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Handbook on the Management of Ordnance and Explosives at Closed,Transferred, and Transferring Ranges

DRAFT

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GLOSSARY OF TERMS

Anomaly. A geophysical signal above geological background from a detected subsurface object.

Archives search report. A detailed investigation to report past OE activities conducted on an installation.

Arming device. A device designed to perform the electrical and/or mechanical alignment necessary to initiate an explosive train.

Blast overpressure. The pressure, exceeding the ambient pressure, manifested in the shock wave of an explosion.

Blow-in-place. To destroy UXO, by use of explosives, in the location the item is encountered.

Buried munitions. Munitions that have been intentionally discarded by being buried with the intent of disposal. Such munitions may be either used or unused military munitions. Such munitions do not include unexploded ordnance that become buried through product use.

Caliber. The diameter of a projectile or the diameter of the bore of a gun or launching tube. Caliber is usually expressed in millimeters or inches. In some instances (primarily with naval ordnance), caliber is also used as a measure of the length of a weapon's barrel. For example, the term "5 inch 38 caliber" describes ordnance used in a 5-inch gun with a barrel length that is 38 times the diameter of the bore.

Cancer slope factor. A plausible upper-bound estimate of the probability of an individual developing cancer as a result of a lifetime of exposure to a particular level of a potential carcinogen.

Casing. The fabricated outer part of ordnance designed to hold an explosive charge and the mechanism required to fire this charge.

Chemical agent. A substance that is intended for military use with lethal or incapacitating effects upon personnel through its chemical properties.

Clearance. The removal of UXO from the surface or subsurface to a preestablished depth.

Closed range. A range that has been taken out of service and either has been put to new uses that are incompatible with range activities or is not considered by the military to be a potential range area. A closed range is still under the control of the military.

Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). CERCLA, commonly known as Superfund, is a Federal law that provides for the cleanup of releases from abandoned waste sites that contain hazardous substances, pollutants, and contaminants.

DoD Explosives Safety Board (DDESB). The DoD organization charged with promulgation of ammunition and explosives safety policy and standards, and with reporting on the effectiveness of the implementation of such policy and standards.

Deflagration. A rapid chemical reaction in which the output of heat is enough to enable the reaction to proceed and be accelerated without input of heat from another source. The effect of a true deflagration under confinement is an explosion. Confinement of the reaction increases pressure, rate of reaction, and temperature, and may cause transition into a detonation.

Demilitarization. The act of disassembling chemical or conventional military munitions for the purpose of recycling, reclamation, or reuse of components. Also, rendering chemical or conventional military munitions innocuous or ineffectual for military use. The term encompasses various approved demilitarization methods such as mutilation, alteration, or destruction to prevent further use for its originally intended military purpose.

Depleted uranium. After uranium ore is processed to remove most of the fissile isotope (235U), the residual material is referred to as depleted uranium. It is primarily used for purposes requiring high-density material and is used in weapons fabrication.

Detonation. A violent chemical reaction within a chemical compound or mechanical mixture evolving heat and pressure. The result of the chemical reaction is exertion of extremely high pressure on the surrounding medium, forming a propagating shock wave that originally is of supersonic velocity. A detonation, when the material is located on or near the ground surface, is normally characterized by a crater.

Dud-fired. Munitions that failed to function as intended or as designed. They can be armed or unarmed or at some stage in between.

Electromagnetic induction. Transfer of electrical power from one circuit to another by varying the magnetic linkage.

EOD incident. The suspected or detected presence of a UXO or damaged military munition that constitutes a hazard to operations, installations, personnel, or material. Not included are accidental arming or other conditions that develop during the manufacture of high explosives material, technical service assembly operations, or the laying of landmines or demolition charges.

Explosion. A chemical reaction of any chemical compound or mechanical mixture that, when initiated, undergoes a very rapid combustion or decomposition, releasing large volumes of highly heated gases that exert pressure on the surrounding medium. Also, a mechanical reaction in which failure of the container causes sudden release of pressure from within a pressure vessel. Depending on the rate of energy release, an explosion can be categorized as a deflagration, a detonation, or pressure rupture.

Explosive. A substance or mixture of substances that can undergo a rapid chemical change without an outside source of oxygen, generating large quantities of energy generally accompanied by hot gases.

Explosive ordnance disposal. The detection, identification, field evaluation, rendering-safe recovery, and final disposal of unexploded ordnance or munitions. It may also include the rendering-safe and/or disposal of explosive ordnance (EO), which has become hazardous by damage or deterioration, when the disposal of such EO is beyond the capabilities of the personnel normally assigned the responsibilities for routine disposal.

Explosive soil. Explosive soil refers to any mixture of explosives in soil, sand, clay, or other solid media at concentrations such that the mixture itself is explosive.

Explosives safety. A condition in which operational capability, personnel, property, and the environment are protected from the unacceptable effects of an ammunition or explosives mishap.

Explosives safety submission. The document that serves as the specifications for conducting work activities at the project. It details the scope of the project, the planned work activities and potential hazards, and the methods for their control.

False alarm. The incorrect classification of subsurface ordnance as clutter (e.g., fragments of exploded ordnance or naturally occurring substances) or of clutter as ordnance.

Formerly Used Defense Sites (FUDS). Real property that was formerly owned by, leased by, possessed by, or otherwise under the jurisdiction of the Secretary of Defense or the components, including organizations that predate DoD.

Fragmentation. The breaking up of the confining material of a chemical compound or mechanical mixture when an explosion occurs. Fragments may be complete items, subassemblies, or pieces thereof, or pieces of equipment or buildings containing the items.

Fuze. 1. A device with explosive components designed to initiate a train of fire or detonation in ordnance. 2. A nonexplosive device designed to initiate an explosion in ordnance.

Gradiometer. Magnetometer for measuring the rate of change of a magnetic field.

Ground penetrating radar. A system that uses pulsed radio waves to penetrate the ground and measure the distance and direction of subsurface targets through radio waves that are reflected back to the system.

Hazard Ranking System (HRS). The principal mechanism EPA uses to place waste sites on the NPL. It is a numerically based screening system that uses information from initial, limited investigations — the preliminary assessment and the site inspection — to assess the relative potential of sites to pose a threat to human health or the environment.

Illumination. Term applied to ordnance indicating that it is primarily intended to produce light of high intensity. Such ordnance usually contains a flare and may contain a parachute for suspension in the air.

Incendiary. Any flammable material that is used as a filler in ordnance intended to destroy a target by fire.

Installation Restoration Program (IRP). A program within DoD that funds the identification, investigation, and cleanup of hazardous substances, pollutants, and contaminants associated with past DoD activities at operating and closing installations, and at FUDS.

Institutional controls. Nonengineering measures designed to prevent or limit exposure to hazardous substances left in place at a site or assure effectiveness of the chosen remedy. Institutional controls are usually, but not always, legal controls, such as easements, restrictive covenants, and zoning ordnances.

Land use controls. Any type of physical, legal, or administrative mechanism that restricts the use of, or limits access to, real property to prevent or reduce risks to human health and the environment.

Lead agency. The agency that provides the on-scene coordinator or remedial project manager to plan and implement response actions under the NCP....In the case of a release or a hazardous substance, pollutant, or contaminant, where the release is on, or the sole source of the release is from, any facility or vessel under the jurisdiction, custody or control of Department of Defense (DoD) or Department of Energy (DOE) then DoD or DOE, will be the lead agency.

Magnetometer. An instrument for measuring the intensity and direction of magnetic fields.

Materiel. All items necessary for the equipment, maintenance, operation, and support of military activities without distinction as to their application for administrative or combat purposes; excludes ships or naval aircraft.

Maximum credible event. The worst single event that is likely to occur from a given quantity and disposition of ammunition and explosives. Used in hazards evaluation as a basis for effects calculations and casualty predictions.

Military Munition. All ammunition products and components produced or used by or for DoD or the U.S. Armed Services for national defense and security, including military munitions under the control of the Department of Defense, the U.S. Coast Guard, the U.S. Department of Energy (DOE), and National Guard personnel. The term military munitions includes: confined gaseous, liquid, and solid propellants, explosives, pyrotechnics, chemical and riot control agents, smokes, and incendiaries used by DoD components, including bulk explosives and chemical warfare agents, chemical munitions, rockets, guided and ballistic missiles, bombs, grenades, demolition charges, and devices and components thereof. Military munitions do not include wholly inert items, improvised explosive devices, and nuclear weapons, nuclear devices, and nuclear components thereof. However, the term does include non-nuclear components of nuclear devices, managed under DOE's nuclear weapons program after all required sanitization operations under the Atomic Energy Act of 1954, as amended, have been completed.

Mishap. An accident or an unexpected event involving DoD ammunition and explosives.

Most probable munition. The round with the greatest hazardous fragment range that can reasonably be expected to exist in any particular OE area.

The National Oil and Hazardous Substances Pollution Contingency Plan (NCP). The regulations for responding to releases and threatened releases of hazardous substances, pollutants, or contaminants.

National Priorities List (NPL). A national list of hazardous waste sites that have been assessed against the Hazard Ranking System and score above 28.5. The listing of a site on the NPL takes places under the authority of CERCLA and is a regulatory effort that is published in the *Federal Register*.

Obscurant. Man-made or naturally occurring particles suspended in the air that block or weaken the transmission of a particular part or parts of the electromagnetic spectrum.

On-scene coordinator (OSC). The Federal official predesignated by the EPA or the U.S. Coast Guard or the official designated by the lead agency to coordinate and direct response actions.

Open burning. The combustion of any material without (1) control of combustion air to maintain adequate temperature for efficient combustion, (2) containment of the combustion-reaction in an enclosed device to provide sufficient residence time, and (3) mixing for complete combustion and control of emission of the gaseous combustion products.

Open detonation. A chemical process used for the treatment of unserviceable, obsolete, and or waste munitions whereby an explosive donor charge initiates the munitions to be detonated.

Ordnance and explosives (OE). OE consists of (1) ammunition, ammunition components, chemical or biological warfare materiel, and explosives that have been abandoned, expelled from demolition pits or burning pads, discarded, buried, or fired. Such ammunition, ammunition components, and explosives are no longer under accountable record control of any DoD organization or activity. (2) Soil presenting explosive hazards (see "explosive soil"). (3) Buildings with explosive residues that present explosive hazards. The term OE is used at various places in the handbook where requirements apply to all OE, not just UXO.

Ordnance and explosives area (OE area). Any area that may contain ordnance and explosives and that requires an explosives safety plan prior to investigation and/or cleanup. Entire ranges or subparts of ranges may be OE areas that are the target of investigation and cleanup activities.

Other constituents. Potentially hazardous chemicals that are located on or originate from CTT ranges and are released from military munitions or UXO, or have resulted from other activities on military ranges. Other constituents may be subject to other statutory authorities, including, but not limited to, CERCLA (42 U.S.C. 9601, *et seq.*) and RCRA (42 U.S.C. 6901, *et seq.*).

Overpressure. The blast wave or sudden pressure increase resulting from a violent release of energy from a detonation in a gaseous medium.

Preliminary assessment (PA) and site inspection (SI). A PA/SI is a preliminary evaluation of the existence of a release or the potential for a release. The PA is a limited-scope investigation based on existing information. The SI is a limited-scope field investigation. The decision that no further action is needed or that further investigation is needed is based on information gathered from one or both types of investigation. The results of the PA/SI are used by DoD to determine if an area should be designated as a "site" under the Installation Restoration Program. EPA uses the information generated by a PA/SI to rank sites against Hazard Ranking System criteria and decide if the site should be listed on the NPL.

Projectile. An object projected by an applied force and continuing in motion by its own inertia, as a bullet, bomb, shell, or grenade. Also applied to rockets and to guided missiles.

Propellant. An agent such as an explosive powder or fuel that can be made to provide the necessary energy for propelling ordnance.

Quantity-distance (Q-D). The relationship between the quantity of explosive material and the distance separation between the explosive and people or structures. These relationships are based on levels of risk considered acceptable for protection from defined types of exposures. These are not absolute safe distances, but are relative protective or safe distances.

Range. Any designated land mass or water body that is or was used for the conduct of training, research, development, testing, or evaluation of military munitions or explosives.

Real property. Lands, buildings, structures, utilities systems, improvements, and appurtenances thereto. Includes equipment attached to and made part of buildings and structures (such as heating systems) but not movable equipment (such as plant equipment).

Record of decision (ROD). A public decision document for a Superfund site that explains the basis of the remedy decision and, if cleanup is required, which cleanup alternative will be used. It provides the legal record of the manner in which the selected remedy complies with the statutory and regulatory requirements of CERCLA and the NCP.

Reference dose (RfD). An estimate of a daily exposure level for the human population, including sensitive subpopulations, that is likely to be without an appreciable risk of deleterious effects.

Remedial action. A type of response action under CERCLA. Remedial actions are those actions consistent with a permanent remedy, instead of or in addition to removal actions, to prevent or minimize the release of hazardous substances into the environment.

Remedial design (RD). The phase in CERCLA site cleanup during which the technical specifications for cleanup remedies and technologies are designed.

Remedial investigation/feasibility study (RI/FS). The RI/FS is the process used under the remedial program to investigate a site, determine if action is needed, and select a remedy that (a) protects human health and the environment; (b) complies with the applicable or relevant and appropriate requirements; and (c) provides for a cost-effective, permanent remedy that treats the principal threat at the site to the maximum extent practicable. The RI serves as the mechanism for collecting data to determine if there is a potential risk to human health and the environment from releases or potential releases at the site. The FS is the mechanism for the developing, screening, and evaluating of alternative remedial actions against nine criteria outlined in the NCP that guide the remedy selection process.

Remedial project manager (RPM). The official designated by the lead agency to coordinate, monitor, and direct remedial or other response actions.

Removal Action. Short-term response actions under CERCLA that address immediate threats to public health and the environment.

Render safe procedures. The portion of the Explosive Ordnance Disposal Procedure, which is designed to preclude the detonation or functioning of explosive ordnance, that involves the application of special military EOD techniques.

Resource Conservation and Recovery Act (RCRA). The Federal statute that governs the management of all hazardous waste from cradle to grave. RCRA covers requirements regarding identification, management, and cleanup of waste, including (1) identification of when a waste is solid or hazardous; (2) management of waste — transportation, storage, treatment, and disposal; and (3) corrective action, including investigation and cleanup, of old solid waste management units.

Response action. This term is defined in Section 101 of CERCLA and means "remove, removal, remedy, or remedial action..." As used in this handbook, the term response action incorporates cleanup or clearance activities undertaken under any statutory authority.

Smoke. 1. Filling for ordnance such as bombs, projectiles, and grenades. 2. Term applied to ordnance indicating that it is primarily intended to produce smoke of the types or colors specified.

Transferred ranges. Ranges that have been transferred from DoD control to other Federal agencies, State or local agencies, or private entities (e.g., formerly used defense sites, or FUDS). A military range that has been released from military control.

Transferring ranges. Ranges in the process of being transferred from DoD control (e.g., sites that are at facilities closing under the Base Realignment and Closure Act, or BRAC). A military range that is proposed to be leased, transferred, or returned from the Department of Defense to another entity, including Federal entities.

Unexploded ordnance (UXO). Military munitions that have been primed, fused, armed, or otherwise prepared for action, and that has been fired, dropped, launched, projected, or placed in such a manner as to constitute a hazard to operations, installation, personnel, or material and that remains unexploded by malfunction, design, or any other cause.

Warhead. That part of a missile, projectile, rocket, or other munition that contains the explosive system, chemical or biological agents, or inert materials intended to inflict damage.

Waste Military Munition. An unused munition that has been abandoned by being disposed of, removed from storage for purposes of disposal or treatment prior to disposal; is deteriorated, leaking, or damaged to the point that it is unserviceable; or has been determined by an authorized military official to be solid waste. Also, a used or fired military munition that has been removed from its landing spot and then either managed off-range or disposed of on-range.

Sources:

1. Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), 42 U.S.C. § 9601 et seq.
2. National Oil and Hazardous Substances Pollution Contingency Plan (more commonly called the National Contingency Plan), 40 C.F.R. § 300 et seq.
3. Resource Conservation and Recovery Act (RCRA), 42 U.S.C. § 6901 et seq.
4. Military Munitions Rule: Hazardous Waste Identification and Management; Explosives Emergencies; Manifest Exception for Transport of Hazardous Waste on Right-of-Ways on Contiguous Properties, Final Rule, 40 C.F.R. § 260, et seq.
5. Military Munitions Rule: Hazardous Waste Identification and Management; Explosives Emergencies; Redefinition of On-Site; Proposed Rule, 40 C.F.R. § 260, et seq.
6. Joint Publication 1-02, "DoD Dictionary of Military and Associated Terms," April 12, 2001.
7. Closed, Transferred, and Transferring Ranges Containing Military Munitions, Proposed Rule, 62 FR 187, September 26, 1997.
8. DoD 6055.9-STD, Department of Defense Ammunition and Explosives Safety Standards.
9. Department of Defense Directive 6055.9. "DoD Explosives Safety Board (DDESB) and DoD Component Explosives Safety Responsibilities," July 29, 1996.
10. Office of the Deputy Under Secretary of Defense (Environmental Security), "Management Guidance for the Defense Environmental Restoration Program," March 1998.
11. Federal Advisory Committee for the Development of Innovative Technologies, "Unexploded Ordnance (UXO): An Overview," Naval Explosive Ordnance Disposal Technology Division, UXO Countermeasures Department, October 1996.
12. Department of the Army Pamphlet No. 1110-1-18. "Engineering and Design Ordnance and Explosives Response," April 24, 2000.
13. Center for Public Environmental Oversight glossary.
14. Joint Army Regulation 75-14, OPNAVINST 8027.1G, MCD 8027.1D, AFR 136-8, "Interservice Responsibilities for Explosive Ordnance Disposal," February 14, 1992.
15. Air Force Policy Directive 32-30, "Explosive Ordnance Disposal," July 20, 1994.
16. U.S. Army Corps of Engineers Pamphlet No. 1118-1-18, "Engineering and Design Ordnance and Explosives Response," April 24, 2000.
17. EPA Federal Facilities Restoration and Reuse Office. "Institutional Controls and Transfer of Real Property Under CERCLA Section 120(h)(3)(A), (B), or (C), Interim Final Guidance," January 2000.
18. U.S. EPA. "Risk Assessment Guidelines for Superfund, Volume 1, Human Health Evaluation Manual (Part A)," Interim Final, December 1989.

ACRONYMS

ARAR	applicable or relevant and appropriate requirements
ARL	U.S. Army Research Laboratory
ASR	archives search report
ATR	aided or automatic target recognition
ATSDR	Agency for Toxic Substances and Disease Registry
ATV	autonomous tow vehicle
BRAC	Base Realignment and Closure Act
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CSM	conceptual site model
CTT	closed, transferred, and transferring [ranges]
DARPA	Defense Advanced Research Project Agency
DDESB	Department of Defense Explosives Safety Board
DERA	Defense Environmental Restoration Account
DERP	Defense Environmental Restoration Program
DGPS	differential global positioning system
DoD	Department of Defense
DOE	Department of Energy
DQO	data quality objective
EPA	Environmental Protection Agency
EPCRA	Emergency Planning and Community Right-to-Know Act
EMI	electromagnetic induction
EOD	explosive ordnance disposal
EMR	electromagnetic radiation
ESS	explosives safety submission
FFA	Federal facility agreements
FFCA	Federal Facility Compliance Act
FUDS	Formerly Used Defense Sites
GIS	geographic information system
GPR	ground penetrating radar
GPS	global positioning system
HMX	octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine
IAG	interagency agreement
IR	infrared
IRIS	Integrated Risk Information System
JUXOCO	Joint UXO Coordination Office
JPGTD	Jefferson Proving Ground Technology Demonstration Program
MCE	maximum credible event
MTADS	Multisensor Towed Array Detection System
NCP	National Contingency Plan
NPL	National Priorities List
OB/OD	open burning/open detonation
OE	ordnance and explosives
PA/SI	preliminary assessment/site investigation

PCB	polychlorinated biphenyls
PEP	propellants, explosives, and pyrotechnics
PPE	personnel protective equipment
PRG	preliminary remediation goals
QA/QC	quality assurance/quality control
Q-D	quantity-distance
RCRA	Resource Conservation and Recovery Act
RDX	Royal Demolition Explosive
RF	radio frequency
RfD	reference dose
RI/FS	remedial investigation/feasibility study
ROD	Record of Decision
SAR	synthetic aperture radar
SARA	Superfund Amendments and Reauthorization Act
SERDP	Strategic Environmental Research and Development Program
SODS	seismic ordnance detection system
TNT	trinitrotoluene
USACE	U.S. Army Corps of Engineers
USAEC	U.S. Army Environmental Center
USATCES	U.S. Army Technical Center for Explosives Safety
UXO	unexploded ordnance
UWB	ultra wide band
WP	white phosphorous

1.0 INTRODUCTION

1.1 Overview

This handbook on unexploded ordnance (UXO) and other ordnance and explosives (OE) has been written for regulators and the interested public to facilitate understanding of the wide variety of technical issues that surround the investigation and cleanup of closed, transferred, and transferring (CTT) ranges at current and former Department of Defense (DoD) facilities and/or other sites. The handbook is designed to provide a common nomenclature to aid in the management of ordnance and explosives (OE) at closed, transferring, and transferred ranges, including:

- Unexploded Ordnance (UXO),
- Buried munitions, and
- Explosive soil.

Why is This Handbook Focused on CTT Ranges and Other Sites?

EPA's major regulatory concern is CTT ranges and other sites where the industrial activity may have ceased and OE and other constituents may be present. This focus occurs for several reasons:

- Transferred and transferring ranges are either in or about to be in the public domain. EPA, States, Tribes, and local governments have regulatory responsibility at the Base Realignment and Closure Act (BRAC) facilities and the Formerly Used Defense Sites (FUDS) that make up the transferred and transferring ranges.
- EPA, States, Tribes, and local governments have encountered numerous instances where issues have been raised about whether transferred and transferring ranges are safe for both their current use and the uses to which they may be put in the future.
- Closed ranges at active bases are sites that have been taken out of service as a range, and may be put to multiple uses in the future that may not be compatible with the former range use.
- The Military Munitions Rule (see chapter 2) makes clear that the most likely sites where used and fired military munitions are a regulated solid waste, and therefore a potential hazardous waste are at CTT ranges.
- Other sites that are addressed by this handbook include hazardous waste sites where OE may be encountered, such as scrap yards, disposal pits, ammunition plants, DoD ammunition depots, open burning/open detonation (OB/OD) units, and research and testing facilities.
- Finally, EPA anticipates that the military will oversee and manage environmental releases at their active and inactive ranges as part of their compliance program.

This handbook also discusses common chemical residues of explosives that may not retain energetic properties but could have a potential impact on human health and the environment. For the purposes of simplifying the discussion, when the term ordnance and explosives (OE)[1] is used, the handbook is referring to the three groups listed above. When chemical residues that *may or may not* have energetic characteristics are being discussed, they will be called "other constituents."

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[1]The reader should be aware that "ordnance and explosives" is a term used by the U.S. Army Corps of Engineers (USACE). Other military organizations/or components may use different terms to refer to the same thing.

The handbook is designed to facilitate a common understanding of the state of the art of OE detection and cleanup, and to present U.S. Environmental Protection Agency (EPA) guidance on the management of OE at CTT ranges and other sites. The handbook is currently organized into seven chapters that are designed to be used as resources for regulators and the public. Each of the chapters presents basic information and defines key terms. The handbook is a living document and additional chapters are under development. Therefore, it is presented in a notebook format so that replacement pages can be inserted as new technical information becomes available and as policies and procedures evolve.

Policy Background

The reader should keep in mind that the regulatory context for OE investigation and cleanup is evolving. The writing of this handbook has taken place against a backdrop of extensive discussions involving Congress, DoD, the U.S. Environmental Protection Agency (EPA), Federal Land Managers, States, and the public over the cleanup and regulation of CTT ranges.

1.2 The Common Nomenclature

Listed below are selected key terms that are necessary for understanding the scope of this handbook. For additional definitions, the user is directed to the Glossary.

About These Definitions

The user of this handbook should be aware that the definitions below are not necessarily official or regulatory definitions. Instead, they are an attempt to "translate" the formal definition into "plain English." However, the glossary associated with this handbook uses official definitions when available. The user should not rely on the definitions in this chapter for legal understanding of a key term, but should instead refer to the Glossary and to other promulgated or official documents.

1. **Unexploded Ordnance** — The term UXO, or unexploded ordnance, means military munitions that have been primed, fused, armed, or otherwise prepared for action, and have been fired, dropped, launched, projected, or placed in such a manner as to constitute a hazard to operations, installations, personnel, or material and remain unexploded either by malfunction, design, or any other cause.

2. **Range** — A range is any land mass and/or water body that is or was used for the conduct of training, research, development, testing, or evaluation of military munitions or explosives.

3. **Closed, transferring, and transferred ranges** — The term "closed range" is defined in the EPA Military Munitions Rule and described in section 2.1.5. A **closed range** is a range that has been taken out of service and either has been put to new uses that are incompatible with range activities or is not considered by the military to be a potential range area, yet it remains in the control of the Department of Defense. **Transferring**

ranges are those ranges in the process of being transferred from DoD control or ownership (e.g., sites that are at facilities closing under the Base Realignment and Closure Program, or BRAC). **Transferred ranges** are those ranges that have been transferred from DoD control or ownership to other Federal agencies, State or local agencies, or private entities (e.g., Formerly Used Defense Sites, or FUDS).

4. **Ordnance and Explosives (OE**) — This term is used by U.S. Army explosives safety personnel to refer to all military munitions that have been used, discarded, and so forth. The term encompasses the concerns that are the subject of this handbook, such as UXO, energetic materials in soil from partially exploded or decomposing ordnance, and munitions that have been discarded or buried. The term is used at various places in the handbook where the reference is to all ordnance and explosives, not just UXO.

5. **Ordnance and Explosives Area (OE Area)** — An OE area is any area that may contain ordnance and explosives and that requires an explosives safety plan prior to investigation and/or cleanup. Entire ranges or subparts of ranges may be OE areas that are the target of investigation and cleanup activities.

6. **Buried Munitions** — Buried munitions are used or unused military munitions that have been intentionally discarded and buried under the land surface with the intent of disposal.

7. **Explosive Soil** — Soil containing concentrations of explosives or propellants such that an explosion hazard is present. This term includes explosives found outside a containment in any form, including bulk explosives.

8. **Other Constituents** — This term refers to the chemical constituents of military munitions that remain in the environment, including (1) residuals of explosives that contain energetic properties, and (2) chemical residuals of explosives that are not energetic (explosive) but may pose a potential threat to human health and the environment through their toxic properties.

9. **Anomaly** — The term is applied to any identified subsurface mass that may be geologic in origin, UXO, or some other man-made material.

10. **Clearance** — The removal of UXO from the surface or subsurface to a preestablished depth is called clearance.

1.3 Organization of This Handbook

The remaining six chapters of this handbook are organized as follows:

Chapter 2 — Regulatory Overview
Chapter 3 — Characteristics of Ordnance and Explosives
Chapter 4 — Detection of UXO
Chapter 5 — Cleanup Technologies

Chapter 6 — Safety
Chapter 7 — Site/Range Characterization
Chapter 8 — Remedy Selection: Making a Risk Management Decision Under CERCLA (Reserved)
Chapter 9 — Chemical Munitions and Agents (Reserved)

At the end of each chapter is a section titled "Sources and Resources." The information on those pages directs the reader to source material, websites, and contacts that may be helpful in providing additional information on subjects within the chapter. In addition, this section documents some of the various publications and written material used in the preparation of this handbook.

The handbook is organized in a notebook format because of the potential for change in a number of important areas, including the regulatory framework and detection and remediation technologies. The reader will also note that there are occasional notes indicating that a section is under development.

2.0 REGULATORY OVERVIEW

The cleanup and management of OE (UXO, buried munitions, and explosive soil) and other constituents at CTT ranges is governed by a comprehensive mix of Federal, State, and local laws and may involve interaction among several Federal agencies, along with State and local authorities. Several issues arise in this context:

- Whether the process of range cleanup will follow the processes of the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA), and if so, which CERCLA process — removal or remedial or a combination of the two.
- Whether the Department of Defense (DoD) will have the final decision-making role in cases of disputes at CTT ranges, and what role will be played by EPA, Federal land managers, States, and Tribes.
- Uncertainty over the final structure, scope, and acceptability of a DoD-developed regulation regarding the management of UXO at CTT ranges.

On March 7, 2000, EPA and DoD entered into an interim final agreement to resolve some of these issues between the two agencies.[2] Some of the central management principles developed by DoD and EPA are quoted in the next text box. A number of other important issues are addressed by the principles, which are reprinted as an attachment to this chapter. Some of these will be referred to in other parts of this regulatory overview, as well as in other chapters of this handbook.

The discussion that follows describes the current regulatory framework for OE and other constituents, identifies issues that remain uncertain, and identifies specific areas of regulatory concern in the investigation of and decisions at CTT ranges. The reader should be aware that interpretations may change and that final promulgation of a DoD range regulation may alter some assumptions.

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[2] U.S. Department of Defense, Deputy Under Secretary of Defense for Environmental Security, and U.S. EPA Office of Solid Waste and Emergency Response. Interim Final Management Principles for Implementing Response Actions at Closed, Transferring, and Transferred (CTT) Ranges, March 7, 2000.

Key DoD/EPA Interim Final Management Principles

- The legal authorities that support site-specific response actions at CTT ranges include, but are not limited to,...CERCLA, as delegated by Executive Order (EO 12580) and the National Oil and Hazardous Substances Pollution Contingency Plan (the National Contingency Plan, or NCP); the Defense Environmental Restoration Program (DERP); and the DoD Explosives Safety Board (DDESB).
- A process consistent with CERCLA and these management principles will be the preferred response mechanisms used to address UXO at CTT ranges. This process will meet any RCRA corrective action requirements.
- DoD will conduct response actions on CTT ranges when necessary to address explosives safety, human health, and the environment. DoD and the regulators must consider explosives safety in determining the appropriate response actions.
- DoD and EPA commit to the substantive involvement of States and Indian Tribes in all phases of the response process, and acknowledge that States and Indian Tribes may be the lead regulators in some cases.
- Public involvement in all phases of the response process is considered to be crucial to the effective implementation of a response.
- These principles do not affect Federal, State, and Tribal regulatory or enforcement powers or authority... nor do they expand or constrict the waiver of sovereign immunity by the United States in any environmental law.

Finally, it is not the purpose of this chapter to provide detailed regulatory analysis of complex issues that must be decided site-specifically. Instead, this chapter discusses the regulatory components of decisions and offers direction on where to obtain more information (see "Sources and Resources" at the end of this chapter).

2.1 Regulatory Overview

Based on the DoD/EPA Interim Final Management Principles cited above and on EPA's draft OE policy,[3] the principal regulatory programs that guide the cleanup of CTT ranges include CERCLA, the Defense Environmental Restoration Program (DERP), and the programs of the DoD Explosives Safety Board (DDESB). In addition, the principles assert a preference for cleanups that are consistent with CERCLA and the CERCLA response process. The RCRA program also provides an important regulatory framework for the management of OE on CTT ranges. The substantive requirements of the Resource Conservation and Recovery Act (RCRA) must be achieved when cleanup proceeds under CERCLA and those requirements are either applicable, or relevant and appropriate to the site situation (see Section 2.2.1.1). In addition, State regulatory agencies will frequently use their own hazardous waste authorities to assert their role in oversight of range investigation and cleanup. The Federal regulatory programs are described briefly in the sections that follow.

[3]EPA, Office of Solid Waste and Emergency Response, Federal Facilities Restoration and Reuse Office, Policy for Addressing Ordnance and Explosives at Closed, Transferring, and Transferred Ranges and Other Sites, May 14, 2001.

2.1.1 Defense Environmental Restoration Program

Although the Department of Defense has been implementing its Installation Restoration Program since the mid-1970s, it was not until the passage of the Superfund Amendments and Reauthorization Act of 1986 (SARA), which amended CERCLA, that the program was formalized by statute. Section 211 of SARA established the Defense Environmental Restoration Program (DERP), to be carried out in consultation with the Administrator of EPA and the States, Tribal authorities, and local governments. The program has three goals:

- Cleanup of contamination from hazardous substances, pollutants, and contaminants, consistent with CERCLA cleanup requirements as embodied in SARA and the National Oil and Hazardous Substances Pollution Contingency Plan (NCP).
- Correction of environmental damage, such as the detecting and disposing of used or fired military munitions, that creates an imminent and substantial endangerment to public health and the environment.
- Demolition and removal of unsafe buildings and structures, including those at Formerly Used Defense Sites (FUDS).

Based on the language in DERP and in CERCLA (see below), EPA believes that the cleanup of OE should be handled under CERCLA authorities, through the processes established by the NCP. This does not preclude the use of other regulatory authorities, such as RCRA.[4]

2.1.2 CERCLA

CERCLA (otherwise known as Superfund) is the basic Federal law that provides for the cleanup of releases of hazardous substances, pollutants, or contaminants. It is governed by an extensive Federal regulatory structure found in 40 CFR Parts 300-374. The framework regulation to implement CERCLA is the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) (40 CFR 300). It applies equally to private parties and governmental entities who own or operate sites, or who generated the waste at the sites. Although the Federal Government (through EPA and/or the other Federal agencies) is responsible for implementation of CERCLA, the States and communities play a significant role in the law's implementation.

CERCLA authorizes a response in two instances:

- When there is a release or threat of a release of a hazardous substance into the environment
- When there is a release or threat of a release into the environment of any pollutant or contaminant that may present an imminent and substantial danger to the public health or welfare

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[4]EPA, Office of Solid Waste and Emergency Response, Federal Facilities Restoration and Reuse Office, Policy for Addressing Ordnance and Explosives at Closed, Transferring, and Transferred Ranges and Other Sites, May 14, 2001.

The CERCLA process (described briefly below) examines the nature of the releases (or potential releases) to determine if there is a threat to human health and the environment. In other words, the process examines whether the concentration of material and availability of pathways to receptors are of such a nature that the release poses an unacceptable risk. If they do pose a risk, cleanup under CERCLA then occurs.

The principal investigation and cleanup processes implemented under CERCLA involve removal or remedial actions in one of two ways:

1. Generally, removal actions are designed to address emergency problems or immediate concerns, or to put in place a temporary or permanent remedy to prevent, minimize, or mitigate a release.
2. Remedial actions are designed to provide for a more detailed and thorough evaluation of risks and cleanup options, and a permanent remedy.

Whether a removal or remedial action is undertaken is a site-specific determination. In either case, the process generally involves a timely assessment of whether a more comprehensive investigation is required, a detailed investigation of the site or area to determine if there is unacceptable risk, and identification of appropriate alternatives for cleanup, documentation of the decisions, and design and implementation of a remedy. As noted in the DoD and EPA Interim Final Management Principles, CERCLA response actions may include removal actions, remedial actions, or a combination of the two.

The CERCLA processes are implemented at three kinds of sites:

- Sites placed on the National Priorities List (NPL) (both privately owned sites and those owned or operated by governmental entities). These are sites that have been assessed against a series of criteria, the application of which results in a numeric score. Those sites that score above 28.5 are found to warrant national attention. The listing of a site on the NPL is a regulatory effort that is published in the *Federal Register*. Both removal and remedial actions are implemented at these sites.
- Private-party sites that are not placed on the NPL but are found to require near-term or immediate response under the removal program.[5]
- Non-NPL sites owned or controlled by Federal agencies (e.g., Department of Defense, Department of Energy). Both removal and remedial actions are implemented at these sites. These sites must be investigated and cleaned up in accordance with CERCLA (see section 2.1.3 below).

When SARA was enacted, the authority to implement the CERCLA program was given to the President of the United States. Executive Order 12580 (January 23, 1987) delegates most of the management of the program to the Environmental Protection Agency. However, DoD and the

[5]Generally, actions taken at private party sites that are not NPL sites are removal actions. However, in some cases, remedial response actions are taken at these sites as well. This will typically occur if the site has been deferred from listing on the NPL to another authority and/or if the responsible party is taking voluntary action to clean up quickly.

Department of Energy (DOE) are delegated response authority at their facilities. When a DoD or DOE facility is on the NPL, EPA must concur with the Record of Decision (decision document). When the site is not on the NPL, or the activity being undertaken is a removal action, DoD or DOE must consult with Federal and State regulatory authorities, but makes the final decision.

Whether EPA concurrence is required or not, EPA and the States have substantial oversight responsibilities that are grounded in both the CERCLA and DERP statutes. CERCLA and the NCP require:

- Extensive State involvement in the remedial program (CERCLA Section 121(f)). A number of very specific requirements for State involvement in the remedial program are contained in the NCP (particularly, but not exclusively, Subpart F).
- Notification requirements. Notification requirements apply to all removal actions, no matter what the time period. State and community involvement is related to the amount of time available before a removal action must start. If the removal action will not be completed within 4 months (120 days), then a community relations plan is to be developed and implemented. If the removal action is a non-time-critical removal action, and more than 6 months will pass before it will be initiated, implementation of the community relations plan, and review and comment on the proposed action, is required before the action is initiated. (National Contingency Plan, 40 CFR 300.415)

In addition, DERP also explicitly discusses State involvement with regard to releases of hazardous substances:

- DoD is to promptly notify Regional EPA and appropriate State and local authorities of (1) the discovery of releases or threatened releases of hazardous substances and the extent of the threat to public health and the environment associated with the release, and (2) proposals made by DoD to carry out response actions at these sites, and of the start of any response action and the commencement of each distinct phase of such activities.
- DoD must ensure that EPA and appropriate State and local authorities are consulted at these sites before taking response actions (unless emergency circumstances make such consultation impractical) (10 U.S.C. § 2705).

2.1.3 <u>CERCLA Section 120</u>

Section 120 of CERCLA is explicit as to the manner in which CERCLA requirements are to be carried out at Federal facilities. Specifically, Section 120 mandates the following:

- Federal agencies (including DoD) have to comply with the requirements of CERCLA in the same manner as nongovernmental entities.
- The guidelines, regulations, and other criteria that are applicable to assessments, evaluations, and cleanups by other entities apply also to Federal agencies.
- Federal agencies must comply with State laws governing removal and remedial actions to the same degree as private parties.

- When the facility or site is on the NPL, an interagency agreement (IAG) is signed between EPA and the Federal agency to ensure expeditious cleanup of the facility. This IAG must be signed within 6 months of completion of EPA review of a remedial investigation/feasibility study (RI/FS) at the facility.
- When hazardous substances were stored for one or more years, and are known to have been released or disposed of, each deed transferring real property from the United States to another party must contain a covenant that warrants that all remedial actions necessary to protect human health and the environment with respect to any such [hazardous] substance remaining on the property have been taken (120(h)(3)).[6]
- Amendments to CERCLA (Section 120(h)(4)) through the Community Environmental Response Facilitation Act (CERFA, PL 102-426) require that EPA (for NPL installations) or the States (for non-NPL installations) concur with uncontaminated property determinations made by DoD.

2.1.4 Resource Conservation and Recovery Act (RCRA)

The Federal RCRA statute governs the management of all hazardous waste from generation to disposal, also referred to as "cradle to grave" management of hazardous waste. RCRA requirements include:

- Identification of when a material is a solid or hazardous waste
- Management of hazardous waste — transportation, storage, treatment, and disposal
- Corrective action, including investigation and cleanup, of solid waste management units at facilities that treat, store, or dispose of hazardous waste

The RCRA requirements are generally implemented by the States, which, once they adopt equivalent or more stringent standards, act through a permitting process in lieu of EPA to implement the program. Thus, each State that is authorized to implement the RCRA requirements may have its own variation of hazardous waste laws that must be considered. A brief discussion of some of the relevant RCRA requirements is provided in section 2.2.2.

When cleanup is conducted under CERCLA, the substantive (as opposed to administrative) RCRA requirements may be considered to be either applicable, or relevant and appropriate (see CERCLA discussion below), and must be complied with accordingly; however, DoD, the lead agency, need not obtain permits for on-site cleanup activities.

[6]Under CERCLA §120(h)(3)(C), contaminated property may be transferred outside the Federal Government provided the responsible Federal agency makes certain assurances, including that the property is suitable for transfer and that the cleanup will be completed post-transfer.

2.1.5 Federal Facility Compliance Act of 1992 and the Military Munitions Rule

> **What Is a Military Munition?**
>
> All ammunition products and components produced or used by or for DoD or the U.S. Armed Services for national defense and security.

The Federal Facility Compliance Act of 1992, or FFCA (PL102-386), amended RCRA (also called the Solid Waste Disposal Act). FFCA required the EPA Administrator to identify when military munitions become hazardous wastes regulated under RCRA Subtitle C, and to provide for the safe transport and storage of such waste.

As required by the FFCA, EPA promulgated the Military Munitions Rule (62 FR 6622, February 12, 1997; the Munitions Rule), which identified when conventional and chemical military munitions become hazardous wastes subject to the RCRA Subtitle C hazardous waste management requirements. Under the rule, routine range clearance activities – those directed at munitions used for their intended purpose at active and inactive ranges – are deemed to not render the used munition a regulated solid or hazardous waste. On-range disposal (e.g., recovery, collection, and subsequent burial or placement in a landfill) is subject to RCRA Subtitle C, even at active ranges.

Unused munitions are not a solid or hazardous waste when being managed (e.g., stored or transported) in conjunction with their intended use. They may become regulated as a hazardous or solid waste under four circumstances:

> **Unused Munitions Are a Solid (and Potentially Hazardous) Waste When They Are**
>
> - Discarded and buried in an on-site landfill
> - Destroyed through open burning and/or open detonation or some other form of treatment
> - Deteriorated to the point where they cannot be used
> - Removed from storage for the purposes of disposal
> - Designated as solid waste by a military official

- The unused munition is "abandoned by being disposed of, burned, or incinerated, or treated prior to disposal."
- The unused munition is removed from storage for purposes of disposal or treatment prior to disposal.
- The unused munition is deteriorated, leaking, or damaged to the point that it can no longer be put back into serviceable condition or be reasonably recycled or used for other purposes.
- The munition has been determined by an authorized military official to be a solid waste.

An unused munition is not a solid and potentially hazardous waste when it is being repaired, reused, recycled, reclaimed, disassembled, reconfigured, or otherwise subjected to materials recovery actions.

Under the EPA Munitions Rule, **fired or used munitions** are not regulated solid waste and therefore potentially hazardous waste when the munitions are used for their intended purpose (e.g., training, research, range clearance at active ranges).

Used or Fired Munitions

Military munitions that (1) have been primed, fused, armed, or otherwise prepared for action *and* have been fired, dropped, launched, projected, placed, or otherwise used; (2) are munitions fragments (e.g., shrapnel, casings, fins, and other components that result from the use of military munitions); or (3) are malfunctions or misfires.

When Are Used or Fired Munitions a Regulated Solid Waste and a Potentially Hazardous Waste?

At active and inactive ranges:

- When they are transported off-range or from the site of use for storing, reclaiming, treating, and disposing of or treating prior to disposal.
- When they are recovered, collected, and then disposed of by burial or landfilling either on or off the range.
- When a munition is recovered that landed off-range and was not promptly rendered safe and/or retrieved.

At closed, transferred, and transferring ranges:

- Whenever the munitions are picked up and managed for any purpose (e.g., transportation, storage, treatment, or disposal).

When Is OE a Hazardous Substance Under CERCLA?

OE itself is not listed as a hazardous substance; however, EPA believes that OE typically meets the definition of a hazardous substance because most OE consists of or contains listed hazardous substances and/or exhibits characteristics of hazardous substances, such as reactivity and ignitability (as defined in 40 CFR 261.20 through 261.24). Therefore, in most cases, CERCLA jurisdiction may apply to OE. In other cases, certain OE-related materials may not be considered a hazardous substance if they do not contain any listed hazardous substances, if they are excluded from regulation as a hazardous waste (under 40 CFR 251.4), or if they do not exhibit any of the characteristics of hazardous substances.

In addition to addressing when a munition becomes a regulated solid waste and potentially hazardous waste, the Military Munitions Rule provides for certain conditional exemptions from RCRA Subtitle C requirements **for conventional waste military munitions**. Exemptions may include RCRA transportation and storage requirements, if DDESB standards are followed. Military chemical waste munitions do not qualify for exemptions under the Military Munitions Rule. The conditional exemptions recognize an equivalency between the DDESB standards and the RCRA standards for transportation and storage of waste military munitions. However, States that operate the RCRA program in lieu of the Federal Government may have more stringent requirements than the Federal Government. Therefore, if the State has not adopted the Munitions Rule with its conditional exemptions, then the exemptions from RCRA storage and transportation requirements may not apply. Regardless of the conditional exemption from RCRA, the U.S. Department of Transportation (DOT) regulations apply to the transport of hazardous materials.

2.1.6 Department of Defense Explosives Safety Board (DDESB)

The DDESB was established by Congress in 1928 as a result of a major disaster at the Naval Ammunition Depot in Lake Denmark, New Jersey, in 1926. The accident caused heavy damage to the depot and surrounding areas and communities, killed 21 people, and seriously injured 51 others. The mission of the DDESB is to provide objective expert advice to the Secretary of Defense and the Service Secretaries on matters concerning explosives safety, as well as to prevent hazardous conditions for life and property, both on and off DoD installations, that result from the presence of explosives and the environmental effects of DoD munitions. The roles and responsibilities of the DDESB were expanded in 1996 with the issuance of DoD Directive 6055.9, on July 29, 1996. The directive gives DDESB responsibility for serving as the DoD advocate for resolving conflicts between explosives safety standards and environmental standards.

DDESB is responsible for promulgating safety requirements and overseeing their implementation throughout DoD. These requirements provide for extensive management of explosive materials, such as the following:

- Safe transportation and storage of munitions
- Safety standards for the handling of different kinds of munitions
- Safe clearance of real property that may be contaminated with munitions

Chapter 6 expands on and describes the roles and responsibilities of DDESB, as well as outlines its safety and real property requirements.

In addition to promulgating safety requirements, DDESB has established requirements for the submission, review, and approval of Explosives Safety Submissions for all investigations and responses regarding UXO at FUDS and at BRAC facilities.

DoD/EPA Interim Final Management Principles Related to DDESB Standards

- In listing the legal authorities that support site-specific response actions, the management principles list CERCLA, DERP, and the DDESB together.
- With regard to response actions, in general the principles state that "DoD and the regulators must consider explosives safety in determining the appropriate response actions."
- Regarding response actions under CERCLA, the principles state that "Explosives Safety Submissions (ESS), prepared, submitted, and approved per DDESB requirements, are required for Time-Critical Removal Actions, Non-Time-Critical Removal Actions, and Remedial Actions involving explosives safety hazards, particularly UXO."

2.1.7 Emergency Planning and Community Right-to-Know Act (EPCRA)

Another source of regulatory requirements may come from local emergency planning committees (LEPCs) that are established under Title III of SARA (commonly called the Emergency Planning and Community Right-to-Know Act (EPCRA)). These provisions require each governor to appoint a State Emergency Response Commission (SERC). Each SERC then creates LEPCs. In most States there is one LEPC per county. In some States, the LEPCs are formed at the township or borough level.

LEPCs develop and update emergency response plans for their communities. In addition, they provide for training and community outreach. Because of the large number of LEPCs and the variability of their plans, it is impossible to summarize how the LEPCs' requirements may apply to all potential situations; however, they will likely be an issue in at least the following situations:

- Transportation of explosive waste
- Any storage of explosive waste
- Investigation and clearance activities at FUDS (i.e., sites that no longer belong to DoD)

2.1.8 Proposed DoD Range Rule

DoD's draft range rule was proposed in the *Federal Register* on September 26, 1997. This draft rule was withdrawn from administration review on November 13, 2000, because of the inability of Federal agencies to reach consensus on several key issues. DoD is considering its options in developing another regulation. However, the UXO and range management principles described in the introduction to this chapter (and further described in section 2.2) will guide range investigation and response at CTT ranges.

2.2 Existing Standards and Requirements for Range Response at Closed, Transferring, and Transferred Ranges

The sections below summarize some of the major requirements that may apply at CTT ranges. The discussion of requirements is not meant to be exhaustive, but rather to point you to specific areas that may be relevant to your CTT range or OE area.

2.2.1 CERCLA Requirements

The basic process of investigating a site that potentially requires cleanup and cleaning it up is similar under any legal authority. The process generally involves a rapid assessment of whether a more comprehensive investigation is required, a detailed investigation of the site or area to determine if there is risk, and identification of appropriate alternatives for cleanup, documentation of the decisions, and design and implementation of a remedy. As noted in the DoD and EPA Interim Final Management Principles (see Chapter 2, attachment), CERCLA response actions may include removal actions, remedial actions, or a combination of the two.

Both the removal and remedial programs have extensive requirements for public involvement and for consultation with regulatory agencies. When removal requirements must be initiated rapidly, some of those requirements are modified to recognize the emergency nature of the situation. In addition, both the removal and the remedial programs must comply with the substantive requirements of other laws (applicable, or relevant and appropriate requirements, or ARARs – see section 2.2.1.1 on ARARs). However, the level of achievement of ARARs during removal actions can be adjusted to take into account the urgency and particular circumstances (called "exingencies") of the situation and the scope of the removal action.

DoD/EPA Interim Final Management Principles Related to Response Actions

DoD components may conduct CERCLA response actions to address explosives safety hazards, to include UXO, on CTT ranges per the NCP. Response activities may include removal actions, remedial actions, or a combination of the two.

In addition to the CERCLA cleanup process, the RCRA program implements a "corrective action program" that follows steps similar to CERCLA's for investigating and cleaning up a site but uses different terminology. Table 2-1 outlines the general stages of investigation and cleanup and the different terminologies of these stages under the two regulatory programs. Although this section discusses CERCLA requirements, the terminology of the RCRA corrective action program is included in the table for comparison. In addition to the different terms applied to the same stages of the cleanup process, depending on which regulatory program the investigation is proceeding under, different terms are sometimes used by EPA and DoD to describe a specific CERCLA or RCRA stage. These are also noted in the table.

Although the table below is organized in accordance with basic functions, its purpose is to familiarize you with the basic terms that may be used to describe similar activities and is not meant to imply that all processes are equivalent. In general, the level of detail and analysis required by the removal program will be considerably less than the level of detail required by the remedial program. This is because the remedial program is focused on analysis of more complex site situations and permanent solutions, while the removal program is designed to address emergencies and activities in the short term that will provide temporary protection of human health and the environment (see section 2.2.1.2 for further discussion).

Table 2-1. Overview of Terminology of Cleanup for RCRA and CERCLA[7]

Stage of Cleanup	Definition	CERCLA Term	RCRA Term*
Preliminary Assessment	Preliminary review of area or site prior to deciding if more detailed investigation or cleanup is necessary. In Superfund, assessment can lead to ranking and prioritization of site or facility for placement on NPL.	Preliminary Assessment/ Site Investigation (PA/SI)	RCRA Facilities Assessment (RFA)
Investigation	Detailed investigation of area or site to determine the level of risk (or if there is no risk) and to decide which remedy is appropriate.	Remedial Investigation/ Feasibility Study (RI/FS) — for **remedial program**	RCRA Facilities Investigation (RFI) Corrective Measures Study (CMS)/Corrective Action Plan
	Qualitative risk evaluation with focused engineering and cost evaluation to implement short-term measures.	Removal Investigation or Engineering Evaluation/ Cost Analysis (EE/CA) — for **removal program**	
Decision on Cleanup/Response	Formal decision as to what the cleanup activity should be (or the formal decision not to clean up). Usually involves public review (except some time-critical removal actions).	Record of Decision (ROD) – decision document for remedial program	Statement of Basis
		Action Memorandum – the decision record for removal program	
Cleanup/Response	Construction of a remedy to clean up the problem, or physical removal of the waste from a site. This will include design phase where applicable. Design occurs between decision and cleanup and involves the engineering design of the remedy.	Remedial Design Remedial Action	Corrective Measures Implementation
		Removal Action	Interim Stabilization Measures

[7]Information in this table is adapted from **The Environmental Site Closeout Process Guide,** September 1999. Published by the Department of Defense in association with the U.S. Environmental Protection Agency.

Stage of Cleanup	Definition	CERCLA Term	RCRA Term*
Post-remedial/ Post-removal Activities	Completion of Construction.	Construction completion (EPA term) Remedy in place (DoD term)	Certification of Remedy Completion or Construction Complete
	Completion of Cleanup. Achievement of cleanup objectives.	Response Complete	
	Long-term operation of groundwater cleanup systems or other long-term soil cleanup such as soil vapor extraction or bioremediation.	Long-Term Remedial Actions (EPA term) Remedial Action Operations (DoD term)	
	Operation and maintenance of a remedy such as a groundwater treatment system.	Operating properly and successfully (for BRAC sites, prior to transfer) Operation and Maintenance	
	Long-term monitoring of a completed remedy ("response complete") that has left waste in place, in order to ascertain that the remedy remains protective.	Five-Year Review (EPA) Long-Term Monitoring (DoD)	
	Final completion of any Government action at a site.	Site Closure	Corrective Action Process Terminated

*Any of the RCRA activities may be accomplished under a corrective action order or a RCRA permit containing corrective action requirements.

Note: The purpose of this table is to define terms in each stage of the CERCLA and RCRA processes. It is not intended to suggest that the processes are equivalent.

2.2.1.1 *Compliance with Other Laws*

On-site cleanup under both the removal and the remedial programs of CERCLA must comply with the substantive requirements of regulations promulgated to implement Federal and State environmental laws (e.g., RCRA, the Clean Water Act, the Clean Air Act).[8] These Federal and State environmental laws are identified as requirements that are either applicable, or relevant and appropriate (ARAR) to the CERCLA activity.[9]

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[8]The levels of stringency at which the requirements are imposed differ for the remedial program and the removal program. Under the removal program, the law recognizes that it may not always be practicable to comply with other laws in emergency situations.

[9]All waste taken off-site must comply with any legally applicable Federal, State, and local laws.

