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

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GLOSSARY OF TERMS

Anomaly. Any identified subsurface mass that may be geologic in origin, unexploded ordnance (UXO), or some other man-made material. Such identification is made through geophysical investigation and reflects the response of the sensor used to conduct the investigation.

Anomaly reacquisition. The process of confirming the location of an anomaly after the initial geophysical mapping conducted on a range. The most accurate reacquisition is accomplished using the same instrument used in the geophysical survey to pinpoint the anomaly and reduce the area the excavation team needs to search to find the item.[2]

Archives search report. An investigation to report past ordnance and explosives (OE) activities conducted on an installation.[3]

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.[8]

Blow-in-place. Method used 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 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.[5]

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

Chemical warfare agent. A substance that is intended for military use with lethal or incapacitating effects upon personnel through its chemical properties.[4]

Clearance. The removal of UXO from the surface or subsurface at active and inactive ranges.

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.[6]

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.[7]

Deflagration. A rapid chemical reaction occurring at a rate of less than 3,300 feet per second 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.[8]

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.[10]

Department of Defense 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.[8]

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. The rate of a detonation is supersonic, above 3,300 feet per second.[4]

Disposal. The discharge, deposit, injection, dumping, spilling, leaking, or placing of any solid waste or hazardous waste into or on any land or water so that such solid waste or hazardous waste or any constituent thereof may enter the environment or be emitted into the air or discharged into any waters, including groundwaters.[9]

Dud-fired. Munitions that failed to function as intended or as designed. They can be armed or not armed as intended or at some stage in between.

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

Excavation of anomalies. The excavation, identification, and proper disposition of a subsurface anomaly.[2]

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.[4]

Explosive. A substance or mixture of substances, which is capable, by chemical reaction, of producing gas at such a temperature, pressure and rate as to be capable of causing damage to the surroundings.

Explosive filler. The energetic compound or mixture inside an OE item.

Explosive ordnance disposal (EOD). 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) that 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.[11]

EOD incident. The suspected or detected presence of a UXO or damaged military munition that constitutes a hazard to operations, installations, personnel, or material. Each EOD response to a reported UXO is an EOD incident. 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 land mines or demolition charges.

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 reactive or ignitable. Defined by the U.S. Army Corps of Engineers (USACE) as soil that is composed of more than 12 percent reactive or ignitable material. See also *ignitable soil* and *reactive soil*.

Explosive train. The arrangement of different explosives in OE arranged according to the most sensitive and least powerful to the least sensitive and most powerful (initiator - booster - burster). A small quantify of an initiating compound or mixture, such as lead azide, is used to detonate a larger quantity of a booster compound, such as tetryl, that results in the main or booster charge of a RDX composition, TNT, or other compound or mixture detonating.

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.[9]

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.[3] It is prepared, submitted, and approved per DDESB requirements. It is required for all response actions that deal with energetic material (e.g., UXO, buried munitions), including time-critical removal actions, non-time-critical removal actions, and remedial actions involving explosive hazards.

False alarm. The incorrect classification of nonordnance (e.g., clutter) as ordnance, or a declared geophysical target location that does not correspond to the actual target location.

False negative. The incorrect declaration of an ordnance item as nonordnance by the geophysical instrument used, or misidentification in post-processing, which results on potential risks remaining following UXO investigations.

False positive. The incorrect identification of anomalous items as ordnance.

Federal land manager. With respect to any lands owned by the United States Government, the secretary of the department with authority over such lands.

Formerly Used Defense Site (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.[3]

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.[4]

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.[5]

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 National Priorities List (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.[7]

Hazardous substance. Any substance designated pursuant to Section 311(b)(2)(A) of the Clean Water Act (CWA); any element, compound, mixture, solution, or substance designated pursuant to Section 102 of CERCLA; any hazardous waste having the characteristics identified under or listed pursuant to section 3001 of the Solid Waste Disposal Act (but not including any waste the regulation of which under the Solid Waste Disposal Act has been suspended by an Act of Congress); any toxic pollutant listed under Section 307(a) of the CWA; any hazardous air pollutant listed under Section 112 of the Clean Air Act; and any imminently hazardous chemical substance or mixture with respect to which the EPA Administrator has taken action pursuant to Section 7 of the Toxic Substances Control Act.[12]

Hazardous waste. A solid waste, or combination of solid waste, which because of its quantity, concentration, or physical, chemical, or infectious characteristics may (a) cause, or significantly contribute to an increase in mortality or an increase in serious irreversible, or incapacitating reversible, illness; or (b) pose a substantial present or potential hazard to human health or the environment when improperly treated, stored, transported, or disposed of, or otherwise managed.[8] Chemical agents and munitions become hazardous wastes if (a) they become a solid waste under 40 CFR 266.202, and (b) they are listed as a hazardous waste or exhibit a hazardous waste characteristic; chemical agents and munitions that are hazardous wastes must be managed in accordance with all applicable requirements of RCRA.[13]

Ignitable soil. Any mixture of explosives in soil, sand, clay, or other solid media at concentrations such that the mixture itself exhibits any of the properties of ignitability as defined in 40 CFR 261.21.

Inactive range. A military range that is not currently being used, but that is still under military control and considered by the military to be a potential range area, and that has not been put to a new use that is incompatible with range activities.[13]

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

Indian Tribe. Any Indian Tribe, band, nation, or other organized group or community, including any Alaska Native village but not including any Alaska Native regional or village corporation, which is recognized as eligible for the special programs and services provided by the United States to Indians because of their status as Indians.[12]

Inert. The state of some types of ordnance, which have functioned as designed, leaving a harmless carrier, or ordnance manufactured without explosive, propellant or pyrotechnic content to serve a specific training purpose. Inert ordnance poses no explosive hazard to personnel or material.[14]

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 ensure effectiveness of the chosen remedy. Institutional controls are usually, but not always, legal controls, such as easements, restrictive covenants, and zoning ordinances.[15]

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 National Contingency Plan (NCP). EPA, the U.S. Coast Guard, another Federal agency, or a State operating pursuant to a contract or cooperative agreement executed pursuant to section 104(d)(1) of CERCLA, or designated pursuant to a Superfund Memorandum of Agreement (SMOA) entered into pursuant to subpart F of the NCP or other agreements may be the lead agency for a response action. 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 a Federal agency, that agency will be the Lead Agency.[7]

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

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.[3]

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, warheads, mortar rounds, artillery ammunition, small arms ammunition, mines, torpedoes, depth charges, cluster munitions and dispensers, 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.[3]

Military range. Any designated land and water areas set aside, managed, and used to conduct research on, develop, test, and evaluate military munitions and explosives, other ordnance, or weapon systems, or to train military personnel in their use and handling. Ranges include firing lines and positions, maneuver areas, firing lanes, test pads, detonation pads, impact areas, and buffer zones with restricted access and exclusionary areas.[13]

Mishap. An accident or an unexpected event involving DoD ammunition and explosives.[9]

Most probable munition. The round with the greatest hazardous fragment range that can reasonably be expected to exist in any particular OE area.[3]

Munition 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. Munition 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.).

Munitions response. DoD response actions (removal or remedial) to investigate and address the explosives safety, human health or environmental risks presented by munition and explosives of concern (MEC, also known as ordnance and explosives or OE) and munition constituents. The term is consistent with the definitions of removal and remedial actions that are found in the National Contingency Plan. The response could be as simple as an administrative or legal controls that preserve a compatible land use (i.e. institutional controls) or as complicated as a long-term response action involving sophisticated technology, specialized expertise, and significant resources.

National Oil and Hazardous Substances Pollution Contingency Plan, or National Contingency Plan (NCP). The regulations for responding to releases and threatened releases of hazardous substances, pollutants, or contaminants under CERCLA.[7]

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 place under the authority of CERCLA and is published in the *Federal Register*.[7]

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 designated by EPA, DoD, or the U.S. Coast Guard or the official designated by the lead agency to coordinate and direct response actions. Also, the Federal official designated by EPA or the U.S. Cost Guard to coordinate and direct Federal responses under subpart D, or the official designated by the lead agency to coordinate and direct removal actions under subpart E of the NCP.[7]

Open burning. The combustion of any material without (1) control of combustion air, (2) containment of the combustion reaction in an enclosed device, (3) mixing for complete combustion, and (4) control of emission of the gaseous combustion products.[10]

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.[10]

Ordnance and explosives (OE). OE, also known as munitions and explosives of concern (MEC), are any of the following: (1) military munitions that are unexploded ordnance (UXO) or are abandoned. (2) Soil with a high enough concentration of explosives to present an explosive hazard. (3) Facilities, equipment, or other materials contaminated with a high enough concentration of explosives such that they present a hazard of explosion.

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 sites. Sites, such as scrap yards, ammunition depots, disposal pits, ammunition plants, and research and testing facilities no longer under DoD control and that may contain OE.

Overpressure. The blast wave or sudden pressure increase resulting from a violent release of energy from a detonation in a gaseous medium.[11]

Practice ordnance. Ordnance manufactured to serve a training purpose. Practice ordnance generally does not carry a full payload. Practice ordnance may still contain explosive components such as spotting charges, bursters, and propulsion charges.[14]

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 proposed for listing on the NPL.

Projectile. An object projected by an applied force and continuing in motion by its own inertia, as mortar, small arms, and artillery shells. 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.[3]

Reactive soil. Any mixture of explosives in soil, sand, clay, or other solid media at concentrations such that the mixture itself exhibits any of the properties of reactivity as defined in 40 CFR 261.23.

Real property. Land, buildings, structures, utility 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.[7]

Release. Any spilling, leaking, pumping, pouring, emitting, emptying, discharging, injecting, escaping, leaching, dumping, or disposing into the environment (including the abandonment or discarding of barrels, containers, and other closed receptacles containing any hazardous substance or pollutant or contaminant).[12]

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.[12]

Remedial investigation and feasibility study (RI/FS). 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 developing, screening, and evaluating 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.[7]

Removal action. Short-term response actions under CERCLA that address immediate threats to public health and the environment.[12]

Render-safe procedures. The portion of EOD procedures involving the application of special EOD methods and tools to provide for the interruption of functions or separation of essential components of UXO to prevent an unacceptable detonation.[11]

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.[8]

Response action. As defined in Section 101 of CERCLA, "remove, removal, remedy, or remedial action, including enforcement activities related thereto." As used in this handbook, the term response action incorporates cleanup activities undertaken under any statutory authority.[12]

Solid waste. Any garbage, refuse, sludge from a waste treatment plant, water supply treatment plant, or air pollution control facility and other discarded material, including solid, liquid, semisolid, or contained gaseous material resulting from industrial, commercial, mining, and agricultural operations, and from community activities, but not including solid or dissolved material in domestic sewage, or solid or dissolved materials in irrigation return flows or industrial discharges which are point sources subject to permits under section 402 of the Federal Water Pollution Control Act as amended, or source, special nuclear, or byproduct material as defined by the Atomic Energy Act of 1954, as amended.[8] When a military munition is identified as a solid waste is defined in 40 CFR 266.202.[13]

State. The several States of the United States, the District of Columbia, the Commonwealth of Puerto Rico, Guam, American Samoa, the Virgin Islands, the Commonwealth of Northern Marianas, and any other territory or possession over which the United States has jurisdiction. Includes Indian Tribes as defined in CERCLA Chapter 103 § 9671.[7]

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.[6]

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.[6]

Treatment. When used in conjunction with hazardous waste, means any method, technique, or process, including neutralization, designed to change the physical, chemical, or biological character or composition of any hazardous waste so as to neutralize such waste or so as to render such waste nonhazardous, safer for transport, amenable for recovery, amenable for storage, or reduced in volume. Such term includes any activity or processing designed to change the physical form or chemical composition of hazardous waste so as to render it nonhazardous.[8]

Unexploded ordnance (UXO). Military munitions that have been primed, fuzed, 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, installation, personnel, or material and that remain unexploded either by malfunction, design, or any other cause.[13]

Warhead. The payload section of a guided missile, rocket, or torpedo.

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3. U.S. Army Corps of Engineers Pamphlet No. 1110-1-18, “Engineering and Design Ordnance and Explosives Response,” April 24, 2000.
4. DoD 6055.9-STD, Department of Defense Ammunition and Explosives Safety Standards.
5. 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.
6. Closed, Transferring, and Transferred Ranges Containing Military Munitions, Proposed Rule, 62 FR 187, September 26, 1997.
7. National Oil and Hazardous Substances Pollution Contingency Plan (more commonly called the National Contingency Plan), 40 C.F.R. § 300 et seq.
8. Department of Defense Directive 6055.9. “DoD Explosives Safety Board (DDESB) and DoD Component Explosives Safety Responsibilities,” July 29, 1996.
9. Resource Conservation and Recovery Act (RCRA), 42 U.S.C. § 6901 et seq.
10. Department of Defense. Policy to Implement the EPA’s Military Munitions Rule. July 1, 1998.
11. Joint Publication 1-02, “DoD Dictionary of Military and Associated Terms,” April 12, 2001.
12. Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), 42 U.S.C. § 9601 et seq.
13. 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.
14. Former Fort Ord, California, Draft Ordnance Detection and Discrimination Study Work Plan, Sacramento District, U.S. Army Corps of Engineers. Prepared by Parsons. August 18, 1999.
15. 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.

ACRONYMS

ARAR	applicable or relevant and appropriate requirements
ATR	aided or automatic target recognition
ATSDR	Agency for Toxic Substances and Disease Registry
ATV	autonomous tow vehicle
BIP	blow-in-place
BRAC	Base Realignment and Closure Act
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CSM	conceptual site model
CTT	closed, transferring, and transferred [ranges]
DDESB	Department of Defense Explosives Safety Board
DERP	Defense Environmental Restoration Program
DGPS	differential global positioning system
DoD	Department of Defense
DOE	Department of Energy
DQO	data quality objective
EMI	electromagnetic induction
EMR	electromagnetic radiation
EOD	Explosive ordnance disposal
EPA	Environmental Protection Agency
EPCRA	Emergency Planning and Community Right-to-Know Act
ESS	Explosives Safety Submission
FFA	Federal facility agreement
FFCA	Federal Facility Compliance Act
FUDS	Formerly Used Defense Sites
GIS	geographic information system
GPR	ground-penetrating radar
GPS	global positioning system
HMX	Her Majesty’s Explosive, High Melting Explosive
IAG	interagency agreement
IR	infrared
IRIS	Integrated Risk Information System
JPGTD	Jefferson Proving Ground Technology Demonstration Program
JUXOCO	Joint UXO Coordination Office
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 inspection
PEP	propellants, explosives, and pyrotechnics
PPE	personal protective equipment
PRG	preliminary remediation goal

QA/QC	quality assurance/quality control
Q-D	quantity-distance
RCRA	Resource Conservation and Recovery Act
RDX	Royal Demolition Explosive
RF	radio frequency
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
TNT	2,4,6-Trinitrotoluene
USACE	U.S. Army Corps of Engineers
USAEC	U.S. Army Environmental Center
UWB	ultra wide band
UXO	unexploded ordnance

1.0 INTRODUCTION

1.1 Overview

This handbook 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, transferring, and transferred (CTT) ranges and other sites at current and former Department of Defense (DoD) facilities (see text box below). The handbook is designed to provide a common nomenclature to aid in the management of ordnance and explosives (OE) at CTT ranges and other sites, including:

- Unexploded Ordnance (UXO),
- Abandoned and/or buried munitions, and
- Soil with properties that are reactive and/or ignitable due to contamination with munition constituents.

The definition of OE also includes facilities and equipment; however, the focus of this handbook is on the three items above.

The handbook also discusses common chemical residues (called munition constituents) of explosives that may or may not retain reactive and/or ignitable properties but could have a potential impact on human health and the environment through a variety of pathways (surface and subsurface, soil, air and water).

Why Does This Handbook Focus 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 munition constituents may be present. This focus occurs for several reasons:

- **Transferring and transferred 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 transferring and transferred ranges.
- EPA, States, Tribes, and local governments have encountered numerous instances where issues have been raised about whether transferring and transferred 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 most likely sites where used and fired military munitions will be a regulated solid waste, and therefore a potential hazardous waste, are at CTT ranges.
- Other sites that are addressed by this handbook include nonoperational, nonpermitted sites where OE may be encountered, such as scrap yards, disposal pits, ammunition plants, DoD ammunition depots, and research and testing facilities.
- Finally, EPA anticipates that the military will oversee and manage environmental releases at their active and inactive ranges and at permitted facilities as part of their compliance program.

For the purposes of simplifying the discussion, when the term **ordnance and explosives** is used, the handbook is referring to the three groups listed above. When the handbook is referring to chemical residues that *may or may not* have reactive and/or ignitable characteristics, they are called **munition constituents**.

Buried or stored bulk explosives are not often found at CTT ranges, but may be found on other sites (e.g., old manufacturing facilities). Although bulk explosives are not explicitly identified as a separate OE item, the information in this handbook often applies to bulk explosives, as well as other OE items.

The handbook is designed to facilitate a common understanding of the state of the art of OE detection and munitions response, 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. In addition, a number of areas covered by the handbook are the subject of substantial on-going research and development and may change in the future (see text box below). Therefore, the handbook 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. Replacement pages will be posted on the Federal Facilities Restoration and Reuse Office web page, a website of the Office of Solid Waste and Emergency Response (www.epa.gov/swerffrr).

Policy Background on Range Cleanup

The regulatory basis for OE investigation and cleanup on CTT ranges is evolving. This handbook has been prepared within the context of extensive discussion involving Congress, DoD, EPA, Federal land managers, States, Tribes, and the public about 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 (see text box at right). For additional definitions, the user is directed to the glossary at the beginning of this document.

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. Those definitions that come from official sources (e.g., statutes, regulations, formal policy or standards) are appropriately footnoted. The user should not rely on the definitions in this chapter or the glossary for legal understanding of a key term, but should instead refer to the promulgated and/or other official documents.

1. **Unexploded ordnance** — The term UXO, or unexploded ordnance, means military munitions that have been primed, fuzed, 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. **Military Range —** A range is any designated 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 —** 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.[1] **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), also called munitions and explosives of concern, or MEC —** This term is used by U.S. Army explosives safety personnel to refer to all military munitions that have been used, discarded, buried, or abandoned. The term encompasses the materials that are the subject of this handbook, such as UXO, materials in soil from partially exploded or decomposing ordnance that make the soil reactive and ignitable, and munitions that have been discarded or buried. It also encompasses facilities, equipment, and other materials that have high enough concentrations of explosives to present explosive hazards. The term OE 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 is considered explosive when it contains concentrations of explosives or propellants such that an explosion hazard is present and the soil is reactive or ignitable.

8. **Munition constituents —** This term refers to the chemical constituents of military munitions that remain in the environment, including (1) residuals of munitions that retain reactive and/or ignitable properties, and (2) chemical residuals of explosives that are not

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[1]The definition of *closed range* is taken from Department of Defense Policy to Implement the Munitions Rule, July 1998. It is consistent with the definitions in the Munitions Rule described.

reactive and/or ignitable 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. Such identification is made through geophysical investigations and reflects the response of the sensor used to conduct the investigation.

10. **Clearance** — Clearance is the removal of UXO from the surface or subsurface to a specific depth at active and inactive ranges. This term has been frequently used to describe responses at CTT ranges. However, the term used in this handbook to describe responses at CTT ranges and other nonoperational, nonpermitted sites is **munitions response**.

11. **Munitions response** — The term includes DoD response actions (removal or remedial) to investigate and address the explosives safety, human health, or environmental risks presented by ordnance and explosives (OE), also known as munitions and explosives of concern (MEC) or munition constituents (MC). The term is consistent with the lengthy definitions of removal and remedial actions that are found in the National Contingency Plan (NCP). The response could be as simple as administrative or legal controls that preserve a compatible land use (i.e., institutional controls), or as complicated as a long-term response action involving sophisticated technology, specialized expertise, and significant resources.

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 — Response Technologies
Chapter 6 — Explosives Safety
Chapter 7 — Site/Range Characterization and Response

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, it documents some of the publications and materials 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. Notes are used to indicate that a section is under development.

Warning

UXO poses a threat to life and safety. All areas suspected of having UXO should be considered unsafe, and potential UXO items should be considered dangerous. All UXO should be considered fuzed and capable of detonation. Only qualified UXO technicians or military explosive ordnance disposal (EOD) personnel should consider handling suspected or actual UXO. All entry into suspected UXO areas should be with qualified UXO technicians or EOD escorts.

2.0 REGULATORY OVERVIEW

The management of and response to OE (UXO, buried munitions, and explosive soil) and munitions constituents at CTT ranges and other sites is governed by numerous Federal, State, Tribal and local laws and may involve interaction among multiple regulatory and nonregulatory authorities.

On March 7, 2000, EPA and DoD entered into an interim final agreement to resolve some of the 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 munitions constituents, identifies issues that remain uncertain, and identifies specific areas of regulatory concern in the investigation of and decisions at CTT ranges and other sites. The reader should be aware that interpretations may change and that final EPA and DoD policy guidance and/or regulations may alter some assumptions.

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 standards of 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 is expected to 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 issues that should 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).

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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.

2.1 Regulatory Overview

As recognized in the DoD/EPA Interim Final Management Principles cited above and in 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 requirements 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. A number of other regulatory processes provide important requirements.

Federal, State and Tribal laws applicable to off-site response actions (e.g., waste material removed from the contaminated site or facility), must be complied with. 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 RCRA program provides a particularly 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 response proceeds under CERCLA **and if** those requirements are either applicable, or relevant and appropriate (ARAR) to the site situation (see Section 2.2.1.1). Substantive requirements of other Federal, State and Tribal environmental laws must also be met when such laws are ARARs.

The following sections briefly describe the Federal regulatory programs that may be important in the management of OE.

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 (including Tribal authorities). In addition, State, Tribal and local governments are to be given the opportunity to review and comment on response actions, except when emergency requirements make this unrealistic. The program has three goals:

- Cleanup of contamination from hazardous substances, pollutants, and contaminants, consistent with CERCLA cleanup requirements as embodied in Section 120 of CERCLA and the National Oil and Hazardous Substances Pollution Contingency Plan (NCP).
- Correction of environmental damage, such as the detecting and disposing of unexploded ordnance, 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).

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[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, July 16, 2001, Draft.

2.1.2 CERCLA

CERCLA (otherwise known as Superfund) is an important Federal law that provides for the cleanup of releases of hazardous substances, pollutants, or contaminants. The National Oil and Hazardous Substances Pollution Contingency Plan (NCP) (40 CFR 300) provides the blueprint to implement CERCLA. Although the Federal Government (through EPA and/or the other Federal agencies) is responsible for implementation of CERCLA, the States, Federally recognized Tribal governments, and communities play a significant role in the law's implementation.

CERCLA (Section 104) authorizes a response when:

- There is a release or threat of a release of a hazardous substance into the environment, or
- 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

The CERCLA process (described briefly below) examines the nature of the releases (or potential releases) to determine if there is an unacceptable threat to human health and the environment.

The principal investigation and cleanup processes implemented under CERCLA may involve removal or remedial actions. Generally:

1. **Removal actions** are time sensitive actions often designed to address emergency problems or immediate concerns, or to put in place a temporary or permanent remedy to abate, prevent, minimize, stabilize, or mitigate a release or a threat of release.
2. **Remedial actions** are actions consistent with a permanent remedy, taken instead of or in addition to removal actions to prevent or minimize the release of hazardous substances. Remedial actions often provide for a more detailed and thorough evaluation of risks and response options than removal actions. In addition, remedial actions have as a specific goal attaining a remedy that "permanently reduces the volume, toxicity, or mobility of hazardous substances, pollutants, or contaminants."

Whether a removal or remedial action is undertaken is a site-specific determination. In either case, the process generally involves a number of steps, including 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.

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.

For the most part, the CERCLA process is 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 using a series of criteria, the application of which results in a numeric score. Those sites that score above 28.5 are proposed for inclusion on the NPL. The listing of a site on the NPL is a regulatory action that is published in the *Federal Register*. Both removal and remedial actions can be implemented at these sites.
- Private-party sites that are not placed on the NPL but are addressed under the removal program.[4]
- Non-NPL sites owned or controlled by Federal agencies (e.g., Department of Defense, Department of Energy). Both removal and remedial actions may be implemented at these sites. These sites generally are investigated and cleaned up in accordance with CERCLA.

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.[5]

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[4] 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.

[5] 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.

The authority to implement the CERCLA program is granted 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 Department of Energy (DOE), and other Federal land managers (e.g., Department of Interior) are delegated response authority at their non-NPL facilities, for remedial actions and removal actions other than emergencies. They must still consult with Federal, State, and Tribal regulatory authorities, but make the "final" decision at their sites. DoD and DOE are delegated responsibility for response authorities at NPL facilities as well. When a DoD or DOE facility is on the NPL, however, under Section 120, EPA must concur with the Record of Decision (decision document).

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.

- Extensive State and Tribal involvement in the removal and remedial programs is provided for (CERCLA Section 121(f)). A number of very specific provisions addressing State and Tribal involvement are contained in the NCP (particularly, but not exclusively, Subpart F).
- Notification requirements apply to all removal actions, no matter what the time period. Whether or not the notification occurs before or after the removal is a function of time available and whether it is an emergency action. State, Tribal 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, issuance of the community relations plan, and review and comment on the proposed action, occurs 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 (i.e. have an opportunity to review and comment) at these sites before taking response actions (unless emergency circumstances make such consultation impractical) (10 U.S.C. § 2705).

