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Handbook on the Management of Munitions Response Actions

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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.[1]

Archives search report. An investigation to report past ordnance and explosives (OE) activities conducted on an installation.[2]

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.[6]

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.[3]

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

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.[5]

Defense Sites. Locations that are or were owned by, leased to, or otherwise possessed or used by the Department of Defense. The term does not include any operational range, operating storage or manufacturing facility, or facility that is used for or was permitted for the treatment or disposal of military munitions.

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.[6]

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.[8]

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.[6]

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.[3]

Discarded Military Munitions (DMM). Military munitions that have been abandoned without proper disposal or removed from storage in a military magazine or other storage area for the purpose of disposal. The term does not include unexploded ordnance, military munitions that are being held for future use or planned disposal, or military munitions that have been properly disposed of consistent with applicable environmental laws and regulations 10 U.S.C. 2710 (e)(2).[14]

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.[7]

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.[1]

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.[3]

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 a munitions 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 that has become hazardous by damage or deterioration, when the disposal of such explosive ordnance is beyond the capabilities of the personnel normally assigned the responsibilities for routine disposal. EOD activities are performed by active duty military personnel.[9]

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. The concentration of a particular explosive in soil necessary to present an explosion hazard depends on whether the explosive is classified as “primary” or “secondary.” Guidance on whether an explosive is classified as “primary” or “secondary” can be obtained from Chapters 7 and 8 of TM 9-1300-214, Military Explosives.[2]

Explosive train. The arrangement of different explosives in munitions 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.[7]

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.[2] 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 such misidentification in post-processing; this results in potential risks remaining following UXO investigations.

False positive. When the geophysical sensor indicates an anomaly and nothing is found that cause the instrument to detect the anomaly.

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.[2]

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.[3]

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.[4]

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.[5]

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.[10]

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.[6] 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.[11]

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.[11]

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.[10]

Inert. The state of some types of ordnance that 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.[12]

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 to ensure effectiveness of the chosen remedy. Institutional controls are usually, but not always, legal controls, such as easements, restrictive covenants, and zoning ordinances.[13]

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.[5]

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.[2]

Military munitions. All ammunition products and components produced for or used by the armed forces for national defense and security, including ammunition products or components under the control of the Department of Defense, the Coast Guard, the Department of Energy, and the National Guard. The term includes confined gaseous, liquid, and solid propellants, explosives, pyrotechnics, chemical and riot control agents, chemical munitions, rockets, guided and ballistic missiles, bombs, warheads, mortar rounds, artillery ammunition, small arms ammunition, grenades, mines, torpedoes, depth charges, cluster munitions and dispensers, demolition charges, and devices and components thereof.

The term does not include wholly inert items, improvised explosive devices, and nuclear weapons, nuclear devices, and nuclear components, other than non-nuclear components of nuclear devices that are managed under the nuclear weapons program of the Department of Energy after all required sanitization operations under the Atomic Energy Act of 1954 (42 U.S.C. 2011 et seq.) have been completed (10 U.S.C. 101 (e)(4).[14]

Mishap. An accident or an unexpected event involving DoD ammunition and explosives.[7]

Most Probable Munition (MPM). For a Munitions Response Site (MRS) the MEC item that has the greatest hazard distance based on calculations of the explosion effects of the MEC items anticipated to be found at a site. Typically, the MPM is the MEC item with the greatest fragmentation or overpressure distance based on the type of munitions that were historically used at the site.[1]

Munitions constituents (MC). Any materials originating from unexploded ordnance, discarded military munitions, or other military munitions, including explosive and nonexplosive materials, and emission, degradation, or breakdown elements of such ordnance or munitions. (10 U.S.C. 2710 (e)(4)).[14] Munitions 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 and Explosives of Concern (MEC). This term, which distinguishes specific categories of military munitions that may pose unique explosives safety risks, means: (1) Unexploded ordnance (UXO); (2) Discarded military munitions (DMM); or (3) Munitions Constituents (e.g. TNT, RDX) present in high enough concentrations to pose an explosive hazard. Formerly known as Ordnance and Explosives (OE).[14]

Munitions response. Response actions, including investigation, removal and remedial actions to address the explosives safety, human health, or environmental risks presented by unexploded ordnance (UXO), discarded military munitions (DMM), or munitions constituents.[14] 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.

Munitions Response Area (MRA). Any area on a defense site that is known or suspected to contain UXO, DMM, or MC. Examples include former ranges and munitions burial areas. A munitions response area is comprised of one or more munitions response sites. An MRA is equivalent to a response area on a range that was formerly referred to as "closed, transferred or transferring" or CTT.[14]

Munitions Response Site (MRS). A discrete location within a MRA that is known to require a munitions response.[14]

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.[5]

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*.[5]

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

On-scene coordinator (OSC). The Federal Official 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. Coast 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.[5]

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.[8]

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.[8]

Operational range. A range that is under the jurisdiction, custody, or control of the Secretary of Defense and (A) that is used for range activities; or (B) although not currently being used for range activities, that is still considered by the Secretary to be a range and has not been put to a new use that is incompatible with range activities.[14]

Overpressure. The blast wave or sudden pressure increase resulting from a violent release of energy from a detonation in a gaseous medium.[9]

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.[12]

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 projectiles. 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.[2]

Range. Means designated land and water areas set aside, managed, and used to research, 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. (40 CFR 266.601) A recent statutory change added Airspace areas designated for military use in accordance with regulations and procedures prescribed by the Administrator of the Federal Aviation Administration. (10 U.S.C. 101 (e)(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.[5]

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).[10]

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.[10]

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.[5]

Removal action. Short-term response actions under CERCLA that address immediate threats to public health and the environment.[10]

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.[9]

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.[6]

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.[10]

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 that 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.[6] When a military munition is identified as a solid waste is defined in 40 CFR 266.202.[11]

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.[5]

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.[6]

Unexploded ordnance (UXO). These Guidelines will use the term "UXO" as defined in the Military Munitions Rule. "UXO 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, installation, personnel, or material and that remain unexploded either by malfunction, design, or any other cause." This definition also covers all ordnance-related items (e.g., low-order fragments) existing on a non-operational range. (40 CFR Part 266.201, 62 FR 6654, February 12, 1997).[11]

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

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2. U.S. Army Corps of Engineers Pamphlet No. 1110-1-18, "Engineering and Design Ordnance and Explosives Response," April 24, 2000.
3. DoD 6055.9-STD, Department of Defense Ammunition and Explosives Safety Standards.
4. 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.
5. National Oil and Hazardous Substances Pollution Contingency Plan (more commonly called the National Contingency Plan), 40 C.F.R. § 300 et seq.

6. Department of Defense Directive 6055.9. "DoD Explosives Safety Board (DDESB) and DoD Component Explosives Safety Responsibilities," July 29, 1996.
7. Resource Conservation and Recovery Act (RCRA), 42 U.S.C. § 6901 et seq.
8. Department of Defense. Policy to Implement the EPA's Military Munitions Rule. July 1, 1998.
9. Joint Publication 1-02, "DoD Dictionary of Military and Associated Terms," April 12, 2001.
10. Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), 42 U.S.C. § 9601 et seq.
11. 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.
12. 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.
13. 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.
14. Department of Defense Memorandum,"Definitions Related to Munitions Response Actions," from the Office of the Under Secretary of Defense, December 18, 2003.

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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
DDESB	Department of Defense Explosives Safety Board
DERP	Defense Environmental Restoration Program
DGPS	differential global positioning system
DMM	discarded military munitions
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
MEC	munitions and explosives of concern
MRA	munitions response area
MRS	munitions response site
MTADS	Multisensor Towed-Array Detection System
NCP	National Contingency Plan
NPL	National Priorities List
OB/OD	open burning/open detonation
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	Research Demolition Explosive
RF	radio frequency
RI/FS	remedial investigation/feasibility study
ROD	Record of Decision
RSP	render-safe procedure
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 munitions response actions 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 munitions and explosives of concern (MEC) which includes:

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

The definition of MEC 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 munitions 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 Munitions Response Areas/Sites?

EPA's major regulatory concern is MRAs that were former ranges and sites where the industrial activity may have ceased and MEC and munitions constituents may be present. This focus occurs for several reasons:

- MRAs are often 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 represent a significant portion of those sites.
- EPA, States, Tribes, and local governments have encountered numerous instances where issues have been raised about whether former defense sites are safe for both their current use and the uses to which they may be put in the future.
- Ranges at active bases may have been taken out of service as a range and could 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 defense sites that were formerly used as ranges.
- Other sites that are addressed by this handbook include nonrange defense sites where MEC 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 **munitions and explosives of concern (MEC)** 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 **munitions constituents (MC)**.

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

The handbook is designed to facilitate a common understanding of the state of the art of MEC detection and munitions response, and to present U.S. Environmental Protection Agency (EPA) guidance on the management of munitions response actions. The handbook is currently organized into 10 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 future revisions are likely. A number of areas covered by the handbook are the subject of substantial ongoing 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 MEC investigation and cleanup 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 MRSs 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.

Changing Terminology

The terminology related to munitions and explosives of concern and related activities, is evolving. On December 18, 2003, the Department of Defense published a memorandum titled *Definitions Related to Munitions Response Actions*. The memorandum explained that these definitions are part of an evolving effort to implement a Military Munitions Response Program (MMRP) and are designed to "promote understanding, provide clarity, and consistency in both internal and external discussions." The most current terms and definitions from the Department of Defense are used in this publication. However, previously existing publications and references may use older terminology such as "ordnance and explosives (OE)" to refer to MEC and "closed, transferring, and transferred (CTT) ranges" to refer to ranges that are no longer operational. Titles of, and quotes from, these prior documents have not been changed. to reflect the new terms.

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.

> **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.

2. **Range** — The term "range," when used in a geographic sense, means a designated land or water area that is set aside, managed, and used for range activities of the Department of Defense. Such terms includes the following: (a) firing lines and positions, maneuver areas, firing lanes, test pads, detonation pads, impact areas, electronic scoring lines, buffer zones with restricted access, and exclusionary areas; (b) airspace areas designated for military use in accordance with regulations and procedures prescribed by the administrator of the Federal Aviation Commission.

3. **Operational range —** A range that is under the jurisdiction, custody, or control of the Secretary of Defense and (a) that is used for range activities, or (b), although not currently used for range activities, that is still considered by the Secretary of Defense to be a range and has not been put to a new use that is incompatible with range activities.[16]

4. **Munitions and Explosives of Concern (MEC)** — This term, which distinguishes specific categories of military munitions that may pose unique explosives safety risks, means: (1) unexploded ordnance (UXO), (2) discarded military munitions (DMM) (e.g., buried munitions), or (3) munitions constituents (e.g., TNT, RDX) present in high enough concentrations to pose an explosive hazard. Formerly called ordnance and explosives (OE).[16]

5. **Munitions Response Area (MRA).** Any area on a defense site that is known or suspected to contain UXO, DMM, or MC. Examples include former ranges and munitions burial areas. A munitions response area is a large area where MEC may be known or suspected to be present. An MRA is typically comprised of one or more munitions response sites.

6. **Munitions Response Site (MRS).** A discrete location within a MRA that is known to require a munitions response.

7. **Discarded Military Munitions (DMM).** Military munitions that have been abandoned without proper disposal or removed from storage in a military magazine or other storage area for the purpose of disposal. The term does not include unexploded ordnance, military munitions that are being held for future use or planned disposal, or military

munitions that have been properly disposed of consistent with applicable environmental laws and regulations. It does include buried munitions that have been disposed of with or without authorization.

8. **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. The overarching term for buried munitions is discarded military munitions.

9. **Defense sites** — Locations that are or were owned by, leased to, or otherwise possessed or used by the Department of Defense. The term does not include any operational range, operating storage or manufacturing facility, or facility that is used for or was permitted for the treatment or disposal of military munitions.

10. **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.

11. **Munitions 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 reactive and/or ignitable but may pose a potential threat to human health and the environment through their toxic properties.

12. **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.

13. **Clearance** — The removal of UXO from the surface or subsurface at active and inactive ranges. This term used to be in widespread use at ranges that are no longer operational. Many published documents use this term when referring to removal of MEC at MRSs. The official term now used is Munitions Response (see below).

14. **Munitions response** — Response actions, including investigation and removal and remedial actions to address the explosives safety, human health, or environmental risks presented by UXO, discarded military munitions (DMM), or munitions 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 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 nine chapters of this handbook are organized as follows:

Chapter 2 — Regulatory Overview
Chapter 3 — Characteristics of Ordnance and Explosives
Chapter 4 — Detection of UXO and Buried Munitions
Chapter 5 — Response Technologies
Chapter 6 — Explosives Safety
Chapter 7 — Planning OE Investigations
Chapter 8 — Devising Investigation and Response Strategies
Chapter 9 — Underwater Ordnance and Explosives
Chapter 10 — Chemical Munitions and Agents

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

Unexploded ordnance 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.

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2.0 REGULATORY OVERVIEW

Munitions response actions are governed by numerous Federal, State, Tribal and local laws and may involve interaction among multiple regulatory and nonregulatory authorities.

On March 7, 2000, the U.S. Environmental Protection Agency and the Department of Defense entered into an interim final agreement to resolve some of the issues between the two agencies.[1] 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 munitions response actions identifies issues that remain uncertain, and identifies specific areas of regulatory concern. 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 munitions response actions 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 MEC. This process is expected to meet any RCRA corrective action requirements.
- DoD will conduct munitions response actions 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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[1]DoD, 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. These principles are provided in their entirety at the end of this chapter.

2.1 Regulatory Overview

As recognized in the DoD/EPA Interim Final Management Principles cited above and in EPA's draft MEC policy,[2] the principal regulatory programs that guide the cleanup of MRSs 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 munitions response actions. 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 2.1.4). Substantive requirements of other Federal, State and Tribal environmental laws must also be met when such laws are ARARs.

> **Military Instructions**
>
> Each service has its own set of instructions on how to comply with environmental regulations. These are usually expressed as standards or regulations (e.g., Army uses AR 200-1 and 200-2 for environmental regulations). Some of the commonly referred to DoD regulations are listed in the "Sources and Resources" section of this chapter but are not discussed here.

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

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:

1. 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).
2. Correction of environmental damage, such as the detecting and disposing of unexploded ordnance, that creates an imminent and substantial endangerment to

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[2] 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.

public health and the environment.

3. Demolition and removal of unsafe buildings and structures, including those at formerly used defense sites (FUDS).

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, they involve the following:

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, at MRSs 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.[3]
- 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 MRS 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.

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

[3]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.

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, such as the following:

- 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 <u>CERCLA Section 120</u>

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

- Federal agencies (including DoD) are subject to the requirements of CERCLA in the same manner as nongovernmental entities.

- C The guidelines, regulations, and other criteria that are applicable to assessments, evaluations, and remedial actions by other entities apply also to Federal agencies.
- C 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.
- C 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.
- C 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)).[4]
- C 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:

- C Identification of when a material is a solid or hazardous waste
- C Management of hazardous waste — transportation, storage, treatment, and disposal
- C 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.

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. Similarly, all substantive requirements of other Federal and State environmental laws that are ARARs must be met under CERCLA.

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[4]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.

The Federal Facility Compliance Act of 1992, or FFCA (PL 102-386), 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 outlines its safety and real property requirements.

In addition to promulgating safety requirements, DDESB has established requirements for the submission, review, and approval of Explosives Safety Submissions for all 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 munitions response actions 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 munitions and explosives of concern is another step. As DoD works with EPA, States, and Tribal organizations and other stakeholders to consider the appropriate nature of range regulation at MRSs, 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 on Unexploded Ordnance. ***Report on 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 for (Acquisition and Technology), Apr. 1998.

