the UXO is not available. However, data for how many holes contain some type of Ordnance and Explosive (OE) material is available. The OE material may be similar in size to the UXO or significantly different in size. Nevertheless, it is the best available surrogate for the amount of "UXO-like" material found at a site. Figure D-5 shows the number of holes dug per hole containing either UXO or other OE material.

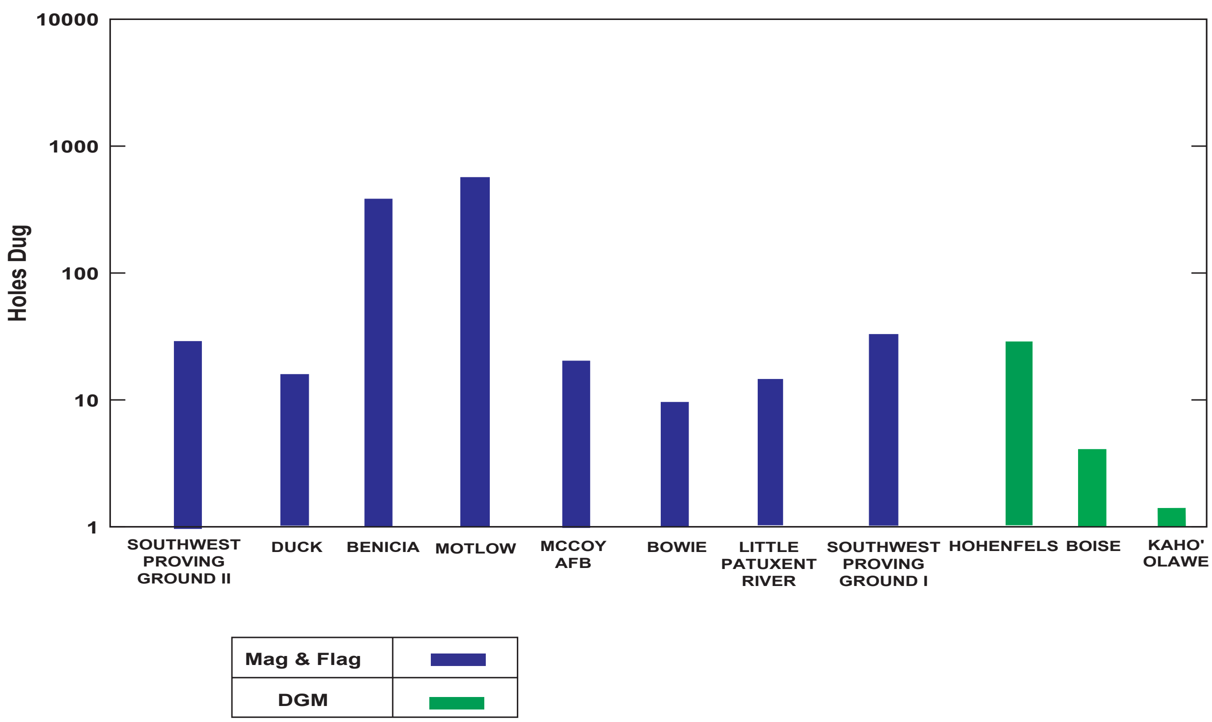


Figure D-5. Number of Holes Dug per UXO or OE Found

If it were possible to reduce the number of holes dug that did not contain UXO, the overall cost of cleanup could be reduced. The cost of digging holes is currently the major cost component in the UXO process. Reduction in cost for a median site as a function of the number of holes dug per UXO is shown in Figure D-6.

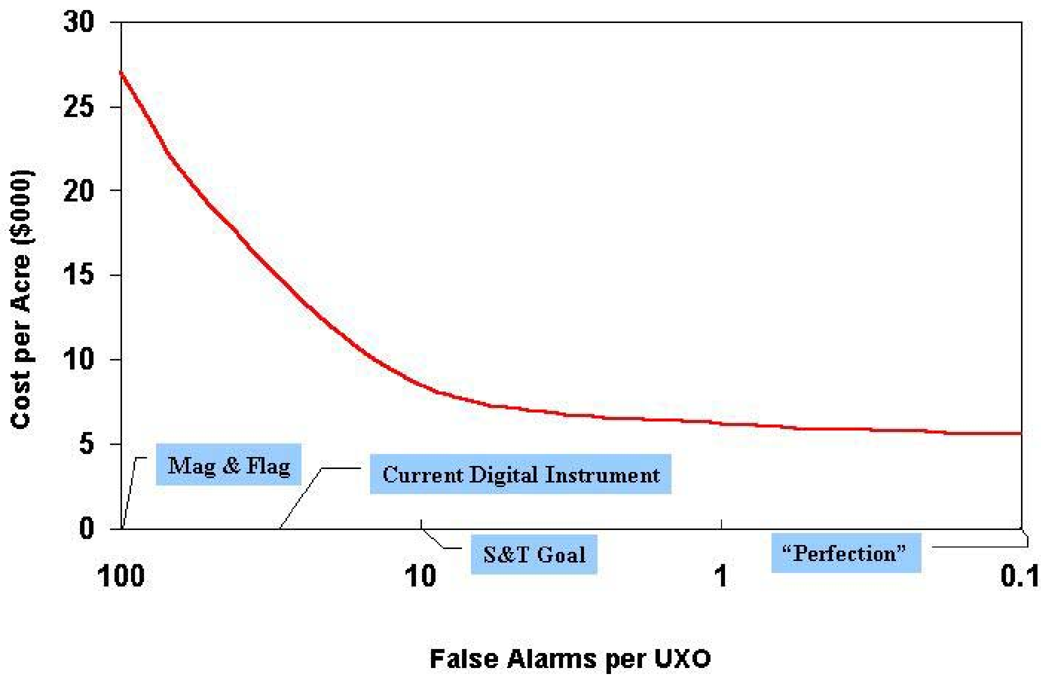


Figure D-6. Impact of Holes Dug on Cleanup Costs

Achieving a ten-fold decrease in holes dug would produce a corresponding threefold reduction in cost. Further reductions in the number of holes dug, even down to "perfection" where one hole is dug per UXO, does not have a significant payoff.

2. Sensors for Detection of UXO's

Overview

The types of sensors that have been most successful in detection of UXO's are magnetometers and electro-magnetic induction (EMI) devices.

Magnetometers are passive instruments that detect irregularities in the earth's magnetic field caused by ferrous objects, such as steel. They will not detect non-ferrous materials, such as aluminum. This is the most commonly used detection device at OE sites..

Electromagnetic Induction devices (EMI) are active sensors that employ multiple coils, in which a transmitted electrical current produces a secondary eddy current when in the presence of metallic objects. EMI devices used to detect UXO come in two general categories, time domain and frequency domain. Typical bandwidths are on the order of tens of kilohertz.

Other Sensor Types

Experimentation with other sensor technologies has included Electro Optical/Infrared (EO/IR), Ground Penetrating Radar GPR), Foliage Penetrating Synthetic Aperture Radar (SAR), and seismics. These are mostly of limited value and will be discussed only briefly.

Electro-optical and infrared red have some potential value for surface survey and very shallow metallic objects, but no capability for deeply buried objects.

Ground penetrating radar is limited by moisture and soil constituents. The low frequencies which provide best penetration preclude angle resolution for imaging. Resolution in range only limits the ability to resolve closely spaced buried objects. Foliage penetrating synthetic aperture radar may have value for surface scanning in shrubbery or forest canopy. Seismic techniques have had little success.

Current Technology Baseline

Subsurface UXO clearance of large areas is a new DoD undertaking. It was never attempted until recently. When clearance of large areas first began during the decade of the 1990s, the same tools and approaches were utilized that EOD personnel had used to detect and remove UXO from small sites. Personnel scanning an area with a simple analog system, such as a hand-held magnetometer, which produces an audio signal for the operator to interpret. At each detection, the operator marked the location with a small flag, hence the expression "mag and flag". Later, all locations are excavated. This technique might typically result in hundreds of flags per acre, with an attendant large digging cost. Mag and flag remains a necessary tool in areas of difficult terrain and vegetation where more complex systems are unuseable.

Improvement to analog systems consists of digital recording of the signals, combined with a mechanism that accurately locates and records the instantaneous location of the sensor head (e.g., differential GPS). These improvements provide a permanent record of the data collected and allow subsequent detailed computer analysis of the data. These digital systems increase the land area scan rate, up to several acres per day.

Digitally recorded, geo-referenced systems, including cesium vapor magnetometers and EMI sensors are the current sensor technology baseline. Combinations of sensor technologies and development of more complex EMI systems are emerging as the next generation of sensors. Current systems are largely restricted to total field magnetometers, and single axis, single time-gate EMI.

Examples of Systems Built

Cesium-Vapor magnetometers measure magnetic total field and can be used individually, or in systems of multiple detectors. An array in of eight such Cesium Vapor magnetometers is shown in Figure D-7.

Figure D-7. MTADS Magnetometer Array

The magnetic changes resulting from magnetic objects or geologic objects distorting the geomagnetic field are measured. The magnetic anomaly can be inverted to determine target position in three dimensions and the dipole moment, as shown in Figure D-8.

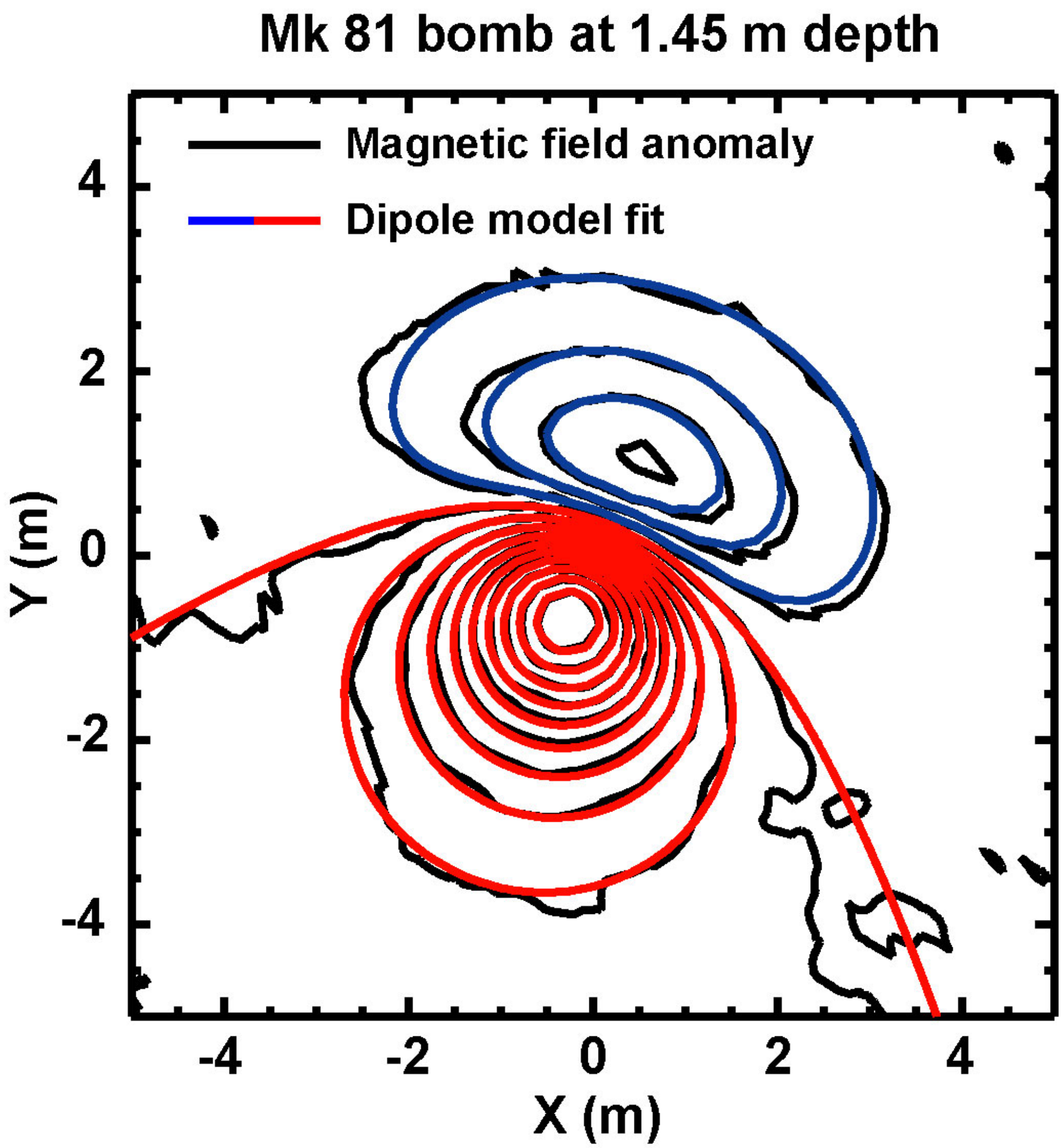


Figure D-8. Dipole Moment

The ability to categorize projectiles is illustrated from the Yuma Proving Ground test site data, shown in Figure D-9.

