MEC DETECTION, RECOVERY, AND DISPOSAL TECHNOLOGY ASSESSMENT REPORT

Prepared For:

U.S. ARMY ENGINEERING AND SUPPORT CENTER, HUNTSVILLE

December 2005

.

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DISPOSAL TECHNOLOGIES
(Continued)

TABLE OF CONTENTS

EXECUTIVE SUMMARY v

1.0 Introduction **1-1**
1.1 Purpose 1-1

2.0 Background **2-1**
2.1 Sources of MEC 2-1
2.2 Pre-CERCLA Solutions for MEC 2-1
2.3 CERCLA Responses to MEC 2-2
2.4 RI/FS Process 2-2
2.4.1 Development and Screening of Remedial Action Alternatives 2-5
2.4.2 Identify and Screen Appropriate Technologies and Representative Process Options 2-5
2.4.3 Assemble Technologies into Alternatives 2-6
2.4.4 Detailed Analysis of Remedial Action Alternatives 2-8
2.4.5 Feasibility Study Report 2-10

3.0 MEC Technology Assessment-Detection **3-1**
3.1 Objective 3-1
3.1.1 Evaluation Criteria – Effectiveness, Implementability, and Cost 3-1
3.1.2 Detection Technology Components - Acquisition Platforms 3-3
3.2 Sensor Technologies 3-5
3.2.1 Magnetometry 3-5
3.2.2 Electromagnetics 3-11
3.2.3 Magnetometer-Electromagnetic Detection Dual Sensor Systems 3-18
3.2.4 Marine Side-Scan Sonar 3-19
3.2.5 Airborne Multispectral/Hyperspectral Imaging System 3-21
3.2.6 Airborne Laser and Infrared Sensors 3-21
3.3 Supporting Technology Options 3-22
3.3.1 Site Preparation 3-22
3.3.2 Positioning Systems 3-23
3.3.3 Navigation 3-26
3.3.4 Data Processing and Analysis 3-27
3.3.5 Detection and Discrimination 3-27

4.0 MEC Technology Assessment-Removal **4-1**
4.1 Objectives 4-1
4.1.1 Evaluation Criteria – Effectiveness, Implementability, and Cost 4-1
4.2 Technology Process Options - Removal 4-1
4.2.1 Hand Excavation 4-1
4.2.2 Mechanized Removal of Individual Anomalies 4-3
4.2.3 Mass Excavation and Sifting 4-5
4.2.4 Magnetically Assisted Recovery 4-10

TABLE OF CONTENTS
(Continued)

5.0 MEC Technology Assessment - Disposal **5-1**
5.1 Objectives 5-1
5.1.1 Evaluation Criteria – Effectiveness, Implementability, and Cost 5-1
5.2 Technology Process Options – Explosive Disposal 5-1
5.2.1 Blow-In-Place 5-2
5.2.2 Consolidate and Blow 5-3
5.2.3 Laser Initiation 5-6
5.2.4 Contained Detonation Chambers 5-8
5.2.5 Disassembly or Render Safe Procedures 5-10
5.3 Technology Process Options – MEC Residual Processing 5-11
5.3.1 Chemical Decontamination 5-12
5.3.2 Flashing Furnaces 5-14
5.3.3 Shredders and Crushers 5-16

6.0 REFERENCES **6-1**

List of Figures

Figure 2-1 Components of the Remedial Investigation 2-3
Figure 2-2 Components of the Feasibility Study 2-4
Figure 2-3 An Example of Evaluation of Process Options 2-7
Figure 4-1 Equipment with Non Armored Cab 4-7
Figure 4-2 Equipment with Armored Cab 4-7
Figure 4-3 Shaker Type Screen 4-9
Figure 4-4 Trommel Type Screen 4-9

List of Appendices

Appendix A Technology Summary Tables
Appendix B Sensor Technology and Data Acquisition Platform Examples

ACRONYMS AND ABBREVIATIONS

3D	Three Dimensional
APHE	Armor-Piercing High Explosive
AR	Army Regulation
ARAR	Applicable or Relevant and Appropriate Requirement
BIP	Blow In Place
CEA	Captured Enemy Ammunition
CEHNC	U.S. Army Corps of Engineers, Huntsville Center
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CMC	Coalition Munitions Collection
COTS	Commercial Off-the-Shelf
DGM	Digital Geophysical Mapping
DGPS	Differentially Corrected Global Positioning System
DID	Data Item Description
EE/CA	Engineering Evaluation/Cost Analysis
EM	Engineer Manual
EMI	Electromagnetic Induction
EOD	Explosive Ordnance Disposal
EP	Engineer Pamphlet
EPA	Environmental Protection Agency
ER	Engineer Regulation
FAA	Federal Aviation Administration
FDEMI	Frequency-Domain Electromagnetic Induction
FS	Feasibility Study
FUDS	Formerly Used Defense Site
GOTS	Government Off-the-Shelf
GPR	Ground Penetrating Radar
GPS	Global Positioning System
GRA	General Response Action
ICM	Improved Conventional Munition
JDTP	Joint Demilitarization Technology Program
MC	Munitions of Concern
MEC	Munitions and Explosives of Concern
MHE	Material Handling Equipment
MSO	Molten Salt Oxidation
NEW	Net Explosive Weight
OASA (I&E)	Office of the Assistant Secretary of the Army – Installations and Environment
O&M	Operation and Maintenance
OB/OD	Open Burn / Open Detonation
ODC	Ordnance Demolition Container
OE	Ordnance and Explosives
Pd	Probability of Detection
PPE	Personal Protective Equipment
QA	Quality Assurance
QC	Quality Control
RAO	Remedial Action Objective
R&D	Research and Development

ACRONYMS AND ABBREVIATIONS
(Continued)

RCRA	Resource Conservation and Recovery Act
RF	Radio Frequency
RFD	Remote Firing Device
RI	Remedial Investigation
RI/FS	Remedial Investigation/Feasibility Study
ROD	Record of Decision
RSP	Render Safe Procedure
RTS	Robotic Total Station
SAM	Sub-Audio Magnetics
SAR	Synthetic Aperture Radar
SCWO	Supercritical Water Oxidation
SOW	Statement of Work
SR	Stationary Receiver
SUXOS	Senior UXO Supervisor
TDEMI	Time Domain Electromagnetic Induction
TNT	Trinitrotoluene
U.S.	United States
USACE	U.S. Army Corps of Engineers
USACERL	U.S. Army Construction Engineering Research Laboratories
USRADS	Ultrasonic Ranging and Data System
UXO	Unexploded Ordnance

EXECUTIVE SUMMARY

This report is designed to assist those responsible for planning and/or reviewing Remedial Investigations/Feasibility Studies (RI/FS) for Munitions and Explosives of Concern (MEC) projects in identifying and evaluating potentially applicable response technologies. It describes and discusses known and evolving processes for MEC detection, recovery, and disposal. This Report also evaluates commercial off-the-shelf (COTS), government off-the-shelf (GOTS), and well-developed Research and Development (R&D) technologies potentially available for application to remedial response detection, recovery, and disposal operations at MEC sites.

An introduction to the MEC problem is provided in Chapter 2 of this report, including discussions on sources of MEC; historical responses under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA); and a description of the RI/FS process as applied to MEC projects. Chapter 2 also describes how this document was developed, including technology assessment methods.

Chapters 3, 4 and 5 of the document describe processes and technologies for detection, removal and disposal of MEC. Chapter 3 (MEC) provides information on sensors and supporting technologies, including site preparation, positioning systems, navigation, data processing/analysis, and discrimination. Chapter 4 describes methods and technologies for removing MEC from subsurface environments. Chapter 5 describes processes and technologies for disposal of MEC, including treatment technologies for resultant waste streams.

Abridged tables are provided in Appendix A to this document as an additional quick reference tool for prospective users of this document. These are designed to provide succinct and relevant information "at a glance" and thus allow planners and reviewers to select technologies for further consideration.

In summary, this document is designed to provide planners and reviewers with first-cut descriptions and evaluations of technologies, and thus assist in the development of CERCLA RI/FS documentation. Information included in this and/or referenced/related documents is based on the best available information available during development of the report. Readers are advised that new and updated information may be available and should be researched during project-specific MEC RI/FS planning.

1.0 INTRODUCTION

This MEC Detection, Recovery, and Disposal Technology Assessment Report was prepared for the United States (U.S.) Army Corps of Engineers, Huntsville Center (CEHNC). The project was authorized as Task Order 0002, under Contract W912DY-04-D-0011. The report has been formatted in accordance with the Delivery Order, Statement of Work (SOW), and Data Item Description (DID) MR-010.

1.1 PURPOSE

Munitions and Explosives of Concern (MEC) operations are generally conducted in accordance with the provisions of Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). A significant number of these operations are expected to include a requirement for a Remedial Investigation/Feasibility Study (RI/FS) to support decision documents and assure that the selected remedial alternative is appropriate, effective, and efficient. An RI/FS requires a thorough evaluation of all feasible response alternatives, which includes consideration of the full range of technologies that might be applied to achieve MEC response objectives. This Report discusses the processes for consideration and evaluation of MEC technologies for Detection, Recovery, and Disposal. This Report also evaluates commercial off-the-shelf (COTS), government off-the-shelf (GOTS), and well-developed Research and Development (R&D) technologies potentially available for application to remedial response detection, recovery, and disposal operations at MEC sites. This report is targeted to assist those planning and/or reviewing an MEC RI/FS to identify and evaluate potentially applicable response technologies.

2.0 BACKGROUND

The term Munitions and Explosives of Concern (MEC) is defined by the Office of the Assistant Secretary of the Army – Installations and Environment (OASA (I&E)) as follows:

2.0.1 "Munitions and Explosives of Concern (MEC). This term, which distinguishes specific categories of military munitions that may pose unique explosives safety risks means: (A) Unexploded Ordnance (UXO), as defined in 10 U.S.C. 101(e)(5); (B) Discarded Military Munitions (DMM), as defined in 10 U.S.C. 2710(e)(2); or (C) Munitions Constituents (e.g., TNT, RDX), as defined in 10 U.S.C. 2710(e)(3), present in high enough concentrations to pose an explosive hazard."

2.0.2 Because of their explosive potential, MEC present a unique hazard to human safety and the environment. Traditionally, the focus of environmental restoration programs was contamination caused by hazardous and toxic materials in the environment. Hazardous and toxic materials have the capability to migrate and be influenced by natural environmental conditions, as well as human interactions, and expand the areas of contamination. While not always the case, MEC generally takes the form of discrete devices that have little opportunity for mobility and pose little or no hazard to human health or the environment in the absence of human interactions. A noted exception to this would be munitions constituents (MC), which represent a potential migratory contaminant.

2.1 SOURCES OF MEC

Sources of MEC include military training activities, weapons development and testing, weapons system production, combat operations, and various other activities. During our country's history, many areas have been used for military purposes and now potentially have MEC present in varied degrees. These munitions were not intentionally placed as contamination, but as a result of changing uses of the land they have come to be viewed as contamination.

2.2 PRE-CERCLA SOLUTIONS FOR MEC

In most cases, property that was used for military purposes was restored to its original condition, or the owners compensated for any residual damage to the property. Historically, military activities were conducted in remote, unpopulated areas and the presence of MEC was not considered a significant impairment to future uses. Military Organizations performed surface clearances on many of the properties previously used for firing of explosive ordnance. In some cases, subsurface clearance was conducted to an extent deemed necessary for the particular property. However, technologies that were available were only partially effective and interest in performing highly effective removals was not generally present.

2.3 CERCLA RESPONSES TO MEC

Enactment of CERCLA was primarily focused on hazardous and toxic contamination. The Formerly Used Defense Sites (FUDS) Program created the first substantial opportunity for an environmental program to focus on unexploded ordnance (UXO) (note: terminology has recently been revised. This material is now referred to as Munitions and Explosives of Concern (MEC)).

2.3.1 The majority of MEC response actions have been performed based on Engineering Evaluation/Cost Analysis (EE/CA) results. With increasing involvement by state and federal regulatory agencies in MEC response actions, an increasing number of MEC projects are being evaluated using RI/FSs.

2.4 RI/FS PROCESS

Since this Report has been prepared to assist in the planning and/or reviewing of an MEC RI/FS, it is important to first understand the basic steps of the RI/FS process. The objective of the RI/FS process is to gather information to support an informed risk management decision that selects a remedy that is most appropriate for a given site. This approach is a dynamic, flexible process that is tailored to specific circumstances of individual sites. The first step in the RI/FS process is scoping activities. Scoping is simply planning the RI/FS process. Scoping includes conducting a kickoff meeting, evaluating any existing data, conducting a site visit, developing a conceptual site model, identifying preliminary Remedial Action Objectives, and identifying preliminary General Response Actions.

2.4.0.1 **The Remedial Investigation Process.** The second step in the RI/FS process is the remedial investigation. Figure 2-1 depicts the basic steps in the RI phase. In the RI phase, a field investigation is conducted to characterize the site. Site information such as geography, geology, ownership, vegetation, special environmental, social, or cultural resources is collected. Laboratory analysis, data evaluation, and data management are also important components in this phase. At the conclusion of the remedial investigation phase, the source of the contamination, the extent of the contamination, and the physical analysis of the site are summarized in the RI report.

2.4.0.2. **The Feasibility Study Process.** The final step in the RI/FS process is the feasibility study. The feasibility study can be divided into three components: (1) Development and Screening of Remedial Alternatives, (2) Detailed Analysis of Remedial Action Alternatives, and (3) Issuance of the Feasibility Study Report. The following paragraphs provide more details on the feasibility study. Figure 2-2 depicts the basic steps of a feasibility study.

Figure 2-1 Components of the Remedial Investigation

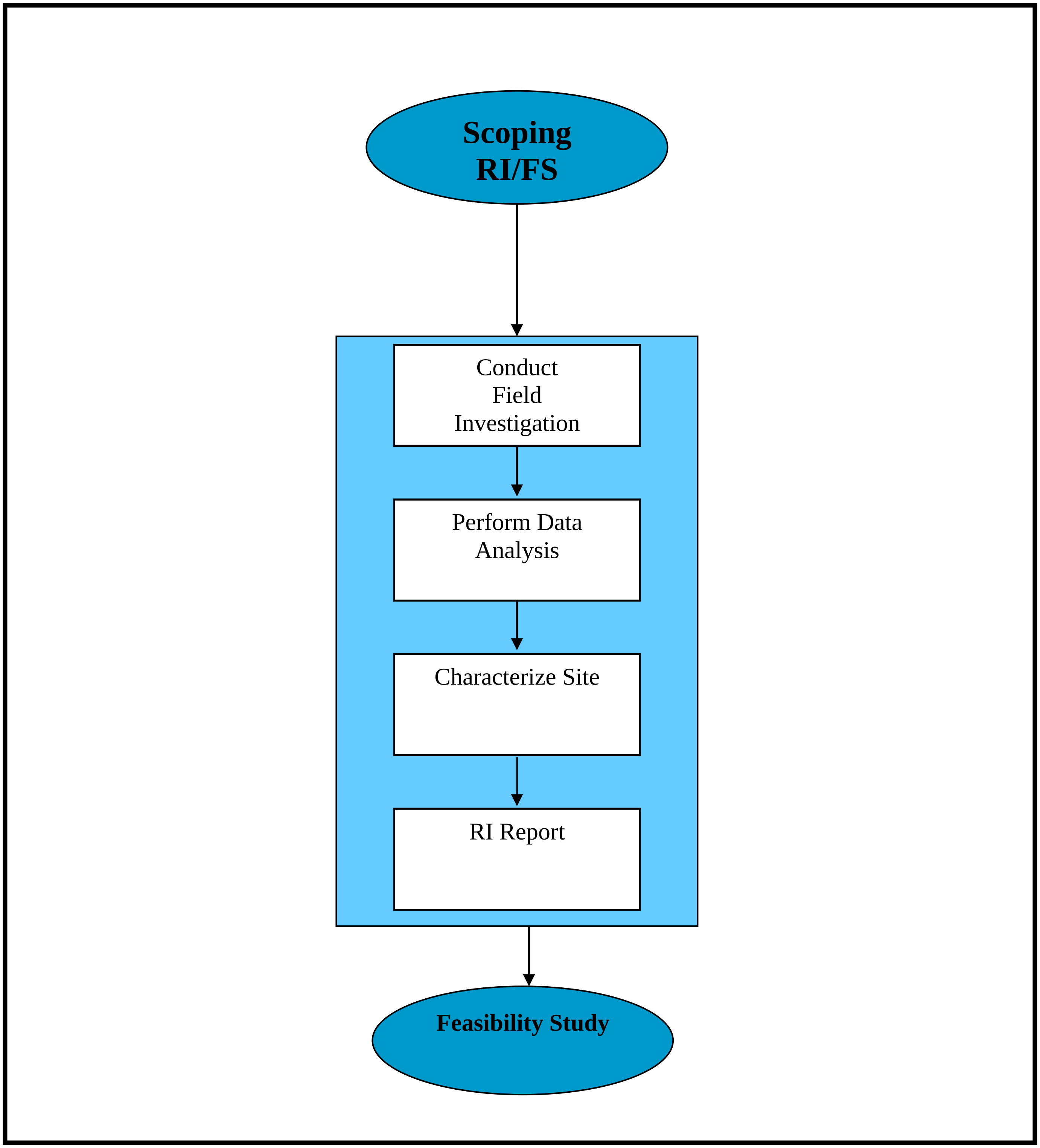
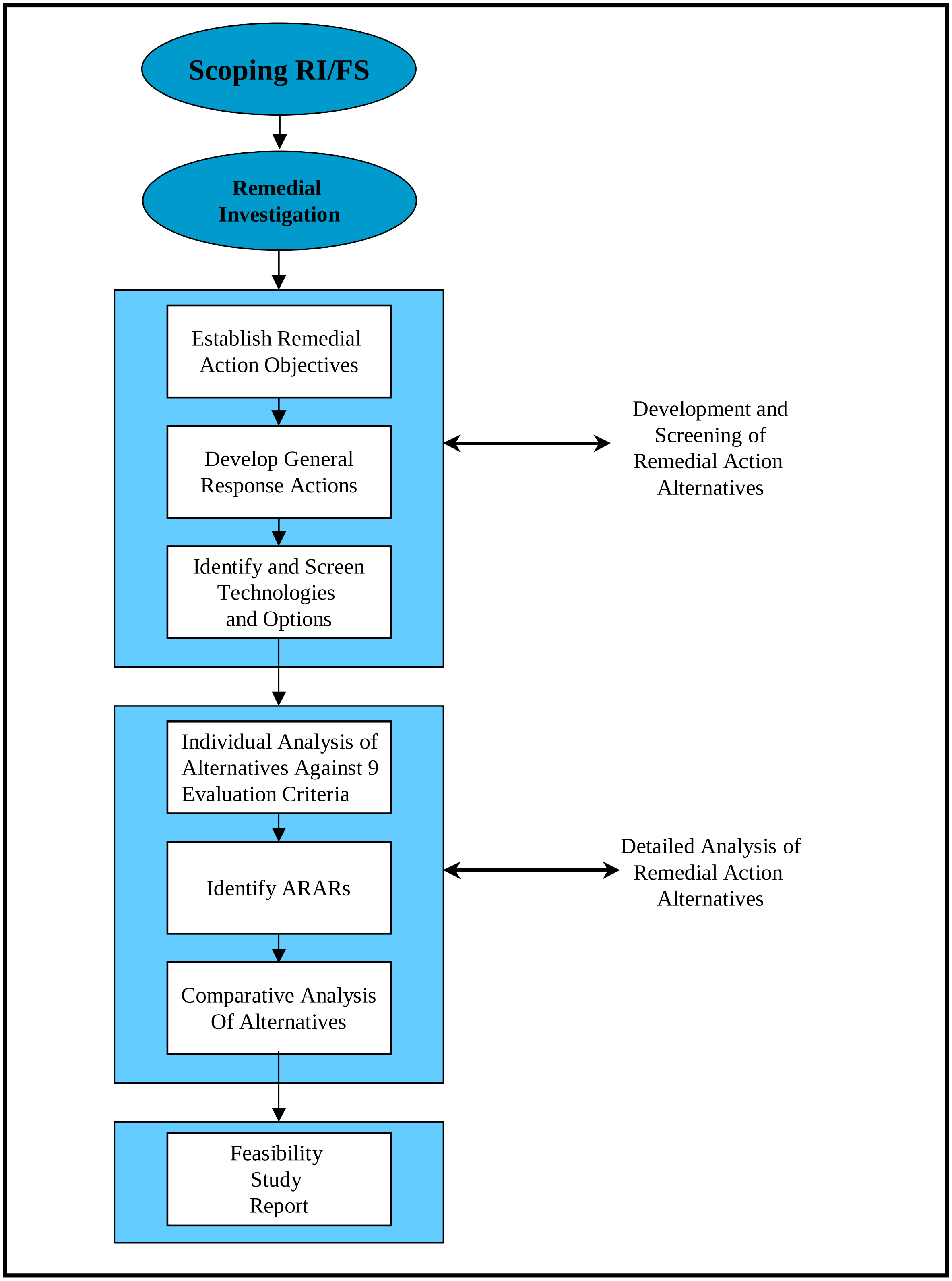


Figure 2-2 Components of the Feasibility Study



2.4.1 Development and Screening of Remedial Action Alternatives

2.4.1.1 Remedial Action Objectives

One of the first steps in the feasibility study is to establish Remedial Action Objectives or RAOs. The preliminary RAOs identified during project scoping are refined as necessary during the FS phase of the RI/FS to develop specific goals for protecting human health and the environment. Remedial action objectives specify the area(s) of concern; the exposure route(s) and receptor(s); and the remediation goal(s) for each exposure expectation.