U.S. Department of Defense, Operation and Environmental Executive Steering Committee for Munitions (OEESCM). ***Munitions Action Plan: Maintaining Readiness through Environmental Stewardship and Enhancement of Explosives Safety in the Life Cycle Management of Munitions***. Nov. 2001.

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

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

Information Sources

U.S. Department of Defense
Washington Headquarters Services
Directives and Records Branch (Directives Section)
http://www.dtic.mil/whs/directives

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

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P.O. Box 1600
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http://www.hnd.usace.army.mil/

Guidance

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

Preamble

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

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

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

General Principles

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

- DoD will conduct response actions on CTT ranges when necessary to address explosives safety, human health and the environment. DoD and the regulators must consider explosives safety in determining the appropriate response actions.
- DoD is committed to communicating information regarding explosives safety to the public and regulators to the maximum extent practicable.
- DoD and EPA agree to attempt to resolve issues at the lowest level. When necessary, issues may be raised to the appropriate Headquarters level. This agreement should not impede an emergency response.
- The legal authorities that support site-specific response actions at CTT ranges include, but are not limited to, the Comprehensive Environmental Response, Compensation, and Liability

Act (CERCLA), as delegated by Executive Order (E.O.) 12580 and the National Oil and Hazardous Substances Contingency Plan (NCP); the Defense Environmental Restoration Program (DERP); and the DoD Explosives Safety Board (DDESB).

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

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

1. State and Tribal Participation

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

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

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

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

- Review records and reports.

2. Response Activities under CERCLA

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

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

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

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

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

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

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

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

3. Characterization and Response Selection

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

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

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

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

Statistical or other mathematical analyses should be updated to include actual site data as it becomes available.

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

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

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

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

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

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

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

4. UXO Technology

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

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

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

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

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

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

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

5. Land Use Controls

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

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

- DoD shall provide timely notice to the appropriate regulatory agencies and prospective federal land managers of the intent to use Land Use Controls. Regulatory comments received during the development of draft documents will be incorporated into the final land use controls, as appropriate. For Base Realignment and Closure properties, any unresolved regulatory comments will be included as attachments to the Finding of Suitability to Transfer (FOST).

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

- The land use controls must be enforceable.

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

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

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

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

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

6. Public Involvement

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

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

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

3.0 CHARACTERISTICS OF MUNITIONS AND EXPLOSIVES OF CONCERN

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

Nonexplosive risks from MEC result from the munitions' constituents and include both human health and environmental risks. As the munitions constituents of MEC 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 MEC that you will want to consider when planning for an investigation of MEC. As will be discussed in Chapter 7, planning an investigation requires a careful and thorough examination of the actual use of munitions at the site that is under investigation. Many MRAs/MRSs 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 from conventional munitions and munitions constituents.
- The human health and environmental effects of munitions constituents that come from conventional munitions.
- Other activities that may result in releases of munitions constituents.

3.1 Overview of Explosives

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

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.A mixture of potassium nitrate, sulfur, and powdered charcoal or coal. [5] 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.[6]

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.[7]

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[8] began to be used as a bursting charge for projectiles. Additional diverse mixtures of various compounds with inert or stabilizing fillers were developed for use as propellants and as bursting charges.[9]

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

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

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

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

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

[9]*Military Explosives*, 1984.

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.[10] By 1909, diphenylamine had been introduced as a stabilizer.

Because of its corrosive action on metal casings to form shock-sensitive metal salts, picric acid was replaced by TNT[11] as a bursting charge for artillery projectiles. Ammonium picrate, also known as "Explosive D," was also standardized in the United States as the bursting charge for armor-piercing projectiles.

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 projectile charges.[12]

3.1.1.4 *The Decades Between the Two World Wars*

The decades following World War I saw the development of RDX,[13] PETN,[14] lead styphnate, DEGDN,[15] 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.[16] Flashless propellants were developed in the United States, as well as diazodinitrophenol as an initiator.[17]

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[10] Ibid.

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

[12] *Military Explosives*, 1984.

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

[14] 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.

[15] DEGDN, Diethylene glycol dinitrate.

[16] An equal mixture of TNT and PETN.

[17] *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[18] and picratol,[19] special-purpose binary explosives used in demolition work and in semi-armor-piercing bombs, were also developed by the United States.[20]

RDX and HMX[21] came into use during World War II, but HMX was not produced in large quantities, so its use was limited.[22] 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,[23] torpex,[24] and minol,[25] 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.[26]

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 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

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

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

[20]*Military Explosives*, 1984.

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

[22]Bailey and Murray.

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

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

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

[26]*Military Explosives*, 1984.

implosion devices used in nuclear weapons.[27]

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.[28]

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.[29]

Military explosives are grouped into three classes:[30]

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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[27]Bailey and Murray.

[28]*Military Explosives*, 1984.

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

[30]Ibid.

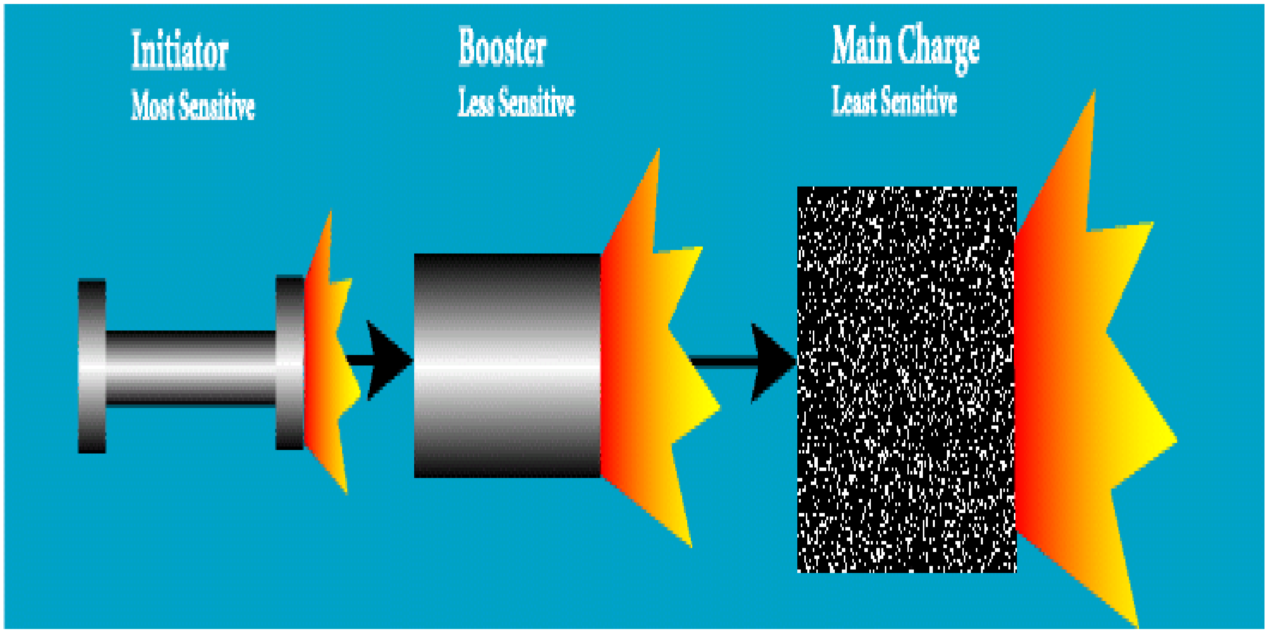

Figure 3-1. Schematic of an Explosive Train

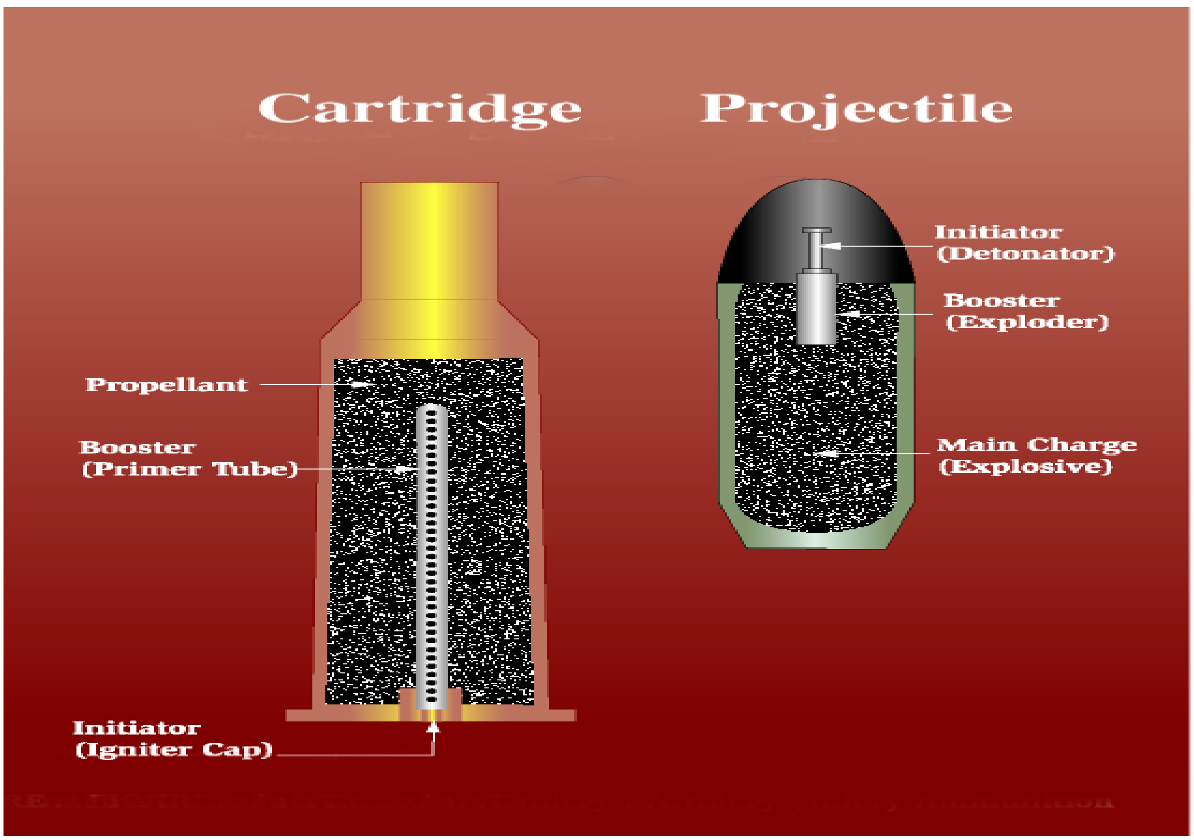

Figure 3-2. Explosive Trains in a Round of Artillery Ammunition

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.[31] The categories **low explosive** and **high explosive** are based on the velocity of the explosion. High explosives are characterized by their extremely rapid rate of decomposition. When a high explosive is initiated by a blow or shock, it decomposes almost instantaneously, 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.[32] 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

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

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

[32] Ibid.

traps, or land mines.[33] Table 3-1 shows examples of pyrotechnic special effects.[34]

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.[35]

Modern gun propellants consist of one or more explosives and additives (see text box). 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.[36]

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

Chemicals Found in Gun Propellants

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

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

[34] Bailey and Murray.

[35] *Military Explosives*, 1984.

[36] Bailey and Murray.

nitrocellulose. Other propellant ingredients include nitroglycerine and nitroguanidine.[37]

Modern gun propellants, classified according to composition, include the following:[38]

- Single-base. Nitrocellulose is the chief ingredient. In addition to a stabilizer, single-base propellants may contain inorganic nitrates, nitrocompounds, and nonexplosive materials as metallic salts, metals, carbohydrates, and dyes.
- Double-base. In addition to nitrocellulose, a double-base propellant contains a liquid organic nitrate such as nitroglycerine. Double-base propellants frequently contain additives, in addition to a stabilizer.
- Composite. Composite propellants do not contain nitrocellulose or organic nitrates. Generally, they are a physical mixture of an organic fuel and an inorganic oxidizing agent. An organic binding agent holds the mixture together in a heterogeneous physical structure.

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.[39]

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.[40]

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%).

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[37]Ibid.

[38]*Ammunition, General*. Department of the Army, TM 9-1300-200, October 3, 1969..

[39]Ibid.

[40]Ibid.

Modified double-base propellants provide a higher performance than double-base propellants. Two typical compositions for modified double-base propellants are (a) nitrocellulose (20%), nitroglycerine (30%), triacetin (6%), ammonium perchlorate (11%), aluminum (20%), HMX (11%), and a stabilizer (2%); or (b) nitrocellulose (22%), nitroglycerine (30%), triacetin (5%), ammonium perchlorate (20%), aluminum (21%), and a stabilizer (2%). Composite propellants consist of a polymer structure and an oxidizer. The oxidizer of choice is ammonium perchlorate.

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 detonate violently when ignited.

Primary Explosives

Lead azide
Lead styphnate
Mercury fulminate
Tetrazene
Diazodinitrophenol

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.

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

Booster Explosives

RDX
Tetryl
PETN

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

Bursting Explosives

TNT
RDX compositions
HMX
Explosive D

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,[41] such as 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 Characteristics and Location of MEC

This section describes the sources of safety hazards posed by explosives and munitions.

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.

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

Ammunition Classification

Ammunition is typically classified in accordance with the following five factors:

- **Type:** see following text box
- **Use:** service, practice, inert
- **Filler:** explosive, chemical, leaflet, or inert
- **Storage:** amount of explosives (quantity-distance classes)
- **Compatibility:** for storage purposes

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.

Ammunition Types

Ammunition is classified according to the following types:

(1) **Small arms ammunition.** Small arms ammunition (less that 20mm) consists of cartridges used in rifles, carbines, revolvers, pistols, submachine guns, and machine guns and shells used in shotguns. They do not contain explosives; therefore, they present minimal explosive risks (propellant or tracer only) but do contain lead projectiles and may cause lead contamination.
(2) **Grenades.** Grenades are explosive- or chemical-filled projectiles of a size and shape convenient for throwing by hand or projecting from a rifle. These munitions are designed to land on the ground surface and therefore are more accessible. Fragmentation grenades, most commonly used, break into small, lethal, high-velocity fragments and pose the most hazards.
(3) **Artillery ammunition.** Artillery ammunition consists of cartridges or shells that are filled with high-explosive, chemical, or other active agents; and projectiles that are used in guns, howitzers, mortars, and recoilless rifles. They are typically deployed from the ground, but may also be placed on aircraft and generally used in the indirect fire mode. Fuze types include proximity, impact, or time-delay, depending on the mission and the intended target. They may also contain submunitions that are sensitive to any movement.
(4) **Bombs.** Bombs are containers filled with explosive, chemical, or other active agents, designed for release from aircraft. Bombs penetrate the ground to depths than other munitions due to the size and weight of the munition. They may also contain submunitions that are very sensitive to movement.
(5) **Pyrotechnics.** Pyrotechnics consist of containers filled with low-explosive composition, designed for release from aircraft or for projection from the ground for illumination or signals (colored smokes).
(6) **Rockets.** Rockets are propellant-type motors fitted with rocket heads containing high-explosive or chemical agents. The residual propellant may burn violently if subjected to sharp impact, heat, flame, or sparks.
(7) **Jet Assisted Take-Off System (JATOS).** JATOS consists of propellant-type motors used to furnish auxiliary thrust in the launching of aircraft, rockets, guided missiles, target drones, and mine-clearing detonating cables.
(8) **Land mines.** Land mines are metal or plastic containers that contain high-explosive or chemical agents designed for laying in (normally within the first 12 inches or the topsoil) or on the ground for initiation by, and effect against, enemy vehicles or personnel.
(9) **Guided missiles.** Guided missiles consist of propellant-type motors fitted with warheads containing high-explosive or other active agent and equipped with electronic guidance devices.