2.1.3 CERCLA Section 120

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) are subject to the requirements of CERCLA in the same manner as nongovernmental entities.
- The guidelines, regulations, and other criteria that are applicable to assessments, evaluations, and remedial actions 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 such facilities are not included on the NPL.
- 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 their own State permitting and enforcement processes in lieu of EPA's to implement the program. Thus, each State that is authorized to implement the RCRA requirements may have its own set of hazardous waste laws that must be considered.

[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.

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

The Federal Facility Compliance Act of 1992, or FFCA (PL102-386), amended RCRA. 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.

What Is a Military Munition?

According to the Military Munitions Rule, a military munition is all ammunition products and components produced or used by or for DoD or the U.S. Armed Services for national defense and security.

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 solid wastes, and therefore potentially 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 potential hazardous waste. The phrase "used for their intended purpose" does not apply to on-range disposal (e.g., recovery, collection, **and** subsequent burial or placement in a landfill). Such waste will be considered a solid waste (and potential hazardous waste) when burial is not a result of a product use.

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

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, repaired, or recycled or used for other purposes
- Removed from storage for the purposes of disposal
- Designated as solid waste by a military official

Finally, the Military Munitions Rule provides an exemption from RCRA procedures (e.g., permitting or manifesting) and substantive requirements (e.g., risk assessment for open burning/open detonation, Subpart X) in the response to an explosive or munitions emergency. The rule defines an explosive or munitions emergency as:

Used or Fired Munitions

Military munitions that (1) have been primed, fuzed, 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.

> "...A situation involving the suspected or detected presence of unexploded ordnance (UXO), damaged or deteriorated explosives or munitions, an improvised explosive device (IED) or other potentially harmful chemical munitions or device that creates an actual or potential imminent threat to human health, including safety or the environment..."

In general, the emergency situations described in this exemption parallel the CERCLA description of emergency removals – action must be taken in hours or days. However, the decision as to whether a permit exemption is required is made by an explosives or munitions emergency response specialist.

2.1.5 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 issues 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 outlining 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 DoD 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."

2.2 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 were 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, Transferring, and Transferred Military Ranges,*** letter to Deputy Under Secretary of Defense (Environmental Security), April 22, 1999.

Information Sources

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/

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,*** September 2001.

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.

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.

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 reactive or ignitable soil) and other munition 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 munitions' constituents and include both human health and environmental risks. As the munition constituents 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 will be 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 were used for decades and had different missions that required the use of different types of munitions. Even careful archives searches will likely reveal knowledge gaps in how the ranges were 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 the hazards at CTT ranges from conventional munitions and munition constituents.
- The human health effects of munition constituents that come from conventional munitions.
- Other activities at CTT ranges that may result in releases of munition 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 materials 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.[7] 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.[8]

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, nitroglycerine 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 nitroglycerine were hampered by the danger of handling the liquid material and by the difficulty of safely detonating it by flame, the common method for detonating black powder. Alfred Nobel would solve these problems by mixing the liquid nitroglycerine 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 nitroglycerine with nitrates and combustible material created a new class of explosives he named "straight dynamite." In 1875 Nobel discovered that a mixture of nitroglycerine and nitrocellulose formed a gel. This led to the development of blasting gelatin, gelatin dynamites, and the first double-base gun propellant, ballistite.[9]

In the latter half of the nineteenth century, events evolved rapidly with the first commercial production of nitroglycerine 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[10] began to be used as a bursting charge for shells. Additional diverse mixtures of various compounds with inert or stabilizing fillers were developed for use as propellants and as bursting charges.[11]

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[7]A mixture of potassium nitrate, sulfur, and powdered charcoal or coal.

[8]*Military Explosives*, TM 9-1300-214, Department of the Army. September 1984.

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

[10]Picric acid, 2,4,6-Trinitrophenol.

[11]*Military Explosives*, 1984.

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.[12]

Because of its corrosive action on metal casings to form shock-sensitive metal salts, picric acid was replaced by TNT[13] as a bursting charge for artillery shells. By 1909, diphenylamine 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.

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.[14]

3.1.1.4 ***The Decades Between the Two World Wars***

The decades following World War I saw the development and use of RDX,[15] PETN,[16] lead styphnate, DEGDN,[17] 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 more powerful and castable explosives such as pentolite.[18] Flashless propellants were developed in the United States, as well as diazodinitrophenol as an initiator.[19]

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[12] Ibid.

[13] TNT, 2,4,6-Trinitrotoluene.

[14] *Military Explosives*, 1984.

[15] RDX, Hexahydro-1,3,5-trinitro-1,3,5-triazine.

[16] Use of 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.

[17] DEGDN, Diethylene glycol dinitrate.

[18] An equal mixture of TNT and PETN.

[19] *Military Explosives*, 1984.

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 nitroglycerine or nitrocellulose and DEGDN. Tetrytol[20] and picratol,[21] special-purpose binary explosives used in demolition work and in semi-armor-piercing bombs, were also developed by the United States.[22]

RDX and HMX[23] came into use during World War II, but HMX was not produced in large quantities, so its use was limited.[24] 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,[25] torpex,[26] and minol,[27] which have powerful blast effects. 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.[28]

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. Mixing RDX, HMX, or PETN into oily or polymer

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[20] A binary bursting charge explosive containing 70% tetryl and 30% TNT.

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

[22] *Military Explosives*, 1984.

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

[24] Bailey.

[25] A mixture of 80% TNT and 20% flaked aluminum.

[26] A mixture of 41% RDX, 41% TNT, and 18% aluminum.

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

[28] *Military Explosives*, 1984.

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.[29]

3.1.2 Classification of Military Energetic Materials

Energetic materials used by the military consist of energetic chemical compounds or mixtures of chemical compounds. These are divided into three uses: explosives, propellants, and pyrotechnics. Explosives and propellants, if properly initiated, will evolve large volumes of gas over a short period of time. The key difference between explosives and propellants is the reaction rate. Explosives react rapidly, creating a high-pressure shock wave. Propellants react at a slower rate, creating a sustained lower pressure. Pyrotechnics produce heat but less gas than explosives or propellants.[30]

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.[31]

Military explosives are grouped into three classes:[32]

1. Inorganic compounds, including lead azide and ammonium nitrate
2. Organic compounds, including:
   a. Nitrate esters, such as nitroglycerine and nitrocellulose
   b. Nitro compounds, such as TNT and Explosive D
   c. Nitramines, such as RDX and HMX
   d. Nitroso compounds, such as tetrazene
   e. Metallic derivatives, such as mercury fulminate and lead styphnate
3. Mixtures of oxidizable materials, such as fuels, and oxidizing agents that are not explosive when separate. These are also known as binary explosives.

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.

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[29]Bailey.

[30]*Military Explosives*, 1984.

[31]*Military Explosives*, Department of the Army, TM 9-1910, April 1955.

[32]Ibid.

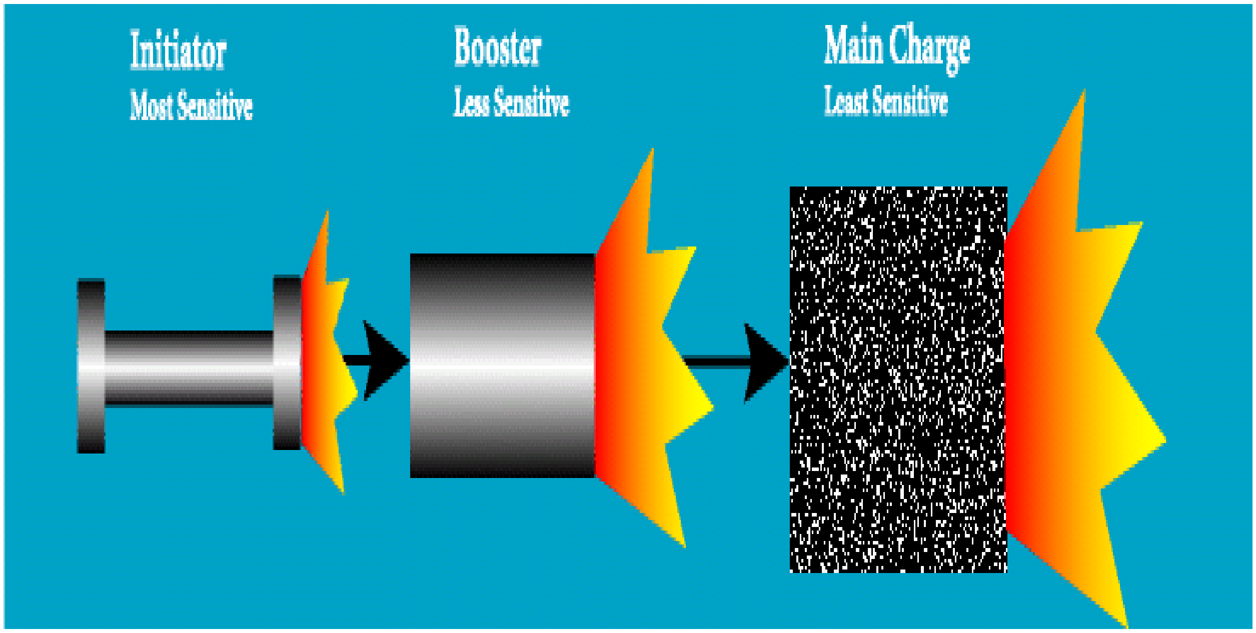

Figure 3-1. Schematic of an Explosive Train

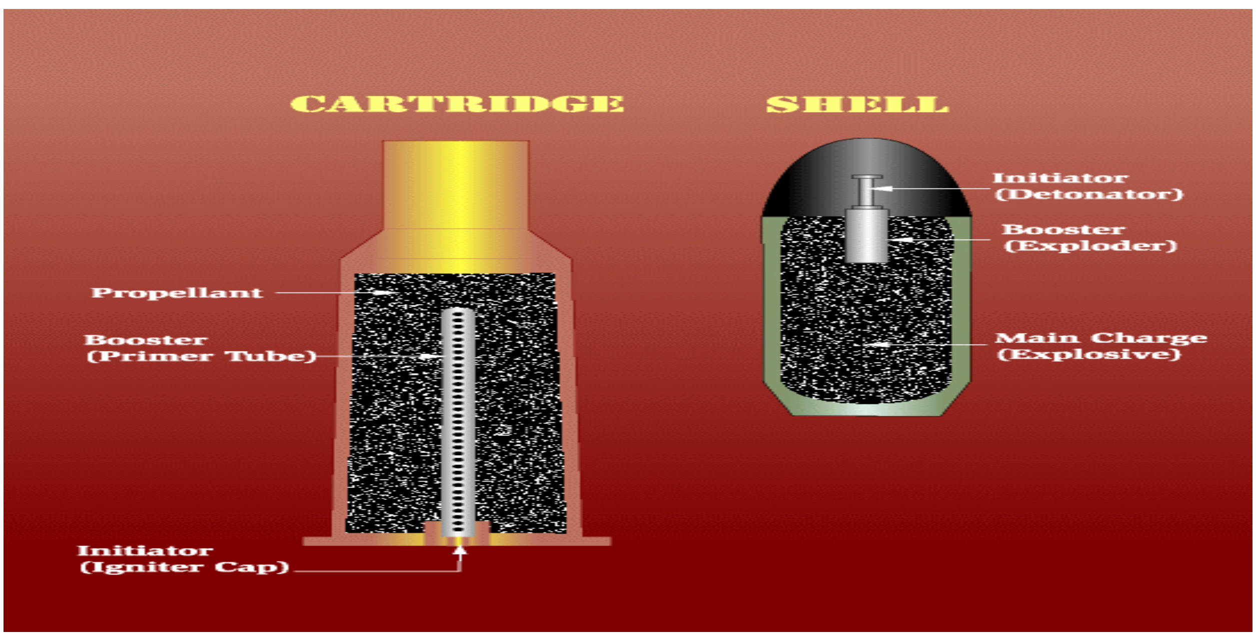

Figure 3-2. Explosive Trains in a Round of Artillery Ammunition

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 with the evolution of large amounts of heat and gas.[33] The

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

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, a process called detonation. A detonation is a reaction that proceeds through the reacted material toward the unreacted material at a supersonic velocity (greater than 3,300 feet per second). 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 smokeless powder 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. 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.

3.1.3.1 *Low Explosives, Pyrotechnics, Propellants, and Practice Ordnance*

Low explosives include such materials as smokeless powder and black powder. 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 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. Pyrotechnics consist of a wide range of materials that in combination produce the desired effects. Some examples of these materials are found in the text box to the right.[34] Some pyrotechnic devices are used as military simulators and are designed to explode. For example, the M80 simulator, a paper cylinder containing the charge composition, is used to simulate rifle or artillery fire, hand grenades, booby traps, or land mines.[35] Table 3-1 shows examples of pyrotechnic special effects.[36]

Chemicals Found in Pyrotechnics

Aluminum
Barium
Chromium
Hexachlorobenzene
Hexachloroethane
Iron
Magnesium
Manganese
Titanium
Tungsten
Zirconium
Boron
Carbon
Silicon
Sulfur
White Phosphorus
Zinc

Chlorates
Chromates
Dichromates
Halocarbons
Iodates
Nitrates
Oxides
Perchlorates

[34]Ibid.

[35]*Pyrotechnic Simulators*, TM 9-1370-207-10, Headquarters, Department of the Army, March 31, 1991.

[36]Bailey.

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 explosives that can 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 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.

Historically, 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 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.[37]

Modern gun propellants consist of one or more explosives and additives (see text box below). 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.[38]

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 nitroglycerine and nitroguanidine.[39]

Chemicals Found in Gun Propellants

Dinitrotoluenes (2,4 and 2,6)
Diphenylamine
Ethyl centralite
N-nitroso-diphenylamine
Nitrocellulose
Nitroglycerine
Nitroguanidine
Phthalates

There are three compositions of gun propellants: single-base, double-base, and triple-base. A single-base propellant

[37]*Military Explosives*, 1984.

[38]Bailey.

[39]Ibid.

contains nitrocellulose as its primary explosive ingredient. Some compositions contain dinitrotoluenes (DNTs) as well. Single-base propellants are used in all manner of guns, from pistols to artillery. A double-base propellant contains nitroglycerine in addition to nitrocellulose. The amount of nitroglycerine present is lower now than when double-base propellants were introduced because modern automatic weapons are eroded by the hotter gases produced by propellants of higher nitroglycerine composition propellants. Double-base propellants are largely used in ammunition for pistols and submachine guns. Triple-base propellants contain up to 55 percent by weight of nitroguanidine, as well as nitrocellulose and a small amount of nitroglycerine. The use of triple-base propellants is especially effective in large guns, because their use reduces barrel erosion, extends barrel life, and reduces flash.

Rocket propellants are explosives designed to burn smoothly without risk of detonation, thus providing smooth propulsion. Some classes of rocket propellants are similar in composition to the previously described gun propellants. However, due to the different requirements and operating conditions, there are differences in formulation. Gun propellants have a very short burn time with a high internal pressure. Rocket propellants can burn for a longer time and operate at a lower pressure than gun propellants.[40]

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 commonly 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 those used on the U.S. Army's tactical Lance missile. The Lance missile's fuel is an unsymmetrical 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.[41]

Unlike the liquid-fueled rocket motors, in which the propellant is introduced into a combustion chamber, the solid fuel motor contains 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 nitroglycerine 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%),

[40]Ibid.

[41]Ibid.

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.

Practice ordnance is ordnance used to simulate the weight and flight characteristics of an actual weapon. Practice ordnance usually carries a small spotting device to permit the accuracy of impact to be assessed.

3.1.3.2 *High Explosives*

High explosives includes compounds such as TNT, tetryl, RDX, HMX, and nitroglycerine. 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 explosives (see 3.1.3.1). Some high explosives, such as nitrocellulose and nitroglycerine, are used 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 into primary and secondary high explosives according to their susceptibility to initiation. 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 that are 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

Bursting Explosives

TNT
RDX compositions
HMX
Explosive D

Explosive D, must be initiated by means of a booster explosive. Some common explosive compositions are discussed in the following text box.

> **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.

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,[42] 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.

3.2 Sources of Hazards from Explosives, Munition Constituents, and Release Mechanisms

3.2.1 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. However, munitions that were abandoned or buried cannot be assumed to meet the criteria for safe shipment and handling without investigation. In addition, munitions that have been used but failed to function as designed (called unexploded ordnance, duds, or dud-fired) may be armed or partially armed. As a category of munitions, UXO is the most hazardous and is normally not safe to handle or transport. Although it may be easy to identify the status (fuzed or not fuzed) of some munitions (e.g., abandoned), this is generally not the case with buried munitions or UXO. Many munitions use multiple fuzing options; one fuze may be armed and others may not be armed. Therefore, common sense dictates that all munitions initially be considered armed until the fuze can be properly investigated and the fuze condition determined.

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 UXO 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.

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

Conventional Munitions Commonly Found as UXO

- **Small arms munitions** present minimal explosive risks, but because they often consist of lead projectiles, they may cause lead contamination of the surrounding environment. Small arms include projectiles that are 0.6 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, blast, riot control, 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 munitions launched from gun tubes at a very high arc. Mortar shells range from approximately 2 to 11 inches in diameter and are filled with explosives, white phosphorus, red phosphorus, illumination flares, chemical agents, or other fillers. Typical U.S. sizes include the 60mm, 81mm, and 4.2-inch mortars. Mortar shells, like projectiles, can be either fin stabilized or spin stabilized and are common ordnance deployed by ground troops. Mortar shells are sensitive to disturbances.
- **Projectiles/artillery rounds** range from approximately 0.6 to 16 inches in diameter and from 2 inches to 4 feet in length. Projectiles are typically deployed from ground gun platforms but in certain configurations the guns can be mounted on an aircraft. A typical projectile configuration consists of a bullet-shaped metal body, a fuze, and a stabilizing assembly. Fillers include antipersonnel submunitions, high explosives, illumination, smoke, white phosphorus, riot control agent, or a chemical filler. Fuzing may be located in the nose or base. Fuze types include proximity, impact, and time delay, depending upon the mission and intended target.
- **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.
- **Rockets and missiles** pose serious hazards, as the potential exists for residual propellant to burn violently if subjected to sharp impact, heat, flame, or sparks. Rockets and missiles consist of a motor section, a warhead, and a fuze. A rocket is an unmanned, self-propelled ordnance, with or without a warhead, designed to travel about the surface of the earth and whose trajectory or course can not be controlled during the flight. Missiles also have a guidance system that controls their flight trajectory. The warhead can be filled with explosives, toxic chemicals, white phosphorus, submunitions, riot-control agent, or illumination flares. Rockets and missiles may be fuzed with any number of fuzes. The fuze is the most sensitive part of an unexploded rocket or missile.
- **Bombs** may penetrate the ground at variable depths. Dud-fired bombs that malfunction and remain on or near the ground surface can be extremely hazardous. Bombs commonly range from 100 to 3,000 pounds in weight and from 3 to 12 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: Naval Explosive Ordnance Disposal Technology Division, UXO Countermeasures Department, *Unexploded Ordnance (UXO): An Overview*, October 1996, and DoD Office of the Deputy Under Secretary of Defense (Environmental Security), BRAC Environmental Fact Sheet, Unexploded Ordnance (UXO), Spring 1999. Also based on comments received from NAVEODTECHDIV.

3.2.2 Areas Where OE Is Found

Areas that are most likely to contain OE include 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.

The types of munition constituents 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 commonly found munition constituents 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 contaminated soil samples collected[43] and up to 94 percent of contaminated water samples collected.[44]

Military Ranges

The typical setup of **bombing and gunnery ranges (including live-fire and training ranges)** consists of one or more "targets" or "impact areas," 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**, **troop maneuver area, or troop training area** is used for conducting military exercises in a simulated conflict area or war zone. A training range can also be used for other nonwar simulations such as UXO training. 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.

Early (World War I era) munitions tended to be TNT- or Explosive D (ammonium picrate)-based. To a lesser extent, tetryl and ammonium nitrate were

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

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

used as well. 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 phosphorus also were used in World War II.

3.2.3 Release Mechanisms for OE

The primary mechanisms for the occurrence and/or release of OE at CTT ranges are based on the type of OE activity or are the result of improper functioning (e.g., detonation) of the OE. For example, when a bomb or artillery shell is dropped or fired, it will do one of three things:

- It will detonate completely. This is also called a "high order" detonation. Complete detonation causes a "kick-out" of both munition debris (e.g., fragments) and small quantities of munition constituents (e.g., energetic compounds such as TNT and RDX, lead and other heavy metals) into the environment. Kick-out also may occur during open detonation of OE during range clearing operations.
- It will undergo an incomplete detonation, also called a "low order" detonation. This causes a kick-out of not only munitions debris and larger amounts of munition constituents into the environment, but also larger pieces of the actual munition itself.
- It will fail to function, or "dud fire," which results in UXO. The UXO may be completely intact, in which case releases of munition constituents are less likely; or the UXO may be damaged or in an environment that subjects it to corrosion, thus releasing munition constituents over time.

In addition, OE could be lost, abandoned, or buried, resulting in bulk OE that could be fuzed or unfuzed. If such an OE item is in an environment that is corrosive or otherwise damaging to the OE item, or if the OE item has been damaged, munition constituents could leach out of the ordnance item.

The fate and transport of some munition constituents in the environment have not yet received the level of focus of some more commonly found chemicals associated with other military operations (such as petroleum hydrocarbons in groundwater from jet fuels). For example, TNT adsorbs to soil particles and is therefore not expected to migrate rapidly through soil to groundwater. However, the behavior in the environment of TNT's degradation products is not well understood at this time, nor is the degree to which TNT in soil might be a continuing low-level source of groundwater contamination.

DoD is currently investing additional resources to better understand the potential for corrosion of intact UXO in different environments and to better quantify the fate and transport of other munition constituents.

3.2.4 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 will react with alkalis to form dangerously sensitive compounds.[45] 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. 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 disposed of. These conditions may exist on ranges.

3.3 Sources and Nature of the Potential Hazards Posed by Conventional Munitions

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

The potential for the hazards posed by conventional munitions 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 munition constituents
- The likelihood that the munition will be in a location where disturbance is possible or probable

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

3.3.1 <u>Probability of Detonation as a Function of Fuze Characteristics</u>

Most military munitions contain a fuze that is designed to either ignite or cause the detonation of the payload containing the munition. Although there are many types of fuzes, all are in one of three broad categories – mechanical, electronic, or a combination of both. 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”).

[45] *Military Explosives*, 1955.

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**. 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. Also, 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.[46] 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. A proximity fuze by design uses an electrical signal as the initiation source for the detonation. In a dud-fired condition, the main concern is the outside influence exerted by an electromagnetic (EM) source. EM sources include two-way radios and cell phones; therefore, the use of such items must not be permitted in these types of environments. However, proximity fuzes sometimes can be 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. (An example of an all-way-acting fuze is shown in Figure 3-3.) 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. Moving UXO with this type of fuze may also cause a detonation. An example is shown in Figure 3-4.
- **Powder train time fuzes** use a black powder train to function at a predetermined time after firing.

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

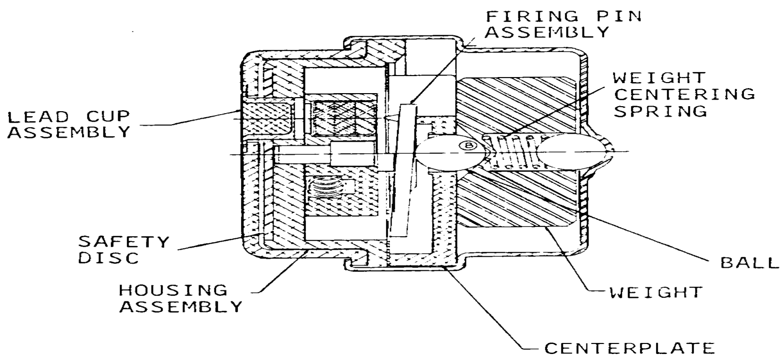

Figure 3-3. Mechanical All-Way-Acting Fuze

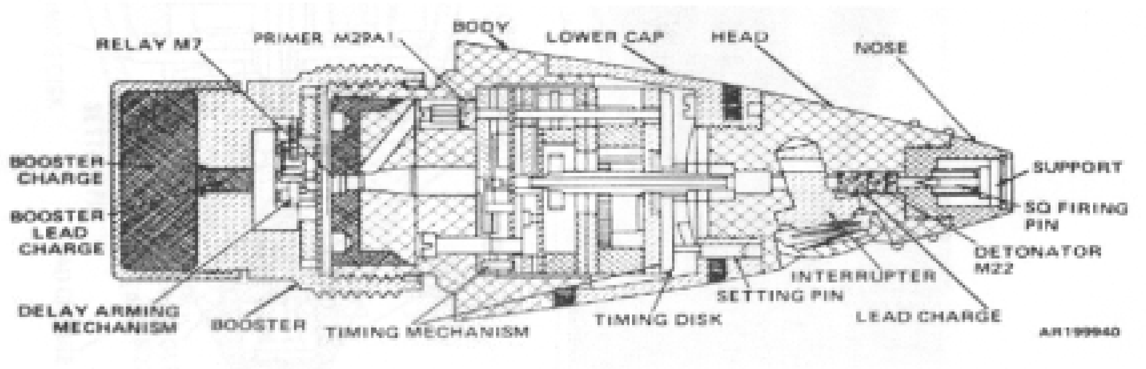

Figure 3-4. Mechanical Time Fuze

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 intentional and accidental explosions.[47] (DDESB is currently in the process of revising the safety standards.) 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

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

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, and thermal hazards. Shock hazards are also a concern but are more of an issue with respect to storage of munitions in underground bunkers at active ranges. Each of these hazards is described below. Many OE hazards in the field may result in more than one type of explosive output.