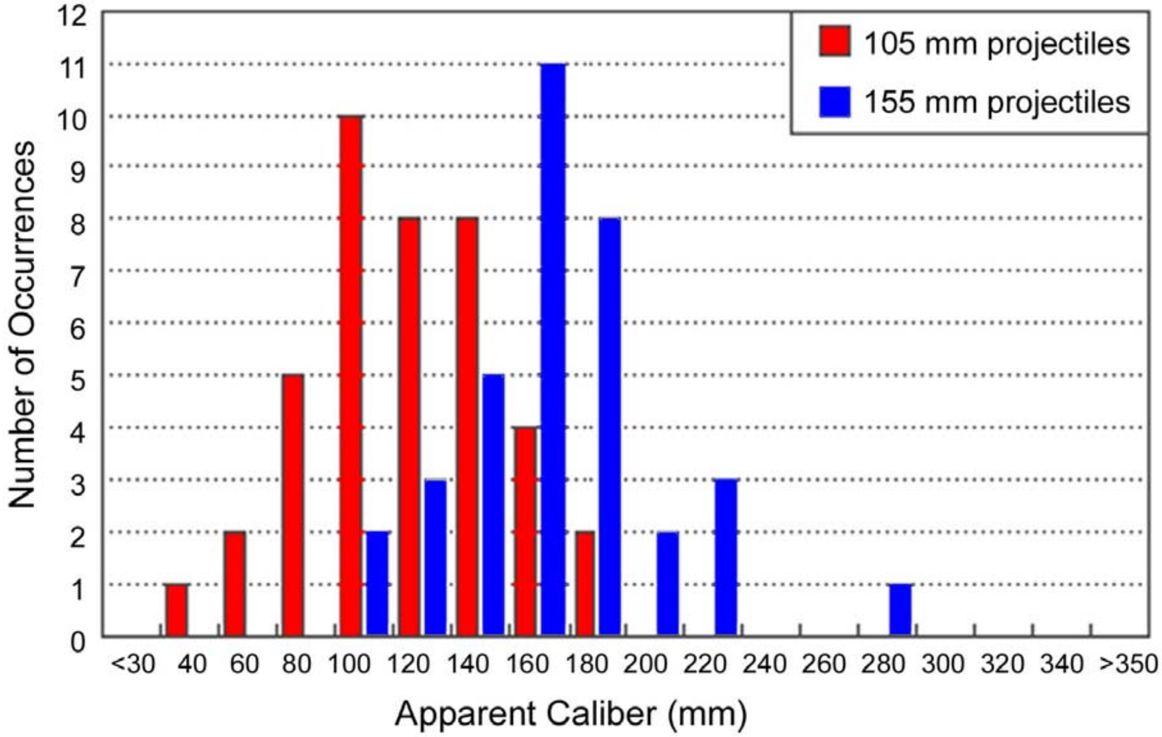


Figure D-9. Target Size & Dipole Moment

It is seen that the mean estimates for 105 mm and 155 mm projectiles are well separated, but there is considerable overlap, owing to unknown orientation of the projectile and remnant magnetization.

The concept of operation for electromagnetic induction is shown in Figure D-10.

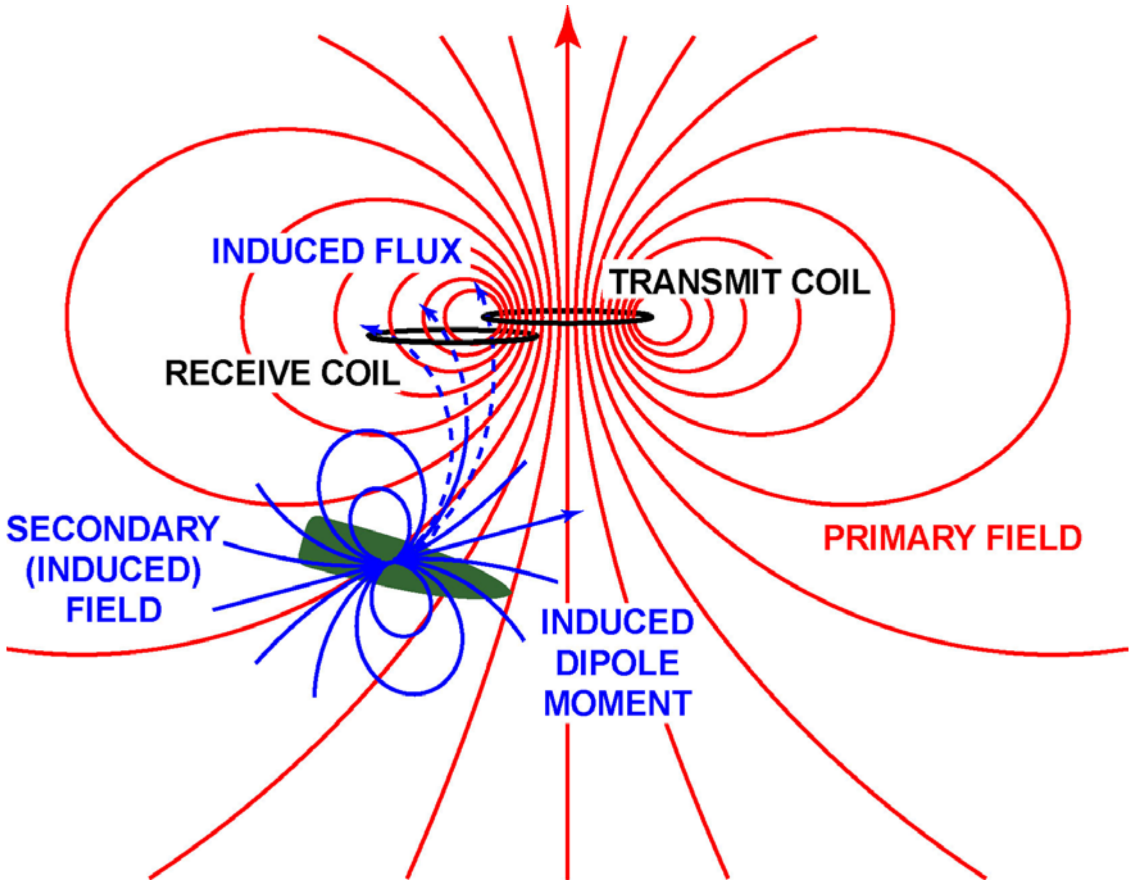


Figure D-10. Electromagnetic Induction (EMI)

Separate systems measure the decay of the receive signal in the time domain and frequency domain.

The GEM-3 is a multi-channel frequency domain EMI system that collects data over many audio frequencies. Frequency response data are used to separate UXO targets from man made and natural clutter. Although this system has performed well in field tests for discrimination of UXO's from clutter, it is not as effective as other systems in detecting deeper objects.

The EM-61, a time domain sensor, is the most commonly deployed EMI sensor for UXO detection. It can be operated as a handheld, cart based, or as an array of three sensors as shown in Figure D-11. When its data is optimally processed it has demonstrated significant improvement over traditional “mag and flag” operations.

Figure D-11. EMI Array

Tests providing data from both magnetometer and EMI arrays have been run on MTADS (Multiple-sensor Towed Array Detection System). This system is useful over reasonably flat ground, and provides a significant improvement in data gathering rates. When the ground is rough causing platform motion relative to the ground, the sensor output (signal strength) varies leading to false or missed detections.

Wide Area Surveillance Technology

Previous cost analysis in this report has shown the importance of rapid surveillance to reduce the number of acres in a typical site to those which actually contain UXO's in order to:

1) clear 80-90% of the site for other uses without requiring precision mapping(most bang for the buck);

2) provide early on in the total program a good estimate of what the remaining task will require in the way of schedule and funding;

A helicopter-borne sensor array appears attractive for this application. Figure D-12 shows an example of an MTADS sensor kit mounted on a helicopter.

Figure D-12. MTADS Sensor Kit Mounted on Helicopter

Initial work on sensors has been focussed on the technology which will permit greater sensitivity than currently achievable and the use of magnetic tensor gradiometer measurements for improved discrimination.

Additional sensitivity over that of hand-held or towed sensors is needed for flexibility in flying the helicopter platform at higher than the current 1-2 meter height in order to clear shrubbery and forest canopy.

Additional sensitivity can be obtained from SQUID (Super conducting Quantum Interference Device) detections, cooled in a cryogenically-cooled liquid nitrogen (77°K) environment though the logistics are challenging.

Sensitivity improvements of SQUID compared with flux gate or magneto resistive are up to 3 orders of magnitude greater, measured in femto-Tesla rather than nano-Tesla sensitivity. However, the signal-to-noise ratio does not appear to be much improved.

Development of gradiometry tensor measurements shows promise for: 1) sharpened response, 2) reduced helicopter interference noise, 3) improved object size discrimination.

Examples of magnetic and EMI arrays with gradiometer are shown in Figure D-13.

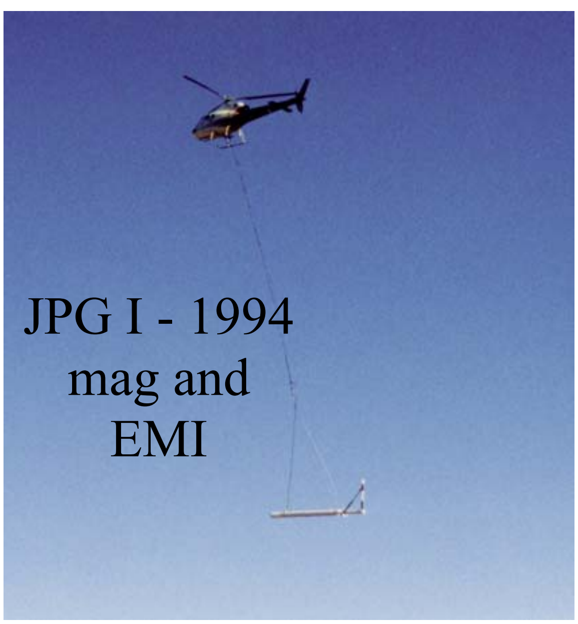


Figure D-13. Technology Evolution

Future Development Trends

The major impetus in new development will be the goal of reducing false alarms by a factor of 10 (say from 100 to 10 per acre). This goal coincides with the point of diminishing returns, (e.g. minimal additional cost savings even if a perfect system with no false alarms could be built).

Future systems may combine passive magnetometers and active EMI to enrich the data set for improved UXO discrimination. The two types of sensor arrays are currently used independently or sequentially. Vector field sensors will replace total field devices resulting in greater discrimination capability. Sophisticated signal processing and improved discrimination algorithms will evolve to more effectively capitalize on improved sensor capabilities.

More sensitive detectors (SQUID) will provide sub-nano Tesla sensitivity, important to the airborne wide area surveillance systems.

Incorporation of these advanced sensing techniques combined with advanced signal processing capabilities should provide the desired 10 to 1 reduction in false alarms. This cannot be guaranteed because the underground medium is complex and highly varied. In other fields, such as radar and sonar, improved sensors and processing often provide 10 or 100 to 1 reductions in false alarms. The payoff in the UXO case is so high that pursuit of a 10 to 1 reduction is the obvious approach.

3. Physics of Sensors for UXO Detection and Discrimination

The Department of Defense has investigated a wide variety of sensor technologies to determine their applicability to the UXO detection problem. In addition to the mainstream magnetic and electromagnetic sensing devices classically used in geophysical measurements, the list of alternate technologies explored includes low frequency ground penetrating radar and airborne synthetic aperture radar, electro-optical and infrared imaging, seismic and acoustic detection, trace gas analysis techniques, and even animal sensing by canines and honey bees. Most of these alternate technologies have failed to date to come anywhere near the performance obtained using magnetometers and electromagnetic induction devices, although the search for new sensors and techniques continues. Consequently, the main focus of this section will be in the area of magnetic and electromagnetic sensors.

Magnetometers

The invention of the first device for detection and measurement of magnetic fields occurred in 1832, based on the work of Carl Friedrich Gauss and Wilhelm Eduard Weber. A magnetometer is a passive sensor that detects the energy of the ambient magnetic field in which the device is placed. For geophysical applications such as the detection of buried UXO, the predominant magnetic field is that of the Earth itself. To first order, the Earth's magnetic field at most places on the surface of the Earth may be characterized by a magnetic intensity and a direction. The intensity of the field is measured in units called Tesla, although for practical reasons, the nanoTesla (nT) or 10^{-9} Tesla is most often used in UXO detection. A typical value of the Earth's field intensity is about 50,000 nT, but has considerable diurnal variation. Similarly the field lines within a local region are generally parallel to one another, their angle depending on the location of the region with respect to the Earth's magnetic poles. The basis for the use of magnetometry in the detection of buried UXO is the fact that the presence of a ferrous object induces distortions in the magnitude and direction of the Earth's field lines in a small region about the object. The amplitude and/or direction of these distortions can be measured by sensitive magnetometers at distances up to tens of feet from the object, depending on the sensitivity of the sensor and the size of the ferrous object, although most devices fielded today operate at distances under 10 feet. Typical devices used in UXO detection and classification have sensitivities of one nT or less. Nonferrous metals such as copper or precious metals do not create such field anomalies, and consequently are not detectable by a magnetometer.

One problem that occurs when trying to directly measure very small perturbations in the Earth's field due to buried objects is that a very large instrument dynamic range is required. The signals of interest due to the object may be five orders of magnitude smaller than the total field. Some devices are able to achieve this large dynamic range directly. An alternate approach to solving this problem is the gradiometer. This instrument consists of two magnetometers separated from one another by some distance. The signals from the two devices are essentially subtracted from one another to yield a difference signal. In the absence of anomalies in the Earth's field, the two sensors should yield an identical value of the Earth's locally constant magnetic field strength, resulting in a zero difference signal. Conversely, given the presence of a buried ferrous object, the lower sensor that is closer to the object will yield a different measurement than the more distant upper sensor. As a consequence, the difference signal will be nonzero in the presence of the object, and may be recorded or presented to an operator using a very narrow dynamic range mechanism such as an audio tone.