Some key concepts and terms are outlined below:

- To be ARAR, the requirements must be promulgated under a formal process such as the administrative processes used by EPA to propose and finalize regulations through notice and comment in the *Federal Register*. States have similar processes for promulgating rules.
- The emphasis in CERCLA is with the substantive not administrative requirements. If an action is taken on a CERCLA site — for example, building an incinerator for destruction of hazardous waste — a permit is not required. However, full compliance with the substantive management standards is required for building an incinerator. In the case of the incinerator, State and Federal management standards were designed for incineration of hazardous waste. They are considered to be directly applicable to the situation.
- On the other hand, there are a number of instances where a Federal or State law is not considered to be applicable to the situation (in that the situation does not meet the legal criteria for applicability), but the requirements may have been designed for a similar situation. In these cases, an evaluation process is conducted to determine if a requirement may be "relevant and appropriate." If the requirement is determined to be relevant and appropriate to a situation, then it will be applied as if it is applicable. For this reason, the substantive requirements of RCRA Subtitle C (e.g., open burning and open detonation standards) may be considered relevant and appropriate for management of waste military munitions even though a permit is not required under CERCLA.

Applicable or Relevant and Appropriate Requirements (ARARs) – Waivers

ARARs are considered threshold requirements and must be met for all remedies, along with protection of human health and the environment. However, CERCLA and the NCP allow for six waivers from ARARs. These waivers include:

- Interim measures (the action is not the permanent, final action)
- Equivalent standards of protection
- Greater risk to human health and the environment (e.g., greater risk in taking action than in not taking action)
- Technical impracticability
- Waiver of inconsistent application of State standard
- Fund balancing waiver (applicable only when Federal Superfund trust fund monies are involved)

With the exception of the fund balancing waiver, any one of these waivers can be used at CERCLA cleanups. Use of the waiver must be documented and justified in the Record of Decision or Decision Document.

The process of determining which requirements are relevant and appropriate is particularly complex. It is often subject to judgment, and although the NCP and extensive guidance offer criteria for making such judgments, the judgments are often disputed. Recent initiatives to reauthorize Superfund and streamline the process of cleanup have proposed to eliminate compliance with requirements that are relevant and appropriate. However, the Superfund law appears, at this time, to be far from reauthorization, and these requirements still apply.

2.2.1.2 *Removal Actions*

All removal actions must meet certain statutory and regulatory criteria. The management principles reference these criteria (NCP, 40 CFR 300.410 and 415), which generally establish that a removal action is urgent and should be implemented in the short term, or that the action contributes "to the efficient performance of any long-term remedial action."

There are two types of removal actions – time-critical removal actions, and non-time-critical removal actions. Time-critical removal actions are actions that must be taken quickly and have a planning period of less than 6 months. Classic emergencies are a subset of time-critical removal actions and are generally considered to be those actions that must be taken within hours or days in order to protect human health and the environment. Non-time-critical removal actions are those actions that have a planning period of more than 6 months. Most Federal facility removal actions, including UXO removal, are undertaken as non-time-critical removal actions. Non-time-critical removal actions include the following basic elements:

- Site evaluation and examination of removal alternatives must be documented in an engineering evaluation/cost analysis (EE/CA) or its equivalent.
- The collection of environmental samples is to be documented in a sampling and analysis plan that ensures that a process obtains data "of sufficient quality and quantity to satisfy data needs" (40 CFR 300.415(b)(4)). The sampling and analysis plan consists of two parts: the field sampling plan, describing the number, type, and location of samples, and the Quality Assurance Project Plan (QAPP), describing the data quality objectives and quality measurements. Sampling and analysis plans must be approved by EPA.
- Removal actions must comply with the ARAR requirements of Federal and State environmental or facility siting laws, to the degree practicable "considering the exigencies of the situation."
- Extensive public involvement requirements include (1) establishment of an administrative record of decisions at the site, (2) a public comment period of not less than 30 days on the EE/CA and the planned removal action, (3) development of a response-to-comments document, and (4) preparation of a formal Community Relations Plan, based on interviews with the public, and establishment of an information repository when the removal action will extend more than 120 days from initiation of the action.

However, reliance on removal actions is sometimes controversial for several reasons:

- Removal actions allow certain regulatory requirements to be moderated by the "exigencies" or difficult circumstances of an emergency situation. Use of removal authorities is sometimes perceived by the regulators and the public as a way to avoid compliance with certain laws, consultation with the EPA, State, and local communities, and public involvement requirements.
- Since DoD is the lead agency for removal actions at DoD sites, the agency can make decisions without the approval of regulatory authorities, even at NPL sites. (Consultation is required, however, unless the situation is a true emergency where actions must be taken in hours or days.)

- With the streamlined approach to both site characterization and remedy selection, removal actions may not result in as thorough an examination of alternative approaches to cleanup as might occur in a long-term investigative process.

EPA has recognized the important role of the streamlined removal process in investigating and cleaning up sites for which the cleanup can be accomplished quickly and for which there are limited alternatives available. The Superfund Accelerated Cleanup Model, introduced in April 1992, stressed the need for immediate action to reduce risk — either removal or remedial — using the most appropriate authorities, and recognized that removal actions may be appropriate for short-term cleanups.

Recent guidance concerning the balanced use of the removal and remedial programs at Superfund sites offers the following recommendations:

- "Generally, where a site presents a relatively time-sensitive, non-complex problem that can and should be addressed relatively inexpensively, EPA would normally address the problem by use of removal authority....
- In contrast, absent time sensitivity, remedial authority generally would be used to address complex site problems that will likely require a costly, complicated response....
- A site-specific decision concerning the use of non-time-critical removal or remedial authority will need to be made based on the NCP criteria and considerations of time sensitivity, complexity, comprehensiveness and costs."[10]

DoD/EPA Interim Final Management Principles on Removal Actions

- Removal actions must be carried out in a manner that gives regulators and other stakeholders an opportunity to comment (pursuant to the requirements of DERP), except in the case of "emergency response taken as a result of an imminent and substantial endangerment to human health and the environment and where consultation would be impracticable."
- Removal alternatives will be evaluated under the criteria set forth in the NCP, particularly 40 CFR 300.410 and 415.
- Removal actions shall, to the extent practicable, contribute to the efficient performance of any anticipated long-term remedial action.

2.2.1.3 *Remedial Actions*

Remedial actions are those investigations, decisions, and cleanup activities that adhere to the remedial process requirements. They are generally longer term and more extensive actions, although they can also be narrowly focused and rapid actions. In recent years, EPA has undertaken a number of streamlining initiatives aimed at making decisions and cleanup faster, without sacrificing quality.

[10]Breen, Barry, and Stephen Luftig. Use of Non-Time-Critical Removal Authority in Superfund Response Actions. Memorandum. February 14, 2000.

The essential decisions of the remedial action process are (1) deciding if there is a risk to human health and the environment, and if so, what cleanup level will be met, and (2) deciding what technology (among alternatives) will be used to achieve the cleanup. The decisions that come out of the remedial process are documented in a Record of Decision and evaluated in accordance with nine criteria. These criteria are designed to meet the cleanup standards in CERCLA, as amended by SARA.

The remedial process is similar to the removal process, but it usually differs from the removal process in the following ways:

- Complexity of the environmental problem and the investigations required
- Decision goals of the investigation and cleanup (use of final decisions, as opposed to rapid removal)
- Length of the process
- Number of alternatives evaluated
- Extensiveness of the public involvement activities

In addition, different reports are produced to document the stages of the process:

- As in the removal program, a work plan with a sampling and analysis plan (including a field sampling plan and a QAPP) is produced to start the process.
- The results of the investigations are documented in a remedial investigation/feasibility study. A baseline risk assessment document may be part of the RI/FS or may be a separate document.
- The feasibility study evaluates appropriate alternatives against seven of the nine criteria (State and community concerns are not included at this stage).
- A proposed plan is published to let the regulators and the public comment on the proposed action at the site.
- The final decisions are recorded in a decision document (Record of Decision), which also contains a responsiveness summary that addresses regulator and stakeholder comments.

Information and options are evaluated against the nine criteria (described briefly below) to select the alternative that is protective of human health and the environment, is cost effective, and permanently treats the waste to the "maximum extent practicable." The nine criteria include the following:

- Threshold criteria — must be met for all remedies
  1. Protection of human health and the environment
  2. Compliance with ARARs (unless an explicit waiver is obtained)
- Balancing criteria — weighed to select the most cost-effective alternative that treats the principal threat at the site to the maximum extent practicable
  3. Long-term effectiveness and permanence
  4. Reduction of toxicity, mobility, or volume through treatment
  5. Short-term effectiveness (includes short-term risks from cleanup)
  6. Implementability

7. Cost
- Modifying criteria
  8. State acceptance
  9. Community acceptance

> **When Is Remedial Action More Appropriate Than a Removal Action?**
>
> As described earlier, this question is the center of a great deal of controversy. Guidance referred to in section 2.2.1.2 attempts to address this question – but the answers are far from clear.
>
> A recent court decision regarding range clean up at Fort Ord (Monterey, California) took up this question in order to establish standing for a broader court suit.
>
> **Remedial Versus Removal Actions at Fort Ord**
>
> In a recent Northern California District Court Decision, prescribed burning to remove vegetation prior to OE cleanup was ruled to be a remedial, as opposed to a removal action. The Monterey Bay Unified Air Pollution Control District argued that the Army's effort has been underway for six years and is part of a broader plan to effect a permanent solution, both of which are characteristics of a remedial action. The court agreed with this argument and asserted:
>
> "As the District notes, the government's effort has been proceeding for six years and is part of a broader plan to effect a permanent solution. Both these factors weigh strongly in favor of finding that the OE clearance is a remedial response....it cannot fairly be said that this is a situation in which 'there is no time to safely conduct [detailed] review due to the exigencies of the situation....'"

Guidance documents cited at the end of this chapter ("Sources and Resources"), as well as the NCP itself, provide extensive explanations of how each of these factors is considered.

2.2.1.4 *Interim Final Management Principles and Response Actions*

The Interim Final Management Principles signed by EPA and DoD make a number of statements that bring key elements of the Superfund program into a range cleanup program regardless of the authority under which it is conducted. Some of the more significant statements of principle are quoted here:

- Characterization plans seek to gather sufficient site-specific information to identify the location, extent, and type of any explosives safety hazards (particularly UXO), hazardous substances, pollutants or contaminants, and "other constituents"; identify the reasonably anticipated future land uses; and develop and evaluate effective response alternatives.
- In some cases, explosives safety, cost, and/or technical limitations may limit the ability to conduct a response and thereby limit the reasonably anticipated future land uses....
- DoD will incorporate any Technical Impracticability (TI) determinations and waiver decisions in appropriate decision documents and review those decisions periodically in coordination with regulators.

- Final land use controls for a given CTT range will be considered as part of the development and evaluation of the response alternatives using the nine criteria established under CERCLA regulations (i.e., NCP)....This will ensure that any land use controls are chosen based on a detailed analysis of response alternatives and are not presumptively selected.
- DoD will conduct periodic reviews consistent with the Decision Document to ensure long-term effectiveness of the response, including any land use controls, and allow for evaluation of new technology for addressing technical impracticability determinations.[11]

Although the Interim Final Management Principles have been quoted extensively throughout this chapter, the user of this handbook is encouraged to read them in their entirely. For the convenience of the user, they are reprinted at the conclusion of this chapter.

2.2.1.5 *CERCLA Off-Site Rule*

Provisions in CERCLA 121(d)(3) mandate that transfer of waste from CERCLA response actions must go to facilities that are in compliance with applicable Federal and State laws. Transfer of CERCLA waste to a land disposal facility is only allowable under certain circumstances – the specific unit to which the waste is transferred cannot be releasing any hazardous waste or constituents, and all other releases at the facility must be controlled by an enforceable permit or order. These basic statutory requirements are interpreted by EPA in an amendment to the National Contingency Plan, finalized on September 22, 1993 (40 CFR 440) (see discussion below). The applicability of the off-site policy to Federal facilities was carefully considered by EPA when it promulgated this NCP amendment. EPA found that Federal facilities should be treated no differently than private parties in this regard, and that the off-site policy is applicable to waste transferred from both NPL and non-NPL Federal facilities. EPA makes the key determinations as to the compliance and release status of potential receiving facilities after extensive input from the States.

What Is On-Site Versus Off-Site?

A central issue of the off-site policy is understanding the definition of on-site. CERCLA defines on-site as any place where hazardous substances, pollutants, or contaminants have "come to be located." This can include the surface area where waste is located, as well as the surface area above a groundwater plume (that may extend well beyond the initial source area). In an amendment to the NCP in March 1999, EPA expanded its definition of on-site to include all suitable areas in very close proximity to the contamination necessary for implementation of the response action.

The off-site policy rule-making explicitly acknowledges that off-site management of waste can be said to occur within the boundaries of the same Federal facility. "Federal facilities may transfer CERCLA wastes off the CERCLA site to treatment, storage, or disposal units on the same Federal property, but only if the other units (the larger Federal facility or installation) meet the requirements of this rule." (Preamble, Vol. 58, Federal Register, Page 49204.)

[11] U.S. Department of Defense, Deputy Under Secretary of Defense for Environmental Security, and U.S. EPA Office of Solid Waste and Emergency Response. Interim Final Management Principles for Implementing Response Actions at Closed, Transferring, and Transferred (CTT) Ranges, March 7, 2000.

Key elements of the off-site rule include the following:

- Units receiving CERCLA wastes at RCRA hazardous waste facilities must not be releasing *any* hazardous substances. They must also meet RCRA minimum technology requirements (e.g., for caps, liners, leachate collection, monitoring).
- Releases from **nonreceiving** units at **land disposal facilities** must be addressed by a corrective action program prior to using *any* unit at the facility.
- **Environmentally significant releases** from **nonreceiving units at hazardous waste treatment and storage facilities**, and from **all units at nonhazardous waste facilities**, must be addressed by some kind of enforceable program (e.g., corrective action order, compliance order).
- Emergency removal actions may be exempted under certain circumstances and with the approval of the on-scene coordinator.
- Shipment of samples to laboratories, laboratory waste, and waste from treatability studies are also exempted from these requirements.
- Once EPA has made a decision that a facility/unit is in compliance with requirements, that determination stands until it is affirmatively removed.

Since UXO at CTT ranges will often not be transported off-site, the above elements will most commonly be applicable to chemical contamination (other constituents) from OE sites.

Since the EPA Regions have responsibility for making decisions concerning whether or not the facility is in compliance, each Regional Office has a Regional Off-Site Contact (ROC) who is responsible for knowing the status of potential receiving units and facilities.

2.2.2 RCRA – Transportation, Treatment, Storage, and Disposal Standards

The Resource Conservation and Recovery Act (RCRA), which amended the 1965 Solid Waste Disposal Act, monitors the movement of hazardous waste from production through disposal, or "from cradle to grave." Numerous technical requirements identify when a waste is a solid waste and when a solid waste is a hazardous waste and set specific management standards for solid wastes that are hazardous and nonhazardous, including transportation, storage, treatment, and disposal.

RCRA is generally implemented by States, which may be authorized to implement the Federal program. These States adopt their own regulations, which must be at least as stringent as the Federal regulations but may include additional requirements that are more stringent. The States are generally not required to adopt exemptions to rules that are included in the Federal regulations. Therefore, State requirements may differ from the cited Federal requirements. In addition, given the complexity of the RCRA regulatory structure, numerous policy memoranda provide further interpretations of the requirements. The RCRA Hotline telephone number, which is a good source of information on some of the intricacies of RCRA, is listed at the end of this chapter under "Sources and Resources."

Table 2-2 lists come common scenarios that may be encountered during an OE investigation and clearance activity and directs the reader to some of the potentially applicable regulations.

Readers are reminded that many States have been authorized to implement the RCRA program and those States may have more stringent requirements. Therefore, the appropriate State office should be consulted.

Table 2-2. Examples: Potential RCRA Requirements for Consideration

OE Scenario	Key Questions/Issues To Be Addressed	Potential RCRA Standard(s) and CFR Citation
Munitions wastes and fragments with explosive residue are excavated during investigation and/or cleanup. The waste material is destined to be disposed of off-site.	Is the waste a hazardous waste? What standards for storage, treatment, and disposal must be met?	Munitions Rule (40 CFR 266 Subpart M) RCRA hazardous waste listing and waste characterization requirements (40 CFR 261 and 262) RCRA disposal and treatment standards (40 CFR 268)
Metal fragments from exploded munitions will be disposed of off-site.	Does the metal qualify as "excluded processed scrap metal" that can be recycled?	RCRA waste listing and waste characterization requirements, excluding "processed scrap metal" (40 CFR 261.1(c), 261.2) (40 CFR 261.4(a)(13))
OE waste determined to be hazardous waste will be transported off-site.	Does the Munitions Rule's conditional exemptions for transportation of waste military munitions apply?	RCRA manifesting requirements (40 CFR 262) Transportation standards for hazardous materials (40 CFR 263) Munitions rule transportation conditional exemption Potential applicability of DDESB standards instead (40 CFR 266.205)
UXO or buried munitions will be treated on-site using open burning/open detonation (OB/OD) techniques.*	Is the situation considered an emergency?	RCRA treatment standards for OB/OD (40 CFR 264 Subpart X) Emergency exemption in Munitions Rule (40 CFR 266.204, 262.10, 264.1, 264.1, 270.1, or 270.61)
OE waste will be treated by incineration on-site.*		RCRA incinerator standards (40 CFR 264 Subpart O)
Ordnance fragments will be buried on-site in a landfill.	Is the waste hazardous? What management standards must be met?	RCRA Subtitle C hazardous waste listing and characteristics (40 CFR 261) Land disposal restriction standards (40 CFR 268) Solid or hazardous waste landfill requirements (40 CFR 264/265 Subpart N) or State regulations for nonhazardous solid wastes

OE Scenario	Key Questions/Issues To Be Addressed	Potential RCRA Standard(s) and CFR Citation
Excavated UXO or buried munitions are stored on-site.	Is the waste hazardous? How temporary is the storage (i.e., will the material be stored for less than 90 days)?	RCRA listing and characteristic waste identification (40 CFR 261) RCRA storage standards may apply (40 CFR 262 and 40 CFR 264/265 Subparts B and C) DDESB storage standards take the place of RCRA standards (40 CFR 266.205)

* Even if the treatment is done on CTT ranges, treatment requirements may be relevant and appropriate under CERCLA.

2.2.3 RCRA/CERCLA Interface

The RCRA substantive requirements may be applicable to CERCLA cleanups, even if the investigation and cleanup are proceeding under the CERCLA process. However, the RCRA program does have its own "corrective action" process, which is essentially the same as the CERCLA process but uses a different nomenclature for similar steps (see Table 2-1). The DoD and EPA Interim Final Management Principles state that while cleanups will usually occur under CERCLA authorities, it is anticipated that compliance with CERCLA will result in compliance with RCRA corrective action requirements.

2.3 Conclusion

The regulatory framework for the management of OE is both complex and extensive. The DoD/EPA Interim Final Management Principles for Implementing Response Actions at Closed, Transferring, and Transferred (CTT) Ranges was a first step to providing guiding principles to the implementation of these requirements. EPA's own draft policy for addressing ordnance and explosives is another step. As DoD works with EPA, States, and tribal organizations and other stakeholders to consider the appropriate nature of range regulation at CTT ranges, it is expected that the outlines of this framework will evolve further.

Dialogue will continue over the next few years on a number of important implementation issues, including many that are addressed in this handbook. For this reason, the handbook is presented in a notebook format. Sections of this handbook that become outdated can be updated with the new information.

SOURCES AND RESOURCES

The following publications, offices, laboratories, and websites are provided as a guide for handbook users to obtain additional information about the subject matter addressed in each chapter. Several of these publications, offices, laboratories, or websites were also used in the development of this handbook.

Publications

Defense Science Board Task Force, ***Unexploded Ordnance (UXO) Clearance, Active Range UXO Clearance, and Explosive Ordnance Disposal (EOD) Programs***, Washington, DC, Department of Defense, Office of the Under Secretary of Defense (Acquisition and Technology), April 1998.

Department of Defense Operation and Environmental Executive Steering Committee for Munitions (OEESCM), ***Draft Munitions Action Plan: Maintaining Readiness through Environmental Stewardship and Enhancement of Explosives Safety in the Life Cycle Management of Munitions,*** Draft Revision 4.3, U.S. Department of Defense, February 25, 2000.

Department of Defense and U.S. Environmental Protection Agency, ***Management Principles for Implementing Response Actions at Closed, Transferring, and Transferred (CTT) Ranges, Interim Final***, DoD and EPA, March 7, 2000.

U.S. EPA, Federal Facilities Restoration and Reuse Office, ***EPA Issues at Closed, Transferred, and Transferring Military Ranges,*** letter to Deputy Under Secretary of Defense (Environmental Security), April 22, 1999.

Statutes and Regulations

Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA),42 U.S.C. § 9601 et seq.

Defense Environmental Restoration Program, 10 U.S.C. § 2701-2708, 2810.

Department of Defense Ammunition and Explosives Safety Standards, DoD Directive 6055.9-STD, July 1999.

Department of Defense Explosives Safety Board, 10 U.S.C. § 172.

Department of Defense Instruction (DODI) 4715.7, Environmental Restoration Program, April 22, 1996.

Military Munitions Rule: Hazardous Waste Identification and Management; Explosives Emergencies; Manifest Exception for Transport of Hazardous Waste on Right-of-Ways on Contiguous Properties; Final Rule, 40 C.F.R. § 260 et seq.

National Oil and Hazardous Substances Pollution Contingency Plan (more commonly called the National Contingency Plan), 40 C.F.R. § 300 et seq.

Resource Conservation and Recovery Act (RCRA), 42 U.S.C. § 6901 et seq.

Superfund Implementation, Executive Order (EO) 12580, January 13, 1987, and EO 13016, Amendment to EO 12580, August 28, 1996.

U.S. Army Corps of Engineers, Engineering and Design Ordnance and Explosives Response, EP 1110-1-18, April 24, 2000.

U.S. Army Corps of Engineers, Engineering and Design Ordnance and Explosives Response, EM 1110-1-4009, June 23, 2000.

Guidance

Department of Defense, Deputy Secretary of Defense, ***Finding of Suitability to Transfer for BRAC Property,*** June 1, 1994.

Department of Defense, Office of the Under Secretary of Defense (Acquisition and Technology), ***Management Guidance for the Defense Environmental Restoration Program,*** March 17, 1998.

Department of Defense, Office of the Under Secretary of Defense (Acquisition and Technology), ***Responsibility for Additional Environmental Cleanup after Transfer of Real Property,*** Washington, DC, July 25, 1997.

Department of Defense and U.S. EPA, ***The Environmental Site Closeout Process,*** 1998.

U.S. Army, ***Environmental Restoration Programs Guidance Manual***, April 1998.

U.S. EPA, ***Compliance with Other Laws Manual (Vols 1 & 2),*** August 8, 1988.

U.S. EPA, ***EPA Guidance on the Transfer of Federal Property by Deed Before all Necessary Remedial Action Has Been Taken Pursuant to CERCLA Section 120(h)(3),*** June 16, 1998.

U.S. EPA, ***Guidance on Conducting Non-time-critical Removal Actions Under CERCLA,*** August 1993 (PB93-963402).

U.S. EPA, ***Guide to Preparing Superfund Proposed Plans, Records of Decision, and Other Remedy Selection Decision Documents,*** July 1999 (PB98-963241).

U.S. EPA, ***Institutional Controls and Transfer of Real Property Under CERCLA Section 120(h)(3)(A), (B) or (C),*** February 2000.

U.S. EPA, **Use of Non-Time Critical Removal Authority in Superfund Response Actions,** February 14, 2000.

<u>**Information Sources**</u>

Department of Defense
Washington Headquarters Services
Directives and Records Branch (Directives Section)
http://web7.whs.osd.mil/

Department of Defense Environmental Cleanup (contains reports, policies, general publications, as well as extensive information about BRAC and community involvement)
http://www.dtic.mil/envirodod/index.html

Department of Defense Explosives Safety Board (DDESB)
2461 Eisenhower Avenue
Alexandria, VA 22331-0600
FAX: (703) 325-6227
http://www.hqda.army.mil/ddesb/esb.html

Department of Defense, Office of the Deputy Under Secretary of Defense (Environmental Security)
http://www.acq.osd.mil/ens/

Environmental Protection Agency
Federal Facilities Restoration & Reuse Office
http://www.epa.gov/swerffrr/

Environmental Protection Agency
Office of Solid Waste
RCRA, Superfund and EPCRA Hotline
Tel: (800) 424-9346 – Toll free
(703) 412-9810 – Metropolitan DC area and international calls, (800) 553-7672 – Toll free TDD
(703) 412-3323 – Metropolitan DC area and international TDD calls
http://www.epa.gov/dpaoswer/osw/comments.hem

U.S. Army Corps of Engineers
U.S. Army Engineering and Support Center
Ordnance and Explosives Mandatory Center of Expertise
4820 University Square
P.O. Box 1600
Huntsville, AL 35807-4301
http://www.hnd.usace.army.mil/

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DoD and EPA Management Principles for Implementing Response Actions at Closed, Transferring, and Transferred (CTT) Ranges

Preamble

Many closed, transferring, and transferred (CTT) military ranges are now or soon will be in the public domain. DoD and EPA agree that human health, environmental and explosive safety concerns at these ranges need to be evaluated and addressed. On occasion, DoD, EPA and other stakeholders, however, have had differing views concerning what process should be followed in order to effectively address human health, environmental, and explosive safety concerns at CTT ranges. Active and inactive ranges are beyond the scope of these principles.

To address concerns regarding response actions at CTT ranges, DoD and EPA engaged in discussions between July 1999 and March 2000 to address specific policy and technical issues related to characterization and response actions at CTT ranges. The discussions resulted in the development of this Management Principles document, which sets forth areas of agreement between DoD and EPA on conducting response actions at CTT ranges.

These principles are intended to assist DoD personnel, regulators, tribes, and other stakeholders to achieve a common approach to investigate and respond appropriately at CTT ranges.

General Principles

DoD is committed to promulgating the Range Rule as a framework for response actions at CTT military ranges. EPA is committed to assist in the development of this Rule. To address specific concerns with respect to response actions at CTT ranges prior to implementation of the Range Rule, DoD and EPA agree to the following management principles:

- DoD will conduct response actions on CTT ranges when necessary to address explosives safety, human health and the environment. DoD and the regulators must consider explosives safety in determining the appropriate response actions.

- DoD is committed to communicating information regarding explosives safety to the public and regulators to the maximum extent practicable.

- DoD and EPA agree to attempt to resolve issues at the lowest level. When necessary, issues may be raised to the appropriate Headquarters level. This agreement should not impede an emergency response.

- The legal authorities that support site-specific response actions at CTT ranges include, but are not limited to, the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), as delegated by Executive Order (E.O.) 12580 and the National Oil and Hazardous Substances Contingency Plan (NCP); the Defense Environmental Restoration Program (DERP); and the DoD Explosives Safety Board (DDESB).

- A process consistent with CERCLA and these management principles will be the preferred response mechanism used to address UXO at a CTT range. EPA and DoD further expect that where this process is followed, it would also meet any applicable RCRA corrective action requirements.

- These principles do not affect federal, state, and tribal regulatory or enforcement powers or authority concerning hazardous waste, hazardous substances, pollutants or contaminants, including imminent and substantial endangerment authorities; nor do they expand or constrict the waiver of sovereign immunity by the United States contained in any environmental law.

1. State and Tribal Participation

DoD and EPA are fully committed to the substantive involvement of States and Indian Tribes throughout the response process at CTT ranges. In many cases, a State or Indian Tribe will be the lead regulator at a CTT range. In working with the State or Indian Tribe, DoD will provide them opportunities to:

- Participate in the response process, to the extent practicable, with the DoD Component.

- Participate in the development of project documents associated with the response process.

- Review and comment on draft project documents generated as part of investigations and response actions.

- Review records and reports.

2. Response Activities under CERCLA

DoD Components may conduct CERCLA response actions to address explosives safety hazards, to include UXO, on CTT military ranges per the NCP. Response activities may include removal actions, remedial actions, or a combination of the two.

- DoD may conduct response actions to address human health, environmental, and explosives safety concerns on CTT ranges. Under certain circumstances, other federal and state agencies may also conduct response actions on CTT ranges.

- Removal action alternatives will be evaluated under the criteria set forth in the National Contingency Plan (NCP), particularly NCP §300.410 and §300.415.

- DoD Components will notify regulators and other stakeholders, as soon as possible and to the extent practicable, prior to beginning a removal action.

- Regulators and other stakeholders will be provided an opportunity for timely consultation, review, and comment on all phases of a removal response, except in the case of an emergency response taken because of an imminent and substantial endangerment to human health and the environment and consultation would be impracticable (see 10 USC 2705).

- Explosives Safety Submissions (ESS), prepared, submitted, and approved per DDESB requirements, are required for Time Critical Removal Actions, Non-Time Critical Removal Actions, and Remedial Actions involving explosives safety hazards, particularly UXO.

- The DoD Component will make available to the regulators, National Response Team, or Regional Response Team, upon request, a complete report, consistent with NCP §300.165, on the removal operation and the actions taken.

- Removal actions shall, to the extent practicable, contribute to the efficient performance of any anticipated long-term remedial action. If the DoD Component determines, in consultation with the regulators and based on these Management Principles and human health, environmental, and explosives safety concerns, that the removal action will not fully address the threat posed and remedial action may be required, the DoD Component will ensure an orderly transition from removal to remedial response activities.

3. Characterization and Response Selection

Adequate site characterization at each CTT military range is necessary to understand the conditions, make informed risk management decisions, and conduct effective response actions.

- Discussions with local land use planning authorities, local officials and the public, as appropriate, should be conducted as early as possible in the response process to determine the reasonably anticipated future land use(s). These discussions should be used to scope efforts to characterize the site, conduct risk assessments, and select the appropriate response(s).

- Characterization plans seek to gather sufficient site-specific information to: identify the location, extent, and type of any explosives safety hazards (particularly UXO), hazardous substances, pollutants or contaminants, and "Other Constituents"; identify the reasonably anticipated future land uses; and develop and evaluate effective response alternatives.

- Site characterization may be accomplished through a variety of methods, used individually or in concert with one another, including, but not limited to: records searches, site visits, or actual data acquisition, such as sampling. Statistical or other mathematical analyses (e.g., models) should recognize the assumptions imbedded within those analyses. Those assumptions, along with the intended use(s) of the analyses, should be communicated at the front end to the regulator(s) and the communities so the results may be better understood. Statistical or other mathematical analyses should be updated to include actual site data as it becomes available.

- Site-specific data quality objectives (DQOs) and QA/QC approaches, developed through a process of close and meaningful cooperation among the various governmental departments and agencies involved at a given CTT military range, are necessary to define the nature, quality, and quantity of information required to characterize each CTT military range and to select appropriate response actions.

- A permanent record of the data gathered to characterize a site and a clear audit trail of pertinent data analysis and resulting decisions and actions are required. To the maximum extent practicable, the permanent record shall include sensor data that is digitally-recorded and geo-referenced. Exceptions to the collection of sensor data that is digitally-recorded and geo-referenced should be limited primarily to emergency response actions or cases where impracticable. The permanent record shall be included in the Administrative Record. Appropriate notification regarding the availability of this information shall be made.

- The most appropriate and effective detection technologies should be selected for each site. The performance of a technology should be assessed using the metrics and criteria for evaluating UXO detection technology described in Section 4.

- The criteria and process of selection of the most appropriate and effective technologies to characterize each CTT military range should be discussed with appropriate EPA, other Federal State, or Tribal agencies, local officials, and the public prior to the selection of a technology.

- In some cases, explosives safety, cost, and/or technical limitations, may limit the ability to conduct a response and thereby limit the reasonably anticipated future land uses. Where these factors come into play, they should be discussed with appropriate EPA, other federal, State or Tribal agencies, local officials, and members of the public and an adequate opportunity for timely review and comment should be provided. Where these factors affect a proposed response action, they should be adequately addressed in any response decision document. In these cases, the scope of characterization should be appropriate for the site conditions. Characterization planning should ensure that the cost of characterization does not become prohibitive or disproportionate to the potential benefits of more extensive characterization or further reductions in the uncertainty of the characterization.

- DoD will incorporate any Technical Impracticability (TI) determination and waiver decisions in appropriate decision documents and review those decisions periodically in coordination with regulators.

- Selection of site-specific response actions should consider risk plus other factors and meet appropriate internal and external requirements.

4. UXO Technology

Advances in technology can provide a significant improvement to characterization at CTT ranges. This information will be shared with EPA and other stakeholders.

- The critical metrics for the evaluation of the performance of a detection technology are the probabilities of detection and false alarms. A UXO detection technology is most completely defined by a plot of the probability of detection versus the probability or rate of false alarms. The performance will depend on the technology’s capabilities in relation to factors such as type and size of munitions, the munitions depth distribution, the extent of clutter, and other environmental factors (e.g., soil, terrain, temperature, geology, diurnal cycle, moisture, vegetation). The performance of a technology cannot be properly defined by its probability of detection without identifying the corresponding probability of false alarms. Identifying solely one of these measures yields an ill-defined capability. Of the two, probability of detection is a paramount consideration in selecting a UXO detection technology.

- Explosives safety is a paramount consideration in the decision to deploy a technology at a specific site.

- General trends and reasonable estimates can often be made based on demonstrated performance at other sites. As more tests and demonstrations are completed, transfer of performance information to new sites will become more reliable.

- Full project cost must be considered when evaluating a detection technology. Project cost includes, but is not limited to, the cost of deploying the technology, the cost of excavation resulting from the false alarm rate, and the costs associated with recurring reviews and inadequate detection.

- Rapid employment of the better performing, demonstrated technologies needs to occur.

- Research, development, and demonstration investments are required to improve detection, discrimination, recovery, identification, and destruction technologies.

5. Land Use Controls

Land use controls must be clearly defined, established in coordination with affected parties (e.g., in the case of FUDS, the current owner; in the case of BRAC property, the prospective transferee), and enforceable.

- Because of technical impracticability, inordinately high costs, and other reasons, complete clearance of CTT military ranges may not be possible to the degree that allows certain uses, especially unrestricted use. In almost all cases, land use controls will be necessary to ensure protection of human health and public safety.

- DoD shall provide timely notice to the appropriate regulatory agencies and prospective federal land managers of the intent to use Land Use Controls. Regulatory comments received during the development of draft documents will be incorporated into the final land use controls, as appropriate. For Base

Realignment and Closure properties, any unresolved regulatory comments will be included as attachments to the Finding of Suitability to Transfer (FOST).

- Roles and responsibilities for monitoring, reporting and enforcing the restrictions must be clear to all affected parties.

- The land use controls must be enforceable.

- Land use controls (e.g., institutional controls, site access, and engineering controls) may be identified and implemented early in the response process to provide protectiveness until a final remedy has been selected for a CTT range.

- Land use controls must be clearly defined and set forth in a decision document.

- Final land use controls for a given CTT range will be considered as part of the development and evaluation of response alternatives using the nine criteria established under CERCLA regulations (i.e., NCP), supported by a site characterization adequate to evaluate the feasibility of reasonably anticipated future land uses. This will ensure that land use controls are chosen based on a detailed analysis of response alternatives and are not presumptively selected.

- DoD will conduct periodic reviews consistent with the Decision Document to ensure long-term effectiveness of the response, including any land use controls, and allow for evaluation of new technology for addressing technical impracticability determinations.

- When complete UXO clearance is not possible at military CTT ranges, DoD will notify the current land owners and appropriate local authority of the potential presence of an explosives safety hazard. DoD will work with the appropriate authority to implement additional land use controls where necessary.

6. Public Involvement

Public involvement in all phases of the CTT range response process is crucial to effective implementation of a response.

- In addition to being a requirement when taking response actions under CERCLA, public involvement in all phases of the range response process is crucial to effective implementation of a response.

- Agencies responsible for conducting and overseeing range response activities should take steps to proactively identify and address issues and concerns of all stakeholders in the process. These efforts should have the overall goal of ensuring that decisions made regarding response actions on CTTs reflect a broad spectrum of stakeholder input.

- Meaningful stakeholder involvement should be considered as a cost of doing business that has the potential of efficiently determining and achieving acceptable goals.

- Public involvement programs related to management of response actions on CTTs should be developed and implemented in accordance with DOD and EPA removal and remedial response community involvement policy and guidance.

7. Enforcement

Regulator oversight and involvement in all phases of CTT range investigations are crucial to an effective response, increase credibility of the response, and promote acceptance by the public. Such oversight and involvement includes timely coordination between DoD components and EPA, state, or tribal regulators, and, where appropriate, the negotiation and execution of enforceable site-specific agreements.

- DoD and EPA agree that, in some instances, negotiated agreements under CERCLA and other authorities play a critical role in both setting priorities for range investigations and response and for providing a means to balance respective interdependent roles and responsibilities. When negotiated and executed in good faith, enforceable agreements provide a good vehicle for setting priorities and establishing a productive framework to achieve common goals. Where range investigations and responses are occurring, DoD and the regulator(s) should come together and attempt to reach a consensus on whether an enforceable agreement is appropriate. Examples of situations where an enforceable agreement might be desirable include locations where there is a high level of public concern and/or where there is significant risk. DoD and EPA are optimistic that field level agreement can be reached at most installations on the desirability of an enforceable agreement.

- To avoid, and where necessary to resolve, disputes concerning the investigations, assessments, or response at CTT ranges, the responsible DoD Component, EPA, state, and tribe each should give substantial deference to the expertise of the other party.

- At NPL sites, disputes that cannot be mutually resolved at the field or project manager level should be elevated for disposition through the tiered process negotiated between DoD and EPA as part of the Agreement for the site, based upon the Model Federal Facility Agreement.

- At non-NPL sites where there are negotiated agreements, disputes that cannot be mutually resolved at the field or project manager level also should be elevated for disposition through a tiered process set forth in the site-specific agreement.

- To the extent feasible, conditions that might give rise to an explosives or munitions emergency (e.g., ordnance explosives) are to be set out in any workplan prepared in accordance with the requirements of any applicable agreement, and the appropriate responses to such conditions described, for example as has been done In the Matter of Former Nansemond Ordnance Depot Site, Suffolk, Virginia, Inter Agency Agreement to Perform a Time Critical Removal Action for Ordnance and Explosives Safety Hazards.

- Within any dispute resolution process, the parties will give great weight and deference to DoD's technical expertise on explosive safety issues.

8. Federal-to-Federal Transfers

DoD will involve current and prospective Federal land managers in addressing explosives safety hazards on CTT ranges, where appropriate.

- DoD may transfer land with potential explosives safety hazards to another federal authority for management purposes prior to completion of a response action, on condition that DoD provides notice of the potential presence of an explosives safety hazard and appropriate institutional controls will be in place upon transfer to ensure that human health and safety is protected.

- Generally, DoD should retain ownership or control of those areas at which DoD has not yet assessed or responded to potential explosives safety hazards.

9. Funding for Characterization and Response

DoD should seek adequate funding to characterize and respond to explosives safety hazards (particularly UXO) and other constituents at CTT ranges when necessary to address human health and the environment.

- Where currently identified CTT ranges are known to pose a threat to human health and the environment, DoD will apply appropriate resources to reduce risk.

- DoD is developing and will maintain an inventory of CTT ranges.

- DoD will maintain information on funding for UXO detection technology development, and current and planned response actions at CTT ranges.

10. Standards for Depths of Clearance

Per DoD 6055.9-STD, removal depths are determined by an evaluation of site-specific data and risk analysis based on the reasonably anticipated future land use.

- In the absence of site-specific data, a table of assessment depths is used for interim planning purposes until the required site-specific information is developed.

- Site specific data is necessary to determine the actual depth of clearance.

11. Other Constituent (OC) Hazards

CTT ranges will be investigated as appropriate to determine the nature and extent of Other Constituents contamination.

- Cleanup of other constituents at CTT ranges should meet applicable standards under appropriate environmental laws and explosives safety requirements.

- Responses to other constituents will be integrated with responses to military munitions, rather than requiring different responses under various other regulatory authorities.

References

A. Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), 42 U.S.C. § 9601 et seq.

B. National Oil and Hazardous Substances Pollution Contingency Plan (more commonly called the National Contingency Plan), 40 C.F.R. § 300 et seq.

C. Resource Conservation and Recovery Act (RCRA), 42 U.S.C. § 6901 et seq.

D. Military Munitions Rule: Hazardous Waste Identification and Management; Explosives Emergencies; Manifest Exception for Transport of Hazardous Waste on Right-of-Ways on Contiguous Properties; Final Rule, 40 C.F.R. § 260, et al.

E. Defense Environmental Restoration Program, 10 U.S.C. § 2701-2708, 2810.

F. Department of Defense Explosives Safety Board, 10 U.S.C. § 172

G. Executive Order (E.O.) 12580, Superfund Implementation, January 13, 1987, and E.O. 13016, Amendment to Executive Order 12580, August 28, 1996.

H. DoD Ammunition and Explosives Safety Standards, DoD Directive 6055.9-STD, dated July 1999

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3.0 CHARACTERISTICS OF ORDNANCE AND EXPLOSIVES

By their nature, ordnance and explosives (OE, including UXO, buried munitions, and explosive soil) and other constituents present explosive, human health, and environmental risks. When disturbed, OE may present an imminent hazard and can cause immediate death or disablement to those nearby. Different types of OE vary in their likelihood of detonation. The explosive hazards depend upon the nature and condition of the explosive fillers and fuzes.

Nonexplosive risks from OE result from the chemical constituents of explosive residues and include both human health and environmental risks. As the chemical constituents and explosive residues of OE come into contact with soils, groundwater, and air, they may affect humans and ecological receptors through a wide variety of pathways including, but not limited to, ingestion of groundwater, dermal exposure to soil, and various surface water pathways.

This chapter provides an overview of some of the information on OE that you will want to consider when planning for an investigation of OE. As discussed in Chapter 7, planning an investigation requires a careful and thorough examination of the actual use of munitions at the CTT range that is under investigation. Many CTT ranges have been in use for decades and had different missions that required the use of different types of munitions. Even careful archival searches will likely reveal gaps in the knowledge as to how the range was used. This chapter provides basic information on munitions, and factors that affect when they were used, where they may be found, and the human health and environmental concerns that may be associated with them. Information in this chapter provides an overview of:

- The history of explosives, chemicals used, and explosive functions.
- The nature of explosive hazards at CTT ranges.
- The sources and nature of explosive risks from conventional munitions.
- The human health effects of chemical constituents that come from conventional munitions.
- Other activities at CTT ranges that may result in releases of explosive constituents.

3.1 Overview of Explosives

In this section, we discuss the history of explosives in the United States, the nature of the explosive train, and the different classifications of explosives and the kinds of chemicals associated with them.

3.1.1 <u>History of Explosives in the United States</u>

The following section presents only a brief summary of the history of explosives in the United States. Its purpose is to provide an overview of the types of explosive material and chemicals in use during different time periods. This overview may be used in determining the potential types of explosives that could be present at a particular site.

3.1.1.1 *Early Development*

The earliest known explosive mixture discovered was what is now commonly referred to as black powder.[12] For over 1,200 years, black powder was the universal explosive and was used as a propellant for guns. For example, when ignited by fire or a spark from a flint, a loose charge of black powder above a gun's borehole or in a priming pan served as a priming composition. The train of black powder in the borehole served as a fuze composition. This combination resulted in the ignition of the propellant charge of black powder in the gun's barrel. When the projectile in the gun was a shrapnel type, the black powder in the delay fuze was ignited by the hot gases produced by the propellant charge, and the fuze then ignited the bursting charge of black powder.[13] Black powder was used by the American military up to the time period between the Spanish-American War and World War I.

3.1.1.2 *Developments in the Nineteenth Century*

Black powder had its limitations; for example, it lacked the power to blast through rock for the purpose of making tunnels. The modern era of explosives began in 1838 with the first preparation of nitrocellulose. Like black powder, it was used both as a propellant and as an explosive. In the 1840s, nitroglycerin was first prepared and its explosive properties described. It was first used as an explosive by Alfred Nobel in 1864. The attempts by the Nobel family to market nitroglycerin were hampered by the danger in handling the liquid material, and by the difficulty of safely detonating it by flame, the common method for black powder. Alfred Nobel would solve these problems by mixing the liquid nitroglycerin with an absorbent, making it much safer to handle, and by developing the mercury fulminate detonator. The resulting material was called dynamite. Nobel continued with his research and in 1869 discovered that mixing nitroglycerin with nitrates and combustible material created a new class of explosives he named "straight dynamite." In 1875 Nobel discovered that a mixture of nitroglycerin and nitrocellulose formed a gel. This led to the development of blasting gelatin, gelatin dynamites, and the first double-base gun propellant, ballistite.[14]

In the latter half of the nineteenth century, events evolved rapidly with the first commercial production of nitroglycerin and a form of nitrocellulose as a gun propellant called smokeless powder. The usefulness of ammonium nitrate and additional uses of guncotton (another form of nitrocellulose) were discovered. Shortly thereafter, picric acid[15] began to be used as a bursting

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[12] A mixture of potassium nitrate, sulfur, and powder charcoal or coal.

[13] Military Explosives, Technical Manual No. 9-1910, Technical Order No. 11A-1-34. Departments of the Army and the Air Force. April 1955.

[14] A. Bailey and S.G. Murray, *Explosives, Propellants & Pyrotechnics.* Brassey's (UK) Ltd. 1989.

[15] 2,4,6-Trinitrophenol.

charge for shells. Additional diverse mixtures of various compounds with inert or stabilizing fillers were developed for use as propellants and as bursting charges.[16]

During the Spanish-American War, the United States continued its use of black powder as an artillery propellant. During this period, the U.S. Navy Powder Factory at Indian Head started manufacturing single-base powder. However, the U.S. Army was slow to adopt this material, not manufacturing single-base powder until about 1900. This pyrocellulose powder was manufactured by gelatinizing nitrocellulose by means of an ether-ethanol mixture, extruding the resulting colloid material, and removing the solvent by evaporation.[17]

By 1909, dephenylamine was introduced as a stabilizer. Ammonium picrate, also known as "Explosive D," was also standardized in the United States as the bursting charge for armor-piercing shells. Because of its dangerous properties, which included its all too ease of detonation with the slightest shock, picric acid was replaced by TNT[18] as a bursting charge for artillery shells.[19]

3.1.1.3 *World War I*

The advent of the First World War saw the introduction of lead azide as an initiator and the use of TNT substitutes, containing mixtures of TNT, ammonium nitrate, and in some cases aluminum, by all the warring nations. One TNT substitute developed was amatol, which consisted of a mixture of 80 percent ammonium nitrate and 20 percent TNT. (Modern amatols contain no more than 50 percent ammonium nitrate.) Tetryl was introduced as a booster explosive for shell charges.[20]

3.1.1.4 *The Decades Between the Two World Wars*

The decades following World War I saw the development and use of RDX,[21] PETN,[22] lead styphnate, DEGN[23] and lead azide as military explosives. In the United States, the production of toluene from petroleum resulted in the increased production of TNT. This led to the production of

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[16]Military Explosives.

[17]Ibid.

[18]2,4,6-Trinitrotoluene.

[19]Ibid.

[20]Ibid.

[21]Hexahydro-1,3,5-trinitro-1,3,5-triazine.

[22]PETN, or pentaerythrite tetranitrate, was not used on a practical basis until after World War I. It is used extensively in mixtures with TNT for the loading of small caliber projectiles and grenades. It has been used in detonating fuzes, boosters, and detonators.

[23]Diethyleneglycol dinitrate.

more powerful and castable explosives such as pentolite.[24] Flashless propellants were developed in the United States as well as diazodinitrophenol as an initiator.[25]

3.1.1.5 *World War II*

The industrial development and manufacturing of synthetic toluene from petroleum just prior to World War II in the United States resulted in a nearly limitless supply of this chemical precursor of TNT. Because of its suitability for melt-loading, a process that heats the mixture to a near liquid state for introducing into the bomb casing, and for forming mixtures with other explosive compounds that could be melt-loaded, TNT was produced and used on an enormous scale during World War II. World War II also saw the development of rocket propellants based on a mixture of nitrocellulose and nitroglycerin or nitrocellulose and DEGN. Tetrytol[26] and picratol,[27] special-purpose binary explosives used in demolition work and in semi-armor-piercing bombs, were also developed by the United States.[28]

RDX and HMX[29] came into use during World War II, but HMX was not produced in large quantities so its use was limited.[30] Cyclotols, which are mixtures of TNT and RDX, were standardized early in World War II. Three formulations are currently used: 75 percent RDX and 25 percent TNT, 70 percent RDX and 30 percent TNT, and 65 percent RDX and 35 percent TNT.

A number of plastic explosives for demolition work were developed including the RDX-based C-3. The addition of powdered aluminum to explosives was found to increase their power. This led to the development of tritonal,[31] torpex,[32] and minol,[33] which have powerful blast effects.

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[24] An equal mixture of TNT and PETN.

[25] Military Explosives.

[26] A binary bursting charge explosive containing 70 percent tetryl and 30 percent TNT.

[27] A binary bursting charge explosive containing 52 percent ammonium picrate (Explosive D) and 48 percent TNT.

[28] Military Explosives.

[29] Octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine.

[30] Bailey.

[31] A mixture of 80 percent TNT and 20 percent flaked aluminum.

[32] A mixture of 41 percent RDX, 41 percent TNT, and 18 percent aluminum. It is noted for its powerful blast effects.

[33] A mixture of TNT, ammonium nitrate, and aluminum.

Also developed was the shaped charge, which permits the explosive force to be focused in a specific direction and led to its use for armor-piercing explosive rounds.[34]

3.1.1.6 *Modern Era*

Since 1945, military researchers have recognized that, based on both performance and cost, RDX, TNT, and HMX are not likely to be replaced as explosives of choice for military applications. Research has been directed into the optimization of explosive mixtures for special applications and for identifying and solving safety problems. High-performance propellants for both guns and rockets have used RDX and HMX. Mixing RDX, HMX, or PETN into oily or polymer matrices has produced plastic or flexible explosives for demolition. Other polymers will produce tough, rigid, heat-resistant compositions for conventional missile warheads and for the conventional implosion devices used in nuclear weapons.[35]

3.1.2 Explosive Train

An explosion is the violent bursting or expansion resulting from the generation of pressure or shock wave. This can occur as the result of a pressurized container giving way, such as a steam boiler explosion, or as the result of the chemical reaction of explosive material. An explosive can be a solid, liquid, or gaseous material. Explosives can consist of a single chemical compound or a mixture of chemical compounds or substances. Military explosives are typically formulated to be solids at normal temperature ranges.[36]

The characteristic effects of explosives result from a vast change in temperature and pressure developed when a solid, liquid, or gas is converted into a much greater volume of gas and heat. The rate of decomposition of particular explosives varies greatly and determines the classification of explosives into broadly defined groups.

Military explosives are grouped into three classes:

1. Inorganic compounds, including lead azide and ammonium nitrate.
2. Organic compounds, including:
    a. Nitric esters, such as nitroglycerin and nitrocellulose
    b. Nitro compounds, such as TNT and picric acid
    c. Nitramines, such as RDX
    d. Nitroso compounds, such as tetrazene
    e. Metallic derivatives, such as mercury fulminate and lead styphnate

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[34] Military Explosives.

[35] Bailey.

[36] Military Explosives.

3. Mixtures of oxidizable materials, such as fuels, and oxidizing agents that are not explosive when separate. These are also known as binary explosives. Black powder is an example of this class.

The unique properties of each class of explosives are utilized to make the "explosive train." One example of an explosive train is the initiation by a firing pin of a priming composition that detonates a charge of lead azide. The lead azide initiates the detonation of a booster charge of tetryl. The tetryl in turn detonates the surrounding bursting or main charge of TNT. The explosive train is illustrated in Figures 3-1 and 3-2.