2.4.1.2 General Response Actions

General Response Actions (GRAs) are selected to satisfy the RAOs for each area of concern. These actions, initially defined during the project scoping process, are refined during this phase and relate to response alternatives. These general response actions might include the following:

- No Action;
- Surface Clearance;
- Geophysical Mapping and Removal to Depth of Detection;
- Mass Excavation and Screening of Soils; and
- Fencing and Other Institutional Controls.

2.4.1.2.1 GRAs may be combined to form alternatives, such as pre-treatment of areas with high concentrations of MEC for removal of large munitions with mass excavation and screening of soils to remove the residuals. The areas of concern where GRAs might be applied should be identified at this time based on exposure expectations; known nature and MEC concentration; and preliminary remediation goals and a preliminary list of action-specific Applicable or Relevant and Appropriate Requirements (ARARs).

2.4.1.2.2 Throughout this report, the term “technology” refers to general categories of MEC technologies, such as Detection, Recovery, and Disposal. The term “technology process option” refers to specific alternative processes within each technology family, such as magnetometers or electromagnetic induction metal detectors in the detection technology category. The list of potentially applicable technology categories for MEC is relatively limited, but the number of technology process options can be significant.

2.4.2 Identify and Screen Appropriate Technologies and Representative Process Options

A list of potential technologies and technology options corresponding to the identified general response actions should be compiled, and then reduced by evaluating the technology process options with respect to technical implementability. Existing information on technologies and site characterization data are used to screen out technologies and process options that cannot be effectively implemented at the site. During this screening step, process options and entire technology types may be eliminated from further consideration on the basis of technical implementability. This is accomplished by using available information from the RI site characterization on MEC types, concentrations, distribution, and site characteristics to screen out technologies and process options that cannot be effectively implemented at the site.

2.4.2.1 Technologies and process options are evaluated using the same criteria, which are effectiveness, implementability, and cost – that are used to screen alternatives in the detailed analysis that occurs later in the RI/FS process. An important distinction is that at this time, these criteria are applied only to technologies and the general response areas they are intended to satisfy, and not to the site as a whole. Furthermore, the evaluation should primarily focus on effectiveness factors at this stage with less effort directed at the implementability and cost evaluation. The evaluation of process options is illustrated in Figure 2-3.

2.4.3 Assemble Technologies into Alternatives

To assemble the identified technologies into alternatives, GRAs should be expanded, using different process options applicable to different areas of the site, to meet all RAOs. For example, one of the response actions noted earlier, "Geophysical Mapping and Removal to Depth of Detection" might be defined as:

> *" Digital geophysical mapping using time-domain electromagnetic induction detection and laser navigation systems (e.g. Constellation) in wooded areas and robotic total station in the open; Recovery using manual methods supplemented with mechanical assistance in accessible areas; Disposal by "blow in place" where required and consolidated shots when possible with exclusion zones established based on expected munitions with greatest fragmentation distance, supplemented when needed with engineering controls for blast protection."*

2.4.3.1 Alternatives with the most favorable evaluation of all factors should be retained for further consideration during the detailed analysis. Alternatives selected for further evaluation should, where practicable, preserve the range of process technologies initially developed. It is not a requirement that the entire range of alternatives originally developed be preserved if all alternatives in a portion of the range do not represent distinct viable options.

2.4.3.2 The target number of alternatives to be carried through screening should be set by the Project Manager and the Lead Agency on a site-specific basis. It is expected that the typical target number of alternatives carried through screening (including the no-action alternative) usually should not exceed 10. Fewer alternatives should be carried through screening, if possible, while adequately preserving the range of remedies.

DISPOSAL TECHNOLOGIES
(Continued)

Figure 2-3
An Example of Evaluation of Process Options

General Response Actions	Remedial Technology	Process Options	Effectiveness	Implementability	Cost
No Action	None	Not Applicable	Does not achieve remedial action objectives.	Not acceptable to local government.	None
Surface Clearance	Detection	Flux-Gate Magnetometry	Very effective at locating ferrous items. Does not detect non ferrous items.	Light, compact, easy to use and widely available.	Low Cost
		Electromagnetic Induction	Very effective at locating ferrous and non ferrous items.	Light, compact, easy to use and widely available.	Moderate to Low Cost
	Removal	Hand Excavation	Very effective at removal of surface items. Most commonly used method.	Highly implementable; requires only small hand tools, trained personnel readily available.	Low Cost
	Disposal	Blow-in-Place	Very effective. Results verifiable. Most commonly used method.	Field proven; engineering controls may be required if public exposed.	Low Cost
		Consolidate and Blow	Very effective for MEC items that are safe to move. Results verifiable Less commonly used method.	Detonation of consolidated MEC items requires larger area and greater controls. Requires transport of MEC items.	Moderate Cost, more manpwer intensive, may require MHE.
		Contained Destruction Chamber	Very effective for small fuzes and smaller explosive components.	Requires transportation to central location, may require permitting, requires maintenance.	High Costs; potential permitting, system maintenance/specialized training required.
Fencing and other Institutional Controls	Access Restriction	Fencing	Dependent on long term maintenance. Does not remove MEC.	HIghly Implementable	Moderate Costs, dependent on quantity of fencing required.
		Deed Restrictions	Dependent on continued future implementation. Does not remove MEC.	Requires legal authority	Moderate Costs, legal requirements
		Signage	Dependent on long term maintenance. Does not remove MEC.	HIghly Implementable	Low to moderate costs, dependent on number of signs required.
	Education	Public meetings, fact sheets, videos, exhibits, press releases.	Dependent on public interest and broadness of educational program. Does not remove MEC.	HIghly Implementable	Moderate costs, dependent on elements/size of program.

2.4.3.3 Communication among the lead and regulatory agencies, and their contractor(s), is very important to obtain input and agreement on the technologies or processes and alternatives considered for implementation at the site. This communication should facilitate the initial screening of technologies and process options, foster agreement on what additional site data may be needed, and obtain input and agreement on the choice of representative processes and combinations to be used to assemble alternatives. In addition, the following key coordination points are required:

- The lead and regulatory agencies should agree on the set of alternatives selected for detailed analysis;
- The lead and regulatory agencies must coordinate identification of action-specific ARARs; and
- The lead agency and its contractor are to evaluate the need for any additional investigations that may be needed before they conduct the detailed analysis.

2.4.4 Detailed Analysis of Remedial Action Alternatives

The detailed analysis provides the means by which facts are assembled and evaluated to develop the rationale for a remedy selection. Therefore, it is necessary to understand the requirements of the remedy selection process to ensure that the FS analysis provides sufficient quantity and quality of information to simplify the transition between the FS and the actual selection of a remedy. The analytical process described here has been developed on the basis of statutory requirements of CERCLA Section 121 and program initiatives. Selected alternatives should be analyzed individually against the evaluation criteria. The nine evaluation criteria are:

1. Overall Protection of Human Health and the Environment;
2. Compliance with ARARs;
3. Long-Term Effectiveness and Permanence;
4. Reduction of Toxicity, Mobility, or Volume;
5. Short-Term Effectiveness;
6. Implementability;
7. Cost;
8. State Acceptance; and
9. Community Acceptance.

2.4.4.1 These criteria encompass statutory requirements and technical, cost, and institutional considerations the program has determined appropriate for a thorough evaluation. Assessments against the first two criteria (1. and 2. above) relate directly to statutory findings that <u>must</u> ultimately be made in the Decision Document that results from the RI/FS process. Therefore, these criteria are categorized as <u>threshold criteria</u> since each alternative must meet them. These criteria are briefly described below:

- Criteria 1. (Overall Protection of Human Health and the Environment): The assessment against these criterion describes how the alternative, as a whole, achieves and maintains protection of human health and the environment.

- Criteria 2. (Compliance with ARARs): The assessment against this criterion describes how the alternative complies with ARARs or if a waiver is required and how it is justified. The assessment also addresses other information from advisories, criteria, and guidance that the lead and regulatory agencies have agreed is "to be considered." The remaining criteria listed below are grouped together because they represent the primary criteria upon which the analysis is based.

2.4.4.2 The remaining seven criteria relate to important issues necessary for acceptability:

- Criteria 3. (Long-Term Effectiveness and Permanence): The assessment of alternatives against this criterion evaluates the long-term effectiveness of alternatives in maintaining protection of human health and the environment after response objectives have been met.
- Criteria 4. (Reduction of Toxicity, Mobility, or Volume): The assessment against this criterion evaluates the anticipated performance of the specific treatment technologies an alternative may employ. (note: for MEC responses, toxicity does not typically apply. MEC responses do not exactly fit the conventional CERCLA processes developed for other forms of HTRW).
- Criteria 5. (Short-Term Effectiveness): The assessment against this criterion examines the effectiveness of alternatives in protecting human health and the environment during the construction and implementation of a remedy until response objectives have been met.
- Criteria 6. (Implementability): This assessment evaluates the technical and administrative feasibility of alternatives and the availability of required goods and services.
- Criteria 7. (Cost): This assessment evaluates the capital and operation and maintenance (O&M) costs of each alternative.
- Criteria 8. (State Acceptance): This assessment evaluates the technical and administrative issues and concerns the state (or regulatory agency) may have regarding each of the alternatives. As discussed earlier, this criterion will be addressed in the Decision Document once comments on the RI/FS and proposed plan have been received.
- Criteria 9. (Community Acceptance): This assessment evaluates the issues and concerns the public may have regarding each of the alternatives. As with State acceptance, this criterion will be addressed in the Decision Document once comments on the RI/FS and proposed plan have been received.

2.4.4.3 Implementability evaluation encompasses both the technical and administrative feasibility of implementing a technology process. Technical implementability is used as an initial screen of technology types and process options to eliminate those that are clearly ineffective or unworkable at a site. Therefore, subsequent, more detailed evaluation of process options places greater emphasis on the institutional aspects of implementability, such as the ability to obtain necessary permits for offsite actions, and the availability of necessary equipment and skilled workers to implement the technology.

2.4.4.4 Cost evaluation plays a limited role in the screening of process options, but is usually an important factor in selection of the alternative to be implemented. Relative capital and operational costs are used rather than detailed estimates. At this stage in the process, the cost analysis is made on the basis of engineering judgment and each process is evaluated as to whether costs are high, medium, or low relative to other process options in the same technology type. The greatest cost consequences in site remediation are usually associated with the degree to which different general technology types (i.e., containment, treatment, excavation, etc.) are used. Using different process options within a technology type usually has a less significant effect on cost than does the use of different technology types.

2.4.4.5 Once the individual evaluation has been conducted for each of the alternatives, a comparative analysis should be conducted to select a recommended alternative for the site.

2.4.5 Feasibility Study Report

The Environmental Protection Agency (EPA) RI/FS guidance provides a suggested format for the final FS report. Typically, the FS report will also contain a summary of the RI report. The major elements that should be included in the report are a description of alternatives and individual analysis; a comparative analysis of the alternatives with respect to each evaluation criteria; and documentation of the ARARs.

2.4.5.1 Because the final RI/FS may eventually be subject to judicial review, the procedures for evaluating, defining, and screening alternatives should be well documented, showing the rationale for each step. The following types of information should be documented in the final RI/FS to the extent possible:

- Risk-based remedial objectives associated with the alternative;
- Modifications to any area-specific alternatives initially developed including rationale;
- Definition of each alternative including area, depth of clearance, extent of remediation, expected numbers of munitions, major technologies and technology process options, cleanup timeframes, fragmentation distances (exclusion zones), and other special considerations; and
- Notation of process options that were not initially screened out and are being represented by the processes comprising the alternatives.
- The preceding paragraphs provided a brief discussion of the components required to complete the RI/FS process and the items that should be included in the RI and FS reports. For a more detailed explanation of each step of this process, please reference the 1988 EPA Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA. The remainder of this Report focuses on the technologies that would be included in an FS report.

3.0 MEC TECHNOLOGY ASSESSMENT-DETECTION

3.1 OBJECTIVE

The objective of MEC detection is to determine the presence and location of potential MEC items. Planning, staffing, and funding of a MEC remediation project begins with a site assessment that is based on the location of surface and subsurface anomalies with MEC characteristics. Therefore, the proper selection and use of detection technologies is one of the most important parts of the site investigation process. Selecting the most appropriate detection methods for a site will result in a successful site characterization, which ultimately results in a successful remediation.

3.1.0.1 Geophysical technology, remote sensing technology, and explosives detection technologies are all recognized as having applications in detecting MEC. However, no current geophysical detection or remote sensing technology specifically detects MEC. Rather, these technologies detect anomalies. An anomaly is defined by sensor measurements that are incongruent or inconsistent with the baseline properties of the area where MEC are suspected. The challenge (within the MEC detection technology context) is accurate and precise navigation and positioning, and appropriate implementation of non-intrusive detection technologies to minimize unnecessary excavation.

3.1.1 Evaluation Criteria – Effectiveness, Implementability, and Cost

In 2005, there are more than 2,300 sites in the United States where MEC represents a potential hazard to the public. The primary goal of an MEC project is to identify where, what kind, and to what extent MEC is present (Military Munitions Response Program FY02 report to Congress, pg. 54). In general, this objective is accomplished by performing one or a combination of the following actions:

- Site characterization;
- Removal action; and
- Emergency response action.

3.1.1.1 It is difficult to define the single objective and mission statement applicable to every potential MEC site because MEC project sites are often very large—exceeding several thousands of acres—and the future land use is often unknown or is projected for multiple uses. Other factors that influence the overall effectiveness of an MEC investigation include terrain, vegetation, geology and soils, and weather.

3.1.1.2 To make the best use of available funding, it is preferable to reduce the area that requires detailed investigation (also known as “footprint” reduction) during the initial stages of project execution through review of historical data and visual surface or vehicle\airborne reconnaissance “sweeps”. When specific areas have been defined, it is common to deploy analog and digital geophysical sensor technologies to further assess the potential site hazards. For some applications, positioning equipment (e.g., Global Positioning System (GPS), Differentially Corrected Global Positioning System (DGPS), laser or acoustic methods, etc.) is used to provide georeferenced locations for the geophysical sensor measurements. These sensor measurements are processed to formulate georeferenced color-coded images that represent the intensity of the sensor signals (i.e., anomalies). The coordinates of the anomalies and other relevant information are provided to the project field personnel who reacquire the designated location and excavate the anomaly locations in the field. When MEC is identified during the excavation, the material is neutralized and/or destroyed.

3.1.1.3 In the 2002 MMRP Report, DOD states that for each MEC item that is excavated, 100 excavations are performed that identify scrap metal or “geology”. Based on extensive DOD testing programs from 1993–2005, as well as information that has been evaluated from numerous MEC project sites, digital sensor technologies coupled with precise positioning technologies have the potential to improve the overall effectiveness stated. Accurate and precisely located sensor measurements conserve project costs by allowing the geophysical data to be more efficiently processed and interpreted and by providing the opportunity to use more robust software algorithms that have exhibited potential to discriminate MEC items from non- MEC items (e.g., scrap metal). Precise georeferenced sensor measurements also minimize the time spent searching for the anomaly location in the field, and may also reduce the physical size of the excavation necessary to unearth the object of interest.

3.1.1.4 Because no two sites are the same in terms of terrain, vegetation, geology, and soil composition, man-made features, and weather, it is very challenging to evaluate which detection technology is optimum for a particular job site and project objective in terms of detection capability, ease of use, reliability, availability, and cost. The following evaluation criteria are a widely accepted means of evaluating geophysical sensor technologies:

Effectiveness: Is defined for this document as sensor and site-specific in terms of detection capability and minimization of false positives (e.g., “no finds”, “hot rocks”, etc.), productivity, and degree of quality management necessary to ensure the data are of sufficient quantity and quality to meet the project objectives. Factors such as general ease of use and industry familiarization also play a part in evaluating a system’s overall effectiveness.

Implementability: Is defined for this document in terms of sensor technology and data acquisition platform design considerations with respect to variations in terrain, vegetation, geology and soils, man-made features, and weather. Other factors include equipment availability, weight and power requirements, reliability, and safety considerations.

Cost: Specific cost estimation is not possible for this effort due to the broad range of project objectives and environmental conditions encountered on most MEC projects. Cost will be compared as relative costs to other detection approaches in the document. This will be accomplished by using the broad categories of manpower, equipment and supplies, and other direct charges as identifiable.

3.1.1.5 A summary table of the effectiveness, implementability, and relative cost for each technology is included in Appendix A.

3.1.2 Detection Technology Components - Acquisition Platforms

Data acquisition platforms are designed to ensure that the data collected are of sufficient quality to meet the project objectives and that the ergonomic features are consistent with the intended use. The components of the data acquisition platform include the geophysical sensor and associated electronics, positioning system and associated electronics, data-recording devices, electronic and power cables, and mode of transport. Some of these components may be integrated into a single “unit” by the manufacturer or the contractor during the design of the platform. Important design considerations for the data acquisition platform include the project objectives, ergonomic design, safety, reduction or removal of metal components that are near the geophysical sensor (or the use of non-ferrous metals such as aluminum for magnetometers), and minimization of the movement of any metal with respect to the geophysical sensor.

3.1.2.0.1 For projects of longer duration (several weeks to several months), the ergonomic design of the platform is important. Poor designs increase the frustration of acquisition specialists and may result in lower survey production rates and potential lost work time because of injury or soreness. The best ergonomic designs take into account the weight of the system and how it is best distributed and deployed in a specific environmental setting, especially when the system is man-portable. DGM systems that weigh more than 30 to 40 pounds should be distributed between the field team members, if possible, to prevent fatigue.

3.1.2.0.2 Aside from the safety hazards of the terrain and vegetation, the best platform designs are those that minimize the overall system weight and the number of cables and other electronic components present. Cables should be attached to sensors and positioning equipment using strain-relief devices and positioned on the platform to prevent tripping (or catching the wheels of a cart or vehicle-towed array). All electronic and power cables should be ruggedized to the extent possible (especially connectors), shielded from electromagnetic interference, and durably weatherproofed. Where applicable (i.e., vehicle-towed array, marine or airborne system), power units should be grounded appropriately.

3.1.2.0.3 Electromagnetic sensors (e.g., Time Domain or Frequency Domain Electromagnetic Induction) are sensitive to all metal objects, but magnetometers are only influenced by ferrous metal (metal that can be magnetized). Simplistic examples of non-ferrous metal are aluminum, brass, and some types of stainless steel. The design of any man-portable or vehicle-towed digital geophysical mapping system should account for these details by (1) minimizing the amount of system metal, (2) ensuring metal components that are used remain fixed with respect to the geophysical sensors, and (3) ensuring metal components that are used remain at a sufficient distance from the sensors so that measurements are not adversely affected. System metal that does influence the sensor measurements is one type of geophysical “noise” that can usually be eradicated if the issue is considered in the design stage. An additional important design component is ensuring that the positioning system “receiver” (e.g., DGPS antenna, USRADS crystal, Robotic Total Station (RTS) prism, etc.) is collocated with the geophysical sensor “receiver” (e.g., EM61 coils, magnetometer sensor, GEM disc, etc.) or the offset between the geophysical sensor(s) and positioning "receiver(s)" remains fixed or the amount of (minimal) movement known.

3.1.2.0.4 To summarize: The design and implementation of the data acquisition platform is of primary importance along with the selection of the sensor technology. *Project results may vary significantly even with the optimum sensor technology if the design of the data acquisition platform is not compatible with the environment in which it will be used.*

3.1.2.1 Ground-Based Systems (man portable and towed)

The most common method of operating MEC detection instruments is the man portable method. This involves carrying or pulling the instrument. This method does not have as high a production rate as some of the other platforms, but is useful in rough terrain and wooded areas. Towed arrays have become popular in open areas and have a higher production rate based on the speed in which data is collected and utilizing multiple detectors (larger footprint). The quality of data and detection depth of ground-based systems is generally superior to other platforms due to the proximity of the detection systems to the ground.

3.1.2.2 Airborne Systems

Airborne systems have been evaluated as a regional footprint reduction tool but still have limitations due to the inability of the systems to detect small items from a safe operating altitude. There are also considerably advanced processing procedures required to remove the effects of the fixed-wing or rotary-wing aircraft on the detection system. Another factor, which has limited the popularity of airborne methods, is the costs associated with maintaining and operating an aircraft.

3.1.2.3 Underwater Systems

Most of the previously mentioned detection systems can be modified for underwater use. Perhaps the most popular is the magnetometer, which can be towed from a marine vessel. Implementation of marine-based detection systems is difficult and requires experienced field personnel. Perhaps the most challenging aspect of marine investigations is accurately determining the position of one or more submerged detectors. Typically the soil conditions in the marine environment (silt or sand) support deep penetration of munitions and, in many cases, lateral movement of the items. For this reason, the geophysical sensors must be near the bottom of the water to detect deep into the sediments. A positioning system located on a surface platform (i.e., marine vessel) must project the location of the detector. This is performed by remote communication between the sensor and the positioning instrument. This accurate position is mandatory due to the cost of location identification and recovery of suspect anomalies in the marine environment. Recovery of MEC in the marine environment also should be performed soon after geophysical data acquisition to avoid vertical and horizontal migration of the MEC.

3.1.2.3.1 Examples of some of the more common sensor technologies and data acquisition platforms are provided in Appendix B to exhibit the large variety in sensor technology as well as deployment options. The specific sensor technology and data acquisition platform should be assessed in terms of it's overall effectiveness and implementability at a project site in terms of the terrain, vegetation, geology and soils, man-made features, weather, weight and power requirements, and equipment availability and safety.