The nature of the perturbation introduced into the Earth's field by the buried ferrous object is a function of the size, shape, orientation, and depth of the object. The more complex higher technology instruments can map out the variations in the field strength as measured in a plane directly above the object, and it is possible to deduce some of the object's properties by comparing the measured field to predictions based on assumed target shapes. This field inversion problem is typically able to deduce object depth, orientation, and aspect ratio if the signal-to-noise-ratio of the measured field is sufficiently high. This, of course, depends on the size and depth of the object as well as on the sensitivity of the instrument. It also depends on the magnetic environment in the immediate vicinity of the object, for example, other buried objects or magnetically active rocks and sediments, and on any instrument noise inherent in the measurement device or induced by motion of the device over the ground.

Magnetometer Device Technologies

Two principal classes of devices are the **Total Field Magnetometer** and the **Vector Magnetometer**. The total field device measures the amplitude of the magnetic field at a point in space without regard to the direction of the field lines. The vector device, in contrast, measures the components of the magnetic field along one or more specific directions at each point in space. The vector device, although inherently more complex than the total field device, offers the possibility of providing a larger amount of information towards the solution of the field inversion problem for characterizing buried objects. A number of technological approaches have been taken to achieve magnetometers of various characteristics and sensitivities.

The **flux gate magnetometer**, developed around 1928, is implemented using an inductive coil containing ferromagnetic material in its core. The coil is energized by a high frequency sinusoidal electrical signal, which in the absence of an external magnetic field produces an output signal perfectly symmetric about zero voltage. The presence of an external field, however, destroys the symmetry of the output current waveform. By combining the outputs of two such inductive coils with opposite windings, a signal at twice the incident frequency is generated whose amplitude is directly related to the intensity of the external magnetic field. A flux gate device measures the magnetic field intensity along a specific direction, and consequently is a Vector magnetometer. By aligning three such devices at right angles to each other, the total vector magnetic field may be measured with this device. A well designed flux gate magnetometer is capable of making measurements down to a few hundredths of a nT, although most commercial devices are in the 0.1 nT range.

The **proton-precession magnetometer** is based on the magnetic properties of protons in a fluid, typically hydrocarbon based. The magnetic moments of the protons are aligned by a strong applied magnetic field, which is then abruptly turned off. In the absence of the applied field, the protons attempt to realign themselves with the Earth's magnetic field. But due to their gyroscopic properties associated with their spin, they precess around the Earth's field direction with a frequency which depends on the magnetic field intensity. Measuring the frequency of the precession yields a measure of the total magnetic field intensity, hence this is classified as a total field magnetometer. Typical sensitivity of this type of device is on the order of a tenth of a nT. One advantage of this device is that it is based on fundamental physical properties of matter, and hence provides an absolute measurement reference.

The **optically pumped magnetometer** works on a principle similar to that of the proton precession device, but using the atoms of alkali metals in a gaseous state rather than protons. A light source stimulates the atoms to various excitation levels, where they precess about the ambient magnetic field vector at a frequency governed by the atomic structure of the specific metal. Measurement of the precession frequency leads to the determination of the intensity of the ambient magnetic field. Devices based on this principle are capable of very high sensitivity. For example, when cesium vapor is used, measurements accuracies on the order of a few picoTesla are possible. With potassium vapor, measurements down to about a tenth of a picoTesla have been demonstrated. One disadvantage of this device is that it must be approximately aligned with the ambient field. The device is generally considered to be a total field magnetometer.

The **Superconducting Quantum Interference Device (SQUID) magnetometer** is based on a pair of superconductors separated by a thin layer of insulation in such a way as to form two Josephson junctions, which allow tunneling of electrons between the superconductors. The device is cooled to cryogenic temperatures by liquid nitrogen, liquid helium or other means. The voltage associated with these tunneling electrons oscillates at a rate that is dependent on the changing magnetic flux through the junctions. A device supercooled to 4.2^{O} K by liquid helium is capable of sensitivities on the order of one femtoTesla (i.e., 10^{-6} nT). Such a device would be very difficult to field, however. A more practical implementation for fieldable instruments is a

SQUID magnetometer based on high temperature superconductor technology, requiring cooling only to 77^{O} K using liquid nitrogen. This type of device can achieve sensitivities in the range of 30 femtoTesla. As with the flux gate device, the SQUID device is a vector magnetometer, hence three orthogonally positioned devices are able to measure the entire magnetic field vector at a point in space. Stacking two devices along each axis in a gradiometer configuration permits the rate of change of the field in any direction to be measured as well. The SQUID device is perhaps the most sensitive magnetometer developed to date, and is being actively pursued as a potential solution to the airborne UXO detection problem, where the higher sensitivity of the device offsets the longer distance between sensor and target required for airborne platforms. Currently, existing SQUID devices remain accessible only to the R&D community. They are currently too bulky, unreliable and expensive for widespread use. Signal-to-noise ratio is also an issue.

Electromagnetic Induction Devices

The widespread use of electromagnetic induction for the detection of buried ordnance dates back to World War I, and anyone who has seen a World War II movie is familiar with the picture of a soldier employing a handheld metal detector for seeking out land mines. The basic idea can be traced back at least as far as the work of Alexander Graham Bell in 1876, building on basic science developed by Joseph Henry and Michael Faraday in the early 1800's. The device used so extensively during World War II was initially developed by the Polish Army in exile operating in Scotland in the early days of the war. It consisted of two electromagnetic induction coils, one of which was driven by an oscillating electrical signal operating at audio frequencies. The output of a second, separated coil was amplified and sent to a telephone headset worn by the operator. The time varying magnetic field generated by the first coil passed into the ground, and when impinging on a metal object, induced signals in the second coil that changed as the detector passed over the object. This changing signal was heard by the operator, who flagged the location of the object discovered.

The basic concept of Electromagnetic Induction sensors for buried object detection and characterization is basically the same today as it was in World War II, but the details of the technology reflect a great many technological improvements which have been made in the sensitivity of the instruments and the amount of target information extracted from the data generated. The basic EMI system uses a transmit coil to induce time-varying magnetic fields in the ground. These in turn induce time-varying eddy currents on buried metallic objects, leading to the radiation of a secondary field whose spatial and temporal characteristics are a function of the properties of the buried object as well as of the initial excitation. These reradiated signals are measured in a secondary coil or coils and used to detect or characterize the object. Since the only requirement on the process is that the object be highly conductive, this technique works with any metallic object. By contrast, a magnetometer only works with ferrous object such as iron or steel.

EMI devices for geophysical application come in two general categories, **Time Domain Electromagnetic (TDEM)** and **Frequency Domain Electromagnetic (FDEM)**. A TDEM system operates by transmitting a current pulse of finite duration through an electromagnetic coil, producing a magnetic field that passes into the ground. The excitation is then switched off, and a receiving coil intercepts the transient signals reradiated by subsurface objects in response to the pulse. It is somewhat analogous to the way in which a radar system transmits a pulse of electromagnetic energy, then waits to receive echoes from distant targets. The rate of decay over time of the transient reradiated signals as measured at the receive coils is a function of the location, shape, and other characteristics of the buried object. A simple TDEM system, useful mainly for object detection, typically samples the transient signal once at a fixed delay from the end of the transmitted pulse. More modern systems sample the entire transient waveform using dozens of sample time gates, providing details about the transient decay that is useful in characterizing the location, shape, and orientation of the buried object.

A simple FDEM system operates by continuously transmitting a single frequency alternating magnetic signal into the ground using a transmitting coil, and measuring the resulting total field generated. The primary transmitted field is electronically subtracted from the measured received field to yield a measurement of the secondary reradiated field. As with the TDEM system, the characteristics of the reradiated signal are a function of the buried object's properties, although a single frequency system is generally useful only for detection. More modern FDEM systems operate at multiple simultaneous frequencies, or using a swept frequency signal. As with the multi-time-sample TDEM systems, the multifrequency FDEM system provides a richer set of measurements from which characteristics of the buried object may be deduced.

Both TDEM and FDEM sensors in use today are able to detect very small metallic objects at sufficient depth for satisfying many UXO detection problems. One problem with EM systems is that they respond to any metallic object, regardless of the constituent metal. Consequently, the presence of any metallic scrap in the area being searched for buried ordnance complicates the detection and characterization problem. Since such scrap is virtually always present in any area that has had past human activity, the discrimination of scrap from targets of interest is one of the most important research areas being pursued in the area of UXO detection. The same applies to magnetometers, of course, in the case of ferrous scrap material, but such prevalent scrap items as aluminum cans and other non-ferrous products of human consumption will not interfere with these systems.

Other Sensors

Ground Penetrating Radar

A ground penetrating radar typically operates in the HF through UHF bands between 10 MHz and 1000 MHz, with the low end of this band providing the greatest penetration depth. It transmits a wideband electromagnetic signal into the ground using either a pulsed waveform or a frequency modulated CW waveform. The resulting echoes from subsurface objects are processed to determine the amplitudes of the signals returned at precise time delays relative to the transmitted signal. Repeating this process over an area of ground yields a subsurface radar map which ideally shows the reflectivity of buried objects. The results of using Ground Penetrating Radar (GPR) for the detection and characterization of individual UXO targets has been generally disappointing to date. Systems based on Electro Magnetic (EM) and/or magnetometer sensors virtually always outperform GPR in controlled tests. A major problem with GPR is that the performance of the radar is highly dependent on the moisture content and electrical characteristics of the soil, leading to a wide variability in performance over operating locations. Another problem is that the achievement of high spatial resolution with the sensor requires the use of very wideband waveforms, which of necessity must contain higher frequency components. These higher frequency components, however, have very poor ground penetration capability for many soil types encountered in the field. GPR may still be valuable for large scale characterization of a site as opposed to finding individual pieces of ordnance, but most of the current efforts in this area are focused on magnetic and EM systems.

Airborne Synthetic Aperture Radar

Although low frequency airborne synthetic aperture radar has been proposed as a ground penetrating sensor in the past, no evidence exists that it has any capability for the detection of buried UXO in varied soil conditions. Such radars do have a significant capability for imaging objects under foliage, and are a candidate for assisting in the problem of performing surface surveys of non-buried ordnance items in areas of heavy foliage cover. The ability to reliably recognize small ordnance items under foliage cover requires a very high resolution in both the range and cross-range dimensions, however, leading for a requirement for wide bandwidths and higher Radio Frequency (RF). As with the GPR, such frequencies have limited ability to penetrate foliage, and suffer degradation due to the scattering caused by the trees. Even if such high-resolution images could be reliably achieved, the automatic classification of ordnance items versus the many confusers that would result from non-ordnance objects in the environment is itself a very difficult problem. To date, Synthetic Aperture Radar (SAR) has not made a significant contribution to the UXO problem, though research in this area continues.

EO/IR Sensors

Electro-optic visible wave and infrared (EO/IR) sensors have no capability to sense deeply buried UXO objects, hence are not contributors to the solution of that aspect of the UXO problem. As with the airborne SAR radar, they may offer some capability to assist in surface surveys looking for unburied ordnance items in the clear. They do not, however, offer the capability of looking under foliage. The visible-wave EO sensor can be used to visualize and recognize surface UXO in an uncluttered environment, but it is not clear that it would provide reliable automatic detection of such objects in a cluttered environment with many confusers. The IR systems offer perhaps more capability to visualize very shallow objects such as land mines or near-surface UXO based on the thermal decay characteristics of solar heated metal versus soil, particularly when observed as the sun goes down. A multispectral EO/IR system may contribute significant information towards the problem of automatically classifying surface UXO, but this remains to be demonstrated. The active extension of these imaging technologies is the lidar system, which provides the additional dimension of ranging to the EO images. Most of the limitations of the passive EO/IR techniques are shared by lidar, although the possibility of creating high resolution 3-D images of unobscured surface ordnance objects could lead to a more reliable automatic UXO classification capability contributing to surface surveys. This capability could extend to unburied underwater UXO.

Seismic and Acoustic Sensors

The use of acoustic and seismic sensors, which have been successfully employed in many areas of geophysics such as oil exploration, have been explored for use in UXO detection. The DoD has invested a significant amount of R&D funds in exploring these technologies for UXO detection, with disappointing results to date. Acoustic and seismic signal propagation is highly dependent of the transmission medium, consequently the soil type and sedimentation layers can make it very difficult to invert the signal echoes received. Furthermore, it is extremely difficult to distinguish between an ordnance item and a rock of similar size based on these echoes, since there are no distinguishing differences between the two for acoustic or seismic signals. By contrast, the active and passive magnetic systems respond to the electrical characteristics of the ordnance item, but not to most rocks.

Chemical Detection Systems

A number of sensor technologies have been proposed to detect buried UXO by virtue of chemically sensing constituents that may be diffusing to the surface from the munitions. To date, there has been no conclusive evidence that this mechanism can provide a reliable detection technique for deeply buried UXO, although this approach may prove useful for shallow objects or surface objects.

Micro-navigation Technology

The success of a geophysical survey for detecting and locating buried UXO depends critically on an accurate and precise knowledge of each sensor's location at each point in time. The most widely used technology for this purpose in modern instruments is the Real Time Kinematic Global Positioning System (RTK GPS). An RTK system augments the use of the digital ranging codes used by the baseline GPS receiver technology by tracking the RF phase of the L-band carrier signal on which the ranging codes are modulated. Such systems have advertised accuracies on the order of 1 centimeter horizontal and 2 centimeter vertical accuracy, but this level or performance is under ideal conditions. Motion of the system leads to additional errors, and any foliage or other masking of the line of sight to the GPS satellites further deteriorates performance as fewer satellites are available to the receiver. In dense foliage cover, all satellites will be lost, and the receiver will not work at all. One solution to this problem is to transfer the navigation solution from a base station in the clear through a local network of RF ranging links. These systems will work in dense foliage, and have advertised accuracies of better than 20 centimeters for a moving sensor.