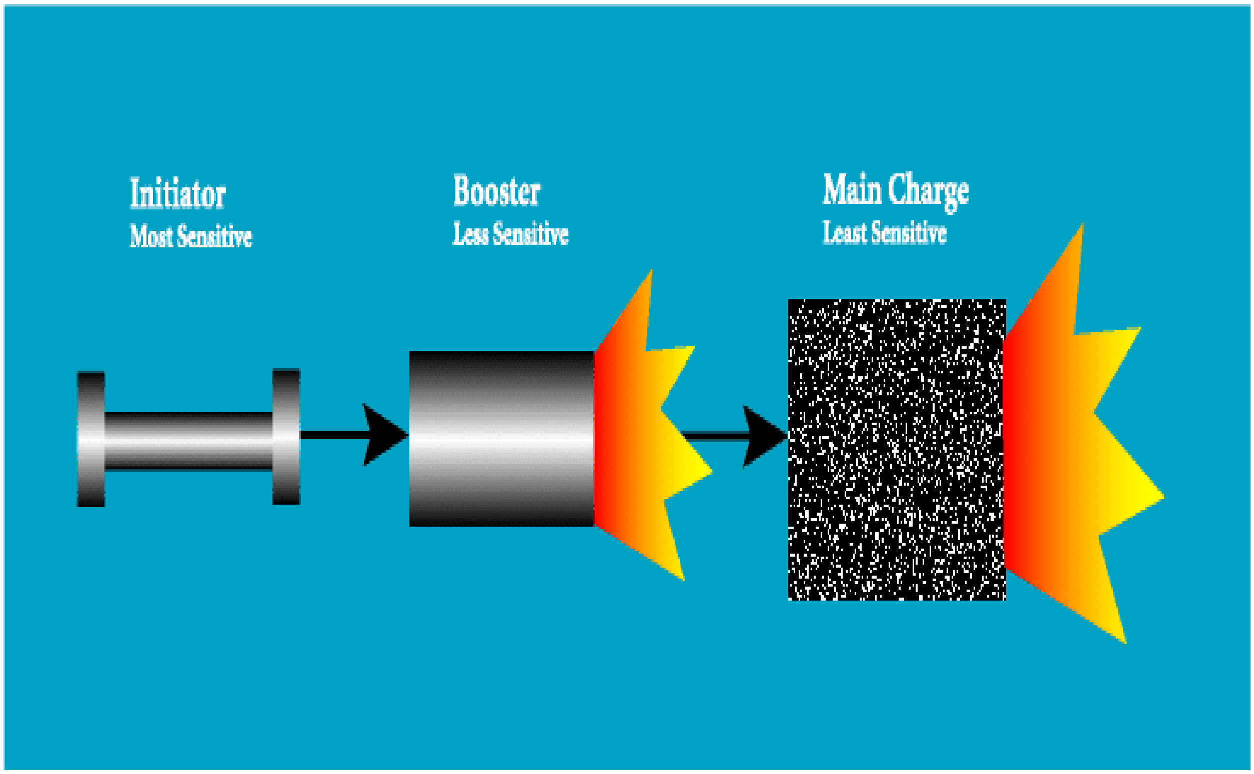

Figure 3-1. Schematic of an Explosive Train

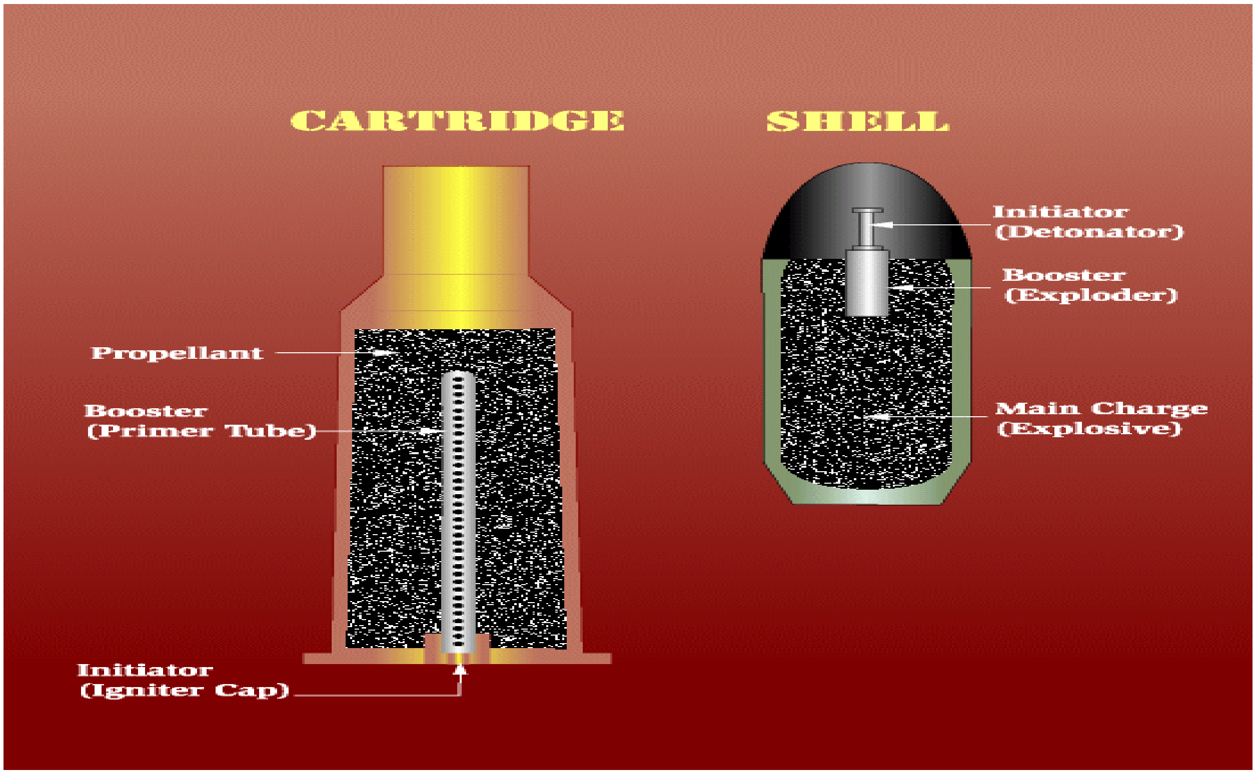

Figure 3-2. Explosive Trains in a Round of Artillery Ammunition

3.1.3 Classification of Explosives

An explosive is defined as a chemical material that, under the influence of thermal or mechanical shock, decomposes rapidly and spontaneously with the evolution of large amounts of heat and gas.[37] The categories **low explosive** and **high explosive** are based on the velocity of the explosion. High explosives are characterized by their extremely rapid rate of decomposition. When a high explosive is initiated by a blow or shock, it decomposes almost instantaneously. High explosives are further divisible by their susceptibility to initiation into primary and secondary high explosives. Primary or initiating high explosives are extremely sensitive and are used to set off secondary high explosives, which are much less sensitive but will explode violently when ignited. Low explosives, such as nitrocellulose and black powder, on the other hand, combust at a slower rate when set off and produce large volumes of gas in a controllable manner. Although black powder is in fact considered a low explosive, it is considered by the military to be a very sensitive explosive. Examples of primary high explosives are lead azide and mercury fulminate. TNT, tetryl, RDX, and HMX are secondary high explosives. There are hundreds of different kinds of explosives and this handbook does not attempt to address all of them. Rather, it discusses the major classifications of explosives used in military munitions.

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[37]R.N. Shreve, *Chemical Process Industries*, 3rd Ed., McGraw-Hill, NY, 1967.

3.1.3.1 *Low Explosives*

Low explosives include such materials as nitrocellulose and black powder. Low explosives also include materials, such as nitroglycerin, that are classified as high explosives (see 3.1.3.2) but can be processed to function as low explosives. Low explosives undergo chemical reactions, such as decomposition or autocombustion, at rates from a few centimeters per minute to approximately 400 meters per second. Examples and uses of low explosives are provided below.

Pyrotechnics are low explosives used to send signals, to illuminate areas of interest, to simulate other weapons during training, and as ignition elements for certain weapons. Pyrotechnics, when ignited, undergo an energetic chemical reaction at a controlled rate intended to produce, on demand in various combinations, specific time delays or quantities of heat, noise, smoke, light, or infrared radiation. Pyrotechnic compositions are considered low explosives because of their low rates of combustion. Pyrotechnics should burn and not explode. Table 3-1 shows examples of pyrotechnic special effects.[38]

Pyrotechnics consist of a wide range of materials that in combination produce the desired effects. Some examples of these materials are found in the following text box.[39]

Chemicals Found in Pyrotechnics

Aluminum
Chromium
Iron
Magnesium
Manganese
Titanium
Tungsten
Zirconium
Boron
Carbon
Silicon
Sulfur
Phosphorus

Chlorates
Chromates
Dichromates
Halocarbons
Iodates
Nitrates
Oxides
Perchlorates

Table 3-1. Pyrotechnic Special Effects

Effect	Examples
Heat	Igniters, incendiaries, delays, metal producers, heaters
Light*	Illumination (both long and short periods), tracking, signaling, decoys
Smoke	Signaling, screening
Sound	Signaling, distraction

* Includes not only visible light but also nonvisible light, such as infrared.

Propellants are low explosives that are able to be used to provide controlled propulsion for a projectile. Projectiles include bullets, mortar rounds, artillery rounds, rockets, and missiles. Because the projectile must be directed with respect to range and direction, the explosive process

[38]Bailey.

[39]Ibid.

must be restrained. In order to allow a controlled reaction that falls short of an actual detonation, the physical properties of the propellant, such as the grain size and form, must be carefully controlled.

The first propellant used was black powder. However, the use of black powder in the form of a dust or fine powder as a propellant for guns did not allow for an accurate control of a gun's ballistic effects. The development of denser and larger grains of fixed geometric shapes permitted greater control of a gun's ballistic effects.[40]

Modern gun propellants consist of one or more explosives and additives. These gun propellants are often referred to as "smokeless powders" to distinguish these materials from black powder. They are largely smokeless on firing compared to black powder, which gives off more than 50 percent of its weight as solid products.[41]

All solid gun propellants contain nitrocellulose. As a nitrated natural polymer, nitrocellulose has the required mechanical strength and resilience to maintain its integrity during handling and firing. Nitrocellulose is partially soluble in some organic solvents. These solvents include acetone, ethanol, ether/ethanol, and nitroglycerine. When a mixture of nitrocellulose and solvent is worked, a gel forms. This gel retains the strength of the polymer structure of nitrocellulose. Other propellant ingredients include nitroglycerin and nitroguanidine.[42]

Chemicals Found in Gun Propellants

Nitrocellulose
Nitroglycerin
Nitroguanidine

There are three compositions of gun propellants: single-base, double-base, and triple-base. A single-base propellant contains nitrocellulose as its only explosive ingredient. It is used in all manner of guns, from pistols to artillery. A double-base propellant contains nitroglycerine in addition to nitrocellulose. The amount of nitroglycerin present is lower now than when double-base propellants were introduced because modern automatic weapons are eroded by hot propellants of higher nitroglycerin composition propellants. Double-base propellants are largely used in ammunition for pistols and sub-machine guns. Triple-base propellants contain up to 55 percent by weight of nitroguanidine, as well as nitrocellulose and a small amount of nitroglycerin. The use of triple-base propellants is restricted to large guns because of their difficulty in igniting and because triple-base propellants give off a minimal gun flash when fired.

A new class of propellant composition has recently been introduced. Called "Energized Propellants," these compositions contain RDX.[43]

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[40] Military Explosives.

[41] Bailey.

[42] Ibid.

[43] Ibid.

Rocket propellants are explosives designed to burn smoothly without risk of detonation, thus providing smooth propulsion. Though similar to gun propellants in composition, solid rocket propellants operate differently. Gun propellants have a very short burn time with a high internal pressure. Rocket propellants can burn for a long time and operate at a lower pressure than gun propellant.[44]

Rocket propellants can be liquid or solid. There are two types of liquid propellants: monopropellants, which have a single material, and bipropellants, which have both a fuel and an oxidizer. Currently, the most used monopropellant is hydrazine. Bipropellants are used on very powerful launch systems such as space vehicle launchers. One or both of the components could be cryogenic material, such as liquid hydrogen and liquid oxygen. Noncryogenic systems include that used on the United States Army's tactical Lance missile. The Lance missile's fuel is an unsymetrical demethylhydrazine. The oxidizer is an inhibited fuming nitric acid that contains nitric acid, dinitrogen tetroxide, and 0.5 percent hydrofluoric acid as a corrosion inhibitor.[45]

Unlike the liquid fueled rocket motors in which the propellant is introduced into a combustion chamber, the solid fuel motor will have all of its propellant in the combustion chamber. Solid fuel propellants for rocket motors consist of double-base, modified double-base, and composites. Double-base rocket propellants are similar to the double-base gun propellants discussed earlier. Thus, they consist of a colloidal mixture of nitrocellulose and nitroglycerin with a stabilizer. A typical composition for a double-base propellant consists of nitrocellulose (51.5%), nitroglycerine (43%), diethylphthalate (3%), potassium sulfate (1.25%), ethyl centralite (1%), carbon black (0.2%), and wax (0.05%).

Modified double-base propellants provide a higher performance than double-base propellants. Two typical compositions for modified double-base propellants are (a) nitrocellulose (20%), nitroglycerine (30%), triacetin (6%), ammonium perchlorate (11%), aluminum (20%), HMX (11%), and a stabilizer (2%); or (b) nitrocellulose (22%), nitroglycerine (30%), triacetin (5%), ammonium perchlorate (20%), aluminum (21%), and a stabilizer (2%). Composite propellants consist of a polymer structure and an oxidizer. The oxidizer of choice is ammonium perchlorate. Two typical compositions are: (a) ammonium perchlorate (42%), ammonium picrate (38%), plasticized PIB (12%), aluminum (5%), oximide (2%), and lecithin (1%); or (b) ammonium perchlorate (57%), ammonium picrate (30%), plasticized PIB (12%), and lecithin (1%).[46]

3.1.3.2 *High Explosives*

The second explosives group, **high explosives,** includes compounds such as TNT, tetryl, RDX, HMX, and nitroglycerin. These compounds undergo reaction or detonation at rates of 1,000 to 8,500 meters per second. High explosives undergo much greater and more rapid reaction than low

[44]Ibid.

[45]Ibid.

[46]Ibid.

explosives (see 3.1.3.1). Some high explosives, such as nitrocellulose, nitroglycerin, and RDX, can be conditioned to function as a low explosive as discussed above for use in propellant mixtures. This conditioning often consists of mixing the explosive with other materials that permit the resulting mixture to be cut or shaped. This process allows for a greater amount of control over the reaction to achieve the desired effect as a propellant.

High explosives are further divisible according to their susceptibility to initiation into primary and secondary high explosives. Primary or initiating high explosives are extremely sensitive and are used to set off secondary high explosives, both booster and burster explosives, which are less sensitive but will explode violently when ignited.

Primary or initiating explosives are high explosives generally used in small quantities to detonate larger quantities of high explosives. Initiating explosives will not burn, but if ignited, they will detonate. Initiating agents are detonated by a spark, friction, or impact, and can initiate the detonation of less sensitive explosives. These agents include lead azide, lead styphnate, mercury fulminate, tetrazene, and diazodinitrophenol.

Primary Explosives

Lead azide
Lead styphnate
Mercury fulminate
Tetrazene
Diazodinitrophenol

Booster or auxiliary explosives are used to increase the flame or shock of the initiating explosive to ensure a stable detonation in the main charge explosive. High explosives used as auxiliary explosives are less sensitive than those used in initiators, primers, and detonators, but are more sensitive than those used as filler charges or bursting explosives. Booster explosives, such as RDX, tetryl, and PETN, are initiated by the primary explosive and detonate at high rates.

Booster Explosives

RDX
Tetryl
PETN

Bursting explosives, main charge, or fillers are high explosive charges that are used as part of the explosive charge in mines, bombs, missiles, and projectiles. Bursting charge explosives, such as TNT, RDX compositions, HMX, and Explosive D, must be initiated by means of a booster explosive.

Bursting Explosives

TNT
RDX compositions
HMX
Explosive D

3.1.3.3 *Incendiaries*

Incendiaries are neither high nor low explosives but are any flammable materials used as fillers for the purpose of destroying a target by fire,[47] such as red or white phosphorus, napalm, thermite, magnesium, and zirconium. In order to be effective, incendiary devices should be used against targets that are susceptible to destruction or damage by fire or heat. In other words, the target must contain a large percentage of combustible material.

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[47] Naval Explosive Ordnance Disposal Technology Division, Countermeasures Department. 1996. Unexploded Ordnance: An Overview.

3.2 Explosive Hazards at CTT Ranges

3.2.1 Areas Where OE Is Found

Areas that are most likely to contain OE include active and former munitions manufacturing plants; load, assemble, and pack operations; military supply depots; ammunition depots; proving grounds; open detonation (OD) and open burning (OB) grounds; range impact areas; range buffer zones; explosive ordnance disposal sites; live fire areas; training ranges; and ordnance test and evaluation (T&E) facilities and ranges. The primary ordnance-related activity will also assist planners in determining the potential OE hazards at the site; for example, an impact area will have predominantly unexploded ordnance (fuzed and armed), whereas munitions manufacturing plants should have only ordnance items (fuzed or unfuzed but unarmed). At all of these sites, a variety of munition types could have been used, potentially resulting in a wide array of OE items at the site. The types and quantities of munitions employed may have changed over time as a result of changes in the military mission and advances in munition technologies, thus increasing the variety of OE items that may be present at any individual site. Changes in training needs also contribute to the presence of different OE types found at former military facilities.

> **Military Ranges**
>
> The typical setup of a **live fire area military range** consists of a central "impact area," where fired munitions are supposed to land. Surrounding the impact area is a buffer zone that separates the impact area from the firing/release zone (the area from which the military munitions are fired, dropped, or placed). Within the live fire area, the impact area usually contains the greatest concentration of UXO. Buried munitions may be found in other areas, including the firing area itself.
>
> A **training range** is used for conducting military exercises in a simulated conflict area or war zone. Training aids and military munitions simulators such as training ammunition, artillery simulators, smoke grenades, pyrotechnics, mine simulators, and riot control agents are used on the training range. While these training aids are safer than live munitions, they may still present explosive hazards.

The types of chemicals potentially present on ranges varies, depending on the range type and its use. For example, a rifle range would be expected to be contaminated with lead rounds and metal casings. For ranges used for bombing, the most immediately hazardous chemicals would consist of explosive compounds such as TNT and RDX. This has been confirmed by environmental samples collected at numerous facilities. For example, TNT or RDX is usually present in explosives-contaminated soils. Studies of sampling and analysis at a number of explosives-contaminated sites reported "hits" of TNT or RDX in 72 percent of the soil samples collected[48] and up to 94 percent of water samples collected.[49]

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[48]Field Sampling and Selecting On-Site Analytical Methods for Explosives in Soils. A. B. Crockett, H. D. Craig, T. F. Jenkins, and W. E. Sisk. U.S. Environmental Protection Agency. EPA/540/R-97/501. November 1996.

[49]Field Sampling and Selecting On-Site Analytical Methods for Explosives in Water. A. B. Crockett, H. D. Craig, and T. F. Jenkins. U.S. Environmental Protection Agency. EPA/600/S-99/002. May 19, 1999.

Early (World War I era) explosive munitions tend to be TNT based. To a lesser extent, tetryl and ammonium nitrate were used as well. However, ammonium nitrate is a plant nutrient and would not persist in the environment. TNT is still used but mixtures of RDX, HMX, ammonium picrate, PETN, tetryl, and aluminum came into use during World War II. Incendiary charges consisting of white phosphorous were also used in World War II.

3.2.2 Explosive Hazards Associated with Common Types of Munitions

The condition in which a munition is found is an important factor in assessing its likelihood of detonation. Munitions are designed for safe transport and handling prior to use. Munitions encountered with the fuze unarmed pose a reduced risk of explosion, while those with armed fuzes are usually a greater hazard. However, it is very difficult to tell if a fired munition has been armed, and common sense safety practice requires that all munitions be handled as if they were armed. Munitions that failed to function as designed are called unexploded ordnance,"duds," or "dud-fired," and may be armed, partially armed, armed and functioning, or unarmed. Many ordnance items utilize multiple fuzing options; therefore, one fuze may be armed and others unarmed. Munitions that detonate only partially are said to have undergone a "low order" detonation, which may result in exposed explosives scattered in the immediate vicinity. In addition to the detonation hazard of OE varying with the condition in which it is found, the explosive hazard also varies with the type of munition, as briefly described in the following text box.

Conventional Munitions Commonly Found as UXO

- **Small arms munitions** present minimal explosive risks, but because they often consist of lead shells, they may cause lead contamination of the surrounding environment. Small arms include projectiles that are 0.5 inch or less in caliber and no longer than approximately 4 inches. They are fired from various sizes of weapons, such as pistols, carbines, rifles, automatic rifles, shotguns, and machine guns.
- **Hand grenades** are small explosive- or chemical-type munitions that are very hazardous, in part because they are designed to land on the ground surface, making unexploded items accessible to the public. Various classes of grenades may be encountered as UXO, including fragmentation, smoke, and illumination grenades. All grenades have three main parts: a body, a fuze with a pull ring and safety clip assembly, and a filler. Grenades have metal, plastic, cardboard, or rubber bodies and may contain explosives, white phosphorus, chemical agents, or illumination flares, depending on their intended use. Fragmentation grenades, the most frequently used type of grenade, break into small, lethal, high-velocity fragments and pose the most serious explosive risks.
- **Mortar shells** are likely to explode when disturbed. They range from approximately 1 to 11 inches in diameter and are filled with explosives, white phosphorus, illumination flares, or other fillers.
- **Projectiles/artillery rounds** may also be sensitive to disturbances. They range from approximately 1 to 16 inches in diameter and from 2 inches to 4 feet in length.
- **Submunitions** typically land on the ground surface, making them potentially accessible and hazardous to humans and animals. Submunitions include bomblets, grenades, and mines that are filled with either explosives or chemical agents. Submunitions are used for a variety of purposes, including antipersonnel, antimateriel, antitank, dual-purpose, and incendiary. They are scattered over large areas by dispensers, missiles, rockets, or projectiles. Submunitions are activated in a number of ways, including pressure, impact, movement, or disturbance, while in flight or when near metallic objects.
- **Missiles** are extremely hazardous. Both exploded and unexploded missiles can be very dangerous to anyone coming into contact with them because of residual propellant that may remain after landing. This residual propellant can ignite and cause violent burning if missiles are disturbed. Missiles consist of a warhead, a motor section, a guidance section, and a fuze, and they are guided to their target by any number of systems, including radar, infrared, video, and programmable flight. They use gas pressure from rapidly burning propellants to transport a payload to a desired location and may be fuzed with any number of fuzes, including impact and proximity fuzes.
- **Rockets** also pose serious hazards, as the potential exists for residual propellant to burn violently if disturbed. Rockets consist of a motor section, a warhead, and a fuze. The warhead can be filled with explosives, toxic chemicals, white phosphorus, submunitions, riot-control agent, or illumination flares. Rockets may be fuzed with any number of fuzes.
- **Bombs** may penetrate the ground at variable depths. However, human disturbance is unlikely at deeper depths; however, both exploded and unexploded bombs that malfunction and remain on or near the ground surface can be extremely hazardous. Bombs range from 1 to 3,000 pounds in weight and from 3 to 10 feet in length. Bombs consist of a metal container (the bomb body), a fuze, and a stabilizing device. The bomb body holds the explosive chemical or submunition filler, and the fuze (nose and/or tail) may be anti-disturbance, time delay, mechanical time, proximity, or impact or a combination thereof.

Adapted from: Unexploded Ordnance (UXO): An Overview. October 1996. Naval Explosive Ordnance Disposal Technology Division, UXO Countermeasures Department, and BRAC Environmental Fact Sheet, Unexploded Ordnance (UXO). Spring 1999. DoD Office of the Deputy Under Secretary of Defense (Environmental Security).

3.2.3 Chemical Reactivity of Explosives

Standard military explosives are reactive to varying degrees, depending on the material, conditions of storage, or environmental exposure. Precautions must be taken to prevent their reacting with other materials. For example, lead azide will react with copper in the presence of water and carbon dioxide to form copper azide, which is an even more sensitive explosive. Ammonium nitrate will react with iron or aluminum in the presence of water to form ammonia and metal oxide. TNT and RDX will react with alkalies to form dangerously sensitive compounds. Picric acid easily forms metallic compounds, many of which are very shock sensitive.

Because of these reactions, and others not listed, military munitions are designed to be free of moisture and any other impurities, and not to be in contact with any metals other than the metal(s), such as aluminum, forming the explosive mixture. Therefore, munitions that have not been properly stored may be more unstable and unpredictable in their behavior, and more dangerous to deal with than normal munitions. This is also true for munitions that are no longer intact, have been exposed to weathering processes, or have been improper dispose of. These conditions may exist on ranges.

3.3 Sources and Nature of Explosive Risks from Conventional Munitions

This section of the handbook addresses two factors that affect explosive hazards: (1) the sensitivity of the UXO and its components (primarily the fuze and fuze type) to detonation and (2) the environmental and human factors that affect the deterioration of the UXO or the depth at which UXO is found.

The potential for explosive damage is a result of the following:

- Type of munition
- Type and amount of explosive(s) contained in the munition
- Type of fuze
- The potential for deterioration of the intact UXO and the release of explosive materials
- The likelihood that the munition will be in a location where disturbance is possible or probable

However, a full understanding of explosive hazards is not possible prior to initiating an investigation unless the munition items have been identified in advance, the state of the ordnance is known, and the human and environmental factors (e.g., frost heave) are well understood.

3.3.1 Probability of Detonation as a Function of Fuze Characteristics

Most military munitions contain a fuze that is designed to initiate a train of fire or a detonation. Fuzes can be one of two general types – mechanical and electronic. These fuze types describe the method by which a fuze is armed and fired. Modern fuzes are generally not armed until the munition has been launched. For safety purposes, DoD policy is that all munitions and OE found on ranges should be assumed to be armed and prepared to detonate and should be approached with extreme caution (see Chapter 6, "Safety").

The type of fuze and its condition (armed or unarmed) directly determine its sensitivity. It should always be assumed that a fuzed piece of ordnance is armed, in the absence of evidence to the contrary. Many fuzes have backup features in addition to their normal method of firing. For example, a proximity fuze may also have an impact or self-destruct feature. Certain types of fuzes are more sensitive than others and may be more likely to explode upon disturbance. Some of the most common fuzes are described below.

- **Proximity fuzes** are designed to function only when they are at a predetermined distance from a target.[50] They are used in air-to-ground and ground-to-ground operations to create airbursts above the target, and they do not penetrate and detonate within the target, as do impact fuzes. However, proximity fuzes are sometimes backed up with an impact fuze, which is designed to function on target impact if the proximity mode fails to function.
- **Impact fuzes** are designed to function upon direct impact with the target. Some impact fuzes may have a delay element. This delay lasts fractions of a second and is designed to allow the projectile to penetrate the target before functioning. Examples of specific impact fuzes include impact inertia, concrete piercing, base detonating, all-way acting, and multi-option. In order for a proximity or impact fuze to arm, the projectile must be accelerating at a predetermined minimum rate. If the acceleration is too slow or extends over too short a period of time, the arming mechanism returns to its safety position; however, munitions with armed proximity fuzes that have not exploded may be ready to detonate on the slightest disturbance.
- **Mechanical time fuzes** use internal movement to function at a predetermined time after firing. Some of these fuzes may have a backup impact fuze. An example is shown in Figure 3-3.
- **Powder train time fuzes** use a black powder train to function at a predetermined time after firing.

Several different fuze types are listed according to their relative sensitivity levels in Table 3-2.

[50] Major N. Lantzer, et al. "Risk Assessment: Unexploded Ordnance." Prepared for NAVEODTECHDIV, 1995.

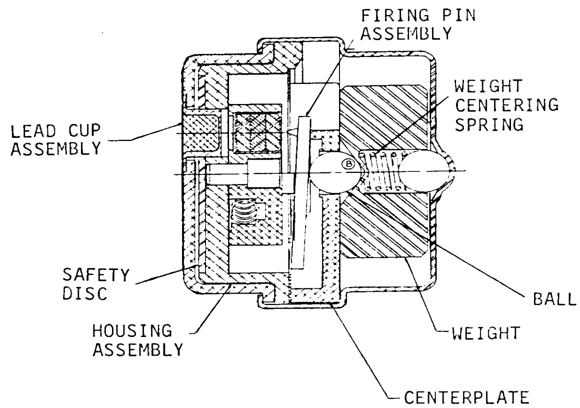

Figure 3-3. Mechanical All-Way-Acting Fuze

Table 3-2. Sensitivity Listing of Fuze Families (least sensitive to most sensitive)

Fuze
Armor Piercing (AP)
Electronic Time (ET)
Powder Train Time (PTT)
Impact Inertia, Submunitions (II)
Proximity (VT)
Electronic Delay Hand Grenade (ED)
Base Detonating (BD)
Point Detonating (PD)
Point Detonating Self-Destruct (PDSD)
Impact (Submunitions)
Electronic Long Delay Antidisturbance (ELDA)
Striker Release Hand Grenade
Mechanical All-Way Acting (MAA)
Point Detonating, 40 mm Grenade (PD)
Mechanical Clockwork Long Delay (MCLD)
Mechanical Time Super Quick (MTSQ)
Mechanical Time (MT)

Fuze
Chemical Delay Booby Trap (CDBT)
Time Delay (TD)
Point Initiating Base Detonating "Spit Back" (PIBD)
Point Initiating Base Detonating-Lucky (PIBD-L)

3.3.2 Types of Explosive Hazards

Both planned and accidental detonations can cause serious injury or even death and can seriously damage structures in the vicinity of the explosion. Explosive hazards from munitions vary with the munition components, explosive quantities, and distance from potential receptors. The DDESB has established minimum safety standards for the quantity of explosives and their minimum separation distance from surrounding populations, structures, and public areas for the protection of personnel and facilities during render-safe procedures (see Chapter 5 for a discussion of render-safe procedures) and planned and accidental explosions.[51] These DDESB standards, called Quantity-Distance Standards, are based on research and accident data on the size of areas affected by different types of explosions and their potential human health and environmental impacts (see Chapter 6 for a discussion of Quantity-Distance Standards). State and local authorities may have additional and/or more stringent quantity-distance requirements.

Understanding the explosive hazards specific to the munitions at your site will help you plan the appropriate safety precautions and notification of authorities. The primary effects of explosive outputs include blast pressure, fragmentation, thermal hazards, and shock hazards, which are described below. Many UXO hazards in the field may result in more than one type of explosive output.

Blast pressure is the almost instantaneous pressure increase resulting from a violent release of energy from a detonation in a gaseous medium (e.g., air). The health hazards of blast pressure depend on the amount of explosive material, the duration of the explosion, and the distance from the explosion, and can include serious damage to the thorax or the abdominal region, eardrum rupture, and death.

Fragmentation hazards result from the shattering of an explosive container or from the secondary fragmentation of items in close proximity to an explosion. Fragmentation can cause a variety of physical problems ranging from skin abrasions to fatal injuries.

Thermal hazards are those resulting from heat and flame caused by a deflagration or detonation. Direct contact with flame, as well as intense heat, can cause serious injury or death.

[51]DoD 6055.9-STD, DoD Ammunition and Explosives Safety Standards. July 1999. Chapters 2, 5, and 8.

Shock hazards are those that result from explosions that may damage buildings or other structures. In an accidental explosion beneath the surface, the confinement caused by the limited space in underground facilities, particularly in storage areas, can cause very high pressures of prolonged duration. Blast waves and dynamic flow fields can travel at high velocities throughout the underground facility, and ground shocks will be produced with resulting breakup of the earth cover.[52]

3.3.3 Factors Affecting Potential for Ordnance Exposure to Human Activity

Because exposure to OE is a key element of explosive risk, any action that makes OE more accessible adds to its potential explosive risks. The combined factors of naturally occurring and human activities, such as the following, increase the explosive risks of OE:

- Flooding and erosion
- Frost heaving
- Agricultural activities
- Construction
- Recreational use (may provide open access)

Heavy flooding can loosen and displace soils, causing UXO located on or beneath the ground surface to be moved or exposed. In flooded soils, UXO could potentially be moved to the surface or to another location beneath the ground surface. Similarly, soil erosion due to high winds, flooding, or inadequate soil conservation could displace soils and expose UXO, or it could cause UXO to migrate to another location beneath the surface or up to the ground surface.

Frost heaving is the movement of soils during the freeze-thaw cycle. Water expands as it freezes, creating uplift pressure. In nongranular soils, UXO buried above the frost line may migrate with frost heaving.

Human activities can also increase the potential for UXO exposure. Depending on the depth of UXO, agricultural activities such as plowing and tilling may loosen and disturb the soil enough to cause UXO to migrate to the surface, or such activities may increase the chances of soil erosion and UXO displacement during flooding. Further, development of land containing UXO may cause the UXO to be exposed and possibly to detonate during construction activities. Excavating soils during construction can expose UXO, and the vibration of some construction activities may create conditions in which UXO may detonate. All of these human and naturally occurring factors can increase the likelihood of UXO exposure and therefore the explosive risks of UXO.

[52]DoD 6055.9-STD, DoD Ammunition and Explosives Safety Standards. July 1999. Chapter 9.

3.3.4 <u>Depth of UXO</u>

The depth at which OE is located is a primary determinant of both potential human exposure and the cost of investigation and cleanup. In addition, the DoD Ammunition and Safety Standards require that an estimate of expected depth of OE be included in the site-specific analysis for determining remediation depth.[53] A wide variety of factors may affect the depth at which OE is found, including penetration depth — a function of munition size, shape, propellant charge used, soil characteristics, and other factors — as well as movement of OE due to frost heave or other factors, as discussed in section 3.3.3.

There are several methods for estimating the ground penetration depths of ordnance. These methods vary in the level of detail required for data input required (e.g., ordnance weight, geometry, angle of entry, and more), the time and level of effort needed to conduct analysis, and the assumptions used to obtain results. Some of the specific soil characteristics that affect ordnance penetration depth include soil type (e.g., sand, loam, clay), whether vegetation is present, and soil moisture. Other factors affecting penetration depth include munition geometry, striking velocity and angle, relative location of firing point and striking point, topography between firing point and striking point, and angle of entry. Table 3-3 provides examples of the potential effects that different soil characteristics can have on penetration depth. These depths do not reflect the variety of other factors (e.g., different striking velocities and angles) that affect the actual depth at which the munition may be found. The depths provided in Table 3-3 are taken from a controlled study to determine fragment penetration into earth. They are presented here to give the reader an understanding of the wide variability in the depths at which individual munitions may be found, based on soil characteristics alone.

While Table 3-3 provides a few examples of penetration depths, it does not illustrate the dramatic differences possible within ordnance categories. For example, rockets can penetrate sand to depths of between 0.4 and 8.1 feet, and clay to depths of between 0.8 and 16.3 feet, depending on the type of rocket and a host of site-specific conditions.[54]

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[53]DoD 6055.9, DoD Ammunition and Safety Standards. July 1999. Chapter 12.

[54]U.S. Army Corps of Engineers. Interim Guidance for Conventional Ordnance and Explosives Removal Actions. October 1998.

Table 3-3. Examples of Depths of Penetration of Ordnance into Soil

Type of Munition	Ordnance Item	Depth of Penetration (ft)			
		Limestone	Sand	Soil Containing Vegetation	Clay
Projectile	155 mm M107	2.0	14.0	18.4	28.0
Projectile	75 mm M48	0.7	4.9	6.5	9.9
Projectile	37 mm M63	0.6	3.9	5.2	7.9
Grenade	40 mm M822	0.5	3.2	4.2	6.4
Projectile	105 mm M1	1.1	7.7	10.1	15.4
Rocket	2.36" Rocket	0.1	0.4	0.5	0.8

Sources: U.S. Army Corps of Engineers. Engineering and Design Ordnance and Explosives Response, Manual No. 1110-1-4009, June 23, 2000; and Ordata II, NAVEODTECHDIV, Version 1.0, and Cruell, Michell, et al. "Estimating Ordnance Penetration Into Earth." Presented at UXO Forum 1999. May 1999.

A unique challenge in any investigation of OE is the presence of underground munition burial pits, which often contain a mixture of used, unused, or fired munitions as well as other wastes. Munition burial pits, particularly those containing a mixture of deteriorated munitions, can pose explosive and environmental risks. The possibility of detonation is due to the potentially decreased stability and increased likelihood of explosion of commingled and/or degraded munition constituents.

Buried munitions may detonate from friction, impact, pressure, heat, or flames of a nearby OE item that has been disturbed. Adding to the challenge, some burial pits are quite old and may not be secured with technologically advanced liners or other types of controls. Further, because some burial pits are very old, records of their contents may be incomplete or absent altogether.

3.3.5 Environmental Factors Affecting Decomposition of Explosives

Deteriorated UXO can present serious explosive hazards. As UXO casings degrade under certain environmental conditions, their fillers, propellants, and other constituents may leach into the surrounding soils and groundwater, break down, and commingle, creating a potentially highly explosive environment. The synergistic effects of commingled explosives may potentially increase the probability of an uncontrolled detonation. In addition, deteriorated explosive compounds may also pose greater explosive risks than their predecessors. Over time, regardless of the soil conditions, seals used to contain explosive charges may disintegrate or, at a minimum, loosen enough to allow explosive compounds to migrate into the surrounding environment. Finally, deteriorated explosives can result in explosives contaminated soils that may be sensitive to disturbances. Several environmental factors can affect the corrosion rate of UXO containment casings and explosive constituents, including soil characteristics.[55]

In general, the likelihood of UXO deterioration depends on the integrity and thickness of the UXO casing. Most munitions are designed for safe transport and handling prior to use. However, if they do not explode upon impact or as they are otherwise designed to perform, and they are damaged or corroded, it is possible that the fillers, propellants, and other constituents may leach into surrounding soils and groundwater, potentially polluting the soil and groundwater and/or creating a mixture of explosives and their breakdown products. Anecdotal evidence at a number of facilities suggests the presence of adverse impacts to soil and groundwater from ordnance-related activities.

The soil characteristics that affect the likelihood and rate of UXO corrosion include but are not limited to the following:

- Soil moisture
- Soil type
- Soil pH
- Buffering capacity
- Resistivity
- Electrochemical (redox) potential
- Oxygen

Moisture, including precipitation, high soil moisture, and the presence of groundwater, contribute to the corrosion of UXO and to the deterioration of explosive compounds. Soils with a low water content (i.e., below 20 percent) are slightly corrosive on UXO casings, while dry soils are neutral and soils with periodic groundwater inundation are moderately corrosive. Explosive D, for example, breaks down to picric acid and other constituents in moist conditions, potentially evolving into highly explosive picrate salts.

The texture and structure of soil affect its corrosivity (its ability to corrode UXO casings). Cohesive soils, those with a high percentage of clay and silt material, are much less corrosive than sandy soils. Soils with high organic carbon content, such as swamps, peat, fens, or marshes, as well as soils that are severely polluted with fuel ash, slag coal, or wastewater, tend to be highly corrosive.

The pH level also affects soil corrosivity. Normal soils with pH levels between 5 and 8 do not contribute to corrosivity. In fact, soils with pH above 5 may form a calcium carbonate coating on buried metals, protecting them from extensive corrosion. However, highly acidic soils, such as those with a pH below 4, tend to be highly corrosive.

Buffering capacity, the measure of the soil's ability to withstand extreme changes in pH levels, also affects its corrosion potential. Soils with a high buffering capacity can maintain pH

[55]Joseph Bucci, and Paul Buckley. Modeling the Degradation of Unexploded Ordnance (UXO) and Its Use As a Tool in the Development of Risk Assessments. 1999.

levels even under changing conditions, thereby potentially inhibiting corrosive conditions. However, soils with a low buffering capacity that are subject to acid rain or industrial pollutants may fluctuate in pH levels and promote corrosivity.

Another factor affecting the corrosive potential of soils is resistivity, or electrical conductivity, which is dependent on moisture content and is produced by the action of soil moisture on minerals. At high resistivity levels (greater than 20,000 ohm/cm) there is no significant impact on corrosion; however, corrosion can be extreme at very low resistivity levels (below 1,000 ohm/cm). High electrochemical potential can also contribute significantly to UXO casing corrosion. The electrochemical or "redox" potential is the ability of the soil to reduce or oxidize UXO casings (the oxidation-reduction potential). Aerated soils have the necessary oxygen to oxidize metals as well as certain anaerobic bacteria that can create an oxidizing environment.

3.3.6 Explosives-Contaminated Soils

A variety of situations can create conditions of contaminated and potentially reactive soils, including deterioration of the UXO container and leaching of material into the environment, residual propellants that end up in soils, and OB/OD, which disperses explosive material. Soils suspected of being contaminated with primary explosives may be very dangerous, and no work should be attempted until soil analysis has determined the extent of contamination and a detailed work procedure has been approved.[56] Soils with a 12 percent or greater concentration of secondary explosives, such as TNT and RDX, are capable of propagating through soil if initiated by flame. Soils containing more than 15 percent secondary explosives by weight are susceptible to initiation by shock. In addition, chunks of bulk explosives in soils will detonate if initiated, but will not propagate through the soil without a minimum explosive concentration of 12 percent. To be safe, the U.S. Army Environmental Center considers all soils containing 10 percent or more of secondary explosives or mixtures of secondary explosives to be explosive soil.[57]

3.4 Toxicity and Human Health and Ecological Impacts of Explosives and Other Constituents

The human health and environmental risks of other constituents from UXO are caused by explosives or other chemical components in munitions and from the compounds used in or produced during munitions operations. When exposed to some of these hazardous chemicals and residues, humans may potentially face long-term health problems, including cancer, and animals may develop physical health and behavioral problems. The adverse effects of UXO and UXO residues are dependent on the concentration of the chemicals and the pathways by which receptors become exposed. Understanding the human health and environmental risks of UXO residues and byproducts requires information about the inherent toxicity of these chemicals and the manner in which they

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[56] U.S. Army Corps of Engineers. Engineering and Design Ordnance and Explosives Response. EP 1110-1-18, April 2000.

[57] Federal Remediation Technologies Roundtable and USACE, ETL Ordnance and Explosives Response, 110-1-8154, May 14, 1999.

may migrate through soil and water toward potential human and environmental receptors. This section provides an overview of some commonly found explosive compounds and their potential health and ecological impacts.

Explosive compounds that have been used in or are byproducts of munitions use, production, operations (load, assemble, and pack), and demilitarization or destruction operations include, but are not limited to, the list of substances in Table 3-4. Other toxic materials, such as lead, are found in the casings of small arms. These explosive and otherwise potentially toxic compounds can be found in soils, groundwater, surface waters, and air and have potentially serious human health and ecological impacts. The nature of these impacts, and whether they pose an unacceptable risk to human health and the environment, depend upon the dose, duration, and pathway of exposure, as well as the sensitivity of the exposed populations.

Table 3-4 illustrates the chemical compounds used in munitions and their potential human health effects as provided by EPA's Integrated Risk Information System (IRIS), the Agency for Toxic Substances and Disease Registry (ATSDR), and material safety data sheets (MSDS).

Table 3-5 shows the uses of the same compounds found on Table 3-4. It illustrates that many compounds have multiple uses, such as white phosphorus, which is used both in pyrotechnics and incendiaries. The list of classifications on Table 3-5 is not intended to be all-inclusive but to provide a summary of some of the more common uses for various explosive materials.

Perchlorate is a component of solid rocket fuel that has recently been detected in drinking water in States across the United States. Perchlorate interacts with the thyroid gland in mammals, with potential impacts on growth and development. Research continues to determine the maximum safe level for human drinking water. While perchlorate is not currently listed on EPA's IRIS database, several States, including California, have developed interim risk levels.

Table 3-4. Potential Toxic Effects of Exposure to Explosive Chemicals and Components

Contaminant	Chemical Composition	Potential Toxicity/Effects
TNT	2,4,6-Trinitrotoluene $C_7H_5N_3O_6$	Possible human carcinogen, targets liver, skin irritations, cataracts.
RDX	Hexahydro-1,3,5-trinitro-1, 3,5-triazine $C_3H_6N_6O_6$	Possible human carcinogen, prostate problems, nervous system problems, nausea, vomiting. Laboratory exposure to animals indicates potential organ damage.
HMX	Octahydro-1,3,5,7-tetranitro -1,3,5,7-tetrazocine $C_4H_8N_8O_8$	Animal studies suggest potential liver and central nervous system damage.
PETN	Pentaerythritol tetranitrate $C_5H_8N_4O_{12}$	Irritation to eyes and skin; inhalation causes headaches, weakness, and drop in blood pressure.

Contaminant	Chemical Composition	Potential Toxicity/Effects
Tetryl	2,4,6-Trinitrophenyl-N-methylnitramine $C_7H_5N_5O_8$	Coughing, fatigue, headaches, eye irritation, lack of appetite, nosebleeds, nausea, and vomiting. The carcinogenicity of tetryl in humans and animals has not been studied.
Picric acid	2,4,6-Trinitrophenol $C_6H_4N_3O_7$	Headache, vertigo, blood cell damage, gastroenteritis, acute hepatitis, nausea, vomiting, diarrhea, abdominal pain, skin eruptions, and serious dysfunction of the central nervous system.
Explosive D	Ammonium picrate $C_6H_6N_4O_7$	Moderately irritating to the skin, eyes, and mucous membranes; can produce nausea, vomiting, diarrhea, skin staining, dermatitis, coma, and seizures.
Tetrazene	$C_2H_6N_{10}$	Associated with occupational asthma; irritant and convulsants, hepatotoxin, eye irritation and damage, cardiac depression and low blood pressure, bronchial mucous membrane destruction and pulmonary edema; death.
DEGN	Diethylene glycol dinitrate $(C_2H_4NO_3)_2O$	Targets the kidneys; nausea, dizziness, and pain in the kidney area. Causes acute renal failure.
Nitrocellulose	Collodion	Intoxicant; impaired motor function, slurred speech, sweating, nausea, vomiting, coma. Possible human carcinogen.
Ammonium nitrate	NH_4NO_3	Prompt fall in blood pressure; roaring sound in the ears with headache and associated vertigo; nausea and vomiting; collapse and coma.
Nitroglycerin (Glycerol trinitrate)	$C_3H_5N_3O_9$	Eye irritation, potential cardiovascular system effects including blood pressure drop and circulatory collapse.
Lead azide	N_6Pb	Headache, irritability, reduced memory, sleep disturbance, potential kidney and brain damage, anemia.
Lead styphnate	$PbC_6HN_3O_8$ CH_2O	Widespread organ and systemic effects including central nervous system, immune system, and kidneys. Muscle and joint pains, weakness, risk of high blood pressure, poor appetite, colic, upset stomach, and nausea.
Mercury fulminate	$Hg(OCN)_2$	Inadequate evidence in humans for carcinogenicity; causes conjunctival irritation and itching; mercury poisoning including chills, swelling of hands, feet, cheeks, and nose followed by loss of hair and ulceration; severe abdominal cramps, bloody diarrhea, corrosive ulceration, bleeding, and necrosis of the gastrointestinal tract; shock and circulatory collapse, and renal failure.
White phosphorus	P_4	Reproductive effects. Liver, heart, or kidney damage; death; skin burns, irritation of throat and lungs, vomiting, stomach cramps, drowsiness.

Contaminant	Chemical Composition	Potential Toxicity/Effects
Perchlorates	ClO_4^-	Exposure causes itching, tearing, and pain; ingestion may cause gastroenteritis with abdominal pain, nausea vomiting, and diarrhea; systemic effects may follow and may include ringing of ears, dizziness, elevated blood pressure, blurred vision, and tremors. Chronic effects may include metabolic disorders of the thyroid.
Hydrazine	N_2H_4	Possible human carcinogen; liver, pulmonary, CNS, and respiratory damage; death.
Nitroguanidine	$CH_4N_4O_2$	No human or animal carcinogenicity data available. Specific toxic effects are not documented.

Table 3-5. Primary Uses of Explosive Materials

Compound	Propellant	Primary or Initiator	Booster	Burster Charge	Pyrotechnics	Incendiary
TNT				C		
RDX			C	C		
HMX			C	C		
PETN			C			
Tetryl			C			
Picric acid				C		
Explosive D				C		
Tetrazene		C				
DEGN	C					
Nitrocellulose	C					
Ammonium nitrate	C		C			
Nitroglycerin	C			C		
Lead azide		C				
Lead styphnate		C				
Mercury fulminate		C				
White phosphorus					C	C

Compound	Propellant	Primary or Initiator	Booster	Burster Charge	Pyrotechnics	Incendiary
Perchlorates	C				C	
Hydrazine	C					
Nitroguanidine	C					

White Phosphorus

One of the most frequently used pyrotechnics is white phosphorus, which is used for "spotting" or marking an area. White phosphorus burns rapidly when exposed to oxygen and may spontaneously ignite at temperatures 10-15 ^{o}F above room temperature. In soils with low oxygen, unreacted white phosphorus can lie dormant for years, but as soon as it is exposed to oxygen, it may react. If ingested, white phosphorus can cause reproductive, liver, heart, or kidney damage, or death. Skin contact can burn the skin or cause organ damage.[58]

Explosive Compositions

Explosive compounds are the active ingredients in many types of explosive compositions, such as Compositions A, B, and C. Composition A is a wax-coated, granular explosive consisting of RDX and plasticizing wax that is used as the bursting charge in Navy 2.75- and 5-inch rockets and land mines. Composition B consists of castable mixtures (substances that are able to be molded or shaped) of RDX and TNT and, in some instances, desensitizing agents that are added to the mixture to make it less likely to explode. Composition B is used as a burster in Army projectiles and in rockets and land mines. Composition C is a plastic demolition explosive consisting of RDX, other explosives, and plasticizers. It can be molded by hand for use in demolition work and packed by hand into shaped charge devices.

Trinitrotoluene (TNT)

TNT is soluble and mobile in surface water and groundwater. It is rapidly broken down into other chemical compounds by sunlight, and is broken down more slowly by microorganisms in water and sediments. TNT is not expected to bioaccumulate under normal environmental conditions. Human exposure to TNT may result from breathing air contaminated with TNT and TNT-contaminated soil particles stirred up by wind or construction activities. Workers in explosive manufacturing who are exposed to high concentrations of TNT in workplace air experience a variety of organ and immune system problems, as well as skin irritations and cataracts. Both EPA and ATSDR have identified TNT as a possible human carcinogen.

[58] Toxicological Profile for White Phosphorous. (ATSDR) Atlanta, GA: U.S. Department of Health and Human Services, Public Health Service. 1970.

Toxicological Profiles of RDX and TNT

The EPA's IRIS uses a weight-of-evidence classification for carcinogenicity that characterizes the extent to which the available data support the hypothesis that an agent causes cancer in humans. IRIS classifies carcinogenicity alphabetically from A through E, with Group A being known human carcinogens and Group E being agents with evidence of noncarcinogenicity. IRIS classifies both TNT and RDX as Group C, possible human carcinogens, and provides a narrative explanation of the basis for these classifications.[59]

The ATSDR is tasked with preventing exposure and adverse human health effects and diminished quality of life associated with exposure to hazardous substances from waste sites, unplanned releases, and other sources of pollution present in the environment.

The ATSDR has developed toxicological profiles for RDX and TNT to document the health effects of exposure to these substances. The ATSDR has identified both TNT and RDX as possible human carcinogens.[60]

The ecological impacts of TNT include blood, liver, and immune system effects in wildlife. In addition, in laboratory tests, male test animals treated with high doses of TNT developed serious reproductive system effects.

Royal Demolition Explosive (RDX)

RDX, also known as Royal Demolition Explosive or Research Department Explosive, is another frequently found synthetic explosive chemical. RDX dissolves in and evaporates from water very slowly. RDX does not bind well to soil particles and can migrate to groundwater, but the rate of migration depends on the soil composition. If released to water, RDX is degraded mainly by direct photochemical degradation that takes place over several weeks. RDX does not biologically degrade in the presence of oxygen, but anaerobic degradation is a possible fate process under certain conditions. RDX's potential for bioaccumulation is low. Human exposure to RDX results from breathing dust with RDX particles in it, drinking contaminated water, or coming into contact with contaminated soils. RDX inhalation or ingestion can create nervous system problems and possibly organ damage. As discussed previously, RDX has been identified as a possible human carcinogen.

The ecological effects of RDX suggested by laboratory studies include neurological damage including seizures and behavioral changes in wildlife that ingest or inhale RDX. Wildlife exposure to RDX may also cause damage to the liver and the reproductive system.

3.5 Other Sources of Conventional Explosive Residues

Contamination of soils and groundwater with explosive compounds results from a variety of activities, including the release of other constituents during planned munitions training and testing. Residues also result from the deterioration of intact ordnance, the open burning and open

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[59]Carcinogenicity Assessment for Lifetime Exposure of Hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX). Carcinogenicity Assessment for 2,4,6-trinitrotoluene (TNT) for Lifetime Exposure. EPA Integrated Risk Information System, 1993.

[60]Toxicological Profile for 2,4,6-trinitrotoluene (update). (ATSDR) Toxicological Profile for RDX. Atlanta, GA: U.S. Department of Health and Human Services, Public Health Service. 1995.

detonation of ordnance, and the land disposal of explosives-contaminated process water from explosives manufacturing or demilitarization plants. The section below describes specific sources of explosive residues.

3.5.1 Open Burning/Open Detonation (OB/OD)

High concentrations of residues from explosive materials have been found at former OB/OD areas. OB/OD operations are used to destroy excess, obsolete, or unserviceable munitions and energetic materials. OB operations employ self-sustained combustion, which is ignited by an external source such as heat or a detonation wave. In OD operations, explosives and munitions are destroyed by a detonation, which is normally initiated by the detonation of an energetic charge. In the past, OB/OD operations have been conducted on the land surface or in shallow burn pits. More recently, burn trays and blast boxes have been used to help control and contain emissions and other contamination resulting from OB/OD operations. See Chapter 5 for a full discussion of OB/OD.

Incomplete combustion of munitions and energetic materials can leave uncombusted TNT, RDX, HMX, PETN and other explosives. Also, heavy metals can be left behind. These can contribute to potentially adverse human health and ecological effects.

3.5.2 Explosives Manufacturing and Demilitarization

Explosives manufacturing and demilitarization plants are also sources of explosive residues. These facilities are usually commercial sites that are not often co-located with CTT ranges. Many of these facilities have contaminated soils and groundwater. The manufacture; load, assemble, and pack operations; and demilitarization of munitions create processing waters that in the past were often disposed of in unlined lagoons, leaving explosive residues behind after evaporation.

> **Demilitarization of Munitions**
>
> Demilitarization is the processing of munitions so they are no longer suitable for military use.
>
> Demilitarization of munitions involves several techniques, including both destructive and nondestructive methods. Destructive methods include OB/OD and incineration. Nondestructive methods include the physical removal of explosive components from munitions. Munitions are generally demilitarized because they are obsolete or their chemical components are deteriorated.

Red water, the effluent from TNT manufacturing, was a major source of explosive residues in soils and groundwater at army ammunition plants. TNT production ended in the mid-1980s in the United States; however, contamination of soils and groundwater from red water remains in some areas.

In the demilitarization operations conducted in the 1970s, explosives were removed from munitions with jets of hot water or steam. The effluent, called pink water, flowed into settling basins, and the remaining water was disposed of in unlined lagoons or pits, often leaving highly concentrated explosive residues behind. In more advanced demilitarization operations developed in the 1980s, once the solid explosive particles settled out of the effluent, filters such as diatomaceous earth filters and activated carbon filters were employed to further reduce the explosive compounds, and the waters were evaporated from lagoons or discharged into water systems.

3.6 Conclusions

The potential for explosive damage by different types of UXO and explosive residues depends on many different factors. These factors include the magnitude of the potential explosion, the sensitivity of the explosive compounds and their breakdown products, fuze sensitivity, the types of explosive hazards present, the potential for OE deterioration, and the likelihood that the item will be disturbed, which depends on environmental and human activities.

OE items may also present other human health and environmental risks depending on the state of the OE item. Specifically, a OE item that is degraded may release propellants, explosives, pyrotechnics, and other chemical compounds into the surrounding area, thereby potentially contaminating the environment and affecting human health. Other human health and environmental risks may result from the explosives and from other chemicals used or produced in munitions operations such as OB/OD; manufacturing; demilitarization; load, assemble, and pack operations; and others.

SOURCES AND RESOURCES

The following publications, offices, laboratories, and websites are provided as a guide for handbook users to obtain additional information about the subject matter addressed in each chapter. Several of these publications, offices, laboratories, or websites were also used in the development of this handbook.

Publications

Agency for Toxic Substances and Disease Registry (ATSDR), ***Toxicological Profile for Benzene (update)***, Atlanta, GA: U.S. Department of Health and Human Services, Public Health Service, 1995.

ATSDR, ***Toxicological Profile for 1,3-Dinitrobenzene/1,3,5-trinitrobenzene (update)***, Atlanta, GA: U.S. Department of Health and Human Services, Public Health Service, 1995.

ATSDR, ***Toxicological Profile for HMX***, Atlanta, GA: U.S. Department of Health and Human Services, Public Health Service, 1997.

ATSDR, ***Toxicological Profile for Polychlorinated Biphenyls (update)***, Atlanta, GA: U.S. Department of Health and Human Services, Public Health Service, 1996.

ATSDR, ***Toxicological Profile for RDX***, Atlanta, GA: U.S. Department of Health and Human Services, Public Health Service, 1995.

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Bailey, A. and S.G. Murray, ***Explosives, Propellants & Pyrotechnics,*** Brassey's (UK) Ltd. 1989.