3.2 SENSOR TECHNOLOGIES

3.2.1 Magnetometry

The earth has a naturally occurring geomagnetic field created by circulation of electrical currents in the plasma outside of the earth's core. The geomagnetic field strength (intensity), declination, and inclination vary with respect to latitude and longitude; the intensity at the poles is about twice that in the equatorial regions. Magnetic sensors are passive (i.e., they utilize the geomagnetic field as their source of energy) and designed to measure localized distortions in the earth's geomagnetic field created by objects and features that have contrasts in magnetic properties (susceptibility or permeability) with the surrounding materials. *Objects made of steel and iron are usually termed "ferrous" and create relatively large distortions in the local geomagnetic field compared to other metallic materials. In general, metals such as brass, aluminum, and some types of stainless steel are considered non-magnetic.*

3.2.1.0.1 The intensity and direction of the signal measured by the magnetic sensor depends on the specific sensor technology and design, distance and direction from the object, and the ferrous mass of the object. In general, the magnetic field strength associated with a ferrous object-diminishes inversely as the cube with respect to the distance from the magnetic sensor. For example, the intensity decreases by a factor of four to eight when the distance between the sensor and object is doubled. However, in general magnetic sensors that measure the total intensity of the geomagnetic field have the ability to detect a given ferrous object at greater distances than electromagnetic sensor technologies. This characteristic is superior for detection but a limiting factor in areas of increased man-made features.

3.2.1.0.2 Magnetic sensor manufacturers utilize a variety of engineering technologies (e.g., fluxgate, proton precession, Overhauser, atomic vapor) to measure the total geomagnetic intensity or specific components (i.e., horizontal, vertical) of the geomagnetic field. Some technology designs incorporate the use of two or more sensors separated in a horizontal or vertical fashion by a constant distance; this design is often refereed to as a "gradiometer". In general, gradiometers delineate complex anomalies (i.e., anomalies created by numerous closely-spaced ferrous items) into their individual constituents more readily than magnetic designs that utilize only a single sensor. *However, the intensity measured by a gradiometer diminishes as the inverse of the 4th power with respect to distance, which sometimes limits its ability to detect deeper objects.*

3.2.1.0.3 The geomagnetic field intensity changes each day in a generally predictable fashion termed a diurnal cycle. Since the geomagnetic field is constantly changing, a reference magnetic sensor is usually positioned near the survey area to record these data so they can be removed from the data collected with the "roving" magnetic sensor used to identify ferrous items. Depending upon the specific magnetic sensor design used (i.e., gradiometer) and the project objectives, it is sometimes not necessary to utilize a reference station. However, when a single sensor (not gradiometer) is employed without a reference station, the data can be rendered useless in times of increased solar activity (e.g., magnetic storms).

3.2.1.0.4 Since the magnetic sensor system is passive, it measures the magnetic field intensity from all sources. Soils and rocks that have increased magnetic susceptibilities (e.g., those that contain elevated amounts of magnetite, maghaemite, etc.) act as a magnetic source and create a degree of "noise" in the magnetic measurements. *This "noise" from the soil and / or rocks can sometimes severely degrade the reliability of the data and lead to higher false alarm rates. Therefore, it is imperative that the project site is assessed in terms of the magnetism of the soils and rocks in the area.* In addition, the presence of ferrous man-made features (buildings, power lines -, tow vehicles, helicopters, boats, utilities, vehicles, fences, etc.) can also limit the overall quality of the magnetic data.

3.2.1.0.5 It is usually desirable to arrange the data acquisition tracks in the direction of magnetic north for most magnetic sensor technologies in order to ensure the measurement of the highest intensity of the magnetic anomaly. As the distance between adjacent data tracks decreases, or the ferrous mass of the object sought increases, this procedure becomes less significant.

3.2.1.0.6 Digitally recorded data require processing prior to be interpreted. Common processing procedures included reference station correction, spike removal, removal of the magnetic field contribution due to geology, and removal of bias and sensor equalization for systems where multiple sensors are used. Magnetic data that are digitally recorded and analyzed can provide information on the declination, inclination, and strength (magnetic moment) of the enhanced magnetic field resulting from a ferrous object. These data are often used to infer the relative size or mass of the ferrous object, and can also be used to estimate induced and permanent magnetization characteristics of the magnetic anomaly. In some case studies and research, it has been noted that medium and large MEC items at some sites have a higher contribution from induced magnetism; therefore, this factor could be used as a potential discriminator for these objects. *A somewhat limiting factor is that magnetic anomalies are usually "dipolar" in nature (as opposed to some electromagnetic measurements, which are "unipolar"), meaning that they consist of two signal components over an individual object; this attribute can be a detriment during interpretation in areas of increased anomaly density and clutter.*

3.2.1.1 Flux-Gate Magnetometers

3.2.1.1.1 Description

Almost all flux-gate magnetometers measure the vertical component of the geomagnetic field along the axis of the sensor, and not the total intensity of the geomagnetic field. Two flux-gate sensors separated vertically by 0.5 m (gradiometer) are commonly employed to negate some of the non-optimum characteristics inherent to flux gate sensors (e.g., misalignment of the sensor). Each sensor is constructed of a high permeability magnetic metal, and an alternating current is passed through wire wound around each sensor. The metal fluctuates between magnetic saturation and no saturation; during the periods of no saturation the external geomagnetic field is measured and a signal is recorded by the electronics, or an audible signal is created. *This entire* *process occurs in .001 seconds, which allows the geomagnetic field to be measured in an almost continuous mode.*

- Effectiveness: Flux-gate systems are currently being used on a wide scale for MEC and similar applications. This detection technology can achieve a high level of effectiveness when used as a geophysical instrument collecting digital data for processing and analysis. As an analog detector, its effectiveness may be limited based on the experience and skill of the operator. Sensitivity of most flux gate gradiometers is on the order to 0.1-0.3 nanoteslas (nT), which is very close to other magnetic sensor technologies. *Due to gradiometer design, is most adept at detecting smaller, shallow items as opposed to relatively large, deeper items*.
- Implementability: Costs, transportation and logistics requirements are equal to or less than other systems. Analog versions (e.g., Schonstedt, Magnatrak) used for MEC investigations most often in “sweep” mode (“mag and flag”) and during surface clearances *due to its continuous ability to measure the geomagnetic field, operational reliability in almost all weather conditions, simplistic operation, low maintenance, and low cost*. Available from several manufacturers and numerous vendors in a variety of models and configurations. Versions are available from several manufacturers (Geoscan, Foerster, Vallon) that allow the geomagnetic field to be digitally recorded at rates of 10-30 Hz and stored for processing and analysis; these digital models are much more expensive than the analog models from manufacturers such as Schonstedt and Chicago Steel and Tape.

3.2.1.1.2 Applicability and Strengths

These magnetometers are commonly used to sweep areas suspected MEC areas for surface clearance and/or “mag and flag” operations. They are relatively inexpensive, durable and easy to acquire and use.

3.2.1.1.2.1 Flux-gate magnetometers have land based, marine and airborne applications and can be used in various configurations and in numbers as sensor arrays. In general, they also have the ability to detect ferrous items to a greater depths than is achieved using some other detection methods. Flux gate detectors are for the most part rugged, portable and applicable for use in various terrain and vegetation.

3.2.1.1.3 Limitations and Weaknesses

Flux-gate magnetometers can be susceptible to magnetic noise from geology and soils with increased magnetism. The effectiveness of magnetometers can be influenced by interference from magnetic minerals or other ferrous objects in the soil or nearby on the surface, leading to higher false alarm rates. Some of these instruments have the ability to digitally record sensor data. Magnetometers have more difficulty than some other sensors in determining the locations of individual ferrous objects within a cluster (i.e. small area of high anomaly density).

3.2.1.1.4 Special Considerations

Flux-gate magnetometers are used for land-based and marine applications and can be used in various configurations and numbers in sensor arrays. Marine acquisition platforms require careful thought to the unique factors in the marine environment such as tides, subsurface water currents, relationship of array width to seafloor topographic variations, and ensuring the equipment is designed to be used underwater and sealed appropriately.

3.2.1.1.5 Relative Cost

A number of the Flux-Gate Magnetometers have a low cost for purchase and operation compared to other MEC detection systems. Units that acquire digital data are more costly than analog units.

3.2.1.2 Proton Precession Magnetometers

3.2.1.2.1 Description

Proton precession magnetometers measure the total intensity of the geomagnetic field, and multiple sensors are sometimes arranged in close proximity to measure horizontal and vertical gradients of the geomagnetic field. The sensor technology operates by using a hydrogen-rich liquid surrounded by a coil winding. When the coil is energized with a small current, the protons are aligned, and when the current is removed the protons precess about the geomagnetic field direction at a characteristic frequency; this frequency is directly related to the intensity of the geomagnetic field at that point. *The time required to perform these functions is on the order of 0.5 to 1 second, therefore, the sampling rate (approximately 1 Hz) for this sensor technology is much lower than that of flux gate and atomic vapor technologies.*

- Effectiveness: Systems have similar sensitivities as flux-gate systems, although they are limited in terms of their sampling rate (approximately 1 Hz). Sensitivity is on the order of 0.1-0.5 nT, however, the sampling rate is relatively slow (1Hz), so productivity can be limited in most investigations when compared to other sensor technologies.
- Implementability: Systems are similar to flux-gate systems in terms of operations and support; however, they are limited in terms of their sampling rate. Implementation compared to other methods is moderate when site conditions are conducive to a magnetic survey. *Due to sample rate limitations, this sensor technology is best-suited for use as a reference magnetometer if one is necessary*. Most equipment manufacturer systems are digital, ruggedized and weatherproof. They are generally heavier and require more battery power than flux gate sensors. Sensor technology is available from several manufacturers in the USA and Canada.

3.2.1.2.2 Applicability and Strengths

Although these units can be used as a detection tool, they are primarily used as base stations for monitoring diurnal variations in the Earth's magnetic field. Proton precession magnetometers may be slightly more sensitive than some flux-gate magnetometers.

3.2.1.2.3 Limitations and Weaknesses

Proton precession magnetometers are especially susceptible to noise from near by power sources. The effectiveness of magnetometers can also be influenced by interference from magnetic minerals or other ferrous objects in the soil or nearby surface, leading to higher false alarm rates. Proton precession magnetometers have relatively slow data collection rates. Magnetometers have more difficulty than some other sensors in determining the locations of individual ferrous objects within a cluster (i.e. small area of high anomaly density).

3.2.1.2.4 Special Considerations

Proton precession magnetometers require specialized training to operate and interpret data. Proton precession magnetometers are used often in marine applications as a single sensor and in multiple sensor arrays due to the logistics of surveying in the marine environment (i.e., system used to find larger objects at heights above the seafloor of at least several meters or tens of meters; at these heights the anomaly width from large objects is broad and can be effectively measured at decreased sample rates). Marine acquisition platforms require careful thought to the unique factors in the marine environment such as tides, subsurface water currents, relationship of array width to seafloor topographic variations, and ensuring the equipment is designed to be used underwater and sealed appropriately.

3.2.1.2.5 Relative Cost

The Proton precession magnetometers have a higher purchase and operating cost than most analog flux-gate systems.

3.2.1.3 Overhauser Magnetometers

3.2.1.3.1 Description

Overhauser magnetometers measure the total intensity of the geomagnetic field, and multiple sensors are sometimes arranged in close proximity to measure horizontal and vertical gradients of the geomagnetic field. The sensor technology operates in a very similar manner to proton precession technology; however, electrons are added to the hydrogen-rich liquid and polarized with radio frequency (RF) instead of direct current. The added electrons enhance the signal strength, and the use of RF reduces the time required to measure the precession of the protons down to several tens of milliseconds. This design feature permits sampling rates of up to 5Hz.

- Effectiveness: Sensitivity is on the order of 0.02, which is almost equal to that of the most sensitive magnetic technology (atomic vapor). Sampling rates of several hertz are possible; therefore the technology is applicable to man portable or marine data acquisition where the sensor velocity does not exceed approximately 3 to 4 feet per second. *Overhauser technology is not susceptible to "heading error" as is the case with atomic vapor magnetic technology.* Heading error is defined as changes in the measured magnetic field intensity based on the direction of travel and orientation of the sensor.

- Implementability: Equipment is digital, ruggedized, and weatherproof. Common Overhauser systems weigh more than most flux gate systems; however, they are the most efficient magnetic sensor technology in terms of the power required for operation. Availability is somewhat limited, as there are only two manufacturers of the systems; one specializes in land-based systems and the other marine; both are located in Canada.

3.2.1.3.2 Applicability and Strengths

Overhauser magnetometers are primarily used for land based and marine applications and can be used in various configurations and in numbers as sensor arrays. They are rugged, portable, and applicable for use in various terrain and vegetation.

3.2.1.3.3 Limitations and Weaknesses

Overhauser magnetometers can be susceptible to magnetic noise from geology and soils with increased magnetism. The effectiveness of magnetometers can be influenced by interference from magnetic minerals or other ferrous objects in the soil or nearby on the surface; leading to higher false alarm rates. Magnetometers have more difficulty than some other sensors in determining the locations of individual ferrous objects within a cluster (i.e. small area of high anomaly density).

3.2.1.3.4 Special Considerations

Operators and data analysts require specialized training to operate and interpret data. Overhauser magnetometers are used in marine applications as a single sensor and in multiple sensor arrays due to the logistics of surveying in the marine environment (i.e., system used to find larger objects at heights above the seafloor of at least several meters or tens of meters; at these heights the anomaly width from large objects is broad and can be effectively measured at decreased sample rates). Marine acquisition platforms require careful thought to the unique factors in the marine environment such as tides, subsurface water currents, relationship of array width to seafloor topographic variations, and ensuring the equipment is designed to be used underwater or sealed appropriately.

3.2.1.3.5 Relative Cost

Overhauser magnetometers have a higher purchase and operating cost than most analog flux-gate systems and proton precession technology.

3.2.1.4 Atomic-Vapor Magnetometers

3.2.1.4.1 Description

Atomic Vapor technology is based on the theory of optical pumping, and operates at the atomic level as opposed to the nuclear level as in proton precession magnetometers. Instead of using a current for polarization, light is used to excite certain elements (cesium, rubidium, potassium) and measure the resultant energy levels that are related to the strength of the geomagnetic field. Atomic vapor magnetometers are very sensitive (.01 nT) due to the high frequency of precession of the elements about the geomagnetic field.

- Effectiveness: These sensors generally have the highest sensitivity of the magnetic sensors discussed. They are commonly used in land based, marine and airborne applications and can be used in various configurations; several detectors can be used together in sensor arrays.
- Implementability: Equipment is digital, ruggedized, and weatherproof. Common systems weigh more than most flux gate systems; and they have increased power requirements compared to other magnetic sensor technology. Atomic vapor technology is also affected by "heading error", which is defined as changes in the measured magnetic field intensity based on the direction of travel and orientation of the sensor.

3.2.1.4.2 Applicability and Strengths

Atomic-vapor magnetometers are one of the most common magnetic sensors used during the digital geophysical mapping (DGM) phase of MEC projects. Atomic-vapor magnetometers are more sensitive than both proton precession and flux-gate magnetometers, and have the capability to digitally record data at high sample rates (generally 10-100 Hz and greater).

3.2.1.4.3 Limitations and Weaknesses

Atomic-vapor magnetometers may not precisely record magnetic activity in all directions, leading to the possibility of "dropouts" (loss of signal) in the collected data. Dropouts can be minimized by proper orientation of the sensors in the earth's field (refer to the instrument manufacturer's equipment manual). The technology is also affected by "heading error".

3.2.1.4.4 Special Considerations

Operators and data analysts require specialized training to operate and interpret data. Proper sensor orientation is mandatory to avoid "dropouts", and pre-project tests should be performed to minimize the effects of "heading error" in the processed data.

3.2.1.4.5 Relative Cost

Atomic-vapor magnetometers have a relatively high purchase cost compared to the other magnetic sensor technologies discussed.

3.2.2 Electromagnetics

Electromagnetic Induction (EMI) is a geophysical technology used to induce a magnetic field beneath the Earth's surface with a transmitter coil, which in turn causes a secondary magnetic field to emanate from nearby objects that have conductive properties. The secondary magnetic field is measured by a receiver coil and that information is used to detect buried metallic objects. The size, shape, depth, material properties, and orientation of the object influence the signal measured by the receiver coil, as well as the geometric relationship between the transmitter and metal object. *Because the transmitter can excite the metal object from different directions, it is better than magnetic sensor technology at providing information on the shape of the object (Bell, 2005). Other benefits of EMI technology include 1) the ability to detect all metals (as opposed to magnetometers, which only respond to ferrous metal, i.e., EMI responds to ferrous and nonferrous MEC); 2)they are generally not affected by magnetic soils and cultural features to the degree that magnetometers are; 3) most sensor designs specifically manufactured to detect small metal objects are better than magnetometers at delineating complex anomalies into their individual constituents, and 4) most systems have the ability to record measurements at different frequencies (or at different times after the current is turned off for time domain systems), which can provide additional information on the material properties of the object*. The two basic types of EMI methods are frequency-domain EMI and time-domain EMI.

3.2.2.1 Time-Domain Electromagnetic Induction

3.2.2.1.1 Description

Time Domain Electromagnetic Induction (TDEMI) is a technology used to induce a pulsed magnetic field beneath the Earth's surface with a transmitter coil, which in turn causes a secondary magnetic field to emanate from nearby objects that have conductive properties. When the pulsed primary field is off, the secondary magnetic field decays and is measured by a receiver coil. The size, shape, depth, and orientation of the object, and size, shape and geometric relationship between the transmitter and receiver coil determine the strength of the signal measured by the receiver coil. Because of this transmitter-receiver relationship, there can be significant differences in the response of particular TDEMI systems to the size and orientation of metal objects, especially those that are representative of smaller MEC (e.g. 20mm to 37mm projectiles).

- Effectiveness: TDEMI sensors specifically developed to detect small metal objects are routinely used in MEC investigations due to the benefits discussed in Paragraph 3.2.2. They are commonly used in land-based applications and to a much lesser degree in marine and airborne surveys due to increased system limitations in these environments. They are used in various configurations; several detectors can be used together in arrays.
- Implementability: Most equipment is portable and ruggedized for use in various terrain and weather conditions. Some systems used for DGM are heavier and consume more power than magnetometers.

3.2.2.1.2 Applicability and Strengths

TDEMI sensors are one of the most common sensors used during the DGM phase of MEC projects; handheld sensors (i.e., common analog metal detectors, also known as "pulse induction" units) are also used for mag and flag operations. TDEMI systems can detect both ferrous and nonferrous MEC. TDEMI sensor systems can be used in various configurations and several detectors can be used together as sensor arrays. The signal from TDEMI detectors decreases with distance much more rapidly compared to magnetometers, therefore, in general they are better suited for use in areas where there are abundant above ground metal objects and features (i.e., sources cultural interference).

3.2.2.1.2.1 The capability of TDEMI systems to energize buried objects from different orientations and digitally capture sensor data is a distinct advantage in that signature responses of various MEC types can be further evaluated to provide valuable information pertinent to discrimination efforts. Time-domain EMI metal detectors can also be used in conjunction with magnetometers to simultaneously collect EMI and magnetic data allowing for potentially further advancements in MEC discrimination. When the emitted pulses of several time-domain EMI metal detectors are synchronized they may be used in numbers as an array to increase production rates of geophysical data acquisition. Handheld TDEMI detectors are generally ergonomic, rugged, and can be "programmed" to reduce sensitivity to certain types of metals and soil magnetism.

3.2.2.1.3 Limitations and Weaknesses

The signal from TDEMI detectors decreases much more rapidly compared to magnetometers, therefore, they have a reduced sensitivity to some relatively deeper MEC objects. Depending upon the sensor, system design, and data acquisition platform, some TDEMI detectors are susceptible to elevated levels of "noise" associated with detector motion and changes in elevation above the ground surface. The system measurements can also "drift" from a pre-defined baseline value, and this aspect of the system should be accounted for in data processing.

3.2.2.1.4 Special Considerations

TDEMI handheld metal detector operators require specific training, and DGM data processors and analysts require training to effectively utilize the full capability of the instruments and measured data.

3.2.2.1.5 Relative Cost

Common analog metal detectors are comparable in cost to analog fluxgate magnetometers. Digital TDEMI systems are generally comparable in cost to Overhauser and Atomic Vapor magnetometers.

3.2.2.2 Frequency-Domain Electromagnetic Induction

3.2.2.2.1 Description

Frequency-Domain (FDEMI) sensors generate one or more defined frequencies in a continuous mode of operation. Depending upon the transmitter and receiver separation, geometry, and frequencies used, the units can be used to obtain information about the variations in conductivity (or resistivity), as well as infer the presence, material properties, and shape of metal objects.

- Effectiveness: Most FDEMI detectors used for MEC investigations are handheld analog units used for mag and flag operations. They are sensitive and adept at detecting smaller items at relatively shallow depths. Some larger scale FDEMI systems are used as part of footprint reduction efforts via airborne platforms. They are used in various configurations; several detectors can be used together in sensor arrays for land-based surveys.
- Implementability: Most handheld equipment is portable and ruggedized for use in various terrain and weather conditions. Systems designed for DGM are generally directly comparable to the TDEMI systems designed for DGM in terms of portability, ruggedness, and reliability in adverse weather conditions. The handheld units are generally light, compact, and ergonomic.

3.2.2.2.2 Applicability and Strengths

Frequency-Domain handheld metal detectors are commonly used for "mag and flag" operations due to their sensitivity, portability, and ability to be programmed to eliminate responses from certain types of metal and magnetic soils. FDEMI detectors designed to detect small metal objects and that have the ability to record digital data possess similar detection capabilities to those TDEMI systems use for DGM. FDEMI systems designed for DGM can capture data at different frequencies, which may provide valuable information that is pertinent to discrimination efforts

3.2.2.2.3 Limitations and Weaknesses

Some systems require more advanced experience for data processing. System electronics can "drift" based on changes in temperature, and the background signal can change abruptly based on slight differences in the distance between the transmitter and receiver coils (e.g., system electronics jarred by bumping into a tree).