Ammunition Types (continued)

(10) **Demolition materials.** Demolition materials consist of explosives and explosive devices designed for use in demolition and in connection with blasting for military construction.
(11) **Cartridge-actuated devices (CAD).** Cartridge-actuated devices are devices designed to facilitate an emergency escape from high-speed aircraft.

Adapted from:

JCS PUB 1-02. DoD Dictionary of Military and Associated Terms. March 23, 1994.
AR 310-25. Dictionary of United States Army Terms. May 21, 1996.
TM 9-1300-200. Ammunition, General.
FM 21-16. Unexploded Ordnance (UXO) Procedures. August 30, 1994.

3.2.2 Areas Where MEC is Found

Areas that are most likely to contain MEC 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 MEC 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 MEC 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 munitions technologies, thus increasing the variety of MEC items that may be present at any individual site. Changes in training needs also contribute to the presence of different MEC types found at former military facilities.

The types of munitions constituents potentially present on ranges varies, de-pending 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 munitions 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.

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.

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[42] and up to 94 percent of contaminated water samples collected.[43]

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 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 also were used in World War II.

3.2.3 Release Mechanisms for MEC

The primary mechanisms for the occurrence and/or release of MEC at MRS are based on the type of MEC activity or are the result of improper functioning (e.g., detonation) of the MEC. For example, when a bomb or artillery projectile 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 "release" of both munitions debris (e.g., fragments) and small quantities of munitions constituents (e.g., energetic compounds such as TNT and RDX, lead and other heavy metals) into the environment. Release also may occur during open detonation of munitions during range-clearing operations.
- It will undergo an incomplete detonation, also called a "low order" detonation. This causes a release of not only munitions debris and larger amounts of munitions 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 munitions constituents are less likely; or the UXO may be damaged or in an environment that subjects it to corrosion, thus releasing munitions constituents over time.

Sampling of Detonation Residues

Analysis of soil samples for explosive residues in areas of high-order and low-order detonation reveals that significantly higher quantities of residue are present at low-order detonation sites. The levels of munitions constituents released from high-order detonations are so low as to be measured in micrograms.

Source: Sampling for Explosives Residues at Fort Greely, Alaska, Reconnaissance Site Visit July 2000, ERDC/CRREL TR-01-015, November 2001.

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

The fate and transport of some munitions constituents in the environment have not yet

[42]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.

[43]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.

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 munitions 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.[44] 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 improperly 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 munition and its components (primarily the fuze and fuze type) to detonation, and (2) the environmental and human factors that affect the deterioration of the MEC or the depth at which MEC 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 munitions constituents
- The likelihood that the munition will be in a location where disturbance is possible or probable

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[44] *Military Explosives*, 1955.

[45] Ibid.

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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 Probability of Detonation as a Function of Fuze Characteristics

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 MEC found on ranges should be assumed to be armed and prepared to detonate and should be approached with extreme caution (see Chapter 6, "Explosives Safety").

The type of fuze and its condition (armed or unarmed) directly determine its sensitivity. **It should always be assumed that a fuzed piece of ordnance is armed**. 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.

- **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, especially if the movement generates a static electric charge.
- **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 of a mechanical time super-quick fuze is shown in Figure 3-4.
- **Powder train time fuzes** use a black powder train to function at a predetermined time after firing.
- **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 a sophisticated sensor to signal the proximity to the target 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

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

be permitted in these types of environments. EM sources also include certain geophysical instruments, such as the EM-61 (see discussion of EM-61 and related geophysical sensors in Chapter 4). Proximity fuzes sometimes are backed up with an impact fuze designed to function on target impact if the proximity mode fails to function.

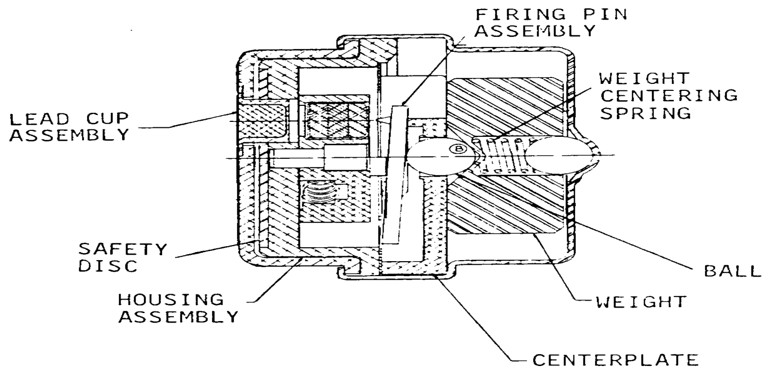

Figure 3-3. Mechanical All-Way-Acting Fuze

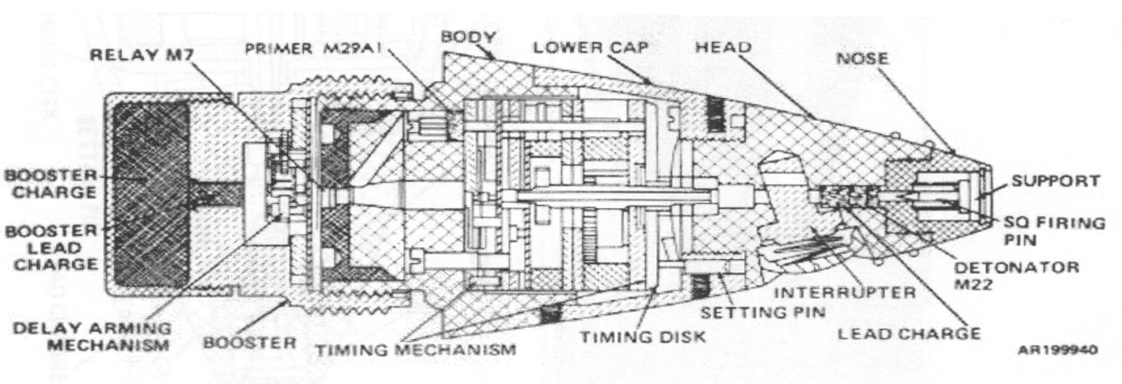

Figure 3-4. Mechanical Time Super-Quick Fuze

Arming of Fuzes

The material that follows is designed to provide an example of how fuzes are armed. This example relates to one specific type of weapons system.

Rocket fuzes are classified according to location in the warhead as point detonating (PD), base detonating (BD), or point initiating, base detonating (PIBD). They are further classified according to method of functioning as time, proximity, or impact.

a. Time fuzes function a preselected number of seconds after the round is fired. Impact fuzes function upon impact with super-quick, delay, or nondelay action.

(1) In the case of super-quick action, the warhead functions almost instantaneously on impact, initiated by a firing pin driven into a detonator.

(2) In delay action fuzes, the warhead functions a fixed time after impact to permit penetration of the target before the warhead explodes. The amount of delay, usually between 0.025 and 0.15 second, depends on the delay element incorporated in the fuze. Arming may be accomplished by mechanical means utilizing gear trains, air stream (air arming), spring action, centrifugal force or inertia, gas pressure (pressure arming), or a combination thereof.

(3) Nondelay action, somewhat slower than super-quick, occurs in delay-action fuzes when the black powder normally contained in the delay element has been removed.

b. The proximity fuze detonates the warhead at a distance from the target to produce optimum blast effect. It is essentially a radio transmitting and receiving unit and requires no prior setting or adjustment. Upon firing, after the minimum arming time, the fuze arms and continually emits radio waves. As the rocket approaches the target, the waves are reflected back to the fuze. The reflected waves are then received by the fuze with a predetermined intensity, as on approaching close to the target, this operates an electronic switch in the fuze. This permits electric current to flow through an electric squib, initiating the explosive train and detonating the rocket.

c. The PIBD fuze detonates the rocket on impact with the target. The fuze consists of a nose assembly and a base assembly connected by a wire passing through a conduit in the rocket head. Pressure of impact on a piezoelectric crystal in the nose assembly generates a surge of electricity. This is transmitted to a low-energy detonator in the base assembly, detonating it. Some PIBD fuzes have a graze-sensitive element which will actuate the fuze if impact does not initiate the piezoelectric crystal.

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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

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

Standards, are based on research and accident data on the size of areas affected by different types of explosions and their potential human health and environmental impacts (see Chapter 6 for a discussion of quantity-distance standards). State and local authorities may have additional 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 MEC hazards in the field may result in more than one type of explosive output.

Blast pressure (overpressure) 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 MRSs than at active ranges or industrial facilities where munitions are found. When a munitions 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 low explosives or pyrotechnic 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 Exposure to MEC

Because exposure to MEC is a key element of explosive risk, any action that makes MEC 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 MEC:

- Flooding and erosion
- Frost heaving

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

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

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

3.3.4 <u>Depth of MEC</u>

The depth at which MEC is located is a primary determinant of both potential human exposure and the cost of investigation and response. In addition, the DoD Ammunition and Safety Standards require that an estimate of expected depth of MEC be included in the site-specific analysis for determining response depth.[48] A wide variety of factors may affect the depth at which MEC is found, including penetration depth — a function of munition size, shape, propellant charge used, soil characteristics, and other factors — as well as movement of MEC 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*, paper presented at UXO Forum 1999, May 1999.

A unique challenge in any investigation of MEC 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 munitions constituents.

Buried munitions may detonate from friction, impact, pressure, heat, or flames of a nearby munitions 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.

3.3.5 Environmental Factors Affecting Decomposition of MEC

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

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

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

The probability of corrosion of an intact MEC item is highly site specific. MEC can resist corrosion under certain conditions. There are sites dating back to World War I in Europe that contain subsurface MEC that remains intact and does not appear to be releasing any munitions constituents. However, there are certain environments, such as MEC exposed to seawater, that can cause the MEC[51] to degrade. In addition, as MEC 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 deterioration depends on the integrity and thickness of the MEC casing, as well as the environmental conditions in which the MEC item is located and the degree of damage to the 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 munitions 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 MEC casing corrosion include but are not limited to the following:

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

Study of Corrosion Rates in Soils

The potential extent of corrosion of the metal casing of intact UXO remains an area of scientific uncertainty. Conditions that facilitate or retard corrosion are clearly site-specific. The Army Environmental Center is undertaking a study of metallic corrosion rates as a function of soil and climatic conditions to create a predictive database of such information.

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

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

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

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 UXO casing corrosion. The electrochemical or "redox" potential is the ability of the soil to reduce or oxidize UXO casings (the oxidation-reduction potential). Aerated soils have the necessary oxygen to oxidize metals.

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 UXO container and leaching of munitions constituents into the environment, residual propellants ending up in soils, and OB/OD, which may disperse chunks of bulk explosives and munitions constituents. 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 or more of secondary explosives or mixtures of secondary explosives to be reactive or ignitable soil.[52] Therefore, 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.[53] The soil analysis can be qualitative, that is, based on visual observations, as soils contaminated in the percent range are easy to spot; or analysis can be quantitative, using a field analysis kit such as those described in Chapter 8. Under no circumstances should soil visibly contaminated with munitions constituents be sampled or shipped offsite to a laboratory as it may create a hazard for the sampling crew members and the laboratory.

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

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

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

The human health and environmental risks of other munitions constituents from MEC 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 munitions constituents, humans may potentially face long-term health problems, including cancer. Similarly, exposure of ecosystems may cause disturbance of habitat and development of health and behavioral problems in the exposed receptors. The adverse effects of munitions 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 munitions 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.

3.4.1 Human Health Effects

Table 3-3 lists common munitions constituents and their uses. Many compounds have multiple uses, such as white phosphorus, which is both a bursting smoke and incendiary and can function as a pyrotechnic. The list of classifications in Table 3-3 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.

Table 3-3. Primary Uses of Explosive Materials

Compound	Propellant	Primary or Initiator	Booster	Burster Charge	Pyrotechnics	Incendiary
TNT				C		
RDX			C	C		
HMX			C	C		

Table 3-3. Primary Uses of Explosive Materials (continued)

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

* Classified as a bursting smoke and incendiary.

Table 3-4 illustrates the chemical compounds used in munitions and their potential human health effects as provided by EPA's Integrated Risk Information System (IRIS), the 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. Potential Toxic Effects of Explosive Chemicals and Components on Human Receptors

Contaminant	Chemical Composition	Potential Toxicity/Effects
TNT	2,4,6-Trinitrotoluene $C_7H_5N_3O_6$	Possible human carcinogen, targets liver, skin irritations, cataracts.
RDX	Hexahydro-1,3,5-trinitro-1,3,5-triazine $C_3H_6N_6O_6$	Possible human carcinogen, prostate problems, nervous system problems, nausea, vomiting. Laboratory exposure to animals indicates potential organ damage.
HMX	Octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine $C_4H_8N_8O_8$	Animal studies suggest potential liver and central nervous system damage.
PETN	Pentaerythritol tetranitrate $C_5H_8N_4O_{12}$	Irritation to eyes and skin; inhalation causes headaches, weakness, and drop in blood pressure.
Tetryl	2,4,6-Trinitrophenyl-N-methylnitramine $C_7H_5N_5O_8$	Coughing, fatigue, headaches, eye irritation, lack of appetite, nosebleeds, nausea, and vomiting. The carcinogenicity of tetryl in humans and animals has not been studied.
Picric acid	2,4,6-Trinitrophenol $C_6H_4N_3O_7$	Headache, vertigo, blood cell damage, gastroenteritis, acute hepatitis, nausea, vomiting, diarrhea, abdominal pain, skin eruptions, and serious dysfunction of the central nervous system.
Explosive D	Ammonium picrate $C_6H_6N_4O_7$	Moderately irritating to the skin, eyes, and mucous membranes; can produce nausea, vomiting, diarrhea, skin staining, dermatitis, coma, and seizures.
Tetrazene	$C_2H_6N_{10}$	Associated with occupational asthma; irritant and convulsants, hepatotoxin, eye irritation and damage, cardiac depression and low blood pressure, bronchial mucous membrane destruction and pulmonary edema; death.
DEGDN	Diethylene glycol dinitrate $(C_2H_4NO_3)_2O$	Targets the kidneys; nausea, dizziness, and pain in the kidney area. Causes acute renal failure.
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.
2,6-Dinitrotoluene	$C_7H_7N_2O_4$	Exposure can cause methemoglobinemia, anemia, leukopenia, and liver necrosis.
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 3-4. Potential Toxic Effects of Explosive Chemicals and Compounds on Human Receptors (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	$PbC_6HN_3O_8 \cdot CH_2O$	Widespread organ and systemic effects including central nervous system, immune system, and kidneys. Muscle and joint pains, weakness, risk of high blood pressure, poor appetite, colic, upset stomach, and nausea.
Mercury fulminate	$Hg(OCN)_2$	Inadequate evidence in humans for carcinogenicity; causes conjunctival irritation and itching; mercury poisoning including chills, swelling of hands, feet, cheeks, and nose followed by loss of hair and ulceration; severe abdominal cramps, bloody diarrhea, corrosive ulceration, bleeding, and necrosis of the gastrointestinal tract; shock and circulatory collapse, and renal failure.
White phosphorus	P_4	Reproductive effects. Liver, heart, or kidney damage; death; skin burns, irritation of throat and lungs, vomiting, stomach cramps, drowsiness.
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.

3.4.2 Ecological Effects

As with human health effects, ecological effects from chemical compounds associated with munitions usage depend on a combination of factors: the toxicity of the compound itself, the pathway by which the compound gets to a receptor, the concentration to which a receptor is exposed, and the reaction of the particular receptor to the compound. Site-specific assessment of the potential for an ecological impact is necessary to understand the manner in which a particular ecosystem (e.g., a wetlands environment) makes munitions constituents available to potential receptors. Ultimate receptors may include not only animal species, but also their habitat, including terrestrial and aquatic plant life. In some cases the habitat may act to biologically remediate concentrations that may otherwise seem harmful.