Blast pressure (over 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.

Shock hazards result from underground detonations and are less likely to occur at CTT ranges than at active ranges or industrial facilities where munitions are found. When an ordnance item is buried in the earth (e.g., stored underground), if detonation occurs, it will cause a violent expansion of gases, heat, and shock. A blast wave will be transmitted through the earth or water in the form of a shock wave. This shock wave is comparable to a short, powerful earthquake. The wave will pass through earth or water just as it does through air, and when it strikes an object such as a foundation, the shock wave will impart its energy to the structure.

Practice rounds of ordnance may have their own explosive hazards. They often contain spotting charges which are explosive fillers designed to produce a flash and smoke when detonated, providing observers or spotters a visual reference of ordnance impact. Practice UXO found on the ranges must be checked for the presence of unexpended spotting charges that could cause severe burns.

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 risk of explosion from OE:

- Flooding and erosion
- Frost heaving

- Agricultural activities
- Construction
- Recreational use (may provide open access)

Heavy flooding can loosen and displace soils, causing OE located on or beneath the ground surface to be moved or exposed. In flooded soils, OE 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 OE, or it could cause OE 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, OE buried above the frost line may migrate with frost heaving. The effects of these and other geophysical processes on the movement of OE in the environment, while known to occur, are being studied more extensively by DoD.

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

3.3.4 Depth of OE

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 response depth.[48] 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 (e.g., ordnance weight, geometry, angle of entry), 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 3-2 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

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

provided in Table 3-2 are taken from a controlled study to determine munition 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 3-2 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.[49]

Table 3-2. Examples of Depths of Ordnance Penetration into Soil

Type of Munition	Ordnance Item	Depth of Penetration (ft)			
		Limestone	Sand	Soil Containing Vegetation	Clay
Projectile	155 mm M107	2	14	18.4	28
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, *Ordnance and Explosives Response: Engineering and Design*, EM 1110-1-4009, June 23, 2000; Ordata II, NAVEODTECHDIV, Version 1.0; and Crull Michelle 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 or location may be incomplete or absent altogether.

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

3.3.5 <u>Environmental Factors Affecting Decomposition of OE</u>

Deteriorated OE can present serious explosive hazards. As the OE ages, the explosive compound/mixtures in the OE can remain viable and could increase in sensitivity.[50]

The probability of corrosion of an intact OE item is highly site specific. OE can resist corrosion under certain conditions. There are OE sites dating back to World War I in Europe that contain subsurface OE that remains intact and does not appear to be releasing any munition constituents. However, there are certain environments, such as OE exposed to seawater, that can cause OE[51] to degrade. In addition, as OE casings degrade under certain environmental conditions, or if the casings were damaged upon impact, their fillers, propellants, and other constituents may leach into the surrounding soils and groundwater.

In general, the likelihood of OE deterioration depends on the integrity and thickness of the OE casing, as well as the environmental conditions in which the OE item is located and the degree of damage to the OE item after being initially fired. Most munitions are designed for safe transport and handling prior to use. However, if they fail to explode upon impact, undergo a low-order detonation, or are otherwise damaged, it is possible that the fillers, propellants, and other munition 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 adverse impacts to soil and groundwater from ordnance-related activities.

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

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

Moisture, including precipitation, high soil moisture, and the presence of groundwater, contribute to the corrosion of OE and to the deterioration of explosive compounds. Soils with a low water content (i.e., below 20 percent) are slightly corrosive on OE casings, and soils with periodic groundwater inundation are moderately corrosive.

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[50]U.S. Army Corps of Engineers, *Ordnance and Explosives (OE) Response Workshop*. Control #399, USACE Professional Development Support Center, FY01.

[51]OE specifically designed for use in a marine environment, such as sea mines and torpedoes, would not be included in this scenario.

The texture and structure of soil affect its corrosivity. 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 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 drop 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 OE casing corrosion. The electrochemical or "redox" potential is the ability of the soil to reduce or oxidize OE casings (the oxidation-reduction potential). Aerated soils have the necessary oxygen to oxidize metals.

3.3.6 Explosives-Contaminated Soils

A variety of situations can create conditions of contaminated and potentially reactive and/or ignitable soils, including the potential for low-order detonations, deterioration of the OE container and leaching of munition constituents into the environment, residual propellants ending up in soils, and OB/OD, which may disperse chunks of bulk explosives and munition constituents. 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.[52] Soils with a 12 percent or greater concentration of secondary explosives, such as TNT and RDX, are capable of propagating (transmitting) a detonation 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 or burn if initiated, but a detonation will not move 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

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

or more of secondary explosives or mixtures of secondary explosives to be reactive or ignitable soil.[53]

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

The human health and environmental risks of other munition constituents from OE are caused by explosives or other chemical components, including lead and mercury, in munitions and from the compounds used in or produced during munitions operations. When exposed to some of these munition constituents, humans may potentially face long-term health problems, including cancer, and animals may develop physical health and behavioral problems. The adverse effects of munition constituents are dependent on the concentration of the chemicals and the pathways by which receptors become exposed. Understanding the human health and environmental risks of munition constituents and byproducts requires information about the inherent toxicity of these chemicals and the manner in which they 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 3-3. Other toxic materials, such as lead, are found in the projectiles 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 3-3 illustrates the chemical compounds used in munitions and their potential human health effects as provided by EPA's Integrated Risk Information System (IRIS), the National Library of Medicine's Toxicology Data Network (TOXNET) Hazardous Substances Data Bank, the Agency for Toxic Substances and Disease Registry (ATSDR), and material safety data sheets (MSDS).

Table 3-4 shows the uses of many of the same compounds found on Table 3-3. 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 3-4 is not intended to be all-inclusive but to provide a summary of some of the more common uses for various explosive materials.

Perchlorate

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.

[53] Federal Remediation Technologies Roundtable and USAEC, *ETL Ordnance and Explosives Response*, 1110-1-8153, May 14, 1999.

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

	Contaminant	Chemical Composition	Potential Toxicity/Effects
2	**Contaminant**	**Chemical Composition**	**Potential Toxicity/Effects**
3	TNT	2,4,6-Trinitrotoluene $C_7H_5N_3O_6$	Possible human carcinogen, targets liver, skin irritations, cataracts.
4	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.
5	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.
6	PETN	Pentaerythritol tetranitrate $C_5H_8N_4O_{12}$	Irritation to eyes and skin; inhalation causes headaches, weakness, and drop in blood pressure.
7	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.
8	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.
9	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.
10	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.
11	DEGDN	Diethylene glycol dinitrate $(C_2H_4NO_3)_2O$	Targets the kidneys; nausea, dizziness, and pain in the kidney area. Causes acute renal failure.
12	2,4-Dinitrotoluene	$C_7H_7N_2O_4$	Exposure can cause methemoglobinemia, anemia, leukopenia, liver necrosis, vertigo, fatigue, dizziness, weakness, nausea, vomiting, dyspnea, arthralgia, insomnia, tremor, paralysis, unconsciousness, chest pain, shortness of breath, palpitation, anorexia, and loss of weight.
13	2,6-Dinitrotoluene	$C_7H_7N_2O_4$	Exposure can cause methemoglobinemia, anemia, leukopenia, and liver necrosis.
14	Diphenylamine	N,N-Diphenylamine $C_{12}H_{11}N$	Irritation to mucous membranes and eyes; pure substance toxicity low, but impure material may contain 4-biphenylamine, a potent carcinogen.

Table 3-3. Potential Toxic Effects of Exposure to Explosive Chemicals and Compounds (Continued)

Contaminant	Chemical Composition	Potential Toxicity/Effects
N-Nitrosodiphenylamine	$C_{12}H_{10}N_2O$	Probable human carcinogen based on an increased incidence of bladder tumors in male and female rats and reticulum cell sarcomas in mice, and structural relationship to carcinogenic nitrosamines.
Phthalates	Various	An increase in toxic polyneuritis has been reported in workers exposed primarily to dibutyl phthalates; otherwise very low acute oral toxicity with possible eye, skin, or mucous membrane irritation from exposure to phthalic anhydride during phthalate synthesis.
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.
Nitroglycerine (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	$PbC_6HN_3O_8 \bullet H_2O$	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.
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 3-4. Primary Uses of Explosive Materials

Compound	Propellant	Primary or Initiator	Booster	Burster Charge	Pyrotechnics	Incendiary
TNT				•		
RDX			•	•		
HMX			•	•		
PETN			•	•		
Tetryl			•			
Picric acid				•		
Explosive D				•		
Tetrazene		•				
DEGDN	•					
Nitrocellulose	•					
2,4-Dinitrotoluene	•			•		
2,6-Dinitrotoluene	•			•		
Ammonium nitrate	•			•		
Nitroglycerine	•			•		
Lead azide		•				
Lead styphnate		•				
Mercury fulminate		•				
White phosphorus					•	•
Perchlorates	•				•	
Hydrazine	•					
Nitroguanidine	•					

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. 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.[54]

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.

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.[55]

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.[56]

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[54]Agency for Toxic Substances and Disease Registry, *Toxicological Profile for White Phosphorous*, U.S. Department of Health and Human Services, Public Health Service, Atlanta, GA, 1970.

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

[56]Agency for Toxic Substances and Disease Registry, *Toxicological Profile for 2,4,6-trinitrotoluene (update), and Toxicological Profile for RDX*, U.S. Department of Health and Human Services, Public Health Service, Atlanta, GA, 1995.

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, 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 Munition Constituents

Contamination of soils and groundwater with explosive compounds results from a variety of activities. These activities include the release of other munition constituents during planned munitions training and testing, munitions disposal/burial pits associated with military ranges, and munition storage sites and build-up locations. Contamination also results from the deterioration of intact ordnance, the open burning and open detonation of ordnance, and the land disposal of explosives-contaminated process water from explosives manufacturing or demilitarization plants. Munition constituents include heavy metals, particularly lead and mercury, because they are components of primary or initiating explosives such as lead azide and mercury fulminate. These metals are released to the environment after a detonation or possibly by leaching out of damaged or corroded OE. The sections below describe specific sources of munition constituents.

3.5.1 Open Burning/Open Detonation (OB/OD)

Concentrations of munition constituents, such as explosives and metals, and bulk explosives have been found at former OB/OD areas at levels requiring a response. 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 fuller discussion of OB/OD.

Incomplete combustion of munitions and energetic materials can leave uncombusted TNT, RDX, HMX, PETN, and other explosives. These materials can possibly be spread beyond the immediate vicinity of the OB/OD operation by the kick-out these operations generate and 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 munition constituents. These facilities are usually commercial sites that are not usually 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 munition constituents 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 munition constituents 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 munition constituents 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 OE, including buried munitions, UXO, and munition constituents, 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 potential for deflagration or detonation, 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, an OE item that is degraded may release propellants, explosives, pyrotechnics, and other munition constituents 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; and load, assemble, and pack operations.

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

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

<u>Information Sources</u>

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

ORDATA II (database of ordnance items)
Available from: NAVEOTECHDIV
Attn: Code 602
20008 Stump Neck Road
Indian Head, MD 20640-5070
E-mail: ordata@eodpoc2.navsea.navy.mil

U.S. Department of Health and Human Services, Public Health Service
Agency for Toxic Substances and Disease Registry (ATSDR)
Division of Toxicology
1600 Clifton Road, E-29
Atlanta, GA 20222
http://www.atsdr.cdc.gov

U.S. Environmental Protection Agency, Technology Innovation Office
Hazardous Waste
Cleanup Information (CLU-IN)
http://www.clu-in.org/

U.S. Environmental Protection Agency
Integrated Risk Information System (IRIS)
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
4820 University Square
Huntsville, AL 35807-4301
http://www.hnd.usace.army.mil/

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4.0 DETECTION OF UXO AND BURIED MUNITIONS

4.1 Introduction

Geophysical detection technologies are deployed in a nonintrusive manner to locate surface and subsurface anomalies that may be UXO or buried munitions. (For purposes of brevity, discussions of UXO and buried munitions will be referred to as UXO throughout this chapter.) 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 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 the accurate and appropriate deployment of nonintrusive geophysical detection technologies to maximize probability of detection and minimize false alarms.

Since the early 1990s, existing geophysical survey technologies have improved in their capabilities to efficiently and cost-effectively detect UXO. Much of the improvement is the result of greater understanding of operational requirements for the use of detection technologies. However, the primary challenge in UXO detection today is the achievement of high levels of subsurface detection in a consistent, reproducible manner with a high level of quality assurance. Distinguishing ordnance from fragments and other nonordnance materials based solely on the geophysical signature, called target discrimination, is also a major challenge in UXO detection and the focus of research and development activities. This problem is known as a **false alarm**, as described in the text box below. Poor discrimination results in lower probability of detection, higher costs, longer time frames for cleanups, and potentially greater risks following cleanup actions.

False Alarms

The term *false alarm* is used when a declared UXO detection location does not correspond to an actual UXO location based upon the groundtruth data. **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 or are misidentified in post-processing, resulting in potential risks remaining following UXO investigations.

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. As discussed in Section 4.2 below and in Chapter 7, a combination of information from a variety of sources (including historical data, results of previous environmental data collection, and knowledge of field and terrain conditions) will be used to make decisions about the detection system to be used, including the particular sensor(s), the platform on which it is deployed, and data acquisition and processing techniques. Detailed fact sheets on each of the detection sensors currently in use are found at the end of this chapter.

Experts in the UXO research and development community have indicated that currently available detection technologies will improve with time and that no revolutionary new systems are likely to 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 "signatures" (e.g., spatial pattern of magnetic signal).

Geophysical sensors have specific capabilities and limitations that must be evaluated when selecting a detection system for a site. The primary types of sensors in use today are:

- **Magnetometry –** a passive sensor that measures a magnetic field. Subsurface ferrous items create irregularities in the Earth's magnetic field and may contain remnant magnetic fields of their own that are detected by magnetometers.
- **Electromagnetic Induction (EMI) –** an active sensor that induces electrical currents beneath the earth's surface. Conductivity readings of the secondary magnetic field created by the electrical currents are used to detect both ferrous and nonferrous ordnance items.

In addition, under specific and limited conditions, ground-penetrating radar (GPR) has been successfully used to detect UXO. This sensor is mainly helpful when the location of larger munitions burial sites is known and boundaries must be identified. Magnetometers, EMI sensors, and GPR sensors are discussed in detail in Section 4.2 and in the fact sheets at the end of the chapter. The results of investigations using any sensor can vary dramatically depending not only on the site conditions, but also on the components of the detection system, the skill of the operator, and the processing method used to interpret the data.

Detection systems that will be available in the near future include advanced electromagnetic systems and airborne magnetometers. Long-term research endeavors include a GPR that can identify UXO at discrete locations, and an airborne EMI sensor. An overview of emerging detection technologies, as well as data processing and modeling for target discrimination, is presented in Sections 4.3 and 4.4.

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. The JPGTD as well as other demonstration programs, such as the Environmental Security Technology Certification Program UXO Technology

Standardized Demonstration Sites and the Fort Ord Ordnance Detection and Discrimination Study (ODDS) are discussed in Section 4.5.

4.2 Selection of the Geophysical Detection System

Many factors should be considered when identifying the detection system appropriate to your site. First, information about the detection sensors currently available, and the factors that contribute to their successful application, should be evaluated. Next, basic site conditions should be evaluated, such as expected targets (size, location, density, depths), terrain, vegetation, and electromagnetic fields. Finally, the role of each system component and how it affects overall performance should be examined to ensure maximum effectiveness.

4.2.1 <u>Geophysical Sensors in Use Today</u>

Magnetometry and electromagnetic induction are the most frequently used sensors for detecting UXO. Both sensors are commercially available and are employed on a variety of systems using various operational platforms, data processing techniques, and geolocation devices.

4.2.1.1 *Electromagnetic Induction (EMI)*

EMI sensors are perhaps the most widely used systems for detecting UXO. The electromagnetic induction system is based on physical principles of inducing and detecting electrical current flow within nearby conducting objects. EMI surveys work by inducing time-varying magnetic fields in the ground from a transmitter coil. The resulting secondary electromagnetic field set up by ground conductors is then measured at a receiver coil. EMI systems can detect all conductive materials but are at times limited by interference from surface or near-surface metallic objects. In general, the EMI response will be stronger the closer the detector head is to the buried target, but close proximity to the ground surface may subject the sensor to interference from shallow fragments. In areas of heavy vegetation, the distance between the detector head and the earth's surface is increased, potentially decreasing signal strength and decreasing the probability of detection. Soil type also plays a role in EMI system detection. EMI systems may have difficulty detecting small items in conductive soils, such as those containing magnetite, or in soils with cultural interferences, such as buildings, metal fences, vehicles, cables, and electrical wires. Because the difficulties with detecting small items in conductive soils are also present for magnetometry, this issue is usually not a limiting factor in selection of an EMI system.

EMI systems operate in time or frequency domains (i.e., regions). Time-domain electromagnetic (TDEM) systems operate by transmitting a magnetic pulse that induces currents in and near conducting objects. These currents produce secondary magnetic fields that are measured by the sensor after the transmitter pulse has ended. The sensor integrates the induced voltage over a fixed time gate and averages over the number

EMI and Electronic Fuzes

EMI is an active system for which there has been concern about increasing the risk of initiating OE with electronic fuzing. However, there is no evidence that the current generation of EMI based systems (e.g., EM61) generate enough power to cause this effect. This may be an issue to watch in the future, however, if more powerful systems are developed.

of pulses. When TDEM detectors are handheld and/or smaller in size, they may have a lessor penetration depth than the more commonly used EMGI.

Frequency domain electromagnetic (FDEM) instruments operate by transmitting continuous electronic signals for a single frequency and measuring the resulting eddy currents. FDEM instruments are able to detect deeply buried munitions that are grouped together. In addition, some types of FDEM instruments are capable of detecting very small individual UXO items that are buried just beneath the ground surface; for example, metal firing pins in plastic land mines. When detecting individual, deeply buried munitions, FDEM instruments should not be used because of the sensor's decreased resolution, as well as difficulty in measuring the amplitude of return of individual targets.

4.2.1.2 *Magnetometry*

Magnetometers are passive systems that use the Earth's magnetic field as the source of the signal. Magnetometers detect distortions in the magnetic field caused by ferrous objects. The magnetometer has the ability to detect ferrous items to a greater depth than can be achieved by other systems. Magnetometers can identify small anomalies because of the instrument's high levels of sensitivity. However, magnetometers are also sensitive to many iron-bearing minerals and "hot rocks" (rocks with high iron content), which affects the detection probability by creating false positives and masking signals from real ordnance.

The two most common magnetometry systems used to detect buried munitions are cesium vapor or fluxgate. Cesium vapor magnetometers measure the magnitude of a magnetic field. These systems produce digital system output. The fluxgate systems also measure the direction and magnitude of a magnetic field. These systems are inexpensive, reliable, and rugged and have low energy consumption.

4.2.1.3 *Ground Penetrating Radar*

GPR is another sensor technology that is currently commercially available, although it is not used as frequently as EMI and magnetometry and is generally not as reliable. GPR systems use high-frequency (approximately 10-1,000 MHz) electromagnetic waves to excite the conducting object, thus producing currents. The currents flow around the object, producing electromagnetic fields that radiate from the target. The signals are received by the GPR antenna and stored for further processing. Most commercial systems measure total energy return and select potential targets based on contrast from background. More advanced processing uses the radar information to produce 2-D or 3-D images of the subsurface or to estimate directly features of the target, such as length or a spectra. Such processing systems are not generally in use at this time.

The GPR system is more accurate when used in areas of dry soil. Water in the soil absorbs the energy from the GPR, thus interfering with UXO detection. GPR may be used to find the boundaries of large caches of buried munitions.

4.2.2 Selection of the Geophysical Detection System

The selection of a detection system is a site-specific decision. Some of the factors that should be considered in selecting a detection system include, but are not limited to:

- Site size
- Soil type, vegetation, and terrain
- Subsurface lithology
- Depth, size, shape, composition, and type of UXO
- Geological and cultural noise (e.g., ferrous rocks and soils, electromagnetic fields from power lines)
- Non-UXO clutter on-site
- Historical land use
- Reasonably anticipated future land use
- UXO density

Each of the above factors should be considered against the decision goals of the investigation in order to select the most appropriate detection system. Table 4-1 highlights the effects of each factor on the investigation process. This list of considerations is not all-inclusive.

Table 4-1. Examples of Site-Specific Factors To Be Considered in Selecting a Detection System

Site Factors	Considerations
Site size	Different operational platforms cover areas at different speeds. If a large area needs to be surveyed, operational platforms such as towed-array or airborne may be considered, if appropriate.
Soil properties	Potential for high conductivity levels to interfere with target signals; potentially reduced detection capabilities using magnetometers in ferrous soils.
Vegetation	Heavy vegetation obstructs view of OE items on surface and may interfere with sensor's ability to detect subsurface anomalies, as well as access to the site and operation of the sensor.
Terrain	Easily accessible areas can accommodate any operational platform; difficult terrain may require man-portable platform.
Subsurface lithology	Soil and rock layers and configurations beneath the ground surface will influence the depth of the UXO and the ability of the sensor to "see" anomalies.
Target size and orientation	Capability of detector to find objects of various sizes and at various orientations.
Target penetration depth	Capability of detector to find targets at depths. Potential for decreased signal when detecting deeply buried targets.
Composition of UXO	Shell and fuze composition may dictate sensor selection. Magnetometers detect only ferrous materials, while EMI systems detect all metals.

Table 4-1. Examples of Site-Specific Factors To Be Considered in Selecting a Detection System (Continued)

Site Factors	Considerations
Noise	Both geological noise (e.g., hot rocks or high ferrous content in soil) and cultural noise (e.g., buried cables, overhead utilities) potentially increase false alarms and mask ordnance signals.
Non-UXO clutter	Potential difficulty discriminating between small objects and metallic scrap, resulting in high numbers of false alarms.
Historical land use	Information about expected target location, types, and density.
Future land use	Enables setting of realistic decision goals for investigation.
UXO density	Enables sensor strengths (e.g., ability to see individual items as opposed to large caches of targets) to be maximized.

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)

"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."

4.2.3 UXO Detection System Components

Table 4-2 identifies the various elements of a detection system and highlights how each element may affect the overall system performance. For example, the three operational platforms — man-held, towed-array, and airborne — directly affect the sensor's distance from the target, which, in turn, affects the sensor's ability to detect targets. The ability of all sensors to "see" targets decreases as distance from the target increases. However, the rate at which the performance drops off with distance varies by individual sensor. An additional consideration when selecting the operational platform includes what is expected to be found beneath the surface. Large caches of ordnance buried deep beneath the surface may remain detectable from large distances, whereas smaller ordnance items may be more easily missed by the sensor at a distance.

1 **Table 4-2. System Element Influences on Detection System Performance**

	System Element	Factors To Be Considered
2	**System Element**	**Factors To Be Considered**
3	Geophysical sensor	Site-specific conditions and the results of the geophysical prove-out are used to determine the sensor and system configuration best suited to achieve the goals of the investigation.
4	Geophysical prove-out	The accuracy with which geophysical prove-out represents field conditions and sampling methods helps to ensure the development of data with a known level of certainty in field operations.
5	Operator capability	The selection and use of detection systems is complex and requires individuals with appropriate qualifications and experience. Geophysical certification of the team to meet prove-out performance is a recommended QA/QC measure.
6	Operational platform	Size and depth of ordnance, sensor sensitivity to height above target, and potential for interference with sensor operation by platform components, and terrain and vegetation restriction need to be taken into account when selecting a platform.
7	Data acquisition	Digital versus analog data, reliability of data points, and ability to merge geophysical signals with global positioning system (GPS) makers affect potential for human error.
8	Data analysis	Experienced and qualified analysts and appropriate procedures help to ensure reliability of results.
9	Positional data	Accuracy and precision in positioning and navigation are needed to locate targets in relation to coordinate systems. Tree cover, terrain, and need for line of sight may restrict choices.

Operational Platforms for UXO Detection Systems

- **Man-Portable –** Man-portable systems can be used in areas that cannot be accessed by other platforms, such as those with heavy vegetation or rough terrain. The use of man-portable systems generally requires extensive man-hours, as the maximum speed with which the system can be operated is that at which an operator can walk the sampling area.

- **Towed Array –** These systems are generally used in flat treeless areas and can cover a larger area using fewer man-hours. Limitations include the inability to use towed-array systems in heavily wooded areas, other areas inaccessible to vehicles, or urban areas with tall buildings.