Bucci, J.E., and P.F. Buckley, ***Modeling the Degradation of Unexploded Ordnance (UXO) and Its Use As a Tool in the Development of Risk Assessments***, U.S. Army Aberdeen Test Center and Army Research Laboratory, Aberdeen Proving Ground.

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Crockett, A.B., H. D. Craig, and T.F. Jenkins, ***Field Sampling and Selecting On-site Analytical Methods for Explosives in Water***, U.S. EPA Federal Facilities Forum Issue, May 1999.

Crull, M.L., Taylor, and J. Tipton, ***Estimating Ordnance Penetration Into Earth***, UXO Forum 1999 Proceedings, 1999.

Federal Advisory Committee for the Development of Innovative Technologies, ***Unexploded Ordnance (UXO): An Overview***, U.S. Navy, Naval Explosive Ordnance Disposal Technology Division, UXO Countermeasures Department, October 1996.

Kleine, H., and A. Makris, ***Protection Against Blast Effects in UXO Clearance Operations***, *UXO Forum 1999 Proceedings,* 1999.

U.S. Army Corps of Engineers, ***Engineering and Design Ordnance and Explosives Response***, Manual No. 1110-1-4009, June 23, 2000.

U.S. Department of Defense, Office of the Under Secretary of Defense (Acquisition and Technology), ***Report to Congress, Unexploded Ordnance Clearance: A Coordinated Approach to Requirements and Technology Development***, Joint Unexploded Ordnance Clearance Steering Group, March 25, 1997.

U.S. EPA, ***Handbook: Approaches for the Remediation of Federal Facility Sites Contaminated With Explosive or Radioactive Wastes***, (EPA/625/R-93/013). September 1993.

U.S. EPA, ***Overview of the Health Effects of Selected Munitions Chemicals***.

Wilcher, B.L., D. Eisen, R. Booth, ***Evaluation of Potential Soil Contamination from Open Detonation During Ordnance and Explosives Removal Actions, Former Fort Ord, California***, UXO Forum 1999 Proceedings, 1999.

<u>**Information Sources**</u>

Agency for Toxic Substances and Disease Registry (ATSDR)
Division of Toxicology
1600 Clifton Road, E-29
Atlanta, GA 20222
http://www.atsdr.cdc.gov

ORDATA II
(Database of ordnance items available from NAVEODTECHDIV items)
Attn: Code 602
20008 Stump Neck Road
Indian Head, MD 20640-5070
Email: ordata@eodpoc2.navsea.navy.mil

U.S. Environmental Protection Agency
Technology Innovation Office
http://clu-in.org/

Integrated Risk Information System (IRIS)
U.S. EPA
U.S. EPA Risk Information Hotline
Tel: (513) 569-7254
Fax: (513) 569-7159
E-mail: RIH.IRIS@epamail.epa.gov
http://www.epa.gov/ngispgm3/iris/index.html

U.S. Army Corps of Engineers
U.S. Army Engineering and Support Center,
Ordnance and Explosives
Mandatory Center of Expertise
P.O. Box 1600
Huntsville, AL 35807-4301
Street Address: 4820 University Square
http://www.hnd.usace.army.mil/

Department of Defense Explosives Safety Board (DDESB)
Department of Defense Explosives Safety Board
2461 Eisenhower Avenue
Alexandria, VA 22331-0600
FAX: (703) 325-6227
http://www.hqda.army.mil/ddesb/esb.html

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4.0 UXO DETECTION

4.1 Introduction

UXO detection technologies are deployed in a nonintrusive manner to locate subsurface anomalies that may be UXO. Proper selection and use of these technologies is an important part of the site investigation, which often takes place on ranges or parts of ranges that cover many acres. Since excavating all the land to depth is usually not practical, UXO detection technologies are used to locate subsurface anomalies that are subsequently verified as UXO or non-UXO. Given the high cost of UXO excavation (due to both range size and safety considerations), the challenge of most UXO investigations is accurate and appropriate deployment of nonintrusive geophysical detection technologies to minimize unnecessary excavation.

The capabilities of advanced UXO detection technologies have improved significantly since the early 1990s. Before that time, the ability to detect anomalies beneath the ground surface was limited.[61] However, the primary challenge in UXO detection today is the achievement of near 100 percent subsurface detection in a consistent, reproducible manner with a high level of quality assurance. Distinguishing ordnance from fragments and other nonordnance materials, called target discrimination, is also a major challenge in UXO detection, and is the focus of research and development activities. Poor discrimination results in higher costs and longer timeframes for cleanups, and potentially greater risks following cleanup actions. This problem is known as ***false alarms,*** as described in the text box below.

> **False Alarms**
>
> The term ***false alarm*** is used to describe the **incorrect** declaration of a subsurface anomaly as either ordnance or nonordnance. ***False positives*** are anomalous items incorrectly identified as ordnance. False positives can result in incorrect estimations of UXO density and often lead to expensive or unnecessary excavation of an anomaly if it is not UXO. Depending on the site-specific conditions, as few as 1 percent of anomalies may actually be UXO items. Because of the difficulty, danger, and time required to excavate UXO, high costs per acre are exacerbated by a high false positive rate. ***False negatives*** occur when ordnance items are not detected by the geophysical instrument used, resulting in potential risks remaining following UXO investigations.

When selecting a UXO detection technology for a particular site, there are many factors that should be considered, some of which are listed in the text box. Different UXO detection technologies have specific capabilities and limitations that must be evaluated when matching a detection system to a site. In

> **Factors To Consider in Selecting a UXO Detection System**
>
> - Site size
> - Soil type, vegetation, and terrain
> - Depth, size, shape, and type of UXO
> - Local noise
> - Non-UXO clutter on-site
> - Historical land use

[61] Unless a site is seeded with UXO for testing purposes, it is not possible to know if 100 percent of UXO has been detected.

addition, levels of uncertainty should also be evaluated when selecting a UXO detection system, as discussed in Chapter 7.

> **DoD/EPA Management Principles on Detection Technologies**
>
> EPA and DoD identified the critical metrics for evaluating the performance of a detection technology as the **probabilities of detection and false alarms**. Specifically, they call for the performance evaluation of detection technologies to consider the following factors:
>
> - Types of munitions
> - Size of munitions
> - Depth distribution of munitions
> - Extent of clutter
> - Environmental factors (e.g., soil, terrain, temperature, and vegetation)
>
> Of the two critical metrics for performance evaluations, probability of detection should be considered before the probability of false alarms.

It should be noted that a particular technology or combination of technologies will never have the highest effectiveness, best implementability, and lowest cost at every site. In other words, there is no "silver bullet" detection technology. It is also important to note that no existing technology or combination of existing technologies can guarantee that a site is completely UXO free. In general, a combination of sensors appears to provide the highest rates of UXO detection. Sensor selection in a multisensor system should be made to best meet the site-specific conditions. As discussed in Chapter 7, a combination of information from a variety of sources (including the results of historical data, nonintrusive detection, and field tools) will be used to make these decisions. Detailed fact sheets on each of these technologies are found at the end of this chapter.

Experts in the UXO research and development community have indicated that currently available detection technologies will only incrementally improve with time and that no revolutionary new systems will be developed that uniformly improve all UXO detection. Much of the performance improvement of current detection technologies has come from a better understanding of how to use the technologies and from the use of combinations of technologies at a site to improve anomaly detection rates. Improvements in detection systems generally focus on distinguishing ordnance from nonordnance. Emerging processing and numerical modeling programs will enhance the target discrimination capabilities of detection systems. In general, these programs rely on identifying UXO and clutter based on their unique "signatures" (e.g., spatial). The Multisensor Towed Array Detection System (MTADS) described in Fact Sheet 4 combines existing technologies (i.e., magnetometry and electromagnetic induction), along with a global positioning system and an integrated data analysis system, to achieve improvements in both target detection and discrimination under certain conditions.

Some of the emerging detection technologies, such as airborne sensor systems, seismic systems, and synthetic aperture radar (SAR), are appropriate only for special applications and not for wide use. An overview of emerging detection technologies as well as data processing and modeling for target discrimination is discussed in section 4.3.

In response to the stagnancy of detection technology development at the beginning of the Base Realignment and Closure (BRAC) Program, the U.S. Congress established the Jefferson Proving Ground Technology Demonstration (JPGTD) program in Madison, Indiana. The JPGTD program was established to demonstrate and promote advanced and innovative UXO systems that are more cost-efficient, effective, and safer.

4.2 Jefferson Proving Ground Technology Demonstration Program

Congress established the JPGTD program in response to the realization that the BRAC process could not take place until thousands of acres of military property littered with UXO were cleaned up. Available technologies were also inefficient and inadequate to address the widespread need to detect and remove UXO on such a large scale. (See Chapter 7. "Mag and flag" had been in use for several decades without any advancements or improvements.)

The JPGTD program was established under the management of the U.S. Army Environmental Center (USAEC) to identify innovative technologies that would provide more effective, economical, and safer methods for removing ordnance from former DoD testing and training areas. The program also was created to examine the capability of commercial and military equipment to detect, classify, and remove UXO and to develop baseline performance standards for UXO systems. The JPGTD program aimed to (1) establish criteria and metrics to provide a framework for understanding and assessing UXO technology; (2) provide funding for technology demonstrations; (3) document the performance of advanced technologies to give decision makers a better understanding of the capabilities and limitations of the technologies; and (4) improve demonstration methodologies so that the results would be applicable to actual UXO clearance operations and decision making. The objectives and results of each of the demonstration projects are outlined in the text box.

Synopsis of Objectives and Results of Jefferson Proving Ground Technology Demonstration Program, Phases I through IV

Phase I, 1994
Objective: Evaluate existing and promising technologies for detecting and remediating UXO.
Results: Limited detection and localization capabilities and inability to discriminate between ordnance and nonordnance. Average false alarm rate was 149 per hectare. Airborne platforms and ground penetrating radar sensors did not perform well; combination electromagnetic induction and magnetometry sensors performed very well, but also had very high false alarm rates.

Phase II, 1995
Objective: Evaluate technologies effective for detecting, identifying, and remediating UXO, and measuring these results against the Phase I baseline.
Results: Significant improvement in detection capabilities. Continued inability to distinguish ordnance from nonordnance. False alarm rates ranged from 3 to 70 per hectare. Again, airborne platforms and ground penetrating radar sensors did not perform well; combination electromagnetic induction and magnetometry sensors performed very well, but continued to have very high false alarm rates.

Phase III, 1996
Objective: Develop relevant performance data of technologies used in site-specific situations to search, detect, characterize, and excavate UXO. Four different range scenarios were used, which had typical groups of UXO.
Results: Improvement in detection, but continued inability to distinguish ordnance from nonordnance. Localization performance for ground-based systems improved. Probability of detection is partially dependent on target size. False alarm rates ranged from 2 to 241 per hectare.

Phase IV, 1998
Objectives: Demonstrate the capabilities of technology to discriminate between UXO and non-UXO; establish discrimination performance baselines for sensors and systems; make raw sensor data available to the public; establish state of the art for predicting ordnance "type"; direct future R&D efforts.
Results: Capability to distinguish between ordnance and nonordnance is developing. Five demonstrators showed a better than chance probability of 50 percent discrimination, and one demonstrator showed a better than 75 percent ability to distinguish ordnance from nonordnance.

UXO detection technologies such as magnetometry, electromagnetic induction, ground penetrating radar, and multisensor systems were tested and analyzed using a variety of platforms and data processing systems at the JPGTD. The platforms analyzed for the detection technologies included airborne, man-portable, vehicle-towed, and combination man-portable and vehicle-towed. Systems were analyzed using evaluation criteria such as probability of detection, false alarm rate, and other parameters, as described in the text box to the right. Certain local and regional

Demonstrator Evaluation Criteria

- Detection capability
- False negative rate
- False positive rate
- Target position and accuracy
- Target classification capability
- Survey rate (used as a measure of system performance in Phase I only)
- Survey costs (used as a measure of system performance in Phase I only)

conditions and soil characteristics (e.g., soil type, moisture, resistivity) may impact the effectiveness of detection systems. Specifically, detector performance may differ significantly at sites with conditions different from those at Jefferson Proving Ground (e.g., ranges in the western U.S. with different soil resistivity/conductivity).

Each of the four phases of JPGTD provided useful data about UXO detection and remediation technologies. In Phase I, conducted in 1994, 26 demonstrators, representing magnetometry, electromagnetic induction (EMI), ground penetrating radar (GPR), synthetic aperture radar (SAR), and infrared (IR) sensors, performed using 20 vehicle-mounted and man-towed platforms and six airborne platforms. Only one demonstrator achieved over a 50 percent detection rate and the false alarm rate was high, 149 false alarms per hectare, an especially disappointing rate considering most of the clutter had been removed prior to the demonstration. Electromagnetic induction, magnetometry, and gradiometry proved to be the most effective sensors, while GPR, IR, and other imaging technologies were not as effective. Airborne systems performed the worst of all the platforms, detecting less than 8 percent of buried ordnance, while hand-held systems had the best performance. At the conclusion of Phase I it was suggested that the geological conditions at the Jefferson Proving Ground may reduce the capabilities of certain sensors. Therefore, live test sites at five other installations were used to compare the detection data obtained in different geological conditions. Results from the live test sites showed that magnetometry and EMI continued to be the best performers. The average probability of detection at the live test sites was 0.44, and there was a continued inability to distinguish between ordnance and nonordnance.

In Phase II, conducted in 1995, demonstrators had better detection performance, with some sensors detecting over 80 percent of buried ordnance. However, the false alarm rate in Phase II was 4 to 20 times greater than in Phase I; thus, the discrimination capabilities decreased as overall anomaly detection increased. The best performing sensors in Phase II were multisensor systems combining electromagnetic induction and magnetometry.

In Phase III, conducted in 1996, over 40 percent of demonstrators had greater than 85 percent detection, and combination magnetometry and EMI systems repeatedly detected close to 100 percent of buried ordnance. In addition, the multisensor system, which consisted of electromagnetic induction and either magnetometry or gradiometry, had a slightly lower than average false alarm rate. However, no single or combination of sensors demonstrated an ability to distinguish baseline ordnance from nonordnance, as no system performed better than chance in this area. Four different range scenarios were used in Phase III to facilitate the development of performance data for technologies used in specific site conditions.

Phase IV, conducted in 1998, was aimed at improving the ability to distinguish ordnance and nonordnance. Fifty percent of the demonstrators showed a better than chance probability of discriminating UXO from clutter, with one demonstrator correctly identifying 75 percent of ordnance and nonordnance items. While advanced data processing has greatly improved target discrimination capabilities in pilot testing, these methods need to be further developed and tested. In order to make advanced processing techniques widely used and to develop a market for constantly improving systems, they need to be made commercially available. With reliable and readily available target discrimination technologies, false alarm rates could be greatly reduced, thereby significantly improving the efficiency and reducing the costs of UXO detection and remediation.

4.3 Emerging UXO Detection Systems

When used in combination, magnetometry and electromagnetic induction provide high UXO detection rates that have not been achieved by single sensors, except at sites with unique conditions. Emerging detection systems build on existing technologies and increase breadth of coverage and/or improve target discrimination. There are a number of emerging approaches to improving target discrimination through the use of databases that rely on unique electronic signatures of different UXO.

4.3.1 Airborne Detection of UXO

Airborne platforms are used to survey large, open areas suspected of UXO contamination. In June of 1999, the U.S. Army Corps of Engineers (USACE) and the Department of Energy's Oak Ridge National Laboratory conducted an airborne remote sensing survey at the former Badlands Bombing Range in South Dakota using a Scintrex CS2 cesium vapor optically pumped magnetometer. A total of 14 survey missions were conducted using a Bell 206L-3 helicopter, which maintained a ground speed of approximately 45 mph and a mean terrain clearance ranging from 1 to 3 meters. A global positioning system (GPS) was used for aircraft navigation and anomaly location.

Data acquired using the airborne system detected ordnance and buried metals with masses of less than 10 kg. This survey was significantly more sensitive than an earlier test at Edwards Air Force Base. The results demonstrate that airborne magnetic methods may be an appropriate tool for detecting ordnance and for screening or characterizing *large* areas of suspected UXO contamination. However, this system would only be effective at sites where low survey altitudes are possible, background geologic response is low, and the expected UXO target size is within range (i.e., over 5 kg).

Unexpected Hazards

In a 2-hour survey flight over an area being used as pasture and considered to be clean, the airborne magnetometer uncovered 3 tons of ferrous debris, including possible live ordnance.

4.3.2 Synthetic Aperture Radar (SAR)

The U.S. Army Research Laboratory (ARL), under the sponsorship of the Strategic Environmental Research and Development Program (SERDP), is conducting experiments to enhance the capability of low-frequency, ultra wide band (UWB) SAR to detect UXO. The low frequency of this radar permits sensing through foliage and soils of low moisture content and low conductivity. The SAR is also capable of operating at higher frequencies for high-resolution imagery, depending on the site characteristics. An example of an SAR system currently under development is ARL's BoomSAR system, which is a side-looking GPR atop a mobile boom platform. From heights of up to 150 feet, the BoomSAR system may be a cost-effective alternative to airborne platforms and can cover a large area with relative ease. However, the data processing time can be very long, with up to 4 hours of processing required for each 1 minute of data acquired. In a four-antenna configuration, the radar proceeds along a track while alternately firing its two impulse transmitters and simultaneously receiving all return signals on both the horizontal and vertical receiving antennas. In operation, the 30-ton BoomSAR system is driven at approximately 1 km/hr, while the radar illuminates a 300-meter swath that starts approximately 50 meters from the boom lift and extends to about 350 meters.

UWB SAR data was collected and then groundtruthed at the Yuma Proving Ground in Yuma, Arizona, and at Eglin Air Force Base in Florida. Different combinations of radar path, radar height, and depression angle were used to provide multiple look angles of targets at various orientations and depths. These data sets are being used to (1) support ongoing research efforts to identify key features of UXO and postprocessing techniques to enhance detection and discrimination capability, and (2) support the refinement and verification of electromagnetic models of various UXO types. Improved UXO discrimination techniques are being developed to reduce false alarm rates, a key factor in establishing UWB SAR as a viable application for UXO detection.

About Electronic Signatures

The various methodologies deployed to detect UXO produce electronic reports – graphs, charts, and maps – that display the presence of an anomalous measurement. Experience has shown that certain patterns appear for certain sizes, types, and orientations of UXO. These patterns are called "signatures." Several types of emerging technologies rely on databases of electronic signatures to help discriminate between types of UXO, fragments of UXO, naturally occurring metals, and non-OE scrap.

4.3.3 Seismic Detection of UXO

Because of the past success of using seismic technologies to discover oil reservoirs and to map subsurface strata, GTE-BBN Technologies, under contract to SERDP, has developed instruments with remote sensing capabilities using seismic sensors to distinguish ordnance from clutter. By gathering data on the mechanical properties and structural vibrations of objects below the ground surface, the broadband high-frequency seismic ordnance detection system (SODS) aims to discriminate between UXO and other objects buried in the top 3 meters of soil.

The SODS operates in a manner similar to that of an active sonar system. The system incorporates a mobile seismic array that sends broadband vibrational energy into the ground. Echoes are received by a variety of geophones and are digitally recorded. The received signals are transformed to locate the objects and to analyze the characteristic echoes of the objects. These characteristic echoes, when used in conjunction with the magnetic and electrical responses, efficiently differentiate UXO from other inert objects.

This effort to develop a SODS system aims to (1) significantly improve the accuracy of UXO site characterization, thereby reducing excavations and cleanup cost, (2) provide UXO detection and classification capabilities in environments where other sensors perform poorly, and (3) detect nonmetallic ordnance and other buried wastes or structures.

4.3.4 Use of Processing and Modeling To Discriminate UXO

The development of advanced processing and modeling to reduce the false alarm rates without affecting ordnance or risk detection performance is evolving. Rather than using raw physical data exclusively, advanced processing methods organize large quantities of data to develop electronic signatures of ordnance and statistically based detection schemes from databases. These signatures are then used in the development of algorithms to classify targets. In contrast, physical or model-based methods rely on a thorough understanding of the target shapes, sizes, and other characteristics, as well as on extensive controlled measurements that are used to verify model assumptions and estimate target parameters. In efforts to encourage the development of algorithms for target discrimination without the expense and burden of field data collection, the Defense Advanced Research Project Agency (DARPA) and the Joint UXO Coordination Office (JUXOCO) have made standard sensor data sets publicly available.

Aided or automatic target recognition, or ATR, is a term used to describe a hardware/ software system that receives sensor data as input and provides target classes, probabilities, and locations in the sensor data as output. ATR is used to design algorithms to improve detection and classification of targets and assist in discriminating system responses from clutter and other noise signals, thereby reducing the false alarm rate.[62] These techniques are under development and are not yet available for use in the field.

AETC, Inc., and Geophex, Ltd., under contract to SERDP, have developed a data-based process using electromagnetic induction data that identifies UXO and nonordnance items based on their shape, size, composition, and orientation. Signature models for a wide variety of UXO and clutter objects were developed at frequencies between 30 Hz and 30 kHz. A database has been set up to organize and make available results from over 60,000 measurements of different sizes and shapes of UXO and non-UXO objects.[63] In addition, software has been developed to analyze the data and identify a wide variety of anomalies.[64]

The Naval Research Laboratory has developed a similar technique that uses data fusion to discriminate data obtained in magnetometry and electromagnetic surveys. By fusing data sets from its MTADS at several different ranges, the laboratory can develop model-based quantitative routines to identify the target's position, depth, shape, and orientation (see Fact Sheet 2 for a full description

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[62]Notes from the Aided Target Recognition Workshop, Unexploded Ordnance Center for Excellence, January 28-29, 1998.

[63]EMI signature database in Microsoft Access available at FTP host: server.hgl.com, log in ID: anonymous, File:/pub/SERDP/GEM3.data.zip.

[64]Bell, T., Miller, J., Keiswetter, D., Barrow, B., Won, I.J., Processing Techniques for Discrimination Between Buried UXO and Clutter Using Multisensor Array Data, Partners in Environmental Technology Conference, December 2, 1999.

of MTADS). Then a probabilistic classification system models the output to identify the UXO type and to distinguish UXO from clutter. This model-based data fusion method is expected to reduce target analysis time by up to 50 percent. In addition, location information, including position, size, and depth, is expected to be improved to a small degree.[65] This data fusion method is primarily effective in the discrimination of large UXO items. However, the major contribution of this system and the AETC/Geophex system described above is anticipated to be their ability to differentiate UXO from ordnance, explosive waste, and other clutter.[66]

4.4 Fact Sheets on Detection Technologies

Four fact sheets on common detection technologies and combinations of technologies are at the end of this chapter as attachments 1 through 4. Information on the nature of the technology and its benefits and limitations is provided.

4.5 Conclusion

Our ability to "find" UXO in subsurface locations has improved dramatically. The JPGTD studies have shown that we have gotten much smarter about how to deploy these technologies and how to locate a high percentage of UXO. However, the results of a controlled study such as the JPGTD should not give us unrealistic expectations about the capabilities of these technologies when used in range investigation. Given the size of the ranges and the cost of investigating anomalies, the greatest challenge to improving UXO detection is being able to discriminate UXO from other subsurface anomalies. Although there have been improvements in this area, much developmental work remains.

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[65] McDonald, J.R., Model-Based Data Fusion and Discrimination of UXO in Magnetometry and EM Surveys, Naval Research Laboratory, May 18, 1999.

[66] McDonald, J.R., MTADS Magnetometer and EM Surveys at Ft. Ord, Naval Research Laboratory, 2001.

ATTACHMENT 4-1. FACT SHEET #1: MAGNETOMETRY

<table>
<tr><th>FACT SHEET #1: UXO DETECTION TECHNOLOGIES</th><th>Magnetometry</th></tr>
<tr><td>What is magnetometry?</td><td>Magnetometry is the science of measurement and interpretation of magnetic fields. Magnetometry, which involves the use of magnetometers and gradiometers, locates buried ordnance by detecting irregularities in the Earth's magnetic field caused by the ferromagnetic materials in the ordnance assembly. The magnetometer can sense only ferrous materials, such as iron and steel; other metals, such as copper, tin, aluminum, and brass, are not ferromagnetic and cannot be located with a magnetometer. Although they have been in use for many years and many newer technologies are available, magnetometers are still considered the most effective technology for detecting subsurface UXO and other ferromagnetic objects. Magnetometry remains the most widely used subsurface detection system today.

The two basic categories of magnetometer are total-field and vector.
The total-field magnetometer is a device that measures the magnitude of the magnetic field without regard to the orientation of the field.
The vector magnetometer is a device that measures the projection of the magnetic field in a particular direction.
A magnetic gradiometer is a device that measures the spatial rate of change of the magnetic field. Gradiometers generally consist of two magnetometers configured to measure the spatial rate of change in the Earth's magnetic field. The gradiometer configuration was designed to overcome large-scale diurnal intensity changes in the Earth's magnetic field; this design may also be used to minimize the lateral effects of nearby fences, buildings, and geologic features.</td></tr>
<tr><td>How are magnetometers used to detect UXO?</td><td>Magnetometers can theoretically detect every UXO target that contains ferrous material, from small, shallow-buried UXO to large, deep-buried UXO, provided that the magnetic signature is larger than the noise. When a magnetometer detects an object that contains ferrous material, the object causes a perturbation in the geomagnetic field. The magnetometer measures this perturbation. The size, depth, orientation, magnetic moment, and shape of the target, along with local noise fields (including ferrous clutter), must all be considered when assessing the response of the magnetometer. In addition, magnetometers are most effective in detecting buried UXO when the sensors can be placed close to the soil surface.</td></tr>
</table>

FACT SHEET #1: UXO DETECTION TECHNOLOGIES

Magnetometry

What are the different types of magnetometers?

There are numerous types of magnetometers, which were developed to improve detection sensitivity. Three of the most common are the **cesium vapor**, **proton precession**, and **fluxgate** magnetometers.

- **Cesium vapor magnetometers** – These magnetometers are lightweight and portable. The sensor can also be mounted on an aluminum frame with plastic wheels. The principal advantage of this type of magnetometer is its rapid data collection capability. The common hand-held sensors are capable of measuring at a rate of 10 times per second, and specially designed sensors are capable of measuring at a rate of 50 times per second. The one disadvantage of this magnetometer is that it is insensitive to the magnetic field in certain directions, and dropouts can occur where the magnetic field is not measured. However, this can be avoided with proper field procedures.

- **Proton precession magnetometers** – These magnetometers have been used in clearing UXO sites, but achieving the data density required for a UXO site is time consuming. *The primary use of these magnetometers today is as a base station for monitoring diurnal variations in the Earth's magnetic field and possible geomagnetic storms*. The primary disadvantage of these types of magnetometers is that accurate measurements require stationary positioning of the sensor for a period of several seconds. Also, these magnetometers require tuning of the local magnetic field.

- **Fluxgate magnetometers –** These magnetometers are used primarily to sweep areas to be surveyed. They are also used in locating UXO items during reacquisition. These magnetometers are relatively inexpensive, locate magnetic objects rapidly, and are relatively easy to operate. The disadvantage of these types of magnetometers is that most of them do not digitally record the data, and accurate measurements require leveling of the instrument.

What are the components of a magnetometer?

A passive magnetometer system includes the following components:

- **The detection sensor**
- **A power supply**
- **A computer data system**
- **A means to record locations of detected anomalies**

More technologically advanced systems typically incorporate a navigation system, such as a differential global positioning system (DGPS), to determine locations. Advanced navigation systems may also include a graphical output device (printer), a mass data storage recorder, and telecom systems.

FACT SHEET #1: UXO DETECTION TECHNOLOGIES

Magnetometry

What are the operational platforms for a magnetometer?

Magnetometers can be transported in a variety of ways:

- **Hand-held**
- **Man-portable**
- **Towed by a vehicle**
- **Airborne platforms**

Magnetometers are most frequently used on a hand-held detector or man-portable platform, but they also perform well when towed on a vehicular platform, as long as the area to be surveyed is accessible to vehicles. Airborne systems are sometimes used but have extremely limited capabilities to detect UXO. *Hand-held detectors and man-portable systems provide access to all areas of a site (including uneven and forested terrain), are the most durable, and require the least amount of maintenance.*

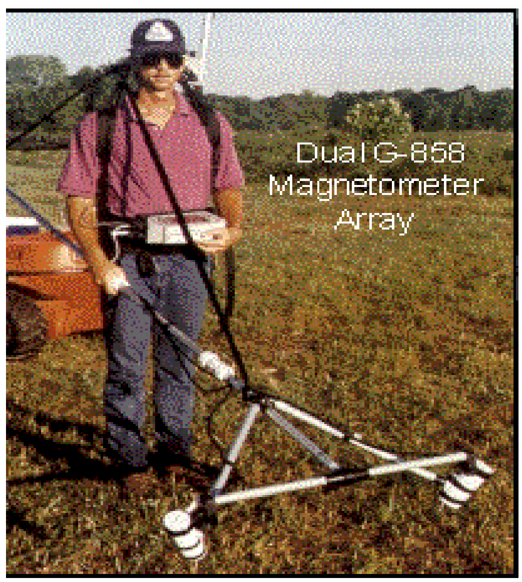

Figure 4-1. Hand-Held Magnetometer

One of the most commonly used and oldest UXO detection methods is the **"Mag and Flag"** process. Mag and flag involves the use of hand-held magnetometers by explosive ordnance disposal (EOD) technicians or civilian technicians, who slowly walk across a survey area and flag those areas where UXO may be located for later excavation. The success of the method is dependent on the competence and alertness of the technician and his ability to identify changes in the audible or visible signals from the magnetometer indicating the presence of an anomaly.

FACT SHEET #1: UXO DETECTION TECHNOLOGIES	Magnetometry

What are the benefits of using magnetometry for detecting UXO?

The **benefits** of using magnetometry for UXO detection include the following:

- Magnetometry is considered one of the *most effective technologies* for detecting subsurface UXO and other ferromagnetic objects.
- Magnetometry is one of the *more developed technologies* for detection of UXO.
- Magnetometers are fairly *simple devices*.
- Magnetometers are *nonintrusive*.
- Relative to other detection technologies, magnetometers have *low data acquisition costs*.
- Magnetometers have the ability to *detect ferrous items to a greater depth* than can be achieved using other methods.
- Magnetometers *provide fair to good information on the size of the detected object*.
- Because magnetometers have been in use since World War II, the *limitations are well understood*.

What are the limitations of using magnetometry for detecting UXO?

The limitations of using magnetometry for UXO detection include the following:

- The effectiveness of a magnetometer can be reduced or inhibited by interference (noise) from *magnetic minerals or other ferrous objects in the soil*, such as rocks, soil, pipes, drums, tools, fences, buildings, and vehicles, as well as UXO debris.
- Magnetometers suffer from *high false alarm rates*, which lead to *expensive excavation efforts.*
- Magnetometers have *low target discrimination ability.*
- Depending on the site conditions, *vegetation and terrain may limit the ability to place magnetometers* (especially vehicle-mounted systems) near the ground surface, which is needed for maximum effectiveness.
- Magnetometers have *limited capability to distinguish targets that are located near each other*. Clusters of ordnance of smaller size may be identified as clutter, and distributed shallow sources (UXO or not) may appear as localized deep targets. Accurately distinguishing between targets depends heavily on coordination between sensors and navigation.
- *Operator limitations* include the experience of the operator in proper application of the sensor; operator fatigue; simplicity of equipment operation given weather, climatic, and lighting conditions; and the proximity/access of operator/sensor to the potential target area.
- Vehicle-mounted systems can be limited by terrain, vegetation, mechanical failures, vehicle interface issues, signal processing, and collection of multiple component data.
- *Airborne systems* can be limited by atmospheric conditions, airborne platform stability, position accuracy, the inability to completely correct for the metallic and electromagnetic noise introduced by the airborne platform itself, and flight altitude.

FACT SHEET #1: UXO DETECTION TECHNOLOGIES

Magnetometry

What are the costs of using magnetometry to detect UXO?

The magnetometer system for UXO detection has relatively low data acquisition costs. Specifically, two-sensor **cesium vapor magnetometers** cost about $23,000. Rental of a two-sensor cesium vapor system costs approximately $100 per day. The cost of a **proton precession magnetometer** is approximately $5,000. The rental rate for a proton precession magnetometer is generally less than $20 per day. **Fluxgate magnetometers** cost anywhere between $600 and $4,000. The rental rate for a fluxgate magnetometer is approximately $10 to $20 a day. (*Note: Taken from "UXO and Explosives Compounds: Field-Based Site Characterization Techniques"*)

Ancillary equipment and multicomponent sensors, necessary to collect and process signal responses in order to improve probabilities of detection and classification, will increase the cost of future systems. Vehicle-mounted system cost will be driven by ancillary equipment and the need to minimize platform noise.

Case Study

In August 1998, Geophysical Technology Limited (GTL) used an eight-sensor magnetometer system towed by an autonomous tow vehicle (ATV) to detect UXO over approximately 200 acres of the Helena Valley in Helena, Montana. The system was navigated by a real-time DGPS.

The system had the following main features:

- The trailer used was low cost and any standard four-wheel bike could be used to tow the array. This means that the system can be easily duplicated and multiple systems can be run on large or concurrent projects.
- The system had a high-speed traverse, a 4-meter swath, and complete DGPS coverage, making it very efficient.
- The TM-4 magnetometer at the center of the system was the same instrument used in the hand-held application for surveying fill-in areas inaccessible to the trailer system.

The one-operator trailer system did not require a grid setup prior to the commencement of the surveys. The survey computer guided the operator along the survey lanes with an absolute cross-track accuracy of 0.75 meters (vegetation and terrain permitting). An expandable array of magnetic sensors with adjustable height and separation allowed the operators to optimize the system for this application. Eight sensors, 0.5 meters apart, were used in the survey.

GTL's proprietary MAGSYS program was used for detailed anomaly interpretation and the printing of color images. Magnetic targets that were identified were then modeled using a semiautomatic computer-aided procedure within MAGSYS. A selection of key parameters (position, depth, approximate mass, and magnetic inclination) was used to adjust the shape of the model for best fit. The confidence that the interpreted items were UXO was scaled as high, medium, and low according to their least squares fit value. GTL's system successfully detected over 95 percent of the emplaced 76 mm and 81 mm mortar shells.

FACT SHEET #1: UXO DETECTION TECHNOLOGIES	**Magnetometry**
Case Study (cont.)	In Montana, accurate, real-time DGPS positioning and navigation resulted in good coverage of the survey areas using the trailer system. The GTL trailer system enables practical, fast collection of high-resolution, accurately positioned magnetic data, as required for UXO detection. The GTL trailer system opens new possibilities of covering large areas efficiently, and it is an important milestone in achieving large-scale remediation with performance that is quantifiable.

ATTACHMENT 4-2. FACT SHEET #2: ELECTROMAGNETIC INDUCTION (EMI)

FACT SHEET #2: UXO DETECTION TECHNOLOGIES	**Electromagnetic Induction (EMI)**
What is electromagnetic induction (EMI) and how is it used to detect UXO?	**Electromagnetic induction** is a geophysical technology used to induce a magnetic field beneath the Earth's surface, which in turn causes a secondary magnetic field to form around nearby objects that have conductive properties. The secondary magnetic field is then measured and used to detect buried objects. *Electromagnetic induction systems are used to detect both ferrous and nonferrous UXO.* In electromagnetic induction, a primary transmitter coil creates a time-dependent electromagnetic field that induces eddy currents in the subsurface. The intensity of the currents is a function of ground conductivity and the possible presence of metallic objects in the subsurface. The secondary, or induced, electromagnetic field caused by the eddy currents is measured by a receiver coil. The voltage measured in the receiver coil is related to the subsurface conductivity. These conductivity readings can then be related to subsurface conditions. The strength and duration of the induced field depend on the size and shape of the object. Furthermore, the same object can have distinctly different signatures depending on its orientation. There are two basic types of EMI methods: frequency domain and time domain. • **Frequency-domain EMI** measures the electrical response of the subsurface at several frequencies (different separation distances between the transmitter and receiver can also be used) to obtain information about variations of conductivity (or its reciprocal, resistivity) with depth. Frequency-domain sensors, such as the **Geophex GEM-3 and the Geonics EM31**, are not widely used for UXO detection but can be useful in detecting boundaries of trenches that may be UXO disposal sites. The **Geonics EM31** has also been used to perform initial sweeps of UXO sites. • **Time-domain EMI** achieves the same results by measuring the electrical response of the subsurface to a pulsed wave at several time intervals. Longer time intervals between transmissions measure greater depths. The only time-domain EMI sensor that is widely recognized for UXO detection is the **Geonics EM61**. Under ideal conditions, the **EM61** instrument is capable of detecting large UXO items at depths of as much as 10 feet below ground surface when ground clutter from debris is not present. The instrument can detect small objects, such as a 20 mm projectile, to depths of approximately 1 foot below ground surface.
How effective is EMI for detecting UXO?	The effectiveness of EMI systems in detecting UXO depends on many factors, including **distance between sensor and UXO, metallic content of UXO**, **concentrations of surface ordnance fragments**, and **background noise levels**. EMI methods are well suited for reconnaissance of large open areas because data collection is rapid. Horizontal resolution with EMI is approximately 2.5 feet, and vertical resolution is transmitter and target dependent. The range of frequencies for electromagnetic instruments used in UXO site characterization is from approximately 75 Hz (cycles per second) to approximately 1,000 kHz. *To optimize performance of EMI systems, the sensor should be placed close to the soil surface.*

FACT SHEET #2: UXO DETECTION TECHNOLOGIES

Electromagnetic Induction (EMI)

What are the components of an EMI system?

The components of an EMI system include the following:

- **Transmitting and receiving units**
- **A power supply**
- **A computer data acquisition system**
- **A means of recording locations of detected metallic anomalies**

Advanced systems incorporate a navigation system as well, such as a **differential global positioning system (DGPS)**.

What are the operational platforms for an EMI system?

In general, EMI systems are configured on man-portable units. Such units often consist of the following items:

- **A small, wheeled cart used to transport the transmitter and receiver assembly**
- **A power supply**
- **An electronics backpack**
- **A hand-held data recorder**

On occasion, multiple EMI systems have been mounted together, requiring the use of a towed vehicle. However, vehicle-towed systems are limited in that they have high potential for mechanical failures. In addition, vehicle-towed systems can only be used on relatively flat and unvegetated areas. *Man-portable systems provide access to all areas of a site, including uneven and forested terrain, and man-portable systems are the most durable and require the least amount of maintenance.*

Figure 4-2. EM61 System

FACT SHEET #2: UXO DETECTION TECHNOLOGIES

Electromagnetic Induction (EMI)

What are the benefits of using EMI for detecting UXO?

The **benefits** of using EMI include the following:

- EMI can be used for *detecting all metallic objects near the surface of the soil*, not only ferrous objects; but it is best at detecting good electrical conductors.
- EMI has potential to *discriminate clusters of UXO from a single item*.
- EMI sensors *permit some measure of control over their response to ordnance and other metal objects*.
- EMI systems are generally *easy to use*.
- EMI is *nonintrusive*.
- EMI systems are *portable*.
- EMI systems provide *quick results.*
- Man-portable EMI systems *provide access to all areas of a site, including uneven and forested terrain*.

What are the limitations of using EMI for detecting UXO?

The **limitations** of using EMI to detect UXO include the following:

- EMI suffers from fairly *large false alarm rates*, particularly in areas with high concentrations of surface ordnance fragments. (Some buried metallic debris can produce EMI signatures that look similar to signatures obtained from UXO, which results in a large false alarm rate.) Consequently, EMI sensors that utilize traditional detection algorithms based solely on the metal content suffer from high false alarm rates as well.
- Implementing EMI systems in areas on the range that may contain electronically fuzed ordnance could be *unsafe because the induced magnetic field could detonate the ordnance.* (However, this is very unlikely because the EMI power density and induced current is very low in most systems.)
- *Large metal objects can cause interference*, typically when EMI is applied within 5 to 20 feet of power lines, radio transmitters, fences, vehicles, or buildings.
- Man-portable EMI systems can be limited by the *speed and stamina of the operators*; *climatic conditions*; *site-specific soil*, *vegetation*, and *topographic characteristics*.
- Vehicle-towed systems are limited in that they have *high potential for mechanical failures and can only be used on relatively flat and unvegetated areas*.

What are the costs of using EMI to detect UXO?

The **Geonics EM31** cost is about $18,000, while the rental fee is approximately $75 per day. The **Geonics EM61** costs about $19,000, while the rental fee is approximately $75 per day. Basic software packages to analyze the data from both instruments is provided. (*Note: Taken from "UXO and Explosives Compounds: Field-Based Site Characterization Techniques"*)

FACT SHEET #2: UXO DETECTION TECHNOLOGIES	**Electromagnetic Induction (EMI)**
1 **Case Study**	**EMI** is most often used in multisensor arrays when employed for the detection of UXO. This case study describes the use of EMI in a multisensor system. It is currently difficult to distinguish the EMI signal of UXO from the signal of scrap metal. A model has been developed that characterizes the EMI signal by the strength of the dipole response both along and orthogonal to the object's primary symmetry axis. From this model, a fitting algorithm is being developed by AETC, Inc., for the Naval Research Laboratory's Multisensor Towed Array Detection System (MTADS) EMI platform. This algorithm will characterize a given EMI signature by the relative dipole response factors along the major axes of an unknown object and determine the orientation of these axes, as well as estimate the location and depth of the object. A developmental version of this algorithm was used in the analysis of MTADS data from Jefferson Proving Ground Technology Demonstration Project (JPGTD), Phase IV. The MTADS was developed to provide high-quality sensor data for the purpose of detecting UXO. The system has two sensor arrays: a set of eight total-field magnetometers and a set of three overlapping modified **Geonics EM61** coils. The sensor data is positioned using a GPS. The modified Geonics EM61 coils used by MTADS consist of a transmitter coil and a lower and upper receiver coil. This **time-domain EMI sensor** pulses at a rate of 150 Hz and induces currents in nearby conducting objects. These currents generate secondary magnetic fields, which are measured in the receiver coils after the transmitter pulse has been turned off. Two surveys were conducted with the coils in their typical configuration, but in two perpendicular directions (i.e., east-west and north-south). When the object is directly under the coils, the transmitter field intersects the object vertically. When the array passes over the object from east to west, the transmitter field ahead of and behind the array intersects the object horizontally in an east-west direction. For a north-south survey, the field intersects horizontally north-south ahead of and behind the array. As long as there is sufficient signal when the object is not directly under the coils this method works well. Out of the 10 demonstrators that reported results at JPGTD Phase IV, MTADS was one of the two that correctly classified more than one-half of both the ordnance and nonordnance items. This result alone shows an ability to discriminate between UXO and clutter. In particular, MTADS did very well on certain objects. Four out of the five 57 mm projectiles and 60 mm mortar shells were identified as ordnance. In terms of nonordnance, three out of the four 9 cm square plates were correctly identified as flat and therefore nonordnance. During Phase IV, a relatively simple, semiempirical model of the Naval Research Laboratory's MTADS EMI array was implemented and a fitting algorithm developed to characterize UXO versus clutter. With the release of the JPGTD Phase IV ground-truth, MTADS was shown to be one of several demonstrators that had some clear discrimination capability.

FACT SHEET #3: UXO DETECTION TECHNOLOGIES

Ground Penetrating Radar (GPR)

What is GPR?

Ground penetrating radar (GPR), sometimes called ground probing radar, georadar, or earth sounding radar, is a well-established remote sensing technology that can detect metallic and nonmetallic objects. Only recently (within the last 10 years) has GPR been applied to locating and identifying UXO at military sites. *Under optimum conditions, GPR can be used to detect individual buried munitions several meters deep. However, such optimum conditions seldom occur and the method has not been extremely successful.*

How is GPR used to detect UXO?

GPR uses high-frequency electromagnetic waves (i.e., radar) to acquire subsurface information. Both time-domain (pulsed) and stepped frequency domain GPR systems are in use today.

- **Time-domain (pulsed)** sensors transmit a pulsed frequency. The transmitter uses a half-duty cycle, with the transmitter on and off for equal periods.
- **Stepped frequency domain** sensors transmit a continuous sinusoidal electromagnetic wave.

The waves are radiated into the subsurface by an emitting antenna.   As the transmitted signal travels through the subsurface, some of the signal strikes “targets,” such as buried munitions or stratigraphic changes, and is reflected back to a receiving antenna. The reflected signal is then recorded and processed into an image. Measurements are continuously recorded with a resolution that is significantly higher than most other surface geophysical methods. The amount of energy reflected, in addition to the travel time, can be used to determine the depth of the obstruction. GPR can potentially be used to verify the **emplacement**, **location**, and **continuity** of a subsurface barrier. The GPR method uses antennas that emit a single frequency between 10 MHz and 3,000 MHz. *Higher frequencies provide better subsurface resolution at the expense of depth of penetration. Lower frequencies allow for greater penetration depths but sacrifice subsurface target resolution.*

In addition to the antenna frequency, the depth of wave penetration is controlled by the electrical properties of the media being investigated. *In general, the higher the conductivity of the media, the more the induced radar wave is attenuated (absorbed), lessening the return wave.* Electrically conductive materials (e.g., many mineral clays and soil moisture rich in salts and other free ions) rapidly attenuate the radar signal and can significantly limit the usefulness of GPR. In contrast, in dry materials that have electrical conductivity values of only a few millimhos per meter, such as clay-free soil and sand and gravel, penetration depths can be as great as 90 feet. Penetration depths typically range between 3 and 15 feet. *As a result, it is important to research the likely subsurface materials in an area before deciding to use this method.*

FACT SHEET #3: UXO DETECTION TECHNOLOGIES	**Ground Penetrating Radar (GPR)**
How is GPR used to detect UXO? (cont.)	GPR measurements are usually made along parallel lines that traverse the area of interest. The spacing of the lines depends on the level of detail sought and the size of the target(s) of interest. Typically, an average walking pace of 2 to 3 miles per hour is used. Some very detailed investigations can be as slow as 0.1 mph, and newer systems can be mounted on vehicles and used at speeds of up to 65 mph for reconnaissance of the shallow subsurface. The data can be recorded for processing off-site, or they can be produced in real time for analysis in the field.
What are the components of a GPR system?	The components of a GPR systems consist of the following: • **A transmitter unit** • **A power supply** • **A receiving unit or antenna** • **A control unit** • **A display and recorder unit** GPR systems are available for commercial use. *The pulsed systems are the most commonly used and are available from a variety of vendors.* Pulsed radar systems provide a selection of antennas that operate at frequency bandwidths. Typically, antennas are available from the gigahertz range for extremely shallow targets to the megahertz range for greater depths of ground penetration. *The stepped frequency radar systems sweep frequency bands with specialized antennas to obtain information at desired penetration depths.*
What are the operational platforms for a GPR system?	GPR can be operated from a variety of platforms: • **Vehicle-towed platforms** • **Man-portable platforms** • **Airborne platforms** *The GPR antenna is most commonly towed by a person or a vehicle.*
What are the benefits of using GPR for detecting UXO?	The **benefits** of using GPR to detect UXO are as follows: • *Under optimum conditions, GPR can be used to detect individual buried munitions several meters deep*. In areas with **dry soils and vegetation**, GPR systems can produce accurate images as long as the antenna is positioned perpendicular to the ground. • GPR is *nonintrusive*. • GPR is *potentially able to identify breach and discontinuity and determine the size of both*. • GPR *provides a three-dimensional image of the structure*. • *GPR is relatively unaffected by above-surface interferences if the GPR antennas are shielded*. For antennas that are not shielded, an experienced operator can often distinguish and ignore reflections from overhead objects.

FACT SHEET #3: UXO DETECTION TECHNOLOGIES

Ground Penetrating Radar (GPR)

What are the limitations of using GPR for detecting UXO?

The **limitations** of using GPR to detect UXO include the following:

- *The primary limitation of the GPR system is that its success is highly site specific*. Low-conductivity soils are necessary if the method is to penetrate the ground. Soils with high electrical conductivity (e.g., many mineral clays and soil moisture rich in salts and other free ions) rapidly attenuate the radar signal, inhibiting the transmission of signals and significantly limiting usefulness. *Even a small amount of clay minerals in the subsurface greatly degrade GPR's effectiveness.*
- GPR cannot be used in areas with high soil moisture and dense forest vegetation because water absorbs the GPR energy, thus interfering with the reflection of the energy and detection of UXO. *The effects of soil moisture on GPR imaging may dominate all other factors*. A surface soil moisture content of less than 2 percent is considered to be the acceptable upper limit for GPR soil penetration.
- *Lower frequencies can penetrate to a greater depth, but result in a loss of subsurface resolution*, therefore requiring more processing. Higher frequencies provide better subsurface resolution, but at the expense of depth of penetration.
- *Interpretation of GPR data is complex*; an experienced data analyst is required.
- *High signal attenuation decreases the ability of GPR systems to discriminate UXO* and increases the relative amount of noise, or clutter.
- *Airborne GPR signals may not even contact the soil surface* because the signals are reflected by the vegetation or are absorbed by water in the vegetation.

What are the costs of using GPR to detect UXO?

A basic GPR system costs about $35,000, including one transducer and all other equipment necessary for typical survey. Additional transducers are available at additional cost. Software to analyze the data would be necessary at additional cost. (*Note: Taken from "UXO and Explosives Compounds: Field-Based Site Characterization Techniques"*)

Case Study

GPR is not often used as a stand-alone UXO detection technology because its detection capabilities are limited. GPR is most commonly used as part of a multisensor system, such as the one described below.

The Air Force Research Laboratory at Tyndall AFB has developed a semiautonomous UXO detection, characterization, and mapping system. The system consists of two major functional components: an unmanned autonomous tow vehicle (ATV) and a multisensor data acquisition system. By combining an ATV, the GPR's highly accurate positioning and mapping systems, and a multiple-sensor platform, operators plan, execute, and analyze collected data while monitoring the vehicle and data acquisition system at a safe distance from the survey site.

FACT SHEET #3: UXO DETECTION TECHNOLOGIES

Ground Penetrating Radar (GPR)

Case Study (cont.)

The multiple-sensor platform (MSP) provides a mounting structure for an array of four cesium vapor magnetometers, three Geonics EM61 inductance coils, and an **impulse GPR system**. The GPR is suspended below the platform frame using a pinned hanger. An encoder at the GPR hanger point measures the relative GPR angular displacement from the platform frame. In general, the ATV/MSP GPR transmits a series of 3-5 nanosecond, 100-250 volt impulses into the ground at a specific pulse repetition interval. Signals received from objects with electrical properties that vary from the surrounding soil are fed through an adjustable attenuator, to a band pass filter, and finally to track-and-hold circuitry, which digitizes and stores collected data. The system uses a single broad-bandwidth antenna, which covers a frequency range of 20 MHz to 250 MHz.

To date, data collection has been conducted at several sites, one of them being Tyndall AFB. The test site in the 9700 area of Tyndall AFB is composed of a loose sandy top layer approximately 20 cm deep and a packed sandy layer that reaches the water table, which starts at a depth of less than 1 meter. The test site provides a homogeneous background in which inert ordnance items, 60 mm mortar shells, 105 mm artillery shells, miscellaneous clutter, angle iron, barbed wire, concrete blocks, and steel plates were placed to simulate an active range. Data collected at the Tyndall test site included those from the magnetometer, electromagnetic induction (EMI), and GPR.

Analysis of magnetometer, EMI, and GPR cursory calibration raw data is performed in situ at the mobile command station. Synthetic aperture radar (SAR) processing was used to focus the complex and large bandwidth information inherent in GPR data. In order to perform this focusing of the SAR images, the waveforms generated by the GPR must be accurately registered in the time domain, with an associated registration of position in the spatial domain.

The original purpose of the ATV/MSP was to evaluate various sensor systems. It quickly became clear that its higher purpose was to provide a powerful aid to the process of analysis. The accuracy, repeatability, and completeness of coverage obtained during autonomous surveys cannot be matched using manual operations.

FACT SHEET #4: UXO DETECTION TECHNOLOGIES

Multisensor System

What is the multisensor approach to UXO detection?

The **multisensor system** combines two or more sensor technologies with the objective of improving UXO detection performance. *With multiple-sensor systems operating in a given area, complementary data sets can be collected to confirm the presence of UXO, or one system may detect a characteristic that another system does not.*

No single technology exists that is both effective and completely reliable for detecting UXO. Each UXO detection technology has some advantages and some disadvantages. For example, magnetometers currently constitute the most effective UXO detection technology, but they can detect only ferromagnetic metallic objects and cannot distinguish between UXO and other ferromagnetic metallic objects. Adding a second sensor technology that detects all types of metals (for example, electromagnetic induction) improves the probability of detecting UXO and improves the overall systems's ability to distinguish between UXO and nonordnance items, thus decreasing the number of false alarms. *The actual effectiveness and performance of a multisensor system depends on the system's configuration, the types of UXO present and their characteristics, and site-specific environmental and climatic factors.*

The technologies that have proven to be most effective in multisensor systems are the **Geonics EM61 electromagnetic detection system** and the **cesium vapor magnetometer**. Other types of sensors have been tested and evaluated, but they are still under development and research continues. Some of these innovative technologies include multispectral scanners, multifrequency electromagnetic systems, neutron-based identification technologies, and magnetoresistive sensor arrays.

Implementing multisensor systems

Implementing a multisensor approach for UXO detection is similar to implementing any of the ground-based sensor technologies (for example, magnetometry and EMI). To be effective, all ground-based UXO detection systems would require some degree of site preparation and vegetation removal, which would be labor-intensive and expensive and would result in adverse environmental impacts. Access to the more densely vegetated or steeply sloped areas of the ranges might be restricted to the smaller, man-portable systems. Penetration depths typically range between 0 and 10 feet. Logistical and support requirements include configuring the necessary systems components and acquiring the appropriate operational vehicle.

What are the components of a multisensor system?

The Multisensor Towed Array Detection System (MTADS), a multisensor system developed by the Naval Research Laboratory, has provided very reliable results. Components for this system include the following:

- **Low-magnetic-signature off-road tow vehicle**
- **Full-field cesium vapor magnetometers**
- **Time-domain electromagnetic pulsed induction sensors**
- **A global positioning system (GPS)**
- **An integrated data analysis system**

Configurations for magnetic systems use as many as eight sensors mounted about one-half meter apart. The electromagnetic sensors have been modified so that data can also be collected at half-meter spacing.

FACT SHEET #4: UXO DETECTION TECHNOLOGIES

Multisensor System

What are the operational platforms for a multisensor system?