Guidance documents are available to assist in the conduct of ecological risk assessment. In addition, the *Wildlife Exposure Factors Handbook* developed by the EPA provides data, references, and guidance for conducting exposure assessments for 35 common wildlife species potentially exposed to toxic chemicals in their environment.[54] A variety of exposure factors (e.g., feeding habits, body weight) are examined and organized to allow the calculation of the potential for exposure.

Research on ecological effects of munitions constituents has been varied and fragmented. Conservative screening levels of the most common munitions constituents have been developed based on literature searches of toxic effects on a variety of species. The general approach is to compile a number of studies on similar categories of species and extrapolate conservative screening estimates based on the results of this compiled research. Little of this data is generated from real-world environmental observations, and instead is often derived from laboratory studies evaluated as part of human health toxicity assessments. Toxicity data on amphibians and reptiles are in general less developed than those for birds and mammals.

Screening Benchmarks

As used in this discussion, *screening benchmarks* are very conservative levels of a chemical that can produce adverse effects in selected species. Practically speaking, these levels are extrapolated and applied to related species to provide conservative levels that, if exceeded, should trigger a site-specific ecological risk assessment. Exceedence of a screening level benchmark need not mean that the potential ecological threat is real, as a variety of site-specific and species-specific factors must be considered.

Two recent efforts to derive screening-level benchmarks for ecotoxicity data are worth particular attention. Oak Ridge National Laboratory (ORNL), under a project sponsored by the U.S. Army and EPA, has developed ecotoxicity screening criteria and benchmarks using available data on eight nitroaromatic compounds, including TNT, RDX, HMX, picric acid, and tetryl.[55] In addition USCHPPM (U.S. Army Center for Health Promotion and Preventive Munitions) has developed Wildlife Toxicity Assessments (WTAs) for military compounds such as TNT, RDX, and HMX.

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[54] U.S. EPA. Office of Research and Development. *Wildlife Exposure Factors Handbook*, EPA/600/R-93/187, December 1993.

[55] S. Talmage, D. Opresko, C. Maxwell, C. Welsh, M. Cretella, P. Reno, and F. Daniel. *Nitroaromatic Munition Compounds: Environmental Effects and Screening Values*. Review of Environmental Contamination Toxicology 161:1-156, 1999.

Table 3-5 presents a compilation of potential adverse effects that these compounds may have on wildlife according to the sources described in the preceding paragraphs.

Table 3-5. Potential Effects of Explosive Chemicals and Compounds on Ecological Receptors

Contaminant	Potential Toxicity and Ecological Effects
TNT	TNT can be taken up by plants from contaminated soil, including edible varieties of garden plants, aquatic and wetland plants and tree species. Male animals treated with high doses of TNT have developed serious reproductive system effects; signs of acute toxicity to TNT include ataxia, tremors, and mild convulsions.[a] Screening benchmarks of toxicity for mammalian and bird wildlife species have been developed by ORNL[b] and CHPPM.[c]
RDX	ATSDR studies conclude that RDX does not build up in fish or in people.[a] Public health assessments conducted at the Iowa AAP concluded that crops are not bioaccumulating RDX and that they are safe for human consumption. In addition, studies at other Army facilities and laboratory studies suggest that deer and cattle do not bioaccumulate RDX in their tissue.[d] However, research does conclude that RDX is taken up by plants from contaminated soils and could be a potential exposure route for herbivorous wildlife. Screening benchmarks of toxicity for mammalian and bird wildlife species have been developed by ORNL and CHPPM. [b,c]
HMX	Research conducted by the ATSDR conclude that it is not known if plants, fish, or animals living in contaminated areas build up levels of HMX in their tissues. It is unknown whether or not HMX can cause cancer or reproductive problems in animals.[a] Screening benchmarks of toxicity for mammalian wildlife species have been developed by ORNL and CHPPM.[b,c]
PETN	Screening benchmarks of toxicity for mammalian wildlife species have been developed by CHPPM. Toxicological effects to laboratory animals studies used to develop TRVs included weight loss, blood pressure and respiratory problems.[c]
Tetryl	Adverse effects on plant and animal species have been identified for this contaminant. The ATSDR cites that it is not known if tetryl builds up in fish, plants, or land animals, nor if it causes birth defects or carcinogenicity in wildlife.[a] Screening benchmarks of toxicity for mammalian wildlife species have been developed by ORNL and are in preparation by CHPPM.[b]
Picric acid	Adverse effects on plant and animal species have been identified for this contaminant. The ATSDR states that these compounds are not likely to build up in fish or people. Results of studies in laboratory rats and wildlife species, such as white footed mice show anemia effects on the blood, behavioral changes, and male reproductive system damage.[a] Screening benchmarks of toxicity for mammalian and bird wildlife species have been developed by ORNL and CHPPM. Data for toxicity to birds, amphibians or reptiles is unavailable.[c]
Explosive D	Unavailable
Tetrazene	Unavailable
DEGDN	Unavailable
2,4-Dinitrotoluene	According to the ATSDR profile, DNT can be transferred to plants by root uptake from contaminated water or soil. Animals exposed to high levels of DNT had lowered number of sperm and reduced fertility. Animals also showed a reduction in red blood cells, nervous system disorders, liver cancer and liver and kidney damage.[a] Screening benchmarks of toxicity for wildlife species are being prepared by CHPPM.
2,6-Dinitrotoluene	The ATSDR profile states that 2,6-DNT has the same effect as 2,4-DNT on biota.[a] Screening benchmarks of toxicity for wildlife species are in preparation by CHPPM.
Diphenylamine	Unavailable

Table 3-5. Potential Effects of Explosive Chemicals and Compounds on Ecological Receptors (continued)

Contaminant	Potential Toxicity and Ecological Effects
N-Nitrosodiphenylamine	According to the ATSDR aquatic organisms take some n-nitrosodiphenylamine into their bodies, but they don't appear to build up high levels. It is not known if land animals or plants take it up and store it in their bodies. Animal studies have identified levels and exposures that can cause death. Animals given high levels of n-nitrosodiphenylamine in their diets for long periods of time developed swelling, cancer of the bladder, and changes in body weight.[a]
Phthalates	Unavailable
Ammonium nitrate	Unavailable
Nitroglycerine (Glycerol trinitrate)	Screening benchmarks of toxicity for mammalian and bird wildlife species have been developed by CHPPM. Mammalian effects included cardiovascular malfunction, decreased weight, and liver, blood, and reproductive problems.[c]
Lead azide	Unavailable
Lead styphnate	Unavailable
Mercury fulminate	Unavailable
White phosphorus	CRREL studies have shown that particles of white phosphorus that entered the bottom sediments of shallow ponds as a result of military training with white-phosphorus are highly toxic and contributed to the death of thousands of waterfowl at Eagle River Flats, Fort Richardson, AK.[a,e,f]
Perchlorates	Unavailable
Hydrazine	The ATSDR profile states hydrazines may build up in some fish living in contaminated water, but are not expected to remain at high levels over long periods of time. Tumors have been seen in many organs (lungs, blood vessels, and colon) of animals that were exposed to hydrazines by ingestion or breathing.[a]
Nitroguanidine	Unavailable

Notes:

[a]Data were taken from the toxicological profiles of these compounds prepared by the Agency for Toxic Substances and Disease Registry (ATSDR), Atlanta, GA: U.S. Department of Health and Human Services, Public Health Service, between 1993 and 1998.

[b]S. Talmage, D. Opresko, C. Maxwell, C. Welsh, M. Cretella, P. Reno, and F. Daniel. *Nitroaromatic Munition Compounds: Environmental Effects and Screening Values*. Prepared for Oak Ridge National Laboratory, Life Sciences Division, and the EPA National Exposure Research Laboratory, and published in Rev Environ Contam Toxicol 161:1-156, 1999.

[c]Data were taken from wildlife toxicity assessments performed for the U.S. Army Center for Health Promotion and Preventive Medicine (USACHPPM), Aberdeen Proving Ground, MD, 2001-2002.

[d]W.M. Weber and G. Campbell. Public Health Assessment, Iowa Army Ammunitions Plant, Middletown, Iowa. Federal Facilities Assessment Branch Division of Health Assessment and Consultation, CERCLIS No. IA7213820445, 1999.

[e]Data on white phosphorus were taken from C.H. Racine, M.E. Walsh, C.M. Collins, S. Taylor, B.D. Roebuck, and L. Reitsma. *Waterfowl Mortality in Eagle River Flats, Alaska: The Role of Munitions Residue*, and *White Phosphorus Contamination of Salt Marsh Pond Sediments at Eagle River Flats, Alaska*. USACE, Cold Regions Research and Engineering Laboratory (CRREL), Hanover, NH, May 1992.

[f]C.H. Racine, M.E. Walsh, C.M. Collins, S. Taylor, and B.D. Roebuck. *White Phosphorus Contamination of Salt Marsh Pond Sediments at Eagle River Flats, Alaska*. USACE, CRREL, Hanover, NH, May 1992.

3.4.3 Human and Ecological Effects from Exposure to Specific Compounds

This section further discusses known effects of specific compounds on human and ecological receptors.

White Phosphorus

One of the most frequently used bursting smoke fillers (also classified as an incendiary) is white phosphorus.[56] 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. White phosphorus has been found in fish caught in contaminated water and in game birds from contaminated areas.[57] Research conducted by CRREL has shown that an unusually high mortality of migratory waterfowl, particularly dabbling species such as ducks and swans, is attributable to the ingestion of elemental white phosphorus particles in the salt marsh sediments at Eagle River Flats, Alaska. Between 1982 and 1988, field and air surveys of the area were conducted. Nearly1,000 dead waterfowl were counted. The highest species-specific numbers included over 200 Northern pintail and over 150 Mallard ducks. Because of its use as an artillery training impact area (with nearly 7,000 rounds of white phosphorus fired in 1989), munitions contamination was suspected as the cause. Tissue studies of gizzard contents, fat tissue, liver, and kidneys found white phosphorus content in all field-collected ducks and swans analyzed. Behavior of exposed birds prior to death included increased thirst, head rolling, and violent convulsions.[58,59]

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.

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[56]Joint Technical Bulletin, Department of Defense Ammunition and Explosive Classification Procedures, 5 January 1998, (TB 700–2/NAVSEAINST 8020.8B/TO 11A-1-47/DLAR 8220.1

[57]ATSDR. Toxicological Profile for White Phosphorous. Atlanta, GA: U.S. Department of Health and Human Services, Public Health Service, 1997.

[58]C.H. Racine, M.E. Walsh, C.M. Collins, S. Taylor, B.D. Roebuck, and L. Reitsma. *Waterfowl Mortality in Eagle River Flats, Alaska: The Role of Munitions Residue*. Hanover, NH: USACE, Cold Regions Research and Engineering Lab, May 1992.

[59]C.H. Racine, M.E. Walsh, C.M. Collins, S. Taylor, and B.D. Roebuck. *White Phosphorus Contamination of Salt Marsh Pond Sediments at Eagle River Flats, Alaska*. Hanover, NH: USACE, CRREL, May 1992.

Toxicological Profiles of RDX and TNT

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.[60]

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.[61]

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.

Research has concluded that RDX, TNT, and other nitroaromatic compounds can be accumulated by plants from contaminated soils and could be a potential exposure route for herbivorous wildlife. Plant studies conducted using TNT-contaminated soil taken from ammunition sites found a direct correlation between concentrations in soil and plants. Large-scale uptake of TNT was found to take place in plants, including edible varieties such as lettuce, beans, and carrots. Studies suggest that because of the prevalence of TNT-contaminated sites, risk assessors should consider the hazard posed to organisms higher in the food chain, including humans and wildlife, which could also be affected by exposure. In addition, seed germination and growth studies conducted on terrestrial higher plants found varied thresholds for phytotoxicity. Some plants (e.g., oat plants) have shown such high tolerances for TNT that they have been considered potential bioremediation species.[62]

Research Demolition Explosive (RDX)

RDX, also known as Research Demolition Explosive, is another frequently found synthetic explosive chemical. RDX dissolves in and evaporates from water very slowly. RDX does not bind

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[60]*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.

[61]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.

[62]K. Schneider, J. Oltmanns, T. Radenberg, T. Schneider, and D. Pauly-mundegar. *Uptake of Nitroaromatic Compounds in Plants: Implications for Risk Assessment of Ammunition Sites*. Environmental Science and Pollution Research International 3(3)135-138, 1996.

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 Munitions Constituents

Contamination of soils and groundwater with explosive compounds results from a variety of activities. These activities include the release of other munitions constituents during planned munitions training and testing, munitions disposal/burial pits associated with military ranges, and munition storage sites and build-up locations. Contamination may also result from the deterioration of intact munitions, the open burning and open detonation of munitions, and the land disposal of explosives-contaminated process water from explosives manufacturing or demilitarization plants. Munitions 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 munitions. The sections below describe specific sources of munitions constituents.

3.5.1 Open Burning/Open Detonation (OB/OD)

Concentrations of munitions 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. 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

> **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.

Explosives manufacturing and demilitarization plants are also sources of munitions constituents. These facilities are usually commercial sites that are not usually co-located with defense sites. Many of these facilities have contaminated soils and ground-water. 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 munitions constituents behind after infiltration and evaporation.

Red water, the effluent from TNT manufacturing, was a major source of munitions 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 up to 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 munitions 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 MEC, including buried munitions, UXO, and munitions 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 MEC deterioration, and the likelihood that the item will be disturbed, which depends on environmental and human activities.

MEC items may also present other human health, ecological and environmental risks, depending on the state of the item. Specifically, a MEC item that is degraded may release propellants, explosives, pyrotechnics, and other munitions 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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Information Sources

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

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/

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 MEC 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, MEC detection technologies are used to locate anomalies that are subsequently verified as UXO or non-UXO. Given the high cost of MEC excavation (due to both range size and safety considerations), the challenge of most MEC 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 MEC. Much of the improvement is the result of greater understanding of operational requirements for the use of detection technologies. However, the primary challenge in MEC detection today is the achievement of high levels of subsurface detection of actual MEC 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 MEC 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 indications where nothing is found that caused the instrument to detect an anomaly at that location. 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 MEC-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 MEC 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 MEC 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. Current improvements in detection systems generally focus on discriminating 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 MEC. 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. In the program, vendors of geophysical systems were invited to test and compare the efficiency and reliability of the systems. It is important to note that the test did not look at the process by which the system was deployed and was not structured to determine why certain approaches worked better than others. In subsequent phases of the JPGTD program, vendors improved the processes by which sensors were deployed, and significantly improved their detection rates. The JPGTD and 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 Geophysical Sensors in Use Today

Magnetometry and electromagnetic induction are the most frequently used sensors for detecting MEC. 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 MEC. 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. 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 of pulses. When

EMI and Electronic Fuzes

EMI is an active system for which there has been concern about increasing the risk of initiating MEC with electronic fuzing. However, there is no evidence that the current generation of EMI-based systems, when used in accordance with the manufacturer specifications (e.g., EM-61), generate enough power to cause this effect. This may be an issue to watch in the future, however, if more powerful systems are developed.

TDEM detectors are hand-held or smaller they may have less penetration depth than the more commonly used large-coil EMI.

Frequency-domain electromagnetic (FDEM) instruments operate by transmitting continuous electronic signals 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 MEC items that are buried just beneath the ground surface, such as metal firing pins in plastic land mines. FDEM instruments are currently not typically used when detecting individual, deeply buried munitions, because of the sensor's decreased resolution and the difficulty of 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 measure the relative intensity of the gradient in the Earth's magnetic field. These systems are inexpensive, reliable, and rugged and have low energy consumption.

4.2.1.3 *Multisensor Systems*

Multisensor systems combine two or more sensor technologies in order to improve UXO detection performance. The technologies that have proved to be most effective in multisensor systems are arrays of full-field cesium vapor magnetometers and time-domain EMI pulsed sensors. Multisensor systems can enhance detector performance by providing complementary data sets that can be used to confirm the presence of MEC.