- **Airborne –** These systems are used to survey large, flat, treeless areas in a short period of time, using current magnetometry sensors requiring minimal standoff. The disadvantage of airborne detection is the high cost of the hardware and potential difficulty of penetrating deep enough below the ground surface, which is a function of both the altitude at which aircraft must fly, as well as of the sensor used. However, airborne systems can be highly cost-effective on large ranges because of the amount of acreage that can be covered and the resulting low cost per acre. In limited use today, airborne platforms are not as widely used as the other platforms.

4.2.4 Costs of UXO Detection Systems

The factors influencing the costs of deploying UXO detection systems are complex, and much broader the simple rental or purchase of a detector or sensor. The entire **life cycle** of the response process and the nature of the detection system must be considered. Life-cycle issues include:

- Costs of capital equipment
- Acreage that can be covered by your detection system over a specific period of time
- Rate of false positives, and costs of unnecessary excavation
- Costs of rework if it is later proven that the system deployed resulted in a number of false negatives
- Required clearance of vegetation
- Costs of cleanup
- Costs of operator salaries, based on the complexity and sophistication of the detection system (including training and certification of operators)

Evaluation of the factors may lead to site-specific decisions related to certain cost tradeoffs, for example:

- That high capital expenditures (e.g., airborne platforms) will result in reduced costs when large acreage is involved.
- Extensive use of expensive target discrimination equipment may be more worthwhile at a transferring base where land uses are uncertain, and transfer will not occur until the property is "cleaned" for the particular use.
- For small acreage, equipment producing a high rate of false positives may be acceptable if excavation is less costly than extensive data processing.
- Investments in systems with sensitive detectors and extensive data processing may be considered worthwhile when the potential of rework, and lack of acceptance of cleanup decisions is considered.

4.2.5 Quality Assurance/Quality Control

As discussed in Chapter 7, there are several aspects of quality assurance/quality control that affect the quality of UXO detection data. Specifically, data acquisition quality is a function of appropriate data management, including acquisition of data in the field, data processing, data entry, and more. In addition, field observation of data acquisition, reacquisition, and excavation procedures will help to ensure that proper procedures that directly affect data quality are followed. In addition, general practices that help to ensure quality include monitoring the functionality of all instruments on a daily basis and ensuring that the full site was surveyed and that there are no data gaps.

4.3 Emerging UXO Detection Systems

The detection systems discussed in the following sections are in various stages of development and implementation. Some are still being researched and tested, while others will be available for operational use in the near future. All of the systems discussed are advanced versions of EMI and magnetometry technologies. The EMI systems discussed below collect vast quantities of data at each position that is used for identification and discrimination purposes, while the magnetometry systems are modifications to accommodate additional operational platforms.

4.3.1 Advanced EMI Systems

There is a whole class of advanced EMI in research and development in DoD.

GEM-3 (Geophex Ltd.). The Geophex Ltd. GEM-3 is a multichannel frequency-domain EMI system that collects the EMI data over many audio frequencies. In other words, the GEM-3 collects multiple channels of information at each survey point. Frequency response data are used for the discrimination of UXO targets from clutter (both manmade and natural). This system has performed well in field tests for discrimination and identification of UXO.

EM-63 (Geonics Ltd.). The EM-63 is a time-domain EM sensor that records multiple channels of time-domain data at each survey point. It is already commercially available.[57] Processing approaches to fully exploit the additional data measured by the EM-63 are currently being researched. NAEVA Geophysics has demonstrated good performance with the EM-63 in field tests. Zonge Engineering has also developed a multitime gate, multiaxis system currently being characterized.

4.3.2 Airborne Detection

Airborne Magnetometry. Low-altitude airborne magnetometry has proved promising in tests on the Cuny Table at the Badlands Bombing Range in Pine Ridge, SD. Because of the conditions at Badlands Bombing Range and other large expanses of flat, open, and treeless ranges in the arid and semiarid climate of the western U.S., aircraft are able to fly close to the ground, providing for increased detection capabilities. Originally, the mission envisioned for airborne magnetics was the identification of concentration of ordnance for further investigation by ground-based sensors. However, performance in initial tests of COTs equipment indicated that for large ordnance (210 kg), individual items were detectable at about 50 percent of the rate of ground-based sensors. Research to improve the probability of detection is ongoing. Aircraft-mounted magnetometers may present a viable option for detecting and characterizing UXO, because the relatively low operation time required to characterize a very large range makes the detection time and cost per acre potentially reasonable despite the high setup and equipment costs.[58]

Airborne EM. Airborne electromagnetic induction is under research and development for use at ranges with characteristics similar to those discussed above (e.g., vast, open, treeless, and flat

[57]ERDC/EL TR-01-20, Advanced UXO Detection/Discrimination Technology Demonstration, U.S. Army Jefferson Proving Ground, Madison, Indiana, Ernesto Cespedes, September 2001.

[58]Evaluation of Footprint Reduction Methodology at the Cuny Table in the Former Badlands Bombing Range, July 2000, Environmental Security Technology Certification Program.

areas). However, unlike airborne magnetometry, airborne EMI could be used at sites with ferrous soils. Because EM signals fall off more quickly with increased distances, the challenge of using this technique from an airborne platform will be greater. Initial tests have shown detectability of large items on seeded sites.

Ground Penetrating Radar Identification. Studies of various GPR systems have been conducted. One study, by Ohio State University with the U.S. Army Corps of Engineers Research and Development Center and the Cold Regions Research and Engineering Laboratory, examined the capabilities of an ultra-wideband, fully polarimetric GPR system to provide information about the size and shape of buried objects. This study was based on UXO with known target locations, and focused on both detecting the UXO items and classifying specific ordnance types.[59]

4.4 Use of Processing and Modeling To Discriminate UXO

The development of advanced processing and modeling to reduce the false alarm rates without affecting an even improved Pd ordnance detection performance is evolving. Rather than using a simple amplitude of response in raw physical data exclusively, advanced processing methods organize large quantities of data. In efforts to encourage the development of algorithms for target discrimination without the expense and burden of field data collection, they have made standard sensor data sets for both controlled and live sites publicly available. For example, EM data in the time-frequency or spatial domain to discriminate particular objects of interest. Statistical methods can be used to associate field geophysical data with signatures of ordnance items that have either been measured or calculated using EM modeling tools. Alternatively, good data can be used to calculate the essential parameters of the targets, such as size, shape, and depth, which can be used to infer the nature of the item giving rise to the return.

About Signatures

The various methodologies deployed to detect UXO produce digital data that is recorded at each survey location. These data are displayed as graphs, charts, and maps that indicate the presence of an anomalous measurement. The graphical reports produce patterns that may be used to estimate the sizes, types, and orientations of UXO. These patterns are called "signatures." Signatures are being used in emerging technologies and rely on databases of electronic signatures to help discriminate between types of UXO, fragments of UXO, naturally occurring metals, and non-OE scrap.

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

[59] M. Higgins, C.C. Chen, and K. O'Neill, U.S. Army Corps of Engineers Research and Development Center (ERDC), Cold Regions Research and Engineering Laboratory, ESTCP Project 199902 – *Tyndall AFB Site Demo: Data Processing Results for UXO Classification Using UWB Full-Polarization GPR System*, 1999.

signals, thereby reducing the false alarm rate.[60] 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-base GEM-3 electromagnetic induction data to support identification of UXO and nonordnance items based on their frequency-domain electromagnetic signature. The signature library 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.[61] In addition, software has been developed to analyze the data and identify a wide variety of anomalies.[62]

The Naval Research Laboratory has developed a technique that uses data fusion to discriminate objects detected in magnetometry and electromagnetic surveys. The laboratory has developed model-based quantitative routines to identify the target's position, depth, shape, and orientation (see Fact Sheet 2 for a full description of MTADS). In addition, location information, including position, size, and depth, is expected to be improved to a small degree.[63] 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 fragments of ordnance and other clutter.

DoD is funding multiple universities for advanced processing research. Duke University, for example, has engaged in both physics-based modeling and statistical signal processing and has shown performance improvements in many diverse data sets, including EMI, magnetometer, and GPR/SAR.

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

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

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

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

4.5 UXO Detection Demonstration Programs

Several demonstration programs have been developed to test the effectiveness of various UXO detection sensors and systems in controlled environments. Because of the lack of technologies available to effectively locate UXO on thousands of acres of DoD ranges being closed or realigned under the BRAC program, Congress established the Jefferson Proving Ground Technology Demonstration Program. Since then, other programs such as the former Fort Ord Detection and Discrimination Study and the Environmental Security Technology Certification Program (ESTCP) UXO Technology Standardized Demonstration Sites have been established to further the development of UXO detection technologies.

SERDP and ESTCP

The Department of Defense (DoD) operates two programs designed to develop and move innovative technologies into the field to address DoD's environmental concerns. The **Strategic Environmental Research and Development Program (SERDP)** is DoD's environmental research and development program. Executed in partnership with both the Department of Energy and EPA, the goal of SERDP is to identify, develop, and transition technologies that support the defense mission. The second program is the **Environmental Security Technology Certification Program (ESTCP)**. The goal of the ESTCP is to demonstrate and validate promising innovative technologies. Both organizations have made heavy investments in detection, discrimination, and cleanup technologies for UXO.

4.5.1 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 with few advances 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 safe methods for detecting and 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 below.

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 performed poorly; combination electromagnetic induction and magnetometry sensors were the best performers, but also had modest probabilities of detection and 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 with commensurate increases in false alarms among better performing technologies. Continued inability to distinguish ordnance from nonordnance. Again, airborne platforms and ground penetrating radar sensors performed poorly; combination electromagnetic induction and magnetometry sensors were the better performers, 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 successful discrimination.

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 adjacent text box. Certain local and regional 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).

Demonstrator Evaluation Criteria

- Detection capability
- False negative rate
- False positive rate
- Target position and accuracy
- Target classification capability
- Survey rate (used in Phase I only)
- Survey costs (used in Phase I only)

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, 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 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 rates increased as overall anomaly detection increased. The best performing sensors in Phase II were multisensor systems combining EMI and magnetometry.

In Phase III, conducted in 1996, four different range scenarios were used in Phase III to facilitate the development of performance data for technologies used in specific site conditions. 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 sensor or combination of sensors demonstrated an ability to distinguish baseline ordnance from nonordnance, and no system performed better than chance in this area.

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.

4.5.2 Former Fort Ord Ordnance Detection and Discrimination Study (ODDS)

A phased geophysical study of ordnance detection and discrimination specific to the former Fort Ord, California, environment has been in existence since 1994. In November 1998, the U.S. Army evaluated OE at Fort Ord in an Ordnance and Explosives Remedial Investigation/Feasibility Study (OE RI/FS) concurrently with removal actions. The RI/FS evaluated long-term response alternatives for cleanup and risk management at Fort Ord. The technologies considered for use during the Fort Ord study were demonstrated during the Jefferson Proving Ground study. The text box below describes the four phases of the Fort Ord study.

Synopsis of Objectives and Results of the Former Fort Ord Ordnance Detection and Discrimination Study, Phases I through IV

Phase I
Objective: Evaluate detection technologies "Static" measurements in free air (i.e., in the air above and away from ground influences/effects) given variable OE items, depths, and orientations.
Results: Signal drop-off in the electromagnetic (EM) response is proportional to the depth of the object to the 6th power. For horizontally oriented OE items, the EM signal response was predicted fairly well.

Phase II
Objective: Evaluate the effectiveness of geophysical instruments' ability to detect and locate "seeded" or planted OE items.
Result: Noise levels increased 3 to 35 times from the static to seeded tests. There was a significant degradation of profile signatures between static and field trial tests.

Phase III
Objective: Evaluate geophysical instruments and survey processes at actual uninvestigated OE sites.
Results: The effects of rough terrain and vegetation on detection and discrimination capabilities can be significant. Removal of range residue before the OE investigation began would have reduced time and effort spent on unnecessary excavations.

Phase IV
Objective: Evaluate discrimination capabilities of OE detection systems.
Results: The instruments with the highest detection rate required the most intrusive investigation. Conversely, instruments with lower detection rates required less intrusive investigations. **The ODDS determined that no one instrument provides the single solution to meet the OE detection needs at Fort Ord.**

The first phase of the ODDS found the electromagnetic and magnetometer systems to be effective in the detection and location of buried OE items. Phase II was conducted in a controlled testing environment. The controlled area consisted of five "seeded" plots. Two of the plots consisted of items with known depths and orientations, while the other three areas consisted of "unknown" plots where target information was withheld. The plots were designed to be representative of the terrain of Fort Ord. The seeded tests concluded that the noise levels of the EMI systems increased 3 to 35 times from the static to seeded tests. In Phase III it was concluded that the effects of terrain, vegetation, and range residues can significantly alter detection and discrimination capabilities of the detectors. Phase IV of the study determined that discrimination capability of the instruments tested was minimal. The Phase IV study also determined that both EMI and magnetometer systems performed well in finding the larger and deeper items, whereas only the

EMI systems consistently found smaller and shallower items. The results indicated that different systems are required for different types of sites, depending on OE expected and the site-specific environmental/geological conditions.

4.5.3 UXO Technology Standardized Demonstration Sites

The U.S. Army Environmental Center (USAEC) is conducting an ESTCP-funded program to provide UXO technology developers with test sites for the evaluation of UXO detection and discrimination technologies using standardized protocols. The USAEC is developing standardized test methodologies, procedures, and facilities to help ensure accuracy and replicability in measurements of detection capability, false alarms, discrimination, target reacquisition, and system efficiency. Data generated from these standardized sites will be compiled into a technology-screening matrix to assist UXO project managers in selecting the appropriate detection systems for their application.

Standardized test sites will be made up of three areas – the calibration lane, the blind grid, and the open field. The calibration area will contain targets from a standardized target list at six primary orientations and at three depths. The target depth, orientation, type, and location will be provided to demonstrators. The calibration area will allow demonstrators to test their equipment, build a site library, document signal strength, and deal with site-specific variables. In the blind grid area, demonstrators will know possible locations of targets and will be required to report whether or not a UXO target clutter or nothing actually exists. If a UXO target is found, they must report the type of target, classification of target, and target depth and a confidence level. The blind grid allows testing of sensors without ambiguities introduced by the system, site coverage, or other operational concerns. The open field will be a 10 or more acre area with clutter and geolocation targets about which demonstrators will be given no information and will be required to perform as if they were performing at an actual DoD range. Testers will report the location of all anomalies, classify them as clutter or UXO, and provide type, classification, and depth information. The open field conditions will document the performance of the system in an actual range operation mode.

In addition to the construction of test sites available to the UXO community, the primary products of this program will be the creation of a series of protocols to establish procedures necessary for constructing and operating a standardized UXO test site. A standardized target repository will be amassed that can be used by installations, technology developers, and demonstrators.

4.6 Fact Sheets and Case Studies on Detection Technologies and Systems

Three fact sheets on UXO sensors and three case studies describing detection systems are found at the end of this chapter as Attachments 1 through 6. Information on the nature of the technology and its benefits and limitations is provided. Since the performance of the instruments is not solely based upon the sensors deployed, the case studies provide more insights on the operation of the systems. The performance of detection systems is dependent upon platform characteristics, survey methodology and quality, data processing, personnel operation/performance, and appropriate quality control measures that should be taken throughout the investigation.

4.7 Conclusion

The performance of many existing and emerging technologies for UXO detection and discrimination is limited by specific site characteristics such as soil type and composition, topography, terrain, and type and extent of contamination. What works at one site may not work at another. 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. Studies at true UXO areas, such as at Fort Ord, provide additional information about the challenges and issues that have to be considered in selecting UXO detection systems. For example, the nature of the targets (e.g., composition, size, and mass), the depth of UXO penetration (a function of the soil and the ordnance item), and expected spatial and depth distribution should be considered along with the geology, terrain, and vegetation. Other factors affecting the results include operator performance and postprocessing techniques. Given the sizes 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.

ATTACHMENT 4-1. FACT SHEET #1: MAGNETOMETRY

FACT SHEET #1: UXO DETECTION TECHNOLOGIES	**Magnetometry**
What is magnetometry?	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 one of the most effective technologies 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.
How are magnetometers used to detect UXO?	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 background noise. A magnetometer detects a perturbation in the geomagnetic field caused by an object that contains ferrous material. 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.

FACT SHEET #1: UXO DETECTION TECHNOLOGIES

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 a nonmagnetic platform. 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 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. *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*.
- **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.

What are the operational platforms for a magnetometer?

Magnetometers can be transported in a variety of ways:

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

Magnetometers are most frequently used on man-portable platform, but they also can perform well when towed on a vehicular platforms, as long as the vehicular platform and sensor array have been carefully designed to minimize magnetic noise and ensure high quality data collection. These platforms are restricted to areas accessible to vehicles. Airborne systems are currently being evaluated for commercial use as discussed in Section 4.3.

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 UXO 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

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.
- Depending on the data acquisition and post processing systems used magnetometers *can 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, pipes, drums, tools, fences, buildings, and vehicles, as well as UXO debris.
- Depending on the data analysis systems used, magnetometers may suffer from *high false alarm rates*, which lead to *expensive excavation efforts*.
- 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, navigation, and processing.

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 physical properties of the subsurface conductor. The strength and duration of the induced field depend on the size, shape, conductivity, and orientation of the object. There are two basic types of EMI methods: frequency domain and time domain. • **Frequency-domain EMI** measures the response of the subsurface as a fraction of frequency. Generally, a receiver coil shielded from the transmitted field is used to measure the response of targets. Frequency-domain sensors, such as the mono-static, multi-frequency **Geophex GEM-3**, are used for UXO detection. In addition, the Geonics EM31 has been used for detecting boundaries of trenches that may be UXO disposal sites. • **Time-domain EMI** measures the response of the subsurface to a pulsed electromagnetic field. After the transmitted pulse is turned off, the receiving coil measures the signal generated by the decay of the eddy currents in any nearby conductor. These measurements can be made at single time gates, which may be selected to maximize the signal of targets sought. In more advanced instruments, measurements can be made in several time gates, which will increase the information obtained about the physical properties of the targets. The time-domain EMI sensor that is commonly used 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 does not exceed the signal level . The instrument can detect small objects, such as a 20 mm projectile, to depths of approximately 1 foot below ground surface, if noise (terrain and instrument) conditions are less than the response of the object.
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. 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.

FACT SHEET #2: UXO DETECTION TECHNOLOGIES

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**

Figure 4-2. EM61 System

In general EMI systems are configured to be man portable or towed by a vehicle. However, vehicle-towed systems are limited in that the platform can be a source of background noise and interference with target detection and 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 easier access to areas of a site that are accessible to personnel. In general, man-portable systems are the most durable and require the least maintenance.*

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.
- 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*.
- Man-portable EMI systems *provide access to all areas of a site, including uneven and forested terrain*.

FACT SHEET #2: UXO DETECTION TECHNOLOGIES	
What are the limitations of using EMI for detecting UXO?	The **limitations** of using EMI to detect UXO include the following: • Depending on the data acquisition and processing systems used EMI may suffer 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.) Specifically, EMI sensors that utilize traditional detection algorithms based solely on the signal magnitude 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.
What are the costs of using EMI to detect UXO?	Per acre costs for EMI vary depending on the operational platform, the terrain, and other factors.

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 on a limited basis. *Under optimum conditions, GPR can be used to detect individual buried munitions up to 5 feet below the ground surface. However, such optimum conditions seldom occur and the method has not been extremely successful in detecting UXO.* GPR is not routinely used to perform detection of individual UXO, but may be useful for detecting large block of ordnance.
How is GPR used to detect UXO?	**GPR** uses high-frequency electromagnetic waves (i.e., radar) to acquire subsurface information. Both time-domain (impulse) and stepped frequency 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, “targets,” such as buried munitions or stratigraphic changes, reflect some the energy back to a receiving antenna. The reflected signal is then recorded and processed. The travel time can be used to determine the depth of the target. 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 radar 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 radar wave is attenuated (absorbed), lessening the return wave.* Electrically conductive materials (e.g., many mineral clays and moist soil 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 significantly greater. Penetration depths typically range between 1 and 5 feet. In addition, subsurface inhomogeneity can cause dispersion, which also degrades the performance of radars. *As a result, it is important to research the subsurface geology in an area before deciding to use this method.* 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. The data can be recorded for processing off-site, or they can be produced in real time for analysis in the field.

FACT SHEET #3: UXO DETECTION TECHNOLOGIES	
What are the components of a GPR system?	The components of a GPR systems consist of the following: • **A transmitter/receiver unit** • **A power supply** • **An antenna** • **A control unit** • **A display and recorder unit** • **Geolocation ability** GPR systems are available for commercial use. *The pulsed systems are the most commonly used and are available from a variety of vendors.* Physically commercial systems provide a selection of antennas that operate at frequency bandwidths. Antennas are available from the gigahertz range for extremely shallow targets to the megahertz range for greater depths of ground penetration.
What are the benefits of using GPR for detecting UXO?	The **benefits** of using GPR to detect UXO are as follows: • GPR is *nonintrusive*. • GPR is *potentially able to identify breach and discontinuity and determine the size of both*. • GPR *may provide a three-dimensional image of the structure*. (Requires very sophisticated processing and data collection.) • GPR can help define boundaries, if you know the location of buried munitions. • *Under optimum conditions, GPR may be used to detect individual buried munitions several meters deep*. In areas with **dry soils and vegetation**, GPR systems may produce accurate images as long as the antenna is positioned perpendicularly to the ground.
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 site specific and not reliable*. Low-conductivity soils are necessary if the method is to penetrate the ground. Soils with high electrical conductivity (e.g., many mineral clays and moist soil rich in salts) 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.* • *Lower frequencies can penetrate to a greater depth, but result in a loss of subsurface resolution*. 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 subsurface inhomogeneity (i.e., soil layers, pockets of moisture, and rocks). • *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.

Case Study on the Use of a Multisensor System

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.*

The technologies that have proven to be most effective both individually and deployed 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.

The Naval Research Laboratory's **MTADS** represents a state-of-the-art, automated, UXO detection system. 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 DGPS 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.

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 found to be one of the most promising system configurations given appropriate site-specific conditions and appropriately skilled operators..*

ATTACHMENT 4-5. CASE STUDY #2: MAGNETOMETRY SYSTEM

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 flat and treeless Helena Valley in Helena, Montana. The system was navigated by a real-time differential global positioning system (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 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.

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 4-6. CASE STUDY #3: GROUND PENETRATING RADAR SYSTEM

Case Study on the Use of Ground Penetrating Radar in a Multisensor Data Acquisition System

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.

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.

The GPR system tested at Tyndall AFB achieved an approximate false alarm rate of 51 percent. Overall, the measured data from the targets and GPR measurements were somewhat close. Currently, the GPR is unable to distinguish between UXO's and non-UXO targets if the length-to-diameter (L/D) ratio is greater than 3. The GPR system also had problems identifying UXO-like items buried at an angle greater than 45 degrees, as well as UXO partially buried in the water table.

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

U.S. Army Corps of Engineers (USACE), Research and Development Center (ERDC). ***Data Processing Results for UXO Classification Using UWB Full-Polarization GRP System***, ESTCP Project 199902, Tyndall AFB Site Demo, 1999.

USACE. ***Geophysical Investigations for Unexploded Ordnance (UXO)***, EM 1110-1-4009, Chapter 7, June 23, 2000.

USACE. ***The Former Fort Ord Ordnance Detection and Discrimination Study (ODDS)***, Executive Summary, 2000.

U.S. 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

Colorado School of Mines
1500 Illinois Street
Golden, CO 80401-1887
Tel: (303) 273-3000
http://www.mines.edu

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

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

Joint UXO Coordination Office (JUXOCO)
10221 Burbeck Road, Suite 430
Fort 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 Ordnance Environmental Support Office
Naval Ordnance Safety and Security Activity
23 Strauss Avenue, Bldg. D-323
Indian Head, MD 26040
Tel: (301) 744-4450/6752
http://enviro.nfesc.navy.mil/nepss/oeso.htm

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

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: (256) 895-1545
http://www.hnd.usace.army.mil

U.S. Army Corps of Engineers
Engineer Research and Development Center
3909 Halls Ferry Road
Vicksburg, MS 39180-6199
Tel: (601) 634-3723
http://www.erdc.usace.army.mil

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

5.0 RESPONSE TECHNOLOGIES

Ordnance and explosives (OE), which may include buried or abandoned munitions, UXO, or reactive or ignitable soil, not only pose explosive hazards but also present disposal challenges to personnel conducting munition response and cleanup. This chapter briefly discusses recovery in addition to treatment technologies. Recovery technologies are often dependent on the subsequent remediation technique. For example, blow-in-place requires no relocation of OE; however, contained detonation chambers require movement of the OE to a secondary location for safe disposal. See the following text box for a discussion of OE relocation techniques.

Treatment technologies have been developed to destroy the reactive and/or ignitable 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 hazards are divided into the following three categories:

- **UXO**
- **Reactive and/or ignitable soils and debris**
- **Buried and abandoned munitions, including bulk explosives**

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 OE are detonated so that they no longer pose explosive hazards. It is often the preferred choice for managing OE because of overarching safety concerns if the items were to be moved. 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.

Reactive and/or ignitable residues found in soils at concentrations above 12 percent can pose hazards similar 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 contamination. However, treatments have been developed that allow reactive and/or ignitable soil and debris to be decontaminated to levels that make it safe to dispose of them or leave them in place for in-situ remediation.