This page intentionally left blank

Appendix E

UXO Cleanup Costs

Dr. John Potter

This page intentionally left blank

The Unexploded Ordnance (UXO) cleanup costs used for this report are rough estimates based on historical costs of Engineering Evaluation/Cost Analyses (EE/CA) and Removal Actions (RA) conducted by the US Army Engineering and Support Center, Huntsville. Costs for individual tasks were determined from whatever historical data was available. Because these data were incomplete, did not represent a rigorous statistical sample and were at best only a useful guideline, we rounded all estimates to one significant figure. Unusual projects, either in scope, site conditions or cost were discarded or weighted lightly to avoid biasing the unit costs for the hypothetical "typical" sites with atypical projects. Depending on the parameter of interest (some common to both EE/CAs and RAs, some exclusive to one or the other), 10-20 projects were used for the cost basis. For future technologies and approaches, the cost savings resulting from current implementations of advanced technology were extrapolated to estimate future costs at full implementation (S&T goals reached).

Site Assessment-This is normally conducted as a CERCLA Engineering Evaluation/Cost Analysis (EE/CA) on a site-by-site basis. The Formerly Used Defense Sites (FUDS) Program estimate includes about 8 million acres of FUDS properties, which will be addressed by about 800 EE/CAs. The total Department of Defense (DOD) acreage is about 10 million acres, so the total DOD inventory could require about 1,000 site assessments. The existing DOD Cost to Complete estimate is about $2B. However, the US Army Engineering Support Center, Huntsville has been conducting these site assessments for about $1M a site plus $10 per acre variable cost, exclusive of Program Management. At this rate, the "wholesale" cost to complete would be $1.1B. It could be lower using advanced assessment platforms such as the helicopter mounted geophysical systems. We used $1B for our one significant figure future estimate.

Surveying and Mapping- This is the process of bringing in survey control, conducting a property boundary survey and laying out survey control for work management, quality control and quality assurance. Internal control typically consists of a grid of 100' squares. The overall survey is done under the auspices of a Professional Land Surveyor, to establish a defensible environmental record. This is often included in contract pricing with other elements, but to the best of our ability to segregate these costs our single order of magnitude estimate is $1,000 per acre. For advanced geophysical systems with on-board navigation systems, the internal layout would not be required. Tying the geophysical navigation system to the boundary survey is much more efficient. Halving the cost, to $500 per acre, represents this case as an Science and Technology (S&T) goal for advanced systems.

Vegetation Removal- Vegetation removal varies by site and season from zero to several thousand dollars per acre. When required, contract costs for this work item are typically around $2,000 per acre. While there is no database of DOD-wide site conditions, we have estimated, perhaps conservatively, that vegetation removal is required on about half of all sites where UXO removal will be required.

False Alarm Ratio (FAR)- This is the ratio between holes dug that contain non-UXO and holes dug that contain UXO. It is different from the False Alarm Rate (a number of items per unit area) that the S&T community customarily uses to measure system performance. However, because we used a constant one UXO per acre as our "standard" UXO density, the FAR definition used here yields the same numerical result as the FAR definition customarily used by the S&T community.

Mag and Flag- This is the traditional, manual process of sweeping property with a handheld metal detector to find all ferrous objects. The detection and excavation processes are usually combined, since they are performed by the same crew, real time or near real time. Because these simple, analog, audio metal detectors do not discriminate UXO from non-UXO, and because the majority of fired ordnance does function generally producing many fragments that are detected by these instruments, the number of holes dug is large compared to the number of UXO typically recovered. False Alarm Ratios (FAR) as high as 1000:1 have been observed, with 100:1 being typical. Lower FAR are only possible when UXO make up almost all of the metallic objects at a site. This is not a typical situation. Costs for this search technique are typically rolled up in the excavation costs since they are performed by the same personnel (UXO Technicians) and are small compared to the cost of digging scrap metal at the generally high false alarm rates that characterize these instruments. However, to highlight the differences between old and new technology, we break the detection process out separately. Our estimate is $1,000 per acre, based upon typical time and labor rates.

Digital Geophysics (Detection)- This is the process of detection and reacquisition, using modern digital geophysical instruments. These will be mounted in arrays on various platforms when site conditions (generally, terrain and vegetation) allow, since production rates are much higher with these configurations. Current geophysical methods produce widely varying False Alarm Ratios, but typical, successful projects produce FARs around 50:1. The current, near-term (5 year) S&T goal is 10:1. Operational costs vary over a wide range from handheld to ground vehicle to airborne systems, but a reasonable average cost is about $1,000 per acre.

Dig Non-UXO- Excavation of non-UXO items proceeds as if the object were a UXO, until such time as a determination can be made. Then, the scrap is removed quickly and collected for recycling. Costs vary widely, from around $10 per hole for large quantities of surface or near surface items at the former Southwest Proving Ground, to $6,000 per hole at Kaho'olawe, when daily transportation costs to and from the island dominate everything else. $150 per hole is a reasonable cost for more typical sites. This represents our only violation of the "one digit" rule, a conscious decision because the difference between $100 per hole and $200 is a factor of two and this item is acted upon by an extremely large multiplier in the case of Mag and Flag technology.

Dig & Dispose of UXO- Excavations of UXO items are conducted slowly and carefully, to avoid causing the item to function. Even when heavy equipment is used for deep excavations, the implements are kept at least one foot from the expected location of the object (as estimated with the metal detector). Once the item is exposed, it is evaluated, and appropriate disposal actions follow. If the item is safe to move, it may be consolidated with other safe to move items for combined demolition. More commonly, the item is destroyed by a dedicated demolition operation. While this operation is being conducted, no other activities or non-essential personnel are allowed within the exclusion zone. The exclusion zone is sized to contain all fragments that may result from the explosion of the UXO and donor charge. The radius of the exclusion zone may exceed one half mile. Counting the inefficiencies in production associated with this process, the cost is in the neighborhood of $1,000 per UXO item.

Overhead and Administration- This includes the added burden for contractor administration and project management costs (10%), government contract management and administration (5%), government quality and safety oversight (5%), and government program management (20%).

This page intentionally left blank

Appendix F

Green Munitions

Cliff McLain
Chester J. Kurys

1. INTRODUCTION

This appendix provides additional information on a few “key” green munitions technology development programs now under way that may mitigate or reduce the number of Unexploded Ordnance (UXO) being created currently with continuing munitions manufacture, training use and disposal. An important finding is that in many cases, the less hazardous substitutes for current energetic materials and toxic components may actually provide higher performance than the materials they replace. The result is improved tactical lethality and effectiveness. Further, advances in “smart” munitions will contribute significantly to the reduction of UXO creation by lowering the number of rounds fired in testing and training with live ammunition. Finally, increased emphasis on improving the reliability of low cost fuzes used in medium caliber munitions can have a marked effect in reducing the number of new UXOs created by future live fire training.

2. OVERVIEW OF THE GREEN MUNITIONS PROGRAM

The Green Munitions programs sponsored under the DoD Strategic Environmental Research and Development Program (SERDP) and the Service programs seek to reduce the environmental impact resulting from production, storage, use and disposal of munitions. Many of these programs were initiated in response to the recommendations of the earlier 1998 DSB UXO Panel Report. Some major areas where current research is being conducted are:

- Lead free small arms munitions
- Improved/More reliable fuzes
- Tags for detection/identification
- Substitutes for energetic materials
- Reduced use of hazardous materials in manufacturing
- Reduced hazardous products of combustion/operation
- Reduced toxicity of smokes and obscurants
- Elimination of heavy metals in primers and paints

In addition to these major areas, programs for the development of more reliable low cost fuzes for medium caliber munitions (20-60mm) are critical in reducing the rate of UXO creation during live fire exercises. These munitions are primarily fired in automatic cannon and the various 40mm grenade launchers. These fuze development programs are not currently listed as green munitions programs but are critically important to the reduction of future UXO risks resulting from live fire exercises (see 4b below).

Beyond SERDP's initiation and support of the basic munitions hazards mitigation development program (green munitions development), SERDP has been very successful to date in encouraging support for other programs in this area by OSD and the Services. These include:

The OSD Energetic Materials Development Programs, particularly the DARPA High Energy Developmental Materials (HEDM) Program and programs under the Navy at NSWC, Indian Head, have been important sources of support for improved performance materials also having improved low hazard properties.

The Army Environmental Quality Technology Program (AERTA) is a Secretary of the Army directed program focusing environmental RDT&E on user needs. It comprises:

Environmental technology requirements validation,

Logical technical and business approaches,

Life-cycle management considerations,

and attempts to find and apply new and innovative technology catalysts.

The US Army Environmental Center (USAEC) and its Technology Focus group (in which all services participate) provides an effective technology exchange vehicle for the "green munitions" technology community.

The Munitions Action Plan (MAP) was prepared by the Operational and Environmental Executive Steering Committee for Munitions, under the DoD and was approved by Deputy Secretary Wolfowitz on March 20, 2002. The MAP addresses the objective of "Maintaining Readiness through Environmental Stewardship and Enhancement of Explosives Safety in the Life Cycle Management of Munitions". The Plan provides for the incorporation of new munition components and systems having both improved performance and significantly reduced UXO and environmental contamination risk than current in-service munitions.

3. GREEN MANUFACTURING TECHNIQUES AND COMPONENTS

Green manufacturing techniques and processing materials seek to reduce the use of volatile organic compounds (VOCs) and ozone depleting compounds (ODCs) in the production of munitions. The benefit of new processing techniques in both allowing the production of green components and in reducing the use of hazardous materials in the production process itself is an important issue in the green munitions technology programs. In addition to the reduction or avoidance of VOC and ODC usage, there are other hazardous production considerations as well. For example, one such area is that of finding cost comparable substitutes for the use of easy machining lead alloy steels which would reduce the lead hazard protection costs associated with such alloys. New production techniques are being developed under the Navy and Army green munitions technology programs, some details of which are described below..

The Navy Green Energetic Materials (GEM) Program supported at NSWC, Indian Head, MD supports a number of specific energetic materials production areas, centered on Gun Propellants, Rocket Propellants, and High Explosives. The objectives of these production methods development efforts include the reduction of total ownership costs of propellants and explosives, and minimization of environmental hazards and waste while maintaining or improving the range (propellant) and lethality (explosive) capabilities of the munitions.

The Navy FY98-FY01 programs were focused on the EX-171 5-Inch Extended Range Guided Munitions (ERGM) and demonstrate a new generation of environmentally preferable green energetic materials that lower total ownership cost for that system, but are applicable to the entire range of munitions using energetic materials. These improved techniques and processes include the development of solvent free processing techniques, optimized processing schedules, methods of recovery or recycling of energetic materials, full-scale testing of techniques and methods, and the development of environmental cost predicting methods for both current and new methodologies.

Continuing programs are focused on a broad range of munitions applications and include the development of a layered gun propellant configuration with improved performance and significantly reduced production use of hazardous materials. This new propellant also features a high level of recycle and recovery capability over conventional types. A series of degradable explosives is also under development, demonstrating improved performance, insensitivity, high re-use capability, and minimal risk of environmental contamination by component leaching.

The Army programs center on the production of small and medium caliber munitions including small arms firing inert projectiles (5.65mm - .50 cal) and medium caliber automatic cannon and grenade launcher munitions (20-60mm). TACOM/ARDEC at Picatinny Arsenal directs the majority of these programs. Objectives are to both reduce the numbers and levels of hazardous substances used in the munitions themselves, and the VOCs and ODCs used in the production of these munitions. The DARPA HEDM program for development of new primer energetic materials is closely coupled with these ARMY efforts.

New substitutes for the current compounds used in painting and sealing the munitions components (primers, case mouths, tracer elements, etc.) are also being developed. Reduced use of hazardous solvents in explosive and propellant processing is an additional objective.

4. EXAMPLE GREEN MUNITIONS DEVELOPMENTS

In this section, we will describe as examples the first three major areas listed in Section 2: Lead Free Small Army Munitions, Improved Fuzes, and Tags for Detection and Identification.

a) LEAD FREE SMALL ARMS MUNITIONS

The Tactical Army Command (TACOM) currently is developing and manufacturing a lead free 5.56 mm (millimeter) bullet using tungsten as the base material. Under this program, a substitute round has been developed that has the same performance as the conventional lead round so that the end user in not aware of any changes. No new adjustments/calibrations are required to the weapon. In addition, there is ongoing work to reduce or eliminate the toxic materials used in the end item and manufacturing process.

In FY-03, the Army will be purchasing approximately 780 million rounds of small arms ammunition at a cost of $0.25 per round. It is estimated they will use 500 million rounds in training exercises. The estimated cleanup cost ranges between $0.12 and $0.77 per round to cleanup a practice bunker into which these rounds are fired. The wide spread in cost is a function of the method used to clean the bunker. The method used is dependent on the requirements placed on the cleanup effort by regulators and local government agencies. A tungsten round costs $0.35 and requires no cleanup. The total life cycle cost of a tungsten round over a conventional round is equal to or less expensive than a conventional round. If regulators require tungsten to be cleaned up, the salvage recovery of tungsten is 8 times more valuable than lead[1] and easier to recover resulting in an additional cost savings.