Multisensor systems are available both as man-portable configurations and as linear arrays on platforms that do not themselves produce a significant geophysical signature while they tow the array over survey sites by all-terrain vehicles.

4.2.1.4 *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 to1,000 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 two-or three-dimensional images of the subsurface or to estimate 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. Because the GPR system uses active electromagnetic waves to locate buried objects, there is concern that electronic fuzes on MEC items could be initiated by these systems. As with EMI, there is no evidence that deployment of GPR has initiated electronic fuzes during MEC investigations.

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, the following:

- Site size
- Soil type, vegetation, and terrain
- Subsurface lithology
- Depth, size, shape, composition, and type of MEC
- Geological and cultural noise (e.g., ferrous rocks and soils, electromagnetic fields from power lines)
- Non-MEC clutter on-site
- Historical land use
- Reasonably anticipated future land use
- MEC 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 MEC 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	Projectile and fuze composition may dictate sensor selection. Magnetometers detect only ferrous materials, while EMI systems detect all metals.
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 MEC 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 munitions buried deep beneath the surface may remain detectable from large distances, whereas smaller items may be more easily missed by the sensor at a distance.

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

System Element	Factors To Be Considered
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.
Positioning system	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.
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.

Table 4-2. System Element Influences on Detection System Performance (continued)

System Element	Factors To Be Considered
Operator capability	The selection and use of detection systems is complex and requires individuals with appropriate qualifications and experience. Qualification of the geophysical team to meet prove-out performance is a recommended QA/QC measure.
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.
Data acquisition	Digital versus analog data, reliability of data points, and ability to merge geophysical signals with a positioning system (e.g., GPS) data affect potential for human error.
Data analysis	Experienced and qualified analysts and appropriate procedures help to ensure reliability of results.

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. Airborne systems can be very useful in detecting larger objects such as those that may be found in a bombing range. They 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. 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.

4.2.3.1 *Positioning Systems*

Positioning systems are used to determine and record where a geophysical sensor is in relation to known points, such as how it is oriented and the pathway of its travel as it is collecting data. Knowing the location of the sensor will allow the geophysical analyst to estimate the location of subsurface anomalies that may be MEC. The accuracy of the positioning system will directly affect the ability of field teams to successfully relocate and excavate subsurface anomalies. The performance of the positioning system used on your project should be assessed at the same time that the performance of the geophysical sensor is assessed.

All positioning systems rely on determining the location of the geophysical sensor in relation to a known point or points. They also all provide a method for correlating the positional data with the geophysical sensor data. Commonly used positioning systems are shown in the table below.

Table 4-3. Description of Positioning Systems

Positioning System	Description
Differential Global Positioning System (DGPS)	C Triangulates the position of the Differential global positioning system receiver with respect to several satellites and terrestrial base stations C Can yield accuracy on the order of 20 cm. C Differential global positioning system signal can be blocked by heavy overhead tree canopy; satellite availability will also strongly influence accuracy. C Differential global positioning system receiver must be in close proximity to the geophysical sensor; with man-portable sensor configurations, the extra weight of the Differential global positioning system receiver and recorder (usually over 50 pounds) can increase personnel requirements during the performance of the geophysical survey.
Acoustic Ranging and Total Station Electronic Distance Meter (EDM)	C Calculates the distance between the receiver and a known point based on return time for either an acoustic or optical (infrared, laser) signal. C Accuracy depends on atmospheric and other conditions that may distort acoustic or optical signal. C Methods require a line of sight between receiver and known points.
Digital Thread	C Hybrid technology uses odometer wheel turned by survey thread; optical switch embeds position mark every 4-6 cm. C Works well in rugged, forested terrain.
“Dead Reckoning” Techniques	C Extrapolates current position from a previously know point by applying information on direction, speed, and time traveled. Locations determined by measurements from known points using survey tapes and trigonometry. C Highly dependent on the competence of the operator. C Assumes geophysical sensor has traveled in a straight line from a known point to the point of measurement.

4.2.3.2 *Anomaly Identification*

The geophysical sensor and positional data collected during the survey are analyzed to identify geophysical "anomalies," that is, readings that are different from the surrounding background. There are two steps to the anomaly identification process; data processing and data analysis. The quality of the anomaly identification process is critical to the performance of the geophysical detection system.

In general, data processing consists of the merging of the geophysical sensor and the positional data, and the creation of a map of the geophysical data. The output from this step should include the aforementioned map showing the locations of the sensor readings, a text narrative or a table describing the data acquisition parameters (e.g., sensor and positioning devices used, adjacent lane overlap for grids), and a narrative describing the data processing details (e.g., method used to synchronize geophysical and positional data, any signal filtering or background leveling applied). Digital outputs should include all raw data, field acquisition and data processing notes, and the merged database.

The primary objective of the data analysis step is to determine if a given geophysical anomaly meets the minimum threshold selection criteria of subsurface munitions. The determination of these selection criteria will be based on the geophysical sensor, the survey pattern, and the type of munitions under investigation, as well as the geological conditions and the analyst's experience. The output from this step should include a clear description of the selection criteria and the rationale for that criteria, a prioritized dig list with a unique identifier for each anomaly, the spatial location (the *x* and *y* coordinates) of each anomaly, and the metric attributes of each anomaly (e.g., the magnitude of the reading above background).

4.2.4 Costs of UXO Detection Systems

The factors influencing the costs of deploying MEC 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 response
- 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 for rework, or for lack of acceptance of cleanup decisions, is considered.

4.2.5 Quality Assurance/Quality Control

As discussed in Chapter 8, a comprehensive quality assurance/quality control (QA/QC) process that addresses every aspect of the selection and use of geophysical detection equipment, as well as evaluation of findings, is absolutely essential. 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. General practices that help to ensure quality include monitoring the functionality of all instruments on a daily basis, ensuring that the full site was surveyed and ensuring that there are no data gaps. Finally, qualification of geophysical operators is critical to ensuring that those operating the equipment can repeat the anticipated performance of the detection system. Chapter 8 describes qualification of geophysical operators in more detail.

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 systems in research and development at 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.[63] Processing approaches to fully exploit the additional data measured by the EM-63 are currently being researched.

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

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 detection platforms have been tested at the Badlands Bombing Range, near Interior, South Dakota. Tests suggest that this platform can be very cost-effective in large expanses of flat, open, and treeless ranges found in the arid and semi-arid climate of the western United States, where aircraft are able to fly close to the ground. Other types of sites where speculation suggests airborne platforms may be appropriate include areas where access is made difficult, such as marshes, swamps, wetlands, and shallow water.

Airborne Magnetometry — Low-altitude airborne magnetometry has proved promising in tests on the Cuny Table at the Badlands Bombing Range, near Interior, South Dakota. Because of the conditions at Badlands Bombing Range, 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 the concentrations of munitions for further investigation by ground-based sensors. However, performance in initial tests of commercial, off-the-shelf 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 at certain ranges, 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.[64]

Airborne MTADS — A second major type of airborne detection is the Airborne MTADS, an adapted version of the vehicular MTADS magnetometry technology for deployment on an airborne platform. The array consists of seven full-field cesium vapor magnetometers (a variant of the Geometrics 822 sensor designated as Model 822A) mounted on a model 206L Bell range helicopter. All sensors are interfaced to a data acquisition computer.

The intent of the adaptation was to provide a MEC site characterization capability for extended, large areas that are inappropriate for vehicular surveys. Because the sensors are deployed further from the ground surface than the vehicular systems, it was understood that some detection sensitivity would be lost. The primary goal of the development was to retain as much detection sensitivity as possible for individual MEC targets. The second primary objective was that the final system must have a production rate and costs appropriate for deployment to explore very large sites that would be prohibitively expensive to survey by other techniques.

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

Defense Science Board Recommendations, December 2003

In December 2003 the DoD Defense Science Board released the report of its Task Force on Unexploded Ordnance (UXO). One recommendation was for a national assessment of 10 million acres of former ranges contaminated with UXO. The purpose of the assessment to reduce the footprint of the 10 million acres for which the presence of UXO is uncertain to as few as 2 million acres where cleanup should be focused. The assessment would use of low-flying airborne platforms for sensors in appropriate circumstances.

"The Task force sees this approach as most useful for initial, large scale, wide area assessments of UXO sites to determine in a quick survey fashion where there are metallic objects in the ground and where there are not. We do not see it as the final instrument in the UXO detection discrimination process."

Although the recommendation is an interesting idea, the reader should keep in mind the following :

- The effective use of any detection system to reduce the footprint of the range is limited by our knowledge of what was done at the site, and what we are looking for. In other words, a good conceptual site model is essential.
- Effective use of airborne systems platforms currently occurs under specific conditions:
  - The airborne system is able to be deployed fairly close to the ground (e.g., relatively flat terrains).
  - Such platforms are most useful for detecting larger munitions items.
  - With current technologies false alarms are likely to continue to be a problem.

Demonstrations of airborne MTADS at Badlands Bombing Range, near Interior, South Dakota, indicate that the system generates high production rates while maintaining reasonable costs when characterizing very large, open areas. Production rates of 300-400 acres/day were demonstrated with airborne MTADS as compared with 18-24 acres/day with vehicular MTADS. This indicates that the airborne MTADS, rates can be 15 times greater than the vehicular system's. It is expected that the cost per acre is three to five times less with airborne MTADS than with a vehicular array. These rates have yet to be tested. As expected, the demonstrations indicated that a major disadvantage associated with the use of airborne MTADS is the system's inability to detect small classes of UXO buried at significant depth. In addition, using airborne MTADS doesn't prove to be as cost-effective on smaller areas compared with vehicular MTADS because of the deployment costs associated with the airborne platform.[65]

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 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

[65]J.R. McDonald, D. Wright, N. Khadr, AETC Inc., and H.H. Nelson, Chemical Dynamics and Diagnostics Branch, Naval Research Laboratory. *Airborne MTADS Demonstration on the Impact Area of the Badlands Bombing Range*, September 2001.

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.[66]

4.4 Use of Processing and Modeling To Discriminate UXO

The development of advanced processing and modeling to reduce the false alarm rates, even as ordnance detection performance improves, 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. One example of a sensor data set is 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-MEC 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 signals, thereby reducing the false alarm rate.[67] These techniques are under development and are not yet available for use in the field.

[66]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.

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

AETC, Inc., and Geophex Ltd., under contract to SERDP, have developed a database of 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 was developed at frequencies between 30 Hz and 30 kHz. The 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.[68] In addition, software has been developed to analyze the data and identify a wide variety of anomalies.[69]

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. **SERDP** is DoD's **Strategic Environmental Research and Development Program**. Executed in partnership with both the Department of Energy and EPA, SERDP is designed 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.

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.[70] This data fusion method is primarily effective in the discrimination of large MEC items. However, the major contribution of this system and the AETC/Geophex system described above is anticipated to be their ability to differentiate MEC 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.

4.5 MEC 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.

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

[69]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.

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

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 munitions 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 next text box.

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)

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).

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 Gradiometer 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 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 Gradiometer, 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.

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.

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 MEC 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 following text box describes the four phases of the Fort Ord study.

Synopsis of Objectives and Results of the Former Fort Ord Ordnance Detection and Discrimination Study (ODDS), 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 ordnance 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 ordnance 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 ordnance 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 munitions response sites.
Results: The effects of rough terrain and vegetation on detection and discrimination capabilities can be significant. Removal of range residue before the munitions response investigation began would have reduced time and effort spent on unnecessary excavations.

Phase IV
Objective: Evaluate discrimination capabilities of ordnance 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 ordnance 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 MEC 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 the MEC expected and the site-specific environmental and 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 there. 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 MEC 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, site characterization, and appropriate quality control measures that should be taken throughout the investigation.

4.7 Conclusion

The performance of many existing and emerging technologies for MEC 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 MEC 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 MEC areas, such as at Fort Ord, provide additional information about the challenges and issues that have to be considered in selecting MEC detection systems. For example, the nature of the targets (e.g., composition, size, and mass), the depth of MEC 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 MEC detection is being able to discriminate MEC 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: MEC 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 MEC 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. C The **total-field magnetometer** is a device that measures the magnitude of the magnetic field without regard to the orientation of the field. C 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 MEC?	Magnetometers can theoretically detect every MEC target that contains ferrous material, from small, shallow-buried MEC to large, deep-buried MEC, 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: MEC DETECTION TECHNOLOGIES	# Magnetometry
What are the different types of magnetometers?	There are numerous types of magnetometers, which were developed to improve detection sensitivity. Three of the most common are the **cesium vapor**, **proton precession**, and **fluxgate** magnetometers. C **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. C **Proton precession magnetometers** – These magnetometers have been used in clearing Munitions Response Sites (MRS), but achieving the data density required for a MRS 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*. C **Fluxgate magnetometers –** These magnetometers are used primarily to sweep areas to be surveyed. They are also used in locating MEC 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: C **The detection sensor** C **A power supply** C **A computer data system** C **A means to record locations of detected anomalies** More technologically advanced systems typically incorporate a navigation system, such as a differential global positioning system (DGPS), to determine locations. Advanced navigation systems may also include a graphical output device (printer), a mass data storage recorder, and telecom systems.

FACT SHEET #1: MEC DETECTION TECHNOLOGIES

Magnetometry

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 MEC technicians, who slowly walk across a survey area and flag those areas where MEC 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.

What are the benefits of using magnetometry for detecting MEC?

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

- Magnetometry is considered one of the *most effective technologies* for detecting subsurface MEC and other ferromagnetic objects.
- Magnetometry is one of the *more developed technologies* for detection of MEC.
- 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*.

FACT SHEET #1: MEC DETECTION TECHNOLOGIES	# Magnetometry
What are the limitations of using magnetometry for detecting MEC?	The **limitations** of using magnetometry for MEC detection include the following: C 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 MEC debris. C Depending on the data analysis systems used, magnetometers may suffer from *high false alarm rates*, which lead to *expensive excavation efforts.* C 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. C 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 (MEC or not) may appear as localized deep targets. Accurately distinguishing between targets depends heavily on coordination between sensors, navigation, and processing.

FACT SHEET #2: MEC DETECTION TECHNOLOGIES	**Electromagnetic Induction (EMI)**
What is electromagnetic induction (EMI) and how is it used to detect MEC?	**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 MEC.* 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. C **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 MEC detection. In addition, the Geonics EM31 has been used for detecting boundaries of trenches that may be MEC disposal sites. C **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 MEC detection is the **Geonics EM-61**. Under ideal conditions, the **EM-61** 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 MEC?	The effectiveness of EMI systems in detecting MEC depends on many factors, including **distance between sensor and UXO, metallic content of MEC**, **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 MEC site characterization is from approximately 75 Hz (cycles per second) to approximately 1,000 kHz.

FACT SHEET #2: MEC DETECTION TECHNOLOGIES

Electromagnetic Induction (EMI)

What are the components of an EMI system?

The components of an EMI system include the following:

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

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

What are the operational platforms for an EMI system?

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

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

Figure 4-2. EM-61 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 MEC?

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 MEC 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: MEC DETECTION TECHNOLOGIES	**Electromagnetic Induction (EMI)**
What are the limitations of using EMI for detecting MEC?	The **limitations** of using EMI to detect MEC include the following: C 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 MEC, 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. C 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.) C *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 MEC?	Per acre costs for EMI vary depending on the operational platform, the terrain, and other factors.

FACT SHEET #3: MEC 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 MEC 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 masses of buried ordnance.
How is GPR used to detect MEC?	**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. C **Time-domain (pulsed)** sensors transmit a pulsed frequency. The transmitter uses a half-duty cycle, with the transmitter on and off for equal periods. C **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: MEC DETECTION TECHNOLOGIES

Ground Penetrating Radar (GPR)

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 MEC?