Excavating OE

There are three general techniques used to excavate subsurface OE 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 OE detected, their depth, and site-specific soil and geological conditions. Retrieval actions should only be conducted by qualified workers after determination by a qualified EOD technician or UXO technician that the risk associated with movement is acceptable.

The only equipment used in **manual excavation** is 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 possibility of an accidental explosion. Also, additional OE detection activities are usually performed when using these methods in order to confirm target removals and increase the probability of clearing all OE in the area. Manual excavation methods are best suited for surface and near-surface OE and are most effective when retrieving smaller OE items, such as small arms munitions, grenades, and small-caliber artillery projectiles. OE 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 OE items at greater subsurface depths should be reserved for mechanized retrieval methods, as the excavation involved is much more labor-intensive and hazardous.

Mechanized OE 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 OE.

Mechanized methods are best suited for excavation efforts where large OE 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. In the future, mechanized methods may have a role in excavating heavily contaminated surface areas. 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 differential 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 OE retrieval. Current systems have variable weather and terrain capabilities, but demonstrate better performance in relatively flat, dry, easy-to-access grassy or unvegetated areas.

5.1 Treatment and Disposal of OE: An Overview

In-place open detonation, or blow-in-place (BIP), is the most commonly used method to destroy OE on CTT ranges. However, other techniques, such as incineration (small arms only), consolidated detonation, and contained detonation may be viable alternatives to blow-in-place, depending on the specific situation. In addition, bioremediation (in-situ, windrow composting, and bioslurry methods), low-temperature thermal desorption, wet air oxidation, and plasma arc destruction are alternatives that can be applied to reactive and/or ignitable soils. 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 may 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 substantive 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 closure requirements for sites at which OB/OD is used, trial burn tests prior to operating incinerators, and a variety of other requirements. Familiarity with the State and Federal requirements will be critical in determining your approach to munitions response.

Table 5-1 summarizes the effective uses of treatment technologies for remediating OE and munition 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 response at CTT ranges. The evaluation of treatment technologies 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
- CERCLA nine criteria remedy evaluation and selection process

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

Explosive Problem	Treatment Options	Situations/Characteristics That Affect Treatment Suitability
Munitions or fragments contaminated with munitions residue	Open burning (OB)	Limits the explosive hazard to the public and response personnel. Inexpensive and efficient, but highly controversial due to public and regulator concern over health and safety hazards. Noise issues. Significant regulatory controls. Used infrequently at CTT ranges.

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

Explosive Problem	Treatment Options	Situations/Characteristics That Affect Treatment Suitability
Munitions or fragments contaminated with munitions residue	Open detonation (OD)	Limits the explosive hazard to the public and response personnel. Inexpensive and efficient, similar to OB, but OD is generally cleaner. This technique can be used to dispose of higher order explosives. A characteristic of OD is complete, unconstrained detonation, which does not allow for the creation of intermediaries and, if successfully implemented, results in more complete combustion.
Variable caliber munitions	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. Actual case throughput of a nontransportable unit destroyed 12,500 projectiles (155 mm in size) in 1 year.
Small-caliber munitions or fragments, debris, soil, and liquid waste	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. Average throughput is 8,700 pounds of 20 mm ammunition per 15-hour operating day.
Small-caliber munitions or fragments, soil	Deactivation furnace	Thick-walled primary combustion chamber withstands small detonations. Renders munitions unreactive. The average throughput is 8,700 pounds of 20 mm ammunition per 15-hour operating day.
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 and debris	Wet air oxidation	Treats slurries containing reactive and/or ignitable material. Very effective in treating RDX; however, may produce hazardous byproducts and gaseous effluents that require further treatment. High capital costs and frequent downtime.
Soil (munition constituents residue)	Windrow composting	Microorganisms break down reactive and/or ignitable residues into less reactive 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 (munition constituents residue)	Bioslurry (soil slurry biotreatment)	Optimizes conditions for maximum microorganism growth and degradation of reactive and/or ignitable material. 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.

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

Explosive Problem	Treatment Options	Situations/Characteristics That Affect Treatment Suitability
Soil/ Groundwater (Munition constituents residue)	Bioremediation	Conditions are maintained that promote growth of microorganisms that degrade reactive and/or ignitable compounds. May not be effective in clayey or highly layered soils and can take years to achieve cleanup goals. Chlorinated compounds may be difficult to degrade.
Soil/ Groundwater (Munition constituents residue)	Chemical remediation	Chemicals are pushed into a medium through injection wells or delivered by pipes or sprinklers to shallow contaminated soils. These chemicals oxidize/reduce reactive and/or ignitable compounds, transforming them to non-toxic compounds. Some reagents may be dangerous.
Soil (Munition constituents residue)	Soil washing	Reduces the total volume of contaminated soil and removes reactive and/or ignitable compounds from soil particles. Requires additional treatment for wastewater and, potentially, for treated soils.
Soil (Munition constituents residue)	Low-temperature thermal desorption	Used to treat soils with low concentrations of some reactive and/or ignitable material. Contaminated soil is heated to separate contaminants by volatilizing them. They are then destroyed. Not very effective for treating explosives.
Equipment, debris, and scrap	Hot gas decontamination	Process uses heated gas to clean reactive and/or ignitable residue from equipment and scrap. The system is designed to clean up to 1 pound of total explosives from 3,000 pounds of material. The advantage of this system is that it does not destroy the equipment it cleans.
Debris and scrap	Base hydrolysis	Process uses heated acid to clean reactive and/or ignitable residue from material. This system can be designed to accommodate a range of throughput needs.

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

5.1.1 Handling OE Safely

The handling of OE at CTT ranges is based on the types of munitions found and the site-specific situation. There is no single approach for every munition, or every site. The complete identification and disarming of munitions is often dangerous and difficult, if not impossible. In most cases, the safest method to address munition items is in place OD (also called BIP). This is particularly true when the munition is located in an area where its detonation would not place the public at risk. It is most appropriate when the munition or its fuzing mechanism cannot be identified, or identification would place a response worker at unacceptable risk. Great weight and deference will be given, with regard to the appropriate treatment, to the explosives safety expertise of on-site OE technical experts. When required, DDESB-approved safety controls (e.g., sandbagging) can be used to provide additional protection to potential harmful effects of in-place OD. In cases where OE experts determine that in-place OD poses an unacceptable risk to the public or critical assets (e.g., natural or cultural resources), munitions items may be transported to another location for consolidated detonation. Such transport must be done carefully under the supervision of OE experts, taking into account safety concerns. Movement with remote-control systems sometimes will be appropriate to minimize danger to OE personnel.

5.1.2 Render-Safe Procedures

In rare cases 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. For ordnance of questionable condition, RSPs may be unsafe. RSPs are conducted by active duty military EOD experts and typically involve disarming OE (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. During these procedures, blast mitigation factors are taken into account (i.e., distance and engineering controls), and EOD personnel disarm the OE items and move them from the location at which they were found to a central area on-site for destruction. Instead of detonating all OE 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).

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 remains the safest and most frequently used method for treating UXO at CTT ranges. When open detonation takes place where UXO is found, it is called blow-in-place. In munitions response, demolition is almost always conducted on-site, most frequently in the place it is found, because of the inherent public safety concerns and the regulatory restrictions on transporting even disarmed explosive materials.

Blow-in-place detonation may be accomplished by adding a small explosive charge or using laser-initiated techniques. It is considered by explosives safety experts to be the safest, quickest, and most cost-effective remedy for destroying OE. 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 OD in recent years is a direct result of these growing concerns and increased restrictions on the use of OD (see text box on following page).

There are significant environmental and technical challenges to treating ordnance and explosives with OB/OD.[64] These limitations include the following:

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

- **Restrictions on emissions.** Harmful emissions may pose human health and environmental risks and are difficult to capture sufficiently for treatment. Areas with emissions limitations may not permit OB 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 reduce the use of OB/OD in the future. However, for CTT ranges addressed under CERCLA, no permits are currently required.
- **Noise.** Extreme noise created by detonations limits where and when OB/OD can be performed.

The Debate Over OD

Because of the danger associated with moving OE, the conventional wisdom, based on DoD’s explosive safety expertise, is to treat UXO on-site using OD, usually blow-in-place. 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. Preliminary studies of OD operations at Massachusetts Military Reservation revealed that during the course of open detonation, explosive residues are emitted in the air and deposited on the soil in concentrations that exceed conservative action levels more than 50 percent of the time. When this occurs, some response action or cleanup is required. It is not uncommon for these exceedances to be significantly above action levels.

Several debates are currently underway regarding the use of blow-in-place OD at CTT ranges. One debate is about whether OD is in fact a contributor to contamination and the significance of that contribution. A second debate is whether a contained detonation chamber (CDC) is a reasonable alternative that is cleaner than OD (albeit limited by the size of munitions it can handle, and the ability to move munitions safety). Another study at Massachusetts Military Reservation revealed that particulates trapped in the CDC exhaust filter contain levels of chlorinated and nitroaromatic compounds that must be disposed of as hazardous waste, thus suggesting the potential for hazardous air emissions in OD. The pea gravel at the bottom of the chamber, after repeated detonations, contains no detectable quantities of explosives, thus suggesting that the CDC is highly effective. The RPM at Massachusetts Military Reservation has suggested that when full life-cycle costs of OD are considered, including the cost of cleanup at a number of the OD areas, the cost of using OD when compared to a CDC may be more even.

Additional information will help shed light on the costs and environmental OD versus CDC. The decision on which alternative to use, however, will involve explosive safety experts who must decide that the munitions are safe to move if they will be detonated in a CDC. In addition, current limitations on the size of munitions that can be handled in a CDC must also be considered.

In open detonation, a small amount of charge is added in order to detonate and destroy 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 OE), well-engineered protective measures can reduce the effects and hazards associated with OD to levels comparable to contained detonation chambers (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.[65] Although some of these alternative treatments have applicability for field use, the majority are designed for industrial-level demilitarization of excess or obsolete munitions that have not been used.

5.2.2.1 *Incineration*

Incineration is primarily used to treat soils containing reactive and/or ignitable compounds. In addition, small quantities of OE, bulk explosives, and debris containing reactive and/or ignitable material may be treated using incineration. Most OE is not suitable for incineration. This technique may be used for small-caliber ammunition (less than 155 mm), but 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.

The strengths and weaknesses of incineration are summarized as follows:

- **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

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

incineration. In addition, the treatment of hazardous and reactive and/or ignitable 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 million 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.[66]
- **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.
- **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 soils and debris contaminated with reactive and/or ignitable material. 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 reactive and/or ignitable 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 contamination levels to destruction and removal efficiencies (DRE) that meet RCRA requirements (40 CFR 264, Subpart O).[67] Specifically, reactive and/or ignitable soil was treated on-site at the former Nebraska Ordnance

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

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

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.[68]

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 reactive and/or ignitable material, but rather render the munitions unreactive.[69]

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).[70] At the former Nebraska Ordnance Plant site, the cost of on-site incineration was $394 per ton of contaminated material.[71] 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.

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

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

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

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

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 °F Soils: 600-800 °F Secondary chamber – Gases: 1,400-1,800 °F	Renders munitions unreactive. Debris or reactive and/or ignitable materials 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 OE, 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 °F	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. *Approaches for the Remediation of Federal Facility Sites Contaminated with Explosive or Radioactive Wastes*, Handbook, September 1993.

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 OD; however, the use of CDCs assumes that the munition item is safe to move. 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 OE. 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 and shock wave hazards. 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 safety issues relating to the moving of munitions, rate of throughput, transportability, and cost.

Both industrial-level (fixed) and mobile (designed for use in the field) CDCs display a range of capabilities. CDCs designed for field use are limited in the amount of explosives they can contain, the types of munitions they can handle, and their throughput capability. Portable units have size constraints and are not designed to destroy munitions larger than 81 mm HE or 10 pounds of HMX, but the nonportable units can handle munitions up to 155 mm or 100 pounds of HMX (130 lb TNT equivalent).[72]

5.3 Treatment of Soils That Contain Reactive and/or Ignitable Compounds

Some of the technologies described in Section 5.2 can also be used to treat reactive and/or ignitable soil (e.g., thermal treatment). However, there are a number of alternative treatment technologies that are specifically applicable to soils containing reactive and/or ignitable materials. 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 reactive and/or ignitable residues in soils into byproducts such as water and carbon dioxide. Bioremediation includes ex-situ treatments such as composting and slurry reactor biotreatment that require the excavation of soils and debris, as well as in-situ methods such as bioventing, monitored natural attenuation, and nutrient amendment. Bioremediation is used to treat large volumes of contaminated soils, and it is generally more publicly accepted than incineration. However, highly contaminated soils may not be treatable using bioremediation or may require pretreatment, because high concentrations of reactive and/or ignitable materials, 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.

[72] DeMil International, Inc., *The "Donovan Blast Chamber" Technology for Production Demilitarization at Blue Grass Army Depot and for UXO Remediation*, Paper presented at the Global Demilitarization Symposium and Exhibition, 1999.

- **Suitability for direct land application.** In general, soil treated using most bioremediation systems is suitable for land application.
- **Limited concentrations of reactive and/or ignitable materials and other contaminants.** Soil with very high levels of reactive and/or ignitable material 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 reactive and/or ignitable materials.
- **Post-treatment.** In some systems, process waters and off-gases may require treatment prior to disposal.[73]

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 incineration.

Biological treatment can be conducted in-situ or ex-situ; however, because reactive and/or ignitable materials 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 reactive and/or ignitable materials 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.

5.3.1.1 *Monitored Natural Attenuation*

Monitored natural attenuation (MNA) is a response action that rules on **natural attenuation processes** (within the context of a carefully controlled and monitored site cleanup approach) to

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

achieve site-specific remediation objectives within a time frame that is reasonable compared to that offered by more active methods.[74]

Monitored natural attenuation uses microbes already present in the soil or groundwater to degrade contaminants. It is never a default or presumptive remedy, but is carefully evaluated prior to selection. The burden of proof as to whether MNA is appropriate rests with the party proposing MNA. EPA's directive on the use of MNA at sites requires substantial analysis and continuous monitoring to prove that MNA can achieve cleanup goals on the particular chemicals of concern within a reasonable timeframe when compared to other response methods. In addition to a comparable timeframe, MNA may be appropriate when plumes are no longer increasing (or are shrinking), and/or when used in conjunction with active remediation measures (e.g., source control, sampling, and treating of hot spots). Monitored natural attenuation is currently employed at several groundwater sites containing reactive and/or ignitable compounds. Louisiana Army Ammunition Plant has used MNA to reduce TNT and RDX in groundwater. Initial results show a marked decrease in both of those compounds. The suitability to use MNA for explosive compounds must be carefully evaluated based on site-specific factors, since explosive compounds do not act in the same manner as the solvents for which MNA has been most frequently used.

5.3.1.2 *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 reactive and/or ignitable compounds biodegrade.

Figure 5-1. 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 5-1. Figures 5-2 and 5-3 provide schematic diagrams of a typical windrow composting process and system.

[74]U.S. EPA, Office of Solid Waste and Emergency Response, *Use of Monitored Natural Attenuation at Superfund RCRA Corrective Action and Underground Storage Tank Sites*, OSWER Directive 9200.4-17, November 1997.

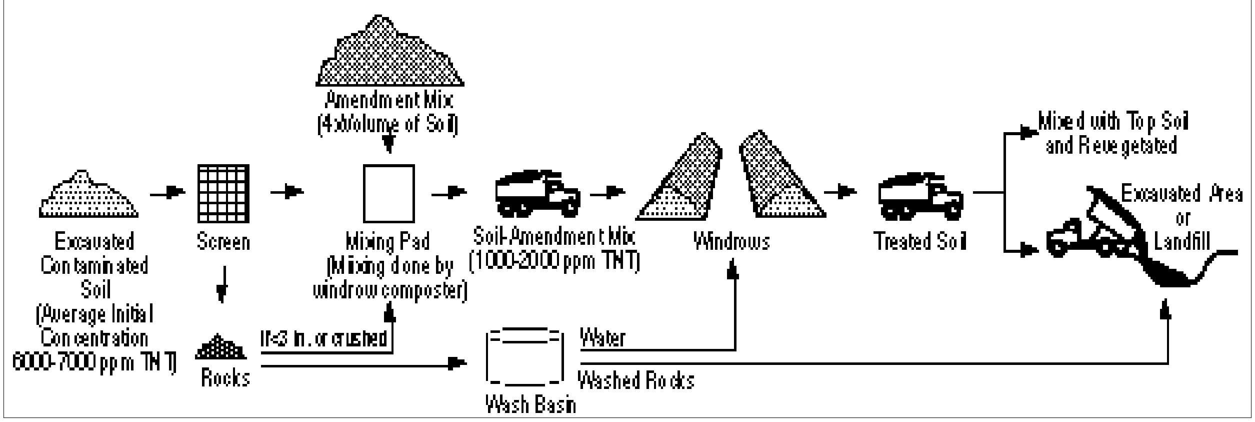

Figure 5-2. Typical Windrow Composting Process

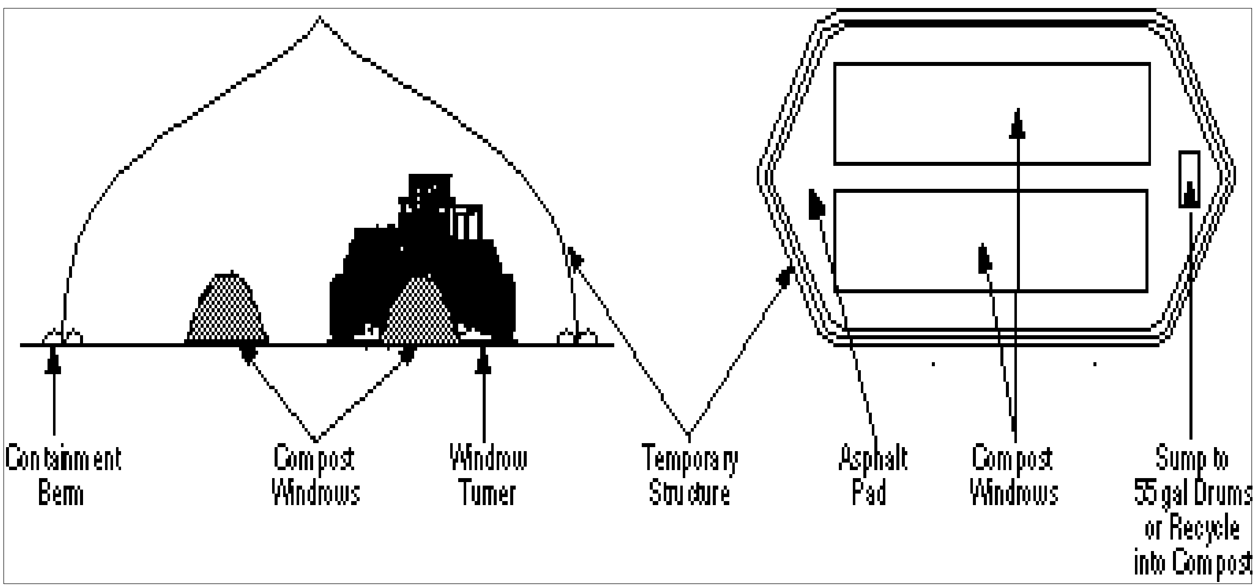

Figure 5-3. Side and Top View of Windrow Composting System

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.[75] 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,

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

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.

5.3.1.3 *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 5-4). 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 5-4. Slurry Reactor

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 reactive and/or ignitable materials 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.[76] Soil slurry biotreatment is expected to cost about one-third less than incineration.[77] 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.
- **Post-treatment.** 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.

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

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

5.3.1.4 *In-Situ Chemical and Biological Remediation*

Treating contaminated soils in-situ involves the introduction of microbes (enhanced or augmented bioremediation), or the addition of nutrients with the intention of inducing a suitable environment for the biological degradation of pollutants. Alternatively, selected reactive compounds may be introduced into the soil to chemically transform reactive and/or ignitable compounds through oxidative or reductive processes. For aqueous media, hydrogen peroxide, oxygen release compounds (e.g., magnesium peroxide), ozone, or microorganisms are added to the water to degrade reactive and/or ignitable materials more rapidly. Depending on the depth of the contaminants, spray irrigation may be used, or for deeper contamination, injection wells may be used. The primary advantage of in-situ remediation 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 remediation is that it may allow reactive and/or ignitable materials to migrate deeper into the soil or into the groundwater under existing site-specific hydrodynamic conditions. Other limitations of this type of remediation include the following:

- There is a high degree of uncertainty about the uniformity of treatment and a long treatment period may be 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 highly heterogeneous subsurface environments (such as complex karst or fractured rock subsurface formations).
- 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 certain reagents (e.g., Fenton’s reagent) can create potentially hazardous conditions.

5.3.2 <u>Soil Washing</u>

Soil washing is a widely used treatment technology that reduces contaminated soil volume and removes contamination from soil particles. Reactive and/or ignitable materials 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 reactive and/or ignitable materials 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 reactive and/or ignitable materials 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.[78]

5.3.3 Wet Air Oxidation

Wet air oxidation (WAO) is a high-temperature, high-pressure oxidation process that can be used to treat contaminated soil. Contaminated slurries are pumped into a heat exchanger and heated to temperatures of 650-1,150 °F. 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 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.[79]

5.3.4 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 reactive and/or ignitable materials, it is not one of the more effective technologies. In general, a carrier gas or vacuum system transports volatilized water and reactive and/or ignitable materials to a gas treatment system such as an afterburner or activated carbon. The relatively low temperatures (200-600 °F) and residence times in LTTD typically volatilize low levels of reactive and/or ignitable materials and allow decontaminated soil to retain its physical properties.[80] In general, LTTD is used to treat volatile organic compounds and fuels, but it can potentially be used on soil containing low concentrations of reactive and/or ignitable materials that have boiling points within the LTTD temperature range (e.g., TNT).

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[78]Ibid.

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

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

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.[81] The primary limitations of LTTD include the following:

- It is only marginally effective for treating reactive and/or ignitable materials.
- Extensive safety precautions must be taken to prevent explosions when exposing 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.
- Additional leaching of metals is a concern with this process.

5.4 Decontamination of Equipment and Scrap

Various chemical and mechanical methods are available for the cleaning and decontamination of equipment and scrap metal. One such method is hot gas decontamination. Demonstrations have shown that a 99.9999 percent decontamination of structural components is possible using this method. Residue from reactive and/or ignitable compounds is volatilized or decomposed during the process when gas is heated to 600 °F for 1 hour. Any off-gases are destroyed in a thermal oxidizer, and emissions are monitored to ensure compliance with requirements. Specifications state that the furnace can accept a maximum of 3,000 pounds of contaminated materials containing less than 1 pound of total explosives. Up to four batch runs can be processed by a two-person crew every 24 hours.[82]

Base hydrolysis is a chemical method of decontaminating material of reactive and/or ignitable compounds. A tank of heated sodium hydroxide is prepared at a concentration of 3 moles per liter. The high pH and high temperature have the effect of breaking apart any reactive and/or ignitable compounds on the scrap metal. Following decontamination, hydrochloric acid is added to lower the pH to a range of 6-9. The cleaned material has no detectable level of reactive and/or

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

[82]U.S. Army Environmental Center, *Hot-Gas Decontamination: Proven Technology Transferred for Army Site Cleanups*, December 2000.

ignitable contaminants following the procedure. This process is scalable to accommodate a variable throughput.[83,84,85]

Other decontamination methods include pressure washing, steam cleaning, and incineration.

5.5 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 Composition 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 carbon-nitrogen 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 underway 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.[86]

5.6 Conclusion

The treatment of OE and reactive and/or ignitable soil and debris is a complex issue in terms of technical capabilities, regulatory requirements, and environmental, public health, and safety considerations. Public concern over OB/OD and incineration has encouraged the development of new technologies to treat reactive and/or ignitable 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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[83]UXB International, Inc., *UXBase: Non-Thermal Destruction of Propellant and Explosive Residues on Ordnance and Explosive Scrap*, 2001.

[84]D.R. Felt, S.L. Larson, and L.D. Hansen, *Kinetics of Base-Catalyzed 2,4,6-Trinitrotoluene Transformation*, August 2001.

[85]R.L. Bishop et al., "Base Hydrolysis of HMX and HMX-Based Plastic Bonded Explosives with Sodium Hydroxide between 100 and 155°C." Ind. Eng. Chem. Res. 1999, 38:2254-2259.

[86]SERDP and ESTCP, "Safe Deactivation of Energetic Materials and Beneficial Use of By-Products," Partners in Environmental Technology Newsletter, Issue 2, 1999.

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

Stratta, J., R. Schneider, N. Adrian, R. Weber, and 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. Department of Defense, Environmental Technology Transfer Committee. ***Remediation Technologies Screening Matrix***, Second Edition, October 1994.

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

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

Information Sources

Center for Public Environmental Oversight
c/o PSC 222B View Street
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

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

U.S. Environmental Protection Agency, Office of Research and Development
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/

<u>Guidance</u>

U.S. EPA, Office of Solid Waste and Emergency Response
Directive 9200.4-17
Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, Underground Storage Tank Sites

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6.0 EXPLOSIVES SAFETY

Substantial safety issues are associated with investigation and munition response activities at sites that may contain UXO. This section describes the statutory and regulatory requirements on 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 OE site personnel, explosive ordnance disposal (EOD) 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 explosives safety requirements throughout DoD (see text box on next page). 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 requires the implementation and maintenance of an "aggressive" explosives safety program that addresses environmental considerations and requires the military components to act jointly.