The good news is that the small arms green munitions program has already demonstrated better or equal performance using green ammunition than the more hazardous components they replace. Tungsten 5.56 mm ammunition is being used exclusively at Stewart River AK and is also being incorporated into the Massachusetts Military Reservation for practice and training.

b) IMPROVED FUZES

Fuzing reliability is the principal contributor to the continuing generation of UXO and the related risk of ground water contamination from unconsumed explosive or pyrotechnic munitions constituents as a result of live fire training. However, the current efforts to improve fuze reliability are primarily based on requirements for improved lethality and impact on logistics and maintenance. There are significant differences in the current fuze reliability levels between standard large caliber (105mm, 155mm, and Navy 5in.) munitions using the standard NATO Fuze in its various forms, medium caliber explosive munitions such as those used in automatic cannon and grenades (20mm - 60mm), submunitions released from a carrier, mortar fired munitions, and the emerging precision cannon fired precision guided munitions (PGM) such as the Navy 5in. Extended Range Guided Munition (ERGM), the Army Excalibur 155mm (XM982), and the Army 120mm Precision Guided Mortar Munition (PGMM).

[1] USAEC briefing on Small Caliber Green Ammunition 5, 6 March 2003.

General Fuze Functions

All standard (non-PGM) fuzes have the following common elements:

A safe and arm function will not allow the fuze to arm (i.e.: be ready to function as a fuze) until an appropriate time after sensing the event of firing, through setback and centrifugal (for spinning projectiles) forces.

A mechanical firing pin or electronic signal initiates the explosive firing train.

A primer and ignition train culminates in a booster charge which in turn sets off the main explosive fill of the projectile. Safe and arm functions provide a mechanical block between the firing train and the booster until removed by firing forces (set-back and spin). All timed and proximity fuzes are backed by a point impact initiation capability. A failure to initiate the explosive projectile fill will result from the failure of any one of these elements in the fuze and produce a UXO. A low order detonation of the explosive fill will result from a failure of the fuze booster charge to properly initiate the explosive fill. In actual experience, such low order failures constitute only a very small percentage of total UXO generation. All of these fuzes are initiated by a combination of set-back and centrifugal (for spinning munitions) forces which cause the fuze to be armed a short distance after leaving the cannon or mortar muzzle (generally 200 ft. or greater) such that "point blank" targets can be successfully engaged but that a premature initiation will not harm the firing unit.

Note that point detonating fuzes may also provide for either a "super quick" initiation (assuring that the munition is exploded at or near the surface) or with a slight delay to allow the munition to achieve a desired penetration into the target. Some added potential for failure exists within this penetration delay chain, if it is used (larger caliber fuzes can be set for either functional option).

NATO Standard Large Caliber Fuzes

The NATO standard family of fuzes has a common interface with all 105mm, 155mm, and 5in. cannon fired munitions and offers the following operational options:

1. Point detonation (PD) relying on impact forces to initiate the fuze,
2. Mechanical time (MT) in which the fuze is set to detonate at a fixed time after firing (to achieve desired height of burst) - the time being measured by mechanical (clockwork) means,
3. Proximity (VT), in which the fuze is activated by active RF sensing of the distance to ground (to achieve desired height of burst),
4. Electronic time (ET), in which the time to burst is measured electronically from the time after firing (to achieve desired height of burst), and
5. Multi-Option (MOFA) fuzes which combine several or all of the above functions.

Note that all time and proximity fuze functions are backed up by a point detonating capability in the event that the timing or proximity mechanism fails.

At this time, the overall dud rate of NATO fuzes is around 1-3%. Note also that most duds using this ammunition are found to be complete misfires, rather than low order detonations. That is, most duds are caused by a failure to initiate the high explosive or submuntion expulsion filler at all, rather than a failure of the explosive load to go to full order detonation. The inference is that the fuze itself has failed to initiate its explosive train or that the train has been interrupted prior to initiating the booster. If the booster ignites, the round will go high order. This tends to hold true for all fuzing types, including those fuze types described below.

Medium Caliber Fuzes

Medium caliber munitions (20-60mm) must necessarily use much smaller and much cheaper fuzes than those of the standard NATO series. The vast bulk of UXO generated in live fire training are due to this class of munitions, generally fired from automatic cannon mounted in aircraft, in ground fighting vehicles, or crew served weapons. All of the basic fuze functions are maintained in the fuzes (arming and fuzing, point detonation backup, firing train sequence). Note that some developmental rounds (generally 40mm and up) have provision for timed initiation or proximity fuzing. Interestingly, the more sophisticated fuzes tend to have lower dud rates. Dud rates for characteristic medium caliber explosive munitions tend to the range of 5-8%, almost all of which are failures to initiate the explosive fill at all (i.e.: very few low order detonation failures).

Mortar and Grenade Fuzes

Mortar fuzes lie somewhere between the large caliber fuzes and the medium caliber munitions fuzes. The larger mortar calibers, especially the new 120mm mortar, use fuzing essentially equivalent to that of the large caliber munitions. Of course, the 120mm PGMM is a precision guided munition similar to ERGM and Excalibur. Smaller mortars (60mm and 81mm) will have fuze failure rates somewhat lower than those for the medium caliber munitions. Note that the 40mm grenades, either shoulder launched or fired by a crew served automatic weapon, are notorious dud generators. Depending on target and terrain characteristics, dud rates can be well above 10%. Snow cover contributes to high dud rate by providing a very low impact force for initiating the 40mm grenade. Due to the low velocity of this munition, 40mm duds will almost always be on the ground surface. Since the 40mm projectile will have almost no discernable target effect if fired inert, most live fire training with this weapon is likely to involve the use of live HE rounds. Rocket propelled grenades (RPGs) will present similarly high potential dud rates under live fire training conditions.

Submunitions Fuzes

Fuzing developed for the family of field artillery scatterable mines (FASCAM - carried as submunitions in larger caliber munitions - such as the Dual

Purpose Improved Conventional Munition - DPICM) provides a timed initiation capability which may be varied within the submunitions load. The submunitions are armed by sensing their dispersion events and such forces as aerodynamic spin. All such submunitions are equipped with an automatic maximum time initiation (sure detonation - SD time) to assure that all detonate within a specific period. This time is generally set at the production facility. These submunitions have anti-disturbance features (explode if disturbed) and can also have a range varying initiation times prior to the SD time. The purpose of varying initiation time is to deny an area to enemy maneuver for a specific time through a continuous spread of detonation times and to assure that the area is completely clear of exploding munitions after a fixed maximum SD time. Such munitions can also be point detonating to provide area coverage against personnel, ground assets such as parked aircraft, or light armor. Such submunitions are seldom used in training exercises, partially due to the dud hazard which is said to be as high as 20% for some of these munitions. Because of low velocity, all FASCAM submunitions will be on the surface, rather than penetrating the ground.

Precision Guided Munitions (PGM)

Fuzing functions for PGM are generally integrated with the other elements of the precision guidance system, but will be backed up by point detonating capability. Since the whole purpose of the PGM is to achieve very high single shot lethality, the overall functional reliability of such munitions will be held to a very high level. When used in training, the per round cost of such munitions alone will dictate a careful examination of any functional failure, virtually eliminating any UXO risk with these munitions as a result of either testing or training. The increased use of PGM will reduce the risk of future large caliber UXO since most training with the PGM will use simulation (due to the high cost per round) and the failure rate of live PGM is projected to be significantly less than 1%.

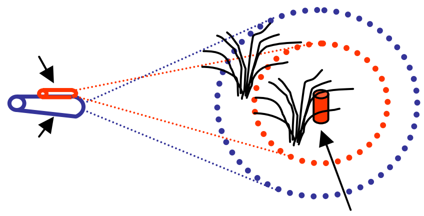
Summary

In general, fuze development efforts which contribute to the significant improvement of dud rates of medium caliber munitions, submunitions, and the 40mm grenade will have the greatest cost effective result in reducing the future generation of UXO in live fire training exercises of any of the green munitions programs. At this time, fuze development programs are not generally regarded as a part of the green munitions program, but should be strongly supported by DoD and the services as a cost effective means of achieve higher lethality and significantly reducing the cost of training range maintenance and UXO clearance in the future. Primary fuze development efforts are centered at the Armaments Research and Development Engineering Center (ARDEC), Picatinny Arsenal, NJ.

c) TAGS FOR DETECTION/IDENTIFICATION

The US Army TACOM/ARDEC programs are investigating the possibility of placing passive detection enhancement devices or modifications on munitions that would significantly enhance the probability of detection of unexploded “dud” rounds. These devices would either provide an enhanced reflective signature from rounds lying on the surface, or a coded very low false alarm signature in response to active electromagnetic interrogation through the use of an integral inductive coil and coded chip attached to the munition body that would identify it as a “live” munition and also the type (size). This latter method would work on buried rounds as well as surface rounds. These interrogation "repeaters" would be used for all large caliber (105 to 155mm) munitions. The tag would be destroyed under normal operating conditions (full detonation of the warhead) and would only remain intact if the round “duded”, i.e., did not explode. If such a device were possible and could be manufactured at low cost, it might even be applicable to the large number of 40 mm rocket propelled grenades that have a history of high dud rates. These devices would also enable discrimination between inert objects and live UXO. Some sketches of these approaches are shown in figure F-1.

UXO PREVENTION (TAGS)



On the Surface

- Retro-reflective coating for cluster-type sub-munitions
- Laser illuminator & detector

Below the Surface

- Electromagnetic tag and interrogator
- Enables ID/Safe and Efficient Location
- Retrieve Tagged Munitions
- Track Dud Rate, Type, and Location

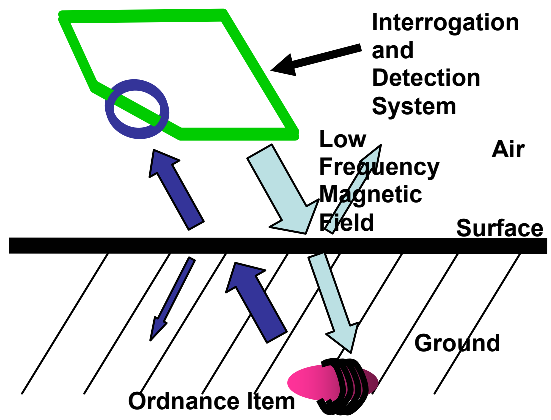


Figure F-1. Examples of Passive Tags

Appendix G

Weapon Station Simulators

Donald Fredericksen

This appendix describes the potential of weapon station simulators to dramatically decrease the need for live-fire training in future years which would reverse the current trend of adding Unexploded Ordnance (UXO) problems at a far greater rate than cleanup efforts can remove them.

Over the last several decades, the increased use of weapon station simulators across the Services including aircraft weapons training has not only reduced the amount of live-fire training but also substantially improved the quality of training of our war fighters. Weapon system simulators are designed to represent a real weapon station with sufficient fidelity (and at reasonable cost) to insure that good performance on the training device transfers to good performance in firing real weapons in combat.

Examples of Successful Weapon Station Simulators

The Abrams and Bradley Conduct of Fire Trainers (COFT) are excellent examples of how weapon system simulators can reduce live-fire training needs and improve training quality for ground forces. Back in the '60s, tank main gun training with the kinetic energy (KE) round – the most numerous and important round in a tank's ammunition load – was a major problem. Because of its high velocity (nearly 5,000'/sec. at launch), firing the round was limited to a few selected ranges and with safety limitations that created an artificial environment for gunner and tank commander training. A surrogate round was developed in the late '60s that roughly matched the KE round's trajectory for the early part of its flight (between 1 and 2km), but this did nothing to train gunners at longer ranges where there was a big payoff in operational effectiveness.

Instead, in the late '70s, a COFT simulator was developed which effectively simulated the tank commander and gunners' stations in the M-1 turret. Both crewmembers observe targets on a screen and take target acquisition and firing actions as they would in a real tank. The simulator provides dozens of firing situations, varying such parameters as target type, target exposure, range, target movement, engagement time, visibility conditions, and clutter environments to the trainee in a graduated and progressive course that pushes trainees to high levels of competence. By the late '80s, M-1 COFTs had increased the average tank crew's firing scores, as measured on qualification ranges, by 40% over those previously achieved. Periodic improvements in the M-1 COFT have added to this success. In Desert Storm and the recently conducted war in Iraq (Operation Iraqi Freedom), U.S. tank crews were routinely hitting and destroying enemy vehicles at ranges greater than 2km – roughly twice the range that enemy tanks could engage our M-1s.

The Bradley COFT offers a similar positive experience. TOW, Bradley's antitank guided missile, is too expensive (about $24K) to fire more than a few familiarization rounds each year. Instead, the Bradley COFT allows the gunner to fire many dozens of simulated rounds under a wide range of battlefield situations so that the Bradley commanders and gunners are well trained for combat. The Bradley COFT also provides simulated firing for its 25mm cannon, saving an enormous number of rounds per year and enhancing training by offering diverse targets and situations.

It would be extremely expensive and impractical to produce a wide range of scenarios for live firing by Abrams and Bradley crews. With simulators, this can be done quite easily.

Other Simulator Training

Aircrews in all the Services have cockpit simulators, which include simulation of weapons firing as well as flight control. These cockpit simulators augment actual flying hours to enhance crew training. Here again, simulated firing provides effective training because it facilitates many replications and diverse combat situations that are neither practical nor affordable with live fire.

Arguably, the most effective training for military units is done at national ranges where firing is simulated, not live. For the Army, the National Training Center (NTC) provides a large maneuver area for training of battalion-size forces. Firing is simulated by laser-scoring devices. Ground combat systems have low-power, eye-safe, laser-beam projector devices that stand in for tank guns, antitank guided missiles, and other weapons. Laser sensors are mounted on each vehicle for recording hits. A central computer determines killer-victim results (kills, damage, etc.) based on the characteristics of the weapon, target, and other factors.

For combat aircraft training, air combat maneuvering ranges like Nellis (AF) and Fallin (Navy) offer huge operating areas where air-to-air, air-to-ground, and ground-to-air engagements are simulated with results calculated by a central control facility. Daily results are fed back to aircrews for lessons learned and effective training.