Multiple operational platforms could easily be incorporated into a multisensor approach. For example, a man-portable active EMI system could be combined with vehicle-towed passive magnetometers to provide greater overall UXO detection. *Combining UXO detection sensors and operational platforms (with the exception of airborne platforms) has been demonstrated to improve overall performance in UXO detection.*

MTADS uses a low-magnetic-signature vehicle that tows the magnetic sensors or electromagnetic sensors. Several other vehicle-towed systems also have been used. The electromagnetic systems can be easily adapted to all-terrain vehicles because the sensors can be placed at an acceptable distance from the vehicle. Magnetic sensors require a tow vehicle that has a low magnetic content.

Figure 4-3. MTADS Behind All-Terrain Vehicle

What are the benefits of using the multisensor system for detecting UXO?

The **benefits** of using the multisensor system to detect UXO are as follows:

- Multisensor systems collect and combine data from two or more sensors, which has been demonstrated to improve overall UXO detection performance. *With multiple sensors operating in a given area, complementary data sets can be collected to confirm the presence of UXO, or one sensor may detect a characteristic that another does not.*
- Multisensor systems have a *higher probability of detection and lower false alarm rate than a single sensor*.
- The evolving ability of the multisensor systems to discriminate between UXO and non-UXO *represents the potential to achieve significant cost savings in remediation operations.*
- Multisensor systems are *nonintrusive*.
- Multisensor systems *provide high-density data collection*.
- Multisensor systems provide *rapid data coverage over large areas*.
- Multisensor systems *require a low level of physical labor*.

FACT SHEET #4: UXO DETECTION TECHNOLOGIES

Multisensor System

What are the limitations of using the multisensor system for detecting UXO?

The **limitations** of using a multisensor system to detect UXO include the following:

- *Access to the more densely vegetated or steeply sloped areas of the ranges might be restricted to the smaller, man-portable systems*. Multisensor systems work well when mobility is not an issue.
- To be effective, all ground-based UXO detection systems *would require some degree of site preparation and vegetation removal*, which would be labor-intensive and expensive and would result in adverse environmental impacts.

What are the costs of using the system?

The capital cost of the MTADS is about $450,000. (*Source:"UXO and Explosives Compounds: Field-Based Site Characterization Techniques"*) The cost of deploying the MTADS System when run by the Naval Research Laboratory or a contractor runs between $500 and $1,000 per acre. (*Source: ESTCP*)

Case Study

The Naval Research Laboratory's **MTADS** represents the state of the art in automated UXO detection technology. The system incorporates arrays of **full-field cesium vapor magnetometers** and **time-domain EMI pulsed sensors**. The sensors are mounted as linear arrays on low-signature platforms that are towed over survey sites by an all-terrain vehicle. The position over ground is plotted using state-of-the-art real-time kinematic technology that also provides vehicle guidance during the survey. An integrated **data analysis system** processes MTADS data to locate, identify, and categorize all military ordnance at maximum probable self-burial depths.

During the summer of 1997 the system was used to survey about 150 acres at a bombing target and an aerial gunnery target on the Badlands Bombing Range on the Oglala Sioux Reservation in Pine Ridge, South Dakota. Following the survey and target analysis, UXO contractors and personnel from the U.S. Army Corps of Engineers, Huntsville, selectively remediated targets to evaluate both the detection and discrimination capabilities of MTADS. Two remediation teams worked in parallel with the surveying operations. The full distribution of target sizes was dug on each target range because one goal of the effort was to create a database of both ordnance and ordnance clutter signals for each sensor system that could be used to develop an algorithm for future data analysis.

An initial area of 18.5 acres was chosen as a test/training range. All 89 analyzed targets were uncovered, documented, and remediated. Recovered targets in the training areas included 40 M-38 100-pound practice bombs, four rocket bodies and warheads, and 33 pieces of ordnance scrap (mostly tail fins and casing parts). The smallest intact ordnance items recovered were 2.25-inch SCAR rocket bodies and 2.75-inch aerial rocket warheads. Information from the training area was used to guide remediation on the remainder of both ranges.

FACT SHEET #4: UXO DETECTION TECHNOLOGIES	# Multisensor System
Case Study (cont.)	**Magnetometry** and **EM** data analysis identified a total of 1,462 targets on both ranges. Of these, 398 targets were selected for remediation. For each target, an extensive digsheet was filled out by the remediation team to augment the photographic and digital electronic GPS records. Recovered ordnance-related targets included 67 sand-filled M-38 practice bombs, four M-57 250-pound practice bombs, and 50 2.25-inch and 2.75-inch rocket bodies and rocket warheads. In addition, 220 items of ordnance-related scrap were recovered. The target depths were generally predicted to within 20 percent of the actual depths of the target centers. MTADS has the sensitivity to detect all ordnance at its likely maximum self-burial depths and to locate targets generally within the dimensions of the ordnance. *On the basis of all evaluation criteria, the MTADS demonstration, survey, and remediation were very successful.*

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SOURCES AND RESOURCES

The following publications, offices, laboratories, and websites are provided as a guide for handbook users to obtain additional information about the subject matter addressed in each chapter. Several of these publications, offices, laboratories, or websites were also used in the development of this handbook.

Publications

United States Army Environmental Center (USAEC), ***Evaluation of Individual Demonstrator Performance at the Unexploded Ordnance Advanced Technology Demonstration Program at Jefferson Proving Ground (Phase I),*** March 1995.

USAEC, ***Unexploded Ordnance Advanced Technology Demonstration Program at Jefferson Proving Ground (Phase II),*** June 1996.

USAEC, ***UXO Technology Demonstration Program at Jefferson Proving Ground, Madison, Indiana, (Phase III)***, April 1997.

U.S. Department of Defense (DoD). ***Unexploded Ordnance (UXO)***, BRAC Environmental Fact Sheet, Spring 1999.

U.S. Department of Defense (DoD), ***Evaluation of Unexploded Ordnance Detection and Interrogation Technologies, For Use in Panama: Empire, Balboa West, and Pina Ranges: Final Report***, February 1997.

Information Sources

Air Force Research Laboratory AFRL/MLQC
104 Research Road, Bldg. 9738
Tyndall AFB, FL 32403-5353
Tel: (850) 283-3725
http://www.afrl.af.mil

Department of Defense Explosives Safety Board (DDESB)
Department of Defense Explosives Safety Board
2461 Eisenhower Avenue
Alexandria, VA 22331-0600
Fax: (703) 325-6227
http://www.hqda.army.mil/ddesb/esb.html

Environmental Security Technology Certification Program (ESTCP)
901 North Stuart Street, Suite 303
Arlington, Virginia 22203
Tel: (703) 696-2127
Fax: (703) 696-2114
http://www.estcp.org

Joint UXO Coordination Office (JUXOCO)
10221 Burbeck Rd.
Ft. Belvoir, VA 22060-5806
Tel: (703) 704-1090
http://www.denix.osd.mil/UXOCOE

Naval Explosive Ordnance Disposal Technology Division
(NAVEODTECHDIV)
UXO Countermeasures Department
Code 30U
2008 Stump Neck Road
Indian Head, MD 20640-5070
http://www.ih.navy.mil/

Naval Research Laboratory
Chemistry Division, Code 6110
Washington, DC 20375-5342
Tel: (202) 767-3340
http://chemdiv-www.nrl.navy.mil/6110/index.html

Naval Ordnance Environmental Support Office
Naval Ordnance Safety and Security Activity
23 Strauss Ave. (BLDG D-323)
Indian Head, MD 26040
Tel: (301) 744-4450/6752
http://enviro.nfesc.navy.mil/nepss/oeso.htm

Strategic Environmental Research and Development Program (SERDP)
901 North Stuart Street, Suite 303
Arlington, VA 22203
Tel: (703) 696-2117
http://www.serdp.org

U.S. Army Corps of Engineers
Engineering and Support Center, Huntsville
4820 University Square
Huntsville, AL 35816-1822
Tel: (205) 895-1545
http://www.usace.army.mil

U.S. Army Environmental Center (USAEC)
Aberdeen Proving Ground, MD 21010-5401
Tel: (800) USA-3845
http://aec.army.mil

U.S. Army Research Laboratory (ARL)
Attn: AMSRL-CS-EA-PA
2800 Powder Mill Road
Adelphi, MD 20783-1197
Tel: (301) 394-2952
http://www.arl.army.mil

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5.0 CLEANUP TECHNOLOGIES

Ordnance and explosives (OE), which may include buried munitions, UXO, or explosive soil, not only pose explosive hazards but also present disposal challenges to personnel conducting range clearance. Treatment technologies have been developed to destroy the explosive material, reduce the amount of contaminated material at a site, remove the component of the waste that makes it hazardous, or immobilize the contaminant within the waste. However, different forms of energetic material require different technological approaches to their treatment and disposal. The types of explosive hazards are divided into the following three categories:

- **UXO**
- **Explosives-contaminated soils and debris**
- **Buried munitions**

The most commonly used technique for treating OE at CTT ranges is in-place open detonation (OD), also known as "blow-in-place." In OD, the explosive materials in UXO are detonated so that they no longer pose explosive hazards. However, OD is controversial because of the concerns of the regulatory community and environmentalists that harmful emissions and residues will contaminate air, soils, and groundwater. This chapter also addresses several alternative treatments for OE.

Explosive residues found in soils and debris can pose hazards equal in magnitude to those of the munitions themselves. The treatment of these wastes can be extremely difficult because they may be prone to detonate when disturbed or exposed to friction or heat, depending on the nature and extent of explosive contamination. However, treatments have been developed that allow explosives-contaminated soil and debris to be decontaminated to levels that make it safe to dispose of them or leave them in place.

5.1 Treatment and Disposal of OE: An Overview

In-place open detonation, or blow-in-place, is the most commonly used method to destroy excess, obsolete, or unserviceable munitions and energetic materials on CTT ranges. However, other techniques, such as incineration (small arms only), contained detonation, bioremediation (in-situ, windrow composting, and bioslurry methods), low-temperature thermal desorption, wet air oxidation, and plasma arc destruction, may be viable alternatives to blow-in-place, depending on the specific situation. Each technology or combination of technologies has different advantages and disadvantages. A combination of safety, logistical, throughput, and cost issues often determines the practicality of treatment technologies.

Significant statutory and regulatory requirements apply to the destruction and disposal of all OE (see Chapter 2, "Regulatory Overview"). The particular requirements that will be either most applicable or most relevant and appropriate to OE remediation are the Federal and State RCRA permitting requirements for open burning and open detonation (OB/OD) and incineration. While the regulations may vary among States and individual sites, they generally include stringent permit and closure requirements for sites at which OB/OD is used, trial burn tests prior to obtaining permits for incinerator operations, and a variety of other requirements. In addition, while permits are not required to conduct on-site cleanups at CERCLA sites, all cleanup activities are subject to the hazardous waste requirements contained in the applicable or relevant and appropriate requirements (e.g., the substantive requirements of incineration). Familiarity with the State and Federal requirements will be critical in determining your approach to remediation.

Table 5-1 (below) summarizes the effective uses of treatment technologies for remediating munitions, UXO, and other constituents found in soils and debris. These technologies are addressed in more detail in subsequent sections of this chapter. Readers should note that many of these treatment technologies are not standard practice at CTT ranges. Some technologies are currently used primarily at industrial facilities, while others are still in the early stages of development. However, when appropriate, alternatives to blow-in-place may be considered in the evaluation of alternatives for the clearance of CTT ranges. The selection of a treatment technology will vary from site to site and will depend on several factors, including, but not limited to:

- Safety considerations
- Scale of project (or throughput)
- Cost and cost effectiveness
- Size of material to be treated and capacity of technology
- Logistics considerations such as accessibility of range and transportability of technology

Table 5-1. Overview of Remediation Technologies for Explosives and Residues

Explosive Problem	Treatment To Address Problem	Situations/Characteristics That Affect Treatment Suitability
Munitions or fragments	OB/OD	Inexpensive and efficient, but potentially produce high levels of toxic air emissions and heavy metal byproducts. Significant regulatory controls. Highly controversial due to public and regulator concern over health and safety hazards. Noise issues.
Munitions or fragments, soil, and debris	Rotary kiln incinerator	Generally effective for removing explosives and meeting regulatory cleanup requirements. Requires large capital investment, especially incinerators that can handle detonation. For incinerators that treat soil, quench tanks clog frequently; clayey, wet soils jam feed systems; and cold conditions exacerbate clogging problems. Controversial due to regulator and public concerns over air emissions and ash byproducts. Nonportable units require transport of all material to be treated, which can be dangerous and costly. Project scale should be considered.
Small-caliber munitions or fragments, soil	Deactivation furnace	Thick-walled primary combustion chamber withstands small detonations. Renders munitions unreactive.
Small-caliber munitions (up to 81 mm mortars)	Contained detonation chamber	Significantly reduces noise and harmful emissions, as well as the overpressure, shock wave, and fragmentation hazards of OB/OD. Available as transportable units.

Explosive Problem	Treatment To Address Problem	Situations/Characteristics That Affect Treatment Suitability
Soil and debris	Wet air oxidation	Treats slurries containing explosives. Very effective in treating RDX; however, may produce hazardous byproducts and gaseous effluents that require further treatment. High capital costs and frequent downtime.
Small-caliber munitions or fragments	Plasma arc thermal treatment	Still under development, prototype systems have been shown to create a benign, nonleachable slag product. Prototype systems claim to not produce toxic air emissions or ash. Large capital investment required.
Munitions or fragments, soil, and debris	Safe deactivation of energetic materials and beneficial use of byproducts	Still under development. At low temperatures, reacts explosives with organic amines that neutralize the explosives, without causing detonation. Some of the liquid byproducts have been found to be effective curing agents for conventional epoxy resins. Low or no discharge of toxic chemicals.
Soil	Windrow composting	Microorganisms break down explosive residues into less explosive or nonexplosive substances. Requires relatively long time periods and large land areas. Highly effective and low process cost, but ineffective with extremely high concentrations of explosives.
Soil	Bioslurry (soil slurry biotreatment)	Optimizes conditions for maximum microorganism growth and explosive degradation. Slurry processes are faster than many other biological processes and can be either aerobic or anaerobic or both, depending on contaminants and remediation goals. Effective on soil with high clay content. In general, treated slurry is suitable for direct land application.
Soil	In-situ bioremediation (including hydrogen peroxide injection)	Soil is left in place and oxygen and nutrients are supplied to microorganisms to promote growth and maximize degradation of explosives. Air and nutrients and/or hydrogen peroxide are pushed into soils through injection wells or delivered by pipes or sprinklers to shallow contaminated soils. May not be effective in clayey or highly layered soils and can take years to achieve cleanup goals. In addition, hydrogen peroxide can create potentially hazardous conditions.
Soil	Soil washing	Reduces the total volume of contaminated soil and removes explosives from soil particles. Requires additional treatment for wastewater and, potentially, for treated soils.
Soil	Low-temperature thermal desorption	Used to treats soils with low concentrations of some explosives. Contaminated soil is heated to separate contaminants by volatilizing them. They are then destroyed. Not very effective for treating explosives.

Note: This table is not exhaustive. Each of the treatment technologies are discussed in more detail in the succeeding pages.

5.1.1 Handling UXO Safely

The handling of UXO at CTT ranges is based on the site-specific situation. There is no single approach that is appropriate for every site. As is often the case at CTT ranges, disarming all munitions is dangerous and difficult, if not impossible. Often, the fuze or detonator is inaccessible, damaged, or rusted such that it cannot be disabled or removed. In such cases, the item will be blown in place or, in limited situations, remotely dragged to a nearby area for treatment, depending on the hazards it presents to personnel, as determined by the on-site explosive ordnance disposal (EOD) expert. For example, near archeological sites, highly explosive UXO that cannot be disarmed may have to be remotely dragged to a destruction area if blow-in-place procedures have the potential to create irreparable damage. While remote dragging may cause a detonation by disturbing the UXO, it is more protective to personnel than render-safe procedures (see below) and affords some chance of protecting the site.

5.1.2 Render-Safe Procedures

When munitions pose an immediate, certain, and unacceptable risk to personnel, critical operations, facilities, or equipment, as determined by on-scene EOD personnel, render-safe procedures (RSPs) may be performed to reduce or eliminate the explosive hazards. RSPs are conducted by active duty military EOD personnel and typically involve disarming UXO (removing or disabling the fuze and/or detonator), or using specialized procedures. Such procedures can dramatically increase explosives safety risks to EOD personnel, and DoD considers their use only in the most extraordinary circumstances. In general, once UXO items are disarmed, EOD personnel move them from the location at which they were found to a central area on-site for destruction (usually using OB/OD). Instead of detonating all UXO items in place, consolidated treatment allows for improved efficiency and control over the destruction (e.g., safe zones surround the OD area; blast boxes and burn trays are used).

Excavating UXO

There are three general techniques used to excavate subsurface UXO once it is detected: **manual, mechanized,** and **remote control**. The selection of a retrieval method or, frequently, a combination of retrieval methods, is based on the types and characteristics of UXO detected, their depth, and site-specific soil and geological conditions. All retrieval actions should be conducted in the presence of explosive ordnance disposal (EOD) personnel or qualified UXO technicians.

The only equipment used in **manual excavation** are shovels and/or other digging tools to move the top layers of soil. Manual excavation is extremely labor-intensive and can be hazardous to workers, as there is no barrier protecting them from an accidental explosion. When using manual retrieval methods in heavily vegetated areas, the vegetation should be removed in order to increase surface visibility and reduce the possibilities of an accidental explosion. Also, additional UXO detection activities are usually performed when using these methods in order to confirm target removals and increase the probability of clearing all UXO in the area. Manual excavation methods are best suited for surface and near-surface UXO and are most effective when retrieving smaller UXO items, such as small arms munitions, grenades, and small-caliber artillery projectiles. UXO located in remote areas, areas with saturated soils, and areas with steep slopes and/or forest may be best suited for manual methods. The retrieval of larger, more hazardous UXO items at greater subsurface depths should be reserved for mechanized retrieval methods, as the excavation involved is much more labor-intensive and hazardous.

Mechanized UXO retrieval methods involve the use of heavy construction equipment, such as excavators, bulldozers, and front-end loaders. Excavation below the groundwater table might require pumping equipment. Mechanized methods are generally faster and more efficient than manual retrieval methods, and they tend to be less hazardous than manual methods, as the machinery provides some separation between workers and UXO.

Mechanized methods are best suited for excavation efforts where large UXO items are buried at significant subsurface depths, such as 1-3 meters below ground surface. Mechanized methods work most efficiently in easy-to-access areas with dry soils. Site preparation, such as vegetation removal and the construction or improvement of access roads, may be required as well. It should also be noted that large excavation efforts, usually performed by mechanized methods, can have a significant negative impact on the environment, as they can destroy soil structure and disrupt nutrient cycling.

The effective use of **remote-controlled mechanized methods** generally requires site conditions similar to those required for mechanized excavation. The primary difference between the two methods is that remote-controlled systems are much safer because the operator of the system remains outside the hazardous area. Remotely controlled retrieval methods may involve the use of telerobotic and/or autonomous systems with navigation and position controls, typically a real-time digital global positioning system (DGPS). DGPS signals, however, can be obstructed by trees and dense vegetation, limiting the accuracy and implementability of remote-controlled systems.

Remote-controlled systems are still being developed and improved. Two remote-controlled systems were demonstrated at the Jefferson Proving Ground Technology Demonstration Program, Phase III. The systems were generally adept at excavating large items; however, they did not reduce the time or cost of UXO retrieval. Remote-controlled systems are best suited for relatively flat, dry, easy-to-access grassy or unvegetated areas; they tend to have problems with hard soil, rainy weather, rough terrain, and deep targets.

5.2 Treatment of OE

5.2.1 Open Burning and Open Detonation

Although open burning and open detonation (OB/OD) are often discussed together, open detonation, also called blow-in-place when it takes place where the OE is found, remains the most frequently used method for treating UXO at CTT ranges. In range cleanups, demolition is almost always conducted on-site because of the inherent public safety concerns and the regulatory restrictions on transporting even disarmed explosive materials.

Blow-in-place involves the open detonation of UXO where it is found. It is considered by explosives safety experts to be the safest, quickest, and most cost-effective remedy for destroying UXO. However, increasing regulatory restrictions and public concern over its human health and environmental impacts may create significant barriers to conducting both OB and OD in the future. The development of alternatives to OB/OD in recent years is a direct result of these growing concerns and increased restrictions on the use of OB/OD.

There are significant environmental and technical challenges to treating ordnance and explosives with OB/OD.[67] These limitations include the following:

- **Restrictions on emissions.** Harmful emissions may pose significant human health and environmental risks and are difficult to capture sufficiently for treatment. Areas with emissions limitations may not permit OB/OD operations.
- **Soil and groundwater contamination.** Soil and groundwater can become contaminated with byproducts of incomplete combustion and detonation.
- **Area of operation.** Large spaces are required for OB/OD operations to maintain minimum distance requirements for safety purposes (see Chapter 6, “Safety”).
- **Location.** Environmental conditions may constrain the use of OB/OD. For example, in OB/OD operations, emissions must be carried away from populated areas, so prevailing winds must be steady. Ideal wind speeds are 4-15 mph, because winds at these speeds are not likely to change direction and they tend to dissipate smoke rapidly. In addition, any type of storm (including sand, snow, and electrical) that is capable of producing static electricity can potentially cause premature detonation.
- **Legal restrictions.** Legal actions and regulatory requirements, such as restrictions on RCRA Subpart X permits, emissions restrictions, and other restrictions placed on OB/OD, may minimize or even eliminate the use of OB/OD in the future.
- **Noise.** Extreme noise created by detonations limit locations where and times when OB/OD can be performed.

[67] EPA Office of Research and Development - September 1993. Handbook: Approaches for the Remediation of Federal Facility Sites Contaminated with Explosive or Radioactive Wastes.

The Debate over OB/OD

The conventional wisdom is to treat UXO on-site using OB/OD. However, coalitions of environmentalists, Native Americans, and community activists across the country have voiced concerns and filed lawsuits against military installations that perform OB/OD for polluting the environment, endangering their health, and diminishing their quality of life. While much of this debate has focused on high-throughput industrial facilities and active ranges, and not on the practices at CTT ranges, similar concerns have also been voiced at CTT ranges. Two examples of the debate over OB/OD involve an industrial facility (Sierra Army Depot) and an active range (Massachusetts Military Reservation). Specifically, citizens groups near the Sierra Army Depot have sued the Army for conducting OB/OD on over 86 million pounds per year of munitions that cause "toxic plumes of carcinogenic chemicals, including mercury, lead, beryllium, copper, etc., to be released into the air, water, and soils...Blast waves rattle windows, walls, and floors of houses located many miles away." In addition, in response to concerns over the public health and environmental effects of OB/OD, EPA Region 1 has prohibited the destruction of UXO on the range impact area of the Massachusetts Military Reservation since 1997, and has recommended render safe procedures (RSPs) and off-site treatment as an alternative. In response to EPA's actions and alternative proposal, the Army has stated, "...This places the military EOD personnel at an increased and unacceptable explosive safety risk,...It is normally not prudent to move unexploded ordnance from ranges, where there is no hazard to personnel (other than EOD), operations, facilities, or property, for disposal elsewhere....Where there are situations...where there is a concern for potential long-term endangerment to the environment, a protocol should be provided for the mitigation by the responsible activity of any effects from the in-place destruction of UXO."

In open detonation, an explosive charge is detonated to destroy high-order energetic materials and munitions. Engineering controls and protective measures can be used, when appropriate, to significantly reduce the effects and hazards associated with blast and high-speed fragments during OD operations. Common techniques for reducing these effects include constructing berms and barricades that physically block and/or deflect the blast and fragments, tamping the explosives with sandbags and/or earth to absorb energy and fragmentation, using blast mitigation foams, and trenching to prevent transmission of blast-shock through the ground. These methods have been effective in reducing the size of exclusion zones required for safe OD and limiting local disruptions due to shock and noise. In some instances (e.g., low explosive weight UXO), well-engineered protective measures can reduce the effects and hazards associated with OD to levels comparable to contained detonation chambers (CDCs) (see section 5.2.2.2).

5.2.2 Alternative Treatment Technologies

Because of growing concern and regulatory constraints on the use of OD, alternative treatments have been developed that aim to be safer, commercially available or readily constructed, cost-effective, versatile in their ability to handle a variety of energetics, and able to meet the needs of the Army.[68] The most commonly used alternative to OD is incineration.

[68]Stratta, J. et al., Alternatives to Open Burning/Open Detonation of Energetic Materials, U.S. Army Corps of Engineers, Construction Engineering Research Lab, August 1998.

5.2.2.1 *Incineration*

Incineration is primarily used to treat soils containing explosives. In addition, small quantities of UXO, bulk explosives, and debris containing explosives may be treated using incineration. However, even the largest incinerators with strong reinforcement cannot handle the detonations of very large munitions. Like OB/OD, incineration is not widely accepted by regulators and the public because of concerns over the environmental and health impacts of incinerator emissions and residues.

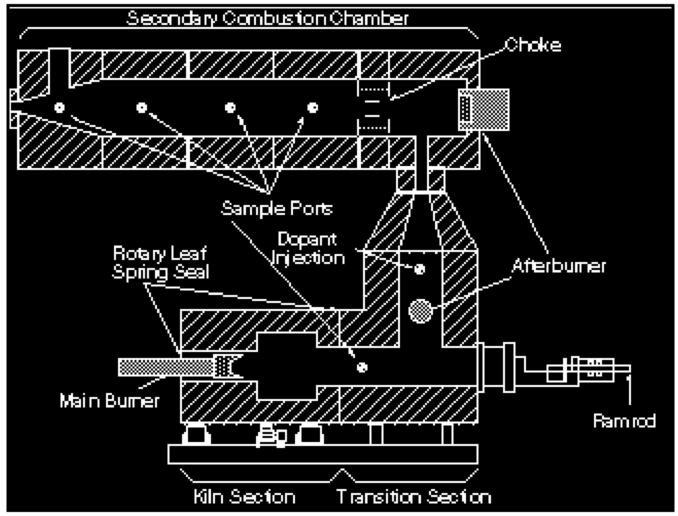

Figure 5-1. Rotary Kiln

The strengths and weaknesses of incineration are summarized as follows:

- C **Effectiveness**. In most cases, incineration reduces levels of organics to nondetection levels, thus simplifying cleanup efforts.
- **Proven success.** Incineration technology has been used for years, and many companies offer incineration services. In addition, a diverse selection of incineration equipment is available, making it an appropriate operation for sites of different sizes and containing different types of contaminants.
- **Safety issues.** Munitions must be considered safe to move in order to relocate them to an incinerator. Determining this may require that RSPs be performed prior to incineration. In addition, the treatment of hazardous and explosive materials with extremely high temperatures is inherently hazardous.
- **Emissions.** Incinerator stacks emit compounds that may include nitrogen oxides (NO_x), volatile metals (including lead) and products of incomplete combustion.
- **Noise.** Incinerators may have 400-500 horsepower fans, which generate substantial noise, a common complaint of residents living near incinerators.
- **Costs.** The capital costs of mobilizing and demobilizing incinerators can range from $1 to $2 million. However, on a large scale (above 30,000 tons of soil treated), incineration can be a cost-effective treatment option. Specifically, at the Cornhusker Army Ammunition Plant, 40,000 tons of soil were incinerated at an average total cost of $260 per ton. At the Louisiana Army Ammunition Plant, 102,000 tons of soil were incinerated at $330 per ton.[69]

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[69]U.S. EPA, Office of Research and Development. September 1993. Handbook: Approaches for the Remediation of Federal Facility Sites Contaminated with Explosive or Radioactive Wastes.

- **Public perception.** The public generally views incineration with suspicion and as a potentially serious health threat caused by possible emission of hazardous chemicals from incinerator smokestacks.
- **Trial burn tests.** An incinerator must demonstrate that it can remove 99.99 percent of organic material before it can be permitted to treat a large volume of hazardous waste.
- **Ash byproducts.** Like OB/OD, most types of incineration produce ash that contains high concentrations of inorganic contaminants.
- **Materials handling.** Soils with a high clay content can be difficult to feed into incinerators because they clog the feed mechanisms. Often, clayey soils require pretreatment in order to reduce moisture and viscosity.
- **Natural resource demands.** Operation of incinerators requires large quantities of electricity and water.

The most commonly used type of incineration system is the rotary kiln incinerator. Rotary kilns come in different capacities and are used primarily for explosives-contaminated soils and debris. Rotary kilns are available as transportable units for use on-site, or as permanent fixed units for off-site treatment. When considering the type of incinerator to use at your site, one element that you should consider is the potential risk of transporting explosive materials.

The rotary kiln incinerator is equipped with an afterburner, a quench, and an air pollution control system to remove particulates and neutralize and remove acid gases. The rotary kiln serves as a combustion chamber and is a slightly inclined, rotating cylinder that is lined with a heat-resistant ceramic coating. This system has had proven success in reducing explosive contamination levels to destruction and removal efficiencies (DRE) that meet RCRA requirements (40 CFR 264, Subpart O).[70] Specifically, explosives-contaminated soil was treated on-site at the Former Nebraska Ordnance Plant Site in Mead, Nebraska, using a rotary kiln followed by a secondary combustion chamber, successfully reducing constituents of concern that included TNT, RDX, TNB, DNT, DNB, HMX, tetryl, and NT to DRE of 99.99 percent.[71]

For deactivating large quantities of small arms munitions at industrial operations (e.g., small arms cartridges, 50-caliber machine gun ammunition), the Army generally uses deactivation furnaces. Deactivation furnaces have a thick-walled primary detonation chamber capable of withstanding small detonations. In addition, they do not completely destroy the vaporized explosives, but rather render the munitions unreactive.[72]

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[70]U.S. EPA, Office of Solid Waste and Emergency Response, Technology Innovation Office. October 1999. On-Site Incineration at the Celanese Corporation Shelby Fiber Operations Superfund Site, Shelby, North Carolina.

[71]Federal Remediation Technologies Roundtable. Incineration at the Former Nebraska Ordnance Plant Site, Mead, Nebraska, Roundtable Report, October 1998.

[72]U.S. EPA, Office of Research and Development. September 1993. Handbook: Approaches for the Remediation of Federal Facility Sites Contaminated with Explosive or Radioactive Wastes.

For large quantities of material, on-site incineration is generally more cost-effective than off-site treatment, which includes transportation costs. The cost of soil treatment at off-site incinerators ranges from $220 to $1,100 per metric ton (or $200 to $1,000 per ton).[73] At the Former Nebraska Ordnance Plant Site, the cost of on-site incineration technology was $394 per ton of contaminated material.[74] A summary of two major types of incinerators used by the Army are discussed in Table 5-2. While incineration is used most often in industrial operations as opposed to at CTT ranges, it may be considered in the evaluation of remedial alternatives at CTT ranges as well.

The operation and maintenance requirements of incineration include sorting and blending wastes to achieve levels safe for handling (below 12 percent explosive concentration for soils), burning wastes, and treating gas emissions to control air pollution. Additional operation and maintenance factors to consider include feed systems that are likely to clog when soils with high clay content are treated, quench tanks that are prone to clog from slag in the secondary combustion chamber, and the effects of cold temperatures, which have been known to exacerbate these problems.

Table 5-2. Characteristics of Incinerators

Incinerator Type	Description	Operating Temps	Strengths and Weaknesses	Effective Uses
Rotary Kiln	A rotary kiln is a combustion chamber that may be designed to withstand detonations. The secondary combustion chamber destroys residual organics from off-gases. Off-gases then pass into the quench tank for cooling. The air pollution control system consists of a venturi scrubber, baghouse filters, and/or wet electrostatic precipitators, which remove particulates prior to release from the stack.	Primary chamber – Gases: 800-1,500 EF Soils: 600-800 EF Secondary chamber – Gases: 1,400-1,800 EF	Renders munitions unreactive. Debris or explosives must be removed from soils prior to incineration; quench tank clogs; clayey, wet soils can jam the feed system; cold conditions exacerbate clogging problems. Requires air pollution control devices.	Commercially available for destruction of bulk explosives and small UXO, as well as contaminated soil and debris.
Deactivation Furnace	Designed to withstand small detonations from small arms. Operates in a manner similar to the rotary kiln except it does not have a secondary combustion chamber.	1,200-1,500 EF	Renders munitions unreactive.	Large quantities of small arms cartridges, 50-caliber machine gun ammunition, mines, and grenades.

Source: U.S. EPA, Office of Research and Development. September 1993. Handbook: Approaches for the Remediation of Federal Facility Sites Contaminated with Explosive or Radioactive Wastes.

[73] DoD, Environmental Technology Transfer Committee. October 1994. Remediation Technologies Screening Matrix and Reference Guide, Second Edition.

[74] Federal Remediation Technologies Roundtable. Incineration at the Former Nebraska Ordnance Plant Site, Mead, Nebraska, Roundtable Report, October 1998.

New incineration systems under development include a circulating fluidized bed that uses high-velocity air to circulate and suspend waste particles in a combustion loop. In addition, an infrared unit uses electrical resistance heating elements or indirect-fired radiant U-tubes to heat material passing through the chamber on a conveyor belt.

5.2.2.2 *Contained Detonation Chambers*

Contained detonation chambers (CDCs) are capable of repeated detonations of a variety of ordnance items, with significant reductions in the air and noise pollution problems of OB/OD. CDCs, or blast chambers, are used by the Army at a few ammunition plants to treat waste pyrotechnics, explosives, and propellants. In addition, several types of transportable detonation chambers are available for emergency responses for small quantities of UXO. In general, blast chambers do not contain all of the detonation gases, but vent them through an expansion vessel and an air pollution control unit. Such a vented system minimizes the overpressure hazard and the shock wave hazard. In addition, CDCs contain debris from detonations as well, eliminating the fragmentation hazards.

Several manufacturers have developed CDCs for both commercial and military use. However, DoD has not implemented CDCs at many military installations because of issues relating to safety, amount of throughput required, transportability, and cost.

CDCs come in a range of capacities, but in general they are designed to destroy anywhere from approximately 5 to 150 pounds of TNT explosive (or equivalent net explosive weights). At this stage of technological development, the blast effects of munitions much greater than 150 pounds of TNT cannot be contained within a chamber; therefore, very large munitions must be treated using OB/OD.

5.2.2.3 *Low-Temperature Thermal Desorption*

Low-temperature thermal desorption (LTTD) is a commercially available physical separation process that heats contaminated soils to volatilize contaminants. The volatilized contaminants are then transported for treatment. While this system has been tested extensively for use on explosives, it is not one of the more effective technologies. In general, a carrier gas or vacuum system transports volatilized water and explosives to a gas treatment system such as an afterburner or activated carbon. The relatively low temperatures (200 to 600 EF) and residence times in LTTD typically volatilize low levels of explosives and allow decontaminated soil to retain its physical properties.[75] In general, LTTD is used to treat volatile organic compounds and fuels, but it can potentially be used on soil containing low concentrations of explosives that have boiling points within the LTTD temperature range (e.g., TNT).

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[75]DoD Environmental Technology Transfer Committee. October 1994. Remediation Technologies Screening Matrix and Reference Guide, Second Edition.

The two commonly used LTTD systems are the rotary dryer and the thermal screw. Rotary dryers are horizontal cylinders that are inclined and rotated. In thermal screw units, screw conveyors or hollow augers are used to transport the soil or debris through an enclosed trough. Hot oil or steam circulates through the augur to indirectly heat the soil. The off-gas is treated using devices such as wet scrubbers or fabric filters to remove particulates, and combustion or oxidation is employed to destroy the contaminants.[76] The primary limitations of LTTD include the following:

- It is only marginally effective for treating explosives.
- Extensive safety precautions must be taken to prevent explosions when exposing explosives-contaminated soil and debris to heat.
- Explosives concentration and particle size can affect the applicability and cost of LTTD.
- Plastic materials should not be treated using LTTD, as their decomposition products could damage the system.
- Soil with a high clay and silt content or with a high humic content will increase the residence time required for effective treatment.
- Soil or sediments with a high moisture content may require dewatering prior to treatment.
- Air pollution control devices are often necessary.

5.2.2.4 *Plasma Arc Destruction*

Plasma arc destruction breaks down explosives into their basic atoms, which then recombine to form harmless gases such as carbon dioxide. A plasma arc operates in a manner similar to lightning. A plasma torch maintains a continuous "lightning bolt" inside a protective chamber as the waste material is fed into the chamber. The intense heat of the plasma breaks down the organic molecules. Solids are melted into a form similar to hardened lava, within which toxic materials are encapsulated, and organic wastes may be converted into hydrogen-rich fuels. In plasma arc destruction, there is no burning or incineration, which eliminates toxic air emissions or ash byproducts. Several companies have developed plasma arc systems to treat explosives and explosive residue. Such systems vary in their operating temperatures and the size of the media they can treat, but all rely on the plasma torch to treat contaminated waste.

Plasma torch demonstration projects are under way at the DOE Hanford Site, at Norfolk Naval Base,[77] and at the Hawthorne Ammunition Depot in Nevada. The project at the Hawthorne Ammunition Depot is specifically designed to destroy small-caliber pyrotechnic ordnance. Currently, there are no production-scale plasma are destruction systems operating in the United States. The results of these demonstration projects will provide information about the effectiveness

[76]EPA Superfund Innovative Technology Evaluation (SITE) Program, October 1999. Thermal Desorption System (TDS), Clean Berkshires, Inc.

[77]DoD Environmental Security Technology Program. 1996. Plasma Arc Destruction of Mixed Hazardous Wastes. 1996 EQ Annual Report.

of this technology for remediating explosives-contaminated soils. The cost of plasma arc destruction systems is high because of the capital cost of the equipment and the substantial labor requirements.[78]

5.2.2.5 *Safe Deactivation of Energetic Materials and Beneficial Use of Byproducts*

A technique for safely eliminating energetic materials and developing safe and useful byproducts is currently under development with funding from the Strategic Environmental Research and Development Program (SERDP). One such process reacts energetic materials, specifically TNT, RDX, and Comp B, with organic amines, which neutralize the energetic materials. The reaction is conducted at low temperatures, safely breaking down the energetic materials without causing detonation.

The gaseous byproducts of this process consist of nitrous oxide, nitrogen, water, and carbon dioxide. The liquid byproducts contain amide groups and C-N bonds. The liquid byproducts of TNT and RDX were discovered to be effective curing agents for conventional epoxy resins. The epoxy polymers produced using the curing agents derived from the liquid byproducts were subjected to safety and structural tests. It was determined that they have comparable mechanical properties to epoxy formed using conventional resins and curing agents. Testing is currently under way to verify their safety and resistance to leaching of toxic compounds.

In preliminary testing, this process has been shown to be a viable alternative to OB/OD and appears to have the potential to achieve high throughput, be cost-effective and safe, and discharge no toxic chemicals into the environment.[79]

5.3 Treatment of Soils That Contain Explosives

Some of the technologies described in section 5.2 can also be used to treat explosive soil (e.g., thermal treatment). However, there are a number of alternative treatment technologies that are specifically applicable to soils containing explosives. These are described in the sections that follow.

5.3.1 Biological Treatment Technologies

Biological treatment, or bioremediation, is a broad category of systems that use microorganisms to decompose explosive residues in soils into byproducts such as water and carbon dioxide. Bioremediation includes ex-situ treatments that require the excavation of soils and debris, such as composting and slurry reactor biotreatment, as well as in-situ bioventing. Bioremediation is used to treat large volumes of explosives-contaminated soils, and it is generally more publicly accepted than incineration and OB/OD, both of which can be used to treat soils as well. However, highly contaminated soils may not be treatable using bioremediation or may require pretreatment,

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[78]Risk Reduction Engineering Laboratory, Office of Research and Development. 1992. Retech, Inc., Plasma Centrifugal Furnace, Applications Analysis Report.

[79]Safe Deactivation of Energetic Materials and Beneficial Use of By-Products. 1999. Partners in Environmental Technology Newsletter. Issue 2.

because high concentrations of explosives, heavy metals, or inorganic salts are frequently toxic to the microorganisms that are the foundation of biological systems. While biological treatment systems generally require significantly lower capital investments than incinerators or other technology-intensive systems, they also often take longer to achieve cleanup goals. Therefore, the operation and monitoring costs of bioremediation must be taken into account. Because bioremediation includes a wide range of technological options, its costs can vary dramatically from site to site. The benefits and limitations of bioremediation include the following:

- **Easily implemented.** Bioremediation systems are simple to operate and can be implemented using commercially available equipment.
- **Relatively low costs.** In general, the total cost of bioremediation is significantly less than more technology-intensive treatment options.
- **Suitability for direct land application.** In general, soil treated using most bioremediation systems is suitable for land application.
- **Limited concentrations of explosives and other contaminants.** Soil with very high explosive levels may not be treatable using bioremediation, so pretreatment to reduce contaminant levels may be required. In addition, the presence of other contaminants, such as metals, may render bioremediation ineffective.
- **Temperature limitations.** Cold temperatures limit the effectiveness of bioremediation.
- **Resource demands.** With the exception of bioslurry treatments, bioremediation systems require large land areas. In addition, many biological treatment systems require substantial quantities of water to maintain adequate moisture levels.
- **Long time frame.** With the exception of bioslurry treatments, bioremediation systems may require long time periods to degrade explosives.
- **Posttreatment.** In some systems, process waters and off-gases may require treatment prior to disposal.[80]

There are many different options to choose from in selecting your biological treatment systems, but your selection will depend on the following factors:

- Types of contaminants
- Soil type
- Climate and weather conditions
- Cost and time constraints
- Cleanup goals at your site

Biological treatment systems that are available can be in-situ and can be open or closed, depending on air emission standards. Other available features include irrigation to maintain optimal moisture and nutrition conditions, and aeration systems to control odors and oxygen levels in aerobic systems. In general, bioremediation takes longer to achieve cleanup goals than either incineration or OB/OD.

[80] DoD, Environmental Technology Transfer Committee. October 1994. Remediation Technologies Screening Matrix and Reference Guide, Second Edition.

Biological treatment can be conducted in-situ or ex-situ; however, because explosives in the soil are usually not well mixed, removing them for ex-situ treatment is usually recommended, as the removal process results in thorough mixing of the soil, increasing the uniformity of degradation. Also, the likelihood of migration of explosives and their breakdown products is reduced with controlled ex-situ remediation of removed soils. Both ex-situ and in-situ treatment systems are discussed below.

Composting

Composting is an ex-situ process that involves tilling the contaminated soils with large quantities of organic matter and inorganic nutrients to create a microorganism-rich environment. An organic agent such as straw, sawdust, or wood chips is usually added to increase the number of microorganism growth sites and to improve aeration. Additional nutrient-rich amendments may be added to maximize the growth conditions for microorganisms and therefore the efficiency with which explosive compounds biodegrade.

Figure 5-2. Windrow Composting

In **windrow composting**, the soil mixture is layered into long piles known as windrows. Each windrow is mixed by turning with a composting machine as shown in Figure 5-2. Figures 5-3 and 5-4 provide schematic diagrams of a typical windrow composting process and system.

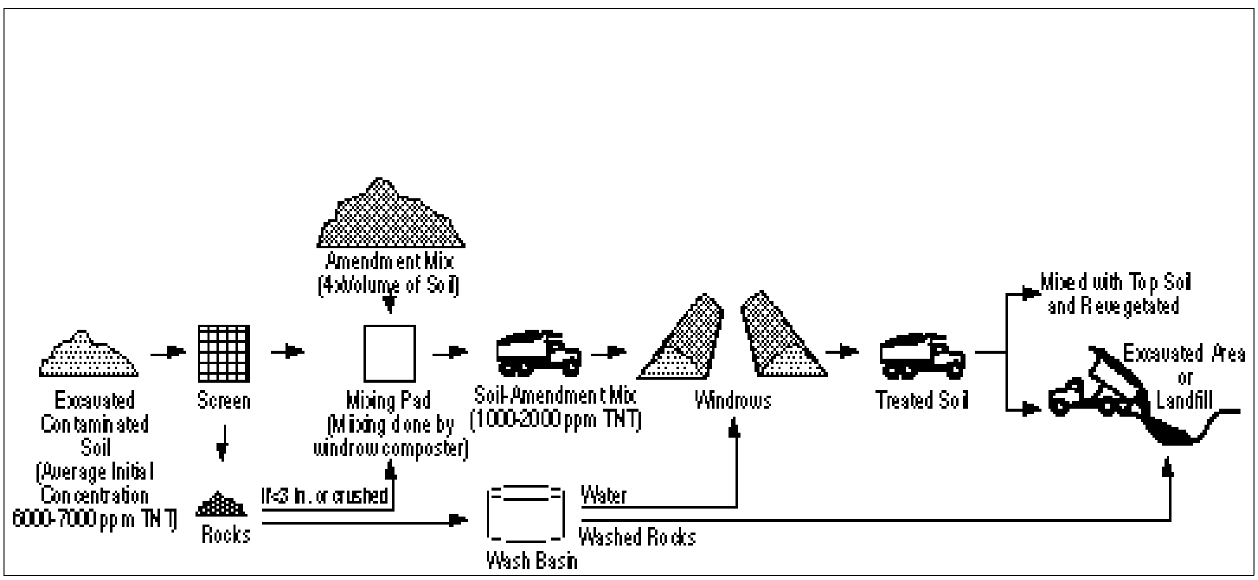

Figure 5-3. Typical Windrow Composting Process

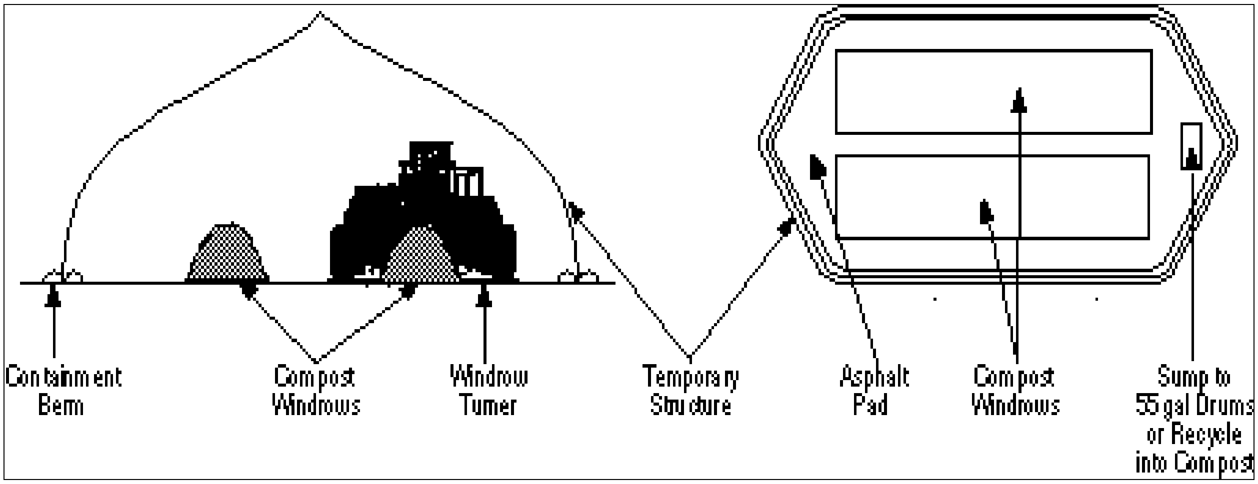

Figure 5-4. Side and Top View of Windrow Composting System

Windrow composting has proved to be highly successful in achieving cleanup goals at a field demonstration at the Umatilla Army Depot Activity in Hermiston, Oregon.[81] At Umatilla, soil was mixed with soil amendments and composted in both aerated and nonaerated windrows for a total of 40 days. The resulting compost generally reduced the levels of the target explosives (TNT, RDX, and HMX) to below cleanup goals. Specifically, TNT reductions were as high as 99.7 percent at 30 percent soil in 40 days of operation, with the majority of removal occurring in the first 20 days. Destruction and removal efficiencies for RDX and HMX were 99.8 and 96.8 percent, respectively. The field demonstration showed the relative simplicity and cost-effectiveness of windrow composting when compared with nonbiological treatment technologies.

Soil Slurry Biotreatment

Soil slurry biotreatment (also known as **bioslurry** or **slurry reactor treatment**) is an ex-situ process that involves the submersion of contaminated soils or sludge in water in a tank, lagoon, or bioreactor to create a slurry (Figure 5-5). The nutrient content, pH, and temperature are carefully controlled, and the slurry is agitated to maximize the nutrient, microorganism, and contaminant contact. Because the conditions are optimized for the microorganisms, slurry processes are faster than those in many other biological processes and, therefore, the operation and maintenance (O&M) costs are lower than in other biological processes. However, the highly controlled environment requires capital investments beyond those of other biological treatment systems. The treated slurry can be used directly on land without any additional treatment.

Figure 5-5. Slurry Reactor

[81] Federal Remediation Technologies Roundtable, Technology Application Analysis, October 1998. Windrow Composting of Explosives Contaminated Soil at Umatilla Army Depot Activity, Hermiston, Oregon.

Bioslurry treatment can be conducted under both aerobic and anaerobic conditions. In aerobic bioslurry, the oxygen content is carefully controlled. In anaerobic bioslurry, anaerobic bacteria consume the carbon supply, resulting in the depletion of oxygen in the soil slurry. Findings of a field demonstration at the Joliet Army Ammunition Plant demonstrated that maximum removal of explosives occurred with operation of a slurry reactor in an aerobic-anaerobic sequence, with an organic cosubstrate, operated in warm temperatures. The same demonstration project showed that bioslurry treatment can remove TNT, RDX, TNB, and DNT to levels that meet a variety of treatment goals.[82] Soil slurry biotreatment is expected to cost about one-third less than incineration.[83] The primary limitations of soil slurry biotreatment include the following:

- **Soil excavation.** Soils must be excavated prior to treatment.
- **Pretreatment requirements.** Nonhomogeneous soils can potentially lead to materials-handling problems; therefore, pretreatment of soils is often necessary to obtain uniformly sized materials.
- **Posttreatment.** Dewatering following treatment can be costly, and nonrecycled wastewaters must be treated before being disposed of.
- **Emissions.** Off-gases may require treatment if volatile compounds are present.

In-Situ Bioremediation

Treating explosives-contaminated soils in-situ involves the percolation or injection of groundwater or uncontaminated water mixed with nutrients and saturated with dissolved oxygen. In some cases, hydrogen peroxide, oxygen release compounds (e.g., magnesium peroxide), ozone, or microorganisms are added to the water to degrade explosives more rapidly. For shallow areas of contamination, spray irrigation is often used, and injection wells are used for deeper contaminated soils. The primary advantage of in-situ bioremediation is that soils do not need to be excavated or screened prior to treatment, thus resulting in cost savings. In addition, soils and groundwater can be treated simultaneously. The primary limitation of in-situ bioremediation is that it can cause explosives to migrate deeper into the soil or into groundwater. Other limitations of in-situ bioremediation include the following:

- There is a high degree of uncertainty about the uniformity of treatment and long treatment period required.
- Nutrient and water injection wells may clog frequently.
- The heterogeneity of soils and preferential flow paths may limit contact between injected fluids and contaminants.
- The method should not be used for clay, highly layered, or heterogeneous subsurface environments.

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[82]Manning, J.F., R. Boopathy, and E.R. Breyfogle, 1996. Field Demonstration of Slurry Reactor Biotreatment of Explosives-Contaminated Soils.

[83] DoD Environmental Technology Transfer Committee. October 1994. Remediation Technologies Screening Matrix and Reference Guide, Second Edition.

- High concentrations of heavy metals, highly chlorinated organics, long chain hydrocarbons, or inorganic salts are likely to be toxic to microorganisms.
- The method is sensitive to temperature (i.e., it works faster at high temperatures and slower at colder temperatures).
- The use of hydrogen peroxide for treating explosives-contaminated soil can create potentially hazardous conditions.

5.3.2 Soil Washing

Soil washing is a widely used treatment technology that reduces contaminated soil volume and removes contamination from soil particles. Explosives are removed from soils by separating contaminated particles from clean particles using particle size separation, gravity separation, and attrition scrubbing. The smaller particles (which generally are the ones to which explosives adhere) are then treated using mechanical scrubbing, or are dissolved or suspended and treated in a solution of chemical additives (e.g., surfactants, acids, alkalis, chelating agents, and oxidizing or reducing agents) or treated using conventional wash-water treatment methods. In some cases, the reduced volume of contaminated soil is treated using other treatment technologies, such as incineration or bioremediation. Following soil washing, the contaminated wash water is treated using wastewater treatment processes.

Soil washing is least effective in soils with large amounts of clay and organic matter to which explosives bind readily. Soil washing systems are transportable and can be brought to the site. In addition, soil washing is relatively inexpensive ($120 to $200 per ton), but in many cases it is only a step toward reducing the volume of soil that requires additional treatment, such as when another technology is used to treat the reduced volume of contaminated soil following soil washing.

The operation and maintenance components of soil washing include preparing soils for treatment (moving soils, screening debris from soils), treating washing agents and soil fines following treatment, and returning clean soils to the site. The time required for treating a 20,000-ton site using soil washing would likely be less than 3 months.[84]

5.3.3 Wet Air Oxidation

Wet air oxidation (WAO) is a high-temperature, high-pressure oxidation process that can be used to treat explosives-contaminated soil. Contaminated slurries are pumped into a heat exchanger and heated to temperatures of 650-1,150 EF. The slurries are then pumped into a reactor where they are oxidized in an aqueous solution at pressures of 1,000-1,800 psi.

WAO has been proven to be highly effective in treating RDX. However, the method also produces hazardous byproducts of TNT and gaseous effluents that require additional treatment. The technology has high capital costs and a high level of downtime resulting from frequent blockages

[84] DoD Environmental Technology Transfer Committee. October 1994. Remediation Technologies Screening Matrix and Reference Guide, Second Edition.

of the pump system and heat exchange lines. Laboratory tests have indicated that some WAO effluents can be further treated using biological methods such as composting.[85]

5.4 Conclusion

The treatment of UXO and explosives-contaminated soil and debris is a complex issue in terms of technical capabilities, regulatory requirements, and environmental, public health, and safety considerations. Public outcry over OB/OD and incineration has encouraged the development of new technologies to treat explosive wastes, but there is still a long way to go before some of the newer technologies, such as plasma arc destruction, become commercially available and widely used. Further, many of the newer technologies have been developed for industrial facilities with high throughput levels not found at CTT ranges. However, with the appropriate site-specific conditions, alternative technologies may be considered at CTT ranges.