The policies of DoD 6055.9-STD (the DoD explosives safety standard) include the following:

- Provide the maximum possible protection to personnel and property, both inside and outside the installation, from the damaging effects of potential accidents involving DoD ammunition and explosives.
- Limit the exposure to a minimum number of persons, for a minimum time, to the minimum amount of ammunition and explosives consistent with safe and efficient operations.

These policies 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 and the capabilities and limitations of the most current UXO detection and discrimination technologies.

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, that may result from explosives or the environmental effects of military 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 responsibility for resolving any potential conflicts between explosives safety standards and environmental standards.

To protect human health and property from hazards from explosives, 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. 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 OE contamination exists or is suspected to exist. Plans to conduct munitions response actions at FUDS are also submitted to the DDESB for approval of the explosives safety aspects.[87] All explosives safety plans are to be documented in **Explosives Safety Submissions** (ESSs), which are submitted to DDESB for approval prior to any munitions response action being undertaken, or prior to any transfer of real property where OE may be present (see Section 6.3.2 for a discussion on ESSs). Several investigation and documentation requirements 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 OE. Adherence to DoD safety standards and to 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.[88,89] 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:

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

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

[89] National Oil and Hazardous Substances Pollution Contingency Plan, 40 C.F.R. § 300.430 (b)(6).

- **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.[90]
- **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 set minimum standards for separating a potential explosion site from an exposed site.
- **Theater of operations quantity-distance**, setting standards outside the continental United States and inside the United States in certain CONUS training situations where the premise "to train as we fight" would be compromised.
- **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 munition 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 (40 C.F.R 260) *Federal Register* 62(29): 6621-6657 (February 12, 1997).

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. Each has established its own procedures. 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.

[90] Hazard classification procedures have been updated in *Changes to Department of Defense Ammunition and Explosives Hazard Classification Procedures*, DDESB-KT, July 25, 2001.

6.2.1 General Safety Rules

The following commonsense safety rules apply to all munitions response actions and explosives ordnance disposal (EOD) activities:

> **Radio Frequencies**
>
> Some types of ordnance are susceptible to electromagnetic radiation (EMR) devices in the radio frequency (RF) range (i.e., radio, radar, cellular phone, 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).

- Only **qualified UXO/EOD personnel** can be involved in munitions response actions. 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 essential project personnel and authorized, escorted visitors are allowed within the exclusion zone. Essential personnel are those who are needed for the operations being performed. 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.
- **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 munitions.

6.2.2 Transportation and Storage Requirements

The DoD explosives 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 Committee of Experts 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 munitions and explosives. Guidelines are also provided for segregating munitions 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.

The DoD Ammunition and Explosives Hazard Classification Procedures calls for the following safety precautions for transporting conventional UXO in a nonemergency response:[91]

- EOD-qualified personnel must evaluate the UXO and affirm in writing that the item is safe for transport prior to transport from the installation or FUDS.
- UXO should be transported in a military vehicle using military personnel where possible.
- All UXO shall be 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 separately from serviceable munitions.[92]
- 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 munitions 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.

6.2.3 Quantity-Distance (Q-D) Requirements

The DoD explosives safety standard establishes guidelines for maintaining separation between the explosive material expected to be encountered in the OE action and potential receptors such as personnel, 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.

These Q-D siting requirements must be met in the ESS for all OE areas where response actions 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.

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[91] *Changes to Department of Defense Ammunition and Explosives Hazard Classification Procedures,* DDESB-KT, July 25, 2001.

[92] For the sake of convenience, the term munition has been used throughout this chapter, in some cases where the source used the term ammunition.

Examples of Quantity-Distance Siting Requirements

The following are examples of key concepts used in establishing Q-D requirements (USACE Engineering Manual 1110-1-4009, 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 on the basis of 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. The two key elements considered in establishing the hazard distance for the MPM are 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).
- 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.

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 response actions. The DDESB and military components have established guidelines for implementing such measures. UXO/EOD personnel conducting OE investigations and response actions 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 personal protective equipment (PPE) programs.

6.2.5 Emergency Response and Contingency Procedures

In the event that an OE incident occurs during response actions 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 **qualified emergency medical technician (EMT)** with 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 procedures**.
- 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. In addition, handle practice rounds with extreme caution and use chain-of-custody procedures similar to those for live UXO items (practice rounds may contain explosive charges).
- 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 <u>Personal Protective Equipment (PPE)</u>

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 plan
- Medical considerations (e.g., work limitations due to temperature extremes)

6.2.7 <u>Personnel Standards</u>

Personnel standards are designed to ensure that the personnel working on or overseeing the site are appropriately trained. Typical requirements for personnel training 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, Eglin Air Force Base, Florida (or Indian Head, Maryland, prior to Spring 1999)
- 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 EOD 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.[93]

6.2.8 Assessment Depths

In addition to safeguarding UXO personnel from the hazards from explosives, the DoD explosives 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 munitions response action has been completed. The types and levels of public safeguards will vary with the level of uncertainty and risk at a site. Public safeguards include property clearance (e.g., depth of response) to the appropriate depth for planned land uses and enforcement of designated land uses.

DDESB standards establish assessment depths to be used for **interim planning in the absence of adequate site-specific information** (See Table 6-1 and text box). ESS approvals rely on the development of site-specific information to determine response 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.

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.

The response depth selected for response actions is determined using site-specific information such as the following:

- Geophysical characteristics such as bedrock depth and frost line (see Chapters 3 and 7 and text box on the next page).
- 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.

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

- 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 response depth a minimum of 4 feet below the excavation depth planned for construction (DDESB requirement).
- Presence of cultural or natural resources (e.g., potential risk to soil biota or archeologically sensitive areas)

Other factors that affect the munitions response depth include the size of the range, the cost of the munition response (depends on 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 depth needed to meet site specific response requirements, 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 in agricultural areas), a procedure must be put in place to monitor the site for migration of ordnance. (See Chapter 3, Section 3.3.3, 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*, DoD Directive 6055.9-STD, Chapter 12, July 1999. The DDESB is in the process of revising Chapter 12 of DoD 6055.9-STD.

6.2.9 Land Use Controls

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 potential hazards. They are designed to reduce ordnance and explosive risk over the long term without physically removing all of the OE. Land use controls are necessary at many sites because of the technical limitations and prohibitive costs of adequately conducting a munitions response at CTT ranges to allow for certain end uses, particularly unrestricted use (see text box).

The DoD explosives safety standard specifically addresses a requirement for institutional controls when OE contamination has been or may still be on the site: "Property transfer records shall detail past munition 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."[94]

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

The appropriate land use control depends on site-specific factors such as proximity to populations, land use, risk of encountering OE, 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 response action has been completed (see text box on next page).

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:[95]

- **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 designated party or entity responsible for enforcement.
- **Enforce** the institutional controls should a violation or failure of the 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 whomever may gain ownership or control of the property in the future.

[94] Department of Defense, *DoD Ammunition and Explosives Safety Standard*, DoD 6055.9-STD, July 1999.

[95] *Institutional Controls and Transfer of Real Property Under CERCLA Section 120 (h)(3)(A), (B), or (C)*, Interim Final Guidance, U.S. EPA, January 2000.

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. The military components conduct similar reviews within their respective services. At ranges where investigation, response action, 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 are often part of a 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 DoD ESSs are submitted to and approved by DDESB, as described in Section 6.3.2 and 6.3.3.

Many requirements documented in detail in the SSHP are summarized in the ESS.

6.3.1 <u>Site Safety and Health Plans</u>

SSHPs fulfill detailed requirements for compliance with the occupational safety and health program requirements of CERCLA, OSHA, and the military components.[96,97,98] 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

[96]National Oil and Hazardous Substances Pollution Contingency Plan, 40 C.F.R. § 300.430 (b)(6).

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

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

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.[99] SSHPs are typically prepared by industrial hygiene personnel at the installation level.[100] 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 (see text box on next page).

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.[101] 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.

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.

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[99] *Safety and Health Requirements*, U.S. Army Corps of Engineers, EM 385-1-1, September 3, 1996.

[100] *Safety and Occupational Health Requirements for Hazardous, Toxic, and Radioactive Waste (HTRW) Activities*, ER 385-1-92, September 1, 2000.

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

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 response 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, and 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.
- **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
  - — Personal 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

Sources: Engineering and Design of 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 Explosives Safety Submissions for OE Response Actions

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 an OE investigation and response action and approved by appropriate authorities prior to commencing work (see text box at right). 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, Addressing DoD Environmental Restoration Activities under SARA).
- Final approval of ESSs for closed ranges at active facilities is provided by the command (e.g., 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.

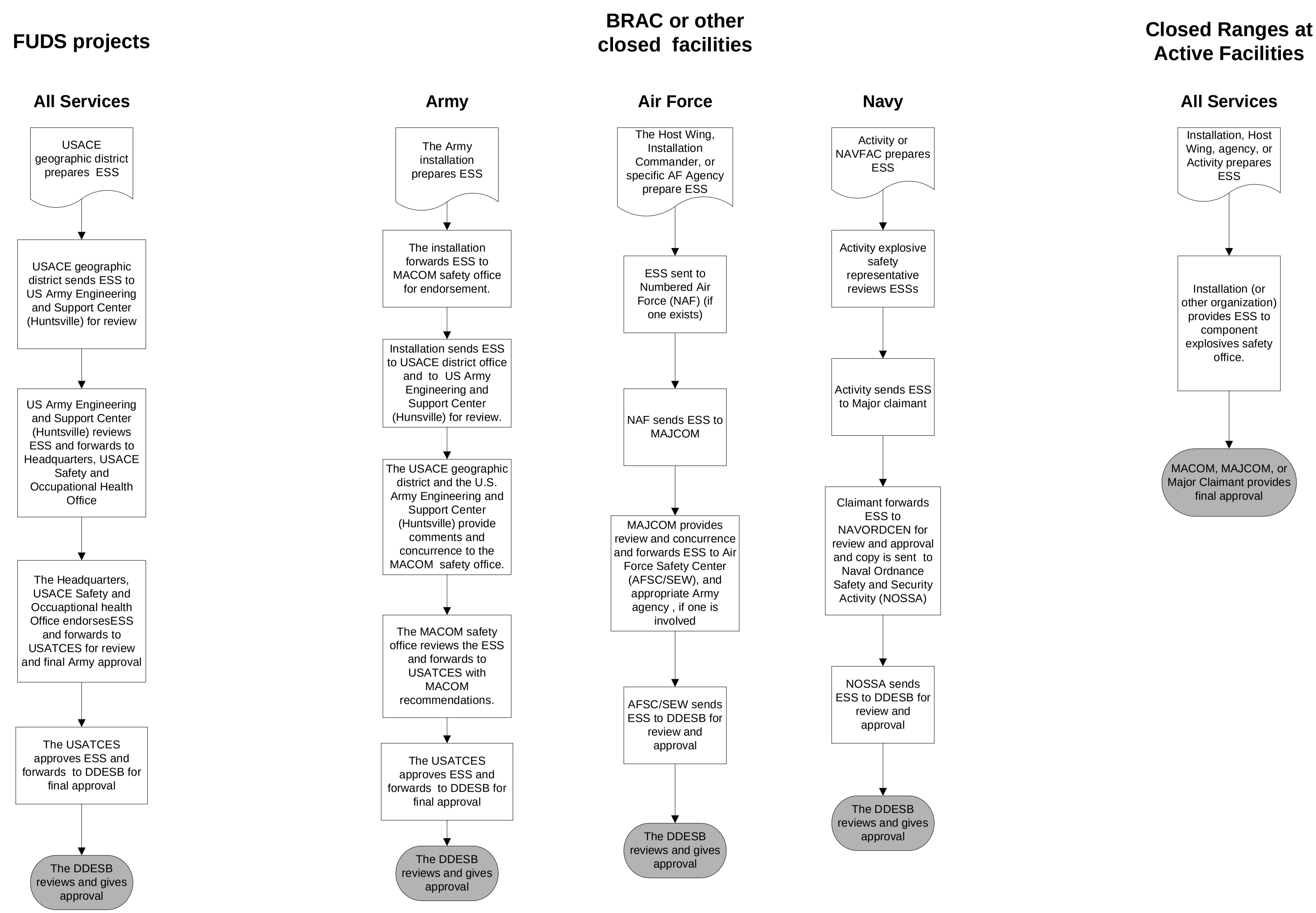
An ESS is not required for military EOD emergency response actions (on DoD or non-DoD property); for interim removal actions taken to abate an immediate, extremely high hazard; and for normal maintenance operations conducted on active ranges. Figure 6-1 outlines the approval processes for OE projects 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 response actions. The potential explosive hazards must be assessed and documented prior to submitting an explosives safety plan, as outlined in the next text box.[102]

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:

[102] *Explosives Safety Policy for Real Property Containing Conventional Ordnance and Explosives,* U.S. Army, DACS-SF HQDA LTR 385-00-2, June 30, 2000.



Sources: DACS-SF HQDA LTR 385-00-2, 30 June 2000 (Expires 30 June 2002). 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, 7 March 2000

Figure 6-1. Routing and approval of explosives safety submission (ESS) for OE response actions

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- 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 techniques to detect, recover, and destroy OE[103]

The amount and type of OE expected in each OE area is identified in the ESS. The submission must specify the most probable munition likely to be present. The most probable munition is the round with the greatest fragmentation distance that is anticipated to be found in any particular OE area. 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). These data are input into formulas for establishing the damage or injury potential of the OE on-site. See the text box in Section 6.2.3 on Q-D requirements for additional information about the use of these data in the ESS.

Explosives Safety Submission Requirements

Safety plans are submitted at least 60 days prior to the planned response action and typically cover the following elements:

1. Reason for OE presence
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’s 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 Station Adak in Alaska, it is technically and economically impossible to remove all of the OE littered throughout the island. In such a situation, educating the public about hazards posed by OE is a necessity in protecting the public. Also, at other, less contaminated sites where cleared areas are being opened

[103] *Explosives Safety Submissions for Removal of Ordnance and Explosives (OE) from Real Property*, Guidance for Clearance Plans, DDESB-KO, February 27, 1998.

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 NAS 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 have been/are being 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 includes a description of 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** ensure that future purchasers of property aware of potential contamination on the property.
- **Signage** for restricted and nonrestricted property 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 alarming the public. The types of information conveyed to the public should include the fact that any UXO item 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.

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, cellular phone, 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 engineer's 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 OE workers 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 response actions, and ESSs for OE removal actions. SSHPs require that protective measures be taken for OE 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 explosives 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 will help to prevent accidents and to give 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, 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***, March 7, 2000.

Guidance Documents

Air Force Manual 91-201, ***Safety: Explosives Safety Standards***, March 7, 2000.

Air Force Instruction 32-9004, ***Civil Engineering. Disposal of Real Property***, July 21, 1994.

Department of the Army, U.S. Army Corps of Engineers, ***Safety and Occupational Health Requirements for Hazardous, Toxic, and Radioactive Waste (HTRW) Activities***, ER 385-1-92, September 1, 2000.

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, AFJI 32-3002, 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.

Department of Defense Explosives Safety Board, ***Changes to Department of Defense Ammunition and Explosives Hazard Classification Procedures***, DDESB-KT, July 25, 2001.

Department of Defense Explosives Safety Board, DDESB-KO, ***Guidance for Clearance Plans***, February 27, 1998.

U.S. Army, Headquarters, ***Explosives Safety Policy for Real Property Containing Conventional Ordnance and Explosives***, DACS-SF HQDA LTR 385-00-2, June 30, 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. Army Corps of Engineers, ***Ordnance and Explosives Response: Engineering and Design***, Pamphlet No. 1110-1-18, 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, ***Basic Safety Concepts and Considerations for Ordnance and Explosives Operations,*** EP 385-1-95a, June 29, 2001.

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, ***U.S. Navy Explosives Safety Policies, Requirements, and Procedures,*** **Explosives Safety Policy Manual**, OPNAV Instruction 8023.2C., January 29, 1986.

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.

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 22060-5806
Tel: (703) 704-1090
Fax: (703) 704-2074
http://www.denix.osd.mil/UXOCOE

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 Avenue, Bldg. D-323
Indian Head, MD 26040
Tel: (301) 744-4450/6752

Ordata II (database of ordnance items)
Available from: NAVEODTECHDIV, Code 602
2008 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
4820 University Square
Huntsville, AL 35807-4301
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 AND RESPONSE

Characterizing OE contamination is a challenging process that requires specialized investigative techniques. Unlike traditional hazardous waste contamination, OE may not be distributed in a predictable manner; OE contamination is not contiguous, and every ordnance item and fragment is discrete. The use of existing technologies by investigators to detect anomalies, and find the ordnance, and then discriminate between UXO, fragments of exploded ordnance, and background levels of ferrous materials in soils may be technically challenging or infeasible. Locating buried munitions whose burial may not have been well documented can also be difficult. The technical and cost issues become even more daunting when the large land areas associated with many ranges (potentially tens of thousands of acres), as well as other range characteristics, such as heavy vegetation or rock strata and soils, are considered. Some level of uncertainty is expected for any subsurface environmental investigation; however, the consequences of potential uncertainties related to OE investigations (e.g., accidental explosion resulting in possible 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 you will make to tailor the investigation to your site. Specifically, this chapter is designed to:

- Present an overview of the elements and issues associated with sampling and the systematic planning process (SPP).
- Discuss development of the goals of the investigation.
- Help you prepare for the investigation: gathering information, preparing the Conceptual Site Model, and establishing data quality objectives.
- Discuss the design of the sampling and analysis effort (including the role of statistical sampling).
- Demonstrate the integration of quality assurance/quality control (QA/QC) throughout the investigation.
- Identify analytical methods for analyzing munition constituents.
- Outline how to pull together the information developed in the sampling and analysis process to develop a site response strategy.

What Is the Systematic Planning Process?

"Systematic planning" is a generic term used to describe a logic-based scientific process for planning environmental investigations and other activities. EPA developed a systematic planning process called the Data Quality Objectives Process and published a document called *Guidance for the Data Quality Objectives (DQO) Process* (EPA/600/R-96/055, 1996). While not mandatory, this seven-step process is recommended for many EPA data collection activities. The planning processes used by other Federal agencies do not necessarily follow the seven steps of the DQO process. For example, using different terminology, but a similar systematic planning process, the U.S. Army Corps of Engineers adopted a four-step Technical Project Planning Process to implement systematic planning for cleanup activities. Confusion is caused by the different names applied to similar processes used by different Federal agencies and departments. Therefore, EPA is moving toward a more general descriptor of this important process that can be used to describe a number of different systematic planning processes. (EPA Order, "Policy and Program Requirements for the Mandatory Quality System" (5360.1 A2, May 2000).

This chapter does not focus on the investigation of munition constituents except where there are issues unique to such constituents that should be addressed. Except for OE-unique issues such an investigation would be similar to the investigation of other hazardous wastes, and the numerous guidance documents that have been written on the investigation of hazardous wastes would apply. (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:

- Munitions that have not exploded, including UXO (e.g., duds) or buried or otherwise discarded munitions, including bulk explosives
- Ordnance fragments from exploded munitions that may retain residues of sufficient quantity and type to be explosive
- Concentrations of reactive and/or ignitable materials in soil (e.g., munition constituents in soil from partly exploded, i.e., low-order detonation, or corroded ordnance that are present in sufficient quantity and weight to pose explosive hazards)

7.1 Overview of Elements of 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 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 there is no evidence of ordnance use, thereby reducing the size of the area to be investigated
  - — Prioritize the investigation in terms of likelihood of ordnance presence, type of ordnance used, potential hazard of ordnance, 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 response actions to facilitate investigation
- Selection of appropriate geophysical system(s) and determination of site-specific performance of the selected geophysical detection system
- Establishment and verification of measurement quality objectives in the sampling and analysis methodologies (QA/QC measurements)
- Geophysical survey of areas of concern (i.e., areas likely to be contaminated)
- Analysis of geophysical survey data to identify metallic anomalies, and possibly to help discriminate between OE, ordnance fragments, and non-OE-related metal waste, and QA/QC of that analysis

- Anomaly reacquisition and excavation to identify the sources of the geophysical anomalies, to verify geophysical mapping results, and to gather data on the nature and extent of OE contamination
- Analysis of investigation results to test 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 nature and extent of UXO contamination and resulting uncertainty
- Performing 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 an OE 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 must take place in the context of a systematic planning process (Figure 7-1). The process starts with identifying the **decision goals** of the project. Available information is then used to identify data requirements that support the decision goals and to 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

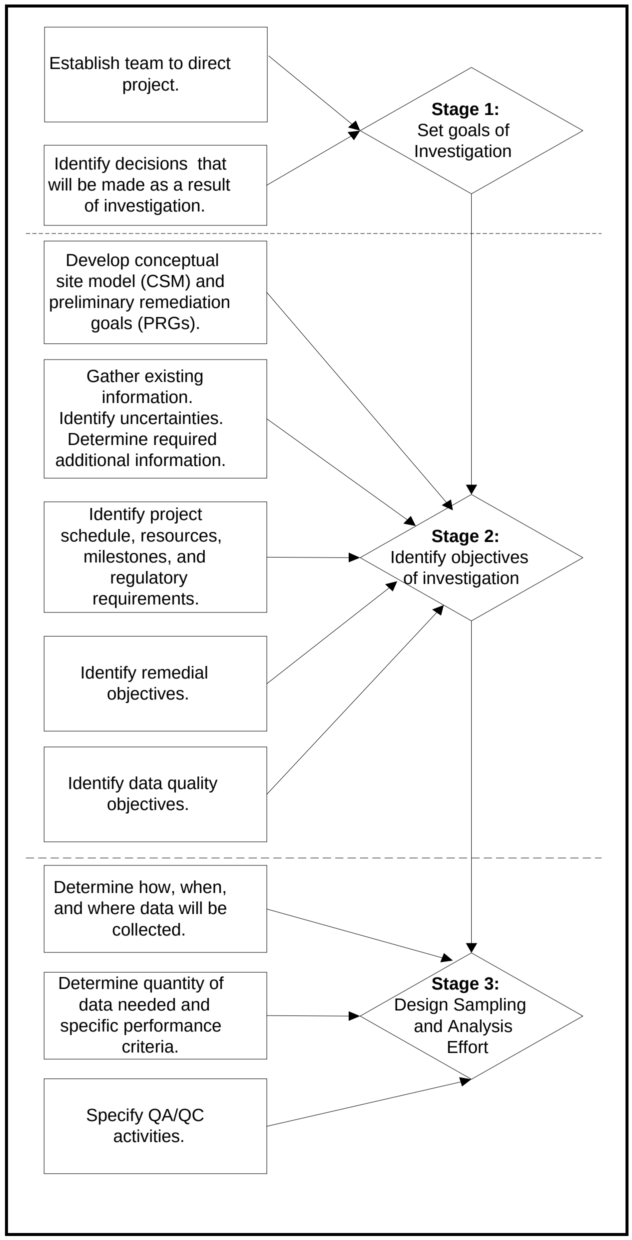

Figure 7-1. Systematic Planning Process

goals. Each stage of the systematic planning process is carefully refined by the succeeding 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, in practice, the process involves a number of concurrent steps and iterative decisions.

The steps you will take to plan and carry out your investigation will be similar regardless of which regulatory program governs the investigation (e.g., removal or remedial action under CERCLA or investigations performed under RCRA). The significance and complexity of any particular step will depend on your decision goals, the data quality objectives (DQOs), and a variety of site-specific conditions.

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 important, however, that you understand the uncertainty associated with the available data on the presence, absence, or types of UXO so that decisions you make 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 a response 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 among your project team, 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 for achieving 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 <u>Establishing the Team</u>

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 are 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, natural/cultural resource experts, and regulatory personnel from the appropriate Federal, State, Tribal, 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 (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, evidence of past ordnance use and 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 "safe" for the subsurface investigations. The subsurface investigations themselves often take place in stages. The first is a nonintrusive stage that uses geophysical detection equipment designed to detect subsurface anomalies. Generally, positional data are collected as the geophysical survey is being conducted. The second stage involves processing of data to co-locate geophysical data with geographic positional data points identified with a Global Positioning System (GPS). The third stage, called anomaly reacquisition, is designed to verify the location of anomalies. Finally, anomaly excavation is conducted, and the results are fed back into the anomaly identification process. Anomaly excavation includes a verification of clearance using geophysical detectors.

7.4 Stage 2: Preparing for the Investigation: Gathering Information To Design a Conceptual Site Model and Establishing Sampling and Analysis Objectives

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 sources, 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 PRGs and the CSM will likely change as more information is gathered. Documentation of the CSM is explained at the conclusion of this section.