3.2.2.2.4 Special Considerations

FDEMI handheld metal detector operators require specific training, and DGM data processors and analysts require advanced training to effectively utilize the full capability of the instruments and measured data.

3.2.2.2.5 Relative Cost

Common analog metal detectors are comparable in cost to analog fluxgate magnetometers. Digital FDEMI systems are generally comparable in cost to Overhauser and Atomic Vapor magnetometers.

3.2.2.3 Ground Penetrating Radar (GPR)

3.2.2.3.1 Description

Ground Penetrating Radar works by propagating electromagnetic waves into the ground via an antenna. These transmitted signals are reflected by objects and features that possess contrasts in electrical properties with the surrounding medium. This reflected energy is continuously recorded by a receiver antenna. Typically, GPR antennas are available to operate in different transmission frequencies from the gigahertz range for extremely shallow targets to the megahertz range for greater ground penetration depths. In the case of MEC detection, the amount of energy reflected depends on the MEC item's size, shape, distance and orientation with respect to the transmitting antenna, as well as the magnetic, conductive, and dielectric properties of the surrounding soil and the coupling of the antenna to the ground surface. *Because the electrical properties of the soil and the "micro-topography" of the terrain can influence the measurements to a very high degree, the use of GPR for MEC investigations should only be considered after a thorough evaluation of the environmental and electrical properties of the soils in the survey area*.

- Effectiveness: Extremely sensitive systems that respond to changes in the magnetic, conductive, and dielectric properties of the subsurface (i.e., the system detects a large variety of metallic and non-metallic items and naturally occurring features, as well as changes in soil moisture content and compaction). Measurements are frequency dependent, and signal penetration depths can vary from several hundred meters in ice to less than 0.5 meters in soils where certain mineralogical clays are present. GPR energy does not pass through metal. GPR antennas can be used in fresh water; however, they are not effective in saline water.
- Implementability: In general, most man portable systems are cumbersome to operate in areas of varying terrain with thick and diverse near surface vegetation. Most equipment is ruggedized and created for use in adverse weather conditions. Some antennas are unshielded and radiate energy in all directions; therefore, reflections are apparent in the data from above ground features (e.g., tree branches, power lines, vehicles, etc.). Power requirements are higher than most magnetometer and EMI systems

3.2.2.3.2 Applicability and Strengths

GPR systems can detect both metallic and nonmetallic objects yet are very sensitive to soil composition, type, and subsurface structure. GPR works best in areas of coarse grained resistive soils with low mineralogical clay content and sparse ground vegetation. For the detection of MEC, GPR is not often used as a stand-alone technology but is used as part of a multisensor system in conjunction with EMI or magnetic sensors.

3.2.2.3.3 Limitations and Weaknesses

GPR waves do not penetrate satisfactorily in soils characterized by increased conductivity (e.g., most clay-rich soils with elevated moisture content). GPR waves do not pass through metal. Most sensors are adversely affected by topographical changes (micro topography), as well as dense and uneven ground vegetation. GPR is usually more difficult to implement on the majority of MEC sites due to the limitations discussed. The instruments are usually bulky and more difficult to operate in rough terrain compared to man portable magnetometer and EMI systems deployed on effective data acquisition platforms. Data acquisition, processing, analysis, and interpretation of GPR data is relatively much more complex and time consuming in comparison to magnetic and EMI systems.

3.2.2.3.4 Special Considerations

GPR systems require relatively skilled operators. Data processors/interpreters are required that possess advanced GPR-specific knowledge in order to realize the full potential of the technology.

3.2.2.3.5 Relative Cost

GPR systems are approximately 1.5-2 times the cost of comparable magnetometer and EMI systems used for DGM.

3.2.2.4 Airborne Synthetic Aperture Radar (SAR)

3.2.2.4.1 Description

SAR is a technology applicable to the detection of MEC via airborne data acquisition platforms. Typical radar measures the strength and round-trip time of the microwave signals that are emitted by a radar antenna and reflected off a distant surface or object. The radar antenna alternately transmits and receives pulses at particular microwave wavelengths and polarizations. The pulse covers a band of frequencies centered on the frequency selected for the radar. At the Earth's surface, the energy in the radar pulse is scattered in all directions, with some energy reflected back toward the antenna. The reflected echo (backscatter) returns to the radar as a weaker radar echo and is then received by the antenna in a specific polarization. These echoes are converted to digital data and recorded for later processing and image display. In the case of imaging radar, the radar moves along a flight path and the area illuminated by the radar is moved along the surface in a swath, building the image as it does so. The chosen pulse bandwidth determines the resolution in the range (cross-track) direction. The speed of the aircraft and length of the radar antenna determines the resolution in the azimuth (along-track) direction. So, higher bandwidths translate to finer resolution in the cross-track direction and longer antennas translate to finer resolution in the along-track direction. SAR refers to a technique used to synthesize a very long antenna by combining reflected echo signals received by the radar as it moves along the flight track. Aperture refers to the opening used to collect the reflected energy that is needed to form an image. A synthetic aperture is constructed by moving a real aperture or antenna through multiple positions along the flight track.

- Effectiveness: Designed for footprint reduction as opposed to detailed MEC detection.
- Implementability: Requires aircraft platform, increased power, and robust data recording systems. The methods and equipment are relatively more complex to implement due to the nature of data acquisition.

3.2.2.4.2 Applicability and Strengths

SAR technology demonstrates some applicability for the detection of MEC in that this technology is capable of detecting large MEC and covering large amounts of area in a relatively short time period on airborne platforms. SAR may be effective for the detection of large, very near surface MEC items but ineffective in detecting MEC buried at depth. SAR technology may be useful in broad scale characterization of MEC sites. Because the radar wavelengths are much longer than those of visible or infrared light, SARs can penetrate through cloudy and dusty conditions that visible and infrared instruments cannot.

3.2.2.4.3 Limitations and Weaknesses

Because the application of SAR technology for MEC detection is considered to still be in developmental stages (R&D technology), and because of relatively high equipment costs, this technology is not frequently used at MEC sites. SAR imagery-based systems do not detect small or deeper subsurface MEC. Initial testing of SAR systems also indicates significant limitations due to variances in ground conductivity. Data processing and analysis of SAR data is relatively complex in comparison to Magnetic and EMI systems.

3.2.2.4.4 Special Considerations

SAR systems require very experienced operators and involve fairly complex data processing routines.

3.2.2.4.5 Relative Cost

SAR applications are among the highest cost options due to use of aircraft and high costs of detection equipment. This high equipment cost is partially mitigated by the increased production rates possible, often in the range of several hundred acres per day.

3.2.2.5 Sub Audio Magnetics (SAM)

3.2.2.5.1 Description

SAM is a patented methodology by which a total field magnetic sensor is used to simultaneously acquire both magnetic and electromagnetic response of subsurface MEC. A cable is first placed in a large loop surrounding the area to be searched (which may be several acres in size). A time-varying current is then transmitted at a sub-audio frequency of up to 32 hertz. The total field magnetic measurements are acquired at a rate of up to 8 kilohertz while systematically traversing the area within the loop.

3.2.2.5.1.1 SAM technology is a relatively new technology and has not been utilized widely at MEC sites. SAM has the potential, however, to enhance the individual detection performance of both magnetics and electromagnetics due to the design of the system. With SAM technology, each of several electrical and magnetic properties of the ground may be simultaneously measured with one instrument and these data can potentially be used to detect and effectively discriminate MEC items.

- Effectiveness: SAM technology detects both ferrous and non-ferrous metallic objects and is a good tool for detection of shallow and deep MEC.
- Implementability: compared SAM technology has high data processing requirements and is available from one source. The system also has high power requirements and relatively long setup times.

3.2.2.5.2 Applicability and Strengths

SAM technology has potential for supporting discrimination processes and also has the ability to detect shallow and deep MEC. Due to the nature of the setup, the system is most ideal in open areas.

3.2.2.5.3 Limitations and Weaknesses

The disadvantages of SAM based systems are that they are not in abundant supply and that they require a lengthened amount of setup time to utilize effectively even with experienced operators. These systems are relatively expensive and have high power requirements. Furthermore, these systems require advanced processing procedures.

3.2.2.5.4 Special Considerations

SAM technology is not commercially available and at this point tin time does not have a documented track record on numerous MEC projects.

3.2.2.5.5 Relative Cost

The relative cost compared to other methods is high, partially due to the limited availability.

3.2.3 Magnetometer-Electromagnetic Detection Dual Sensor Systems

3.2.3.1 Description

Recent discoveries indicate that it is possible to combine both magnetic and electromagnetic induction sensors into a single unit allowing for potential improvements in MEC discrimination performance. These dual sensor systems are expected to be effective in detecting all types of MEC as magnetometers respond to large deep ferrous targets and EMI sensors respond to non-ferrous metallic targets. The notion is to use target orientation estimates from the EMI data to improve target size estimates from the magnetic data and use the depth estimates from the magnetic data to improve classification.

3.2.3.1.1 This technology exhibits some benefits for enhancing MEC discrimination techniques. Dual Mag-EM sensor systems have land based, marine and airborne applications and could be used in various configurations and in numbers as sensor arrays. These systems currently are in developmental stages as only a few dual magnetic–EMI systems are available for use at MEC sites.

- Effectiveness: These systems detect both ferrous and non-ferrous metallic objects and have potential for increased levels of discrimination.
- Implementability: Data processing requires more extensive time and more experienced personnel. These systems are available from few sources.

3.2.3.2 Applicability and Strengths

Magnetometer-Electromagnetic Detection Dual Sensor Systems technology has potential for increased levels of discrimination.

3.2.3.3 Limitations and Weaknesses

There are challenges associated with the integration of the two technologies regarding noise and synchronization issues, however, several companies have developed designs where these issues are addressed and the resulting data are not adversely affected. The technology is currently limited to towed array configurations, therefore, it is applicable for projects where the objective and environmental characteristics (e.g., terrain, vegetation) support the use of towed sensor arrays.

3.2.3.4 Special Considerations

Magnetometer-Electromagnetic Detection Dual Sensor Systems are still under development and are only available from one or two sources.

3.2.3.5 Relative Cost

The relative cost compared to other methods is somewhat higher due to the use of both technologies and the data processing and interpretation effort.

3.2.4 Marine Side-Scan Sonar

3.2.4.1 Description

Side-scan sonar technology is associated with marine-based systems. Side-scan sonar technology uses acoustic (i.e., sound) waves to locate objects and record water bottom structure in a swath on one or both sides of its sensors. This is similar to a radar system in that sonar uses sound echoes instead of electromagnetic pulses. A side scan sonar transmits sound energy from a "towfish" and analyzes the return signal that has bounced off the water body floor or other objects lying upon the water body floor. In a side scan, the transmitted energy is formed into the shape of a fan that sweeps the water body floor from directly under the "towfish" to either side. The strength of the return echo is continuously recorded by a transducer creating an image of the water body floor. This technology has applicability for the detection of MEC in marine type environments in that it demonstrates the capability to detect larger MEC items on a water body floor. Also, in open calm waters, large coverage areas are attainable within a relatively small time frame.

- Effectiveness: Side-scan sonar produces a photo-like image of the sea floor; it does not detect objects below the sea floor. The resulting "mosaic" shows the shape and location of objects and features of the sea floor. There is a low industry familiarization with Side Scan sonar method for MEC detection.
- Implementability: The system requires a trained operator and experienced field crew. Vegetation in the water column near the "towfish" can hinder acoustic signal propagation.

3.2.4.2 Applicability and Strengths

This technology has applicability for the detection of MEC in marine type environments in that it demonstrates the capability to detect larger MEC items on a water body floor. Also, in open calm waters, large coverage areas are attainable within a relatively small time frame.

3.2.4.3 Limitations and Weaknesses

Unlike magnetic methods or electromagnetic methods, Side-Scan sonar images cannot differentiate between metallic and non- metallic objects. For this reason, MEC recovery based solely on Side Scan sonar data may result in the recovery of non-metallic objects such as sticks, rocks and other forms of non-metallic debris. Additionally, the system only detects items on sea floor. It is anticipated that most underwater MEC would be buried under a layer of silt. Side scan sonar technology cannot supply depth information nor detect MEC beneath the water body floor. Again, as with most acoustic technologies, side scan sonar technology has applicability in characterizing MEC anomalies at marine sites if MEC exists on the sea floor.

3.2.4.4 Special Considerations

Few have applied these technologies towards MEC detection.

3.2.4.5 Relative Cost

The cost for less expensive digital side-scan sonar systems is comparable to some atomic vapor magnetometers and digital TDEMI equipment. Most systems are 2-10 times the cost of a magnetometer or EMI system used for DGM.

3.2.5 Airborne Multispectral/Hyperspectral Imaging System

3.2.5.1 Description

This airborne method utilizes unique spectral signatures produced by an item to determine the item composition and size. Multispectral techniques can be used since they provide more information than images from common broadband cameras. The multispectral systems themselves operate over several wavelength bands, e.g. from ultraviolet to visible and thermal infrared (0.2-14 mm).

- Effectiveness: The system detects both metallic and non-metallic objects and the objects must be fairly large (81mm or greater). The system requires line of sight (on the surface) and has a low industry familiarization. Effectiveness increases when used for wide area assessment in conjunction with other airborne technologies.
- Implementability: Requires aircraft and an experienced pilot, substantial data processing and management requirements and is available from only a few sources.

3.2.5.2 Applicability and Strengths

The only notable strength to this technology is the amount of data that can be collected in a relatively short period of time due to the aircraft platform.

3.2.5.3 Limitations and Weaknesses

Very expensive equipment requirements and typically does not detect MEC very effectively.

3.2.5.4 Special Considerations

Use of this technology requires aircraft.

3.2.5.5 Relative Cost

Airborne Multispectral/Hyperspectral Imaging Systems are relatively very expensive to purchase and operate, but rapid area coverage results in relatively small cost per unit area

3.2.6 Airborne Laser and Infrared Sensors

3.2.6.1 Description

Infrared (IR) and laser sensor technologies can be used to identify objects by measuring their thermal energy signatures. MEC on or near the soil surface may possess a different heat capacity or heat transfer properties than the surrounding soil, and this temperature difference can theoretically be detected and used to identify MEC. For IR and laser sensor technologies to produce results useful for detecting MEC, a sharp thermal contrast must exist between the MEC and its surroundings (usually the soil surface). IR and laser sensor technology results also depend on the type and density of vegetation present, weather conditions, time of day (thermal loading and gradient), and specific size and properties of the MEC. In practice, IR and laser sensor technologies can only detect MEC located on a vegetated soil surface.

- Effectiveness: These systems detect both metallic and non-metallic objects and have a low industry familiarization. Effectiveness increases when used for wide area assessment in conjunction with other airborne technologies.
- Implementability: System requires aircraft and an experienced pilot. There are substantial data processing and management requirements associated with these methods.

3.2.6.2 Applicability and Strengths

There are no notable strengths associated with use of this method for MEC detection.

3.2.6.3 Limitations and Weaknesses

Very expensive methodology and typically does not detect MEC very well. This method is also limited due to the difficulty associated with an aircraft platform.

3.2.6.4 Special Considerations

Few have applied these technologies towards MEC detection. Aircraft is required.

3.2.6.5 Relative Cost

Airborne Laser and Infrared Sensor technologies are very expensive to purchase and operate but rapid area coverage results in a relatively low cost per unit area.

3.3 SUPPORTING TECHNOLOGY OPTIONS

To accurately evaluate and select a particular detection technology, it is important that the characteristics of candidate technologies are conducive to use at the project site. For example, a number of methodologies are not applicable in rough terrain and some positioning systems do not work well in wooded areas. For this reason it is necessary to evaluate the conditions at the site prior to selecting the detection technology. Some of the factors to consider are terrain, vegetation, obstructions (trees, rocks etc.), water (is there standing water?), geology, soil types, accessibility (for towed arrays), and expected MEC (size, depth and fuzing).

3.3.1 Site Preparation

Effective, efficient, and safe investigation of a MEC site requires that the site be easily and safely accessible to the field teams operating the detection systems. This is generally accomplished with a combination of vegetation removal and surface clearance of MEC and other residual metals.

3.3.1.1 The data collection teams need to be able to freely traverse the site, covering as much of the area as possible, at a reasonable speed, and in the safest manner possible. To affect this, brush removal is performed to the extent necessary to satisfy the data collection objectives. Removal focuses on removing brush and small trees that block the path of the instrument, removal of low hanging limbs that may interfere with positioning, and removal of brush to within several inches of the ground to allow for visual observation of the ground surface as well as permit unhindered movement of the collection team.

3.3.1.2 Surface clearance of all metal objects is required to make the area safe for the collection teams to traverse the site and to improve the quality of collected data. If brush removal is performed, surface clearance is performed prior to brush clearance for safety purposes. Surface clearance has two objectives. The first is removal of dangerous MEC items. The second is the removal of all MEC related scrap and other metallic debris that can mask subsurface anomalies and thus interfere with the effectiveness of the subsurface geophysical data collection.

3.3.2 Positioning Systems

Data location is important for almost all detection technologies. All detection technologies that require data processing, at a minimum, require that the data location be accurate and precise so that if targets are selected, they can be relocated In a time effective manner. Current trends in detection technologies are to acquire digital geophysical data. Accurate and precise positions for the geophysical data are necessary to extract the maximum value from the data. The GPS has been popular for years, however; this system is limited for some applications in wooded areas with thick canopy. For this reason, a number of other existing positioning systems have been introduced for use on MEC projects. The following technologies will be briefly discussed:

- Global Positioning System;
- Ranger – Radio-Based Positioning System;
- Robotic Total Station;
- Acoustic Positioning Systems;
- Laser Positioning Systems;
- Inertial Navigation Systems;
- Fiducial Methods; and
- Odometer Methods.

3.3.2.1 The relative strengths and weaknesses of each of these methods are summarized in the tables located in Appendix A.

3.3.2.1 Global Positioning System

The use of GPS technology is increasing in earth science disciplines due to the inherent benefits of obtaining accurate and precise position locations. Benefits include the ability to make better decisions, for example, in reacquisition of anomalies, and in improving survey cost effectiveness and time management.

3.3.2.1.1 GPS is a worldwide positioning and navigation system that uses a constellation of twenty nine satellites orbiting the earth. GPS uses these "man-made stars" as reference points to calculate positions on the earth's surface. Advanced forms of GPS like DGPS, can provide locations to centimeter accuracy. The basic theory behind GPS is:

- GPS satellites transmit accurate and precise information on their position and time;
- Land- based GPS receiver measures the time delay of the satellite signal from multiple satellites and derives the distance (often termed pseudo range) to each satellite ; and
- The distance to each satellite used is used to determine the location of the land-based GPS receiver (three satellites provide position only; a minimum of four satellites is necessary to provide position and altitude).

3.3.2.1.2 Each GPS satellite that orbits the earth provides data on the approximate location of all satellites in the GPS constellation (almanac data) as well as very accurate and precise data on their own orbital parameters (ephemeris data). Most land-based GPS receivers have a minimum of 12 channels; i.e., each channel collects information from a single satellite. If that satellite becomes "lost" (e.g., moves below the earth's horizon) the land-based receiver knows where to look for the next available satellite based on the almanac data. Since there are usually 5-9 satellites in view at all times from earth locations, GPS is a viable positioning system for use on most projects, especially those where reconnaissance mapping is implemented. However, when high resolution DGM surveys are necessary, a different mode of GPS (differential GPS or DGPS) is usually necessary.

3.3.2.1.3 When a single land-based GPS receiver (rover) is used to determine position using only the orbiting satellites, position accuracy may vary from several meters to many tens of meters. If a second land-based GPS receiver is fixed at a known reference point (base station), the reference GPS can be used to correct (in "real time" or "after the fact") the rover GPS data and improve the accuracy to << 1 meter (depending upon the specific GPS receiver and application, the accuracy obtained can be on the order of several centimeters or less). There are also other methods to improve the accuracy of the data obtained from a single GPS receiver; Wide Area Augmentation System (WAAS) and Coast Guard Beacons are commonly used to provide accuracies that vary from 0.3 meters to several meters.

3.3.2.1.4 The radio-frequency signals used for GPS require an uninterrupted path from the satellite to the land-based receiver in order to achieve the highest position accuracies. The GPS signal can be can be severely degraded in areas of canopy (e.g., wooded areas) and obstructions (e.g., urban areas with buildings).

3.3.2.1.5 Most GPS antennae weigh less then 1-lb and are easily attached to the data acquisition platform for DGM. Survey grade GPS receivers typically weigh several pounds; the power components of some systems increase the weight to 7-10 pounds..

3.3.2.2 RANGER

The RANGER positioning system has recently been developed to provide accurate positions in areas where other positioning systems (e.g., DGPS) do not provide adequate position and navigation capabilities, such as in dense, wooded areas and canyons.

3.3.2.2.1 RANGER is an RF system that uses four to eight fixed radio transponders and a mobile radio integrated to the geophysical detector system. The system can be set up over a 5 acre area and record the positions of the detector to an accuracy of approximately 20-60 cm depending upon the number of transponders used and the thickness of the vegetation

3.3.2.2.2 The system integrates the geophysical detector data (Geonics EM61 or Geometrics G858) with the position data in real time.