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[85] Stratta, J., R. Schneider, N. Adrian, R. Weber, B. Donahue, 1998. Alternatives to Open Burning/Open Detonation of Energetic Materials: A Summary of Current Technologies. USACERL Technical Report 98/104.

SOURCES AND RESOURCES

The following publications, offices, laboratories, and websites are provided as a guide for handbook users to obtain additional information about the subject matter addressed in each chapter. Several of these publications, offices, laboratories, or websites were also used in the development of this handbook.

Publications

DoD Environmental Technology Transfer Committee, ***Remediation Technologies Screening Matrix***, Second Edition, October 1994.

Stratta, J., R. Schneider, N. Adrian, R. Weber, B. Donahue, ***Alternatives to Open Burning/Open Detonation of Energetic Materials: A Summary of Current Technologies***, U.S. Army Corps of Engineers, Construction Engineering Research Laboratories, August 1998.

U.S. EPA, Office of Solid Waste and Emergency Response, ***Completed North American Innovative Remediation Technology Demonstration Projects***, August 1996 (PB 96-153-127).

U.S. EPA, ***Handbook: Approaches for the Remediation of Federal Facility Sites Contaminated with Explosive or Radioactive Wastes***, September 1993 (EPA/625/R-93/013).

Information Sources

Center for Public Environmental Oversight
c/o PSC 222B View St.
Mountain View, CA 94041
Tel: (650) 961-8918
Fax: (650) 968-1126
http://www.cpeo.org

Environmental Security Technology Certification Program (ESTCP)
901 North Stuart Street, Suite 303
Arlington, VA 22203
Tel: (703) 696-2127
Fax: (703) 696-2114
http://www.estcp.org

U.S. EPA, Office of Research and Information
Alternative Treatment Technology Information Center (**ATTIC**)
(a database of innovative treatment technologies)
http://www.epa.gov/bbsnrmrl/attic/index.html

U.S. EPA, Technology Information Office
Remediation and Characterization Innovative Technologies (REACH-IT)
http://www.epareachit.org/index.html

U.S. EPA, Technology Information Office
Hazardous Waste Clean-Up Information (CLU-IN)
http://www.clu-in.org/

Federal Remediation Technologies Roundtable
U.S. EPA, Chair
(5102G) 401 M Street, S.W., Washington, DC 20460
http://www.frtr.gov

Joint UXO Coordination Office (JUXOCO)
10221 Burbeck Road, Suite 430
Fort Belvoir, VA 22060
Tel: (703) 704-1090
Fax: (703) 704-2074
http://www.denix.osd.mil/UXOCOE

Naval Explosive Ordnance Disposal Technology Division
(NAVEODTECHDIV)
UXO Countermeasures Department
Code 30U, 2008 Stump Neck Road
Indian Head, MD 20640-5070
http://www.ih.navy.mil/

Strategic Environmental Research and Development Program (SERDP)
901 North Stuart Street, Suite 303
Arlington, VA 22203
Tel: (703) 696-2117
http://www.serdp.org

U.S. Army Corps of Engineers
U.S. Army Engineering and Support Center,
Ordnance and Explosives Mandatory Center of Expertise
P.O. Box 1600
Huntsville, AL 35807-4301
Street Address: 4820 University Square
http://www.hnd.usace.army.mil/

U.S. Army Environmental Center (USAEC)
Aberdeen Proving Ground, MD 21010-5401
Tel: (800) USA-3845
http://aec.army.mil

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6.0 EXPLOSIVES SAFETY

Substantial safety issues are associated with investigation and clearance activities at sites that may contain UXO. This section describes the statutory and regulatory requirements of explosives safety, as well as common practices for managing explosives safety. General safety practices are addressed, as are the specific requirements for the health and safety of ordnance and explosives (OE) site personnel and protection of the public.

6.1 Introduction to DoD Explosives Safety Requirements and the DoD Explosives Safety Board (DDESB)

Explosives safety is overseen within the DoD by the DoD Explosives Safety Board (DDESB). This centralized DoD organization is charged with setting and overseeing explosive safety requirements throughout DoD. DoD Directive 6055.9 (DoD Explosives Safety Board and DoD Component Explosives Safety Responsibilities) authorized the DoD Ammunition and Explosives Safety Standards (July 1999, 6055.9-STD). This directive also updates DDESB policy and responsibilities and requires the military components to act jointly. The directive also requires the implementation and maintenance of an "aggressive" explosives safety program that addresses environmental considerations.

The policies of DoD 6055.9-STD (the DoD explosives safety standard), apply to UXO contaminated property currently owned by DoD, property undergoing realignment or closure, and Formerly Used Defense Sites (FUDS), and require that every means possible be used to protect the public from exposure to explosive hazards. Property known to be or suspected of being contaminated with UXO must be decontaminated with the most appropriate technology to ensure protection of the public, taking into consideration the proposed end use of the property.

The Role of the DoD Explosives Safety Board

The DDESB was established by Congress in 1928 as a result of a major disaster at the Naval Ammunition Depot in Lake Denmark, New Jersey, in 1926. The accident caused heavy damage to the depot and surrounding areas and communities, killed 21 people, and seriously injured 51 others.

The mission of the DDESB is to provide objective advice to the Secretary of Defense and Service Secretaries on matters concerning explosives safety and to prevent conditions that may be hazardous to life and property, both on and off DoD installations, from the explosives and from the environmental effects of DoD munitions.

The roles and responsibilities of the DDESB were expanded in 1996 with the reissuance of DoD Directive 6055.9, on July 29, 1996. The directive gives the DDESB responsibilities for resolving conflicts between explosives safety standards and environmental standards.

The DDESB (or the organizations to which it delegates authority) has established requirements for overseeing all activities relating to munitions at property currently owned by DoD, property undergoing realignment or closure, and FUDS to protect human health and property from explosive hazards. As part of those responsibilities, the DDESB or its delegates must review and approve the explosives safety aspects of all plans for leasing, transferring, excessing, disposing of, or remediating DoD real property when ammunition, explosives, or other chemical agent contamination exists or is suspected to exist. Plans to remediate FUDS are also submitted to the DDESB for approval of the explosives safety aspects.[86] All explosives safety plans are to be documented in explosives safety submissions (ESSs), which are submitted to DDESB for approval prior to any time-critical or non-time-critical removal action being undertaken, or prior to any transfer of real property where UXO may exist (see section 6.3.2 for a discussion on ESSs). There are many different investigation and documentation requirements that must be fulfilled in order to complete an ESS (see section 6.3.3).

The DoD explosives safety standard (6055.9-STD) also applies to any investigation (either intrusive or nonintrusive) of any ranges or other areas that are known or suspected to have unexploded ordnance. Adherence to DoD safety standards and with the standards and requirements of the Occupational Safety and Health Administration (OSHA) is documented in approved project-specific Site Safety and Health Plans (SSHPs) for investigations and cleanup actions.[87,88] The DDESB may review SSHPs if requested to do so, but approval of these plans is generally overseen by the individual component's explosives safety center. Elements of the SSHP and the ESS are likely to overlap, particularly when the SSHP addresses response actions.

The DoD explosives safety standard is a lengthy document with a great deal of technical detail. It is organized around 13 technical chapters, plus an introduction. These chapters address:

- ***Effects of Explosions and Permissible Exposures*** as they relate to buildings, transportation, and personnel.
- ***Hazard Classification and Compatibility Groups*** to guide the kinds of explosives that may and may not be stored together.
- ***Personnel Protection*** from blast, fragmentation, and thermal hazards.
- ***Facilities Construction and Siting**,* as they apply to potential explosion sites.
- ***Electrical Standards**,* establishing minimum requirements for DoD buildings and areas containing explosives.
- ***Lightning Protection*** for ammunition and explosives facilities, including safety criteria for the design, maintenance, testing, and inspection of lightning protection systems.
- ***Hazard Identification for Fire Fighting***, providing criteria to minimize risk in fighting fires involving ammunition and explosives.
- ***Quantity-Distance (Q-D)**,* which sets minimum standards for separating a potential explosion site from an exposed site.
- ***Theater of Operations Quantity Distance***, setting standards outside the continental United States.

[86] DoD Ammunition and Explosives Safety Standards, July 1999, Chapter 12, DoD Directive 6055.9-STD.

[87] Occupational Safety and Health Administration Standard, 29 C.F.R. § 1910.120 (b)(4) 29 C.F.R. § 1926.65 (b)(4).

[88] National Oil and Hazardous Substances Pollution Contingency Plan, 40 C.F.R. § 300.430 (b)(6).

- ***Chemical Agent Standards*** for protecting workers and the general public from the harmful effects of chemical agents.
- ***Real Property Contaminated with Ammunition, Explosives, or Chemical Agents***, establishing the policies and procedures necessary to protect personnel exposed "as a result of DoD ammunition, explosives, or chemical agent contamination of real property currently and formerly owned, leased, or used by the Department of Defense."
- ***Mishap Reporting and Investigation Requirements***, establishing procedures and data to be reported for all ammunition and explosive mishaps.
- ***Special Storage Procedures for Waste Military Munitions*** under a conditional exemption from certain RCRA requirements or a new RCRA storage unit standard, as set forth in the Military Munitions Rule (62 FR 6621).

6.2 Explosives Safety Requirements

Safety standards published by DDESB are to be considered minimum protection criteria. In addition to 6055.9-STD, explosives safety organizations are in place in each of the military components. A number of these centers have developed additional technical guidance. The following sections highlight key safety considerations as described in 6055.9-STD or in various other guidance documents published by military components. While they often contain similar requirements, guidance documents produced by different components may use different terminology.

6.2.1 <u>General Safety Rules</u>

The following commonsense safety rules apply to all UXO clearance and EOD activities:

- Only **qualified UXO/EOD personnel** can be involved in UXO procedures. However, non-UXO-qualified personnel may be used to perform UXO-related procedures when supervised by UXO-qualified personnel. All personnel must be trained in explosives safety and be capable of recognizing hazardous situations.
- An **exclusion zone** (a safety zone established around an OE work area) must be established. Only project personnel and authorized, escorted visitors are allowed within the exclusion zone. Unauthorized personnel must not be permitted to enter the area of activity.
- **Warning signs** must be posted to warn the public to stay off the site.
- **Proper supervision** of the operation must be provided.
- **Personnel are not allowed to work alone** during operations.

> **Radio Frequencies**
>
> Some types of ordnance are susceptible to electromagnetic radiation (EMR) devices in the radio frequency (RF) range (i.e., radio, radar, and television transmitters). Preventive steps should be taken if such ordnance is encountered in a suspected EMR/RF environment. The presence of antennas and communication and radar devices should be noted before initiating any ordnance-related activities. When potential EMR hazards exist, the site should be electronically surveyed for EMR/RF emissions and the appropriate actions taken (i.e., obey the minimum safe distances from EMR/RF sources).

- **Exposure should be limited** to the minimum number of personnel needed for a minimum period of time.
- Appropriate use of **protective barriers or distance separation** must be enforced.
- **Personnel must not be allowed to become careless** by reason of familiarity with ammunition.

6.2.2 Transportation and Storage Requirements

The DoD safety standard requires that explosives be stored and transported with the highest possible level of safety. The standard calls for implementation of the international system of classification developed by the United Nations organization for the transport of dangerous goods and the hazardous material transportation requirements of the U.S. Department of Transportation. The classification system comprises nine hazard classes, two of which are applicable to ammunition and explosives. Guidelines are also provided for segregating ammunition and explosives into compatibility groups that have similar characteristics, properties, and potential accident effects so that they can be transported together without increasing significantly either the probability of an accident or, for a given quantity, the magnitude of the effects of such an accident.

DoD Ammunition and Explosives Hazard Classification Procedures call for the following safety precautions for transporting conventional UXO in a nonemergency response[89]:

- UXO should be transported in a military vehicle using military personnel where possible.
- UXO must be examined by appropriately qualified UXO technicians, as well as military EOD personnel, to ensure that it meets transportation safety requirements.
- All unidentified UXO shall be handled, transported, and stored as hazard class 1.1 (defined as UXO capable of mass explosion), and with the appropriate compatibility group. UXO shall be stored as an unserviceable munition.
- Military components, working with EOD units, will determine the appropriate packaging, blocking and bracing, marking, and labeling, and any special handling requirements for transporting UXO over public transportation routes.

Similarly, storage principles require that ammunition and explosives be assigned to compatibility groups, munitions that can be stored together without increasing the likelihood of an accident or increasing the magnitude of the effects of an accident. The considerations used to develop these compatibility groups include chemical and physical properties, design characteristics, inner and outer packing configurations, Q-D classification, net explosive weight, rate of deterioration, sensitivity to initiation, and effects of deflagration, explosion, or detonation.

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[89] Joint Technical Bulletin, Department of Defense Ammunition and Explosives Hazard Classification Procedures, January 5, 1998.

6.2.3 Quantity-Distance (Q-D) Requirements

The DoD safety standard establishes guidelines for maintaining separation between the explosive material expected to be encountered in the OE action and potential receptors such as buildings, explosive storage magazines, and public traffic routes. These encounters may be planned encounters (e.g., open burning/open detonation) or accidental (e.g., contact with an ordnance item during investigation). The standard provides formulas for estimating the damage or injury potential based on the nature and quantity of the explosives, and the minimum separation distance from receptors at which explosives would not cause damage or injury.

Examples of Quantity-Distance Siting Requirements

The following are examples of key concepts used in establishing Q-D requirements (USACE Engineering Manual 110-1-4009, June 2000):

- Extensive and well-documented historical information is essential to understanding the blast and damage potential at a given OE site.
- For all OE sites, a most probable munition (MPM) is determined based on OE items anticipated to be found at the site. The MPM is the OE item that has the greatest hazard distance (the maximum range fragments and debris will be thrown) based on calculations of explosive effects. Fragmentation (the breaking up of the confining material of a chemical compound or mechanical mixture, when an explosion takes place) and overpressure (the blast wave or sudden pressure increase) are two key elements considered in establishing the hazard distance for the MPM.
- For explosive soils, a different concept, called maximum credible event (MCE), applies. The MCE is calculated by relating the concentration of explosives in soil to the weight of the mix. Overpressure and soil ejection radius are considered in determining Q-D requirements for explosive soils.

These Q-D siting requirements must be met in the ESS for all OE areas where removal will occur, for storage magazines used to store demolition explosives and recovered OE, and for planned or established demolition areas. In addition, “footprint” areas, those in which render-safe or blow-in-place procedures will occur during the response action, are also subject to Q-D siting requirements, but they are not included in the ESS because they are determined during the actual removal process.

6.2.4 Protective Measures for UXO/EOD Personnel

The DoD safety standard and CERCLA, OSHA, and component guidance documents require that protective measures be taken to protect personnel during investigation and remediation activities. The DDESB and military components have established guidelines for implementing such measures. UXO/EOD personnel conducting OE investigations and clearance activities face potential risk of injury and death during these activities. Therefore, in addition to general precautions, DoD health and safety requirements include (but are not limited to) medical surveillance and proper training of personnel, as well as the preparation and implementation of emergency response and personnel protective equipment (PPE) programs.

6.2.5 Emergency Response and Contingency Procedures

In the event that a OE incident occurs during clearance or disposal, injuries can be limited by maintaining a high degree of organization and preparedness. CERCLA, OSHA, and military component regulations call for the development and implementation of emergency response procedures before any ordnance-related activities take place. The minimum elements of an emergency response plan include the following:

- Ensure availability of a **first-aid kit**.
- Ensure that **communication lines and transportation** (i.e., a designated vehicle) are readily available to effectively care for injured personnel.
- Maintain **drenching and/or flushing facilities** in the area for immediate use in the event of contact with toxic or corrosive materials.
- Develop **procedures for reporting incidents** to appropriate authorities.
- Determine **personnel roles, lines of authority, and communications**.
- Post **emergency instructions** and a **list of emergency contacts**.
- **Train personnel** in emergency recognition and prevention.
- Establish the **criteria and procedures for site evacuation** (emergency alerting procedures, place of refuge, evacuation routes, site security, and control).
- Plan **specific procedures for decontamination and medical treatment** of injured personnel.
- Have **route maps to nearest prenotified medical facility** readily available.
- Establish the **criteria for initiating a community alert program**, contacts, and responsibilities.
- Critique the **emergency responses and follow-up activities** after each incident.
- Develop procedures for the **safe transport and/or disposal** of any live UXO items.
- Plan the **procedures for acquisition, transport, and storage** following demolition of recovered UXO items.

Equipment such as first-aid supplies, fire extinguishers, a designated emergency vehicle, and emergency eyewashes/showers should be immediately available in the event of an emergency.

6.2.6 Personnel Protective Equipment (PPE)

As required by CERCLA, OSHA, and military component regulations, a PPE program should be in place at all OE sites. Prior to initiating any ordnance-related activity, a hazard assessment should be performed to select the appropriate equipment, shielding, engineering controls, and protective clothing to best protect personnel. Examples of PPE include flame-resistant clothing and eye and face protection equipment. A PPE plan is also highly recommended to ensure proper selection, use, and maintenance of PPE. The plan should address the following activities:

- PPE selection based on site-specific hazards
- Use and limitations of PPE
- Maintenance and storage of PPE
- Decontamination and disposal of PPE

- PPE training and fitting
- Equipment donning and removal procedures
- Procedures for inspecting equipment before, during, and after use
- Evaluation of the effectiveness of the PPE program
- Medical considerations (i.e., work limitations due to temperature extremes)

6.2.7 Personnel Standards

Personnel standards are designed to ensure that the personnel working on or overseeing the site are appropriately trained. Typical requirements for personnel training will vary by level and type of responsibility, but will specify graduation from one of DoD's training programs. USACE, for example, requires that all military and contractor personnel be graduates of one of the following schools or courses:

- The U.S. Army Bomb Disposal School, Aberdeen Proving Ground, Maryland
- U.S. Naval Explosive Ordnance Disposal School, Indian Head, Maryland
- The EOD Assistant's Course, Redstone Arsenal, Alabama
- The EOD Assistant's Course, Eglin Air Force Base, Florida
- Other DoD-certified course

USACE specifically requires that UXO safety officers be graduates of the Army Bomb Disposal School and/or the Naval EOP School and have at least 10 years of experience in all phases of UXO remediation and applicable safety standards. Senior UXO supervisors must be graduates of the same programs and have had at least 15 years of experience in all aspects of UXO remediation and at least 5 years of experience in a supervisory capacity.[90]

6.2.8 Assessment Depths

In addition to safeguarding UXO personnel from explosive hazards, the DoD safety standard also mandates protecting the public from UXO hazards. Even at a site that is thought to be fully remediated, there is no way to know with certainty that every UXO item has been removed. Therefore, the public must be protected from UXO even after a site has been remediated. The types and levels of public safeguards will vary with the level of uncertainty and risk at a site. Public safeguards include property clearance to the appropriate depth for planned land uses and enforcement of designated land uses.

EPA/DoD Management Principles on Standards for Depths of Clearance

- In the absence of site-specific data, a table of assessment depths is used for interim planning purposes until the site-specific information is developed.
- Site-specific data are necessary to determine the actual depth of clearance.

DDESB standards establish assessment depths to be used for **interim planning purposes in the absence of adequate site-**

[90]Engineering and Design Ordnance and Explosives Response, U.S. Army Corps of Engineers, EP 1110-1-18, April 24, 2000.

specific information (See Table 6-1). ESS approvals rely on the development of site-specific information to determine clearance depth requirements. When site-specific data are not available, DDESB interim planning assessment depths are used in an ESS and amended as site-specific data are developed during the course of a response action.

The clearance depth selected for remediation is determined using site-specific information such as the following:

- Geophysical characteristics such as bedrock depth and frost line (see Chapters 3 and 7).
- Estimated UXO depth based on surface detection and intrusive sampling.
- In the absence of sampling data, information about the maximum depth of ordnance used on-site based on maximum penetration source documents.
- Actual planned land use that may require deeper excavation than the default clearance depths (e.g., a commercial or industrial building with foundations deeper than 10 feet).
- Remediation clearance depth a minimum of 4 feet below the excavation depth planned for construction (DDESB requirement).

Other factors that affect the depth of clearance include the size of the range, the cost of clearance (includes many variables, including range size and terrain), and the practicality of finding and excavating all of the UXO.

If UXO detection capabilities are not sensitive enough or funds are not available to remove UXO to the required remediation depth, then the proposed land use must be changed so that risks to human health and the environment are managed appropriately. Site records should include information concerning the depth to which UXO was removed, the process by which that depth was determined, and notice of the risks to safety if the end land use is violated.

Frost Line and Erosion

The ultimate removal depth must consider the frost line of the site and the potential for erosion. A phenomenon known as **frost heave** can move ordnance to the surface during the freeze and thaw cycles. If ordnance is not cleared to the frost line depth, or if the site conditions indicate erosion potential (such as at agricultural areas), a procedure must be put in place to monitor the site for migration of ordnance. (See Chapter 3 for more information on this topic.)

Table 6-1. Assessment Depths To Be Used for Planning Purposes

Planned Land Use	Depth
Unrestricted – Commercial, Residential, Utility, Subsurface Recreational (e.g., camping), Construction Activity	10 ft*
Public Access – Agricultural, Surface Recreational, Vehicle Parking, Surface Supply Storage	4 ft
Limited Public Access – Livestock Grazing, Wildlife Preserve	1 ft
Not Yet Determined	Surface

* Assessment planning at construction sites for any projected end use requires looking at the possibility of UXO presence 4 feet below planned excavation depths.

Source: DoD Ammunition and Explosives Safety Standards, July 1999, Chapter 12, DoD Directive 6055.9-STD.
Note: The DDESB is in the process of revising Chapter 12 of DoD 6055.9-STD.

6.2.9 Land Use Controls

Examples of Land Use Controls

- Security fencing or other measures to limit access
- Warning signs
- Postremoval site control (maintenance and surveillance)
- Land repurchase
- Deed restrictions

Land use controls include institutional controls (e.g., legal or governmental), site access (e.g., fences), and engineering controls (e.g., caps over contaminated areas) that separate people from risk. They are designed to reduce ordnance and explosive risk over the long term without physically removing all of the UXO. Land use controls are necessary at many sites because of the technical limitations and prohibitive costs of adequately clearing CTT ranges to allow for certain end uses, particularly unrestricted use.

The DoD safety standard specifically addresses a requirement for institutional controls when UXO contamination has been or may still be on the site: "Property transfer records shall detail past ammunition and explosive contamination and decontamination efforts; provide requisite residual contamination information; and advise the user not to excavate or drill in a residual contamination area without a metal detection survey."

The appropriate land use control depends on site-specific factors such as proximity to populations, land use, risk of encountering UXO, community involvement, and site ownership (both current and future). It is important to coordinate activities with the appropriate Federal, State, local, and Tribal governments in the development and implementation of land use controls to ensure their effectiveness even after the remediation has been completed.

The EPA policy Institutional Controls and Transfer of Real Property under CERCLA Section 120 (h)(3)(A), (B), or (C) recognizes that although a variety of land use controls may be used to manage risk at sites, the maintenance of site access and engineering controls depends on institutional controls. Institutional controls include the governmental and legal management controls that help ensure that engineering and site access controls are maintained. The Federal agency in charge of a site has responsibilities beyond implementing the institutional controls. EPA policy requires the responsible agency to perform the following activities:[91]

- **Monitor** the institutional controls' effectiveness and integrity.
- **Report** the results of such monitoring, including notice of violation or failure of controls, to the appropriate EPA and/or State regulator, local or Tribal government, and the designated party or entity responsible for reporting.
- **Enforce** the institutional controls should a violation or failure of controls occur.

In order to ensure long-term protection of human health and safety in the presence of potential explosive hazards, institutional controls must be enforceable against whoever may gain ownership or control of the property in the future.

EPA/DoD Interim Final Management Principles on Land Use Controls

- Land use controls must be clearly defined, established in coordination with affected parties, and enforceable.
- Land use controls will be considered as part of the development and evaluation of response alternatives for a given CTT range.
- DoD will conduct periodic reviews to ensure the long-term effectiveness of response actions, including land use controls.

6.3 Managing Explosives Safety

DoD Directive 6055.9 establishes the roles and responsibilities for DDESB and each of the military components. DDESB oversees implementation of safety standards throughout DoD and may conduct surveys to identify whether such standards are appropriately implemented. At ranges where investigation, cleanup, and real property transfer are the major focus, the implementation of explosives safety requirements is normally documented in two ways.

- **Site Safety and Health Plans (SSHPs)** describe activities to be taken to comply with occupational health and safety regulations. SSHPs accompany each work plan for investigation and response. Although implementation is overseen by DDESB, approval of specific SSHPs is typically conducted by the individual military component responsible for the response action (e.g., Army, Navy, or Air Force) through their explosives safety organizations.

- **Explosives Safety Submissions (ESSs)** describe the safety considerations of the planned response actions, including the impact of planned clearance depths on current and future land use. All ESSs are submitted to and approved by DDESB, as described in section 6.3.3.

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[91]Institutional Controls and Transfer of Real Property Under CERCLA Section 120 (h)(3)(A), (B), or (C), Interim Final Guidance, January 2000, USEPA.

Many requirements documented in detail in the SSHP are summarized in the ESS.

6.3.1 Site Safety and Health Plans

SSHPs fulfill detailed requirements for compliance with the occupational safety and health program requirements of CERCLA, OSHA, and the military components.[92,93,94] SSHPs are based on the premise of limiting the exposure to the minimum amount of OE and to the fewest personnel for the shortest possible period of time. Prior to the initiation of on-site investigations, or any design, construction, or operation and maintenance activities, an SSHP must be prepared and submitted for review and acceptance for each site task and operation described in the work plan.[95] SSHPs are typically prepared by industrial hygiene personnel at the installation level.[96] The SSHP review and approval processes vary with the type of property (e.g., FUDS, BRAC, active installations), the stage of the investigation, and the military component responsible. Typically, however, the component's explosives safety organization will be responsible for the review and approval of SSHPs.

The SSHP describes the safety and health procedures, practices, and equipment to be used to protect personnel from the OE hazards of each phase of the site activity. The level of detail to be included in the SSHP should reflect the requirements of the site-specific project, including the level of complexity and anticipated hazards. Nonintrusive investigation activities such as site visits or pre-work-plan visits may require abbreviated SSHPs.[97] Specific elements to be addressed in the SSHP include several of those discussed in previous sections, including:

- Personnel protective equipment,
- Emergency response and contingency planning, and
- Employee training.

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[92]National Oil and Hazardous Substances Pollution Contingency Plan, 40 C.F.R. § 300.430 (b)(6).

[93]Occupational Safety and Health Administration Standard, 29 C.F.R. § 1910.120 (b)(4), 29 C.F.R. § 1926.65 (b)(4).

[94]Engineering and Design Ordnance and Explosives Response, U.S. Army Corps of Engineers, EP 1110-1-18, April 24, 2000.

[95]Safety and Health Requirements Manual, U.S. Army Corps of Engineers, EM 385-1-1, September 3, 1996.

[96]Safety and Occupational Health Document Requirements for Hazardous, Toxic and Radioactive Waste (HTRW) and Ordnance and Explosive Waste (OEW) Activities, U.S. Army Corps of Engineers, ER 385-1-92, March 18, 1994.

[97]Engineering and Design Ordnance and Explosives Response, U.S. Army Corps of Engineers EP 1110-1-18, April 24, 2000.

Other commonly required elements of SSHPs include, but are not limited to:

- Employee medical surveillance programs;
- Frequency and type of air monitoring, personnel monitoring, and environmental sampling techniques and instrumentation to be used;
- Site control measures to limit access; and
- Documented standard operating procedures for investigating or remediating OE.

Implementation of Explosives Safety at the Site Level

Each military component has its own set of specific requirements for work plans and Site Safety and Health Plans (SSHPs). The nomenclature and organization may vary by component. USACE requires the following plans in the implementation of explosives safety requirements. These will not necessarily be separate plans, but may be subplans of removal or remedial action work plans.

- **Explosives Management Plan**, regarding the procedures and materials that will be used to manage explosives at the site, including acquisition, receipt, storage, transportation, and inventory.
- **Explosives Siting Plan**, providing the safety criteria for siting explosives operations at the site. This plan should provide a description of explosives storage magazines, including the net explosive weight (NEW) and quantity-distance (Q-D) criteria; OE areas, including separation distances and demolition areas, all of which should be identified on a site map. The footprint of all areas handling explosives also should be identified. Explosives siting plans should be incorporated into the Q-D section of the ESS.
- **Geophysical Plan**, describing the requirements for all geophysical activities that will occur during the project, including geophysical sampling for UXO detection.
- **Site Safety and Health Plan (SSHP)**, addressing the safety and health hazards of each phase of site activity and the procedures for their control. The SSHP includes but is not limited to the following elements:
  - — Safety and health risk or hazard analysis for each site task identified in the work plan
  - — Employee training assignments
  - — Personnel protective equipment program
  - — Medical surveillance requirements
  - — Frequency and type of air monitoring, personnel monitoring, and environmental sampling techniques and instrumentation to be used
  - — Emergency response plan
  - — Site control program
- **Environmental Protection Plan**, identifying the procedures and methods that will be employed to minimize pollution, protect and conserve natural resources, restore damage, and control noise and dust within reasonable limits.

Sources: Engineering and Design Ordnance and Explosives Response, U.S. Army Corps of Engineers, EM 1110-1-4009, June 23, 2000; and Safety and Health Requirements Manual, U.S. Army Corps of Engineers, EM-385-1-1, September 3, 1996.

6.3.2 <u>Explosives Safety Submissions for OE Response Actions</u>

EPA/DoD Interim Final Management Principles on Explosives Safety Submissions

Explosives safety submissions (ESS), prepared, submitted, and approved per DDESB requirements, are required for time-critical removal actions, non-time-critical removal actions, and remedial actions involving explosives safety hazards, particularly UXO.

An explosives safety submission (ESS) must be completed by those wishing to conduct OE investigation and cleanup activities, and approved by appropriate authorities prior to commencing work. Although the DDESB oversees the approval process, the internal approval processes are slightly different for each military component. However, all ESSs should be written in coordination with the DDESB, as well as with stakeholder, public, and Tribal participation. In addition, the DDESB's role in approving ESSs is slightly different, depending on whether the OE area is a FUDS project, a BRAC-related project involving property disposal, or a project at an active facility:

- For all DoD-owned facilities, the ESS is prepared at the installation level (either the active installation or the BRAC facility) and sent through the designated explosives safety office for initial approval. The role of the explosives safety organization in the approval chain differs slightly by component.
- For FUDS, the initial ESS is prepared by the USACE district with responsibility for the site.
- The DDESB reviews and gives approval to all ESSs at BRAC facilities and other closed facilities (i.e., a facility that has been closed by a component but is not part of the BRAC program).
- Regulators and other stakeholders will be provided an opportunity for timely consultation, review, and comment on all phases of a removal response, except in the case of an emergency response taken because of an imminent and substantial endangerment to human health and the environment, for which consultation would be impractical (see 10 U.S.C. 2705).
- Final approval of ESSs for closed ranges at active facilities is provided by the MAJCOM, MACOM, or major claimant, often in coordination with the DDESB.

Coordination Prior to Submission of the ESS

ESSs, reviewed by the DDESB, must include a description of public and regulator involvement before they are approved. The extent to which involved parties agree with the proposed response action is important to avoiding unnecessary conflict and delay of the proposed cleanup. This issue has received specific attention during development of the UXO Interim Final Management Principles.

Source: Interview with DDESB secretariat member.

An ESS is not required for military EOD emergency response actions (on DoD or non-DoD property); for interim removal actions taken to abate an immediate, extremely high hazard; and for normal maintenance operations conducted on active ranges. Figure 6-1 outlines the approval processes for OE projects under different types of DoD ownership. "Sources and Resources," at the end of this chapter, lists the location of the various explosives safety offices for each of the military components.

6.3.3 Explosives Safety Submission Requirements

Safety planning involves a thorough assessment of the explosive hazards likely to be encountered on-site during the investigation and removal activities. The potential explosive hazards must be assessed and documented prior to submitting an explosives safety plan, as outlined in the next text box.[98]

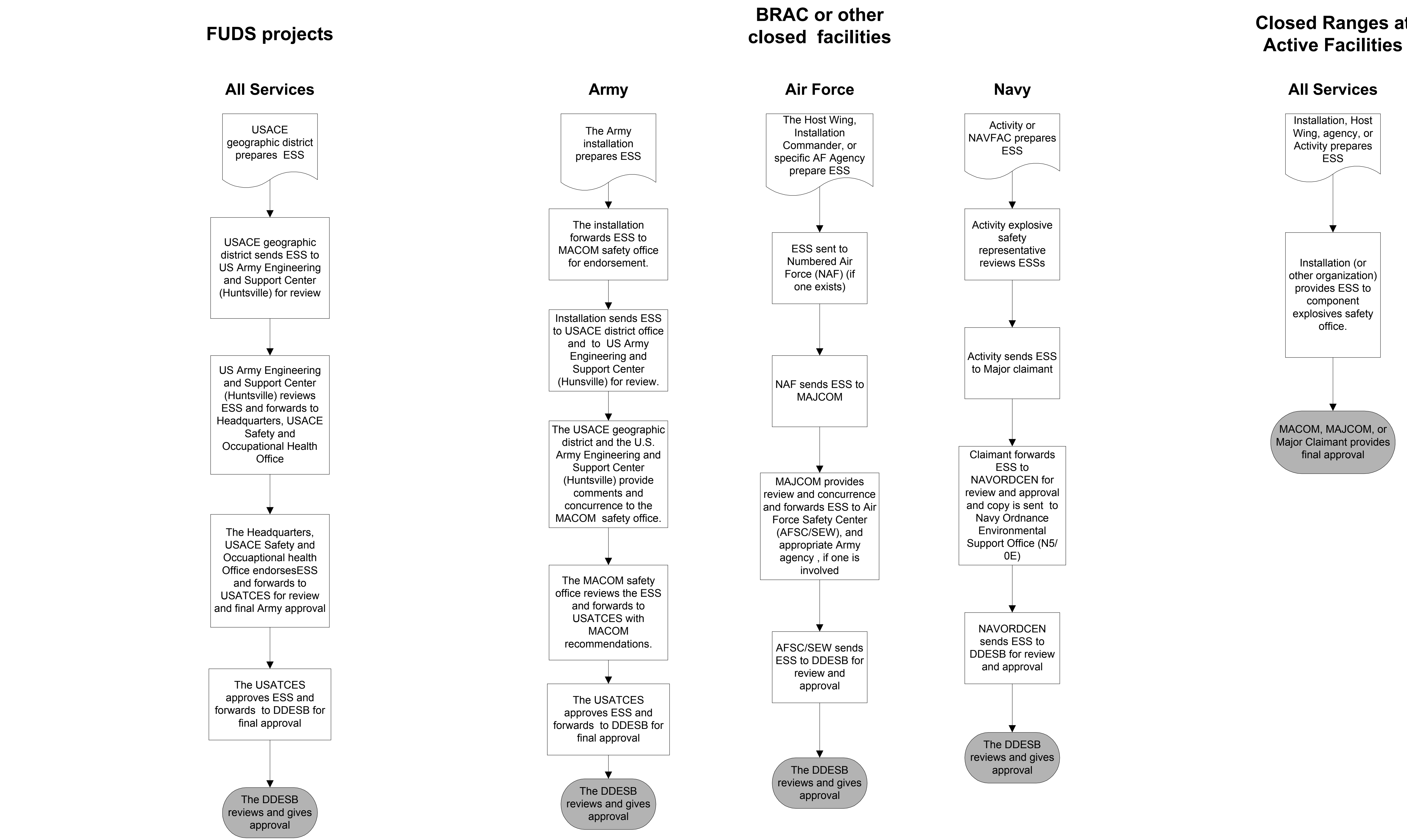
The ESS often includes information obtained in preliminary studies, historical research, previous OE sampling reports, and SSHPs. Specific information required in the submission includes the following:

- Quantity-distance (Q-D) maps describing the location of OE, storage magazines, and demolition areas
- Soil sampling maps for explosives-contaminated soils
- The amounts and types of OE expected based on historical research and site sampling
- Planned clearance techniques to detect, recover, and destroy OE[99]

The amount and type of OE expected in each OE area is identified in the ESS. The submission must specify the most probable munition (defined as the round with the greatest fragmentation distance that is anticipated to be found). The ESS also identifies explosives-contaminated soils, which are expressed as the maximum credible event (established by multiplying the concentration of explosives times the weight of the explosives-contaminated soil).[3] These data are input into formulas for establishing the damage or injury potential of the OE on-site. See the text box on Q-D requirements for additional information about the use of these data in the ESS.

[98]Explosives Safety Policy for Real Property Containing Conventional Ordnance and Explosives, U.S. Army, DACS-SF HQDA LTR 385-98-1, June 30, 1998.

[99]Explosives Safety Submissions for Removal of Ordnance and Explosives (OE) from Real Property, DDESB-KO, February 27, 1998, Subject: Guidance for Clearance Plans.



Sources: DACS-SF HQDA LTR 385-98-1, 30 June 1998, Expires 30 June 2000. Subject: Explosives Safety Policy for Real Property Containing Conventional Ordnance and Explosives
NAVSEA OP 5, Ammunition and Explosives Ashore: Safety Regulations for Handling, Storing, Production, Renovation and Shipping, Vol. 1, Rev. 6, Chg. 4.
Air Force Manual 91-201, Explosives Safety Standards, May 1, 1999

Figure 6-1. Routing and approval of explosives safety submission (ESS) for OE response actions

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Explosives Safety Submission Requirements

Safety plans are submitted at least 60 days prior to the planned response action and cover the following elements:

1. Reason for OE
2. Maps (regional, site, quantity-distance, and soil sampling)
3. Amounts and types of OE
4. Start date of removal action
5. Frost line depth and provisions for surveillance (if necessary)
6. Clearance techniques (to detect, recover, and destroy OE)
7. Alternate techniques (to destroy OE on-site if detonation is not used)
8. Q-D criteria (OE areas, magazines, demolition areas, “footprint” areas)
9. Off-site disposal (method and transportation precautions, if necessary)
10. Technical support
11. Land use restrictions and other institutional controls
12. Public involvement plan
13. After action report (list OE found by type, location, and depth)
14. Amendments and corrections to submission

Note: This list is not inclusive. See military component guidance for full requirements.

6.4 Public Education About UXO Safety

Public education is an important component of managing explosive hazards and their potential impacts on human health and safety. At some sites, such as at Naval Air Facility Adak in Alaska, it is technically and economically impossible to remove all of the UXO littered throughout the island. In such a situation, educating the public about UXO hazards is a necessity in reducing UXO risks. Also, at other, less contaminated sites where cleared areas are being opened to the public but where a small number of UXO items may remain, public education is also necessary in the event that someone encounters a previously undetected UXO item. A discussion of the highly successful public education program at NAF Adak is presented in the following text box.

Adak Island, Alaska

The northern half of Adak Island was used by the Army Air Corps and then the Navy for over 50 years, resulting in UXO and OE materials in and around the former range areas. Some portions of the property have been made suitable for transfer while others are retained by the Navy because of the presence of known ordnance. The parcels of land that are being transferred to local commercial interests may still contain isolated OE in developed and undeveloped portions of the property. The Reuse Safety Plan stipulates permitted land use activities and regulatory, legal, and educational requirements to ensure the safety of residents (both current and future) and visitors to the island.

Historically, the U.S. Fish and Wildlife Service (USFWS), which now owns the land, implemented a comprehensive program to provide education about ordnance to visitors to Adak. This program, along with other institutional controls, has resulted in a very low number of ordnance-related injuries on Adak Island over the past 50 years.

The islandwide ordnance education program now includes several approaches:

- **Ordnance safety videos** are shown to new visitors or future residents before they are allowed to work or reside on the island. The videos cover the following topics:
  - Dig permit requirements
  - OE identification
  - Safety requirements for construction personnel
  - Geophysical screening
  - Locations of UXO sites and clearance activities
  - Ordnance descriptions
  - Safety protocols
  - Access restrictions and warning signs
  - Emergency procedures
- An ordnance education program is incorporated into the **educational system at the lower grades** to educate and protect local children.
- The **Adak On-line Safety Program** was developed by the Navy to assist in the annual ordnance safety certification process for residents and visitors. The program describes the types of ordnance hazards that may potentially exist, an automated dig permit application, an on-line graphic glossary of historical ordnance locations and schematics of the most commonly found ordnance types, emergency procedures, and a database to record the training records of everyone who has taken the on-line training.
- **Deed restrictions** that make future purchasers of property aware of potential contamination on the property.
- **Signage** for restricted and nonrestricted property that is posted at entrances and exits and at specified intervals along the perimeter.

Education about the hazards associated with UXO should be available to everyone in the community, with special attention paid to those who reside, work, and play at or near affected areas. Public education should be directed at both the adults and children of the community and should be reinforced on a regular basis. However, a balance must be found between addressing explosives safety and frightening or alienating the public. The types of information that should be conveyed to the public about UXO hazards should include the fact that any UXO poses the risk of injury or death to anyone in the vicinity. UXO can be found anywhere – on the ground surface, or partially or fully buried. UXO can be found in any state – fully intact or in parts or fragments. An encounter with UXO should be reported immediately – either to site EOD personnel or, if they are not available, the military provost marshal or the local law enforcement agency.

Public Encounters with UXO

Those living, working, or recreating in or near areas thought to contain UXO should be taught what to do and what not to do in the event of an encounter with UXO, including whom they should notify. The Navy EOD Technology Division has developed instructions for the public and site personnel to follow in the event of an encounter with UXO, as described in the following text box.

Instructions for Responding to and Reporting UXO Hazards

1. After identifying the potential presence of UXO, do not move any closer to it. Some types of ordnance have magnetic or motion-sensitive proximity fuzes that may detonate when they sense a target. Others may have self-destruct timers built in.
2. Do not transmit any radio frequencies in the vicinity of a suspected UXO hazard. Signals transmitted from items such as walkie-talkies, short-wave radios, citizens band (CB) radios, or other communication or navigation devices may detonate the UXO.
3. Do not attempt to remove any object on, attached to, or near a UXO. Some fuzes are motion-sensitive, and the UXO may explode.
4. Do not move or disturb a UXO because the motion could activate the fuze, causing the UXO to explode.
5. If possible, mark the UXO hazard site with a standard UXO marker or with other suitable materials, such as engineers tape, colored cloth, or colored ribbon. Attach the marker to an object so that it is about 3 feet off the ground and visible from all approaches. Place the marker no closer than the point where you first recognized the UXO hazard.
6. Leave the UXO hazard area.
7. Report the UXO to the proper authorities.
8. Stay away from areas of known or suspected UXO. This is the best way to prevent accidental injury or death.

REMEMBER: "IF YOU DID NOT DROP IT, DO NOT PICK IT UP!"

6.5 Conclusion

DoD has developed extensive requirements aimed at protecting UXO personnel and the public from explosive hazards. These safeguards include general precautions as well as highly technical explosives safety and personnel health and safety requirements. Management requirements include preparing and submitting SSHPs for all OE investigations and removal actions, and ESSs for OE removal actions. SSHPs require that protective measures be taken for UXO personnel, including the development and implementation of emergency response and contingency plans, personnel training, medical surveillance, and personnel protective equipment programs. The development of ESSs requires knowledge about the munitions likely to be found on-site and the devising of plans for separating explosive hazards from potential receptors.

DoD safety guidance also addresses the protection of public health and safety. The DoD safety standard (6055.9-STD) provides assessment depths to be used for planning purposes, storage and transport principles, and land use controls, all of which are designed to ensure long-term protection of human health and safety.

Public health and safety can also be protected by educating the public about explosives safety. In addition, educating the public about procedures to follow upon encountering OE helps to prevent accidents and gives the public control over protecting themselves from explosive hazards.

SOURCES AND RESOURCES

The following publications, offices, laboratories, and websites are provided as a guide for handbook users to obtain additional information about the subject matter addressed in each chapter. Several of these publications, offices, laboratories, or websites were also used in the development of this handbook.

Publications

Department of Defense Operation and Environmental Executive Steering Committee for Munitions (OEESCM), ***Draft Munitions Action Plan: Maintaining Readiness through Environmental Stewardship and Enhancement of Explosives Safety in the Life Cycle Management of Munitions,*** Draft Revision 4.3, U.S. Department of Defense, February 25, 2000.

Department of Defense and U.S. Environmental Protection Agency, ***Management Principles for Implementing Response Actions at Closed, Transferring, and Transferred (CTT) Ranges***, DoD and EPA, March 7, 2000.

Guidance Documents

Air Force Manual 91-201, ***Safety: Explosives Safety Standards***, May 1, 1999.

Air Force Instruction 32-90004, ***Civil Engineering. Disposal of Real Property***, July 21, 1994.

Department of the Army, U.S. Army Corps of Engineers, ***Safety and Occupational Health Document Requirements for Hazardous, Toxic, and Radioactive Waste (HTRW) and Ordnance and Explosive Waste (OEW) Activities***, Regulation No. 385-1-92, March 18, 1994.

Departments of the Army, Navy, and Air Force, ***Interservice Responsibilities for Explosive Ordnance Disposal***, Joint Army Regulation 75-14, OPNAVINST 8027.1G, MCO 8027.1D, AFR 136-8. February 14, 1992.

Department of Defense, DoD 6055.9-STD, ***DoD Ammunition and Explosives Safety Standards***, July 1999.

Department of Defense Directive 6055.9. ***DoD Explosives Safety Board (DDESB) and DoD Component Explosives Safety Responsibilities,*** July 29, 1996.

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U.S. Army, Headquarters, ***Explosives Safety Policy for Real Property Containing Conventional Ordnance and Explosives***, DACS-SF (3 October 1997), HQDA LTR 385-98-1, June 30, 1998.

U.S. Army Corps of Engineers, Huntsville Center, ***Basic Safety Concepts and Considerations for Ordnance and Explosives Operations,*** OE-CX Interim Guidance Document, March 2000.

U.S. Army Corps of Engineers, ***Engineering and Design Ordnance and Explosives Response***, Pamphlet No. 111-1-18, April 24, 2000.

U.S. Army Corps of Engineers, ***Engineering and Design Ordnance and Explosives Response***, Manual No. 1110-1-4009, June 23, 2000.

U.S. Army Corps of Engineers, Huntsville Center, Ordnance and Explosives Center of Expertise, ***Public Involvement Plan for Ordnance and Explosives Response***, Interim Guidance (Draft ETL 1110-1-170), September 15, 1995.

U.S. Army Corps of Engineers, Engineering and Design, ***Safety and Health Aspects of HTRW Remediation Technologies,*** Engineer Manual (EM 1110-1-4007), September 30, 1999.

U.S. EPA, ***Institutional Controls and Transfer of Real Property Under CERCLA Section 120(h)(3)(A), (B) or (C)***, February 2000.

U.S. Navy, ***Ammunition and Explosives Ashore: Safety Regulations for Handling, Storing, Production, Renovation and Shipping***, NAVSEA, OP 5, Vol. 1, Rev. 6, Chg. 4, March, 1999.

U.S. Navy, ***U.S. Navy Explosives Safety Policies, Requirements, and Procedures,*** **Explosives Safety Policy Manual**, OPNAV Instruction 8023.2C., January 29, 1986.

Information Sources

Department of Defense Explosives Safety Board (DDESB)
2461 Eisenhower Avenue
Alexandria, VA 22331-0600
Fax: (703) 325-6227
http://www.hqda.army.mil/ddesb/esb.html

Joint UXO Coordination Office (JUXOCO)
10221 Burbeck Road, Suite 430
Fort Belvoir, VA 22060
Tel: (703) 704-1090
Fax: (703) 704-2074

Naval Safety Center
Code 40
375 A Street
Norfolk, VA 23511-4399
Tel: (757) 444-3520
http://www.safetycenter.navy.mil/

Naval Explosive Ordnance Disposal Technology Division
(NAVEODTECHDIV)
UXO Countermeasures Department
Code 30U
2008 Stump Neck Road
Indian Head, MD 20640-5070
http://www.ih.navy.mil/

Naval Ordnance Environmental Support Office
Naval Ordnance Safety and Security Activity
23 Strauss Ave. (BLDG D-323)
Indian Head, MD 26040
Tel: (703) 744-4450/6752

Ordata 21 (database of ordnance items)
Available from: NAVEOTECHDIV
Code 602,
20008 Stump Neck Road,
Indian Head, MD 20640-5070
e-mail: ordata@eodpoe2.navsea.navy.mil

U.S. Air Force Safety Center
HQ AFSC
9700 G Avenue SE
Kirtland AFB, NM 87117-5670
http://www-afsc.saia.af.mil/

U.S. Army Corps of Engineers
U.S. Army Engineering and Support Center,
Ordnance and Explosives
Mandatory Center of Expertise
P.O. Box 1600
Huntsville, AL 35807-4301
4820 University Square
http://www.hnd.usace.army.mil/

U.S. Army Technical Center for Explosives Safety
Attn: SIOAC-ESL, Building 35
1C Tree Road
McAlester, OK 74501-9053
e-mail: sioac-esl@dac-emh2.army.mil
http://www.dac.army.mil/es

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7.0 SITE/RANGE CHARACTERIZATION

Characterizing OE contamination is a challenging process and requires specialized investigative techniques. While existing technologies enable investigators to find ordnance, discriminating between UXO, fragments of exploded ordnance, and background levels of ferrous metals in soils can be costly and technically challenging at both the investigative and clearance/cleanup phases. Locating buried munitions whose burial may not have been well documented can also be difficult. When the large land areas associated with many ranges (tens of thousands of acres) and other characteristics of the ranges (e.g., mountainous, heavy brush, forested, or under water) are considered, the technical and cost issues become even more challenging. Some level of uncertainty is expected for any subsurface environmental investigation; however, the consequences of potential uncertainties related to UXO investigations (e.g., accidental explosion and resulting death or dismemberment) elevate the level of public and regulatory concern.

The purpose of this chapter is to outline an approach to site characterization for OE based on a **systematic planning process** and to identify the choices to be made in tailoring the investigation to your site. This chapter of the handbook does not focus (for the most part) on investigation of nonexplosive chemical residuals of OE because such an investigation would be similar to the investigation of other hazardous wastes, and numerous reports and guidance have been written on non-OE contamination. (See "Sources and Resources" at the end of this chapter for guidance on conducting hazardous waste investigations.) Instead, this chapter addresses site investigations of OE, which generally consists of one of three types of waste products:

- Unexploded munitions (e.g., duds or buried or otherwise discarded munitions)
- Ordnance fragments from exploded munitions that may retain residues of sufficient quantity and type to be explosive
- Concentrations of explosive materials in soil (e.g., explosive residue from exploded or corroded ordnance present in sufficient quantity and weight to pose explosive hazards)

The last section of this chapter addresses pulling together the information gathered during site characterization to develop a site response strategy. This site response strategy may include:

- Further investigation
- Response action, or
- No action

The attributes, steps and role of the site response strategy are discussed, as well as its relationship to the risk management decision processes under CERCLA and RCRA.

7.1 Approaches to OE Site Characterization

An effective strategy for OE site characterization uses a variety of tools and techniques to locate and excavate OE and to ensure understanding of uncertainties that may remain. The selection of and effective deployment of these tools and techniques for the particular investigation will be determined through the systematic planning process. The following steps are included in a typical investigation:

- Use of historical information to:
  - Identify what types of ordnance were used at the facility and where they were used
  - Identify areas of the facility where ordnance was not used, thereby reducing the size of the area to be investigated
  - Prioritize the investigation in terms of likelihood of ordnance presence, type of ordnance used, public access to the area, and planned end uses
  - Consider the need to address explosives safety issues prior to initiating the investigation
- Visual inspection of range areas to be investigated, and surface clearance to facilitate investigation
- Identification and use of appropriate geophysical methods to map the sectors likely to be contaminated and to estimate the anomaly density
- Establishment and verification of confidence levels (measurement quality objectives) in the sampling methodology (quality assurance/quality control measurements)
- Anomaly reacquisition (excavation) to verify geophysical mapping results and to gather data on the nature and density of OE
- Analysis of data to help discriminate between OE and ordnance fragments and background material, and QA/QC of that analysis
- Excavation of some portion of the sector to verify assumptions and set priorities for future work

Some of the particular challenges and issues to consider in using these tools include the following:

- Finding adequate and reliable historical information on the former uses of ranges and the types of munitions likely to be found
- Matching the particular detection technology to the type of UXO expected and to the geology and the topography of the range
- Confirming the field detection data
- Establishing a clear understanding of the percentage of UXO compared to all anomalies detected, and resulting uncertainty
- Phasing the investigation in stages that refine its focus in order to ensure that the data collected are appropriate to the decision required
- Optimizing available resources

There is no single solution for resolving the challenges of a UXO site characterization, but the starting place for every investigation is to establish the decisions to be made and the resulting goal(s) of the investigation.

7.2 Overview of Systematic Planning

As with any environmental investigation, designing the range investigation and judiciously applying investigative tools take place in the context of a systematic planning process. The process starts with identifying the **decision goal** of the project. Available information is then used to identify data requirements that support the decision goal and define the **objectives of the investigation**. Finally, the **sampling strategy** of the investigation is tailored to ensure that the data gathered are of appropriate quantity and quality to support the decision goals. Each stage of the systematic planning process is carefully refined by the preceding stages. Figure 7-1 outlines how the systematic planning process is used to design the investigation to meet the requirements of the project. Although the figure outlines an apparently sequential process, the process involves a number of concurrent steps and iterative decisions.

The steps taken to plan and carry out an investigation will be similar regardless of which regulatory program governs the investigation (e.g., removal or remedial action under RCRA). The significance and complexity of any particular step will depend on the decision goals, the data quality objectives (DQOs), and a variety of site-specific conditions.