The **benefits** of using GPR to detect MEC 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 sparse 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 MEC?

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, MEC 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 Differential global positioning system 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.*

Case Study of a Detection System with Magnetometry

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 Differential global positioning system 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 projectiles.

In Montana accurate real-time Differential global positioning system 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.

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

GPR is not often used as a stand-alone MEC 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 MEC 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 3- to 5-nanosecond 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-to 5 - nanosecond, 100- to 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 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 projectiles, 105 mm artillery projectiles, 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 was 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 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

ESTCP (Environmental Security Technology Certification Program). ***Evaluation of Footprint Reduction Methodology at the Cuny Table in the former Badlands Bombing Range***(2000 ESTCP Project), January 2004.

USACE (U.S. Army Corps of Engineers), 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. ***Former Fort Ord Ordnance Detection and Discrimination Study (ODDS)***. Executive Summary, 2000. [Final Report, January 2002.]

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)***. Mar. 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)***. Apr. 1997.

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

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

U.S. DoD. ***Final Report of the Defense Science Board Task Force on Unexploded Ordnance***, December 2003.

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.ddesb.pentagon.mil

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

Munitions and Explosives of Concern, 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 MEC; however, contained detonation chambers require movement of the MEC to a secondary location for safe disposal. See the following text box for a discussion of MEC 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 MEC at MRSs is in-place open detonation, also known as blow-in-place. In BIP, the explosive materials in MEC are detonated so that they no longer pose explosive hazards. It is often the preferred choice for managing MEC because of overarching safety concerns if the items were to be moved. However, BIP 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 MEC.

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 MEC

There are three general techniques used to excavate subsurface MEC 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 MEC 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 MEC detection activities are usually performed when using these methods in order to confirm target removals and increase the probability of clearing all MEC in the area. Manual excavation methods are best suited for surface and near-surface MEC and are most effective when retrieving smaller items, such as small arms munitions, grenades, and small-caliber artillery projectiles. MEC 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 MEC items at greater subsurface depths should be reserved for mechanized retrieval methods, as the excavation involved is much more labor-intensive and hazardous.

Mechanized MEC retrieval methods involve the use of heavy construction equipment, such as excavators, bulldozers, and front-end loaders to remove overburden from the site. Excavation below the groundwater table might require pumping equipment. Mechanized methods are best suited for excavation efforts where large MEC 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. It is important to note that although mechanized methods can be used, the final excavation is always done using the EOD technician manual methods so that the condition of the ordnance item can be assessed (fuzed or not fuzed), so the item can be identified, and so it can be determined if it is safe to move the item.

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). Differential global positioning system 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 MEC 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 MEC: An Overview

In-place open detonation, or blow-in-place (BIP), is the most commonly used method to destroy MEC. 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 treatment of all MEC (see Chapter 2, "Regulatory Overview"). The particular requirements that will be either most applicable or most relevant and appropriate to MEC 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 MEC and munitions 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 for munitions responses. 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 should be considered in the evaluation of alternatives for the munitions response. 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 MRSs. Historically, used primarily for bulk explosives.
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. Residuals from donor charges may present a concern.
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 response 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 (munitions 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.

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

Explosive Problem	Treatment Options	Situations/Characteristics That Affect Treatment Suitability
Soil (munitions 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.
Soil/ Groundwater (Munitions 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 (Munitions 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 (Munitions 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 (Munitions 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 Safe Handling of MEC

The safety of handling MEC depends 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 open detonation (OD) using blow-in-place (BIP) methods. 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 technical experts. When required, DDESB-approved safety controls (e.g., sandbagging) can be used to provide additional protection to potential harmful effects of BIP. In cases in which experts determine that BIP poses an unacceptable risk to the public or critical assets (e.g., natural or cultural resources) and the risk to workers is acceptable, munitions items may be transported to another, single location for consolidated detonation. This location is one where the threats to the critical assets and the public can be minimized. Such transport must be done carefully under the supervision of experts, taking into account safety concerns. Movement with remote-control systems sometimes will be appropriate to minimize danger to personnel. Instead of detonating all MEC 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).

5.1.2 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, are not 100 percent effective, and can result in an accidental high-order detonation. RSPs are conducted by active duty military EOD experts and typically involve disarming MEC (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 MEC items and move them from the location at which they were found to a central area on-site for destruction.

5.2 Treatment of MEC

5.2.1 Open Detonation

In most situations, open detonation (OD) remains the safest and most frequently used method for treating UXO. 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 safety concerns and the regulatory restrictions on transporting even disarmed explosive materials. Blow-in-place detonation is accomplished by placing and detonating a donor explosive charge next to the munition which causes a sympathetic detonation of the munition to be disposed of. Blow-in-place can also be accomplished using laser-initiated techniques and is considered by explosives safety experts to be the safest, quickest, and most cost-effective remedy for destroying UXO.

When open detonation takes place in an area other than that where the UXO was found, it is called consolidated detonation. In these cases, experts have determined that the location of the UXO poses an unacceptable risk to the public or critical assets (e.g., a hospital, natural or cultural resources, historic buildings) if it is blown in place. If the risk to the workers is deemed acceptable and the items can be moved, the munitions will be relocated to a place on-site that has minimal or no risk to the public or critical assets. Typically, when consolidated detonations are used on a site, multiple munition items are consolidated into one "shot" to minimize the threat to the public of multiple detonations. The decision to move the UXO from the location in which it is found is made by the explosives safety officer and is based on an assessment that the risks to workers and others in moving this material is acceptable. Movement of the UXO is rarely considered safe, and the safety officer generally tries to minimize the distance moved.

Open Detonation and DMM

Discarded Military Munitions are frequently tracked in the same manner as UXO and blown in place. However, it may be less risky to move DMM elsewhere. If there is any doubt about whether a munitions item is DMM or UXO, it must be tracked as if it is UXO.

Increasing regulatory restrictions and public concern over its human health and environmental impacts may create significant barriers to conducting open detonation in both BIP and consolidation detonation 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 OD.[71] These limitations include the following:

- **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 OD operations.
- **Soil and groundwater contamination** — Soil and groundwater can become contaminated with byproducts of incomplete combustion and detonation as well as with residuals from donor charges.
- **Area of operation** — Large spaces are required for OD operations in order to maintain minimum distance requirements for safety purposes (see Chapter 6, "Explosives Safety").
- **Location** — Environmental conditions may constrain the use of OD. For example, in 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.

[71] 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.

- **Legal restrictions** — Legal actions and regulatory requirements, such as restrictions on RCRA Subpart X permits, emissions restrictions, and other restrictions placed on OD, may reduce the use of OD in the future. However, for munitions responses addressed under CERCLA, no permits are currently required.
- **Noise** — Extreme noise created by a detonation limits where and when OD can be performed.

The Debate Over OD

Because of the danger associated with moving MEC, 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 ranges, similar concerns have also been voiced at 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 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 response actions at a number of the OD areas, the cost of using OD when compared to a CDC may be even more.

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.

UXO Model Clearance Project

In 1996 the U.S. Navy conducted a UXO Model Clearance Project at Kaho`olawe Island, Hawaii, that demonstrated the effectiveness of using protective works to minimize the adverse effects of detonation in areas of known cultural and/or historical resources. The results of the demonstrations and practical applications revealed that if appropriate protective works are used, the adverse effects of the blast and fragments resulting from a high-order UXO detonation are not as detrimental as originally anticipated. Protective works are physical barriers designed to limit, control, or reduce adverse effects of blast and fragmentation generated during the high-order detonation of UXO. Protective works used at Kaho`olawe included: tire barricades, deflector shields, trenches/pits, directional detonations, fragmentation blankets, and plywood sheets.

Source: UXO Model Clearance Report, Kaho`olawe Island, Hawaii, Protective Works Demonstration Report. Prepared for U.S. Navy Pacific Division Naval Facilities, Engineering Command, Kapolei, Ha. Contract No. N62742-93-D-0610 1996.

In open detonation, an explosive charge is used to create a sympathetic detonation in the energetic materials and munitions to be destroyed. 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 MEC), well-engineered protective measures can reduce the effects and hazards associated with OD to levels comparable to contained detonation chambers (see Section 5.2.3.2).

5.2.2 <u>Open Burning</u>

Although open burning (OB) and open detonation (OD) are often discussed together, they are not often used at the same time. In fact, the use of open burning is limited today due to significant air emissions released during burning and strict environmental regulations that many times prohibit this. The environmental and technical challenges to using OB are the same as those listed in Section 5.2.1 for OD. When OB is used, it is usually applied to munitions areas for treatment of bulk explosives or excess propellant. OB operations have been implicated in the release of perchlorate into the environment, specifically groundwater.

5.2.3 <u>Alternative Treatment Technologies</u>

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.[72] 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.

5.2.3.1 *Incineration*

Incineration is primarily used to treat soils containing reactive and/or ignitable compounds. In addition, small quantities of MEC, bulk explosives, and debris containing reactive and/or ignitable material may be treated using incineration. Most MEC is not suitable for incineration. This technique may be used for small-caliber ammunition (less than 0.50 caliber), 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

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[72] 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.

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 response 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** — 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 to 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.[73]
- **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

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[73] 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.

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).[74] Specifically, reactive and/or ignitable soil was treated on-site at the former Nebraska Ordnance Plant site in Mead, Nebraska, using a rotary kiln followed by a secondary combustion chamber, successfully reducing constituents of concern that included TNT, RDX, TNB, DNT, DNB, HMX, tetryl, and NT to DRE of 99.99 percent.[75]

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.[76]

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).[77] At the former Nebraska Ordnance Plant site, the cost of on-site incineration was $394 per ton of contaminated material.[78] Two major types of incinerators used by the Army are discussed in Table 5-2. While incineration is used most often in industrial operations, it may be considered in the evaluation of alternatives for munitions responses 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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[74]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.

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

[76]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.

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

[78]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 EF Soils: 600-800 EF Secondary chamber – Gases: 1,400-1,800 EF	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 MEC, as well as contaminated soil and debris.
Deactivation Furnace	Designed to withstand small detonations from small arms. Operates in a manner similar to the rotary kiln except it does not have a secondary combustion chamber.	1,200-1,500 EF	Renders munitions unreactive.	Large quantities of small arms cartridges, 50-caliber machine gun ammunition, mines, and grenades.

Source: U.S. EPA, Office of Research and Development. *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.

5.2.3.2 *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 MEC. 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).[79]

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 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. Blending highly reactive material with clean soil is frequently used to ensure that the explosive content of the soil is below 10 percent. This is not considered treatment but rather is a preparation technique to allow the waste to be safely treated.

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

- **Easily implemented** — Bioremediation systems are simple to operate and can be implemented using commercially available equipment.
- **Relatively low costs** — In general, the total cost of bioremediation is significantly less than more technology-intensive treatment options.
- **Suitability for direct land application** — In general, soil treated using most bioremediation systems is suitable for land application.
- **Limited concentrations of reactive and/or ignitable materials and other contaminants** — Soil with very high levels of reactive and/or ignitable material may not

[79]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.

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.[80]

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

- Types of contaminants
- Soil type
- Climate and weather conditions
- Cost and time constraints
- Response 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 relies on natural attenuation processes (within the context of a carefully controlled and monitored site cleanup approach) to achieve site-specific remediation objectives within a timeframe that is reasonable compared to that offered by more active methods.[81]

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

[81]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.

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.

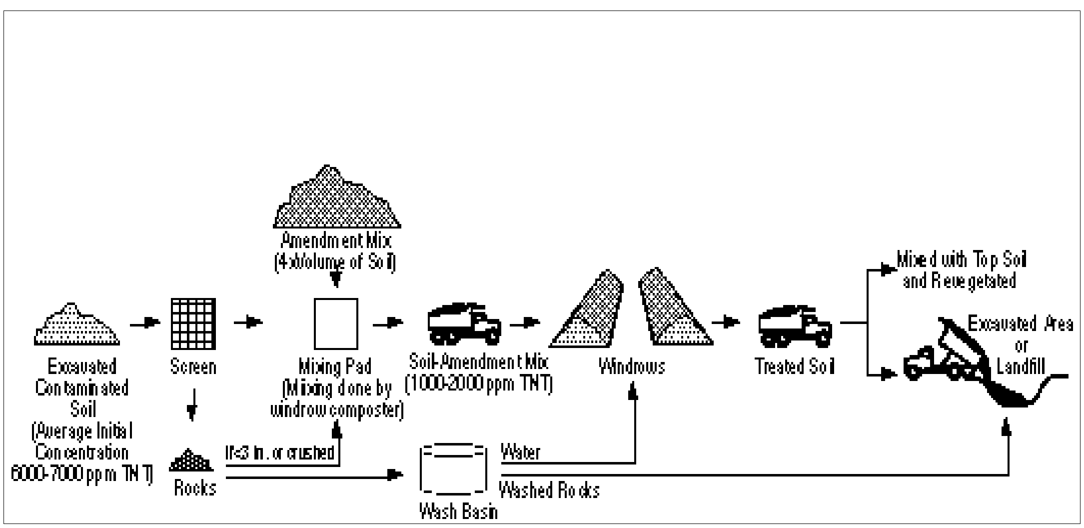

Figure 5-2. Typical Windrow Composting Process

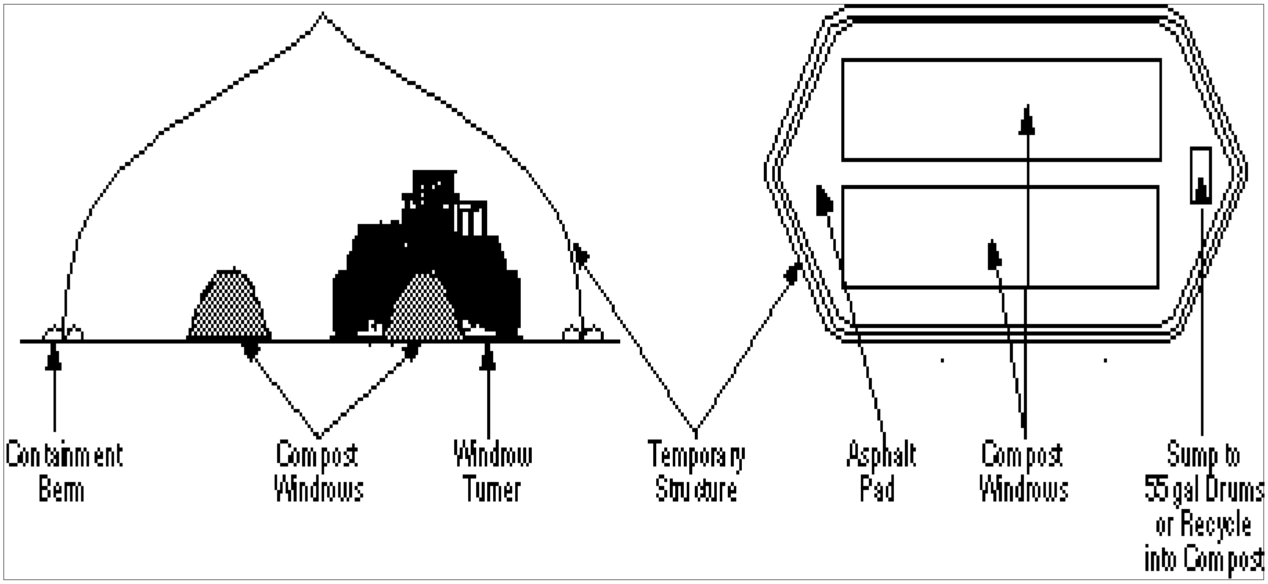

Figure 5-3. Side and Top View of Windrow Composting System

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

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

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

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.[83] Soil slurry biotreatment is expected to cost about one-third less than incineration.[84] 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.

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).