Even for small arms, there are simulators that augment live-fire training by offering a wider range of firing conditions and situations for trainees.

Simulators have grown rapidly in capability in the last decade and continue to evolve with advances in computer processing, displays, and the supporting technologies. These improvements include making the simulations much more realistic and useable. They also benefit from the competitive commercial world where costs for many storage, processing, and display capabilities are actually decreasing.

One of the biggest problems is large-caliber rocket and tube artillery rounds that add many UXOs per year. These systems – mostly Multiple Launch Rocket System (MLRS) and 155 howitzer rounds – can also be simulated.

For 155 howitzers, the Fire Support Combined Arms Tactical Trainer (FSCATT) program recently (2002) developed weapon station simulators for both M109A5 and M109A6 (Paladin) howitzer systems. These simulator systems replicate the howitzer internal configuration and provide training for the entire crew including the forward observer in a separate station. They also provide important interaction with other elements of the combined force. However, only about four dozen of these simulators have been produced and deployed. Thus, to date, they provide valuable training for only a small fraction of our fire support forces. The majority of fire support training is live fire.

In the future, fire support systems will increasingly rely on guided ordnance for rapid destruction and neutralization of targets. As with air-delivered, precision munitions, live firing of indirect-fire guided munitions will be too expensive for routine training. However, it will be decades before precision-guided rounds represent a major part of the artillery munitions inventory. Also, there may be fire support missions where unguided rounds are the most cost-effective choice.

For both guided and unguided munitions, weapon station simulators allow a much wider range of targets, tactical situations, and weather conditions so that the training of artillery crews would be improved over what is possible with live-fire training.

In Operation Iraqi Freedom, the decisive weapons in defeating the Iraqi forces were precision-guided, air-delivered weapons (from fixed-wing and rotary-wing aircraft), Abrams tank guns, and Bradley Tube launched, Optically tracked, Wire guided missiles (TOWs) and 25mm guns. The training for these weapons is done almost exclusively with weapon simulators.

<u>Summary</u>

Today, the Services expend about 2M rounds annually in live ordnance firing for training. At a 5% dud rate, this translates into the creation of about 100,000 new UXOs per year. In general, the approximate location of these rounds in impact areas on training ranges is known. This may seem acceptable if the range will continue in military use. But, if more ranges are converted to civilian use – a distinct possibility, given the likelihood of additional Base Relocation and Closings (BRACs) in the next decade – then the UXO disposal problem will become more complicated unless positive steps are taken now. Perhaps the most serious problem is the long-term effects of constituents contaminating groundwater in areas adjacent to the range.

The Defense Department should seek to drastically reduce the amount of UXO being created each year by live-fire training. An effective way to achieve this is to have an aggressive program for replacing live firing of virtually all weapons with weapon station simulators. It may not be prudent or practical to eliminate all live-fire training. In addition to quality-assurance firing, which might be tied to training, a limited amount of live fire may be necessary for qualification, to reinforce training on simulators, to train people in selected specialty areas (e.g., Forward Observer), and to provide combat environment orientations. However, live-fire training for these purposes would represent a small fraction of the live rounds that are fired today. Thus, a reasonable program objective for a stepped-up simulator program would be to reduce firing of live munitions to 10% of the current annual volume by the end of the decade.

Appendix H

Press Report on Constituents

This page intentionally left blank

Test finds toxic salt in lettuce

By Miguel Bustillo, Los Angeles Times

A laboratory test of 22 types of lettuce purchased at Northern California supermarkets found that four were contaminated with perchlorate, a toxic rocket-fuel
ingredient that has polluted the Colorado River, the source of the water used to grow most of the nation's winter vegetables.

The environmental group that paid for the testing by Texas Tech University conceded that the sample was far too small to draw definite conclusions about how much perchlorate is in the lettuce Americans eat. But the organization, the Environmental Working Group, said the results were alarming enough to warrant a broad examination by the Food and Drug Administration.

"It appears perchlorate in produce is reaching consumers, which should be a wake-up call for the FDA," said Bill Walker, a western representative in the group's Oakland office. "A lot of people might look at this and say it was only four out of 22 -- what is the problem? Well, when nearly one in five samples of a common produce item are contaminated with a chemical component of rocket fuel, that's significant."

In response, FDA officials said they had been planning to begin testing foods for perchlorate at a number of sites across the country, but were still developing the scientific methods to do it.

"We do understand that there is a potential for perchlorate from irrigation water to end up in food," said Terry Troxell, the director of the FDA's office of plant and dairy foods and beverages. "We have already been moving in this area. We will certainly take their results into account."

The four lettuce samples all contained substantial quantities of perchlorate. One, a packaged variety of organic mixed baby greens, had a level of perchlorate contamination at least 20 times as high as the amount California considers safe for drinking water. The other three were packaged butter lettuce and radicchio, romaine lettuce and radicchio and a head of iceberg lettuce. All were at least five times as high as the state considers safe for water.

State and federal environmental officials believe that perchlorate, a salt widely used by the U.S. government to help power missiles and the space shuttle, may cause health problems, even in trace amounts. Because it is known to affect the production of thyroid hormones, which are critical to early brain development, esearchers believe perchlorate exposure may be especially dangerous for pregnant women and young children.

This page intentionally left blank

Appendix I

Cost of Live Fire of Munitions and Demilitarization

William Delaney

This page intentionally left blank

Introduction

The true cost of live-fire use of munitions is not totally obvious since the cost of UXO cleanup may not be fully apparent within DoD. We briefly investigated the relative costs of live firing of a munition compared to the "demilitarization" of the munition. Demilitarization is a formal structured process where the military characteristics of an item are removed. For munitions, the munition is either detonated either by open detonation or by contained detonation, or the high explosive is removed and then the metal parts of the munition are melted down or sold as scrap.

Sample Cost Comparison

As a sample case, we considered the disposal of 1000 rounds of 155 mm high explosive. A typical demilitarization cost is $1,300 a ton or $.65 a pound. Therefore, a 100 pound, 155 mm round costs $65 to demilitarize and one thousand such rounds cost $65,000.

Now consider the cost of UXO cleanup of 1,000 rounds that were live fired. We need to assume a dud rate and for this calculation - we assume 5% (see Table 2 in the main body of this report). This results in 50 UXO to clean up at $1,000 each* or $50,000. One must also dig up some 500 false alarms (assuming a favorable 10:1 false alarm rate) at a cost of $150 each for a false alarm cost of $75,000. Total UXO cost then is $125,000 – about twice the cost of demilitarization.

* The Corp of Engineers cost estimate for removal of a UXO is roughly $1,000, a false alarm roughly $150 (see Appendix F).

Appendix J

A Commentary on False Alarm Reduction

William P. Delaney

Introduction

Appendix D has outlined the technical underpinnings of UXO detection and discrimination (false alarm control) and explored the relevant instruments both present and future. This Appendix is complementary in that it presents an expectation or vision of what can be accomplished in false-alarm reduction.

The Task Force has postulated that dramatic cost avoidance, amounting to tens of billions of dollars, in the UXO cleanup process are possible by the deployment of improved technology instruments in the cleanup process. This postulation is predicated on lowering the false-alarm rate of today's instruments by a factor of 10 or so. This Appendix discusses the prospects for accomplishing this. Importantly, we do not yet have statistically convincing experimental evidence to prove our postulation that a 10:1 reduction is achievable. We are betting that in the UXO detection field we can accomplish false-alarm reduction similar to what the DoD has accomplished in radar, sonar, IR, and laser sensor fields. It is a good bet with an incredibly high payoff so the DoD must try.

False-Alarms

All sensing systems experience false-alarms if they set their detection thresholds sensitive enough to reliably detect their design targets. False-alarm control at very high probabilities of detection (such as 95 or 99 percent) is the research and development goal of essentially all sensor designers. Impressive progress has been made in this field in the last 20 years enabled by the great gains in digital signal and data processing capabilities.

In the UXO case, false-alarms are most often caused by scrap metal which may be fragments of exploded munitions or incidental other metal objects that have accumulated on the site over the many years of site operation. False-alarms may also be non-explosive muniton rounds (e.g., 20 mm or 50 caliber slugs) or munition rocket bodies or other metal residue of munitions such as shell casings or belted ammunition clips. A false-alarm may also be a geologic artifact such as a rock with some magnetic properties. Finally, a false alarm may be nothing at all – a "hiccup" in the sensor operations perhaps due to bouncing over uneven terrain. Whatever their cause, false-alarms dominate the UXO cleanup process because they tend to happen much more often than detection of real UXOs. Digging holes at the locations of false alarms is the dominant cost in today's cleanup as illustrated in Figure 4 of the main body of this report.

Highly Varying False Alarm Rates

Figures 3 and 4 of Appendix D show wild fluctuations in the number of false-alarms experienced at various UXO sites. We are clearly in a site-dependent situation. In today's experience, 100 false alarms per UXO might be a typical average false alarm expectation and we have used it in our simple cost model of Figure 4 of the main body of this report. This is an incredible statistic as one imagines failing 100 times for each success. It results in the extraordinately high cost of UXO cleanup. Our postulate is that this average can be improved by a factor of 10 to a situation where we experience only 10 false-alarms per UXO. At 10:1, we are at a "knee" in the cost curve (Figure 8 of the main report) and there is not much payoff to trying to go lower.

Why do we think we can accomplish substantial false alarm reduction in the technically challenging, site-dependent situations of the UXO case?

False Alarm Reduction

We think we can do it because we have done it many times before in DoD electronic systems. The essence of the approach is twofold: sense additional information from the environment being investigated and subject this multi-sensor, multi-mode information to intense automated analysis and processing. Appendix D explains the wide variety of active and passive sensors and the additional measurement modes that can be implemented to help sense size and orientation of underground objects. We then "process the daylights" out of this data with powerful digitally implemented algorithms and data processing routines. Here we are exploiting the enormous strides in digital processing capability that continues today.

There is one other important favorable feature of the UXO problem that we can capitalize: tests are easy and cheap! We can bury all kinds of munitions, test objects, false alarm objects, magnetic rocks, etc., and practice and refine our sensing and our algorithms over and over again. The author is not aware of such a low-cost experimentation opportunity in any other regime of false-alarm reduction such as radar, sonar, IR or laser sensing.

Recommended Approach

Our recommended approach is a focused S&T program that operates over the next five years to drive sensor performance to the recommended level of 10 false alarms per real UXO (obviously at high probabilities of detection). We estimate $10 M a year for this particular UXO S&T component. The UXO sensor S&T community should prepare itself for this five-year initiative. Senior DoD S&T managers should recognize the incredible payoff that awaits success here and resolve to fiscally support this modest cost effort over the next five years. We recommend the UXO S&T community plan a focused, coherent effort that would include:

- Detection and discrimination algorithm development by a variety of different firms and organizations
- Carefully orchestrated scientific field tests where advanced sensor and advanced algorithms can be tested, compared and refined.
- Regular scientific forums where results are presented and compared and future field exercises are planned.
- A tight coupling to advanced sensor development efforts which we envision as part of the UXO S&T effort but funded separately.

We believe this modest effort over about five years will have handsome payoff in reduction of future UXO cleanup costs. We caution that sustaining this low false alarm vision will take substantial advocacy by the workers in the UXO S&T community. Fortunately, the case to be made for funding support for false-alarm reduction is very easy to make and we suggest that Figures 6 and 7 of the main body of this report make the case.

APPENDIX K

UNDERWATER UXO TECHNOLOGY

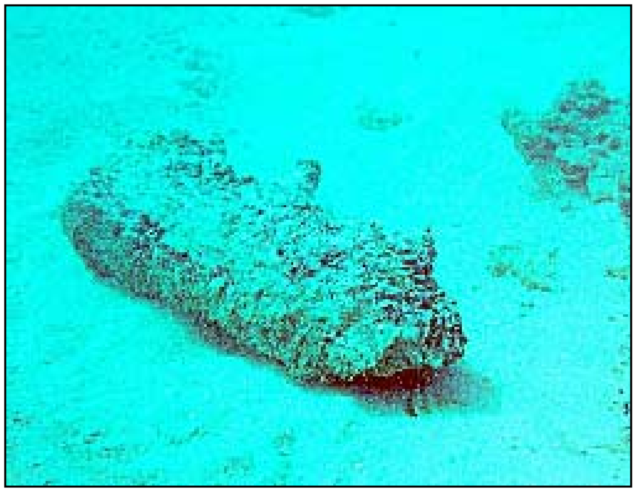
Sherry McCahill

This page intentionally left blank

Background

The majority of the DoD's UXO detection and discrimination technology efforts in the past have focused on land-based areas where the DoD used military munitions for testing or training. However, military operations were not limited to terrestrial environments. DoD munitions training and testing operations, as well as past disposal operations, also took place in marine, estuarine, and other water environs. At or near these sites, potential human contact with underwater ordnance can include direct contact, such as swimming, diving, or wading, or indirect contact such as anchoring, fishing, or dredging. Site specific factors such as water depth, turbidity, temperature, tidal actions, currents, storms, and sediment types present unique challenges and can significantly hinder the use of conventional UXO technologies at underwater sites. In addition, munitions specific factors such as ordnance type, fill materials, fuzing, case integrity, corrosion rates, and munitions constituent fate and transport phenomenon must be considered in the development and deployment of underwater detection and remediation technologies. Photos 1 and 2 depict examples of underwater ordnance.