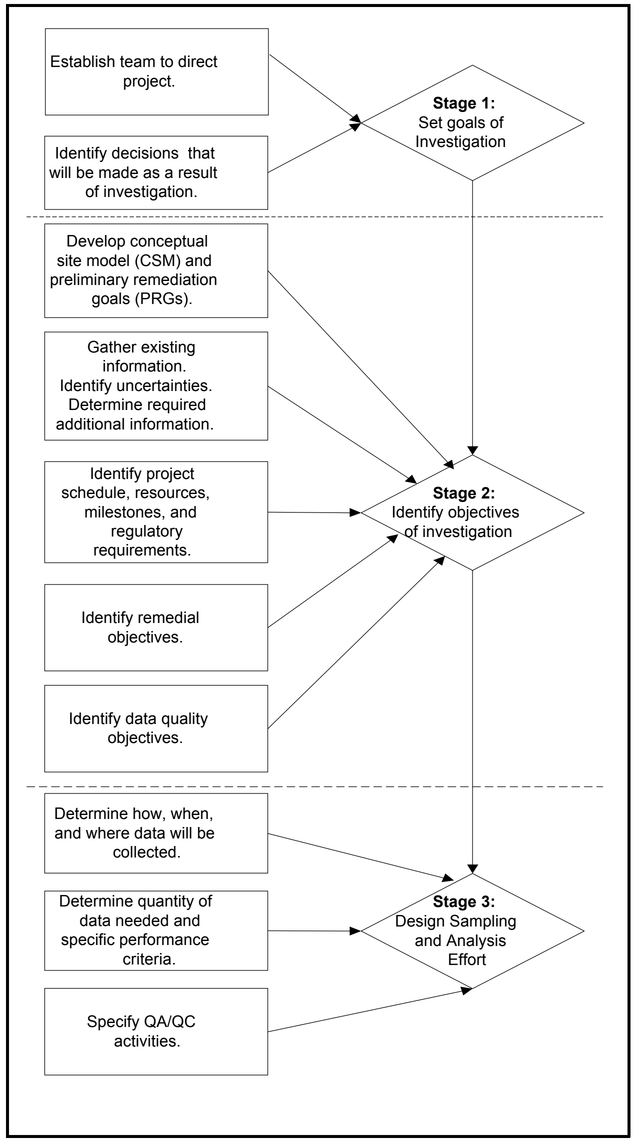

Figure 7-1. Systematic Planning Process

The purpose of any investigation is to obtain enough information to make the decisions that were identified as decision goals of the investigation. It is not necessary to obtain information of 100 percent certainty on every piece of data as long as you understand the uncertainty associated with the data so that decisions are not based on erroneous assumptions. For example, using limited sampling data to estimate the density of UXO may be sufficient to estimate the cost of clearance to a 2-foot depth. On the other hand, a higher level of certainty will be required when the decision goal is a no-action decision and the planned land use is unrestricted.

As with any environmental investigation, you will want to collect data in appropriate stages and be prepared to make changes in the field. Some kinds of information may not be needed if the initial information you collect answers basic questions. In addition, as you collect data, you may find that your initial hypotheses about the site were not correct. New information may cause your investigation to go in different directions. Anticipating field conditions that may potentially modify your investigation, and planning and articulating the decision rules that can lead to such changes, will foster cooperation between the DoD investigators, the regulators, and the public.

7.3 Stage 1: Establishing the Goal(s) of the Investigation

The goal of the investigation is to obtain the information required to make site-specific decisions. Therefore, the stated goal will reflect the final decision goal (e.g., action or no-action decision). As used in the discussion that follows, the **goals** of the investigation differ from the **objectives** of the investigation. The objectives are the specific data needs that will be required to achieve the goals.

Establishing the goals of the investigation requires two key steps. The first step involves selecting an appropriate project team to guide the investigation. The second step is to identify the decisions that will be made at the conclusion of the site characterization process. Both elements will guide the remaining steps of the investigation process.

7.3.1 Establishing the Team

To be scientifically based, the investigation must be planned and managed by those people who will use the data to make decisions. This approach ensures that all of the data needed for decision making is acquired, at an appropriate level of quality for the decision. The project team generally includes an experienced project manager, OE personnel, data processing experts, chemists, geophysicists, a logistics coordinator, health and safety personnel, and regulatory personnel from the appropriate Federal, State, and local regulatory agencies. Involving all of the potential end users in the planning process also has other important outcomes:

- **Common understanding among all of the parties of how the data will be used.** Subsequent review of work plans, with a clear understanding of the decision goals in mind, will result in comments targeted to the agreed-upon goals of the investigation, not unspoken assumptions about those goals.

- **Minimization of rework.** If all of the decision makers and data users are involved from the beginning of the study, the study design will be more likely to include objectives that clearly relate to the goals, and the various investigative tools will be targeted appropriately.

A team-based approach can expedite the process of making decisions and, ultimately, of reaching project goals. By definition, this consensus-oriented approach allows all team members to have input into the project goals, as well as to identify the information needed and methods to be employed to achieve the goals. Further, with this approach, the outcome of the project is more likely to be accepted by all parties later, resulting in a more efficient and less contentious decision-making process.

7.3.2 Establishing the Goals of the Site Characterization Process

Establishing the decision goals of the project will ultimately determine the amount of uncertainty to be tolerated, the area to be investigated, and the level of investigation required. The following are examples of decision goals:

- Confirm that a land area has or has not been used as an OE area in the past.
- Prioritize one or more OE areas for cleanup.
- Conduct a limited surface clearance effort to provide for immediate protection of nearby human activity.
- Identify if cleanup action will be required on the range or ranges under investigation (i.e., to decide if there is a potential risk, and to make an action/no-action decision).
- Identify the appropriate clearance depths and select appropriate removal technologies for the range or ranges under investigation.
- Transfer clean property for community use.

A particular investigation may address one or several decision goals, depending on the scope of the project.

Conducting Investigations in Phases

Most range investigations take place in phases. The first phase of the process involves determining what areas are to be investigated. The range is divided into **ordnance and explosives (OE) areas** or areas of potential concern using a variety of factors, including, but not limited to, safety factors, cost/prioritization issues, and homogeneity of the areas to be investigated.

The individual OE area investigations and clearance activities also often proceed in stages. Prior to detailed subsurface investigation, a surface removal action is usually conducted to ensure that the property is rendered "safe" for the subsurface investigations. The subsurface investigations themselves often take place in stages. The first is a nonintrusive stage that uses surface detection equipment designed to detect subsurface anomalies. The second stage is intrusive sampling that is designed to verify and interpret the results of the nonintrusive investigation. (Note: In some investigations, reacquisition of anomalies (anomaly excavation) takes place simultaneously with the nonintrusive surface detection investigation.)

7.4 Stage 2: Establishing the Objectives of the Investigation and Planning the Investigation

Once the decision goals of the investigation are identified, five steps provide the foundation for designing the sampling and analysis plan that will provide the information required to achieve the desired decision. These five steps result in the project objectives:

- Developing a working hypothesis of the risks, pathways, and receptors at the site (conceptual site model, or CSM)
- Developing preliminary remediation goals (PRGs)
- Comparing known information to the CSM, and identifying information needs

- Identifying project constraints (schedules, resources, milestones, and regulatory requirements)
- Identifying remedial objectives

These steps are iterative, so both the PRG and the CSM will likely change as more information is gathered.

7.4.1 The Conceptual Site Model (CSM)

The CSM establishes a working hypothesis of the nature and extent of UXO contamination and the likely pathways of exposure to current and future human and ecological receptors. A good CSM is used to guide the investigation at the site. The initial CSM is created once project decision goals are defined. The CSM is refined and modified as more information is gathered at each stage of the site characterization process. Key pieces of initial data should be recorded in the CSM:

- The topography and vegetative cover of various land areas
- The probable locations, types, and densities of OE — both horizontal and vertical including buffer zones
- Likely key contaminants of concern
- Potential pathways to human and ecological receptors
- Location of factors such as frost line or groundwater that influence pathways to receptors
- Location of cultural or archeological resources
- The current, future, and surrounding land uses

The purpose of developing this early CSM is to ensure that the collection of initial information will be useful for your investigation. If the conceptual understanding of the site is poor, you may need to conduct limited preliminary investigations before you develop the sampling and analysis plan. Such investigations could include a physical walk-through of the area, collection of limited geophysical data, or collection of additional historical information. In any case, the CSM will be revised at least once in this early planning phase as more data are gathered. The data points of a CSM are usually documented schematically and supplemented by a table. The simplistic example of a CSM in Figure 7-2 illustrates the types of information often conveyed in a CSM. Depending on the complexity and number of OE areas to be investigated, the CSM may be required to show several impact areas as well as overlapping range “fans.”

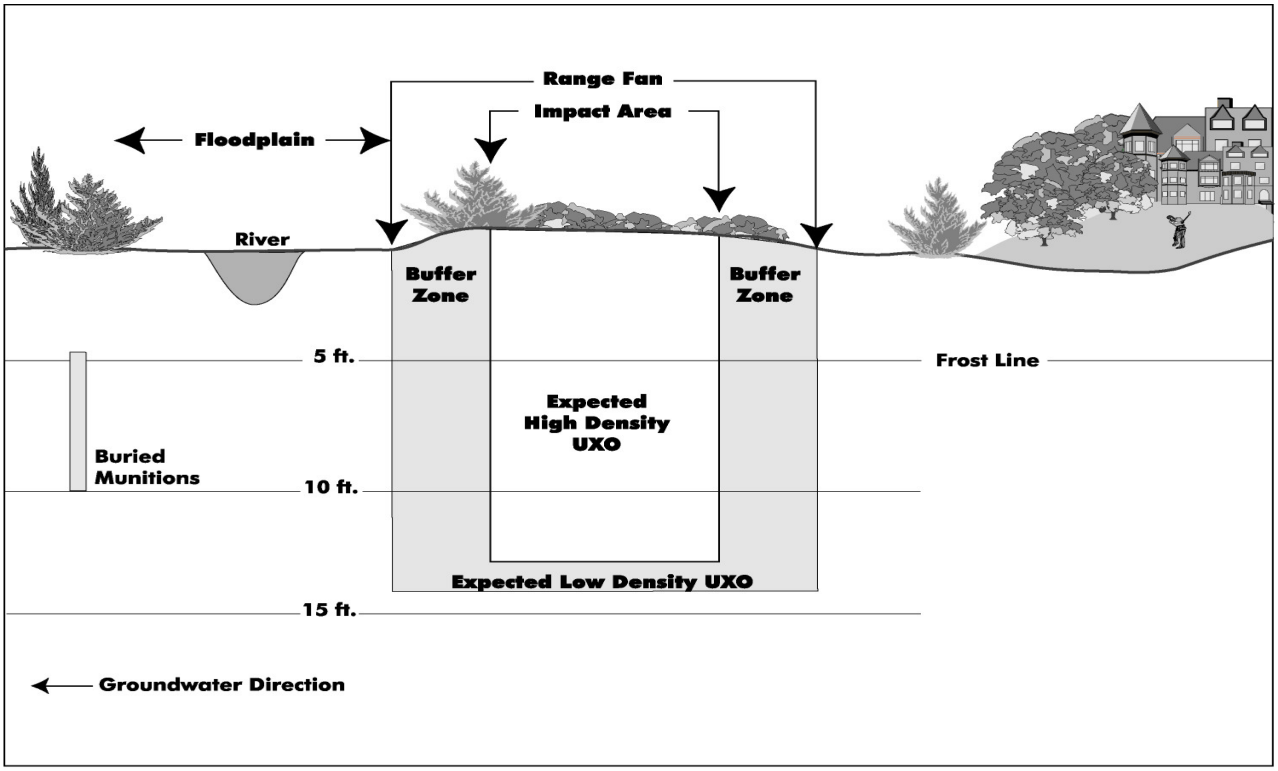

Figure 7-2. Conceptual Site Model

Section 7.4.3 discusses the gathering of information on ordnance use at the site as well as the physical site characteristics that will help you develop a CSM. Historical information on the type of activity that took place and the munitions used will be particularly important to help you identify patterns in the distribution of ordnance and the depth at which it may be found. For example, if the site was used as a projectile range, you would expect to find fired ordnance (including dud-fired rounds) primarily in the target area, buried munitions at the firing point, dud-fired rounds along the projectile path, and a few shells in the buffer zone. Ranges used for different purposes have different firing patterns and different distributions of OE. At a troop training range, you might find buried munitions scattered throughout the training area if returning troops decided to bury their remaining munitions rather than carry them out with them.

A Conceptual Site Model may also be presented from a top view (also called a plan view) as illustrated in Figure 7-3 and overlayed with a map created using a geographic information system (GIS). See Figure 7-3 for plan view of a CSM for an artillery range.

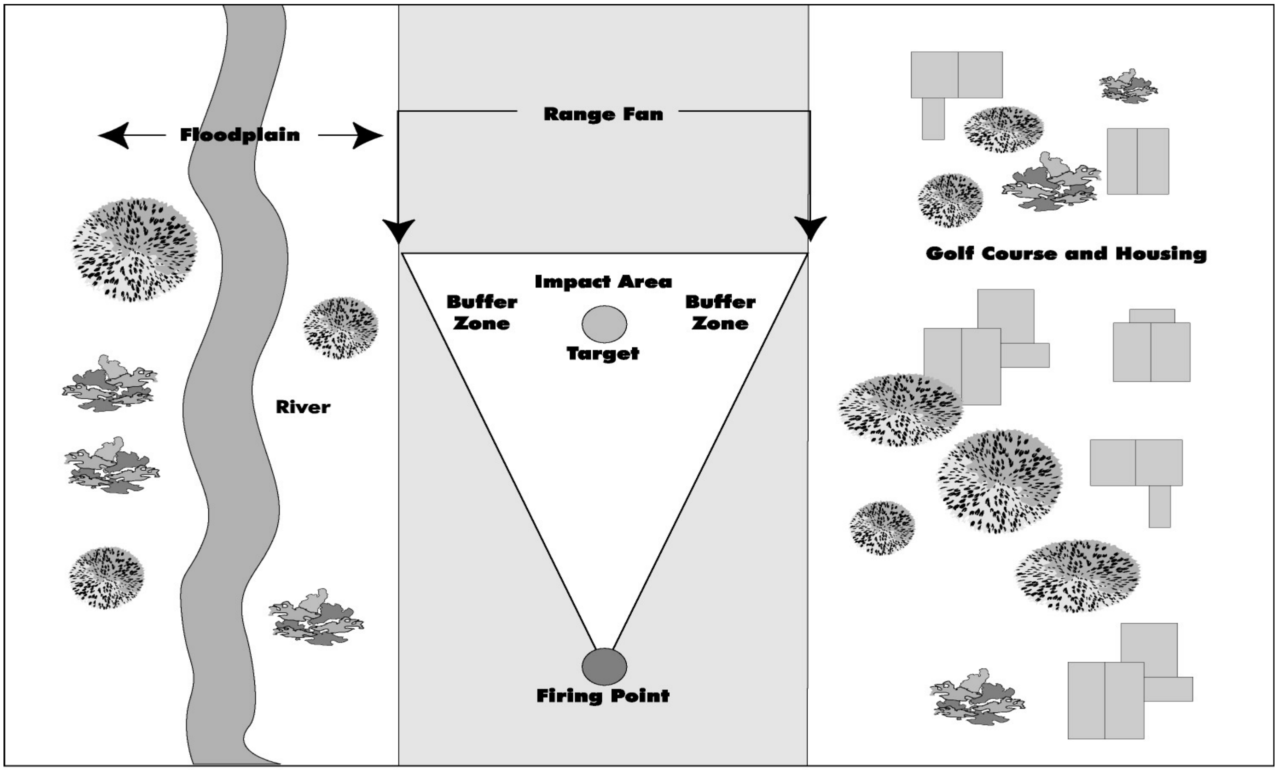

Figure 7-3. Conceptual Site Model: Plan View of a Range Investigation Area

7.4.2 Preliminary Remediation Goals

> **Preliminary Remediation Goals (PRGs)**
>
> PRGs provide the project team with long-term targets to use during analysis and selection of remedial alternatives. Chemical-specific PRGs are concentration goals for individual chemicals in the media in which they are found. For UXO, the PRG will generally address the clearance depth for UXOs.
>
> Source: U.S. EPA. Risk Assessment Guidance for Superfund (RAGS), Volume 1, Human Health Evaluation Manual, Part B, Interim, December 1991.

Preliminary remediation goals (PRGs) are the preliminary goals for depth of UXO clearance and are used for planning purposes. PRGs are directly related to the specific media that are identified in your CSM as potential pathways for UXO exposure (e.g., vadose zone, river bottom, wetland area). The PRG for UXO clearance is a function of the goal of the investigation and the reasonably anticipated land use on the range. For example, if the goal of the investigation is to render the land surface safe for nonintrusive investigations, then the PRG will be designed to promote surface clearance of the land area. Therefore, the PRG will require that no UXO remain on the surface of the land. On the other hand, if the goal of the investigation is to determine the potential risk to human health from UXO, then the PRG will be based on the reasonably anticipated future land use. The PRG in this instance may be to ensure that no UXO is present in the top 10 feet of the subsurface or above the frost line.

The PRG may change at several points during the investigation or at the conclusion of the investigation, as more information becomes available about the likely future land use, about geophysical conditions that may cause movement of OE, or about the complexity and cost of the clearance process. The PRG may also change during the remedy selection process as the team makes its risk management decisions and weighs factors such as protection of human health and the environment, costs, short-term risks of cleanup, long-term effectiveness, permanence, and community and State preferences.

While OE removal PRGs are conceptually easier to understand than chemical-specific PRGs, widely accepted algorithms and extensive guidance have been developed to establish chemical- and media-specific PRGs. Identifying the appropriate PRG for OE sites can be a complex and controversial process. One approach you may consider is to use the DDESB default safety standards for range clearance as the initial PRG until adequate site-specific data become available. The first step in establishing the PRG is to determine the current and reasonably anticipated future land use.

DDESB safety standards establish **interim** planning assessment depths based on different land uses to be used for planning purposes until site-specific data become available. In the absence of site-specific data, these standards call for a clearance of 10 feet for planned uses such as residential and commercial development, and construction activity. For areas accessible to the public, such as those used for agriculture, surface recreation, and vehicle parking, the DDESB recommends planning for remediation to 4 feet. For areas with limited public access and areas used for livestock grazing or wildlife preserves, the DDESB recommends planning for remediation to 1 foot.[100] In all cases, the standards call for clearance to 4 feet below any construction. (See Chapter 6 for a more detailed description of DDESB standards.) **None of these removal depths should be used automatically.** For example, if site-specific information suggests that a commercial or industrial building will be constructed that requires a much deeper excavation than 10 feet, a deeper clearance must considered. In addition, if the clearance depth is above the frost line, then DDESB standards require continued surveillance of the area for frost heave movement.[101]

DoD/EPA Interim Final Management Principles on Standards for Depths of Clearance

Per DoD 6055.9-STD, removal depths are determined by an evaluation of site-specific data and risk analysis based on the reasonably anticipated future land use.

- In the absence of site-specific data, a table of assessment depths is used for interim planning purposes until the required site-specific information is developed.
- Site-specific data are necessary to determine the actual depth of clearance.

A variety of factors are considered when identifying the reasonably anticipated future land use of the property. Current and long-term ownership of the property, current use, and pressure for

[100] DoD Directive 6055.9. DoD Explosives Safety Board (DDESB) and DoD Component Explosives Safety Responsibilities. July 29, 1996.

[101] Department of Defense. *Explosive Safety Submissions for Removal of Ordnance and Explosives (OE) from Real Property.* Memorandum from DDESB Chairman, Col. W. Richard Wright. February 1998.

changes in future use are some of the important considerations.[102] The text box below contains a list of other possible factors. In the face of uncertainty, a more conservative approach, such as assuming unrestricted land use, is prudent. In determining the reasonably anticipated future land use at a Base Realignment and Closure (BRAC) facility, one should consider not only the formal reuse plans, but also the nature of economic activity in the area and the historical ability of the local government to control future land use through deed restrictions and other institutional controls. Several sources of information about planned and potential land use at BRAC sites are available, including base reuse plans.

DoD/EPA Interim Final Management Principles on Land Use

Discussions with local planning authorities, local officials, and the public, as appropriate, should be conducted as early as possible in the response process to determine the reasonably anticipated land use(s). These discussions should be used to scope efforts to characterize the site, conduct risk assessments, and select the appropriate response.

Factors To Consider in Developing Assumptions About Reasonably Anticipated Future Land Uses

- Current land use
- Zoning laws
- Zoning maps
- Comprehensive community master plans
- Population growth patterns and projections
- Accessibility of site to existing infrastructure (including transportation and public utilities)
- Institutional controls currently in place
- Site location in relation to existing development
- Federal/State land use designations
- Development patterns over time
- Cultural and archeological resources
- Natural resources, and geographic and geologic information
- Potential vulnerability of groundwater to contaminants that may migrate from soil
- Environmental justice issues
- Location of on-site or nearby wetlands
- Proximity to a floodplain and to critical habitats of endangered or threatened species
- Location of wellhead protection areas, recharge areas, and other such areas

7.4.3 Assessment of Currently Available Information To Determine Data Needs

The site-specific objectives of the investigation are ultimately based on acquiring missing information that is needed to make the required decision. In order to establish the objectives of the investigation, it is necessary to first identify what is known (and unknown) about the OE area. Your investigation will focus on what is not known, and key questions will improve your understanding of the elements of the risk management decision that is to be made (explosive potential of the

[102] USEPA, OSWER Directive No. 9355.7-04, May 25, 1995, Land Use in the CERCLA Remedy Selection Process.

ordnance, pathways of exposure, and likelihood of exposure), and the costs, effectiveness, and risks associated with remediation. The following are typical questions with which you will be concerned:

- What types of ordnance were used on the range?
- What are the likely range boundaries?
- Is there evidence of any underground burial pits possibly containing UXO on the site?
- At what depth is the UXO likely to be located?
- What are the environmental factors that affect both the location and potential corrosion of UXO?
- Is there explosive residue in the soil?
- Is there explosive residue in ordnance fragments?

7.4.3.1 *Historical Information on Range Use and Ordnance Types*

Historical data are an important element in effectively planning site characterization. Because many ranges and other ordnance-related sites have not been used in years, and because many ranges encompass thousands of acres of potentially contaminated land, historical information is critically important in focusing the investigation.

Historical information can be obtained from many sources, including old maps, aerial photographs, satellite imagery, interviews with former or current personnel, records of military operations, archives of range histories and types of munitions used, and records from old ammunition supply points, storage facilities, and disposal areas. Historical information is important to determine the presence of OE, the likely type of ordnance present at the range or OE area, the density of the ordnance, and the likely location (both horizontal and vertical) of the ordnance. (See "Sources and Resources" at the end of this chapter.)

Historical information is important for **assessing the types of munitions** likely to be found on the range, their age, and the nature of the explosive risk. This information can be used to select the appropriate detection tools and data processing programs to be used during the characterization, as well as to establish

Sources of Historical Data

- National Archives
- U.S. Center of Military History
- History offices of DoD components such as the Naval Facilities Command Historian's Office and the Air Force Historical Research Agency
- Repositories of individual service mishap reports
- Smithsonian Historical Information and Research Center
- Real estate documents
- Historical photos, maps, and drawings
- Interviews with base personnel

Munitions Burial Pits

Underground munitions burial pits present unique challenges to a site characterization. Frequently, the existence of burial pits is not known; if they are known to exist, their exact locations may not be known. Many munitions burial pits are so old that records do not exist and individuals who were aware of their existence at one time are no longer alive. An example of an old munitions burial pit is the Washington, DC, Army Munitions Site at Spring Valley. This site was last used for military purposes during World War I and was developed as residential housing beginning in the 1920s. In 1993, OE was found, and removal and remedial actions were performed. However, in 1999, an additional cache of ordnance was found adjacent to a university on the former installation, necessitating emergency removal actions.

safety procedures and boundaries based on anticipated explosive sensitivity and blast potential. For example, if historical records show that a range was only used for testing 81 mm and 105 mm mortars, a data processing program could then be used to screen out all possible targets larger than 105 mm shells and smaller than 81 mm shells from the investigation. (See section 4.3 for a discussion of data processing techniques.) Historical information about the potential explosive hazards (e.g., thermal, blast overpressure, or fragmentation grenades, or shock hazards) from the expected OE types will dictate separation distance requirements for excavation sites, open detonation areas, and surrounding buildings; public traffic routes; and other areas to be protected. Information about the type, size, and shape of the OE items on the range could simplify OE identification and clarify safety requirements during the detection phase.

Historical information is also necessary for estimating the **probable density** of UXO in the range or OE area under investigation. This information will affect the phasing of the investigation, the technical approach to detection and discrimination of anomalies, the cost and extent of sampling required, the cost of remediation, and the safety plan and procedures used. There will be some areas where, given the density of UXO present, intrusive investigations are considered very dangerous, and expensive safety precautions will be required. In some cases the known density of UXO likely at the OE area will lead to a decision to not clear the area because of the high number of short-term risks.

Historical information is needed in order to estimate the **location of potential OE contamination,** both to focus the investigation (and identify likely OE areas) and to reduce the footprint of UXO contamination by eliminating clean areas from the investigation. Identification of areas of potential UXO contamination may be more difficult than is at first apparent. For decades, many facilities have served a number of different training purposes. Although an impact area for a bombing range may be reasonably clear, the boundaries of that area (including where bombs may have accidentally dropped) are often not clear. In addition, land uses on military bases change, just as they do in communities around the country. Training activities using ordnance may have taken place in any number of locations. In some cases, land uses will change and a building or a recreational area, such as a golf course, will be built over an OE area. Munitions may have been buried at various locations on the base, sometimes in small quantities, without the knowledge or approval of the base commanders.

While historical information is more likely to be used to determine the presence (as opposed to the absence) of OE, comprehensive and reliable historical information may make it possible to reduce the area to be investigated or to eliminate areas from OE investigation. Early elimination of clean areas on bases where a lot of range-related training activity took place may require a higher degree of certainty than on bases where there was no known ordnance-related training activity. For example, an isolated forested wetland might be eliminated from further investigation under certain circumstances. This might be possible if a thorough archival search report indicates the area was never used for training or testing, it was never accessible by vehicle, and these assumptions can be documented through a series of aerial photographs, beginning at the time the base was acquired by the military through the time of base closure. Alternatively, potential OE areas on bases with a history of a variety of ordnance-related training activities, and large amounts of undocumented open space (or forested lands), may be more difficult to eliminate.

Historical data are often incorporated into an archives search report, a historical records search report, or an inventory project report, management tools that are often compiled by OE experts. These reports incorporate all types of documents, such as memoranda, letters, manuals, aerial photos, real estate documents, and so forth, from many sources. After an analysis of the collected information and an on-site visit by technical personnel, a map is produced that shows all known or suspected ordnance and explosives areas on the site.

7.4.3.2 *Geophysical and Environmental Information*

Depending on the level of detail required for the investigation, additional information might be gathered, such as

- Results of previous investigations that may have identified both UXO and explosives-contaminated soil.
- Geophysical data that show the movement (and therefore location) of UXO, the potential corrosion of OE containers/casings, and the ability of detection equipment to locate UXO.

Information about geophysical conditions that will affect the movement, location, detection, and potential deterioration of ordnance and nonordnance explosives may be available on-site from previous environmental investigations (e.g., investigations conducted on behalf of the Installation Restoration Program). The significance of this information is discussed in more detail in Chapter 3.

A limited list of specific types of information that may be important (depending on the purpose of the investigation) is provided in Table 7-1. Some of the information may be so critical to the planning of the investigation that it should be obtained during the planning phase and prior to the more detailed investigation. Other information will be more challenging to gather, such as depth and flow direction of groundwater. If the necessary information is not available from previous investigations, it will likely be an important aspect of the OE area investigation.

Table 7-1. Potential Information for OE Investigation

Information	Purpose for Which Information Will Be Used
Background levels of ferrous metals	Selection of detection technology. Potential interference with detection technologies, such as magnetometers.
Location of bedrock	Potential depth of OE and difficulties associated with investigation.
Location of frost line	Location of OE. Frost heave potential to move UXO from anticipated depth.
Soil type and moisture content	Location of OE (movement through soil). Potential for deterioration/corrosion of casings. Potential for release of explosive material.
Depth and movement of groundwater	Potential for movement of OE and for deterioration/corrosion of containment. Potential for leaching of explosive materials.

Information	Purpose for Which Information Will Be Used
Location of surface water, floodplains, and wetlands	Potential location of explosive material. Potential pathway to human receptors; potential for movement of OE and for deterioration/corrosion of munitions casings; potential leaching of explosive material; selection of detection methods.
Depth of sediments	OE located in wetlands or under water. Location, leaching, and corrosion of OE; selection of detection methods.
Topography and vegetative cover	Potential difficulties in investigation, areas where clearance may be required. Selection of potential detection technologies.
Location of current land population	Potential for exposure.
Current use of range and surrounding land areas	Potential for exposure.
Information on future land use plans	Potential for exposure.

7.4.4 Project Schedule, Milestones, Resources, and Regulatory Requirements

Other information used to plan the investigation includes the proposed project schedule, milestones, resources, and regulatory requirements. These elements will not only dictate much of the investigation, they will also determine its scope and help determine the adequacy of the data to meet the goals of the investigation. If resources are limited and the tolerance for uncertainty is determined to be low, it may be necessary to review the goals of the investigation and consider modifying them in the following ways:

- Reduce the geographic scope of the investigation (e.g., focus on fewer OE areas)
- Focus on surface clearance rather than clearance at depth
- Reduce the decision scope of the investigation (e.g., focus on prioritization for future investigations, rather than property transfer)

In considering the schedule and milestones associated with the project, it is important to consider the regulatory requirements, including the key technical processes and public involvement requirements associated with the CERCLA and RCRA processes under which much of the investigation may occur, as well as any Federal Facility Agreements (FFAs) or Compliance Orders that are in place for the facility. (See Chapter 2, Regulatory Overview.)

Resources

A variety of factors affect the scope and therefore the costs of the investigation. Although high costs are often associated with large range size, other factors can affect the scope and costs of an investigation:

- Difficult terrain (e.g., rocky, mountainous, dense vegetation)
- High density of OE
- Anticipated sensitivity of OE to disturbance or other factors that may require extraordinary safety measures

Key factors to consider when determining the cost of the investigation include the following:

- **Site preparation** may include vegetation clearance, surface UXO removal, and the establishment of survey controls, such as instrument calibration. If there is little vegetation at the site and if the UXO detection can be conducted without removing the vegetation, the costs can be significantly reduced.
- **Geophysical mapping** includes personnel, mapping, and navigation equipment. The operational platform for the selected detection tool can have a major impact on the costs of a site characterization.
- The **data analysis** process requires hardware and software to analyze the data gathered during the geophysical mapping and to reduce background noise and classify anomalies. Data analysis can be conducted in real time during detection or off-site following the detection, with the latter generally being more expensive than the former.
- **Anomaly reacquisition** includes excavating to verify target anomalies and to test the working hypotheses. Reacquisition can be very expensive; the greater the number of anomalies identified as potential UXO, the higher the cost.

Vegetation Clearance

In addition to the high monetary costs of preparing an area to be cleared of UXO, the environmental costs can also be very high. If the project team decides that vegetation clearance is necessary in order to safely and effectively clear UXO from a site, they should aim to minimize the potentially serious environmental impacts, such as increased erosion and habitat destruction, that can result from removing vegetation. The following are three land clearing methodologies:

- **Manual removal** is the easiest technique to control and allows a minimum amount of vegetation to be removed to facilitate the UXO investigation. Tree removal should be minimized, with selective pruning used to enable instrument detection near the trunks. If trees must be removed, tree trunks should be left in place to help maintain the soil profile. Manual removal results in the highest level of potential exposure to UXO of the personnel involved and should not be used where vegetation obscures the view of likely UXO locations.
- **Controlled burning** allows grass and other types of ground cover to be burned away from the surface without affecting subsurface root networks. The primary considerations when using controlled burning are ensuring that natural or manmade firebreaks exist and that potential air pollution is controlled. Favorable weather conditions will be required.
- **Defoliation** relies on herbicides to defoliate grasses, shrubs, and tree leaves. Manual removal of the remaining vegetation may be necessary. Sensitivity of groundwater and surface water bodies to leaching and surface runoff of herbicides will be important considerations.

Because the costs of investigation activities are based in large part on the acreage of the area to be characterized, most methods used to reduce the cost of the investigation involve reducing the size of the sampling area. Some of the techniques used to reduce costs overlap with other tools already described to improve the accuracy of an investigation. For example, a comprehensive historical search enables the project team to minimize the size of the area requiring investigation.

As discussed in section 7.5.2, statistical sampling methods are frequently used to reduce the costs of a site investigation. Controversy with the regulators and the public arises not over the need for statistically based sampling, but on the use of such sampling to make decisions about a site. Despite regulators' frequent rejection of statistical sampling, it is often used by DoD to estimate UXO density on a site and to make remedy selections. In general, however, regulators concur that appropriate uses for statistical sampling are as a screening tool to be used in combination with other information to set priorities, estimate costs, and test hypotheses.

Regulatory Requirements

Regulatory requirements come from a variety of laws and regulations, both State and Federal. The particular requirements that will be most applicable (or relevant and appropriate) to range cleanup activities are the Federal and State RCRA requirements for hazardous waste transportation, treatment, storage, and disposal. Other regulatory requirements may be related to the specific pathway(s) of concern, for example, groundwater cleanup levels. Chapter 2 of this handbook provides an overview of regulatory requirements that may apply. However, knowledge of the applicable requirements will be important to planning the investigation.

Since many OE investigations will take place under the authority of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), it is important to keep in mind that even if not directly and legally applicable to the OE activity or investigation, Federal and State laws may be considered to be "relevant and appropriate" by regulators. If the laws are considered relevant and appropriate, they are fully and legally applicable to a CERCLA cleanup activity.[103]

Important regulatory requirements that may affect both the investigation and the cleanup of the OE area include, but are not limited to, the following:

- CERCLA requirements for removal and remedial actions (including public and State involvement in the process)
- RCRA requirements that determine whether the waste material is to be considered a solid waste and/or a hazardous waste
- Requirements concerning the transportation and disposal of solid and hazardous wastes
- Regulatory requirements concerning open burning/open detonation of waste
- Regulatory requirements concerning incineration/thermal treatment of hazardous waste
- Other hazardous waste treatment requirements (e.g., land disposal restrictions)
- Air pollution requirements
- DDESB safety requirements

This handbook does not present a comprehensive listing of these requirements. Chapter 2 of this handbook provides a more detailed discussion of regulatory structures. Chapter 6 presents an overview of the DDESB safety requirements.

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[103] 40 CFR Section 300.400(g). National Oil and Hazardous Substances Pollution Contingency Plan.

7.4.5 Identification of Remedial Objectives

Decisions regarding cleanup have two components: the remediation goal (or cleanup standard) and the remediation technology. Remediation goals were described in the discussion of the PRG (section 7.4.2). The remediation technology is the manner in which the waste will be managed (e.g., use of institutional controls, removal of waste, treatment of waste once removed), including the treatment technology. The PRG represents the first step in determining the cleanup standard. The PRG is revised as new information is gathered and will be a central part of final cleanup decisions. It is equally important to identify potential cleanup technologies early in the process so that information required to assess the appropriate technology can be obtained during the investigation process (i.e., site findings affecting treatment selection).

The final step in planning the investigation is therefore identifying **remedial objectives**. What kind of cleanup activities are anticipated? Like the PRG and the CSM, this is a working hypothesis (that may change later) of what you will find, the volume of material that you must deal with, the media with which it will be associated (if it is explosive residue), and the nature of the technology that will be used to conduct the cleanup. Early screening of alternatives to establish remedial action objectives is important. Identifying appropriate alternatives may direct the geophysical investigations to help determine if a particular technology, such as bioremediation, will work at the site. Chapter 4 has a substantial discussion of technologies.

Finally, in addressing remedial objectives at the site, you will want to consider the disposal options for what may be an enormous amount of nonexplosive material. Typical range clearance activities excavate tons of trash and fragments of ordnance. In addition, the removal of explosive residues from bombs (often through open burning/open detonation) will leave additional contaminated materials and media to be disposed of. Some of the trash, such as target practice material, may be contaminated with hazardous waste. Some of the metal fragments may be appropriate for recycling. Information collected during the investigation will be used to assess not only the treatment and the potential for recycling of explosive and nonexplosive residue, but also the disposal of other contaminated materials and media from the site.

7.4.6 The Data Quality Objectives of the Investigation

You now have the information necessary to develop the data quality objectives (DQOs) of the investigation. The DQOs will reflect the information that you require to make the decision goals identified at the beginning of the planning phase. DQOs are based on gaps in the data you will need to make your decision. They should be as narrow and specific as possible and should reflect the certainty required for each step of the investigation. Objective statements that are carefully crafted, with regulator involvement and community review, will help ensure that discussions at the end of the investigation are about the risk management decisions, not about the relevance or quality of the data.

DoD/EPA Interim Final Management Principles on DQOs

Site-specific data quality objectives (DQOs) and QA/QC approaches, developed through a process of close and meaningful cooperation among the various governmental departments and agencies involved at a given CTT military range, are necessary to define the nature, quality, and quantity of information required to characterize each CTT military range and to select appropriate response actions.

Examples of typical DQOs may include the following:

- Determine the outer boundaries of potential UXO contamination on a range with a ___ percent probability of detection at a ___ percent confidence level.
- Determine with ___ percent probability of detection, at ___ percent confidence level, the density of UXO found in the top 2 feet of soil.
- Verify that there are no buried munitions pits under the range (___ percent probability of detection, ___ percent confidence level).
- Determine with __ percent certainty if there is UXO in the sediments that form the river bottom.
- Determine the direction of groundwater flow with a ___ percent certainty.

The DQOs for your site will determine the amount and quality of data required, as well as the level of certainty required. Which statements are appropriate for your range will depend on the previously identified goals of the investigation, the information that is already known about the site, and the acceptable levels of uncertainty.

Planning for Uncertainty

To a significant degree, data quality objectives will depend on the project team's and the public's tolerance for uncertainty. Ultimately, the amount of uncertainty that is acceptable is a qualitative judgment that must be made by all of the involved parties acting together.

As in any subsurface investigation, it is impossible to resolve all uncertainties. For example, regardless of the resources expended on an investigation, it is not possible to identify 100 percent of OE on a range. Likewise, unless the entire range is dug up, it is often impossible to prove with 100 percent certainty that the land area is clean and that no OE is present. The project team will need to decide whether uncertainties in the investigation are to be **reduced, mitigated, or deemed acceptable**. Planned land use is an important factor in determining the acceptable level of uncertainty. Some uncertainties may be more acceptable if the military will continue to control the land and monitor the site than if the site is to be transferred to outside ownership.

Uncertainties can be **reduced** through process design, such as a thorough sampling strategy, or through the use of stringent data quality acceptance procedures. Uncertainties can also be reduced by planning for contingencies during the course of investigation. For example, it may be possible to develop decision rules for the investigation that recognize uncertainties and identify actions that will be taken if the investigation finds something. A decision rule might say that if X is found, then Y happens. (In the simplest example, if any anomalies excavated prove to be ordnance, either exploded or unexploded, then a more intensive sampling process will be initiated.)

The results of uncertainties can be **mitigated** in a variety of ways, including by monitoring and contingency planning. A situation in which some uncertainties were mitigated occurred at Ft. Ritchie Army Garrison, a BRAC facility. UXO contamination was suspected beneath buildings that were constructed decades ago and were located on property designated for residential development. Because the buildings were to be reused following the land transfer, regulators chose not to require an investigation beneath the buildings because it would have necessitated razing them. As a risk management procedure, legal restrictions were established to ensure Army supervision of any future demolition of these buildings. The presence of UXO under buildings on land slated for transfer is an uncertainty the project team at Ft. Ritchie chose to accept. Risks are mitigated through the use of institutional controls.

Finally, uncertainties in the investigation may be **deemed acceptable** if they will be insignificant to the final decision. Information collected to "characterize the site" should be considered complete when there is sufficient information to determine the extent of risk, the proposed clearance depth, and the appropriate remedial technology. If information has been collected that makes it clear that action will be required, it may not be necessary to fully understand the boundaries of the range or the density or distribution of OE prior to making the remediation decision and starting clearance activities. Some amount of uncertainty will be acceptable, since the information required will be obtained during the clearance operation. (Note: This scenario assumes that there is sufficient information both for safety planning and for estimating the costs of the remediation.)

7.5 Stage 3: Designing the Sampling and Analysis Effort

Developing the data collection plan is often the most difficult part of the UXO investigation. Given the size of the ranges and the costs involved in investigating and removing UXO, judgments of acceptable levels of uncertainty often come into conflict with practical cost considerations when determining the extent of the field investigation.

Sampling and measurement errors in locating OE on your range will come from several sources:

- Inadequacy of detection methods to locate and correctly identify anomalies that may be potential OE
- Inappropriate extrapolation of the results of statistical sampling to larger areas
- Measurement errors introduced in laboratory analysis (either on-site or off-site)

Given that no subsurface investigation technique can eliminate all uncertainty, the sampling design (and supporting laboratory analysis) will be structured to account for the measurement error and to ensure that the data collected are of a known quality.

Field sampling activities include the following basic considerations:

- Safety planning and safety submissions (see Chapter 6)
- Detection technologies that are matched to the characteristics of the site and the UXO and to the objectives of the investigation (see Chapter 4)
- Specification of QA/QC measurements
- Determination of the quantity and quality of data needed and data acceptance criteria
- Determination of how, when, and where data will be collected
- Appropriate use of field analysis and fixed laboratory analysis to screen for explosive residues

There are typically four types of data collection methods employed during UXO investigations:

- Nonintrusive identification of anomalies using surface-based detection equipment
- Intrusive removal of ordnance (usually to verify the results of nonintrusive sampling)
- Soil sampling of potentially explosive materials
- Environmental sampling to establish the basic geophysical characteristics of the site (e.g., stratigraphy, groundwater depth and flow), including background levels.

The following decisions are to be made when designing the data collection plan:

- Establishment of a known level of confidence in the capabilities of subsurface detection techniques
- How to phase the investigation so that data collected in one phase can be used to plan subsequent phases
- Establishment of decision rules for addressing shifts in investigation techniques determined by field information
- The degree to which statistical sampling methods are used to estimate potential future risks
- How data obtained through the application of statistical sampling approaches can be verified
- The types of field analytical methods that will be used to test for explosive residues
- The appropriate means of separating and storing waste from the investigation
- Information required for the safety submission

The design of the sampling and analysis effort usually includes one or more iterations of geophysical studies, which incorporate geophysical mapping, anomaly reacquisition, and data processing to obtain a level of precision that will help you achieve your project objectives. Depending on your project objectives, more extensive geophysical studies may be necessary to evaluate the potential for OE impacts at the site. As a simple, instructive example, if your project objective is to confirm that an area is "clean" (free from UXO), and you detect a UXO item during your first geophysical sweep of the ground surface, you can conclude that the area should not be considered clean, and you must modify your objective. However, no additional data collection is necessary at this point.

Conversely, your objective may be to determine the depth of OE contamination. In this case, you use the combination of detection tools and data processing techniques deemed appropriate for your site by your project team, but you encounter interference from previously undetected metallic objects (e.g., agricultural tools) just under the ground surface. You may have to conduct a secondary geophysical study using another detection system that is not as sensitive to interference from metallic objects near the ground surface. If you believe the particular problem is localized, you may dig up the tools and try again.

The design of the sampling and analysis effort should recognize that fieldwork takes place in stages. The first stage will often be a surface clearance effort to render the OE area safe for nonintrusive investigation. A second stage will field test the detection technologies that you plan to use to verify QA/QC measurement criteria and establish a known level of precision in the investigation. The subsequent stage will involve the iterative geophysical studies discussed above. Observations in the field could cause a redirection of the sampling activities.

The bullets and discussion below address four important elements of the design of the sampling and analysis effort:

- Selection of detection technologies
- Use of statistics to determine the location and amount of both intrusive and nonintrusive sampling
- Development of QA/QC measures for your sampling strategy
- Use of both fixed lab and field screening analytical techniques

7.5.1 Identification of Appropriate Detection Technologies

Selection of the appropriate detection technology is not an easy task, as there is not one "best" tool that has the highest effectiveness, ease of implementation, and cost effectiveness in every situation. Rather, a combination of systems that include sensors, data processing systems, and operational platforms should be configured to meet the site-specific conditions. The project team should develop a process to identify the best system for the particular site.

The site-specific factors affecting the selection of appropriate technologies include the following:

- The ultimate goals of the investigation and the level of certainty required for UXO detection
- The amount and quality of historical information available about the site
- The nature of the UXO anticipated to be found on-site, including their material makeup and the depth at which they are expected to be found
- Background materials or geological or topographical factors that may interfere with UXO detection

Site-specific information should be used with information about the different detection systems (see Chapter 4) to select the system most appropriate for the project. Three key factors in selecting a detection technology are effectiveness, ease of implementation, and cost.

The **effectiveness** of a system may be measured by its proven ability to achieve detection objectives. For example, the probability of detection and the false alarm rate (or the ability to distinguish ordnance from nonordnance) affect a detection system's ability to achieve the objectives of an investigation. The science of OE detection has improved over the past decade to the point where today the probability of detection is, in general, not a limiting factor for most detection tools; however, the ability to discriminate between ordnance and nonordnance remains deficient in most detection tools. (See Chapter 4 for a discussion of detection systems.)

The **ease of implementation**, although a characteristic of the technology, is influenced by the project requirements. For example, a towed operational platform (typically a multisensor array towed behind a vehicle) may not be implementable in mountainous and rocky terrain. For another site, implementability might mean that a single detection system has to work on all types of terrain because of budgetary or other constraints.

Detection system **costs** generally depend on the operational platform and the data processing requirements. For example, an airborne platform is typically more costly to operate than a land-based system, and a system that requires off-site data processing will cost more than one with a real-time automatic data processing system.

7.5.2 UXO Detection Methods

Until the Jefferson Proving Ground Technology Demonstration (JPGTD) Project was established in 1994 to advance the state of OE detection, classification, and removal, "Mag and Flag" had been the default UXO detection method, with only marginal improvement in its detection and identification capabilities since World War II. Using Mag and Flag, an operator responds to audible or visible signals representing anomalies as detected by a hand-held magnetometer (or similar device), and places flags into the ground corresponding to the locations where signals were produced. While Mag and Flag has improved with advances in magnetometry, it produces higher false alarm rates than other available

What Is the Effectiveness Rate of UXO Detection Using Existing Technologies?

The answer to this question is centered around the definition of "detection." Debates over the answer to this apparently simple question reflect underlying values about how to conduct a UXO investigation and what costs are "worthwhile" to incur. Some parties assert that technology exists for UXO detection with a 95 percent accuracy or better. These parties are referring to the literal ability of existing technology to "find" many UXO objects. Other parties assert that the ability of current technology to "detect" UXO underground is much lower. UXO objects are "seen" as underground anomalies that must be interpreted. It is often difficult to distinguish between UXO, fragments of EO, other metallic objects, and magnetically charged rocks, boulders, and other underground formations. This inability to discriminate, and the resulting high number of false positives, is a contributing factor to the high cost of UXO clearance.

DoD/EPA Interim Final Management Principles on UXO Detection

The critical metrics for the evaluation of the performance of a detection technology are the probabilities of detection and false alarms....Identifying only one of these measures yields ill-defined capability. Of the two, probability of detection is a paramount consideration in selecting a UXO detection technology.

technologies. This is particularly true in areas with high background levels of ferrous metals. In addition, the Mag and Flag system is highly dependent on the capabilities of the operator. Efficiency and effectiveness have been shown to trail off at the end of the day with operator fatigue or when the operator is trying to cover a large area quickly. Because Mag and Flag is conducted manually, the data obtained is neither replicable nor easily verifiable. In order to verify the data or excavate anomalies, an operator or excavator needs to go over the same area again with a magnetometer. Because of these limitations and the availability of more reliable systems, the use of Mag and Flag is decreasing. However, under certain conditions, such as difficult terrain (e.g., mountainous, densely forested), and in nonferrous soils, Mag and Flag may be the best method for detecting UXO.

Under the JPGTD program, developers test and analyze UXO detection technologies such as magnetometry, electromagnetic induction, ground penetrating radar, and multisensor systems. Emerging technologies such as infrared, seismic, synthetic aperture radar, and others are tested and developed at JPGTD. Table 7-2 lists several commonly used and emerging detection technologies and their strengths and weaknesses. A full discussion of each of these technologies is provided in Chapter 4.

Table 7-2. UXO Detection Technologies

UXO Detection Technology	Strengths and Limitations	Effective Uses
Magnetometry	High probability of detection, low ability for target discrimination	For ferrous targets in nonferrous soils, near soil surface
Electromagnetic (EM) Induction	Moderate probability of detection, low ability for target discrimination	All metallic targets near the soil surface
Ground Penetrating Radar (GPR)	Moderate probability of detection, low ability for target discrimination; severely inhibited by soil moisture and vegetative cover	Dry sandy soils
Multisensor Arrays	High probability of detection, moderate ability for target discrimination	Effectiveness determined by suitability of sensors and operational platform to site

While most detection technologies have an adequate probability of identifying anomalies beneath the ground surface, many cannot accurately distinguish between ordnance and nonordnance, such as ferrous rocks. In addition, they often cannot distinguish dud-fired munitions and fragments from fully exploded munitions. A resulting higher number of false positives increases the number of anomaly excavations required, both during the QA/QC process and during the clearance process. Unless false positives can be positively identified as nonordnance items, they are likely to be excavated during the investigation or clearance phase, a time-consuming and costly undertaking. Therefore, minimizing false alarms can greatly reduce the cost of and time for the project.

The primary goal of Phase IV of the JPGTD was to improve the ability to distinguish between ordnance and nonordnance. While progress has been made in distinguishing UXO from clutter such as UXO fragments, additional work is still needed to further advance target discrimination technologies, to make them commercially available, and to increase their use. With reliable and readily available target discrimination technologies, false alarm rates should be greatly reduced, thereby significantly reducing the costs of UXO investigations. A number of data processing/modeling tools have been developed to screen nonordnance targets from raw detection data. These discrimination methods typically rely on a comparison of the signatures of targets with a variety of sizes and shapes against a database of known UXO and clutter signatures. Additional information about data processing for UXO discrimination is provided in Chapter 4.

Identifying UXO Locations

In the past, the primary method used by UXO personnel to identify the location of UXO was to manually mark the locations at which UXO detection tools produced a signal indicating the presence of an anomaly. If operators wished to record the UXO location data, they would use GIS or other geographic programs to calculate the UTM (Universal Transverse Mercator) grid coordinates for each flag. Since the development of automatic data recording devices and digital georeference systems, data quality has improved significantly. Using digital geophysical mapping, a UXO detection device and a digital global positioning system identify the location of the UXO on the earth's surface within a centimeter of accuracy, and the location is recorded automatically. Therefore, flags are not needed to find the location of the UXO, and regulators and/or excavators do not need to resurvey in order to verify detection data. Because digital geophysical mapping records location data automatically, there is no risk of an operator missing or misrecording a location as when manually recording anomaly locations, and the data can be more available for future investigations and for further data processing.

DoD/EPA Management Principles on Data Recording

A permanent record of the data gathered to characterize a site and a clear audit trail of pertinent data analysis and resulting decisions and actions are required. To the maximum extent practicable, the permanent record shall include sensor data that is digitally recorded and geo-referenced. Exceptions to the collection of sensor data that is digitally recorded and geo-referenced should be limited primarily to emergency response actions or cases where impracticable. The permanent record shall be included in the Administrative Record. Appropriate notification regarding the availability of this information shall be made.

7.5.3 Use of Statistically Based Methodologies To Identify UXO

The next key element of your sampling plan will be to select the quantity and location of samples of the area to be sampled. In reality, there are three questions to be answered:

- Where to deploy your detection equipment
- Where and how many anomalies are to be excavated to see what you have actually found
- How to use the information from detection and anomaly reacquisition to make a decision at your site

Given the size of the ranges investigated, these questions are often answered through the use of a variety of statistical sampling approaches.

This section addresses four topics pertinent to statistically based sampling: the rationale for statistically based sampling, how DoD currently uses the data from such sampling programs, regulator concerns with the use of statistically based data, and recommendations on appropriate use of these data to make appropriate closure decisions for a range.

Terms Used in Statistical Sampling

Because many familiar terms are used in slightly different ways in the discussion of statistical sampling, the following definitions are provided for clarification:

Detection: Determining the presence of UXO from system responses (UXO Center of Excellence Glossary, 2000).

Sampling: The act of investigation of a given area to determine the presence of UXO. It may encompass both the detection and excavation of anomalies.

Location: Determination of the precise geographic position of detected UXO. Includes actions to map locations of detected UXO. (UXO Center of Excellence Glossary, 2000).

Recovery: Removal of UXO from the location where detected (UXO Center of Excellence Glossary, 2000).

Identification/evaluation: Determination of the specific type, characteristics, hazards, and present condition of UXO (UXO Center of Excellence Glossary, 2000).

7.5.3.1 *Rationale for Statistically Based Sampling*

Statistically based sampling was developed to address the limitations of noninvasive UXO detection technologies and the use of those technologies on the large land areas that may make up a range. Current methodologies for identifying anomalies in a suspected UXO area have various deficiencies, as described previously (see section 7.5.1). The most common deficiencies include probability of detection and ability to differentiate between UXO and/or fragments and background interference (objects or natural material not related to ordnance). Thus, most detection technologies have a moderate to high false alarm rate. This means that there is a high degree of uncertainty associated with the data generated by the various detection methods. No analogous situation exists for compounds usually found at conventional hazardous waste sites. The problem of highly uncertain anomaly data is magnified for three reasons:

- The areas suspected of containing UXO could be hundreds or even thousands of acres; therefore, it is often not practicable to deploy detection equipment over the entire area.
- Even within sectors suspected of containing UXO, it is often not practicable to excavate all detected anomalies during sampling to confirm whether they are in fact UXO. Excavation to the level appropriate for the future land use is normally done during the remediation phase.
- When detection tools detect anomalies in areas where it is not known if ordnance has been used, it is difficult to know (in the absence of excavation) if the detected anomaly is in fact ordnance.

Statistically based sampling methods were developed to address the issue of how to effectively characterize a range area without conducting either nonintrusive detection or intrusive sampling on 100 percent of the land area. Statistically based sampling methods extrapolate the results of small sample areas to larger areas.

7.5.3.2 *Statistical Sampling Tools*

A variety of statistical sampling methodologies exist, each serving a different purpose, and each with its own strengths and weaknesses. Table 7-3 identifies seven statistical sampling methodologies and summarizes their strengths and weaknesses and the applications for which they are used.

What Is SiteStats/GridStats?

SiteStats/GridStats is a computer program that combines random sampling with statistical analysis. The controversy over this method is the use of random sampling to detect UXO. Unlike traditional chemical pollutants, UXO is rarely, if ever, uniformly distributed across a given area. However, random sampling assumes uniform distributions, making it an inappropriate technique for sampling UXO contamination unless homogeneity can be proven.