3.3.2.3 Robotic Total Station

RTS is a laser-based survey station that derives its position from survey methodology and includes a servo-operated mechanism that tracks a prism mounted on the geophysical sensor. One difficulty with these systems is maintaining and subsequently reacquiring lock in heavy vegetation by predicting the location of the sensor and then reacquiring it after lock has been lost. The RTS continuously records accurate, centimeter level positions by tracking the location of a 360° prism centered over the top of the detection device. Positional data is recorded several times per second to give an accurate position to correlate with the geophysical data collected.

3.3.2.4 Acoustic Positioning Systems - Ultrasonic Ranging and Data System (USRADS)

This navigation system utilizes ultrasonic techniques to determine the location of a geophysical instrument each second. It consists of three basic elements, a Data Pack, up to 15 Stationary Receivers (SRs) and a Master Control Center. The Data Pack creates an ultrasonic pulse and by measuring the time-of-flight to the stationary receivers, the location of the geophysical sensor can be determined. The SRs are placed throughout the survey area with about 10 required per acre. At least two SRs are required to be on surveyed points. The system software automatically determines the locations of the SRs by utilizing the time-of-flight information between all SRs. The Master Control Center and laptop computer acts as the master timer between the components, as the data processor and as the data collector. The computer calculates the sensor position location and displays the survey data. Position accuracy of 15-20 cm is normal with Stationary Receivers distributed at up to 150 ft spacing.

3.3.2.5 Laser Positioning Systems - ArcSecond Constellation System

The ArcSecond constellation system calculates locations by triangulating the signals of stationary lasers placed on the edge of a grid. The system uses four laser transmitters, although only two are required to calculate the position in 3-dimensions (3D). This property makes the system useful in wooded areas where most navigation systems function poorly or not at all. Accurate track paths can be measured in all but the most densely wooded areas. The high accuracy of this positioning system has benefits for MEC detection because the system has the ability to track the full position and orientation of a geophysical sensor.

3.3.2.6 Inertial Navigation Systems

Inertial navigation systems measure the acceleration of an object in all three directions and calculate the location relative to a starting point. The starting point is input and periodically refreshed using another navigation system, typically DGPS. The accuracy of the inertial navigation degrades with time, thus requiring periodic recalibration of the location. When used in conjunction with other navigation systems, an inertial system can be used to calculate locations even when the primary system is unavailable. This system is not in use due to the quick degradation of accuracy; making the system an uneconomical choice.

3.3.2.7 Fiducial Methods

The fiducial method consists of digitally marking a data string (data set) with an indicator of a known position. Typically, lines or markers are placed on the ground at known positions (e.g., 25ft). When the operator crosses over the marked location, he places a fiducial (fid) in the data record indicating the distance traveled. The location is then interpolated over that distance assuming constant speed and travel in a perfectly straight line.

3.3.2.8 Odometer Methods

This method utilizes an odometer, which physically measures the distance traveled. Two of the more popular methods are wheel-mode, which measures the distance covered by the circumference of the wheel, and the string method, which measures the length of cotton string which has been released from an odometer; the string pulls out as the operator walks causing the odometer to rotate and "count". Both methods assume constant speed and that the data is in a perfectly straight line.

3.3.3 Navigation

Navigation is defined as the manner in which the acquisition specialists transport the data collection system across the project area to ensure that the sample density is of sufficient quantity and quality to meet the project objectives. One of the most significant aspects of this process involves ensuring that the required distance between adjacent transects is maintained for two dimensional grids. This procedure becomes increasingly difficult in heavily vegetated areas (e.g., dense woods) and in project areas with an increased number of obstacles (e.g., a housing development).

3.3.3.1 For man-portable surveys, there are a variety of procedures that allow the field crew to keep track of their location within the survey area. These procedures include the use of a system of endpoints and intermediate waypoints that are positioned along each transect. Endpoints and waypoints are often physically represented by traffic cones, non-metallic pin flags, ropes, or spray paint. The degree of difficulty in navigating an area increases substantially as the number of obstructions increase and the variations in terrain become more significant.

3.3.3.2 For vehicle-towed and airborne or marine applications, swath guidance systems are often used to assist the tow vehicle operator or pilot in maintaining the necessary swath spacing. These systems are integrated with the positioning system and use the coordinate information provided by the positioning system to ensure accurate navigation within the survey area. The most common positioning system used for this application is DGPS.

3.3.3.3 The end product for the DGM process is a set of geophysical sensor measurements that are precisely located and of sufficient quantity to meet the project objectives. *Navigation is a critical component in determining whether or not this goal is achieved. In conjunction with the appropriate sensor selection and data acquisition platform design, it is during navigation activities that the end product is subject to the greatest variation in overall quality.*

3.3.4 Data Processing and Analysis

In recent years, survey data analysis and processing techniques for use with commercial sensors have been developed that improve detection capabilities and discrimination between MEC and other metallic clutter. These developments have been demonstrated for use with magnetometer data and EMI sensor data. The procedures rely on physics-based models in which estimated model parameters are correlated with target features from actual geophysical sensor data. Those target features include the target's spatial parameters such as their location, orientation and depth; the target's physical parameters such as their size, shape and density; and the target's magnetic and electromagnetic properties.

3.3.5 Detection and Discrimination

3.3.5.1 Detection

Detection efficiency is often defined for MEC projects in terms of the probability of detection (Pd). Depending upon the project SOW, Pd can be defined as the ability of the detection system to detect all metal objects, metal objects within a certain range of sizes, or the ability of the system to differentiate MEC items from non-MEC items (see Discrimination below). In conjunction with Pd, there are occurrences of false alarms and background alarms. False alarms should be defined in the SOW, and can be defined as the number of excavations that are not related to MEC, or results in items that are outside of the size range specified in the SOW. Background alarms should also be defined in the SOW and are usually defined as excavations that unearth non-metallic items (e.g., hot rocks, geology, no finds, etc.).

3.3.5.2 Discrimination

Discrimination is specifically defined for MEC projects as the ability to discriminate or distinguish between actual hazardous MEC items (e.g., UXO) and other pieces of metal such as nails, horse shoes, cans, pipe, etc. This process is performed by determining (or measuring) the geophysical characteristics of a sub surface item (anomaly) and comparing those characteristics to modeled or actual results (e.g., the Geophysical Prove Out). The primary variables defining the geophysical characteristics are the shape, orientation, distance and direction, and material composition of an item, as well as the ambient magnetic and/or electromagnetic field. Variations in these parameters have the potential to change the geophysical signature. Additionally, an item large and deep can have similar signal intensity to an item small and shallow. This is the challenge facing the industry. Research in this field is ongoing and further improvements in MEC discrimination techniques are anticipated as researchers and field geophysicists compare and evaluate data from a variety of MEC sites and DoD test programs. The primary objective of discrimination is to reduce the number of intrusive investigations required and thus, the cost of investigating MEC sites.

4.0 MEC TECHNOLOGY ASSESSMENT-REMOVAL

4.1 OBJECTIVES

Recovery of MEC represents the first opportunity to physically reduce the hazards to the public. Whether on or below the surface, the physical removal of MEC from an area definitively and verifiably removes the hazard. Recovery can often eliminate all potential explosives-related exposure associated with an event, such as when all MPPEH, MEC and MD are recovered and positively identified. The objective of recovery operations is to gain actual control of the MEC for immediate or future disposition. Recovery is also normally required to fully determine MEC characteristics and hazards, and to plan and execute appropriate disposal activities.

4.1.1 Evaluation Criteria – Effectiveness, Implementability, and Cost

Effectiveness: Is defined as the likelihood that the item will be safely recovered?

Implementability: Is defined for this document in terms of removal technology and design considerations with respect to variations in terrain, vegetation, geology and soils, man-made features, and weather. Other factors include equipment availability, weight and power requirements, reliability, and safety considerations.

Cost: Specific cost estimation is not possible for this effort due to the broad range of project objectives and environmental conditions encountered on most MEC projects. Cost will be compared as relative costs to other removal approaches in the document. This will be accomplished by using the broad categories of manpower, equipment and supplies, and other direct charges as identifiable.

4.1.1.1 A summary table of the effectiveness, implementability, and relative cost for each technology is included in Appendix A.

4.2 TECHNOLOGY PROCESS OPTIONS - REMOVAL

4.2.1 Hand Excavation

4.2.1.1 Description

Hand excavation consists of digging individual anomalies using commonly available hand tools. This is the industry standard method for performing MEC removals and investigations. The individual UXO Technicians dig an anomaly that was either located using hand held instruments or geophysical mapping. The method involves using the hand tools (shovels, picks, trowels, etc.) to excavate the selected item using only human power to do the work. Depending on a number of criteria (e.g., expected MEC and operating environment), actual techniques can vary from removal in shallow layers of the covering surfaces to use of pick and shovel for deeper items.

Techniques can also be combined. UXO Technicians are trained to conduct these operations with great care and with full awareness of the hazards associated with these operations.

- Effectiveness compared to other methods: Medium. Hand removal is very effective for removal of MEC. Focus is on recovering each item/anomaly one at a time, and the results of each "dig" are verified in real-time.
- Implementability compared to other methods: High. Hand removal is currently the most widely used method for removal of MEC. All firms and personnel in the MEC industry have developed effective methods for this removal technology.

4.2.1.2 Applicability and Strengths

Hand excavation can be used for most MEC recoveries. It can be used very effectively in most terrain, soil and vegetation conditions and is the only choice in very tough terrain (steep, reduced access, etc.). The main strength of manual excavation is that it can be accomplished in almost any location and is the industry standard by which all other recoveries are measured. Hand excavation is also less likely than most other removal techniques to expose MEC to inadvertent movement, jarring and impact; these can lead to unplanned detonation of some MEC.

4.2.1.3 Limitations and Weaknesses

Hand removal can be very difficult and time-consuming in soil that is very hard or for items that are very deep (greater than three feet). This can also be true in areas with MEC debris concentrations. Hand removal also requires one of the highest degrees of direct MEC exposure for workers, compared to other removal methods.

4.2.1.4 Special Considerations

Hand removal is a labor-intensive operation performed by skilled personnel. Project managers and other planners must assess the related cost and schedule impacts when considering hand removal operations for a project.

4.2.1.5 Relative Cost

Hand removal is average cost compared to other options. The cost for manual excavations can vary greatly depending on terrain, soils, vegetation and amount/types of MEC to be excavated. Engineering controls (e.g., fragmentation protection devices) will also impact removal costs and the progress rates at each site. Manual excavation is the industry standard removal method.

4.2.2 Mechanized Removal of Individual Anomalies

4.2.2.1 Mechanically-Assisted Removal Using Excavating Equipment

Mechanical excavation and removal methods offer potential advantages in terms of safety and production rates. As these methods become more refined, they will also become more cost effective to deploy and employ at MEC projects and sites.

4.2.2.1.1 Description

This method of removing single anomalies uses commonly available mechanical excavating equipment, such as a back-hoe or excavator to assist in the excavation of anomalies. It is considered an assist because for safety reasons the equipment can only be used to dig to within one foot (vertically or horizontally) of any targeted anomaly. The equipment is normally used to dig a hole beside the anomaly, with UXO Technicians manually finishing the excavation and removal approaching from the side of the anomaly.

- Effectiveness compared to other methods: Medium. Mechanically assisted excavation and removal has medium effectiveness compared to other technologies. These methods are being employed regularly on MEC projects. They are very effective and almost mandatory when handling larger items such as aircraft bombs.
- Implementability compared to other methods: High. Mechanical removal technologies are regularly employed on MEC sites. Equipment costs and site accessibility may affect implementability when compared to hand removal methods.

4.2.2.1.2 Applicability and Strengths

Mechanized removal generally excavates anomalies at a slower rate than hand digging in softer soils, but can be very useful in assisting manual dig teams when working in hard to dig soils. Mechanized removal is also well suited for deep (over 3 ft depth) excavations. With a skilled operator and a well-trained team the production rates for a mechanically assisted intrusive team can be significantly better than hand removal operations under similar conditions. For sites with few anomalies in deep locations and/or with hard to excavate strata, mechanized removal should be a primary method to consider.

4.2.2.1.2.1 Mechanical excavation methods can reduce actual exposure time for MEC personnel. Reduced time on site may also present schedule and cost advantages.

4.2.2.1.3 Limitations and Weaknesses

Mechanical excavation methods are designed for bulk removal rather than detailed work. The equipment generally lacks the precision required for working closely with hazardous MEC. For this reason, mechanical excavations are typically restricted to no closer than one foot (horizontally and/or vertically) from any anomaly. Other methods may be better suited in heavy concentration areas with anomalies in close proximity. Terrain and other considerations such as slopes and use of engineering controls may also limit employment of mechanical excavation equipment.

4.2.2.1.4 Special Considerations

The operation of heavy equipment in proximity to MEC requires highly skilled operators and an MEC team leader who can effectively use the equipment to improve production rates.

4.2.2.1.5 Relative Cost

The costs of obtaining and using mechanical excavation equipment must be compared to the costs of labor saved on any given project. This would tend to support the use of mechanical excavation equipment on projects with significant excavations required. In such cases the relative costs of renting the equipment are low in comparison to the man hours that can be saved in digging deep or hard to reach anomalies. This method can be a valuable augmentation to most manual recovery operations.

4.2.2.2 Remotely-Operated Equipment

4.2.2.2.1 Description

Remotely operated equipment is COTS excavating equipment that has had additional control equipment added that allows the equipment to be operated remotely. The remote method can be via wireless or wired control. The work is monitored by video cameras that are attached to the excavation equipment and/or independently positioned. The mechanical equipment operates as designed with the exception of being remotely-controlled.

- Effectiveness compared to other methods. Low/medium: Remotely-operated equipment has less physical effectiveness than mechanically assisted methods. Observation and control issues make these technologies more difficult to operate.
- Implementability compared to other methods: Low/medium. Remotely-operated equipment is expensive, and production rates are not yet comparable to other methods available. Maintenance and operator training requirements are also higher compared to other methods.

4.2.2.2.2 Applicability and Strengths

The greatest and most obvious strength of remotely-operated equipment is significantly reduced human risk. The risks to the actual excavation equipment are typically reduced through application of armoring of key components.

4.2.2.2.2.1 Remotely-operated equipment is a well-suited method for removal of more sensitive MEC. Pertinent examples of such MEC include 40mm grenades and projectiles, anti-tank rockets and projectiles, and submunitions. These type of munitions are considered to be the most hazardous to range clearance and UXO Technician personnel, and also require extensive time at risk during removal and disposal operations.

4.2.2.2.3 Limitations and Weaknesses

At this time remotely operated equipment is primarily in the research and development stage. The equipment has limited availability, is very expensive to obtain and deploy, and is prone to long periods of maintenance down time. Due to the current developmental status of remotely operated equipment, components requiring replacement/repair (e.g., damaged significantly as the result of MEC detonation) may not be readily available.

4.2.2.2.3.1 As with mechanized methods, remotely-operated equipment is not well-suited for operations requiring great precision. MEC can also be rendered in a more hazardous condition than originally found through rough handling by mechanical systems.

4.2.2.2.4 Special Considerations

If an area has to be cleared but contains very hazardous items, this method may be of use. The extra time and costs may be off set by reducing the hazard posed and minimizing the need for those hazards to be manually removed.

4.2.2.2.5 Relative Cost

The relative cost is high. With the equipment still in development stages, or very early in the production phase, most equipment is expensive and difficult to use. These costs may reduce over time, but currently they are high for most MEC recovery actions.

4.2.3 Mass Excavation and Sifting

4.2.3.1 Armored Excavation and Transportation

4.2.3.1.1 Description

Armored excavation and transportation is COTS earth moving equipment that has been armored to protect the operator and equipment from unexpected detonation while performing dig and move MEC operations. Unlike the smaller equipment described above for excavating single anomalies, this equipment is heavier, larger and designed for high-volume earth moving activities. The armor for this equipment can range from complicated cab-replacement with armor made from certified armor plating to simple placement of thick Plexiglas over the front of a vehicle. Determination of the materials, thickness and placement of the armor is determined by the types of hazards expected. For open burn/open detonation (OB/OD) areas the usual method of armoring is to place the proper thickness of Plexiglas over the front of the equipment. For impact or target areas, full cab replacement armor is the normal option. This method involves major modification to the equipment to remove the existing cab and replace it with a cab that has been constructed of armor. Once the proper equipment is armored the excavation can begin. This includes the actual excavation of the soil and loading onto either conveyors or transport trucks to move to the processing area. Once processed, the same equipment can be used to r return the soil to its original location. For backfill, the equipment does not normally have to be armored since the explosive hazard was removed during the processing phase. Figures 4-1 and

4-2 show examples of construction equipment with and without armored equipment (note: two separate pieces of equipment are shown).

- Effectiveness compared to other methods: High. Effectiveness is equivalent to or better than hand or mechanically assisted methods, particularly for conditions requiring significant earth moving.
- Implementability compared to other methods: Medium. Armored equipment may be easier to use on site than remotely-operated equipment due to the presence of an operator with the machinery. Special armor may have to be designed/developed for a piece of equipment, impacting schedule.

4.2.3.1.2 Applicability and Strengths

This method is most applicable to high MEC concentration areas. Large amounts of soil can be removed and transported to processing areas, thereby clearing large and deep areas.

4.2.3.1.3 Limitations and Weaknesses

This method would not be good for small areas, or areas with minimal MEC concentrations. It is a very time consuming and management heavy task that requires skilled equipment operators and extra time for equipment maintenance. This method also requires some experience in earth moving for the removal to be performed correctly.

4.2.3.1.3.1 This method would not be effective for removal of large munitions. Detonations resulting from larger munitions can severely damage or destroy expensive components.

4.2.3.1.4 Special Considerations

This method should only be considered for areas with heavy MEC concentrations, and is dependent on equipment being available and deployable.

4.2.3.1.5 Relative Cost

The relative cost is high. The rent of the equipment as well as the cost of maintenance is very high compared to the other methods. For areas with high MEC concentartions however, the over all cost can be lower than the cost of extended man hours for a manual removal. The other major advantage is improved safety afforded by the armored equipment on heavily impacted ranges.

Figure 4-1
Equipment with Non Armored Cab

Figure 4-2
Equipment with Armored Cab

4.2.3.2 Mechanized Soil Processing (Screens/Conveyors/Magnets)

4.2.3.2.1 Description

These methods are useful with the armored excavation described above. Once the soil has been excavated and transported to the processing area it is then processed through a series of screening devices and conveyors to produce segregated soils of different grain sizes. Screen grid sizes are selected to trap different sized item(s) at various points in the process, and to allow non-MEC materials (soils) to move through the system with minimal handling. These different sized soils are known as "waste streams" and can be either clean or contaminated based on the type of processing being done. There are many manufacturers of soils screens and various types such as shakers and trommels. Shakers are usual square in shape and physically shake the soil loose and trommels are long round tubes that rotate to loosen and divide the soils into waste streams. Within the process stream the use of conveyors to move the soil and to help control the large volume of soil is needed for a successful screening operation. Another item that can be used to assist in locating MEC during this operation is to use magnetic separators on the conveyor belts to help remove the ferrous items from the soil streams. These rollers are placed at the end of the conveyor and direct the ferrous items away from the soil piles. Observation of these activities is conducted from one or more protected positions. Figures 4-3 and 4-4 are examples of the shaker and Trommel feed systems that may be employed.

- Effectiveness compared to other methods. High. Soil screening technologies have proven effective in soil processing for MEC and other materials for some number of years.
- Implementability compared to other methods. High. Soil screening processes are one of the most easily implemented technologies available for soil treatment.

4.2.3.2.2 Applicability and Strengths

This method is used in conjunction with major soil excavations. The strength of this method is the ability of the equipment to separate the soils into manageable streams of soils that are different sizes. When the maximum particle size in the waste stream is smaller than the smallest MEC item in the excavation area, it is very easy to spot check this stream and then return it as backfill to the excavation area with little if any manual contact with the soil. This leaves only the larger-sized streams that require detailed inspection by personnel to locate the MEC.

4.2.3.2.3 Limitations and Weaknesses

This method is complex and requires skilled operators and management personnel that are familiar with the earth moving operations. Effectiveness of these systems can be degraded by cohesive soils and excessive root mass. It is a high maintenance activity that requires considerable time and cost for refueling, cleaning and general maintenance activities and also requires protected location for quality and safety personnel observing operations.

DISPOSAL TECHNOLOGIES
(Continued)

Figure 4-3 Shaker Type Screen

Figure 4-4 Trommel Type Screen

4.2.3.2.4 Special Considerations

The availability of the equipment armor and skilled operators has to be taken into account, as well as skilled personnel to trouble-shoot and maintain screening and conveyor equipment.

4.2.3.2.5 Relative Cost

The relative cost is medium to high. However, this technology can be less expensive than the cost of labor required to manually clear areas of heavy MEC concentration. Rental, maintenance and fuel costs will be high. The cost of the armor is an additional cost that has to be considered as well.

4.2.4 Magnetically Assisted Recovery

The employment of magnetic-based technologies on MEC projects has been limited to post-removal scrap handling applications with rare exception. The most promising application of MEC-applicable magnetic technology is found in scrap and soil processing. Magnetic devices are also employed as a component of some soil processing systems to segregate ferrous materials from waste streams. These are normally offered as an option on conveyors and other soil processing equipment, and are not addressed in these paragraphs.

- Effectiveness compared to other methods. Magnetic technologies have not been used on a large enough scale to truly evaluate their effectiveness for MEC projects.
- Implementability compared to other methods. Magnetic technologies appear to be readily obtainable, easily installed and simple to operate for surface removal environments. Again, they have not been used to any considerable degree on MEC projects.

4.2.4.1 Surface Removals

A number of industrial products are available for magnetic removal of ferrous materials from surfaces. While not specifically designed for MEC applications, these are designed to pick up similar objects ranging from bolts on sidewalks to fence posts and rebar at construction sites.