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

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

- 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 Soil Washing

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.[85]

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 to 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.[86]

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[85]Ibid.

[86]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.

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 EF) and residence times in LTTD typically volatilize low levels of reactive and/or ignitable materials and allow decontaminated soil to retain its physical properties.[87] 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).

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.[88] 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

Decontamination of equipment and scrap is essential in order to ensure that explosive residues no longer remain on the material. Attention to this process can significantly decrease safety hazards to workers and the public. Several instances of improperly treated range scrap sent to scrap yards for recycling have resulted in deaths in association with unplanned explosions. 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

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

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

reactive and/or ignitable compounds is volatilized or decomposed during the process when gas is heated to 600 EF 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.[89]

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 to 9. The cleaned material has no detectable level of reactive and/or ignitable contaminants following the procedure. This process is scalable to accommodate a variable throughput.[90,91,92] 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.[93]

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

[90]UXB International, Inc. *UXBase: Non-Thermal Destruction of Propellant and Explosive Residues on Ordnance and Explosive Scrap*, 2001.

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

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

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

5.6 Conclusion

The treatment of MEC 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 usually not found at MRS. However, with the appropriate site-specific conditions, alternative technologies may be considered for munitions responses.

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, Aug. 1998.

U.S. Department of Defense, Environmental Technology Transfer Committee. ***Remediation Technologies Screening Matrix***. 2d ed., Oct. 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, Sept. 1993.

U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response. ***Completed North American Innovative Remediation Technology Demonstration Projects***. NTIS No. PB96-153127; Aug. 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
4820 University Square
Huntsville, AL 35807-4301
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/

Guidance

U.S. EPA, Office of Solid Waste and Emergency Response. ***Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, Underground Storage Tank Sites***. Directive 9200.4-17P; Apr. 21, 1999.

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6.0 EXPLOSIVES SAFETY

Substantial safety issues are associated with investigation and munition response activities at sites that may contain MEC. 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 munitions response 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.

> **Revision of Safety Standards**
>
> The 6055.9-STD is currently under revision by the DDESB. The revised standards are posted on the DDESB website as soon as they are voted in by the board (www.ddesb.pentagon.mil). Revisions of the standard dated October 2004 have been published on the DDESB website, and its use is mandated by DDESB. Several important revisions, however, including changes to Chapter 12 and a chapter on UXO, have not yet been completed or posted. This chapter of the handbook will be revised when the revision of the standards are complete.

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 MEC 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 MEC 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 MEC 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 MEC 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.[94] 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 MEC 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 MEC. 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.[95,96] 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[97], plus an introduction. These chapters address the following:

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

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

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

[97] Chapter titles reflect changes in DoD's 6055.9-STD, rev. 5 dated June 2004.

- **Reaction effects —** as they relate to buildings, transportation, and personnel.
- **Hazard classification, storage principles, and compatibility groups** — to guide the kinds of explosives that may and may not be stored together.[98]
- **Personnel protection —** from blast, fragmentation, and thermal hazards.
- **Construction criteria permitting reduced separation distances —** 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 and emergency planning** — providing criteria to minimize risk in fighting fires involving ammunition and explosives.
- **Quantity-distance (Q-D) and siting** — minimum standards for separating a potential explosion site from an exposed site.
- **Contingencies, combat operations, military operations other than war (MOOTW) and associated training** — 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.
- **Toxic chemical munitions and agents** — 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."
- **Accident notification and reporting 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.

[98] 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 electro-magnetic 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

- 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 MEC 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:[99]

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

- 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. For FUDS, such transport, when it occurs, will be by UXO personnel in accordance with the work plan.[100]
- 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.[101]
- 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 response 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 munitions response actions, for storage magazines used to store demolition explosives and recovered MEC, 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.

[100]Written comment from U.S. Army.

[101]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 MRS.
- For all MRSs, a most probable munition (MPM) is determined on the basis of munitions items anticipated to be found at the site. The MPM is the 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 MEC 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 MEC 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 nearby 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 MEC 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 Personnel Protective Equipment (PPE)

As required by CERCLA, OSHA, and military component regulations, a PPE program should be in place for all munitions response actions. 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 Personnel Standards

Personnel standards are designed to ensure that the personnel working on or overseeing the site are appropriately trained. Typical requirements for personnel training 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.[102]

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 MEC hazards. Even at a site that is thought to be fully remediated, there is no way to know with certainty that every MEC item has been removed. Therefore, the public must be protected from MEC 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.

ESS approvals rely on the development of site-specific information to determine response depth requirements. The response depth selected for response actions is determined using site-specific information such as the following:

> **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.

- Geophysical characteristics such as bedrock depth and frost line (see Chapters 3 and 7 and text box on the next page).
- Estimated MEC depth based on surface detection and intrusive sampling.
- In the absence of sampling data, information about the maximum depth of ordnance used on-site based on maximum penetration source documents.
- Actual planned land use that may require deeper excavation than the default clearance depths (e.g., a commercial or industrial building with foundations deeper than 10 feet).
- Remediation 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 MEC. [103]

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

[103] Attachment 1 at the conclusion of this chapter contains a table that has historically been part of the DDESB standard in Chapter 12. This table provided assessment depths to be used for planning purposes when site-specific information is not available. It is provided to the reader for historical reference.

If MEC detection capabilities are not sensitive enough or funds are not available to remove MEC 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 MEC 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.)

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 MEC. Land use controls are necessary at many sites because of the technical limitations and prohibitive costs of adequately conducting munitions responses to allow for certain end uses, particularly unrestricted use (see text box).

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 DoD explosives safety standard specifically addresses a requirement for institutional controls when MEC 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."[104]

The appropriate land use control depends on site-specific factors such as proximity to populations, land use, risk of encountering MEC, 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

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

responsible agency to perform the following activities:[105]

- **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.

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 munitions response.
- DoD will conduct periodic reviews to ensure the long-term effectiveness of response actions, including land use controls.

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.

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. 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. SSHPs and other components of the work plan are used to incorporate the requirements of 6055.9-STD into investigation plans. They are not reviewed individually by DDESB.
- **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 Sections 6.3.2 and 6.3.3.

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

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

- **Explosive Safety Plans (ESPs)** describe safety considerations associated with anomaly disposal, treatment, and storage during investigations. DDESB approval of such plans is required when locations used for such activities are permanent (more than 12 months) or recurring.[106]

6.3.1 Site Safety and Health Plans

SSHPs fulfill detailed requirements for compliance with the occupational safety and health program requirements of CERCLA, OSHA, and the military components.[107,108,109] SSHPs are based on the premise of limiting the exposure to the minimum amount of MEC and to the fewest personnel for the shortest possible period of time. Prior to the initiation of on-site investigations, or any design, construction, or operation and maintenance activities, an SSHP must be prepared and submitted for review and acceptance for each site task and operation described in the work plan.[110] SSHPs are typically prepared by industrial hygiene personnel at the installation level.[111] 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 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 MEC 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.[112] 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

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[106]Department of Defense. *DoD Ammunition and Explosives Safety Standard*, Chapter 10, DoD 6055.9-STD, October 2004.

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

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

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

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

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

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

sampling techniques and instrumentation to be used;
- Site control measures to limit access; and
- Documented standard operating procedures for investigating or remediating MEC.

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 MRSs, 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 Munitions Response Actions

An Explosives Safety Submission (ESS) must be completed by those wishing to conduct an MEC 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 it is related to a FUDS project, a BRAC-related project involving property disposal, or a project at an active facility:

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.

- 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.

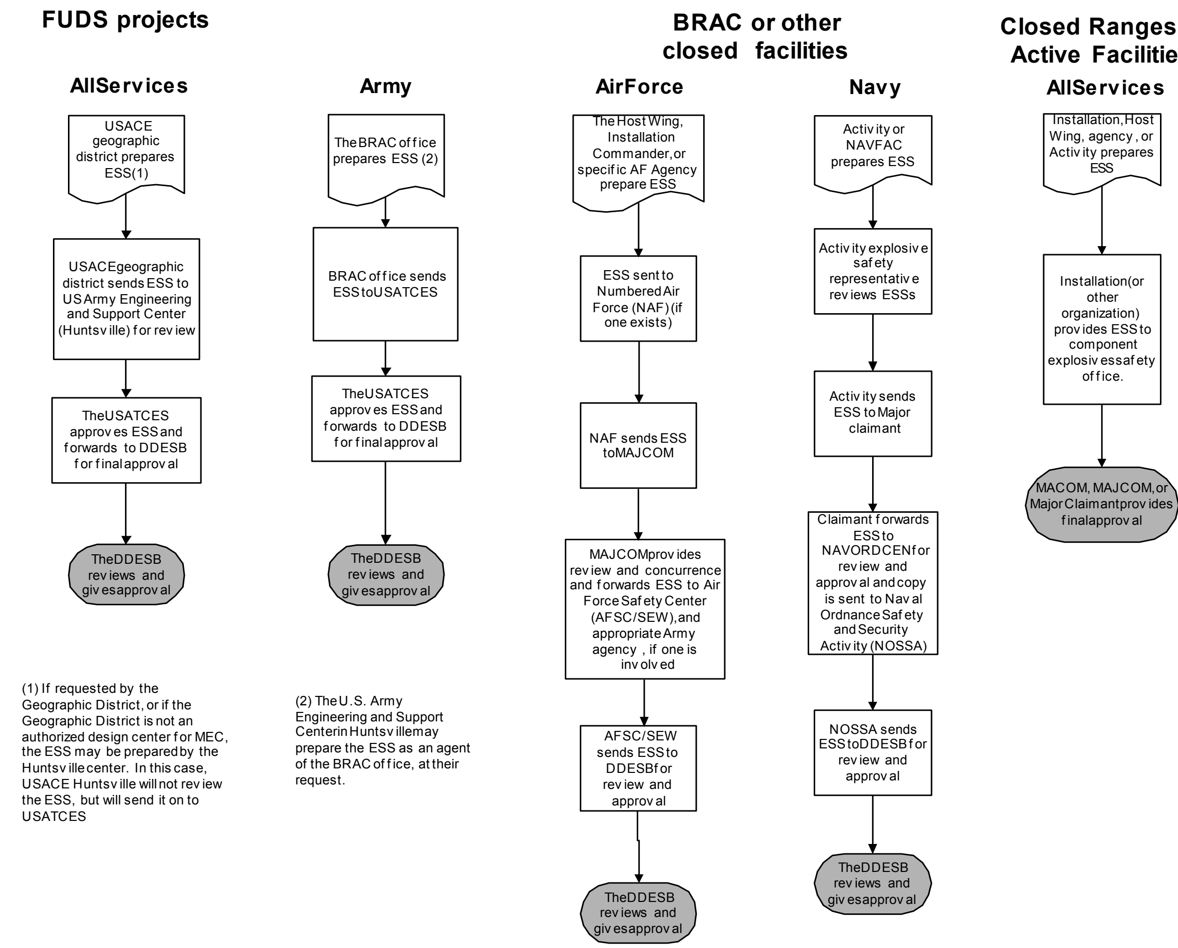
- For FUDS, the initial ESS is prepared by the USACE district with responsibility for the site.
- The DDESB reviews and gives approval to all ESSs at BRAC facilities and other closed facilities (i.e., a facility that has been closed by a component but is not part of the BRAC program).
- Final approval 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 in the selection of the response 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 MEC 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.



Sources: Personal communication with Clifford H. Doyle, Safety and Occupational Health Manager, USATACES, June 1, 2004
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 Munitions Response Actions

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.[113]

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

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 MEC presence
2. Maps (regional, site, quantity-distance, and soil sampling)
3. Amounts and types of MEC
4. Start date of removal action
5. Frost line depth and provisions for surveillance (if necessary)
6. Clearance techniques (to detect, recover, and destroy MEC)
7. Alternate techniques (to destroy MEC on-site if detonation is not used)
8. Q-D criteria (MRAs, 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
13. After-action report (list MEC found by type, location, and depth)
14. Amendments and corrections to submission

The ESS often includes information obtained in preliminary studies, historical research, previous MEC sampling reports, and SSHPs. Specific information required in the submission includes the following:

- Quantity-distance (Q-D) maps describing the location of MEC, storage magazines, and demolition areas
- Soil sampling maps for explosives-contaminated soils
- The amounts and types of MEC expected based on historical research and site sampling
- Planned techniques to detect, recover, and destroy MEC[114]

The amount and type of MEC expected in each MRS 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 MRS. 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 MEC 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.

6.3.4 Explosives Safety Plans

An Explosive Safety Plan (ESP) is another document through which the components and DDESB implement the 6055.9-STD at ammunition and explosive locations. Such plans are required to be prepared with regard to the siting of locations used for the treatment or disposal of MEC (e.g., open burn or open detonation), prior to disposal. These plans must be approved by DDESB when

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

they are either permanent locations (in use more than 12 months) or in recurrent use (periodic use, regardless of the duration of the operation). Plans for temporary operations or those for which advanced planning and approval is impracticable are approved by the applicable commander.[115]

General requirements for Explosive Safety Plans include, but are not limited to:

- Description of the use of the location;
- Maps;
- Quantity distance areas and all activities;
- Facilities and infrastructure potentially impacted by the location;
- Design procedures for engineering protections that DDESB has not already approved;
- Information on the type and arrangement of explosives operations or chemical processing equipment; and
- A topography map with contours.

When chemical agents are involved, a variety of specific information such as personnel protective clothing and equipment, wind direction and speed, warming and detection systems; and other requirements related to chemical safety.

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 MEC littered throughout the island. In such a situation, educating the public about hazards posed by MEC is a necessity in protecting the public. Also, at other, less contaminated sites where cleared areas are being opened to the public but where a small number of UXO items may remain, public education is also necessary in the event that someone encounters a previously undetected UXO item. A discussion of the highly successful public education program at NAS Adak is presented in the following text box.

[115]Department of Defense. *DoD Ammunition and Explosives Safety Standard*, DoD 6055.9-STD, rev. 5, June 2004.

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 MEC 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 MEC 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
  - MEC 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 are 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 MEC 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 MEC item poses the risk of injury or death to anyone in the vicinity. MEC can be found anywhere – on the ground surface, or partially or fully buried. MEC can be found in any state – fully intact or in parts or fragments. An encounter with MEC 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 MEC should be taught what to do and what not to do in the event of an encounter with MEC, 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 MEC, as described in the following text box.

Instructions for Responding to and Reporting MEC Hazards

1. After identifying the potential presence of MEC, 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 MEC 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 MEC.
3. Do not attempt to remove any object on, attached to, or near a MEC. Some fuzes are motion-sensitive, and the MEC may explode.
4. Do not move or disturb a MEC because the motion could activate the fuze, causing the MEC to explode.
5. If possible, mark the MEC hazard site with a standard MEC 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 MEC hazard.
6. Leave the MEC hazard area.
7. Report the MEC to the proper authorities.
8. Stay away from areas of known or suspected MEC. 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 MEC 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 MEC investigations and response actions, and ESSs for munitions removal actions. SSHPs require that protective measures be taken for MEC 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 MEC will help to prevent accidents and to give the public control over protecting themselves from explosive hazards.

ATTACHMENT 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 (1.22 m)
Limited Public Access – Livestock Grazing, Wildlife Preserve	1 ft (0.30 m)
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, June 2004, rev. 5.
The DDESB is in the process of revising Chapter 12 of DoD 6055.9-STD**.**

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. 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, Feb. 25, 2000.

U.S. Department of Defense and U.S. Environmental Protection Agency. ***Management Principles for Implementing Response Actions at Closed, Transferring, and Transferred (MRSs) Ranges***. Mar. 7, 2000.

Information Sources

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

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

Guidance Documents

U.S. Air Force. ***Civil Engineering – Disposal of Real Property***. AFI 32-9004; July 21, 1994.