A grid is located within a (presumed) homogeneous sector (typically 50 x 50, 100 x 100, or 100 x 200 feet) that is cleared of vegetation and scanned using a detection device selected for the particular site. Anomalies are marked, and if less than 20 anomalies are detected within a grid, then all anomalies are excavated. When more than 20 anomalies are detected, 25 to 33 percent of them are selected for excavation based on a combination of statistical sequential probability ratio test (SPRT) and ad hoc stopping rules. Once the anomalies are identified, results are fed into the software program. The software then uses principles of random sampling to determine which anomalies to excavate next, which grids to sample next, and so forth. The software determines when an adequate portion of the site has been sampled and the investigation is complete. Finally, based on the investigation of a sufficient number of grids within a number of sectors, the density of UXO is extrapolated to the entire range.

The two most common statistical sampling approaches used by DoD are SiteStats/GridStats and the UXO Calculator. The general principles of the two approaches are similar. First, the sector is evaluated to determine if it is homogeneous. If it is not homogeneous, a subsector is then evaluated for homogeneity, and so forth, until the area to be investigated is determined to be homogeneous. The sampling area is divided into a series of grids and detection devices used to identify subsurface anomalies. The software, using an underlying probability distribution, randomly generates the location and number of subsequent samples within a grid, or the user can select the location of subsequent samples. Based on the results of each dig, the model determines which and how many additional anomalies to excavate, when to move on to the next grid, and when enough information is known to characterize the grid. (See the following text box for a discussion of homogeneity.)

Table 7-3. Comparison of Statistical Sampling Methodologies*

Sampling Methodology	Description	Strengths and Weaknesses	Intensity of Coverage	Typical DoD Use
Full coverage	Detection of 100% of a site.	Most reliable results. Expensive and may be environmentally destructive if removal of all vegetation is necessary.	High	Used for investigation and cleanup of small areas.
Fixed pattern sampling	Detection conducted at evenly spaced grids. Generally, 10% of a site is investigated.	Even coverage of entire site. Gaps between plots minimized.	Medium	Useful for locating hotspots and for testing clean sites.
UXO Calculator	Determines the size of the area to be investigated in order to meet investigation goals, confidence levels in ordnance contamination predictions, and UXO density in a given area.	Very small area investigated to prove to varying levels of confidence that a site is "safe" for transfer. All computations are based on an assumption of sector homogeneity with respect to UXO distribution.	Low	Used with digital geophysical mapping data. Used to make a yes/no decision as to the presence or absence of ordnance. Used to determine confidence levels in ordnance contamination predictions.
SiteStats/ GridStats	Random sampling is based on computer program. Usually less than 5% of a total site is investigated and 25-33% of anomalies detected are excavated.	Potentially huge gaps between sampling plots, very small investigation areas, no consideration of fragments or areas suspected of contamination. Relies on a rarely valid assumption that UXO contamination is uniformly distributed. Hot spots may not be identified.	Low	Designed for use with Mag and Flag data. Reduces the required amount of excavation to less than 50% of levels required by other techniques. Used by DoD to extrapolate results to larger area.
Hybrid grid sampling	Biased grids investigated in areas suspected of contamination or in areas with especially large gaps between SiteStats/GridStats sampling plots.	Compensates for some of the limitations of SiteStats/GridStats. Relies on invalid assumption that UXO contamination is uniformly distributed.	Medium	Used to direct sampling activity to make site determinations.
Transect sampling	Detection conducted along evenly spaced transects.	Used in areas with high UXO concentrations. Should not be used in heavily vegetated areas. Limited applications.	Medium	Useful for locating boundaries of high-density UXO areas.
Meandering path	Detection conducted along a serpentine grid path through entire site using GPS and digital geophysical mapping.	Reduced distances between sampling points; environmentally benign because vegetation clearance is not required. Digital geophysical mapping records anomaly locations to within centimeter of accuracy.	Medium	Used to direct sampling activity to make site determinations in ecologically sensitive areas.

*Any of these sampling methodologies may include limited excavation of anomalies to verify findings.

The Importance of Homogeneity

The applicability of statistical sampling depends on whether the sector being sampled is representative of the larger site. Statistical sampling as incorporated in SiteStats/GridStats and UXO Calculator assumes that a sector is homogeneous in terms of the likelihood of UXO being present, the past and future land uses, the types of munitions used and likely to be found, the depths at which UXO are suspected, and the soils and geology. Because statistical sampling assumes an equal probability of detecting UXO in one location as in another, if the distribution of UXO is not truly homogeneous, the sampling methodologies could overlook UXO items. Environmental conditions such as soils and geology affect the depth and orientation at which munitions land on or beneath the ground surface. If, on one part of a range munitions hit bedrock within a few inches of the ground surface, they will be much closer to the surface (and probably easier to detect) than others that hit sandy soil on top of deeper bedrock. In addition, different types and sizes of munitions reach greater depths beneath the surface.

Attempts to assess homogeneity can include, but should not be limited to the following activities: conducting extensive historical research about the types of munitions employed and the boundaries of the range, surveying the site; or using previously collected geophysical data.

There are two main differences between SiteStats/GridStats and the UXO Calculator. First, the technologies typically used for input differ. SiteStats/GridStats is most commonly used with a detection tool or combination of tools, whereas UXO Calculator is used with both a detection tool and a digital geophysical mapping device. Second, SiteStats/GridStats produces a UXO density estimate based only on the statistical model. The data from SiteStats/GridStats is then input into OECert, a program that contains a risk management tool as well as a screening-level estimator for the cost of remediation.

The SiteStats/GridStats results are generally presented as having a confidence level that is based on a set of assumptions and may not be justified. The UXO density estimates are often used as input to OECert to evaluate the public risk and to cost-out removal alternatives. The OECert model is a tool that compares the costs of remediation alternatives to the number of public exposures likely under each remediation scenario. OECert then generates development recommendations that minimize remediation costs while maintaining risk levels that are acceptable to the U.S. Army Corps of Engineers (USACE) but may not be acceptable to regulators and the public.

Assuming homogeneous UXO distribution within a sector, UXO Calculator also estimates UXO density, but the program contains an additional risk management tool that allows the operator to input an assumed acceptable UXO density based on land use. UXO Calculator then calculates the number of samples required to determine if this density has been exceeded. However, acceptable UXO target densities are neither known nor approved by regulators. As with SiteStats/GridStats, the sample size obtained is also based on an assumption of homogeneity within a sector. The UXO Calculator software contains a density estimation model, risk management tool, and cost estimator tool. The risk management tool requires assumptions about land use and from that information assumes a value for the number of people who will frequent a site. The justification of the land use assumptions and the resulting population exposure are not well documented.

7.5.3.3 *USACE's Use of Statistically Based Sampling Results*

The USACE statistical models are used to determine the following:

- When sufficient sampling has been conducted within a grid
- How many grids within a sector need to be investigated
- How many sectors need to be investigated
- The UXO density for the range under investigation
- The clearance depth and land use for the site

While statistical sampling is supposed to be one of many factors considered when making a risk management decision, there are instances where it appears to be the only basis for the decision. Consequently, where this has occurred, EPA and State regulators have generally rejected the proposed remedy, including that of "no further action."

> **Assessing Risk at Ft. Ritchie Army Garrison**
>
> USACE contractors conducted a site characterization of Ft. Ritchie Army Garrison, some of which was to be turned over to private ownership for residential development. This site characterization consisted of investigations of approximately 50 100 x 100-foot grids, which represented approximately 7 percent of the identified UXO area. SiteStats/GridStats identified that 95 percent of the UXO was located within 1 foot of the ground surface. Using OECert, contractors determined that the appropriate remedy for this site was surface clearance.
>
> However, regulators expressed concern with the adequacy and reliability of SiteStats/GridStats and OECert methods, and the remedy was revised to include cleanup to a depth of 4 feet in all areas slated for industrial/commercial and residential use, cleanup to 1 foot in a heavily wooded area with high probability of UXO, and deed restrictions on the entire identified UXO area. In addition, the Army will clear areas to be developed in the future to a depth of 4 feet. This approach is expected to save money in the future by reducing vulnerability to frost heave, the severity of restrictions, monitoring efforts, and mobilization costs for construction support.

7.5.3.4 *Regulator Concerns Regarding the Use of Statistical Sampling Procedures*

The use of statistical sampling is a source of debate between the regulatory community (EPA and the States) and DoD.[104] Faced with large land areas requiring investigation, and the high costs of such investigation, DoD has used several statistical approaches to provide an estimate of the UXO density at a site as a basis for selecting remedies or making no-action decisions. Regulatory concerns have generally focused on four areas: (1) the inability of site personnel to demonstrate that the assumptions of statistical sampling have been met, (2) the extrapolation of statistical sampling results to a larger range area without confirmation or verification, (3) the use of the density estimates in risk algorithms to make management decisions regarding the acceptable future use of the area, and (4)

[104] "Interim Guidance on the Use of SiteStats/GridStats and Other Army Corps of Engineers Statistical Techniques Used to Characterize Military Ranges." Memo from James E. Woolford, Director, EPA Federal Facilities Restoration and Reuse Office, to EPA Regional Superfund National Policy Managers, January 19, 2001.

the use of statistical sampling alone to make site-based decisions. Criticisms of statistical sampling include the following:

> **DoD/EPA Interim Final Management Principles on Statistical Sampling**
>
> Site characterization may be accomplished through a variety of methods, used individually or in concert with one another, and including, but not limited to, records searches, site visits, or actual data acquisition, such as sampling. Statistical or other mathematical analyses (e.g., models) should recognize the assumptions imbedded within those analyses. Those assumptions, along with the intended use(s) of the analyses, should be communicated at the front end to the regulator(s) and the communities so the results may be better understood. Statistical or other mathematical analyses should be updated to include actual site data as it becomes available.

- Statistical sampling is based on assumptions that the area being sampled is homogeneous in terms of the number of anomalies, geology, topography, soils, types of munitions used and depths at which they are likely to be found, and other factors. Often, too little information is known to ensure that the assumptions on which statistical sampling is based are met, and the procedures used to test sector homogeneity are not effective enough to detect sector nonhomogeneity.
- Statistical procedures used in SiteStats/GridStats to determine when the sector has been sufficiently characterized and also to test sector homogeneity are not statistically sound.
- Statistical procedures are often overridden by ad hoc procedures.
- The use of statistical techniques often results in the sampling of a relatively small area in comparison with the size of the total area suspected of contamination. The small sampling area may not necessarily be representative of the larger area.
- The ability of statistical sampling to identify UXO in areas where military activities occurred is questionable.
- The capabilities of statistical methods to identify hot spots are limited.
- A nonconforming distribution may not be identified by the program and thus not be adequately investigated.
- The distances between sampling grids are often large.
- Relying exclusively on actual UXO effectively ignores UXO fragments as potential indicators of nearby UXO.
- Confidence statements based on the assumed probability distribution do not account for uncertainties in the detection data.
- Confidence statements also relate to an expected land use that is not carefully justified.
- Results of confirmatory sampling are not presented or summarized in a manner that allows a regulator to evaluate the quality and limitation of the data that are used in the risk management algorithms.
- There is no sensitivity analysis of the applicability of the risk management tools to the input parameters. For example, there is nothing analogous to EPA's "most probable," "most exposed individual," and "worst case" assumptions for baseline risk assessments at Superfund sites.

7.5.3.5 *Recommendations on the Use of Statistical Sampling*

In general, regulatory agencies believe that statistical sampling is best used as a screening tool or to provide preliminary information that will be confirmed during the clearance process. Applications of statistically based sampling tools, when used in conjunction with other tools, may be used for the following purposes:

- Prioritizing range areas for thorough investigation and/or clearance
- Analyzing the practicality and cost of different clearance approaches, as well as the usefulness of different remedial alternatives
- Establishing the potential costs of clearance for different land uses
- Facilitating a determination of which land uses may be appropriate following remediation, and the levels and types of institutional controls to be imposed

Regulatory agencies also believe that statistical sampling alone should not be used to make no-action decisions. Other significant data also will be required, including the following:

- Extensive historical information
- Groundtruthing (comparing the results of statistical sampling to actual site conditions) of randomly selected areas to which results will be extrapolated

Even the use of historical and groundtruth information, combined with statistical sampling results, will be suspect when the presence of ordnance fragments suggests that active range-related activities occurred in the past. Range investigation practices are evolving, but many regulatory and technical personnel agree that statistical sampling tools must be used in conjunction with the other elements of the systematic planning process (including historical research). EPA makes the following recommendations:

- The assumptions on which statistical sampling techniques are based should be both clearly documented and appropriate to the particular site under investigation.
- The density estimates from the statistical sampling procedure should be carefully scrutinized and computed using statistically correct algorithms.
- Any risk estimates based on computer algorithms (e.g., OECert) should be adequately documented for regulatory review.

Given the size of many OE areas, it is likely that some form of statistical sampling will be used at your site. Decisions regarding the acceptability of statistical sampling involve the following issues:

- The nature of the decision to be made
- Agreement on the criteria on which the decision will be made
- Agreement on the assumptions and decision rules that are used in the statistical model
- The level of confidence in the detection technology
- The use and amount of anomaly reacquisition to verify findings of detection technology

- The presentation of these data, summarized in an appropriate format
- The quality and quantity of information from historical investigations

7.5.4 Establishment of QA/QC Measures

There are two main types of measurement uncertainty you must consider when developing investigation plans for OE: (1) the uncertainties associated with the detection methodology and target classification, and (2) the uncertainty associated with the use of statistically based sampling methods. The amount of measurement uncertainty can be controlled using a number of QC approaches.

7.5.4.1 *Detection Capability QA/QC*

The quality assurance/quality control procedures vary with the type of investigation, but standard QC practices include regular instrument inspection and calibration. Detection equipment is inspected daily to identify equipment fatigue or damage, and repairs or adjustments are made promptly. Detection instruments are calibrated in the field using QC grids in areas that have geology and topography similar to the area being investigated. QC grids are seeded with statistically significant numbers of buried target items. Using the detection system selected for the area of concern, the detection team investigates the QC grid and makes a calculation to determine a meaningful confidence interval for the detection capability and statistical support for clearance certification (e.g., a 90 percent probability of 85 percent detection). Depending on the project goals, if the confidence interval and the probability of detection for the project cannot be achieved, the detection equipment may need to be better calibrated or changed, or the detection system operators may need additional training.

Similarly, for surface sweeps, search effectiveness probability validation is used to test the team and the detection equipment. In search effectiveness probability validation, the area being investigated is “salted” with controlled inert ordnance items that are flagged or collected as the sweep team proceeds through the salted area. The number of planted items collected is compared with the total number of planted items, and a percentage for search effectiveness probability is calculated. At investigations on Kaho’olawe Island Reserve in Hawaii, a minimum search effectiveness probability of 90 percent is required in order for operations to continue. Following the surface sweep, visual searches are conducted by a QC team. An area that is 12 to 15 percent of the total area is inspected by the QC team. The identification of one UXO item or three ordnance-like or inert UXO items is considered a quality defect that requires the sweep team to resweep the area.[105]

Other QA/QC measures include the independent verification of distance or angular measurements. UXO survey teams may be required to independently perform distance or angular measurements two times to identify deviations resulting from human error. For geophysical mapping performed without digital geophysical reference systems, Universal Transverse Mercator

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[105]Final Report, Unexploded Ordnance Model Clearance Project, Kaho’olawe Island, Hawaii, OHM Remediation Services Corp., June 1996.

(UTM) grid coordinate values created in GIS or other geographic programs are verified by QC teams using a differential global positioning system (DGPS) to ensure correct target locations.

Investigation calibration tests almost always rely on the excavation of a small area that has been mapped to verify detection capability, called "in-process QA." Using in-process QA, a representative subplot of a sampled area is excavated and the number and types of anomalies found are compared with the number and types detected in the sampled area. The acceptable probabilities of detection and confidence intervals are determined by the team and should be based on the goals of the characterization.

7.5.4.2 *Verifying Statistical Sampling*

One of the criticisms of many statistical sampling methodologies regards the extrapolation of results of sampling in one grid or area to a much larger area. Any results of statistical sampling should be groundtruthed in a randomly selected area to which statistical sampling results will be extrapolated.

7.5.5 Analytical Methods

Two approaches may be used to determine the presence and concentration of explosives and explosive residues in the environment. One approach is to conduct real-time analysis in the field. This approach generates quantitative and qualitative data, depending on the exact method chosen, the compounds present, and their concentration range. The other approach is to collect samples in the field and analyze the samples in a laboratory. The laboratory can be either an on-site mobile laboratory or an off-site fixed laboratory.

The integrated use of both on-site field methods and laboratory methods provides a comprehensive tool for determining the horizontal and vertical extent of contamination, identifying potential detonation hazards, indicating the volume of contaminated media requiring remediation, and determining whether remediation activities have met the cleanup goals.

Real-time field analysis provides nearly immediate results, usually in less than 2 hours, at lower costs than laboratory methods. However, field methods are less accurate than laboratory methods, especially near the quantitation limit. They also have lower selectivity when the samples contain mixtures of explosive compounds, and they are subject to more interferences. For these reasons, a fixed percentage of samples, between 10 and 20 percent of the total samples, should be sent to a laboratory for additional analysis.

7.5.5.1 *Field Methods*

Because of the heterogeneous distribution of explosive compounds in the environment, field analytical methods can be a cost-effective way to assess the nature and extent of contamination. The large number of samples that can be collected, combined with the availability of real-time data, allows investigators to redirect the sampling during a sampling event.

TNT or RDX is usually present in explosives-contaminated soils. Studies of sampling and analysis at a number of explosives-contaminated sites reported "hits" of TNT or RDX in 72 percent of the soil samples collected and up to 94 percent of water samples collected.[106,107] Thus the use of field methods for both of these compounds can be effective in characterizing the contamination at a site.

Two basic types of on-site analytical methods are widely used for explosives in soil: colorimetric and immunoassay. Colorimetric methods generally detect broad classes of compounds, such as nitroaromatics, including TNT, or nitramines, such as RDX, while immunoassay methods are more compound-specific and can also be used with water samples. Water samples can also be analyzed in the field for TNT and RDX using a continuous flow immunosensor and fiber-optic biosensor. Most on-site analytical methods have a detection range at or near 1 mg/kg for soil and 0.07 to 15 Fg/L for water.

Field methods can be subject to positive matrix interferences from humic substances found in soils. For colorimetric methods, these interferences can be significant for samples containing less than 10 mg/kg of the target compound. In the presence of these interferences, many immunoassay methods can give sample results that are biased high compared to laboratory results. Commonly applied fertilizers, such as nitrates and nitrites, also interfere with many of these methods. Therefore, it is considered good practice to send a percentage of the samples collected to a fixed laboratory for confirmatory analysis.

Colorimetric methods treat a sample with an organic solvent, such as acetone, to extract the explosives. For example, for soil, a 2 to 20 gram sample is extracted with 6.5 to 100 mL of acetone. After 1 to 3 minutes, the acetone is removed and filtered. A strong base, such as potassium hydroxide, is added to the acetone, and the resulting solution's absorbance at a specific light wavelength is measured using a spectrophotometer. The resulting intensity is compared with a control sample to obtain the concentration of the compound of interest.

Colorimetric methods, though designated for a specific compound, such as TNT or RDX, will respond to chemically similar compounds. For example, the TNT methods will respond to TNB, DNB, 2,4-DNT, and 2,6-DNT. The RDX methods will respond to HMX. Therefore, if the target compound, TNT or RDX, is the only compound present, the method will measure it. If multiple compounds are present, they will also respond to the test in the same way as the target compound, adding to the concentration of the target compound being quantified.

The various immunoassay and biosensor methods differ considerably. However, the underlying basis can be illustrated by one of the simpler methods. Antibodies specific for TNT are linked to solid particles. The contaminated media is extracted and the TNT molecules in the extract

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[106]Field Sampling and Selecting On-Site Analytical Methods for Explosives in Soils. A.B. Crockett et al. U.S. Environmental Protection Agency. EPA/540/R-97/501. November 1996.

[107]Field Sampling and Selecting On-Site Analytical Methods for Explosives in Water. A.B. Crockett et al. U.S. Environmental Protection Agency. EPA/600/S-99/002. May 19, 1999.

are captured by the solid particles. A color-developing solution is added. The presence or absence of TNT is determined by comparing it to a color card or a field test meter.

Whereas colorimetric methods will respond to other chemically similar compounds, immunoassay methods are more specific to a particular compound. For example, the TNT immunoassay methods will also respond to a percentage of TNB, 2,4-DNT, and 2,6-DNT when multiple nitroaromatic compounds are present. The RDX immunoassay method has very little response (less than 3 percent) to nitramines such as HMX.

The explosive compounds that can be detected by colorimetric and immunoassay methods are indicated in the table below. In addition, TNT and RDX can be detected and measured in water samples using biosensor methods.

Table 7-4. Explosive Compounds Detectable by Field Analytical Methods

Compound	Colorimetric Test	Immunoassay Test
Nitroaromatics		
2,4,6-Trinitrotoluene (TNT)	X	X
1,3-Dinitrobenzene (DNB)	X	
1,3,5-Trinitrobenzene (TNB)	X	X
2,4-Dinitrotoluene (2,4-DNT)	X	
2,6-Dinitrotoluene (2,6-DNT)	X	X
4-Amino-2,6-dinitrotoluene (4AmDNT)		X
Methyl-2,4,6-trinitrophenylnitramine (Tetryl)	X	
Methyl-2,4,6-trinitrophenylnitramine (Tetryl)	X	
Nitramines		
Hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX)	X	X
Octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine (HMX)	X	

7.5.5.2 *Fixed Lab Methods*

Explosive compounds such as TNT and RDX, as well as the impurities created during their manufacture and their environmental transformation compounds, are classified as semivolatile organic compounds. However, these compounds have a number of important chemical and physical properties that make their analysis by methods used for other semivolatile compounds problematic. Most of these compounds will degrade or explode at temperatures below 300 ^{o}C. Extreme caution must be employed when using gas chromatography methods for the analysis of these compounds. These compounds are also very polar; thus, the use of the nonpolar solvents used in typical semivolatile analytical methods is not feasible.

EPA Method 8330[108]

Samples containing or suspected of containing these compounds are usually analyzed using high-performance liquid chromatography (HPLC) with ultraviolet detection. If explosive compounds are detected, then the samples must be rerun using a second, different HPLC column for confirmation. The currently approved EPA method is SW-846 Method 8330, which provides for the detection of parts per billion (ppb) of explosive compounds in soil, water, and sediments. The compounds that can be detected and quantified by Method 8330 are listed in the text box.

Compounds That Can Be Detected and Quantified by SW-846 Method 8330 (EPA)

- 1,3-Dinitrobenzene (DNB)
- 1,3,5-Trinitrobenzene (TNB)
- 2-Amino-4,6-dinitrotoluene (2AmDNT)
- 2-Nitrotoluene
- 2,4-Dinitrotoluene (2,4-DNT),
- 2,4,6-Trinitrotoluene (TNT)
- 2,6-Dinitrotoluene (2,6-DNT)
- 3-Nitrotoluene,
- 4-Amino-2,6-dinitrotoluene (4AmDNT),
- 4-Nitrotoluene
- Hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX)
- Methyl-2,4,6-trinitrophenylnitramine (Tetryl)
- Nitrobenzene
- Octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine (HMX)

Samples can be extracted with methanol or acetonitrile for TNT, but acetonitrile is preferred for RDX. The sample extracts are injected into the HPLC and eluted with a methanol-water mixture. The estimated quantitation limits in soil can range from 0.25 mg/kg to 2.2 mg/kg for each compound. The estimated quantitation limits in water can range from 0.02 Fg/L to 0.84 Fg/L for low-level samples and 4.0 Fg/L to 14.0 Fg/L for high-level samples.

EPA Method 8095[109]

Method 8330 describe above is the standard EPA test method for explosive compounds. However, Method 8330 has a number of problems associated with it. These problems include high solvent usage, multiple compound coelutions (one or more compounds coming out at the same time) in sample matrices with complex mixtures, and long run times. In order to address these problems, EPA Method 8095 has been proposed as an alternative analytical method. Method 8095 uses gas chromatography with electron capture detection. It can detect and quantify all of the same compounds as Method 8330 (see text box above). In addition, Method 8095 can also detect and quantify 3,5-dinitroaniline, nitroglycerine, and pentaerythritol tetranitrate (PETN).

Samples are extracted using either the solid-phase extraction techniques provided in Method 3535 (for aqueous samples) or the ultrasonic extraction techniques described in Method 8330 (for solid samples). Acetonitrile is the extraction solvent. Further concentration of the extract is only required for low detection limits. The extracts are injected into the inlet port of a gas chromatograph

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[108]SW-846 Method 8330, Nitroaromatics and Nitramines by High Performance Liquid Chromatography (HPLC), U.S. Environmental Protection Agency, Revision 0, September 1994.

[109]Method 8095, Explosives by Gas Chromatography, U.S. Environmental Protection Agency, Revision 0, November 2000.

equipped with an electron capture detector. Each analyte is resolved on a short, wide-bore fused-silica capillary column coated with polydimethylsiloxane. Positive peaks must be confirmed on a different chromatography column.

EPA Method 7580[110]

In addition to explosive compounds, other materials used in military ordinance present hazards to human health and the environment. White phosphorus (P_4) is a toxic, synthetic substance that has been used in smoke-producing munitions since World War I. Due to the instability of P_4 in the presence of oxygen, it was originally not considered an environmental contaminant. However, after a catastrophic die-off of waterfowl at a U.S. military facility was traced to the presence of P_4 in salt marsh sediments, it was discovered that P_4 can persist in anoxic sedimentary environments.

Method 7580, gas chromatography with nitrogen/phosphorus detector, may be used for the analysis of P_4 in soil, sediment, and water samples. Two different extraction methods may be used for water samples. The first procedure provides sensitivity on the order of 0.01 Fg/L. It may be used to assess compliance with Federal water quality criteria. The second procedure provides for a sensitivity of 0.1 Fg/L. The extraction method for solids provides a sensitivity of 1 Fg/kg. Due to the use of the nitrogen/phosphorus detector by this method, no interferences have been reported.

Because P_4 reacts with oxygen, sample preparation must be done in an oxygen-free environment, such as a glove box that has been purged with nitrogen. Samples are extracted with either diethyl ether (low water method), isooctane (high water method), or degassed reagent water/isooctane (solids). The extracts are then injected into the gas chromatograph that has been calibrated with five standards.

EPA Method 314.0[111]

The presence of the perchlorate anion in groundwater and surface waters that are used for drinking water has become a concern. Until recently, a suitable method for analyzing for the perchlorate anion was not available. EPA Method 314.0, the Determination of Perchlorate in Drinking Water Using Ion Chromatography, is the standard method for perchlorate analysis. Due to the possibility of interferences at the low sensitivities of this method, identification of perchlorate should be confirmed by use of a laboratory fortified matrix sample.

To detect and quantify perchlorate, a 1.0 mL volume of sample is introduced into an ion chromatograph. The perchlorate anion is separated and quantified using a system comprised of an ion chromatographic pump, sample injection valve, guard column, analytical column, suppressor device, and conductivity detector.

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[110]Method 7580, White Phosphorus (P_1) by Solvent Extraction and Gas Chromatography, U.S. Environmental Protection Agency, Revision 0, December 1996.

[111]Method 314.0, Determination of Perchlorate in Drinking Water Using Ion Chromatography, U.S. Environmental Protection Agency, Revision 1.0, November 1999.

7.6 Site Response Strategy

Most of this chapter has focused on the essential components of the Systematic Planning Process that will be used to devise the sampling and analysis strategy appropriate for your site. The question remains – what do you do with this information?

The information from your site investigation will be documented in an investigation report (called a remedial investigation report in the CERCLA program and a RCRA Facility Investigation in the RCRA program). In the standard CERCLA process addressing chemical contamination, this information will be evaluated with a site-specific risk assessment to determine whether the concentrations of chemicals present at the site provide a potential risk to human health and the environment and whether pathways between chemicals present at the site and potential receptors will expose receptors to unacceptable levels of risk. When evaluating the chemical (nonenergetic) residues of OE, the standard risk assessment process will be used.[112]

When evaluating the information associated with an OE site (UXO, explosive soil, and buried munitions), two separate decisions are made:

- Is any OE present or potentially present that could pose a risk to human health or the environment
- What is the appropriate **site response strategy** if OE is present or potentially present? Three fundamental choices are evaluated:
  - Further investigation is required.
  - Response action is required (either an active response such as clearance or containment, or a limited response such as institutional controls and monitoring).
  - No action or no further action is required.

7.6.1 <u>Assumptions of the Site Response Strategy</u>

The site response strategy is based on several basic assumptions built on discussions with DoD OE experts:

- There is no acceptable risk level for OE exposure because exposure to only one OE item can result in instantaneous physical trauma. In other words, if the OE has a potential for exposure and a receptor comes into contact with it, and the OE explodes, the result will be death or injury. Unlike noncarcinogenic chemicals, OE does not have an acceptable risk level that can be quantified, above which there is a risk that injury will occur. Unlike carcinogenic chemicals, there is no risk range that is considered to be acceptable. Explosive risk either is or is not present. It is not possible to establish a threshold below

[112]U.S. EPA, Risk Assessment Guidance for Superfund (RAGS), Volume 1, Human Health Evaluation Manual, Part B, Interim, September 1991.

which there would be no risk, other than the absence of OE. Therefore, no attempt is made to quantify the level of explosive risks.

- Once OE is determined to be present or potentially present, a response action will be necessary. This response action may involve removal, treatment, or containment of OE, or it may be a limited action such as the use of institutional controls and monitoring. In any case, whenever the response action will leave OE present or potentially present on-site after the action is complete, some kind of institutional controls will be required.[113]

EPA/DoD Interim Final Management Principles on Land Use and Clearance

- Because of technical impracticability, inordinately high costs, and other reasons, complete clearance of CTT military ranges may not be possible to the degree that allows certain uses, especially unrestricted use. In almost all cases, land use controls will be necessary to ensure protection of human health and public safety.
- Land use controls must be clearly defined and set forth in a decision document.
- Final land use controls for a given CTT range will be considered as part of the development and evaluation of response alternatives using the nine criteria established under CERCLA regulations (i.e., NCP), supported by a site characterization adequate to evaluate the feasibility of reasonably anticipated future land uses. This will ensure that land use controls are chosen based on a detailed analysis of response alternatives and are not presumptively selected.

- The selection of a no-action alternative will require has a high level of certainty that no OE is present on-site. The selection of "further investigation" will usually occur when the site information is qualitatively assessed and deemed sufficiently uncertain that proceeding to some sort of response action (or no action) is inappropriate.
- The final decision at the site (no action, or selection of a type of action) is formally evaluated through whatever regulatory process is appropriate for the site (see Chapters 2 and 8). For example, if the decision is to be made under the CERCLA remedial process, the CERCLA nine criteria are used to evaluate the acceptability of a no-action decision and to select appropriate response actions (including responses such as clearance to depth or containment, or limited response actions such as institutional controls and monitoring).

7.6.2 Attributes of the Site Response Strategy

The site response strategy is not a new document or a new process. Rather, it is the pulling together of the information from your investigation to set the stage for the next steps in the OE management process at your site. The site response strategy can be developed whenever there is enough information available to make the decision you were initially trying to make (or to determine that additional information is necessary). The site response strategy can be documented in a number of ways, including:

[113] Institutional controls are non-engineered measures designed to limit exposure to hazardous substances, pollutants, or contaminants that have been left in place and that are above levels that support unrestricted use. They are sometimes referred to by the broader term "land use controls." The latter term encompasses engineered access controls such as fences, as well as the institutional or administrative mechanisms required to maintain the fence.

- The work plan for the next stage of work (if more investigation is necessary).
- The conclusion section of the RI (if no action is recommended).
- The feasibility study (if a response action is planned).

Key attributes of the site response strategy include the following:

1. **Converging lines of evidence are weighed qualitatively to determine the level and significance of uncertainty.** In the process of developing a site response strategy, information is gathered from a variety of sources – historical data, facility and community interviews, surface inspections, geophysical inspections, and land use and planning information. Decisions are based on a qualitative analysis of the data collected. The gathering of this information takes place during the site characterization phase.

2. **The site response strategy may be determined using varying levels of data at different points in the data collection process, and is thoroughly integrated with the site characterization process**. It is not a separate step. The project team is asked to examine the weight of evidence present, and the amount of uncertainty present, at any stage in your data collection process to determine the next course of action (e.g., more investigation, response, institutional controls only, or no action). Three examples are used to illustrate this point:

   — If historical information from multiple sources over continuous timeframes provides sufficient certainty that no OE is present, then it may not be necessary to conduct geophysical studies to detect OE and determine the depth and boundaries of the OE.

   — If there is uncertainty as to whether ordnance with explosive potential is present, or is present at depths that could lead to exposure, then extensive geophysical investigations may be required to determine the presence or absence of OE and the depth at which it may be found.

   — If ordnance with explosive potential is known to be present at a depth where human exposure is likely, then it may not be necessary to conduct extensive geophysical studies to determine if factors are present that would cause OE to migrate.

3. **The purpose of the site response strategy is to enable the project team to make a risk management decision (the remedy selection process).** The site response strategy considers information gathered in the site characterization phase that validates and/or changes the conceptual site model. The type and location of OE, the availability of pathways to potential receptors, the accessibility of the site(s) to receptors, and the current, future, and surrounding land uses are assessed to determine the type and magnitude of risks that are associated with the site(s). The site response strategy informs the risk management process, which compares the risks associated with clearance with those of exposure management (through physical or institutional controls). The strategy then uses the appropriate regulatory processes (e.g., CERCLA, RCRA, SDWA, etc.) to determine the final remedy at the site. The risk management decision process is described in Chapter 8. (This chapter is deferred.)

Figure 7-4 provides an overview of the process of developing a site response strategy and the various types of investigations, uncertainties, and decisions that go into the development of a site response strategy. The figure illustrates typical investigation and decision scenarios. The reader should note that there are no endpoints on this flow chart, since the stage that follows the site response strategy is either further investigation or evaluation of potential remedies. The discussion that follows outlines in more detail the series of questions and issues to be weighed at each decision point.

7.6.3 Questions Addressed in the Development of the Site Response Strategy

Four questions are addressed in the development of the site response strategy. These issues parallel the factors addressed in a typical risk assessment, but differ significantly from a risk assessment in that after the initial question (presence or absence of ordnance) is addressed, the focus of the remaining questions is to develop a response strategy to support the risk management approach.

7.6.3.1 *Determining the Presence of Ordnance with Explosive Potential*

The central question here is whether ordnance with explosive potential is present or may be present. As discussed earlier, the response to this question is a simple yes or no answer. A former firing range in which the only type of ordnance used was bullets will probably be found to have no explosive risk. (There may of course be risks to human health and the environment from residue such as lead, but such risks are addressed in a chemical risk assessment.) Larger ordnance items (e.g., bombs, projectiles, or fuzes) will have an explosive risk if present or potentially present as OE.

Establishing the Presence or Absence of OE Using Historical Data

- Mission of the facility and/or range
- Actual use of facility and/or range over time
- Types of ordnance associated with the mission and actual use
- Accessibility of the facility and ranges to human activity that could have resulted in unplanned burial of excessed ordnance or souvenir collecting
- Portability of UXO (facilitating unplanned migration to different parts of the facility)

Sources of Information

- Archive reports
- EO incident reports
- Interviews with base personnel and surrounding community
- Aerial photographs
- Newspaper reports

As discussed in Chapters 3 and 4 and in preceding sections of this chapter the investigation to determine the presence or potential presence of OE considers multiple sources of information, including historical information (see box above) and a variety of geophysical studies. An initial gathering of historical information will be necessary to create the conceptual site model that will guide both intrusive and nonintrusive studies of the site. Visual reconnaissance may also be appropriate to identify evidence of range activity and to highlight areas for further investigation. Finally, various types of geophysical studies may be used to locate potential OE.

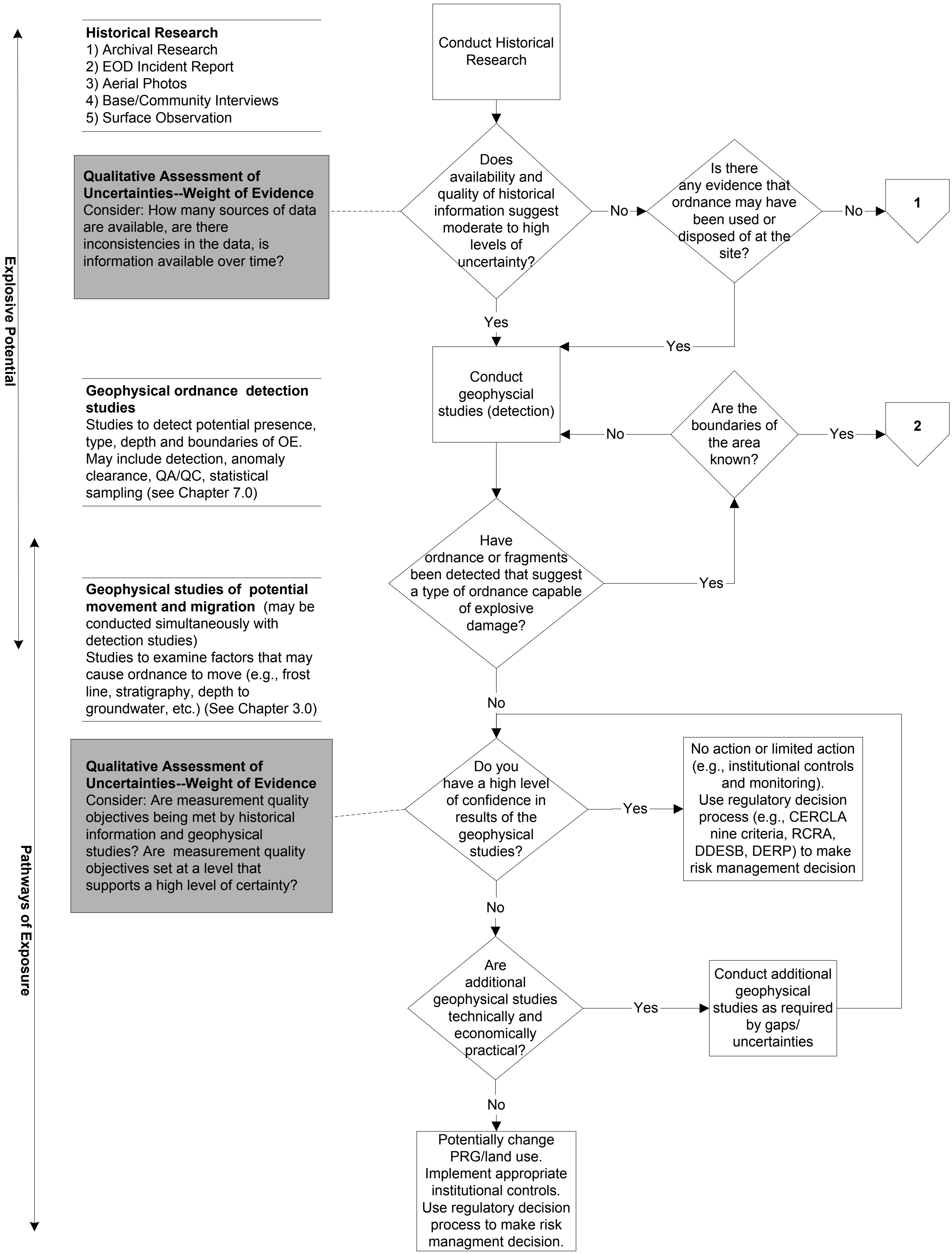
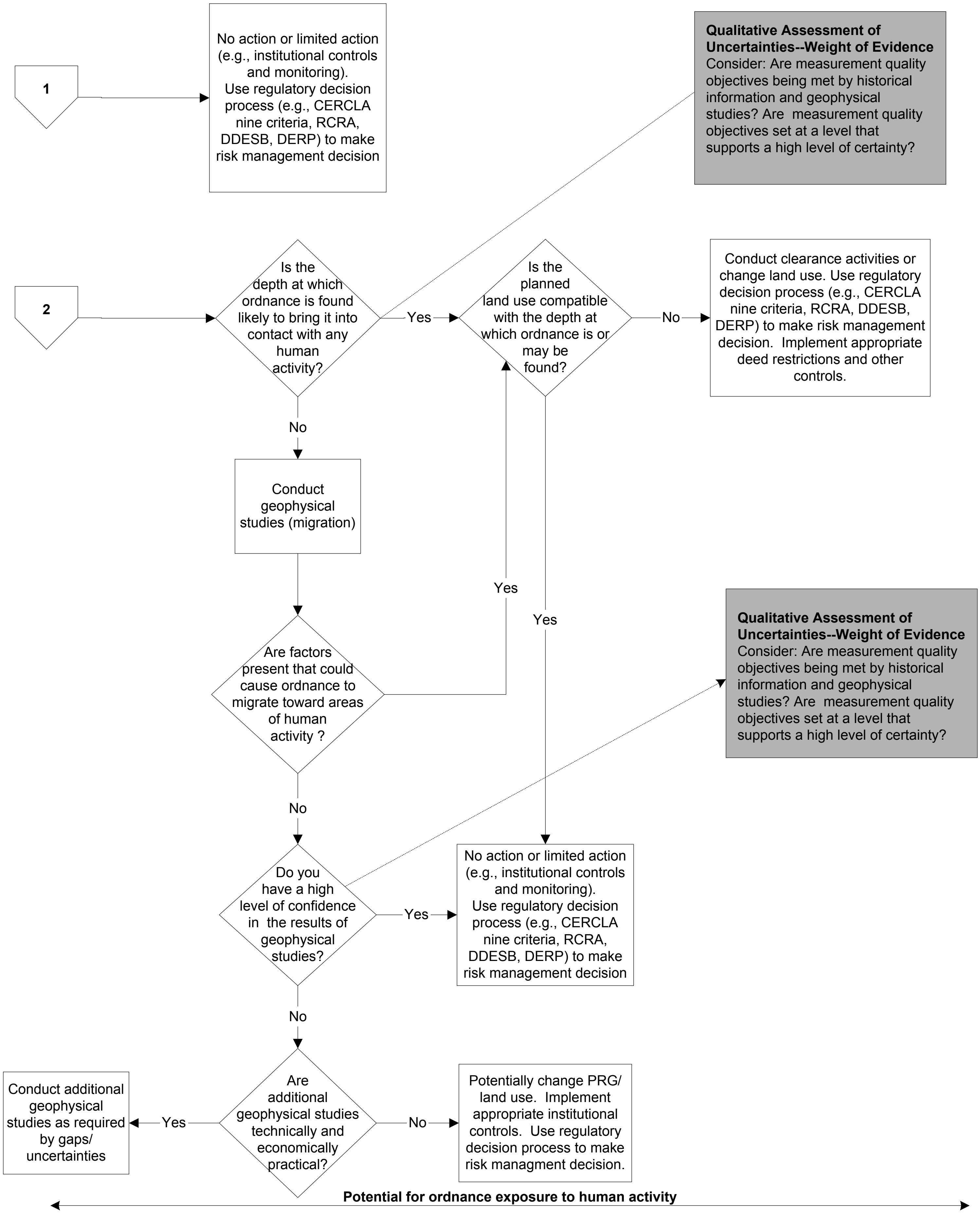


Figure 7-4. Developing a Site Response Strategy


1
No action or limited action (e.g., institutional controls and monitoring). Use regulatory decision process (e.g., CERCLA nine criteria, RCRA, DDESB, DERP) to make risk management decision
Qualitative Assessment of Uncertainties--Weight of Evidence
Consider: Are measurement quality objectives being met by historical information and geophysical studies? Are measurement quality objectives set at a level that supports a high level of certainty?
2
Is the depth at which ordnance is found likely to bring it into contact with any human activity?
Yes
Is the planned land use compatible with the depth at which ordnance is or may be found?
No
Conduct clearance activities or change land use. Use regulatory decision process (e.g., CERCLA nine criteria, RCRA, DDESB, DERP) to make risk management decision. Implement appropriate deed restrictions and other controls.
No
Conduct geophysical studies (migration)
Yes
Yes
Qualitative Assessment of Uncertainties--Weight of Evidence
Consider: Are measurement quality objectives being met by historical information and geophysical studies? Are measurement quality objectives set at a level that supports a high level of certainty?
Are factors present that could cause ordnance to migrate toward areas of human activity ?
No
Do you have a high level of confidence in the results of geophysical studies?
Yes
No action or limited action (e.g., institutional controls and monitoring). Use regulatory decision process (e.g., CERCLA nine criteria, RCRA, DDESB, DERP) to make risk management decision
No
Conduct additional geophysical studies as required by gaps/ uncertainties
Yes
Are additional geophysical studies technically and economically practical?
No
Potentially change PRG/ land use. Implement appropriate institutional controls. Use regulatory decision process to make risk managment decision.
Potential for ordnance exposure to human activity

7.6.3.2 *Identifying Potential Pathways of Exposure*

Once the actual or potential presence of OE has been established, it is then necessary to identify the potential exposure routes. The essential question in this phase is whether the ordnance that is found in the area is, or could be, at a depth that will bring it into contact with human activity. In the site characterization, you established the preliminary remediation goal (PRG), which specifies the depth to which clearance will be required to support the anticipated land use. Using historical information and geophysical data, you should consider two questions:

- Have ordnance, fragments of ordnance, or explosives-contaminated soil been detected, suggesting the presence of OE? (Is there ordnance with explosive potential?)
- Is this material found at a depth that is shallower than the PRG (and likely to bring it into contact with human activity)?

If the ordnance is not found at a depth that is shallower than the PRG, additional geophysical studies may be necessary to determine if there are factors that may cause ordnance to move (e.g., frost line or stratigraphy). (See Chapters 3 and earlier in this chapter.)

If ordnance is found to be present, or potentially present, additional geophysical information will be required to ensure that the boundaries of the range and the density of ordnance are well understood for the purposes of assessing the complexity (and cost) of remediation.

> **Factors To Be Evaluated in Identifying Potential Pathways of Exposure**
>
> In addition to the information highlighted in the previous box (regarding the uses of, and likely ordnance at, the site), factors that affect pathways of exposure include:
>
> - Current and future land use, and depth to which land must be clear of OE to support that land use; level of intrusive activity expected now and in the future
> - Maximum depths at which ordnance is or may be found, considering the nature of the ordnance
> - Location of frost line
> - Erosion potential
> - Portability of type of ordnance for souvenir handling and illegal burial
> - Potential that excessed ordnance may have been buried

> **About Portability**
>
> The potential of exposure to OE through human activity goes beyond the actual uses of ranges. Potential exposures to OE can also occur as a result of unplanned human activity that causes UXO to migrate to different locations. Examples of such common human activities include:
>
> — Burial of chemical protective kits (containing chemical waste material) by soldiers in training exercises.
> — Transport of UXO as souvenirs to residential areas of the base and off base by soldiers.
> — Souvenir-taking by civilians who live either on base or off base and who have access to the sites.

7.6.3.3 *Determining Potential for Human Exposure to Ordnance*

The potential for human exposure is assessed by looking at the types of human activities that might bring people into contact with OE. Key issues for determining the potential of human receptors to come into contact with OE include:

- Depth of ordnance and exposure pathways of concern
- Potential for naturally caused migration to depths of concern
- Accessibility of areas where ordnance is known or suspected to be present to workers, trespassers, etc.
- Potential for intrusive activity (e.g., construction in the OE area)
- Current and potential future ownership of the site(s)
- Current and potential future land use of the site(s) and the surrounding areas (including potential groundwater use)
- Potential portability of the OE (for potential human-caused migration off range)

During the final phase of the analysis, you should consider information and uncertainties from all phases of the investigation to determine whether there is a risk at the depth of concern. If the planned land use is not compatible with the depth at which ordnance is or may be found, then two options are possible:

- Remediate to a depth appropriate for the planned land use.
- Change the planned future land use to be consistent with the depth of cleanup.

Both of these decisions will be made during the risk management decision process under the applicable regulatory framework (e.g., CERCLA or RCRA; see Chapter 8).

Unless you have a high level of certainty that remediation will clear the land for an unrestricted land use, appropriate institutional controls will be required.

7.6.3.4 *Considering Uncertainty*

In every stage of site characterization, including the development of a site response strategy, a qualitative evaluation of uncertainty will help you decide the level of confidence you have in the information collected to determine your next steps. No single source is likely to provide the information required to assess the level of certainty or uncertainty associated with your analysis. Therefore, your qualitative uncertainty analysis will rely on **converging lines of evidence** from a number of different sources of data, including historic information (archival, EOD incident reports, interviews, etc.), results of detection studies and sampling, results of other geophysical studies, assessment of current and future land use, and accessibility of OE areas.

7.7 Making the Decision

The Draft Interim UXO Management Principles agreed to by senior DoD and EPA managers (described in and provided as an attachment to Chapter 2, "Regulatory Overview") establish a framework for making risk management decisions. The principles assert DoD's and EPA's commitment to the promulgation of a range regulation. At the same time, these principles state that "a process consistent with CERCLA and these management principles will be the preferred response mechanism used to address UXO at a CTT range." The principles go on to state that response actions may include CERCLA removal or remedial activities, or some combination of these, in conducting the investigation and cleanup. Chapter 8 describes the manner in which these processes are used to make the basic risk management decisions at the site.

7.8 Conclusion

A focus of this chapter has been on planning the investigation. In the course of the investigation, the initial plan will undoubtably change. The conclusion of the investigation should result in answers to the questions posed in the data quality objectives at a level of certainty that is acceptable to the DoD decision makers, the regulators, and the public.

The purpose of this chapter has been to take the reader through the planning and design of the UXO investigation to the development of a site response strategy. As pointed out in the introduction, the focus of this chapter has primarily been UXO and energetic materials, not the environmental contamination of media by UXO residues. Chapter 3 describes common chemicals of concern that are found in association with OE areas. Typically, the approaches used to investigate explosive compounds will not differ substantially from other environmental investigations of hazardous wastes, pollutants, and contaminants (except that safety considerations will require more extensive health and safety plans and generally be more costly since the potential for UXO in the subsurface must be considered).

The development of a site response strategy is based on the Interim Final UXO Management Principles which call for investigation and cleanup actions to be consistent with both the CERCLA process (either removal or remedial activities, or a combination of these) and the principles themselves. Chapter 8 describes the application of the nine CERCLA criteria to analyze information gathered during the site characterization phase and the site response strategy to make the basic risk management decisions at the site.

SOURCES AND RESOURCES

The following publications, offices, laboratories, and websites are provided as a guide for handbook users to obtain additional information about the subject matter addressed in each chapter. Several of these publications, offices, laboratories, or websites were also used in the development of this handbook.

Publications

Crockett, A.B., Craig, H.D., and Jenkins, T.F., "Field Sampling and Selecting On-site Analytical Methods for Explosives in Water," *U.S. EPA Federal Facilities Forum*, May 19, 1999.

Crockett, A.B., Craig, H.D., Jenkins, T.F., and Sisk, W.E., "Field Sampling and Selecting On-site Analytical Methods for Explosives in Soil," *U.S. EPA Federal Facilities Forum,* November 1996.

Wilcox, R.G., "Institutional Controls for Ordnance Response," Presented at UXO Forum, May, 1997.

Guidance Documents

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Department of Defense, DoD 6055.9-STD, **DoD Ammunition and Explosives Safety Standards**, July 1999.

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U.S. EPA, ***Guidance on Conducting Non-time-critical Removal Actions Under CERCLA,*** August 1993 (PB93-963402)**.**

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U.S. EPA, ***EPA Guidance for Quality Assurance Project Plans, EPA QA/G-5****,* February 1998.

U.S. Navy, ***Environmental Compliance Sampling and Field Testing Procedures Manual,*** NAVSEA T0300-AZ-PRO-0010, July 1997.

<u>Information Sources</u>

Joint UXO Coordination Office (JUXOCO)
10221 Burbeck Road, Suite 430
Fort Belvoir, VA 22060
Tel: (703) 704-1090
Fax: (703) 704-2074

U.S. Army Corps of Engineers
U.S. Army Engineering and Support Center,
Ordnance and Explosives
Mandatory Center of Expertise
P.O. Box 1600
Huntsville, AL 35807-4301
Street Address: 4820 University Square
http://www.hnd.usace.army.mil/

Department of Defense Explosives Safety Board (DDESB)
Department of Defense Explosives Safety Board
2461 Eisenhower Avenue
Alexandria, VA 22331-0600
Fax: (703) 325-6227
http://www.hqda.army.mil/ddesb/esb.html

U.S. EPA
Superfund Risk Assessment
http://www.epa.gov/superfund/programs/risk/index.htm

Sources of Data for Historical Investigations

Air Photographics, Inc.
Aerial photographs
Route 4, Box 500
Martinsburg, WV 25401
Tel: (800) 624-8993
Fax: (304) 267-0918
e-mail: info@airphotographics.com
http://www.airphotographics.com

Environmental Data Resources, Inc.
Aerial photographs, insurance maps, city directories, wetlands maps, flood plain maps, topographical maps
3530 Post Road
Southport, CT 06490
Tel: (800) 352-0050
http://www.edrnet.com

Eros Data Center
Satellite images, aerial photographs, and topographic maps
Customer Services
U.S. Geological Survey
EROS Data Center
47914 252nd Street
Sioux Falls, SD 57198-0001
Tel: (800) 252-4547
Tel: (605) 594-6151
Fax: (605) 594-6589
e-mail: custserv@edcmail.cr.usgs.gov
http://edc.usgs.gov/

Natural Resources Conservation Service
National, regional, and some state and local data and maps of plants, soils, water and climate, watershed boundaries, wetlands, land cover, water quality, and other parameters.
U.S. Department of Agriculture
14th and Independence Ave.
Washington, DC 20250
http://www.nrcs.usda.gov/

National Archives and Records Administration
National Cartographic and Architectural Branch
College Park, MD
http://www.nara.gov

<u>Repositories of Explosive Mishap Reports</u>

Army
U.S. Army Safety Center
Bldg. 4905 5th Ave.
Ft. Rucker, AL 36362-5363

U.S. Army Technical Center for Explosives Safety (maintains a database of explosives accidents)
Database of explosive accidents: www.dac.army.mil/esmam/default.htm
Attn: SIOAC-ESL, Building 35
1C Tree Road
McAlester, OK 74501-9053
e-mail: sioac-esl@dac-emh2.army.mil

Navy
Commander, Naval Safety Center
Naval Air Station Norfolk
375 A Street
Code 03
Norfolk, VA 23511
Tel: (757) 444-3520
http://www.safetycenter.navy.mil/

Air Force
Air Force Safety Center
HQ AFSC/JA
9700 G Avenue SE
Kirtland AFB, NM 87117-5670
Tel: (505) 846-1193
Fax: (505) 853-5798