7.4.1 The Conceptual Site Model (CSM)

The CSM establishes a working hypothesis of the nature and extent of OE 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 and historical information on range use and the results of previous environmental investigations are gathered. It then continues to evolve as new data about the site are collected. In other words, as information is gathered at each stage of the site characterization process, the new data are used to review initial hypotheses and revise the CSM. The CSM describes the site and its environmental setting, and presents hypotheses about the types of contaminants, their routes of migration, and potential receptors and exposures routes. Key pieces of initial data to be recorded in the CSM include, but are not limited to:

- The topography and vegetative cover of various land areas
- Past ordnance-related activities (e.g., ordnance handling, weapons training, ordnance disposal) and the potential releases that may be associated with these activities (e.g., buried munitions, dud-fired UXO, kick-outs from OB/OD areas)
- Expected locations and the depth and extent of contamination (based on the OE activities)
- Likely key contaminants of concern
- Potential exposure pathways to human and ecological receptors (including threatened and endangered species)
- Environmental factors such as frost line, erosion activity, and the groundwater and surface water flows that influence or have the potential to change pathways to receptors
- Human factors that influence pathways to receptors, such as unauthorized transport of UXO
- Location of cultural or archeological resources
- The current, future, and surrounding land uses

The ability to develop a good working hypothesis of the sources and potential releases associated with OE will depend on your understanding the ordnance-related activities that took place on the land area to be investigated, the primary sources of OE contamination, the associated release mechanisms, and the expected OE contamination. Tables 7-1 and 7-2 summarize these characteristics for typically expected ordnance-related activities. Table 7-3 describes the elements of the firing range that should be located on your CSM.

Table 7-1. Ordnance-Related Activities and Associated Primary Sources and Release Mechanisms

Ordnance-Related Activity	Primary Source	Release Mechanisms
Ordnance storage and transfer	Ammunition pier	Mishandling/loss (usually into water)
	Storage magazine	Mishandling/loss, abandonment, burial
	Ammunition transfer point	Mishandling/loss, abandonment, burial
Weapons training	Firing points	Mishandling/loss, abandonment, burial
	Target/impact areas	Firing
	Aerial bombing targets	Dropping
	Range safety fans	Firing, dropping
Troop training	Training/maneuver areas	Firing, intentional placement (minefields), mishandling/loss, abandonment, burial
	Bivouac areas	Mishandling/loss, abandonment, burial
Ordnance disposal	Open burn/open detonation areas	Kick-outs, low-order detonations
	Large-scale burials	Burial

Table 7-2. Release Mechanisms and Expected OE Contamination

Release Mechanism	Expected OE Contamination
Mishandling/loss	Fuzed or unfuzed ordnance, possibly retrograde, bulk OE, OE residue
Abandonment	
Burial	
Firing or dropping – complete detonation	OE debris (fragmentation), OE residue
Firing or dropping – incomplete detonation	OE debris (fragmentation), pieces of OE, OE residue
Firing or dropping – dud fired	UXO
Intentional placement	Mines (usually training), booby traps
Kick-outs	OE Debris, OE components, UXO
Low-order detonations	OE debris (fragmentation), pieces of OE, OE residue

Table 7-3. Example of CSM Elements for Firing Range

Range Configuration	Description	OE Concerns
Range fan	The entire range, including firing points, target areas, and buffer areas	All of those listed below, depending upon area
Target or impact area	The point(s) on the range to which the munitions fired were directed	Dud-fired UXO, low-order detonations with munition fragments and containing munition constituents that may be reactive or ignitable; munition constituents
Firing points	The area from which the munitions were fired	Munition constituents from propellants; buried or abandoned munitions.
Buffer zone	Area outside of the target or impact area that was designed to be free of human activity and act as a shield for munitions that do not hit targets	Same as target or impact area, but likely of less density than UXO and, therefore, munition constituents

Figures 7-2 and 7-3 in Section 7.4.7 illustrate the configuration of a typical **firing range**.

The process of constructing the CSM involves mapping data obtained from historical records, conducting an operational analysis of the munition activity, and analyzing the ordnance-related activities that occurred on the site. 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. As shown in Table 7-1, 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 troops decided to bury their remaining munitions rather than carry them out with them.

The boundaries of suspected contamination, the geology and topography, and the areas of potential concern should be delineated during this process. Using the historical data as inputs, three-dimensional operational analyses of the anticipated locations of OE are developed that address the expected dispersion of munitions and range fan areas as well as the maximum penetration or burial depths of the munitions used at the site. Using these data sources, you can develop an assessment of the ordnance-related activities that were conducted to develop a full picture of what is likely to be found at the site.

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, you should anticipate revising the CSM at least once in this early planning phase as more data are gathered.

Specific data regarding OE that should be addressed in a CSM include, but are not limited to:

- Ordnance types
- Ordnance category (e.g., unfired, inert, dud-fired)
- Filler type
- Fuze type
- Net explosive weight of filler
- Condition (e.g., intact, corroded)
- Location (coordinates)
- Depth (below ground surface)
- Compass bearing

7.4.2 Preliminary Remediation Goals

Preliminary remediation goals (PRGs) for a munitions response are the preliminary goals pertaining to the depth of that response action and are used for planning purposes. PRGs are directly related to the specific media that are identified in your CSM as potential pathways for OE exposure (e.g., vadose zone, river bottom, wetland area). The PRGs for response depths for munitions are a function of the goal of the investigation and the reasonably anticipated land use on the range. For example,

> **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 goals for the concentration of individual chemicals in the media in which they are found. For UXO, the PRG will generally address the clearance depth for UXO.
>
> Source: U.S. EPA. Risk Assessment Guidance for Superfund (RAGS), Volume 1, Human Health Evaluation Manual, Part B, Interim, December 1991.

if the goal of the investigation is to render the land surface safe for nonintrusive investigations, then the PRGs will be designed to promote surface removal of OE from the land area. Therefore, the PRGs will require that no OE remains on the surface of the land. On the other hand, if the goal of the investigation is to establish final response depths to protect human health from OE hazards, then the PRGs will be based on the reasonably anticipated future land use. The PRGs in this instance may be to ensure that no OE is present in the top 10 feet of the subsurface or above the frost line.

The PRGs 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 response process. The PRGs 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/Tribal preferences.

The first step in establishing the PRGs is to determine the current and reasonably anticipated future land use. While OE response depth 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 depending on the land use. Identifying the appropriate PRGs 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 PRGs until adequate site-specific data become available.

DDESB safety standards establish interim planning assessment depths that are based on different land uses, to be used for planning until site-specific data become available. In the absence of site-specific data, these standards call for a clearance depth of 10 feet for planned uses such as residential and commercial development and construction activities. For areas accessible to the public, such as those used for agriculture, surface recreation, and vehicle parking, the DDESB recommends planning for response depth of 4 feet. For areas with limited public access and areas used for livestock grazing or wildlife preserves, the DDESB recommends planning for a response depth of 1 foot.[104] In all cases, the standards call for a response depth of 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, greater response

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.

[104] DoD Directive 6055.9, DoD Explosives Safety Board (DDESB) and DoD Component Explosives Safety Responsibilities, July 29, 1996.

depth must considered. In addition, if the response depth is above the frost line, then DDESB standards require continued surveillance of the area for frost heave movement.[105]

Site-specific information may also lead to the decision that a more shallow response action is protective. For example, if historical information and results of geophysical studies suggest that the only OE to be found is within the top 1 foot of soil, then the actual munitions response will obviously address the depth where munitions are found (e.g., 1 foot).

> **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.

You should consider a variety of factors when identifying the reasonably anticipated future land use of the property. Current and long-term ownership of the property, current use, and pressure for changes in future use are some of the important considerations.[106] The text box on the following page lists a number 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, you 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.

[105]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.

[106]USEPA, OSWER Directive No. 9355.7-04, Land Use in the CERCLA Remedy Selection Process, May 25, 1995.

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 (such as explosive potential of the 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 OE on the site?
- At what depth is the OE likely to be located?
- What are the environmental factors that affect both the location and potential corrosion of OE?
- 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.

> **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

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 determining 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. Potential sources of this information include ammunition storage records, firing orders, and EOD and local law enforcement reports. 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 safety procedures and boundaries based on anticipated explosive sensitivity and blast potential. Historical information based on past UXO and scrap finds may provide data about the type, size, and shape of the OE items on the range, which could simplify OE identification and clarify safety requirements during the detection phase. Such historical data could help investigators plan for the potential explosive hazards (e.g., thermal, blast overpressure, or fragmentation grenades, or shock hazards), which will dictate separation distance requirements for excavation sites, open detonation areas, and surrounding buildings; public traffic routes; and other areas to be protected.

> **Munition 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.

Historical information is also necessary for estimating the **probable locations** 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 extent of sampling required, the cost of remediation, and the safety plan and procedures used. There will be some areas where, given the site conditions, extent, or type of UXO present, physical entry onto the site or intrusive investigations will be too dangerous. 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 potential UXO contamination by eliminating clean areas from the investigation. Identifying 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 civilian 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 an archives 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 OE 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 7-4. 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 7-4. 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 OE from anticipated depth.
Soil type and moisture content	Penetration depth of OE. Potential for deterioration/corrosion of casings. Potential for release of munition constituents.
Depth and movement of groundwater	Potential for movement of OE and for deterioration/corrosion of containment. Potential for leaching of munition residues.
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 munition casings; potential leaching of munition residues; 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 response rather than subsurface response
- 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.”)

7.4.4.1 *Resources*

Many factors affect the scope and therefore the costs of an investigation. Although large range size is often associated with high costs, other factors can affect the scope and costs of an investigation:

- Difficult terrain (e.g., rocky, mountainous, dense vegetation)
- High density of OE
- Depth of OE
- Anticipated sensitivity of OE to disturbance or other factors that may require extraordinary safety measures

Key factors to consider when estimating the cost of the investigation include the following:

- **Site preparation** may include vegetation clearance, surface UXO removal, and the establishment of survey control points. If there is little vegetation at the site and/or if the UXO detection can be conducted without removing the vegetation, the costs can be significantly reduced. In addition, limiting the vegetation clearance can also reduce the impacts on natural and cultural resources, as discussed in the next text box.
- **Geophysical mapping** requires 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 investigation** includes anomaly reacquisition and excavation to determine anomaly sources and to test the working hypotheses. Excavation 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 that 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. Statistical sampling methods are frequently used to reduce the costs of site investigation. These methods and the controversy over the methods are discussed in Section 7.6.

7.4.4.2 *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, since 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.[107]

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/Tribal 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
- Other applicable Federal statutes such as the Endangered Species Act, the Native Americans Graves Protection and Repatriation Act, and the National Historic Preservation Act

This handbook does not present a comprehensive listing of these requirements. Chapter 2 of this handbook provides an overview of regulatory structures. Chapter 6 presents an overview of the DDESB safety requirements.

7.4.5 Identification of Remedial Objectives

Decisions regarding cleanup have two components: the remediation goal (or cleanup standard) and the response strategy. Remediation goals were described in the discussion of PRGs (Section 7.4.2). The **response strategy** is the manner in which the waste will be managed (e.g., use of institutional controls, removal of waste, treatment of waste once it's removed), including the engineering or treatment technologies involved. PRGs represent the first step in determining the cleanup standard. PRGs are 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 do you anticipate? Like the PRGs and the CSM, this is a working hypothesis of what you will find (which may change later), the volume of material that you must

[107] 40 CFR Section 300.400(g), National Oil and Hazardous Substances Pollution Contingency Plan.

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, open burning or detonation will leave additional potentially 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

7.4.6.1 *Developing DQOs*

You now have the information necessary to develop the data quality objectives of the investigation. The DQOs will reflect the information that you require to achieve the decision goals identified at the beginning of the planning phase. DQOs are based on gaps in the data needed 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 within plus or minus ___ feet.
- Determine, with ___ percent probability of detection at ___ percent confidence level, the amount 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 ___ 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 site 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.

7.4.6.2 *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, although expressed in quantitative terms, is a qualitative judgment that must be made by all of the involved parties acting together. For example, it may be possible to quantify the probability that a detector can find subsurface anomalies. However, that probability will be less than 100 percent. The acceptability of a given probability of detection (e.g., 85 percent or 60 percent) will depend on a qualitative judgment based on the decision to be made.

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 ordnance fragments or UXO, 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 Fort Ritchie Army Garrison, a BRAC facility. OE 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 OE under buildings on land slated for transfer is an uncertainty the project team at Fort 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 contamination, the proposed response 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 response activities. Some amount of uncertainty will be acceptable, since the information required will be obtained during the response operation. (Note: This scenario assumes that there is sufficient information both for safety planning and for estimating the costs of the remediation.)

7.4.7 Documentation of the CSM

The data points of a CSM are usually documented schematically and supplemented by a table and a diagram of relationships. 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. A CSM may also be presented from a top view (also called a plan view), as illustrated in Figure 7-3, and overlaid with a map created using a GIS.

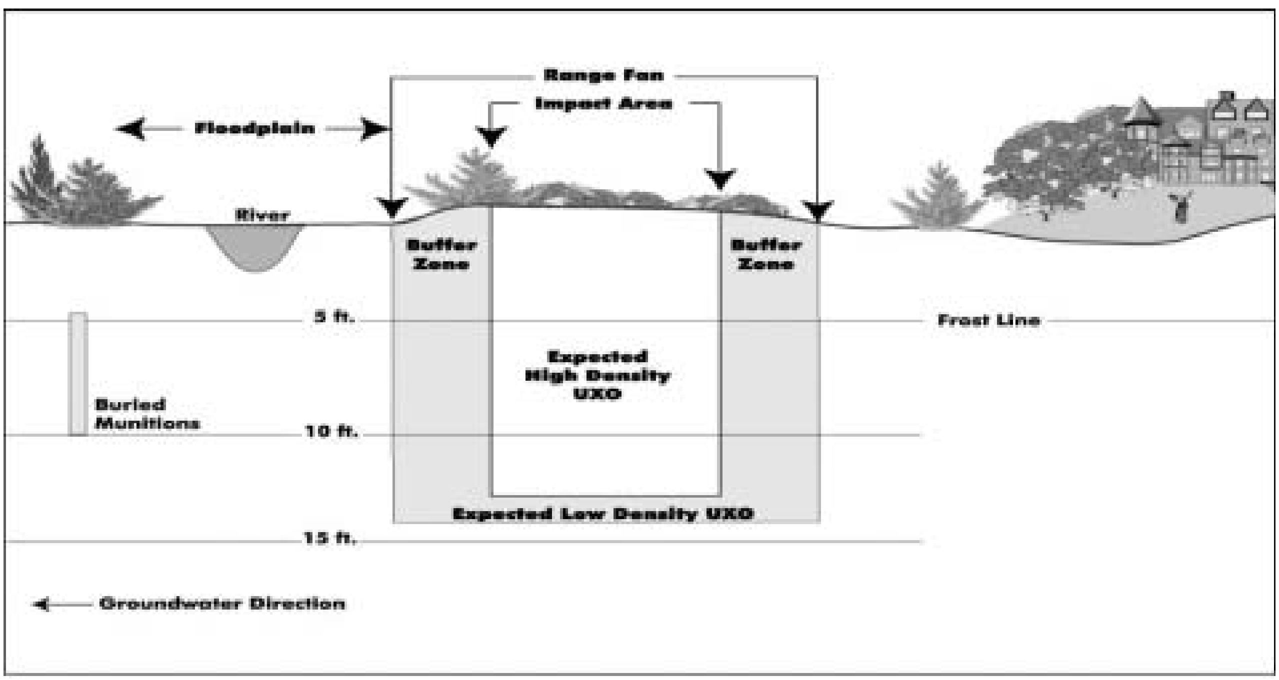

Figure 7-2. Conceptual Site Model: Vertical View

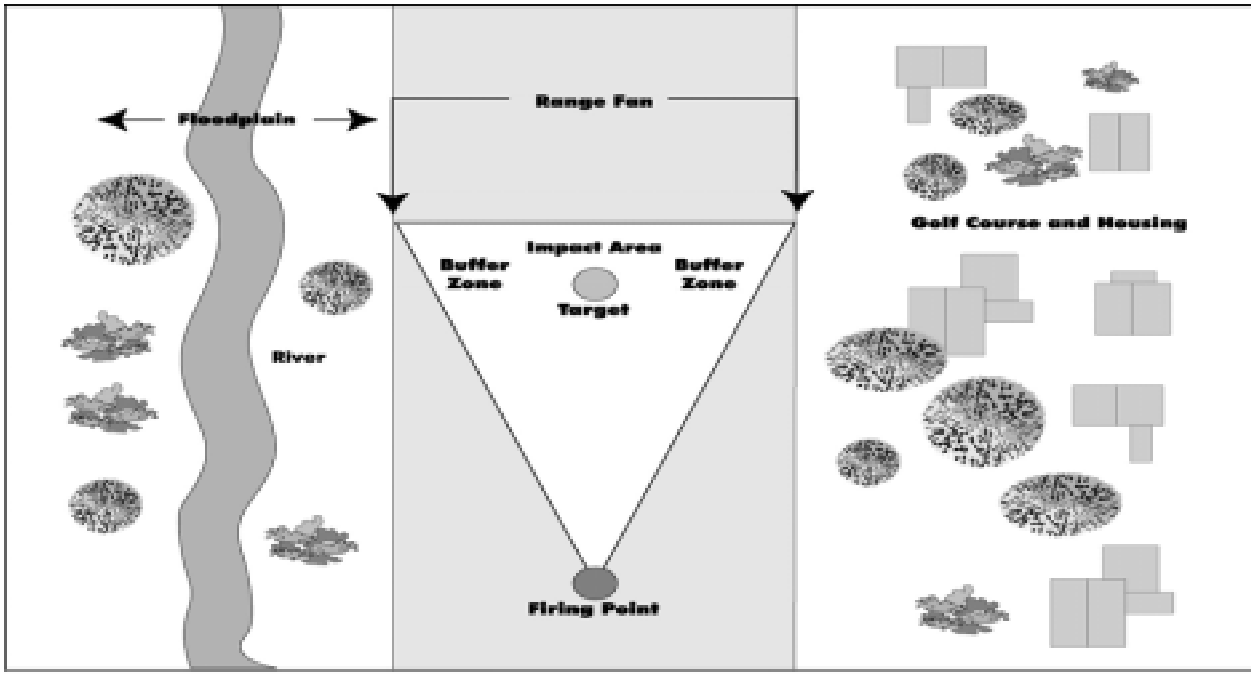

Figure 7-3. Conceptual Site Model: Plan View of a Range Investigation Area

7.5 Stage 3: Designing the Sampling and Analysis Effort

The discussion that follows outlines major considerations in the development of your sampling and analysis plan. Keep in mind, however, that the foundation of your sampling and analysis plan rests on your conceptual site model (see Section 7.4.1).

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) should 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:

- Explosives safety concerns, safety planning, and Explosives 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 geophysical investigations)
- Soil sampling of potential munition residues
- 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 your desired 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 to verify data obtained through the application of statistical sampling approaches
- The types of field analytical methods that should be used to test for explosive residues
- The appropriate means of separating and storing waste from the investigation
- Information required for the Explosives Safety Submission

The design of the sampling and analysis effort usually includes one or more iterations of geophysical studies, which incorporate geophysical survey data processing and anomaly investigation 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. For 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 example, although you are using the combination of detection tools and data processing techniques deemed appropriate for your site by your project team, 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 response effort to render the OE area under investigation safe for geophysical 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 five important elements of the design of the sampling and analysis effort:

- Selection of detection technologies
- Operational analysis of the munitions activities that took place at the site
- Selection of the methodology for determining 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 greatest 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 its material makeup and the depth at which it is expected to be found
- Background materials or geological, topographical, or vegetative 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 significantly over the past decade; however, the limited ability to discriminate between ordnance and nonordnance remains a serious deficiency. (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, hardware costs are higher for an airborne platform than for a land-based system, but an airborne platform can survey a site much faster than a land-based system, thus reducing the cost per acre. Similarly, digital georeferencing systems cost more than a GIS that can be used to manually calculate the position of anomalies, but the time saved by digitally georeferencing anomaly position data, and the associated potential reduction in errors, may speed the process and save money in the end.

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.

UXO objects are "seen" as underground anomalies that must be interpreted. It is often difficult to distinguish between UXO, fragments of OE, 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. The effectiveness of a detection technology is intrinsically tied to the ability of the sensor to discriminate between OE items and other subsurface anomalies. The more sensitive the detector, the more anomalies are found. Unless you intend to dig up every anomaly, only by reducing false alarms can you increase sensitivity and, therefore, the probability of detection.

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.

7.5.2 <u>UXO Detection Methods</u>

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 other detection device such as an EM instrument), 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 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 are 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. A full discussion of each of these technologies is provided in Chapter 4.

While many detection technologies have an adequate probability of identifying anomalies beneath the ground surface, for the most part, they cannot accurately distinguish between ordnance and nonordnance, such as ferrous rocks. In addition, they often cannot distinguish dud-fired munitions, fragments from fully exploded munitions, and anomalies caused by non-ordnance-related sources, such as waste metals or ferrous rocks. A resulting higher number of false positives increases the number of anomaly excavations required, both during the QA/QC process and during the response process. Unless false positives can be positively identified as nonordnance items, they are likely to be excavated during the investigation or response phase, a time-consuming and costly undertaking. Therefore, minimizing false alarms can greatly reduce the cost of and time needed 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 anomalies was to manually mark or flag 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 identifies the anomaly, and a differential global positioning system locates the position of the anomaly on the earth's surface. The accuracy of the positional data depends upon site conditions such as vegetative cover that could interfere with the GPS satellite. Under ideal conditions, however, the differential GPS can be accurate to within several centimeters. The data are then merged and the location of each anomaly is recorded. Therefore, flags are not needed to record and find the location of the UXO. Because digital geophysical mapping records location data automatically, the risk of an operator missing or misrecording a location, as occurs when operators manually record anomaly locations based on analog signals, is minimized, and the data can be made available for future investigations and for further data processing. However, the potential exists for analyst errors in the merging of the anomaly and positional data. Therefore, anomaly reacquisition is employed to verify the field data (see Section 7.7 for a discussion of anomaly reacquisition).

DoD/EPA Interim Final 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 georeferenced. Exceptions to the collection of sensor data that is digitally recorded and georeferenced should be limited primarily to emergency response actions or cases where their use is impracticable. The permanent record shall be included in the Administrative Record. Appropriate notification regarding the availability of this information shall be made.

7.6 Methodologies for Identifying OE Areas

The previous discussions have addressed issues related to preparation for sampling and analysis. The next two sections offer ideas about methodologies you may use to identify OE areas.

7.6.1 Operational Analysis of Munitions Activities

In the design of a good sampling and analysis plan, one of the most important considerations for locating UXO may be an operational analysis of the type of weapon system (e.g., mortar, artillery) used on the range. Army field manuals, for example, provide data that allow the calculation of areas of probable high, medium, and low impact in a normal distribution. Using available operational information, it is possible to assess the most likely distribution of UXO for a particular weapons activity and to plan a sampling strategy that optimizes the probability you will find UXO that may be present.[108]

[108] The process of using operational analysis to design a CSM-based sampling plan is described more fully in the paper *Conceptual Site Model-Based Sampling Design*, presented to the UXO Countermine Forum 2001 by Norell Lantzer, Laura Wrench, and others.

7.6.2 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, anomaly reacquisition, and excavation 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 statistical 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 geophysical anomalies targets from system responses (UXO Center of Excellence Glossary, 2000, and OEW contractors).

Discrimination – Determining the presence of UXO from non-UXO from system responses or post-processing (OEW contractors).

Sampling – The act of investigating a given area to determine the presence of UXO. It may encompass both the nonintrusive detection of surface and subsurface anomalies 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).

7.6.2.1 *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 limiting deficiencies, as described previously (see Section 7.5.1). The most common deficiencies include low probability of detection and low 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 identifying 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.

7.6.2.2 ***Statistical Sampling Tools***

A variety of statistical sampling methodologies exist, each serving a different purpose, and each with its own strengths and weaknesses. The two common statistical sampling tools historically 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.)

Statistical Sampling Using SiteStats/GridStats

SiteStats/GridStats (Site/Grid Statistical Sampling Based Methodology) 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, predictably 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 fewer 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 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 is 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 are then input into OECert, a model that contains a risk management tool as well as a screening-level estimator for the cost of remediation.[109]

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 compares the costs of remediation alternatives to the number of public exposures likely under each remediation scenario. The model then develops recommendations that minimize remediation costs. The risk levels used for the recommendations are acceptable to the U.S. Army Corps of Engineers (USACE).

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, assuming UXO distribution is homogeneous within a sector. 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.

[109] "Site/Grid Statistical Sampling Based Methodology Documentation," available at USACE website: www/hnd/usace.army.mil/oew/policy/sitestats/siteindx.htm.

Table 7-5 summarizes these two tools and their strengths and weaknesses. Table 7-6 provides a general summary of statistical sampling methodologies. Table 7-6 identifies four statistical sampling methodologies and summarizes their strengths and weaknesses and the applications for which they are used.

Table 7-5. Comparison of Statistical Sampling Tools

Sampling Methodology	Description	Strengths and Weaknesses	Intensity of Coverage	Typical DoD Use
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.	Investigates a very small area 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 a 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.

Table 7-6. Comparison of Statistical Sampling Methodologies*

Sampling Methodology	Description	Strengths and Weaknesses	Intensity of Coverage	Typical DoD Use
Fixed pattern sampling	Survey conducted along evenly spaced grids. A percentage of the site (e.g., 10%) is investigated.	Even coverage of entire site. Gaps between plots can be minimized.	Medium	Useful for locating hot spots and for testing clean sites.
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	Survey conducted along evenly spaced transects.	Used in areas with high UXO concentrations.	Medium	Useful for locating boundaries of high-density UXO areas.
Meandering path sampling	Survey 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 with improved 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.