Until recent years, underwater sites were not targeted for UXO technology development. As a result, an effective capability to survey these underwater areas and map the location of UXO for reacquisition and site characterization does not exist. In addition, there is little understanding of the UXO or clutter characteristics from which to establish technology performance requirements, and limited removal and disposal techniques that could be expanded or improved. Factors such as small target size, target burial, shallow water, environmental noise (as from surface waves and reverberation), and water turbidity all impact sensor performance, while the submerged nature of the UXO impedes access and target geo-referencing. In addition, the focus of UXO technology development has expanded to include military munitions' chemical constituents and their associated breakdown products. To satisfy explosives safety and environmental requirements, the DoD initiated the application of existing land-based UXO technologies to water environments, where feasible, and the development of new underwater UXO technologies.

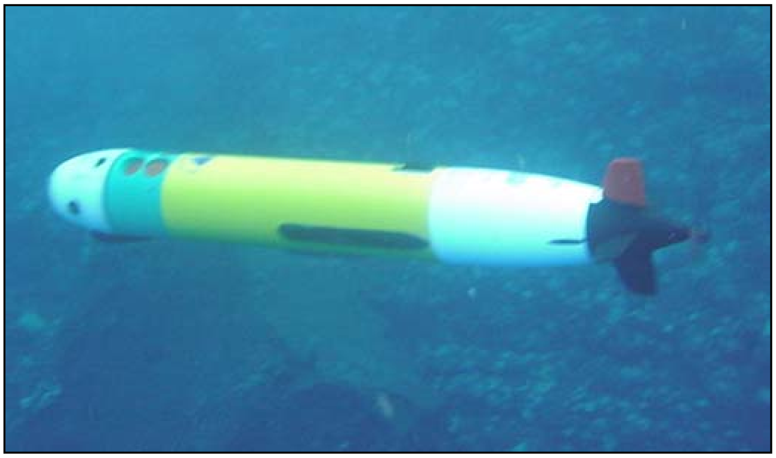


Photos 1 & 2: WW-I and WW-II era coastal defense 6-inch projectile underwater south of Oahu, Hawaii (*top*) and recovered shells from the same area with encrusting growth removed (*bottom*).

Underwater Technology Progress to Date

During the evolution of the DoD's UXO technologies, two programs have provided major funding initiatives. These programs, the Strategic Environmental Research and Development Program (SERDP) and the Environmental Security Technology Certification Program (ESTCP), have provided funding for land-based and underwater projects. While the SERDP focuses on the identification, development, and transition of environmental technologies that relate to the DoD's mission, the ESTCP program concentrates on the demonstration and validation of innovative and cost-effective environmental technologies at DoD sites. In addition to these programs, the Services have also provided funding for specific technology development. While land-based sites normally pose the greatest near-term explosive safety hazards, underwater sites can present risks as well.

To address underwater UXO sites, the DoD has evaluated a number of different technologies and platforms in laboratory and field settings in recent years. The field efforts have included, but were not limited to, divers with hand-held magnetometers, electromagnetic systems mounted on sleds, side scanning sonar and chemical sensors on autonomous underwater vehicles (AUVs). Examples of these AUVs are shown in Photos 3 and 4. Similar to the land-based UXO



Photos 3 & 4: AUV developed for the Office of Naval Research funded Chemical Sensing in the Marine Environment program.

detection and discrimination technology demonstrations held at the Army's Jefferson Proving Grounds, a project to conduct a smaller-scale effort specifically focused on underwater ordnance was funded. The following section details this study and the associated results.

Mare Island Naval Shipyard (MINS) - Validation of Detection Systems (VDS) Test Program

In August 1999, the Navy initiated a five-week Validation of Detection Systems (VDS) Test Program[1] to identify, select, and validate detection equipment and technologies that could be used to locate and detect underwater munitions items at four offshore sites at the former Mare Island Naval Shipyard (MINS). Secondary objectives of this program included:

1. Determining specific types and models of subsurface investigative instruments that are successful underwater;
2. Quantifying the detection capabilities of the equipment, based on achieving an 85 percent probability of detection rate (Pd) with a 90 percent confidence level;
3. Quantifying the False Alarm Ratio (FAR), attempting to minimize it;
4. Determining the detection capabilities for each type of equipment and system used, providing detection capabilities for each type and system in specific detection scenarios;
5. Determining the capabilities of the equipment to accurately match underwater geophysical anomaly data to physical reference points, either through Differential Global Positioning System (DGPS) or through other tracking and mapping techniques;
6. Demonstrating that underwater anomaly data can be recorded for subsequent post processing and analysis; and
7. Demonstrating that the anomaly data collected can be used to re-acquire targets.

Of the 23 firms that responded and received Request for Proposal (RFP) packages, 6 submitted technical proposals and 5 were selected to demonstrate their capability to detect underwater munitions. The demonstrations were held at a Test Site located at MINS, which was covered with up to six feet of water during high tide and could be walked on during low tide.

The selection criteria specified that the proposed equipment and technology be able to both detect ferrous and non-ferrous metallic items and to meet the following goals:

- Locate ordnance objects proud of the bottom as well as buried;
- Withstanding water depths of over 30 feet below mean lower low water with up to an eight-foot tidal influence;
- Detect a 20-millimeter (mm) projectile (only) buried in silt six inches below the bottom with a water depth of from two to nine feet
- Detect a 20-mm round (complete) buried in silt one foot and two feet below the bottom at a water depth from two to nine feet;
- Detect a three-inch 50 round (complete) buried in silt one foot and two feet below the bottom at a water depth of two to nine feet;

[1] NAVFACENGCOM, Pacific Division Final Document VDS Test Program Final Report dated July 7, 2000, Contract No. N62742-98-D-1809-CTO 0001

- Detect a three-inch 50 projectile buried in silt two feet below the bottom at a water depth of two to nine feet;
- Detect a six-inch projectile buried in silt four feet below the bottom at a water depth of two to nine feet.

The five test participants selected were: NOTRA Environmental, Seafloor Systems, Geophex, Ltd., NAEVA Geophysics, and Alpha Geoscience/SONTEC. Each participant was scored against a baseline target set. Probabilities of detection were calculated for the ordnance, non-ordnance items, and total emplaced (seeded) items (Pd_{ord}, Pd_{nonord}, and Pd_{total}) along with a False Alarm Ratio (FAR). The detection efficiencies were reported as follows:

1. Probability of detection of Ordnance items:

$$Pd_{ord} = \frac{\text{Declared Ordnance Targets (within the Critical Radius)}}{\text{Total Emplaced Ordnance Targets}}.$$

2. Probability of detection of Non-Ordnance items

$$Pd_{nonord} = \frac{\text{Declared Non-Ordnance Targets (within the Critical Radius)}}{\text{Total Non- Ordnance Emplaced Targets}}.$$

3. The number of non-anomalies that would be investigated as a percentage of the total anomalies detected or FAR:

$$FAR = \frac{\text{Number of False Alarms}}{\text{Declared Targets, both Ordnance and Non-Ordnance (within the Critical Radius)}}.$$

This FAR calculation assumed that all reported targets would be investigated and sufficient resources would be available to support this effort.

The primary objective of the VDS Test Program, which was to identify, select and validate detection equipment and technologies for the MINS offshore sites was realized. The results indicated that underwater detection systems can match underwater anomaly positioning data to physical reference points using DGPS. They also demonstrated that underwater anomaly-positioning data can be recorded for subsequent post-processing and analysis and that the same data could be used to re-acquire targets.

The project succeeded in evaluating and differentiating between technologies in order to determine the strengths and weaknesses of each. The results show that NAEVA and Geophex had the most success in detecting underwater targets. NAEVA’s detection system consisted of an underwater version of the Geonics EM-61 with a single coil. Geophex’s detection system comprised two systems: a magnetic system using a four-sensor array consisting of a Geometric G- 858 cesium vapor magnetometers that provide initial location data, and an Electro-magnetic (EM) system employing a single GEM-3 sensor, developed by Geophex, that further characterizes the data set.

With respect to the objective of determining which systems had a total probability of detection rate of at least 85 percent or higher with a 90 percent confidence level, an excess of over 250 underwater targets would have been required to establish a total confidence level of 90 percent. Therefore, a decision to employ only as many targets as necessary to establish the probability of detection goal of 85 percent was made. The VDS results showed that NAEVA was able to meet and exceed this goal with a detection rate of 99 percent. Geophex barely missed this goal with a detection rate of 84 percent.

A second objective was to minimize the FAR. With a FAR of 7%, Geophex had the lowest of the five test participants. NAEVA was second with at FAR of 18 %. Both results show very strong detection capability.

The VDS test results show that all of the participants were able to detect and locate targets on the Test Area bottom surface at varying degrees of accuracy. Several equipment detection goals for buried targets were evaluated. A detailed description of these results can be found in the complete VDS report[1].

A final goal was to determine, qualitatively, if the technologies being demonstrated in two to six and one half feet of water could be applied to a water depth of up to and including 30 feet. Each of the selected test participants indicated in their initial technical proposal that their equipment was capable of detecting ordnance underwater at depths to 30 feet. Based on field observations during the project, it appeared that all of the equipment and technologies demonstrated could be applied, either directly or with modifications, in water depths to 30 feet.

Although a summarized version of selected test data is provided in Table 1, a detailed description of these results can be found in the complete VDS report[1]. In addition, Photos 5 through 9 show the different systems that were demonstrated and evaluated.

Table 1. Summarized VDS Program Results

	Alpha Geoscience/ SONTEC	**Geophex Ltd.**	**NAeVA Geophysics, Inc.**	**NOTRA Environmental**	**Seafloor Systems, Inc**
System type	EMI	EMI	EMI	EMI	Sonar
Pd	37%	84%	99%	32%	33%
FAR	74%	7%	18%	48%	81%
Item Classification	28%	63%	68%	12%	0%

Photo 5. Alpha Geoscience/SONTEC mounted AGS-2 Magnetometer.

Photo 6. Geophex's deployed Geonics 858 Magnetometer System.

Photo 7. NAEVA's deployed EM-61 Detection System.

Photo 8: NOTRA's boat towing array.

Photo 9. Seafloor Systems' deployed sonar system..

Future Efforts

The addition of SERDP underwater Statement of Needs reflects the DoD's growing interest in extending research initiatives into the various underwater environs. In 2002, SERDP Statement of Need UXSON-02-04, *Unexploded Ordnance (UXO) Site Characterization and Remediation Technologies for Underwater Sites* resulted in the initiation of four SERDP projects one of which is currently transitioning to ESTCP.

Similarly, this year's Statement of Need UXSON-04-03, *Site Characterization and Remediation Technologies for Unexploded Ordnance (UXO)-Contaminated Underwater Sites* is evidence of the increased level of awareness and continued interest in underwater UXO issues. The objective UXSON-04-03 is the development of technologies to support characterization and/or remediation actions for UXO found on underwater sites. The research and development proposals under this need will focus on one or more of the following:

- Novel engineering-based techniques or platforms that overcome the access limitations for locating UXO present in underwater locations (e.g. coastal areas, marine sediments, harbors, estuaries, lakes, ponds and wetlands).
- Improved sensors or signal processing to aid in detection and discrimination in underwater UXO-contaminated areas.
- Characterization and phenomenology of underwater UXO, including migration and depth of burial in various underwater environments.
- Removal and disposal techniques for underwater UXO.

The primary interest of the program is to address UXO that is accessible and presents a potential hazard. As such, technologies appropriate for the shallow water (15-60 feet) and very shallow water (<15 feet) environments will be favored. These current research priorities will focus on exploiting available technologies to develop a near-term capability to verify the scope of the underwater problem and to begin to collect some real-world data. In turn these efforts will enable algorithm/modeling efforts and guide next generation system developments. Ultimately, the results from this work will provide a new capability to cost effectively characterize and remediate underwater UXO sites resulting in a significant cost savings. More information regarding these efforts can be found on the SERDP and ESTCP webpages at http://www.serdp.org and http://www.estcp.org/, respectively.

Appendix L

Status Update on the 1998 Defense Science Board Report on UXO

Col John Selstrom

This page intentionally left blank

<u>Status Update on the 1998 Defense Science Board Report on UXO</u>

In April 1998, the Office of the Secretary of Defense published the *Report of the Defense Science Board Task Force on Unexploded Ordnance (UXO) Clearance, Active Range UXO Clearance, and Explosive Ordnance Disposal (EOD) Programs*. The 1998 DSB Task Force was asked to undertake two separate studies on different aspects of landmines and unexploded ordnance. Phase I examined US landmines, land mine detection and demining efforts, and alternatives to anti-personnel mines. Phase II, which is the subject of this discussion, was charged to "examine UXO remediation, active range clearance, and Explosives Ordnance Disposal (EOD) efforts. The Task Force made several major recommendations for strengthening the Department's efforts. Over the ensuing 5 years, the Department of Defense has endeavored to accomplish many of the actions called for in the 1998 Task Force recommendations. The 2003 DSB Task Force recommendations are consistent with the 1998 DSB Task Forces' findings and recommendations. DoD has accomplished many of the 1998 Task Force recommendations, has several underway, and has some yet to be acted upon. The 2003 DSB Task Force recommendations sustain two of the most significant 1998 DSB Task Force recommendations:

- Find ways to award and implement larger scale, longer term contracts to achieve economies of scale
- Develop the technology to aggressively lower the false alarm rate

The outline below provides a summary of DoD's actions taken since the 1998 DSB Task Force Report was published, and provides sources for further information.