4.2.4.1.1 Description

Most of these devices are bars or panels designed to be mounted on commercial pickups, forklifts, and construction equipment (for larger devices). They are maneuvered close to the surface over relatively flat and clear surfaces, and collect ferrous debris directly on the surface. Metallic objects collected on the devices are either physically removed by operators or released when the electronic field is turned off.

4.2.4.1.2 Applicability and Strengths

These devices are well suited for the fast removal of MEC residue (metallic scrap) from open, flat areas. They are inexpensive to acquire, easily sourced, and require little operator training.

4.2.4.1.3 Limitations and Weaknesses

These devices offer no inherent MEC protections; vehicles and observers in proximity to the operations would require protection. This device can pick up MEC, MD, range residue and other metallic debris, necessitating the need for inspection of material recovered. Surface conditions limit the use of these magnetic means more severely than other removal methods.

4.2.4.1.4 Special Considerations

These devices are currently in use in both the construction and airport/airfield industries.

4.2.4.1.5 Relative Cost

Magnetic removal of MEC scrap would be considered one of the least expensive removal options. Costs associated with this will increase as protective/engineering measures are applied (e.g., cab protection for vehicles used with magnetic devices), and surface preparations such as brush clearance must also be taken into consideration.

4.2.4.2 Sub-Surface Removals

Magnetically assisted sub-surface recovery has rarely been attempted. In one of the reported attempts at an MEC site, several significant problems were encountered including magnetization of the strata in the area being cleared. The magnet actually polarized the strata such that it prevented further detection capabilities by limiting differentiation between rocks and metal. As of this writing, little information is available regarding the development or use of magnetic technologies for subsurface removal of MEC.

5.0 MEC TECHNOLOGY ASSESSMENT - DISPOSAL

5.1 OBJECTIVES

The ultimate objective of all MEC remediation efforts is to eliminate public exposure to MEC and MC hazards. Disposal of MEC represents the best means of immediately and conclusively eliminating public exposure to explosives hazards. MEC disposal operations are designed and executed to ensure the protection of human health and the environment through the complete elimination or destruction of hazardous MEC.

5.1.1 Evaluation Criteria – Effectiveness, Implementability, and Cost

Effectiveness: Is defined as the likelihood that the item will be safely eliminated or destroyed.

Implementability: Is defined for this document in terms of disposal technology and design considerations with respect to variations in terrain, vegetation, geology and soils, man-made features, and weather. Other factors include equipment availability, weight and power requirements, reliability, and safety considerations.

Cost: Specific cost estimation is not possible for this effort due to the broad range of project objectives and environmental conditions encountered on most MEC projects. Cost will be compared as relative costs to other removal approaches in the document. This will be accomplished by using the broad categories of manpower, equipment and supplies, and other direct charges as identifiable.

5.1.1.1 A summary table of the effectiveness, implementability, and relative costs for each technology is included in Appendix A.

5.2 TECHNOLOGY PROCESS OPTIONS – EXPLOSIVE DISPOSAL

The technologies described in these paragraphs are specifically intended to remove and eliminate the explosives hazards associated with MEC. This is the final stage in the munitions life cycle, and is the point at which MEC is no longer an immediate threat to the public. Technologies are divided into two sections: (1) treatment of MEC and (2) treatment of MEC residue and scrap. Residue treatment technologies are focused on eliminating explosives from metallic MEC components.

5.2.1 Blow-In-Place

5.2.1.1 Description

Blow-in-Place (BIP) is the destruction of any MEC by detonating the item without moving it from the location where it was found. Normally, this is accomplished by placing an explosive charge alongside the item. MEC is dealt with individually in this approach, requiring direct exposure of personnel to each individual item.

- Effectiveness compared to other methods: High. Items are disposed of individually, and confirmation is done immediately after disposal operations.
- Implementability compared to other methods. High. Implementability is high when environment and location permit.

5.2.1.2 Applicability and Strengths

BIP operations are suitable for singular or low-volume MEC items located in areas capable of accommodating high-order detonations and providing the associated safety distances. BIP operations often allow application of certain engineering controls (e.g., shot tamping, barriers and employment of the On-Site Ordnance Demolition Container (ODC)). This may result in reduced safety distance requirements. BIP operations do not require additional movement of MEC. This reduces personnel exposure and contributes to workers' safety. BIP operations also typically require positive control over a minimum area, though control may be required for a longer period.

5.2.1.3 Limitations and Weaknesses

Each MEC item must be dealt with separately during BIP operations. This results in increased exposure (repeated approaches and extended periods in contact/proximity to MEC) of personnel to danger areas, particularly when multiple MEC items must be dealt with in this fashion. Of particular note is the increased and repeated exposure of personnel to primary/initiating explosives. These operations also require a higher ratio of donor/priming explosives for each item (as compared to consolidated disposal operations). If several items are to be treated through BIP processes, positive control of the area may be required for an extended period (i.e., until completion of all disposal activities and verification that no hazardous item/components remain at the conclusion of operations). BIP operations also present the possibility of repeated public exposure to demolition operations.

5.2.1.4 Special Considerations

Engineering controls may be desirable or required. Waste streams generated from BIP operations may fall under further regulatory guidance for treatment and/or final disposition. Waste streams produced by BIP are not contained and thus not as easily dealt with. As regulatory agencies become more involved in MEC projects, this may yield higher life cycle cost for waste (for characterization/treatment/disposal) than technologies that do contain the waste streams.

5.2.1.5 Relative Cost

Relative costs are low compared to other options.

- Man-hours: BIP operations involve approximately the same number of man-hours as consolidate and blow operations (see Paragraph 5.2.2). BIP operations, however, require greater numbers of skilled labor (e.g., UXO technicians). Costs are medium to high when compared to other alternatives.
- Equipment: Little expensive equipment is required for basic BIP operations, with the exception of demolition materials and equipment (e.g., shock tubes, detonating cord, blasting caps, igniters, and remote firing devices (RFD)). Application of engineering controls will require items such as hand shovels or mechanized handling equipment (MHE) for earth moving (tamping), sand bags or specific controls such as the ODC. Costs are lower compared to other options.
- Site Development, Maintenance and Closure: BIP operations require less general area security, signage and access control costs than consolidate and blow operations (see Paragraph 5.2.2). These requirements will increase as the number of demolition (and safety) areas increase. Scrap and residue collection may be required at specific points on site. Overall low costs compared to other options.

5.2.2 Consolidate and Blow

5.2.2.1 Description

Consolidate and Blow operations are defined as the collection, configuration, and subsequent destruction by explosive detonation of MEC. This process can be used either "in grid" (i.e., within a current working sector) or at an established demolition ground, but can only be employed for munitions that have been inspected and deemed acceptable to move. This determination should be made by senior UXO-qualified personnel in accordance with appropriate regulations and guidance. Engineer Pamphlet (EP) 1110-1-17 (Establishing a Temporary Open Burn/Open Detonation Site for Conventional Ordnance and Explosives) provides further definition: *There are two situations that may describe the consolidated shot process: 1) munitions may be collected from anywhere on site and detonated at a designated, sited disposal area or 2) munitions may be collected within a grid and detonated at a designated spot within the grid.*

- Effectiveness compared to other methods: Consolidate and blow operations are very effective compared to other methods. This is particularly true when high donor-to-munitions ratios are achieved. In many cases, MEC items that are being destroyed (such as aerial bombs, large artillery projectiles and explosive mines) can in fact serve as donor explosives for other munitions that are harder to destroy.
- Implementability compared to other methods: The implementability of consolidate and blow operations is medium to high when compared to other methods. Specific requirements regarding surrounding features (buildings, roads, etc) and area size must be addressed, but special tools and equipment are limited to common movers (fork lifts,

trucks) and demolition kits. UXO personnel have the skills necessary to plan and conduct these operations without significant additional training.

5.2.2.2 Applicability and Strengths

Consolidate and blow techniques are suitable for and limited to operations involving large numbers of stable MEC/munitions. Consolidate and blow is not necessarily the best option for loose propellants, phosphorous-filled munitions (in certain environments), or fuzed munitions. Fewer planned explosions are required to effect disposal of the MEC. This may be an important consideration for areas with noise restrictions, significant air traffic, or other conditions that may complicate or limit the frequency of destruction operations. Consolidation of varied (though compatible) types of MEC may provide advantages for the disposal of MEC that is otherwise difficult to destroy. For example, demolition activities involving significant quantities of high explosive munitions may offer opportunities to destroy thick-cased munitions with smaller quantities of explosives (e.g., 57mm Armor Piercing High Explosive (APHE) projectiles). Consolidated disposal operations typically require less donor/initiating explosives per item than blow-in-place operations.

5.2.2.3 Limitations and Weaknesses

Consolidated disposal operations require significantly greater real estate. By comparison, techniques that address individual MEC items require smaller areas that can often be reduced through appropriate engineering controls. Also, more time is required to assemble the shots; potentially creating increased personnel exposure. Movement and configuration of MEC for consolidated disposal operations requires a greater number of personnel to remain in proximity/contact with MEC for a greater period of time. There is also a greater risk of kick-outs as the quantity of munitions in each respective shot increases. An increase in kick-outs results in a larger area potentially affected by kick-outs. This increases the difficulty in locating all kick-outs after demolition operations cease. In addition, the increased shot size will generate increased security/control requirements. More access control measures and security personnel will be required as the perimeter and number of access points increase. More signage will be required to meet safety requirements as well.

5.2.2.3.1 Larger detonations increase the coordination concerns with other agencies (e.g., Federal Aviation Administration (FAA) and/or military air traffic control elements). The potential for encroachment with other work areas also increases as the size of disposal areas increase. Other work areas may include MEC activities, sites supported by MEC activities (e.g., construction zones), and activities unrelated but proximate to the MEC site (e.g., public roads on or near installation boundaries). Expanded demolition areas associated with large scale operations of this nature will have greater site closure requirements. For example, the following requirements are stated in EP 1110-1-17: *During closure of the OB/OD area, the contractor must remove and decontaminate all waste residues, contaminated containment areas, contaminated subsoils, and all contaminated structures and equipment, and manage them as hazardous waste IAW the requirements of the closure plan.* Waste streams generated from consolidate and blow operations may fall under further regulatory guidance for treatment and/or final disposition.

5.2.2.3.2 Finally, overpressures from detonators of greater concern with consolidate and blow operations than with methods designed to address MEC items individually. Overpressure is a primary safety consideration in the planning and design of ammunition storage areas. As consolidated disposal operations grow in size, similar considerations will apply.

5.2.2.4 Special Considerations

Several different methods of consolidated disposal have been developed in conjunction with the USACE Captured Enemy Ammunition (CEA)/Coalition Munitions Collection (CMC) program. Lessons learned from this program may be readily applicable to other consolidate and blow operations. Engineering controls may be desirable or required for consolidated disposal operations. The increased effects of consolidate and blow operations (overpressures, fragmentation, noise, etc) will generate greater liability considerations.

5.2.2.4.1 Waste streams produced by consolidated and blow are not contained and thus as easily dealt with. As regulatory agencies become more involved in the projects, this may yield higher life cycle costs for waste (for characterization/treatment/disposal) than technologies that do contain waste streams. This could be of even greater concern in consolidate and blow operations where there will be more residual generated and thus potentially greater concentrations of regulated analytes.

5.2.2.4.2 Consolidated MEC disposal operations may require MHE and vehicles for movement of munitions. An associated consideration is the fact that MEC is/are typically heavy, possibly damaged and not configured for simple bulk movement. This may result in requirements for special protective packaging and transportation.

5.2.2.4.3 Interruption and/or suspension of planned disposal activities are common due to weather, site incursions, safety pauses and a number of other events. Planning for consolidate and blow operations must take into account the possibility that MEC may have to be temporarily stored during such stoppages. MEC storage and/or demolition site security requirements are often required when these events occur. Specific requirements applicable to U.S. Army Corps of Engineers (USACE) projects can be found in DOD 6055.9-STD (DOD Ammunition and Explosives Safety Standards), Engineer Regulation (ER) 385-1-95 (Safety and Health Requirements for OE), ER 1110-1-8153 (Ordnance and Explosives Response), EP 385-1-95a (Basic Safety Concepts and Considerations for Ordnance and Explosives Operations), EP 385-1-95b (Explosives Safety Submission), Engineer Manual (EM) 385-1-1 (Safety and Health Requirements Manual), and EM 1110-1-4009 (Ordnance and Explosives Response).

5.2.2.4.4 Recent experiences with consolidate and blow operations indicate significant increases in both the occurrence and complexity of site communications. In addition, emergency fire support requirements will increase as sites increase in size in order to ensure adequate coverage in the event of a fire.

5.2.2.5 Relative Cost

Costs for consolidated disposal operations are medium compared to other technologies.

- Man-hours: Consolidate and blow operations probably involve approximately the same number of man-hours as similar BIP operations. Consolidate and blow operations, however, offer the opportunity to use lower technical grades (e.g., UXO Technician I, Ammunition Handler) under the supervision of UXO supervisory personnel for a good percentage of the work on site.
- Equipment: Consolidation of MEC may require additional MHE and vehicles for movement of munitions. These vehicles may be required to meet DoD and other agency requirements for transport of ammunition and explosives.
- Site Development, Maintenance and Closure: Security, signage and access control costs will increase as demolition and safety areas increase. These costs will be significantly greater than for the smaller sites associated with techniques that address individual MEC. Scrap and residue collection will be required for a large area vice specific points on site. This adds time and resources requirements to the closure procedure, again as compared to individual MEC disposal methodologies.

5.2.3 Laser Initiation

5.2.3.1 Description

Portable (vehicle mounted) lasers are used, from a safe distance, to heat MEC laying on the surface resulting in high or low order detonation of the items. MEC can be brought to detonation or deflagration temperatures depending on angle of attack, standoff distances, beam quality, and spot placement on the MEC.

- Effectiveness compared to other methods: Laser initiation processes are still in the developmental stages. They are also heavily reliant on line of sight or direct access (for diode-based transmission) to target MEC. At this time, their effectiveness compared to other methods is considered low to medium. Indications from current field testing, however, shows promising improvement.
- Implementability compared to other methods: Implementability compared to other methods is low to medium. Issues regarding power, MEC accessibility and deployment/maintenance of equipment are still being addressed.

5.2.3.2 Applicability and Strengths

Laser technology has proven effective for munitions up to 81mm that are exposed to view. Preliminary data from field tests being conducted in Afghanistan and Iraq at the time of this writing indicate possible application for larger projectiles as well. Subject areas must be able to withstand high-order detonations of the MEC encountered.

5.2.3.2.1 Laser technologies provide a standoff means to destroy improved conventional munitions (ICMs) and bomblets while minimizing personnel exposure to the MEC. They also present potential for faster operations. For example, Air Force use of laser technologies on submunitions ranges indicate that, with training and practice, a four man explosive ordnance disposal (EOD) team operating two lasers can match the production rate of a twelve-man team employing traditional demolition techniques while reducing personnel exposure levels.

5.2.3.2.2 Laser operations do not require explosives, which can significantly reduce logistics and facility (i.e., explosives storage) requirements and expenses.

5.2.3.2.3 The combination of stand-off distance and lack of first-hand contact with explosives makes for a much safer working environment for UXO personnel. This can reduce risk and liability concerns and costs.

5.2.3.2.4 MEC can be brought to detonation or deflagration temperatures with laser technologies, depending on angle of attack, standoff distances, beam quality, and spot placement on the MEC. This offers treatment options that might not be available with other technologies.

5.2.3.3 Limitations and Weaknesses

Appropriate components of the MEC must be exposed. Targets must be on the surface and line-of-sight accessible. In the case of projectiles, the projectile body must be exposed (as opposed to fuzes and tail fins). Laser systems still have some limitations, including their large size (for chemical lasers) and power generation requirements. Also, secondary waste streams from low order detonations must be addressed.

5.2.3.4 Special Considerations

Laser applications for MEC are still in the development stages, although prototypes have been successfully tested in Afghanistan and Nellis Air Force Base, Nevada. The Air Force continues to use laser methods on ranges containing a variety of submunitions.

5.2.3.4.1 Waste streams produced by laser initiation are not contained and are thus not as easily dealt with. As regulatory agencies become more involved in MEC projects, this may yield higher life cycle costs for waste (for characterization/treatment/disposal) than technologies that do contain waste streams. This may be of even more concern with laser initiated detonation/deflagration as residual contamination may be higher than with traditional BIP. Low order detonations could potentially yield greater environmental contamination than successful BIP operations.

5.2.3.5 Relative Cost

Costs of laser disposal operations are assessed to be low to medium based on currently available information.

- Man-hours: Fewer personnel are required for operation and indicative production rates are promising. Personnel costs can be expected to be significantly lower than other disposal methods.
- Equipment: Transport and operations and maintenance of the system(s) can be expected to be similar to or less than containment vessels. Costs associated with expendables should be easily offset by cost avoidance associated with normal acquisition and storage of explosives.
- Site Development, Maintenance and Closure: Minimal site development or protective works is anticipated. System maintenance is minimal, but repair parts may be costly or hard to obtain. Resultant scrap/residue may require additional processing, as with other methods.

5.2.4 Contained Detonation Chambers

5.2.4.1 Description

Contained Detonation Chambers involves destruction in a chamber, vessel, or facility designed and constructed specifically for the purpose of containing blast and fragments from MEC. MEC items are removed from the areas where they were found; transported to the chamber(s); and disposed of (typically singularly) in the vessel or facility. This method is also known by a variety of similar terms such as thermal decontamination ovens, or trade names such as the Donovan Blast Chamber.

- Effectiveness compared to other methods: Effectiveness compared to other methods is high. MEC is destroyed individually or in small numbers. Results are easily confirmed by post-event inspection of the vessel.
- Implementability compared to other methods: Implementability compared to other methods is low to medium (for stationary facilities) to medium to high (for mobile containment structures). Since movement of the munitions is required to use detonation chambers, this process is only applicable to munitions that have been determined to be acceptable to move.

5.2.4.2 Applicability and Strengths

Contained detonation chambers are successfully being used at formerly used defense sites and inactive training ranges to treat explosive items, where it is unsafe or otherwise not advisable to detonate them in the open. Contained detonation chamber technology is well suited for single munitions items and systems are available to safely contain detonations up to 90 pounds net explosive weight (NEW) (trinitrotoluene (TNT) equivalent). Current technology has also been tested for NEW as high as 66 pounds and designs are under development for systems capable of handling NEW as high as 750 pounds TNT equivalent.

5.2.4.2.1 A number of COTS systems are available to support this approach. These systems offer a variety of capacity, transportability, and cost options. Residue is contained within the structure; no contamination of soil, water or other environmental elements (note: see comments regarding air emissions below) is experienced. The fact that these waste stream is contained and is more easily dealt with (even when hazardous) is an advantage both in terms of public perception and in life cycle cost.

5.2.4.3 Limitations and Weaknesses

Air pollution control equipment may be required to comply with federal/state/local regulatory requirements (on other than CERCLA/FUDS sites). Chambers typically require additional handling of MEC (transport to facilities, movement from collection vehicle to feed mechanisms, etc). The slow feed rates for containment vessels can add time to project duration. The systems require more extensive maintenance, inspection and support requirements than most other options, and the containment or sacrificial components of these vessels have definitive service lives. Systems and/or components are designed to be expended and then replaced. Finally, a relatively high ratio of disposal resources (e.g., donor explosives) is required for each MEC item destroyed.

5.2.4.4 Special Considerations

Cleaning and maintenance of these systems will require PPE and worker training. Permitting issues associated with air emissions and other waste streams can be lengthy processes, significantly affecting the overall project schedule.

5.2.4.4.1 A variation on the containment vessel available for specific types of MEC is the Deactivation Furnace. These furnaces are also referred to as Army Peculiar Equipment because they are used almost exclusively by the Army to deactivate large quantities of small arms cartridges, and 50-caliber machine gun ammunition, mines, and grenades. The deactivation furnace is similar to the rotary kiln incinerator except it is equipped with a thick-walled primary combustion chamber capable of withstanding small detonations. Deactivation furnaces do not have secondary combustion chambers because they are intended not to completely destroy the vaporized explosives but to render the munitions nonreactive. Most deactivation furnaces are equipped with air pollution control equipment to limit emissions. The operating temperature of deactivation furnaces is approximately 650°C to 820 °C.

5.2.4.5 Relative Cost

Overall costs for containment options are medium to high. Stationary containment facilities can be among the highest cost options available.

- Man-hours: Restrictions on feed rates and NEW will require repeated manpower intensive activities. These will have to be performed by personnel qualified to handle

MEC, who are traditionally some of the highest paid wage workers on MEC sites. In addition, the removal and transport of MEC to the vessel/facilities will also require qualified personnel. This will result in relatively high labor costs. Inspection and maintenance must be regularly scheduled, adding downtime to project duration. This methodology will generally require more man-hours than most other options.

- Equipment: Stationary systems may require varying degrees of on-site construction. All systems will require inspection, maintenance and eventual replacement (depending on project duration and frequency of use). Supporting equipment may be required as well (e.g., MHE to lift/move MEC from transport vehicles to feed mechanisms). This method will generally be more expensive than other options from an equipment perspective.
- Site Development, Maintenance and Closure: Stationary facilities will require siting and construction activities. Maintenance requirements are generally greater than other options. Site closure will require breakdown of constructed facilities and subsequent restoration of areas where they were located.