7.6.2.3 *USACE's Use of Statistically Based Sampling Results*

The USACE statistical tools and methodologies 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 response depth and land use for the site

While the results of statistical sampling should be only one of many inputs considered when making a risk management decision, there are instances where it has appeared to be the only basis for the decision. Consequently, where this has occurred, EPA and State regulators have generally rejected the proposed risk management decision (e.g., no action, response to a 1-foot depth) because of the inadequate foundation of the information used to make the decision.

> **Use of Statistical Sampling to Assess Risk at Fort Ritchie Army Garrison**
>
> USACE contractors conducted a site characterization of Fort 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 about the adequacy and reliability of SiteStats/GridStats and OECert methods, and the investigation was revised to include over 700 smaller grids, many of which have irregular shapes. It is expected that these new grid parameters will more accurately reflect site conditions and account for heterogeneity. 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.

7.6.2.4 *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.[110] 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

[110] "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.

in risk algorithms to make management decisions regarding the acceptable future use of the area, and (4) the use of statistical sampling alone to make site-based decisions. Criticisms of statistical sampling have centered around the use of the statistical tools embodied in the SiteStats/GridStats, and UXO Calculator. However, some of the criticisms may be applicable to other statistical methods as well. Criticisms 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 non-homogeneity.
- Statistical procedures used in SiteStats/GridStats to determine when the sector has been sufficiently characterized and to test sector homogeneity are not statistically valid.
- In practice, statistical procedures are often overridden by ad hoc procedures; however, the subsequent analysis does not take these into account.
- 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 OE 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.

7.6.2.5 *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. 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). In examining the use of statistical sampling tools, you should consider the following:

- 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

7.7 Incorporating QA/QC Measures Throughout the Investigation

Quality assurance and quality control should be incorporated into every aspect of your investigation. Begin planning for quality at the start of a project by developing DQOs and standard operating procedures (SOPs). Throughout the process, all data should be managed so as to provide an auditable trail of all data points and every geophysical anomaly detected.

The QA/QC requirements for OE investigations differ from other types of investigations because of the unique characteristics of OE and the tools available for characterizing OE sites. For example, the probability of detection when using any detection system depends on site-specific conditions; therefore, the technology and its capability (performance criteria) must be established for each site at which it will be used. You can determine the effectiveness only by conducting tests of the technology on seeded areas representative of the range itself, and by using the sampling methods to be used in the actual investigation. Similarly, because of the complexities of operating detection systems and analyzing detection data, and the potential ramifications of mischaracterizing an area as clear, operator and analyst skills and capabilities are of paramount importance. Therefore, all personnel working on a site must be qualified and appropriately trained, and certified to work on the site using the detection system selected. Specific QA/QC measures that should be taken include:

- **Development of data quality objectives –** DQOs should clearly relate to the data being collected and to the decisions being made. The DQOs should state the acceptable levels of uncertainty and provide acceptance criteria for assessing data quality.
- **Sampling and analysis plan –** The geophysical survey and the intrusive investigation should be based on a comprehensive CSM. The sampling methods should consider release mechanisms and weapons systems. All primary sources should be addressed and follow-up searches should be performed.
- **Geophysical prove-out –** The geophysical prove-out is used to select the geophysical equipment to be used. In this process, the accuracy of the geophysical equipment is assessed in conditions representative of the actual field conditions, sampling methods to be used, and targets likely to be encountered at specific depths. In general, 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, the detection system operators may need additional training, or the project goals may need to be reconsidered.

- **Geophysical certification –** All members of the geophysical survey team are certified for their ability to meet prove-out performance results to ensure precision of geophysical data. An example of certification for surface sweeps would be "search effectiveness probability validation," which 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.
- **Site preparation** – Prior to the geophysical survey, the site is prepared by setting survey stakes and by removing all metallic debris that could mask subsurface anomalies. In this process, all ordnance-related items found on the surface are documented and proved.
- **Geophysical survey** – The output of the geophysical survey is geophysical and positional data about subsurface anomalies encountered. The results of the survey are affected by the method used to collect positional data and by the performance of the field team. Quality control is conducted on the geophysical survey using several mechanisms: (1) confirmation of proper functioning of detectors, (2) field surveillance to confirm adherence to SOPs, and (3) independent resurvey of a portion of the area under investigation. UXO survey teams may 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 (UTM) grid coordinate values created in GIS or other geographic programs are verified by QC teams using a differential GPS to ensure correct target locations.
- **Anomaly identification –** The merged geophysical and positional data are analyzed to identify and locate anomalies. The QC aspects of anomaly identification include accurately merging data points, incorporating feedback from intrusive investigations, and applying objective criteria to the identification process.
- **Anomaly reacquisition –** Areas in which anomalies were initially detected are reexamined, and the estimated anomaly location is flagged. This process helps to ensure the accuracy of the anomaly location and depth data.
- **Anomaly excavation –** Sources of anomalies are identified and excavated, and the cleared hole is then verified by a detector. Results are fed back into the anomaly identification process. Quality control is then conducted over the entire area to ensure that anomalies have been excavated.

7.8 Selecting Analytical Methods

Two approaches may be used to determine the presence and concentration of munitions and munition residues in the environment. One approach is to conduct 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. However, all shipments of materials with elevated concentrations of explosives must be conducted under Department of Transportation hazardous material transportation requirements.

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.

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.

7.8.1 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 relative speed with which data can be generated using field analysis, 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 contaminated soil samples collected and up to 94 percent of water samples collected that contained munition residues.[111,112] Another source[113] reported that at least 95 percent of the soils contaminated with secondary explosive residues contained TNT and/or RDX. Thus, the use of field methods for both of these compounds can be effective in characterizing explosives 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. 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 μg/L for water.

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[111] A.B. Crockett et al., U.S. Environmental Protection Agency, *Field Sampling and Selecting On-Site Analytical Methods for Explosives in Soils*, EPA/540/R-97/501, November 1996.

[112] A.B. Crockett et al., U.S. Environmental Protection Agency, *Field Sampling and Selecting On-Site Analytical Methods for Explosives in Water*, EPA/600/S-99/002, May 19, 1999.

[113] Thomas F. Jenkins et al., U.S. Army Cold Regions Research and Engineering Laboratory, *Laboratory and Analytical Methods for Explosives Residues in Soil,* Hanover, NH.

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 show a response relative to 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 are extracted and the TNT molecules in the extract 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

Examples of Field Analytical Methods

The EXPRAY Kit (Plexus Scientific) is the simplest colorimetric screening kit. It is useful for screening surfaces and unknown solids. It can also be used to provide qualitative tests for soil. It has a detection limit of about 20 nanograms. Each kit contains three spray cans:

EXPRAY 1 – Nitroaromatics (TNT)
EXPRAY 2 – Nitramines (RDX) and nitrate esters (NG)
EXPRAY 3 – Black powder, ANFO

EnSys Colorimetric Test Kits (EPA SW846 Methods 8515 and 8510) consist of separate colorimetric methods for TNT and RDX/HMX. The TNT test will also respond to 2,4-DNT, tetryl, and TNB. The RDX/HMX test will also respond to NG, PETN, NC, and tetryl. It is also subject to interference from the nitrate ion unless an optional ion exchange step is used. The results of these kits in the field correlate well with SW846 Method 8330.

DTECH Immunoassay Test Kits (EPA SW846 Methods 4050 and 4051) are immunoassay methods for TNT and RDX. Immunoassay assay tests are more selective than colorimetric test kits. The results are presented as concentration ranges. These ranges correlate well with SW846 Method 8330.

The EPA Environmental Technology Verification Program (www.epa.gov/etv) continues to test new methods.

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 other nitramines such as HMX.

The explosive compounds that can be detected by colorimetric and immunoassay methods are indicated in Table 7-7. In addition, TNT and RDX can be detected and measured in water samples using biosensor methods.

Table 7-7. Explosive Compounds Detectable by Common 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	
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	

7.8.2 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 (SVOCs). However, these compounds have a number of important chemical and physical properties that make their analysis by methods used for other SVOCs problematic. For example, if the concentration of energetic/explosive compounds is high enough (approaching 10 percent or less, depending on the specific compound), the possibility of detonation increases with the preparation of samples for analysis. 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.

7.8.2.1 *EPA Method 8330*[114]

Samples containing or suspected of containing explosive 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 to the right.

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 to 0.84 μg/L for low-level samples and 4.0 to 14.0 μg/L for high-level samples.

7.8.2.2 *EPA Method 8095*[115]

Method 8330, described 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

Compounds That Can Be Detected and Quantified by SW-846 Method 8095 (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)
- 3,5-Dinitroaniline
- Nitrobenzene
- Nitroglycerine
- 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)
- Pentaerythritol tetranitrate (PETN)

[114] SW-846 Method 8330, Nitroaromatics and Nitramines by High Performance Liquid Chromatography (HPLC), U.S. Environmental Protection Agency, Revision 0, September 1994.

[115] Method 8095, Explosives by Gas Chromatography, U.S. Environmental Protection Agency, Revision 0, November 2000.

Method 8095 has been proposed as an alternative analytical method. Method 8095 uses gas chromatography with electron capture detection (see text box). It can detect and quantify the same compounds as Method 8330. 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 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.

7.8.2.3 *Other Laboratory Methods for Explosive Compounds*

Two other methods can be mentioned briefly. The first is a CHPPM method for explosives in water. It is a gas chromatography electron capture detection method developed by Hable et al. in 1991. Although it is considered to be an excellent method, it is not commercially available. The second, SW-846 Method 8321, is an LC-MS method that is available at a few commercial laboratories. Explosives are not the target analytes for which the method was developed; however, the method claims to be applicable to the analysis of other nonvolatile or semivolatile compounds.

7.8.2.4 *EPA Method 7580*[116]

In addition to explosive compounds, other materials used in military ordnance 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 μg/L. It may be used to assess compliance with Federal water quality criteria. The second procedure provides for a sensitivity of 0.1 μg/L. The extraction method for solids provides a sensitivity of 1.0 μg/kg. Because this method uses the nitrogen/phosphorus detector, 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

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[116] Method 7580, White Phosphorus (P_1) by Solvent Extraction and Gas Chromatography, U.S. Environmental Protection Agency, Revision 0, December 1996.

water/isooctane (solids). The extracts are then injected into the gas chromatograph that has been calibrated with five standards.

7.8.2.5 *EPA Method 314.0*[117]

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 that comprises an ion chromatographic pump, sample injection valve, guard column, analytical column, suppressor device, and conductivity detector.

7.9 Developing the 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 munition constituents of OE, the standard risk assessment process will be used.[118]

When evaluating the information associated with an OE site (UXO, explosive soil, and buried munitions), two questions are asked:

- 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:

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[117] Method 314.0, Determination of Perchlorate in Drinking Water Using Ion Chromatography, U.S. Environmental Protection Agency, Revision 1.0, November 1999.

[118] U.S. EPA, Risk Assessment Guidance for Superfund (RAGS), Volume 1, Human Health Evaluation Manual, Part B, Interim, September 1991.

- 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.

7.9.1 Assumptions of the Site Response Strategy

The site response strategy is based on several basic assumptions built on discussions with DoD OE experts:

> **What Does "Unacceptable Risk" Imply?**
>
> If there is no acceptable risk level, does that mean 100 percent cleanup at all sites?
>
> The short answer is no. Institutional controls (ICs) will be used along with the active response when that response allows a land use that does not provide for unrestricted use. ICs may be used as the sole response in those circumstances where the CERCLA decision process finds that active response actions are impracticable or unsafe.

- There is no quantifiable risk level for OE exposure below which you can definitively state that such potential exposure is acceptable. This is 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 level 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 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.[119]

[119] 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.

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., the National Contingency Plan, or 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.

- A no-action alternative (i.e., not even institutional controls are required) will usually be selected only where there is 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. For example, if your decision is to be made under the CERCLA remedial process, you would use the nine CERCLA criteria to evaluate the acceptability of a no-action decision and to select appropriate response actions (including depth of response or containment, or limited response actions such as institutional controls and monitoring).

7.9.2 Attributes of the Site Response Strategy

It will not be necessary to create a new report to document your 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 through a number of existing documents, including:

- 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. **It uses a weight-of-evidence approach to decision making.** 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.

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.

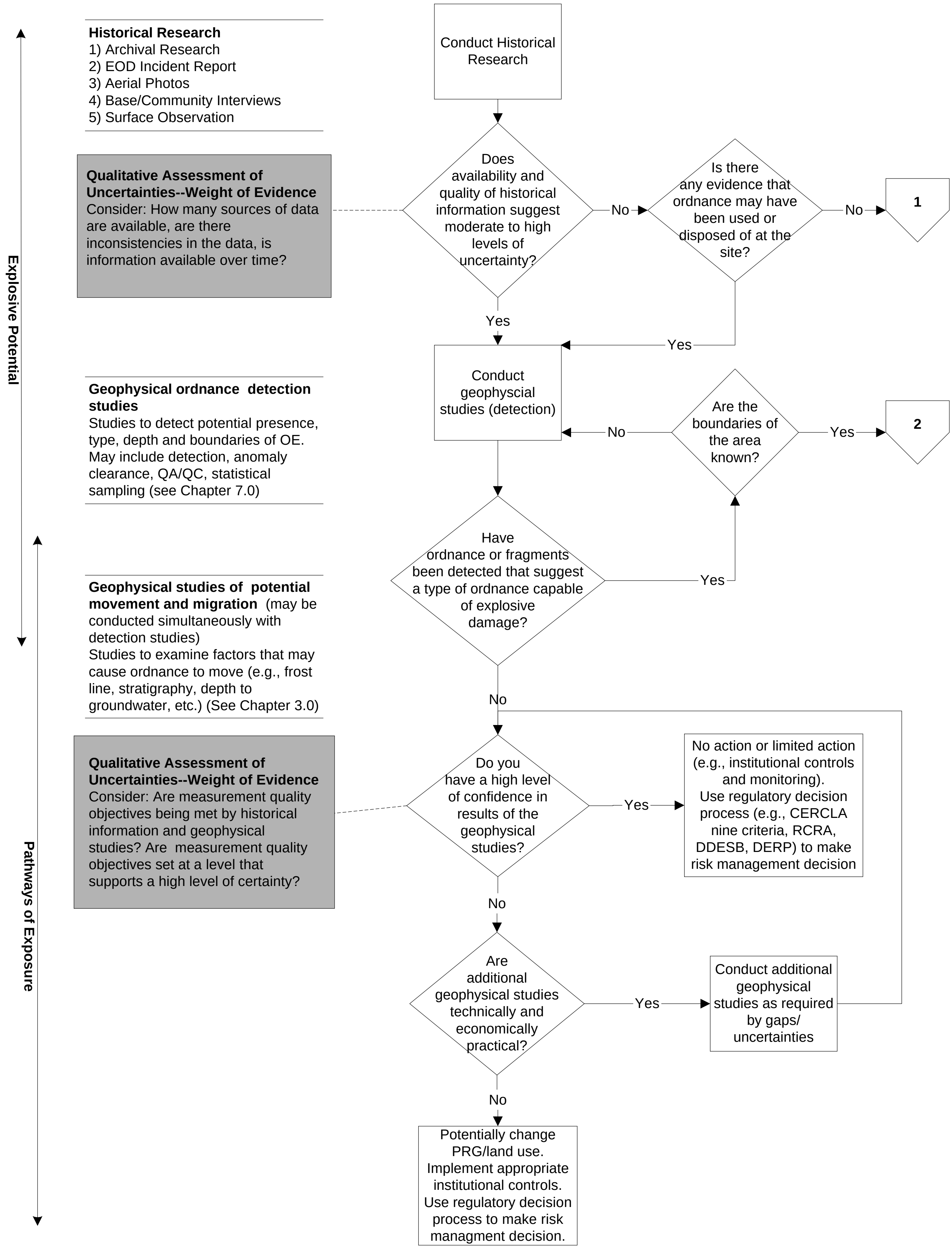
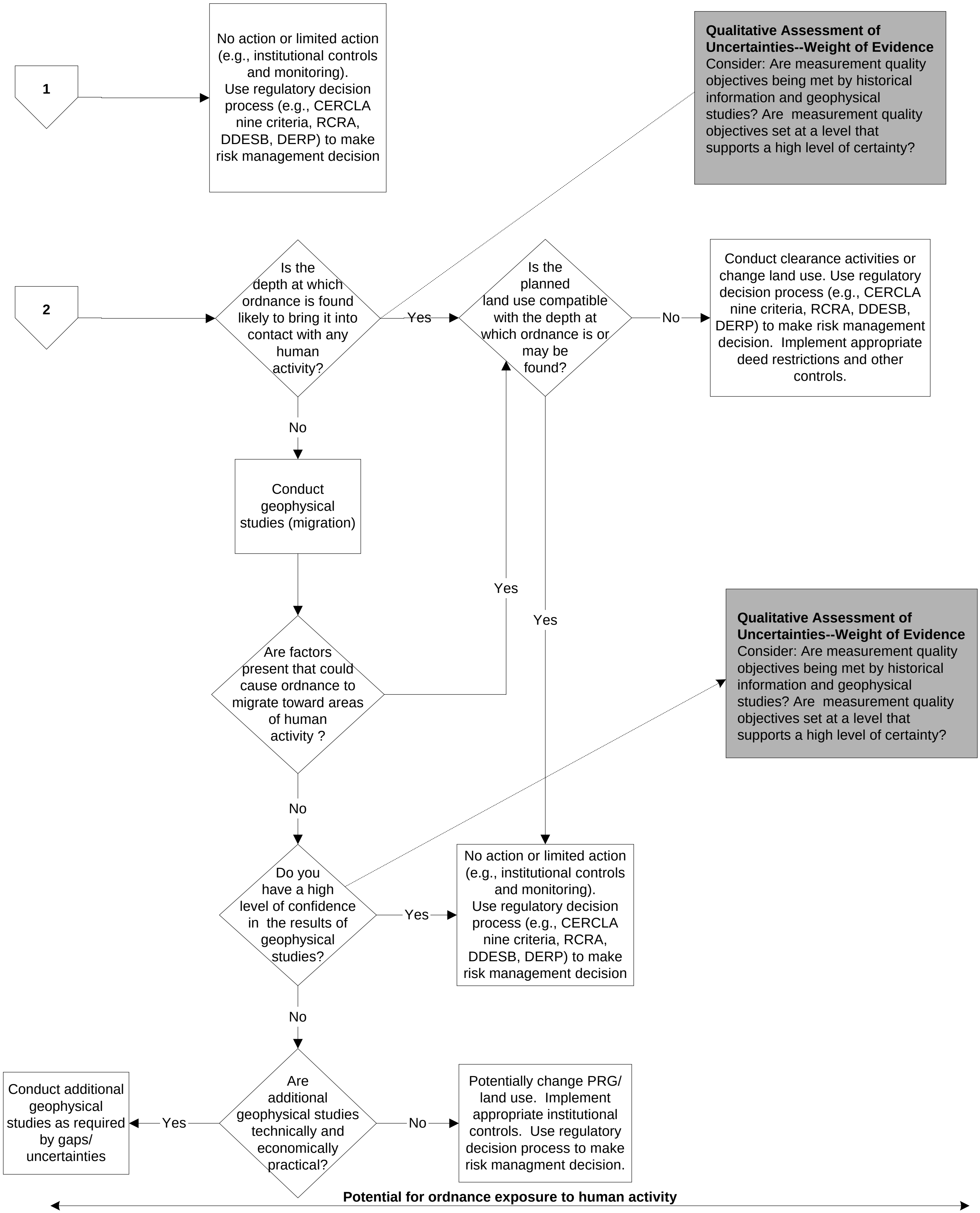


Figure 7-4. Developing a Site Response Strategy


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

7.9.3 Questions Addressed in the Development of the Site Response Strategy

In developing your site response strategy, you will address four issues. These four issues parallel the factors addressed in a typical risk assessment, but the process differs 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.

7.9.3.1 *Determining the Presence of Ordnance with Explosive Potential*

The central question addressed here is whether ordnance with explosive potential is present or may be present at your site. 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 munition constituents 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, in your investigation to determine the presence or potential presence of OE you would consider 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.

7.9.3.2 *Identifying Potential Pathways of Exposure*

Once the actual or potential presence of OE has been established, you will then need 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:

- Has 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 Chapter 3 and earlier in this chapter.)

Factors To Be Evaluated in Identifying Potential Pathways of Exposure

In addition to the information highlighted in the previous box (regarding the historical 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

If ordnance is found to be present or potentially present, you may need additional geophysical information in order 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.

7.9.3.3 *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)

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 human activity that causes OE 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 or civilians.

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). 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.

7.9.3.4 *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 **the weight of the evidence that has converged** from a number of different sources of data, including historical information (archives, 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.

7.10 Making the Decision

The Interim Final 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. 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.

7.11 Conclusion

A focus of this chapter has been on planning your investigation. In the course of the investigation, the initial plan will undoubtedly 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 you through the planning and design of the UXO investigation to the development of a site response strategy. As pointed out in the introduction, this chapter has focused primarily on UXO and energetic materials, not the environmental contamination of media by munition constituents. 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 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. The actual selection of a response will be conducted through the risk management processes defined by the CERCLA removal and remedial programs (or the RCRA Corrective Action Program).

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

American Society for Testing and Materials. ***Guide E1689-95 Standard Guide for Developing Conceptual Site Models for Contaminated Sites***, 2001.

Crockett, A.B., H.D. Craig, T.F. Jenkins, and W.E. Sisk. ***Field Sampling and Selecting On-site Analytical Methods for Explosives in Soil***, Paper presented at U.S. EPA Federal Facilities Forum, November 1996.

Crockett, A.B., H.D. Craig, and T.F. Jenkins. ***Field Sampling and Selecting On-site Analytical Methods for Explosives in Water***, Paper presented at U.S. EPA Federal Facilities Forum, May 19, 1999.

Wilcox, R.G. ***Institutional Controls for Ordnance Response***, Paper presented at UXO Forum, May 1997.

Information Sources

Joint UXO Coordination Office (JUXOCO)
10221 Burbeck Road, Suite 430
Fort Belvoir, VA 22060-5806
Tel: (703) 704-1090
Fax: (703) 704-2074
http://www.denix.osd.mil/UXOCOE

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

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

U.S. Environmental Protection Agency
Superfund Risk Assessment
http://www.epa.gov/superfund/programs/risk/index.htm

<u>**Guidance Documents**</u>

U.S. Air Force, Headquarters, Air Force Center for Environmental Excellence. ***Technical Services Quality Assurance Program***, Version 1.0, August 1996.

U.S. Army Corps of Engineers. ***Interim Chemical Data Quality Management (CDQM) Policy for USACE HTRW Projects***, December 8, 1998.

U.S. Army Corps of Engineers. ***Technical Project Planning (TPP) Process***, Engineer Manual 200-1-2, August 31, 1998.

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

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

U.S. EPA. ***Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA, Interim Final,*** PB89-184626, October 1989.

U.S. EPA. ***Risk Assessment Guidelines for Superfund (RAGS), Volume I – Human Health Evaluation Manual, Part A, Interim Final***, December 1989.

U.S. EPA. ***Risk Assessment Guidance for Superfund (RAGS), Volume I – Human Health Evaluation Manual, Part C (Risk Evaluation of Remedial Alternatives), Interim***, October 1991.

U.S. EPA. ***Risk Assessment Guidance for Superfund (RAGS), Volume I – Human Health Evaluation Manual, Part B, Interim***, December 1991.

U.S. EPA. ***Guidance for Data Usability in Risk Assessment (Part A)***, PB92-963356, April 1992.

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

U.S. EPA. ***Risk Assessment Guidance for Superfund (RAGS), Volume I – Human Health Evaluation Manual, Part D (Standardized Planning, Reporting, and Review of Superfund Risk Assessments), Interim***, January 1998.

U.S. EPA. ***EPA Guidance for Quality Assurance Project Plans, EPA QA/G-5***, February 1998.

U.S. EPA. ***Guide to Preparing Superfund Proposed Plans, Records of Decision, and Other Remedy Selection Decision Documents***, PB98-963241, July 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. ***Environmental Compliance Sampling and Field Testing Procedures Manual***, NAVSEA T0300-AZ-PRO-0010, July 1997.

<u>Sources of Data for Historical Investigations</u>

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; city directories; insurance, wetlands, flood plain, and topographical maps)
3530 Post Road
Southport, CT 06490
Tel: (800) 352-0050
http://www.edrnet.com

U.S. Geological Survey, EROS Data Center
(satellite images, aerial photographs, and topographic maps)
Customer Services
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/

National Archives and Records Administration
National Cartographic and Architectural Branch
College Park, MD
http://www.nara.gov

U.S. Department of Agriculture, 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)
14th and Independence Avenue
Washington, DC 20250
http://www.nrcs.usda.gov/

<u>Repositories of Explosive Mishap Reports</u>

Army
U.S. Army Safety Center
5th Avenue, Bldg. 4905
Fort Rucker, AL 36362-5363

U.S. Army Technical Center for Explosives Safety (maintains a database of explosives accidents)
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/esmam/default.htm

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