<u>Policy:</u>

- Published Policy:
    - *DoD Policy to Implement the EPA's Military Munitions Rule* (July 1998)
    - DoD Directive 4715.11/12, *Environmental and Explosives Safety Management on DoD Active and Inactive Ranges Within/Outside the United States* (August 1999)
    - *DoD and EPA Interim Final Management Principles for Implementing Response Actions at Closed, Transferring and Transferred Ranges* (March 2000), addressed many issues of mutual concern
    - *Defense Environmental Restoration Program Management Guidance* (September 2001), updates previous guidance to establish a Munitions Response Program complimentary to the existing Installation Restoration Program
    - *Munitions Action Plan* (March 2002), provides a roadmap for action
    - DoD Directive 3200.15, *Sustainment of Ranges and Operating Areas (OPAREAS)*, (January 2003)

- Policy Under Development, Nearing Completion:

- DoD Directive 4715.MRP, *Military Munitions Response Policy at Other Than Operational Ranges*
- *Munitions Response Prioritization Protocol*
- DoD Instruction 4140.XX-M, *Management and Disposition of Material Potentially Presenting an Explosive Hazard (MPPEH)*
- DoD Directive on *Operational Range Clearance*
- DoD 6055.9-STD, *DoD Ammunition and Explosives Safety Standards* (Revision to the Standard addressing issues related to munitions responses and unexploded ordnance. This include a rewrite of Chapter 12, "Real Property Contaminated with Ammunition, Explosives or Chemical Agents," to address "Military Munitions Responses," and the addition of two new chapters: Chapters 15, "Unexploded Ordnance" and 16, "Transfer or Release of Material Potentially Presenting an Explosive Hazard (MPPEH)")

Organization:

- *Operational and Executive Steering Committee for Munitions* (OEESCM) – established in 1997 and rechartered in 2002 to better integrate the actions of the operational, environmental, and logistics communities in addressing policy related to the life-cycle management of military munitions
- *Joint Unexploded Ordnance Coordination Office* (JUXOCO) – established in 1997 to leverage information dissemination across five mission areas: EOD, combat countermine, humanitarian demining, active range clearance and UXO-environmental remediation
- *Munitions Response Committee* (MRC) – established in July 2001, as a follow-on effort to the withdrawn Range Rule, to provide for meaningful involvement by state and federal environmental regulators, tribes and federal land managers in developing and implementing a collaborative munitions response program
    - Achieved consensus on a 'mutual agreement framework' for decision-making and dispute resolution
    - White papers on "blow-in-place" decision-making, munitions response site inventory identification and management, emergency response and other emergent issues are in-work
- *Working Integrated Product Team* (WIPT) – established as a working group of the Operational IPT established by the Deputy Secretary of Defense in December 2001 to coordinate encroachment response actions (UXO being one of nine concerns) on operational ranges
- *Special Assistant for UXO Matters* – established in April 2001 to develop a framework for action which led to the establishment of 'operational ranges' and 'munitions response' as being the two primary UXO focus areas.

Information Development and Dissemination:

- September 2000, *Final Report of the National Policy Dialogue on Military Munitions*, provided a summary of discussions with public stakeholders on the life-cycle of military munitions and their effect on surrounding military communities
- May 2001 *UXO Report to the Congress* – provided an initial response to Congressional questions based on their reading of the 1998 DSB Task Force Report
- April 2002 *Defense Environmental Restoration Program Annual Report to Congress* – provides an initial assessment of the technology required by the Military Munitions Response Program in response to the FY 2002 National Defense Authorization Act, Section 313
- April 2003 *Defense Environmental Restoration Program Annual Report to Congress* – responds to Congressional direction to provide an initial inventory of munitions response sites, identify a range of potential costs, and provide a technology roadmap in response to the FY 2002 National Defense Authorization Act, Sections 311, 312, and 313
- *UXO/Countermine Forum* – 1998, 1999, 2000, 2001, 2002 – Annual forums attended by approximately 1000 people dedicated to exchanging information
- DENIX -- Enhancement of the DENIX (*Defense Environmental Information Exchange*) web site (all of the above can be accessed on this website)
    - www.denix.osd.mil

Education and Coordination:

- *UXO Technician Labor Pool Enhancement*
    - Department of Labor Standard under development, with associated DoD implementation policy
    - UXO Technician Level One Course at Texas A&M University – other potential sources identified
- *Interstate Technology Regulatory Council* (ITRC) *UXO Team* – DoD is providing direct support for the:
    - "Understanding UXO" Basic Training Course
    - Technical/Regulatory Documents for Military Munitions - Historical Records Review, Geo-Physical Proveout, Conceptual Site Models, and others
- *National Association for Ordnance and Explosive Waste Contractors* (NAOC)
    - Information exchange
    - Roadmap for hiring UXO Technician trained work force
- *US Environmental Protection Agency* – DoD provided direct support for the:
    - "Management of Ordnance and Explosives at Closed, Transferred, and Transferring (CTT) Ranges and Other Sites" Course
    - "Handbook on the Management of Ordnance and Explosives at Closed, Transferred, and Transferring (CTT) Ranges and Other Sites"

- *UXO Safety Education* – Several tools developed for use by the military and the public can be accessed at:
    - http://www.denix.osd.mil/denix/Public/Library/Explosives/UXOSafety/activities.html
    - http://www.denix.osd.mil/denix/Public/Library/Explosives/UXOSafety/Posters/3rs.pdf
    - http://www.denix.osd.mil/denix/DOD/Library/Explosives/UXOSafety/progprint.html

<u>Technology:</u>

In response to the DSB report, the DoD initiated an R&D program to address the UXO technology issues. Prior to the DSB there was no sustained S&T investment in this area. DoD's investments are leading to the development and transition of a next generation of digital geophysical instruments for both ground based and airborne surveys. In addition, recent R&D investments have led to improved signal processing approaches and established our fundamental understanding and modeling capability to describe the underlying phenomenology which drives the UXO detection and discrimination problem. These investments have yielded significant improvements in our ability to detect UXO and reduced the number of false alarms an average of 50% resulting in substantial cost avoidance and improvements in project quality. These past investments have laid the groundwork to make the large improvements in detection and discrimination for all contaminated sites.

- *Strategic Environmental Research and Development Program* (SERDP) and the *Environmental Security Technology Certification Program* (ESTCP)
    - www.serdp.org
    - www.estcp.org
- *Unexploded Ordnance Center of Excellence* (UXOCOE)
    - Established the Joint UXO Coordination Office (JUXOCO)
    - Continues to coordinate and enhance the leveraging of technologies and technical information developed by the DoD Mission Area Operating Centers (MAOCs), such as SERDP, ESTCP, and Army EQT across the UXO mission areas and community.
    - www.uxocoe.brtrc.com
- *Army Environmental Quality Technology* (EQT) *Program*
    - UXO Screening, Detection, and Discrimination Thrust Area. The Army expects this program to provide comprehensive sensor performance specifications (probability of detection, nuisance alarm rates, false alarm rates, and receiver operating characteristics curves) for UXO target, environmental, geophysical, and clutter combinations using advanced electromagnetic, magnetic, and ground penetrating radar. Validated UXO signature models of emerging sensors to support multisensor systems development and improved analysis techniques will also be developed. The overall goal of the Army program is to reduce nuisance alarm rates by 90% over a wide variety of conditions while maintaining or improving the current probability of detection

levels. Sensors/processor systems will be evaluated under controlled target/background conditions and demonstrated at UXO remediation sites.

- www.asaie.army.mil/Public/ESOH/doc/fy02-army-eqt-arc.pdf

- *Navy Technology Program*
  - Y0817 Research Project – Assessing the environmental fate and effects of underwater munitions and explosives of concern (MEC). Research is focused on four major areas:
    - Multi-species Marine Sediment Toxicity Research to develop a comprehensive data set on toxicity of munitions constituents (MCs) to marine species used in risk assessments and define potential bioaccumulation, cellular level impacts, and trophic transfer.
    - Degradation of Munitions Constituents (MC) in Marine Matrices to develop a comprehensive data set regarding the degradation rates of MC in marine water and sediments, and determine key end products.
    - Prediction of Underwater MEC Corrosion to evaluate the current state of understanding for determining corrosion behavior of MEC in the marine environment and develop a model to be used as a predictive exposure tool.
    - Transport of Underwater to evaluate the current state of understanding of underwater MEC mobility and develop predictive capability that can be applied on a site-by-site basis
  - AQAPS- NAVEODTECHDIV developed Automated Quality Assessment Program System (AQAPS) for use at munitions response sites. The purpose is to provide Unexploded Ordnance (UXO) Quality Assessment personnel with processes for managing, assessing, communicating, controlling, sampling and acceptance testing activities, and techniques, and to facilitate these processes resulting in the contractor's UXO clearance efforts exhibiting a high degree of confidence, meeting stated requirements.
    - Quality Assessment Program is to be used by Navy Quality Assessors to obtain objective evidence about UXO clearance operations.
    - To verify/validated or evaluate clearance data against prescribed measures.
    - To assure that an audit trail of data is collected, documented and maintained.
    - To retain and preserve the integrity of the Quality Assessment data gathered during the process. Office of Naval Research (ONR) – Leveraging R&D demining efforts to develop strategies and testing of technologies for addressing detection of underwater ordnance.
  - www.nfesc.navy.mil/

<u>Program Execution Initiatives:</u>

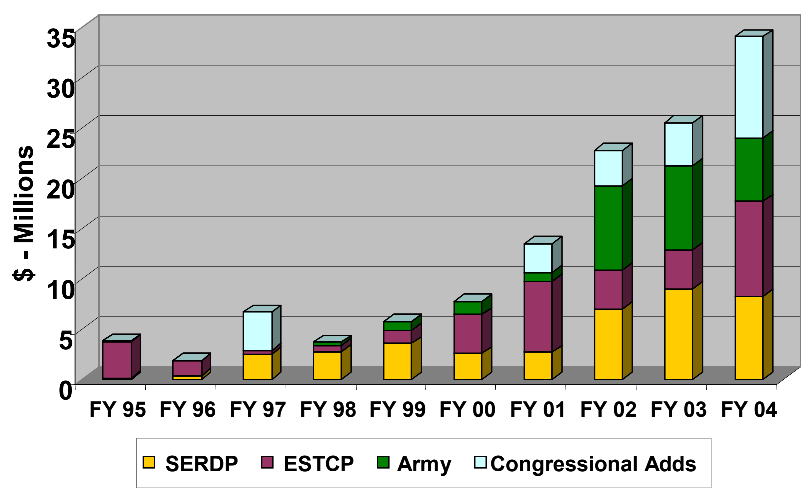
- *Contracting initiatives by the Corps of Engineers* – Firm Fixed Price and Fixed Price Remediation with Insurance contracts are both being developed
- *Navy Contracting Initiative* - $50 million capacity, multi-year Navy UXO Contract (NURC)

- *Green Munitions* – on-going program to replace lead with less toxic materials
    - o Initial success with 5.56 ammunition
- *Model Language for Environmental Land Use Controls* – published and now being promoted for adoption by state governments

Funding:

- FY 2002 NDAA Section 313 Cost Estimate – provided a high and low cost estimate for the cleanup of operational ranges (should they close) and for munitions response activities on other than operational ranges
- Establishment of a unique Defense Environmental Restoration Account Military Munitions Program Element – provides visibility and legitimizes funding of munitions response actions
- Technology Funding - Led by SERDP and ESTCP, the Department significantly increased its investment are shown in the table below.

UXO R&D Investment



Appendix M

Acronyms

This page intentionally left blank

AQAPS	AQAPS – Automated Quality Assessment Program System
AUV	Autonomous Underwater Vehicles
BRAC	Base Realignment and Closure
COFT	Conduct of Fire Trainers
CTT	Closed, Transferred, and Transferring
DENIX	Defense Environmental Information Exchange
DGM	Digital Geophysical Mapping
DGPS	Differential Global Positioning System
DoD	Department of Defense
ESTCP	Environmental Security Technology Certification Program
EMI	Electro-magnetic Induction
EE/CA	Engineering Evaluation and Cost Assessment
EOD	Explosive Ordnance and Demolition
EO/IR	Electro-Optical and Infrared
EQT	Environmental Quality Technology
FAR	False Alarm Ratio
FSCATT	Fire Support Combined Arms Tactical Trainer
FUDS	Formerly Used Defense Site
FY	Fiscal Year
GPR	Ground Penetrating Radar
GPS	Global Positioning System
HE	High Explosive
HUD	Housing and Urban Development
IR	Infrared
ITRC	Interstate Technology Regulatory Council
JUXOCO	Joint Unexploded Ordnance Coordination Office
KE	Kinetic Energy
MAOC	Mission Area Operating Centers
MC	Munitions Constituents
MEC	Munitions and Explosives of Concern
MINS	Mare Island Naval Shipyard
MLRS	Multiple Launch Rocket Systems
mm	millimeter
M/yr	Millions per year
MPPEH	Material Potentially Presenting an Explosive Hazard
MRC	Munitions Response Committee
MTADS	Multiple Towed Array Detection System
NAOC	National Association for Ordnance and Explosive Waste Contractors
NDAA	National Defense Authorization Act
NURC	Navy UXO Contract
NTC	National Training Center
OE	Ordnance and Explosive
OEESCM	Operational and Executive Steering Committee for Munitions
ONR	Office of Naval Research
OUSD (AT&L)	Office of the Under Secretary of Defense (Acquisition Technology and Logistics)
P_d	Probability of detection
P_{fa}	Probability of false alarm
RA	Removal Action
RFP	Request for Proposal

SAR	Synthetic Aperture Radar
SERDP	Strategic Environmental Research and Development Program
TOW	Bradley Tube launched, Optically tracked, Wire guided missiles (p. G 3)
U.S.	United States
UXO	Unexploded Ordnance
UXOCOE	Unexploded Ordnance Center of Excellence
VDS	Validation of Detection Systems
WIPT	Working Integrated Product Team