5.2.5 Disassembly or Render Safe Procedures

5.2.5.1 Description

Disassembly or Render Safe Procedures (RSPs) are the procedures that enable the neutralization and/or disarming of mines and munitions to occur in a recognized and safe manner. In the U.S. military context, RSPs are designed and executed by EOD personnel who are formally trained and authorized to perform these procedures. The following formal definition of render-safe procedures comes from Army Regulation (AR) 75-15: *The portion of the explosive ordnance disposal procedures involving the application of special explosive ordnance disposal methods and tools to provide for the interruption of functions or separation of essential components of unexploded explosive ordnance to prevent an unacceptable detonation.*

- Effectiveness compared to other methods: The effectiveness of RSP is low. RSPs are not designed or primarily intended as final disposal for MEC. Further disposal procedures are normally required, resulting in additional exposure and resource requirements.
- Implementability compared to other methods: Implementability is low due to added exposure and risks. The use of RSPs is currently restricted to military EOD units and personnel.

5.2.5.2 Applicability and Strengths

RSPs are used only under circumstances where the risks associated with a high order detonation outweigh the risks of exposing EOD personnel to hazards in order to prevent detonation. The only advantage offered by RSPs is their exclusive applicability under the most physically constrained situations, where the significantly increased risk is warranted by some special circumstances.

5.2.5.3 Limitations and Weaknesses

RSPs are extremely hazardous to personnel performing the activity as well as personnel and environments that cannot be moved or otherwise protected from adverse outcomes. RSPs are time consuming and require extensive time at risk to conduct surveillance of the area; setup the required tools; conduct RSPs; and to evaluate the results. Specialized tools and training are required and specific authorization/exception to policy for UXO personnel is required to conduct RSPs. RSPs do not provide the same degree of confidence and/or effectiveness as other methods.

5.2.5.4 Special Considerations

The extremely hazardous nature of procedures and high degree of exposure to hazards will result in significant insurance and liability considerations for RSP operations. MEC can potentially become more hazardous as a result of RSP operations, and explosives and other hazardous components can be exposed and/or sensitized as a result of properly applied RSP techniques.

5.2.5.5 Relative Cost

- Man-hours: RSP is very manpower intensive. This process requires highly specialized personnel and multiple approaches for each MEC item.
- Equipment: Specialized tools and equipment are required. RSPs may require multiple sets of these tools if intent is to address multiple MEC simultaneously. Generally less expensive than destruction chambers, but more expensive than BIP.
- Site Development, Maintenance and Closure: RSPs costs are similar to BIP operations.

5.3 TECHNOLOGY PROCESS OPTIONS – MEC RESIDUAL PROCESSING

MEC disposal activities leave behind residue ranging from packaging materials to metal scrap from munitions and targets. Metallic scrap can (and often must) be recycled in accordance with DoD regulations. This scrap must have all hazardous materials (including explosives and other munitions constituents (MC)) removed prior to releasing it to commercial recycling firms. The processes described in these paragraphs are intended to remove MC from residue resulting from MEC disposal operations.

5.3.0.1 MPPEH, MD and/or range debris may require one or more of these processes to meet the requirement of being free of explosives. This is required prior to release to commercial recycling firms and no material can be released from custody until its contents have been smelted and are only identifiable by their basic content.

5.3.1 Chemical Decontamination

5.3.1.1 Description

Chemical decontamination of MEC scrap and residue is still largely in development. This approach is based on the concept that certain ammunition and explosives may be disposed of by chemical decontamination or neutralization. Neutralization can include dissolving water-soluble material and chemical decomposition. Three examples of the more studied chemical decontamination methods include Supercritical Water Oxidation (SCWO), photocatalysis and Molten Salt Oxidation (MSO).

- Effectiveness compared to other methods: The effectiveness of chemical decontamination is low to medium. Most of these methods are still in some stage of development or testing.
- Implementability compared to other methods: Implementability is low to medium due to added equipment, facility, skilled labor and possible hazardous materials requirements.

5.3.1.1.1 The chemical decontamination methods addressed in the following paragraphs are in varying stages of development and implementation.

- SCWO. Explosives decompose rapidly in water above 200^{o} C to small, water soluble, organic and inorganic molecules. Subsequent reactions with oxygen at higher temperatures and high pressures above the mixture's critical point take these intermediate products to carbon dioxide and other inorganic products. Workers at Los Alamos National Laboratory have explored methods to prepare solid explosive for the reactor. Solution in organic solvents has the disadvantage of solvent handling and was dropped from further study. Preparation of water slurries requires use of water jets or grinding, which are potentially dangerous. This method was discarded. The method preferred at Los Alamos is hydrolysis in aqueous NaOH (sodium hydroxide) or NH_4OH (ammonium hydroxide) which yields non-energetic, soluble products suitable for subsequent treatment by hydrothermal processing.
- Photocatalysis. Photolytic oxidation of explosive contaminated water in the presence of ozone or peroxide has been studied extensively. The opacity of some contaminated waters has led to research on "dark" processes not dependent on light and using metal catalysts. The US Army Waterways Experiment Station is currently evaluating a system for explosives-contaminated groundwater treatment using hydrogen peroxide and ozone to oxidize explosive constituents without ultraviolet light.
- MSO. MSO is a thermal, flameless process that has the inherent capability of completely destroying organic constituents of mixed wastes, hazardous wastes, and explosives. MSO, reportedly, can treat a wide variety of solid, liquid, and gaseous waste streams while producing low levels of emissions (off-gasses). Organic materials are converted into carbon dioxide, nitrogen, and water vapor. Metals and other inorganic materials are captured and held in the salt. MSO is advertised as an environmentally friendly alternative to incineration for the treatment of a variety of organic wastes. The Department of Energy and the U.S. Army Defense Ammunition Center currently direct

this technology development. This technology has been in development for over eight years, and prototypes have been employed at DOE and DoD sites.

5.3.1.2 Applicability and Strengths

Chemical decontamination processes target explosive components vice metallic and other components of MEC. As such, these processes have potential application both in treatment of metallic MD/range scrap; and of explosive residues.

Chemical decontamination processes appear to have minimal potential for unintended explosive events during processing. This may be a strong consideration in environments where accidental explosions could have greater than average consequences. Some decontamination processes can yield non-hazardous byproducts, thereby reducing/eliminating certain permitting requirements. Current chemical decontamination research also indicates a high potential for success with propellants.

5.3.1.3 Limitations and Weaknesses

As opposed to the point in the previous paragraph, some decontamination processes can yield byproducts/waste streams with potential long-term environmental effects. Further, chemical decontamination processes are not as well developed as other methods, making applicability and comparison difficult to assess. It must also be noted that most chemical decontamination experimentation has been performed on propellants; effectiveness and applicability on other munitions constituents is still in various states of research.

5.3.1.4 Special Considerations

As a chemical-treatment related alternative, conversion of propellants to fertilizer has been utilized in some instances (as opposed to open burning). This employs a reactant material and a reaction vessel operating at atmospheric pressure and at a temperature of 160 to 180°F. Following completion of the reaction (between 2 and 4 hours), the propellant is neutralized with phosphoric acid and is then ready for application as a fertilizer, thus eliminating the need for Resource Conservation and Recovery Act (RCRA) regulated treatment technologies. A commercial company is reportedly planning to market the resulting product.

5.3.1.5 Relative Cost

Relative costs should be medium to high when compared to other residue treatment options.

- Man-hours: Production-level chemical decontamination operations will likely require skilled personnel familiar with the characteristics (and particularly the safety and environmental concerns) of both MEC and the chemicals used in the decontamination process. Further, chemical decontamination may require longer process times than other means, resulting in more (collective) time on site. Fewer personnel should be required compared to other disposal technologies. Additional manpower or substitute services may be required to handle resultant waste streams.

- Equipment: May require special containers and handling equipment (including PPE). May include lab processes for quality assurance/quality control (QA/QC) of process and resultant products.
- Site Development, Maintenance and Closure: Employment of these methods may involve establishment and breakdown of specialized facilities. Some techniques produce secondary waste streams requiring testing and disposition. Actual areas should remain relatively stable, and should not require excessive post-process restoration.

5.3.2 Flashing Furnaces

The purpose of flashing furnaces is to thermally remove minor explosives residue from metallic scrap.

5.3.2.1 Description

The systems used in this approach are also known by terms such as deactivation chambers, deactivation furnaces and incinerators. Decontamination is achieved by exposing the scrap to high temperatures (between 600 and 1400 degrees Fahrenheit) for specified periods of time. For example, one system is designed to subject scrap to a temperature over 600 degrees for a cycle between 45 and 90 minutes. Other systems advertise use of higher temperatures for shorter durations.

- Effectiveness compared to other methods: The effectiveness of flashing furnaces is high. Flashing furnaces are highly effective in removing minor explosive residue from metal scrap. This is one of the best methods available for obtaining the highest level (i.e., 5X) decontamination standards.
- Implementability compared to other methods: The implementability is medium. Flashing furnaces require additional facilities and equipment, but not as much as other technologies (e.g., blast chambers). These systems also produce hazardous waste streams requiring further disposition.

5.3.2.2 Applicability and Strengths

Flashing furnaces are a recommended means of disposal for small, loaded-ammunition components such as primers, fuzes, boosters, detonators, activators, relays, delays, and all types of small-arms ammunition. It is also a formally recognized treatment method for explosives scrap, tracer and igniter compositions, small quantities of solid propellant, magnesium powder, sump cleanings, absorbent cleaning materials, and similar materials. Flashing furnaces can also be used to decontaminate target debris that is potentially contaminated with explosives. This may eliminate the need to segregate and separately treat metal debris from ranges. It should be noted that thermal treatment is a proven method of obtaining 5X decontamination of MEC (and related) scrap.

5.3.2.3 Limitations and Weaknesses

Flashing furnaces are generally stationary devices with low mobility. They must be deconstructed and reconstructed at subsequent sites, and establishment at each site must be in accordance with applicable federal and state laws. Recent improvements in this technology, however, have provided some transportable options.

5.3.2.3.1 Flashing furnaces typically have slow feed rates, lengthy wait times for approach, and regularly scheduled inspection requirements; which, negatively affects planned/actual production rates. They also have high maintenance requirements on mechanical parts and heating chambers; toxic residue (e.g., lead and mercury) is produced, requiring disposition in accordance with state/federal environmental laws.

5.3.2.4 Special Considerations

Per DoD 4145.26-M, destruction chambers and incinerators should be equipped with suitable pollution-control devices, such as multiple-chamber incinerators with thermal-incinerator afterburners. Cleaning and maintenance crews will require significant personal protective equipment (PPE) to perform routine tasks in maintaining the system. Flashing furnaces must also be remotely controlled.

5.3.2.4.1 Another related option for certain types of scrap/residue is a contaminated waste processor. A contaminated waste processor handles materials, such as surface contaminated debris, that are lighter and less reactive than those processed in the flashing furnace. Contaminated waste processors are thin-walled, stationary ovens that heat contaminated materials to about 600^{o} C for 3 to 4 hours. The purpose of this process is not to destroy contaminated debris but to sufficiently lower contaminant levels through volatilization to meet Army safety standards.

5.3.2.5 Relative Cost

Flashing furnaces present high relative costs among residue treatment options.

- Man-hours: Restrictions on feed rates and NEW may require repeated manpower intensive activities. These will have to be performed by personnel qualified to handle MEC, who are traditionally some of the highest paid wage workers on MEC sites. In addition, transport of MEC scrap/residue to the vessel/facilities will also require qualified personnel. This will result in relatively high labor costs. Inspection and maintenance must be regularly scheduled, adding downtime to project duration. This methodology will generally require more man-hours than most other options.
- Equipment: Establishment of these facilities should be considered as a high-cost option. Routine maintenance and unscheduled repairs must be taken into consideration as well. Additional equipment may be required in the disposition of resultant waste streams. This method will generally be more expensive than most other options from an equipment perspective.

- Site Development, Maintenance and Closure: Stationary facilities will require siting and construction activities. Maintenance requirements are generally greater than other options. Site closure will require breakdown of constructed facilities and subsequent restoration of areas where they were located.

5.3.3 Shredders and Crushers

Shredders and crushers are intended to deform metallic components of MEC, thus making them unusable for weapons purposes.

5.3.3.1 Description

These technologies use large machines to deform metal components. This results in unusable remnants and overall reduced volume of scrap. Systems range from truck-transportable machines to constructed facilities. The use of commercial metals recycler’s equipment is also included in this option.

- Effectiveness compared to other methods: Medium. Explosive components introduced into the system may still be present after treatment, thus requiring additional processes for full disposal of the MEC.
- Implementability compared to other methods: Low to medium depending on either realization or avoidance of significant facility/equipment requirements.

5.3.3.2 Applicability and Strengths

Some commercial metal recycling companies will commonly purchase and/or accept and process scrap at little or no cost. This could result in project savings. (note: see related caution in the Special Considerations paragraph below). Shredders, crushers and associated equipment (e.g., balers) can potentially reduce the volume of lighter MEC scrap, in turn reducing subsequent transport resources and costs for the project.

5.3.3.2.1 No explosives or chemicals are required for these processes, and little to no secondary waste streams are produced by these processes. Resultant scrap metals can potentially be sold to recyclers.

5.3.3.3 Limitations and Weaknesses

Shredders and crushers offer no integral means of eliminating MEC hazards from scrap and residue. Additional processes and equipment are required, normally prior to shredding and/or crushing operations. In addition, equipment associated with heavy, thick and dense MEC elements is large, expensive and difficult to obtain.

5.3.3.4 Special Considerations

Special consideration must be given to safety issues and associated liabilities when considering the use of commercial metal recycling firms for crushing, shredding or otherwise processing MEC-related scrap. Instances of public exposure to MEC hazards (some with injuries and fatalities) have sensitized public and government entities to these hazards. Particular attention must be paid to the decontamination, QA/QC and documentation processes associated with disposition of MEC scrap/residue.

5.3.3.5 Relative Cost

Shredders and crushers are medium to high cost options, particularly for extended projects.

- Man-hours: Certification of any scrap/residue leaving the site will require careful inspection by qualified personnel (e.g., several hours of UXO QA/QC and Senior UXO Supervisor (SUXOS) personnel). Collection effort will require approximately the same manning as other scrap treatment methods. Project managers should also include consideration for downtime of machinery when estimating personnel costs.
- Equipment: Relative costs for shredding/crushing equipment will be significantly higher than costs of equipment for other methods. Frequent downtime should be anticipated and planned for due to the highly dynamic nature of these processes. Use of commercial recyclers can offset these cost concerns. (See note in the Special Considerations paragraph regarding use of commercial recyclers).
- Site Development, Maintenance and Closure. Establishment of shredder and/or crushing processes on site should be considered a high-cost endeavor at both ends of the project. If processes are conducted on-site, disposition of treated scrap must be included in site closure costs. Use of metals recyclers is a possible cost avoidance measure. (See previous notes regarding use of metals recyclers).

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DISPOSAL TECHNOLOGIES
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APPENDIX A
TECHNOLOGY SUMMARY TABLES

The enclosed tables provide summary descriptions and comparisons of the technologies discussed in the base document. These tables were first developed for and presented at the USAESCH OE MCX Stand Down in December 2004.

Example. Buffalo Ranch, located outside of Rapid City, South Dakota, was used in 1951 during the buildup for the Korean War to refresh and familiarize soldiers in the South Dakota Army National Guard with rifles, machine guns, 60mm and 81 mm mortars, and light antitank rockets. All of the ranges fired from the perimeter of the Ranch toward the center. For the last 43 years, the property has been used for cattle grazing. There are periodic reports of discovery of ordnance on this property. The property is now on the edge of Rapid City and is proposed for residential development. All of the property is comprised of rolling hills of shallow topsoil and sparse vegetation. No vegetation is taller than 36 inches.

Controlling Site Conditions

Munitions Types and Conditions	Terrain/Geography/Soils/Vegetation	Future Uses
Rifle Grenades 60 mm High Explosive (HE) Mortars 60 mm Illumination Mortars 81 mm HE Mortars 3.5 inch HE antitank rockets	Easily Traversable Terrain Minimal Vegetation Non-Magnetic Soils Minimal rocks in soil	Residential Light Industrial Retail/Commercial

Applicable Technologies

	Detection Systems		**Removal**	**Disposal**
	Geophysical Detection	**Navigation**		
Technologies With Promise	Gate Magnetometers	Differential Global Positioning System (DGPS)	Hand Excavation	Blow in Place
	Atomic-Vapor Magnetometers	Robotic Total Station (RTS)	Mechanized Removal of Individual Anomalies	Consolidate and Blow
	Time-Domain Electromagnetic Induction Metal Detectors		Mass Excavation and Sifting	Contained Detonation Chambers
	Frequency-Domain Electromagnetic Induction Metal Detectors	Fiducial Method		Flashing Furnaces
	Sub Audio Magnetics	Odometer Method		Shredders and Crushers
	Magnetometer-Electromagnetic Detection Dual Sensor Systems			
Technologies That Are Not Appropriate	Ground Penetrating Radar	Acoustic	Magnetically Assisted Recovery	Render Safe Procedures
	Airborne Synthetic Aperture Radar	Inertial Navigation	Robotic Removal	Laser Initiation
	Marine Side-Scan Sonar	Laser		Chemical Decontamination
	Airborne Multi- or Hyper- spectral Imagery			
	Airborne Laser and Infrared Sensors			

DISPOSAL TECHNOLOGIES
(Continued)

GEOPHYSICAL DETECTION TECHNOLOGIES

Technology	Effectiveness	Implementability	Cost	Representative Systems	Notes
Flux-Gate Magnetometers	**Medium - High:** Have been used as the primary detector in some highly ranked systems. High industry familiarization. Detects ferrous objects only. Due to gradiometer design, is most adept at detecting smaller, shallow items as opposed to relatively large, deeper items.	**High:** Costs, transportation, and logistics requirements are equal to or less than other systems. Light and compact. Can be used in any traversable terrain. Widely available from a variety of sources	**Low** A number of the Flux-Gate Magnetometers have a low cost for purchase and operation compared to other detection systems. Digital units more costly than analog units.	Schonstedt 52-CX Schonstedt 72-CX Foerster FEREX 4.032 Ebinger MAGNEX 120 LW Foerster Ferex 4.032 Vallon EL1302D1	Analog systems not usually co-registered with navigational data. Digital output should be co-registered with navigational data.
Proton Precession Magnetometers	**Medium:** Proton Precession systems Have similar sensitivities as flux-gate systems, but with a relatively slow sampling rate. Detects ferrous objects only.	**Low - Medium:** Systems are similar to flux-gate systems in terms of operation and support. Generally heavier and require more battery power than flux-gate sensors. Sampling rate low. Can be used in any traversable terrain. Widely available from a variety of sources.	**Medium** Costs are comparable to Flux-Gate systems that acquire digital data.	Geometrics G856AX GEM Systems GSM-19T	Typically used as a base station.
Overhauser Magnetometers	**High:** Sensitivity on the order of 0.02; almost equal to the most sensitive magnetic technology. Not susceptible to “heading error”.	**Low - Medium:** Systems are digital, ruggedized, and weatherproof. Weigh more than most flux-gate systems. Only available from two manufacturers; one specializing in land-based and the other marine.	**Medium – High** Purchase and operating cost higher than analog flux-gate systems and proton precession technology.	GEM Systems GSM-19	Primarily used for land-based and marine applications. Can be susceptible to magnetic noise.
Atomic-Vapor Magnetometers	**High:** Used in several highly ranked systems. High industry familiarization. Detects ferrous objects only.	**High:** Equipment is digital, ruggedized, and weatherproof. Common systems weigh more than most flux-gate systems and are affected by “heading error”. Can be used in most traversable terrain. Widely available from a variety of sources. Processing and interpretation requires trained specialists. Discrimination possibilities are limited to magnetic susceptibility/magnetic moment estimates and depth estimates. Detection capabilities are influenced by iron-bearing soils.	**High** High purchase cost compared to other discussed technologies. Less when arrays of multiple detectors are used.	Geometrics G-858 Geometrics G-822 Geometrics 880 Geometrics 882 GEM Systems GSMP-40 Scintrex Smart Mag G-tek TM4	Digital signal should be co-registered with navigational data.
Time-Domain Electromagnetic Induction Metal Detectors	**High:** Used in several highly ranked systems. High industry familiarization. Developed to detect small, metal objects. Detects both ferrous and non-ferrous metallic objects.	**High:** Equipment is portable and ruggedized for use in various terrain and weather conditions. Some systems are heavier and consume more power than magnetometers. Typically utilizes transceiver coil that is one meter wide, but smaller versions are also available. Most commonly used instrument is widely available. Processing and interpretation are relatively straightforward. Discrimination possibilities exist for multi-channel systems.	**Medium – High** Common analog metal detectors are comparable in cost to analog fluxgate magnetometers. Digital systems comparable in cost to Overhauser and Atomic Vapor Magnetometers. Less when arrays of multiple detectors are used.	Geonics EM61 MKI and MKII Geonics EM 63 Zonge Nanotem G-tek TM5-EMU Vallon VMH3	Digital signal should be co-registered with navigational data. Detection depths are highly dependent on coil size and power.
Frequency-Domain Electromagnetic Induction Metal Detectors	**Medium - High:** Some digital units are the primary detector in highly-ranked systems. Demonstrated capability for detecting small items using hand held units. Not optimum for detecting deeply buried objects. High industry familiarization. Detects both ferrous and non-ferrous metallic objects.	**High:** Hand-held detectors are generally light, compact, and ergonomic. Most handheld. Widely available from a variety of sources. Discrimination possibilities exist among some multi-channel systems and some handheld systems.	**Medium-High** Less when arrays of multiple detectors are used. Common handheld metal detectors much lower cost than digital systems.	Schiebel ANPSS-12 White's All Metals Detector Fisher 1266X Geophex GEM 2 and 3 Geonics EM31 and EM34 Apex Max-Min	Analog systems not usually co-registered with navigational data. Digital output should be co-registered with navigational data.
Ground Penetrating Radar	**Low:** Extremely sensitive systems that respond to changes in the magnetic, conductive, and dielectric properties of the subsurface. GPR has a very low success rates as a stand-alone MEC detection system. GPR will detect both metallic and non-metallic objects, but is susceptible to numerous environmental/geological conditions. Medium industry familiarization.	**Low:** Man portable systems are cumbersome to operate in varying terrains with thick vegetation. Power requirements higher than most magnetometer and EMI systems. System requires skilled operators.	**High** GPR Systems are approximately 1.5 to 2 times the cost of comparable magnetometer and EMI systems.	GSSI SIR2, SIR3, SIR8, SIR10 Sensors and Software Pulse Ekko and Noggin RAMAC Mala	Data output is usually viewed in either transects or 2D time slices. These have not been demonstrated to be as successful as profile outputs.
Sub Audio Magnetics	**Medium - High:** Detects both ferrous and non-ferrous metallic objects. Capable tool for detection of deep MEC. Low industry familiarization.	**Low:** High data processing requirements. Only available from one source. High power requirements. Longer than average setup times.	**High** Higher than average operating costs and very low availability.	G-tek SAM	Not commercially available. No established track record.

Magnetometer-Electromagnetic Detection Dual Sensor Systems	**High:** Detects both ferrous and non-ferrous metallic objects. Medium industry familiarization. Higher potential for discrimination.	**Medium - High:** Higher data processing requirements. Available from few sources.	**High** Lower costs obtained by using a towed array platform. Low availability.	GEOCENTERS AETC MTADS	Available from only a few sources.

DISPOSAL TECHNOLOGIES
(Continued)

GEOPHYSICAL DETECTION TECHNOLOGIES

Technology	Effectiveness	Implementability	Cost	Representative Systems	Notes
Marine Side-Scan Sonar	**Low:** Visualizes shapes of both metallic and non-metallic objects. Only detects items on surface of water body floor. Low industry familiarization.	**Medium:** Requires trained operator, experienced field crew; calm water may be needed. Vegetation can hinder acoustic signal propagation.	**High** for marine investigations.	Klein 5500, EdgeTech DF-1000, Triton Elics Sonar Suite, GeoAcoustics, Fishers SSS-100K/600K, Marin Sonic Technologies	Few have applied these technologies to the MEC problem.
Airborne Multi- or Hyper-spectral Imagery	**Low:** Detects both metallic and non-metallic objects. Only detects largest MEC. Requires line of sight. Low industry familiarization. Effectiveness increases when used for wide area assessment in conjunction with other airborne technologies.	**Low:** Requires aircraft and an experienced pilot. Also requires substantial data processing and management. Available from few sources.	**High** Requires aircraft operation and has high maintenance and data processing costs.	There are many multi/hyper spectral imagery providers.	Few have applied these technologies to the MEC problem.
Airborne Synthetic Aperture Radar	**Low:** Detects both metallic and non-metallic objects. Only detects largest MEC. Requires line of sight. Medium industry familiarization. Effectiveness increases when used for wide area assessment in conjunction with other airborne technologies.	**Low:** Requires aircraft platform, increased power, and robust data recording systems. Also require substantial data processing and management. Available from few sources.	**High** Requires aircraft operation and has high maintenance and data processing costs.	--	Few have applied these technologies to the MEC problem.
Airborne Laser and Infrared Sensors	**Low:** Detects both metallic and non-metallic objects. Low industry familiarization. Effectiveness increases when used for wide area assessment in conjunction with other airborne technologies.	**Low:** Requires aircraft and an experienced pilot. Also requires substantial data processing and management. Available from few sources.	**High** Requires aircraft operation and has high maintenance and data processing costs.	--	Few have applied these technologies to the MEC problem.

POSITIONING AND NAVIGATION TECHNOLOGIES

Technology	Effectiveness	Implementability	Cost	Representative Systems	Notes
Differential Global Positioning System (DGPS)	**Medium**: Very effective in open areas for both digital mapping and reacquiring anomalies. Very accurate when differentially corrected. Not effective in wooded areas or near large buildings. Commonly achieved accuracy is a few cm; but degrades when minimum satellites are available.	**High**: Easy to operate and setup. Requires trained operators. Available from a number of vendors. Better systems are typically ruggedized and very durable. Some work time is lost when insufficient satellites are available.	**Low**: High-end system available for $100-200 per day.	Leica GPS 1200 Trimble Model 5800 Thales Ashtech Series 6500	Recommended in open areas.
RANGER	**Medium - High** Can effectively survey open, vegetated, or cluttered areas with varying degrees of position accuracy. Can be set up over a 5-acre area.	**Medium** Technique has not been successfully demonstrated on numerous MEC projects.	**Medium – High** Purchase price estimated to be $20,000 to $30,000**.**	Ensco	There is only one manufacturer of the equipment for this technology. Limited supply at this time
Robotic Total Station (RTS)	**Medium**: Very effective in open areas for both digital mapping and reacquiring anomalies. Effective near buildings and sparse trees. Commonly achieved accuracy is a few cm.	**Medium**: Easy to operate. Requires existing control.	**Low**: System available for $150-200 per day.	Leica TRS 1100 Trimble Model 5600	Recommended near houses or in open areas that have a high tree line.
Laser	**High**: Very effective in wooded areas. Can be used in open areas though limited due to range of transmitters. Extremely accurate positioning system. Commonly achieved accuracy is a few cm	**Low**: Technology has a time consuming setup due to numerous parts and connections . Equipment not ruggedized.	**Medium**: System available for less $200 per day.	ArcSecond “In-door GPS” (Constellation)	Recommended in wooded areas.
Fiducial Method	**Medium**: Medium effectiveness when performed by experienced personnel. Low effectiveness when used by inexperienced personnel. Commonly achieved accuracy is 15-30 cm	**Low**: Difficult to use, requires constant pace, detailed field notes and elaborate setup.	**Low**: Minimal direct costs associated with this method. Similar to Fiducial method.	NA	Requires very capable operators. Useful method if digital positioning systems are unavailable.
Odometer Method	**Medium**: Medium effectiveness when performed by experienced personnel. Low effectiveness when used by inexperienced personnel. Commonly achieved accuracy is 15-30 cm	**Low**: Setup and operation effected by terrain/environment. Requires detailed field notes and lengthy setup. Similar to Fiducial Methods.	**Low**: Very little costs associated with this technology.	NA	--
Acoustic	**Medium-Low**: Not very efficient in open areas due to substantial calibration setup time. Reasonably effective in wooded areas although less accurate then other methods. Commonly achieved accuracy is 10-30cm.	**Low**: This technology is difficult to setup and there is minimal available support. Negatively affected by certain aspects of environment.	**Medium**: System available for around $200 per day.	USRADS	Has been used extensively in wooded areas with success.
Inertial Navigation	**Low - Medium**: Very time consuming with below average accuracy. Accuracy of 4 to 6 cm (open area) is commonly achieved shortly after refreshing baseline data; but degrades quickly with time. Required frequency of refreshing baseline significantly reduces production rates.	**Low**: Difficult to operate, limited support.	**High**: Expensive to purchase or rent.	Ranger	This technology is still under development.

REMOVAL TECHNOLOGIES

Technology	Effectiveness	Implementability	Cost	Representative Systems	Notes
Hand Excavation	**Medium**: This is the industry standard for MEC recovery. It can be very thorough and provides good data on items collected.	**High**: Hand excavation can be accomplished in almost any terrain and climate. Limited only by the number of people available.	**Average**: As the standard by which all others are measured.	Probe, Trowel, Shovel, Pick Axe	Locally available and easily replaced tools.
Mechanized Removal of Individual Anomalies	**Medium**: Used in conjunction with hand excavation when soil is so hard it causes time delays. Method works well for the excavation of single anomalies or larger areas of heavy ferrous metal concentartion.	**High**: Equipment can be rented almost anywhere and is easy to operate. Allows excavation of anomalies in hard soil and to clear large areas with substantial metal concentration.	**Low**: In hard soil this method has a lower cost than that of having the single anomalies hand excavated.	Tracked Mini-Excavator, bull dozers, loaders, etc. Multiple manufacturers	Equipment is easy to rent and to operate.
Mass Excavation and Sifting	**High**: Process works very well in areas of heavy MEC concentration. Can separate several different sizes of material allowing for large quantities of soil to be returned with minimal screening for MEC.	**Medium**: Earth moving equipment is readily available. However, armoring is not as widely available. Equipment is harder to maintain and may require trained heavy equipment operators. Not feasible for large explosively-configured munitions.	**High**: Earth moving equipment is expensive to rent and insure and has the added expense of high maintenance cost.	**Earth Moving Equipment**: Many brands of heavy earth moving equipment are available including excavators, off road dump trucks, and front-end loaders. **Sifting Equipment**: Trommel, Shaker, Rotary Screen from varying manufacturers.	Can be rented, armor installed, and delivered almost anywhere. Significant maintenance costs.
Mechanized Soil Processing	**High** Mechanized processing systems are a proven technology for removing MEC and other solid materials from soil.	**High** Equipment and references for planning and operations are readily available.	**Medium - High** Acquisition and operation of these systems is initially expensive, though savings may be realized for large economy of scale efforts.	A wide variety of equipment and suppliers are available for shaker and trommel systems.	Use of magnetic technology (rollers) can augment capabilities for some MEC applications.
Magnetically Assisted Recovery	**Low**: Primarily used in conjunction with mass excavation and sifting operations. Can help remove metal from separated soils, but does not work well enough to eliminate the need to inspect the smaller size soil spoils. Magnetic systems are also potentially useful to help with surface clearance of frag and surface debris.	**High**: Magnetic rollers are easily obtained from the sifting equipment distributors and are designed to work with their equipment.	**Low**: This method adds very little cost to the already expensive sifting operation.	Magnetic rollers or Magnetic pick ups are available from many manufacturers of the sifting equipment noted above.	Installed by sifting equipment owners.
Remotely Operated Removal Equipment	**Low**: Remotely operated equipment reduces productivity and capability of the equipment. Method is not widely used and is not yet proven to be an efficient means of MEC recovery.	**Low**: Uses earth moving equipment, both mini-excavator type and heavier off road earth moving equipment. Machinery is rigged with hydraulic or electrical controls to be operated remotely.	**High**: Has a combined cost of the base equipment plus the remote operating equipment and an operator. Remote operation protects the operator, but can create high equipment damage costs.	Many tracked excavators, dozers, loaders and other equipment types have been outfitted with robotic remote controls.	EOD robots are almost exclusively used for military and law enforcement reconnaissance and render-safe operations. They were not evaluated for MEC applications.

DISPOSAL TECHNOLOGIES

Technology	Effectiveness	Implementability	Cost	Representative Systems	Notes
Blow in Place	**High** Each MEC item is individually destroyed with subsequent results individually verified (QC/QA).	**High** Field-proven techniques, transportable tools and equipment, suited to most MEC environments. Public exposure can limit viability of this option. Engineering controls can further improve implementation.	**Low** Manpower intensive. Costs increase in areas of higher population densities or where public access must be monitored/controlled.	Electric demolition procedures; non-electric demolition procedures.	Disposition of resultant waste streams must be addressed in BIP operations planning. Waste streams produced by BIP are not contained and thus not as easily dealt with. As regulatory agencies become more involved in MEC projects, this may yield higher life cycle cost for waste (for characterization, treatment and disposal) than technologies that do contain the waste streams.
Consolidate and Blow	**High** Techniques recently developed and refined in Iraq are providing documented successes. Use of donor munitions also proving effective. Limited in use to munitions that are "safe to move".	**Medium - High** Generally employs same techniques, tools and equipment as BIP. Requires larger area and greater controls. Most engineering controls not completely effective/applicable for these operations.	**Medium** Manpower intensive, may require MHE for large scale operations.	Electric demolition procedures; non-electric demolition procedures; forklifts and cranes.	Disposition of resultant waste streams must be addressed. Increased areas require additional access and safety considerations. Waste streams produced by consolidated and blow are not contained and thus as easily dealt with. As regulatory agencies become more involved in the projects, this may yield higher life cycle costs for waste (for characterization, treatment and disposal) than technologies that do contain waste streams. This could be of even greater concern in consolidate and blow operations where there will be more residual generated and thus potentially greater concentrations of regulated analytes
Laser Initiation	**Low - Medium** Still in development, though currently deployed in Iraq for testing. Tests show positive results for 81mm and below, with reported success on munitions up to 155mm. Produces low-order type effect; subsequent debris still requires disposition.	**Low - Medium** MEC targets must be exposed/on surface for attack by directed beam. GATOR Laser System (Diode Laser Neutralization via Fiber-Optic Delivered Energy) does not require line-of-sight within approximately 100m. GATOR system does require approach and placement of fiber-optic cable at appropriate position of MEC. Laser systems still addressing power, configuration, transportability and logistics issues.	**Low - Medium** Greatly reduced manpower; added equipment, transportability and logistics concerns; no explosives required by system.	ZEUS-HLONS GATOR LASER	Offers added safety through significant standoff (up to 300m). (note: acceptable safety standoffs must be evaluated for specific MEC and scenarios). ZEUS prototype deployed/employed in Afghanistan (2003). Waste streams produced by laser initiation are not contained and are thus not as easily dealt with. As regulatory agencies become more involved in MEC projects, this may yield higher life cycle costs for waste (for characterization, treatment and disposal) than technologies that do contain waste streams. This may be of even more concern with laser initiated detonation/deflagration as residual contamination may be higher than with traditional BIP. Low order detonations could potentially yield greater environmental contamination than successful BIP operations.
Contained Detonation Chambers - Stationary	**High** Chambers successfully contain hazardous components. Current literature reviewed shows containment up to 35 lbs (assume NEW). Commonly used for fuzes and smaller explosive components.	**Low - Medium** Stationary facilities typically must meet regulatory and construction standard for permanent/semi-permanent waste disposal facilities. Service life and maintenance are issues. Requires additional handling of MEC. Flashing furnaces have low feed rates due to safety concerns. Produces additional hazardous waste streams.	**High** Siting and construction required. Low feed rates = more hours on-site. Significant requirements for maintenance of system.	Typically designed on case-by-case basis.	System cleaning and maintenance usually requires PPE and worker training. Probable permitting issues with employment of technology.
Contained Detonation Chambers -	**High**	**Medium - High**	**Medium - High**	Donovan Blast Chamber	System cleaning and maintenance usually

DISPOSAL TECHNOLOGIES
(Continued)

Technology	Effectiveness	Implementability	Cost	Representative Systems	Notes
Mobile	Chambers successfully contain hazardous components. Current literature reviewed shows containment up to 35 lbs (assume NEW). Commonly used for fuzes and smaller explosive components.	Designed to be deployed at the project site. Greatly reduced footprint compared to stationary facilities. Service life and maintenance are issues. Requires additional handling of MEC. Produces additional hazardous waste streams	Possible Construction required (e.g., berms and pads). Low feed rates = more hours on site. Significant requirements for maintenance of system.	Kobe Blast Chamber	requires PPE and worker training. Possible permitting issues with employment of technology (on other than CERCLA/FUDS sites). The fact that these waste stream is contained and is more easily dealt with (even when hazardous) is an advantage both in terms of public perception and in life cycle cost.
Disassembly or Render Safe Procedures	**Low** Hazardous components may remain intact after procedure. Some procedures may expose hazardous materials inadvertently or intentionally. Lower probability of success compared to other methods. Presents significant danger to personnel conducting disposal operations.	**Low** Significant personnel exposure in implementation. Specialized tools and equipment commonly are required.	**Medium to High** Manpower intensive, specialized tools and equipment required.	Manual Disassembly Mechanical Disassembly Explosive Dearmer Cryofracture	Procedures not commonly applied even by authorized military EOD personnel, except in rare circumstances.

MEC RESIDUE TREATMENT TECHNOLOGIES

Technology	Effectiveness	Implementability	Cost	Representative Systems	Notes
Chemical Decontamination	**Low to Medium** Great variance in chemicals required to decontaminate various MEC (e.g., propellants, pyrotechnics, explosives). Difficult to test for effectiveness of many methods. May generate additional waste streams (some hazardous).	**Low to Medium** Requires containment of multiple hazardous materials (e.g., MEC and solvents). May require emissions controls. Worker training and PPE typically required.	**Medium to High** Specialized manpower, containment requirements, additional waste stream processing.	Supercritical Water Oxidation (SCWO) Photocatalysis Molten Salt Oxidation (MSO)	--
Flashing Furnaces	**High** Furnaces are designed to contain hazardous components. Methods are proven means of attaining high degrees (5X) of decontamination. Commonly used to destroy and decontaminate fuzes and smaller explosive components.	**Medium** Typically stationary facilities. Service life and maintenance are issues. Requires additional handling of MEC. Flashing furnaces have low feed rates due to safety concerns. Produces additional hazardous waste streams.	**High** Possible Construction required. Low feed rates = more hours on site. Maintenance of system.	Rotary kiln incinerator Explosive waste incinerator (EWI) Transportable flashing furnace	System cleaning and maintenance usually requires PPE and worker training. May require permit to deploy technology.
Shredders and Crushers	**Medium** Renders small arms, fuzes and other components inoperable. Residue will typically still require additional treatment to achieve higher decontamination levels.	**Low to Medium** Typically stationary facilities. Service life and very high maintenance are expected. Requires additional handling of MEC.	**Medium to High** Specialized equipment and operators. High maintenance. Additional waste stream processing.	Shred Tech ST-100H Roll-Off (vehicle mounted)	Disposition of resultant waste streams must be addressed.

Note regarding shipment to landfill: Shipment to landfill would be a disposition. Residue would require treatment prior to shipment.

APPENDIX B

SENSOR TECHNOLOGY & DATA ACQUISITION PLATFORM EXAMPLES

Man-Portable Data Acquisition Platforms

Single-Sensor

G858 Cesium Vapor Magnetometer
with rtk DGPS and swath guidance bar
Courtesy of Geometrics web site

GEM 3 FDEM/TDEM
with DGPS
Courtesy of Geophex web site

GEM 3 FDEM/TDEM cart with DGPS
Courtesy of Geophex web site

EM61 MKII TDEM with DGPS

EM61 TDEM cart w/ USRADS, DGPS, and
RTS Test Program

E G858 cesium magnetometer cart
Courtesy of Geometrics web site

Multiple-Sensor

Cesium vapor magnetometer sensors

G858 cesium vapor magnetometer (4 sensors) with RTS
Courtesy of Geometrics web site

Multiple-Sensor Vehicle-Towed Data Acquisition Platforms

MTADS cesium vapor magnetometer array with rtk DGPS
Courtesy of Geometrics web site

MTADS EM61 TDEM array with rtk DGPS
Courtesy of Geometrics web site

EM61 MKII TDEM VTA with rtk DGPS

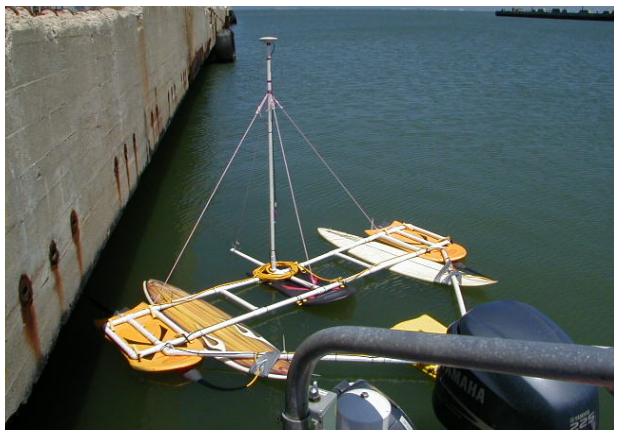
Airborne cesium vapor magnetometer array
with rtk DGPS

G858 cesium vapor magnetometer with rtk DGPS
Courtesy of Geometrics web site

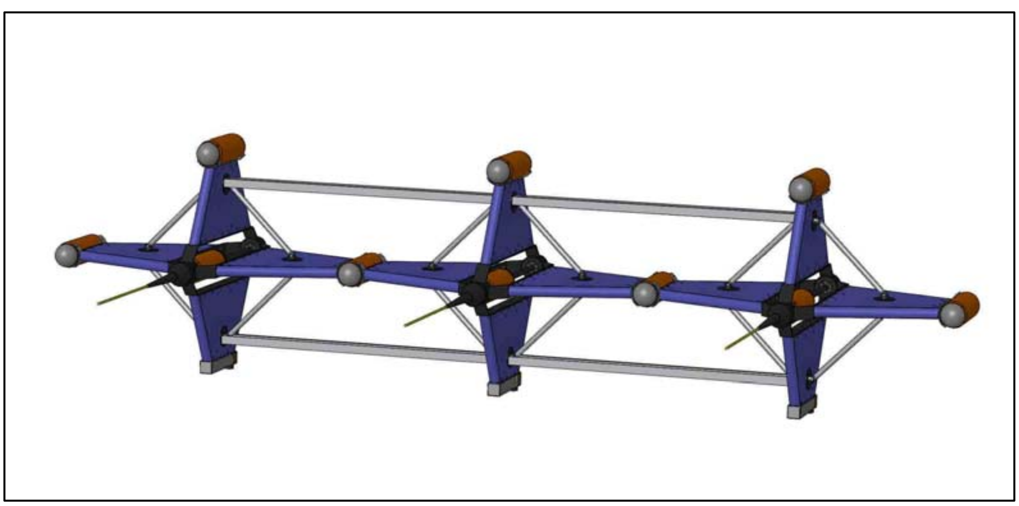
Marine Data Acquisition Platforms

GEM 3 FDEM/TDEM with rtk DGPS
Courtesy of Geophex web site

EM61 MKII TDEM with DGPS



G882 magnetometer with rtk DGPS



Marine Overhauser magnetometer array