U.S. Air Force. ***Explosive Ordnance Disposal***. AFI 32-3001; Oct. 1, 1999.

U.S. Air Force, ***Explosive Ordnance Disposal***. Directive AFPD 32-30, July 10, 1994.

U.S. Air Force. ***Inspection, Storage, and Maintenance of Non-Nuclear Munitions***. AFI 21-201; Dec. 1, 2000.

U.S. Air Force. ***Non-nuclear Munitions Safety Board***. AFI 91-205; July 1, 1998.

U.S. Air Force. ***Safety: Explosives Safety Standards***. Air Force Manual 91-201; Mar. 7, 2000.

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. ***Engineering and Design – Ordnance and Explosives Response***. Manual No. 1110-1-4009, June 23, 2000.

U.S. Army Corps of Engineers. ***Engineering and Design – Safety and Health Aspects of HTRW Remediation Technologies***. Engineer Manual (EM) 1110-1-4007; Sept. 30, 1999.

U.S. Army Corps of Engineers, ***Engineering and Design – Ordnance and Explosives Response***. Pamphlet No. 1110-1-18; Apr. 24, 2000.

U.S. Army Corps of Engineers. ***Safety and Occupational Health Requirements for Hazardous, Toxic, and Radioactive Waste (HTRW) Activities***. ER 385-1-92; Sept. 1, 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. 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); Sept. 15, 1995.

U.S. 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, AFI 32-3002; Feb. 14, 1992.

U.S. DoD. ***Defense Transportation Regulation Part II, Cargo Movement***. DoD 4500.9-R; May 2003. Website: http://www.transcom.mil/j5/pt/dtr.html.

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

U.S. DoD. ***DoD Ammunition and Explosives Safety Standards***. DoD 6055.9-STD, Rewrite 4.5; January 2004.

U.S. DoD. ***DoD Ammunition and Explosives Safety Standards***. DoD 6055.9-STD, October 2004.

U.S. DoD. ***DoD Contractors' Safety Requirements for Ammunition and Explosives***. Instruction 4125.26; Apr. 4, 1996 (updated Dec. 6, 1996).

U.S. DoD. ***DoD Explosives Safety Board (DDESB) and DoD Component Explosives Safety Responsibilities***. Directive 6055.9; July 29, 1996.

U.S. DoD. ***Environmental and Explosives Safety Management on Department of Defense Active and Inactive Ranges Within the United States***. Directive 4715.11; Aug. 17, 1999.

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

U.S. DoD Explosives Safety Board, DDESB-KO. ***Guidance for Clearance Plans***. Feb. 27, 1998.

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

U.S. Marine Corps. ***Ammunition and Explosives Safety Policies, Programs, Requirements, and Procedures for Class V Material***. Directive 8020.1; Oct. 18, 1995.

U.S. Marine Corps. ***Explosive Ordnance Disposal (EOD) Program***. Directive 3571.2F; Aug. 18, 1990.

U.S. Navy. ***Department of the Navy Explosives Safety Policy***. Instruction 8020.14; Oct. 1, 1999.

U.S. Navy. ***Procedures for Conducting Ammunition and Hazardous Materials (Amhaz) Handling Review Boards***. Instruction 8023.13F; Mar. 6, 1985.

U.S. Navy. ***Naval Responsibilities for Explosive Ordnance Disposal***. Instruction 8027.6E; June 1994.

U.S. Navy. ***Navy Munitions Disposition Policy***. Instruction 8026.2A; June 15, 2000.

U.S. Navy. ***Resource Conservation and Recovery Act (RCRA) Hazardous Waste Management Requirements to Conventional Explosive Ordnance Operations***. Navy Memorandum 93-20, Nov. 10, 1993.

U.S. Navy, ***U.S. Navy Explosives Safety Policies, Requirements, and Procedures, Explosives Safety Policy Manual***. OPNAV Instruction 8023.2C.; Jan. 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; Mar., 1999.

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7.0 PLANNING MUNITIONS RESPONSE INVESTIGATIONS

Characterizing MEC contamination is a challenging process that requires specialized investigative techniques. Unlike traditional hazardous waste contamination, MEC may not be distributed in a predictable manner; MEC 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 munitions response 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 planning a munitions response investigation using 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.

Chapter 8 continues the discussion of the planning process, focusing on considerations in the development of investigation and response strategies that will meet the goals and objectives for the site.

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).

Neither Chapter 7 nor Chapter 8 focuses on the investigation of munitions constituents except where there are issues unique to such constituents that should be addressed. Except for unique issues associated with munitions constituents 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 MEC, 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., munitions constituents in soil from partly exploded, i.e., low-order detonation, or corroded munitions items that are present in sufficient quantity and weight to pose explosive hazards)

7.1 Overview of Elements of Site Characterization

An effective strategy for site characterization uses a variety of tools and techniques to locate and excavate MEC 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 MEC, ordnance fragments, and non-MEC-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 MEC 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, vegetation, 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 a MRS 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 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

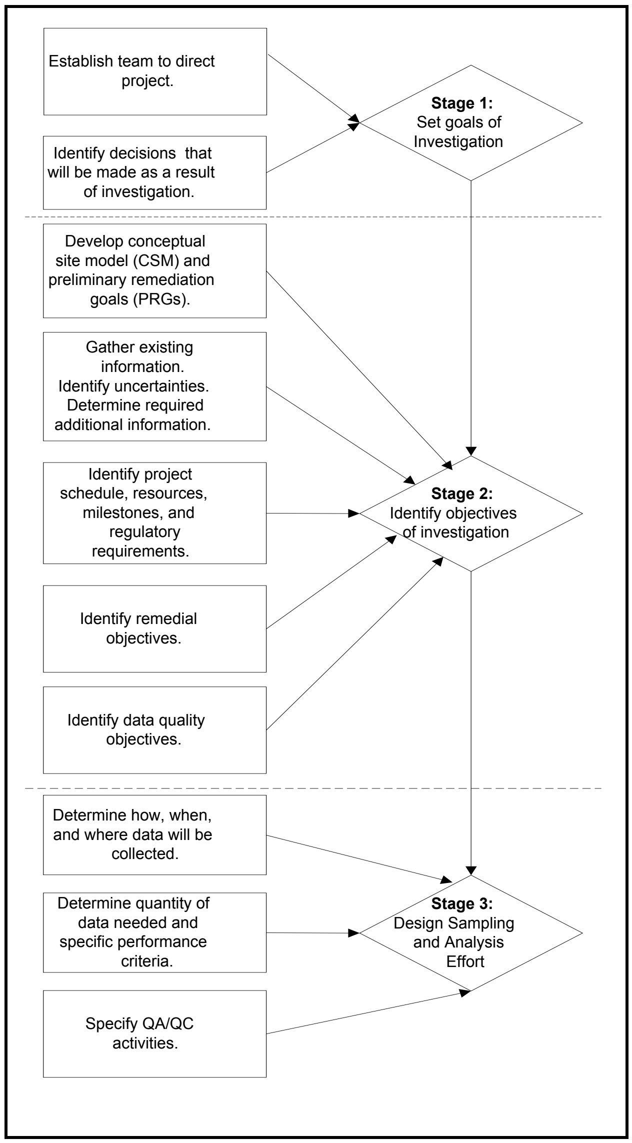

Figure 7-1. Systematic Planning Process

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 MEC 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 Establishing the Team

To be scientifically based, the investigation must be planned and managed by those people who will use the data to make decisions. This approach ensures that all of the data needed for decision making are acquired at an appropriate level of quality for the decision. The project team generally includes an experienced project manager, MEC 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.

It may also be important to include non-DoD landowners of munitions response areas (MRAs), and other stakeholders with contributions to make to the planning process. This inclusion can either be as a member of the team or through various public involvement mechanisms.

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 for munitions related activity in the past.
- Prioritize one or more MRS for response.
- Conduct a limited surface clearance effort to provide for immediate protection of nearby human activity.
- Identify if response action will be required on the MRS under investigation (to decide if there is a potential hazard, and to make an action/no-action decision).
- Identify the appropriate clearance depths and select appropriate removal technologies for the MRS 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 **MRAs** using a variety of factors, including, but not limited to, evidence of past ordnance use and safety factors, cost/prioritization issues, and characteristics of the areas to be investigated.

The individual munitions response 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 and analyzing the resulting data set to identify and locate geophysical anomalies that may be MEC. 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) and their locations on the site
- 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 MEC 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 munitions-related activities (e.g., munitions handling, weapons training, munitions 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 MEC 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 MEC
- Location of cultural or archeological resources
- The current, future, and surrounding land uses

7.4.2 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 MRS. 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 MEC on the site?
- At what depth is the MEC likely to be located?
- What are the environmental factors that affect both the location and potential corrosion of MEC?
- Is there explosive residue in the soil?
- Is there explosive residue in ordnance fragments?

7.4.2.1 *Historical Information on Range Use and Munition 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 MEC, the likely type of ordnance present at the MRA/MRS, 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.)

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, MEC 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 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 munitions items on the range, which could simplify MEC 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.

Historical information is also necessary for estimating the probable locations of MEC in the MRA 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 may 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 suspected amount of UXO at the MRS 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 MEC contamination, both to focus the investigation (and identify likely MRS) and to reduce the footprint of potential MEC contamination by eliminating clean areas from the investigation. Identifying areas of potential MEC 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 obvious, 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 munitions 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 MRS. In many cases ranges were closed shortly after World War II, thus giving ample time for forests and other vegetative regrowth to obscure pastures. Finally, 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 MEC, comprehensive and reliable historical information may make it possible to reduce the area to be investigated or to eliminate areas from munitions response 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 MRAs 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 MEC 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 MRSs on the site at the location.

7.4.2.2 ***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.
- Geological data that affect the movement (and therefore location) of UXO, the potential corrosion of MEC containers/casings, and the ability of detection equipment to locate UXO.

Information about geological conditions that will affect the movement, location, detection, and potential deterioration of ordnance and nonordnance explosives may be available on-site from previous environmental investigations (e.g., investigations conducted on behalf of the Installation Restoration Program). The significance of this information is discussed in more detail in Chapter 3.

A limited list of specific types of information that may be important (depending on the purpose of the investigation) is provided in Table 7-1. Some of the information may be so critical to the planning of the investigation that it should be obtained during the planning phase and prior to the more detailed investigation. Other information will be more challenging to gather, such as depth and flow direction of groundwater. If the necessary information is not available from previous investigations, it will likely be an important aspect of the MRA investigation.

Table 7-1. Potential Information for Munitions Response 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 MEC and difficulties associated with investigation.
Location of frost line	Location of MEC. Frost heave potential to move MEC from anticipated depth.
Soil type and moisture content	Penetration depth of MEC. Reliability of geophysical detection. Potential for deterioration/corrosion of casings. Potential for release of munitions constituents.
Depth and movement of groundwater	Potential for movement of MEC 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 MEC and for deterioration/corrosion of munition casings; potential leaching of munition residues; selection of detection methods.
Depth of sediments	MEC located in wetlands or under water. Location, leaching, and corrosion of MEC; 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.

7.4.3 Key Components of Munitions-Related CSMs

7.4.3.1 *Developing the CSM*

The ability to develop a good working hypothesis of the sources and potential releases associated with MEC will depend on your understanding the munitions-related activities that took place on the land area to be investigated, the primary sources of MEC contamination, the associated release mechanisms, and the expected MEC contamination. Tables 7-2 and 7-3 summarize these characteristics for typically expected ordnance-related activities. Table 7-4 describes the elements of the firing range that should be located on your CSM.

Table 7-2. Munitions-Related Activities and Associated Primary Sources and Release Mechanisms

Munitions-Related Activity	Primary Source	Release Mechanisms
Munitions 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
Munitions disposal	Open burn/open detonation areas	Kick-outs, low-order detonations
	Large-scale burials	Burial

Table 7-3. Release Mechanisms and Expected MEC Contamination

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

Table 7-4. Example of CSM Elements for Firing Range

Range Configuration	Description	MEC 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 munitions constituents that may be reactive or ignitable; munitions constituents
Firing points	The area from which the munitions were fired	Munitions 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 safety zone for munitions that do not hit targets	Same as target or impact area, but likely much lower density of UXO and, therefore, munitions constituents

The same process is used to develop the CSM for explosives and ordnance manufacturing areas. Tables 7-5 and Table 7-6 illustrate the types of munitions-related activities, sources and releases associated with explosives and ordnance manufacturing.

Table 7-5. Munitions-Related Activities and Associated Primary Sources and Release Mechanisms for Explosives and Munitions Manufacturing

Munitions-Related Activity	Primary Source	Release Mechanisms
Explosives manufacturing (e.g., TNT)	Manufacturing areas	Spillage, mishandling, routing of effluent
	Storage areas	Mishandling, abandonment, or loss
	Transfer areas	Mishandling, abandonment, or loss
	Burning and associated disposal areas	Incomplete burning and associated leaching
	Burial areas	Burial
Munitions manufacturing (load, assemble, and pack)	Loading areas	Spillage or mishandling
	Storage areas	Spillage, and mishandling, abandonment, or loss
	Test ranges	See Table 7-2
	Disposal areas	See Table 7-2

Table 7-6. Release Mechanisms and Expected MEC Contamination for Munitions Manufacturing

Primary Source	Release Mechanism	Expected MEC Contamination
Explosives manufacturing areas	Spillage, mishandling, or routing of effluent	Toluene, sulfuric acid, nitric acid, waste acids, nitroaromatic compounds
Explosives storage areas	Mishandling, abandonment, or loss	TNT, sulfuric acid, nitric acid, toluene, waste acids, yellow/red water, nitroaromatic compounds
Explosives transfer areas	Mishandling, abandonment, or loss	TNT, yellow/red water, nitroaromatic compounds
Explosives burning and associated disposal areas	Incomplete burning and associated leaching	Waste acids, TNT, nitroaromatic compounds
Explosives burial areas	Burial	Waste acids, nitroaromatic compounds
Munitions loading areas	Spillage, mishandling, abandonment, or loss	Explosives, propellants, pyrotechnics
Munitions storage areas	Spillage, mishandling, abandonment, or loss	Explosives, propellants, pyrotechnics
Munitions washout plants	Storing of treating water from demilitarization processes	TNT, pink water, any constituent or explosive train

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 projectiles in the buffer zone. Ranges used for different purposes have different firing patterns and different distributions of MEC. 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 MEC 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 MEC that should be addressed in a CSM include, but are not limited to:

- Munitions types
- Munitions 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
- Propellant type

7.4.3.2 *Groundtruthing the CSM*

No matter how extensive your historical research on past ordnance-related activities is, no CSM should be completed without groundtruthing your hypothesis. Groundtruthing should consist of on-site reconnaissance of the area to be investigated in order to provide the following:

- Forensic evidence of ordnance use, including depressions in the ground caused by the impact of an ordnance item and subsequent detonation, as well as fragmented remnants of ordnance
- Verification of geological features such as topography, water bodies, and outcroppings
- Identification of environmental factors that may be at work to move ordnance, including erosion, tidal action, and frost heave
- Identification of surface ordnance that may require clearance prior to beginning the investigation, as well as provide additional evidence about past ordnance use
- Identification of vegetative features that may interfere with the investigation
- Evidence of past ordnance use not identified in historical records
- Evidence of on-site receptor activity

One of the most important considerations in the design of a good sampling and analysis plan for locating UXO may be an operational analysis of the type of weapon system (e.g., mortar, artillery) used on the range. For example, Army field manuals provide information and 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 that UXO may be present.[116]

[116]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.

As with any site visit of a suspected MRA, a site reconnaissance should be conducted in accordance with DDESB safety requirements and in the company of a qualified UXO technician or EOD expert.

7.4.3.3 *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 MRAs 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.

Figures 7-2 and 7-3 illustrate the configuration of a typical firing range.

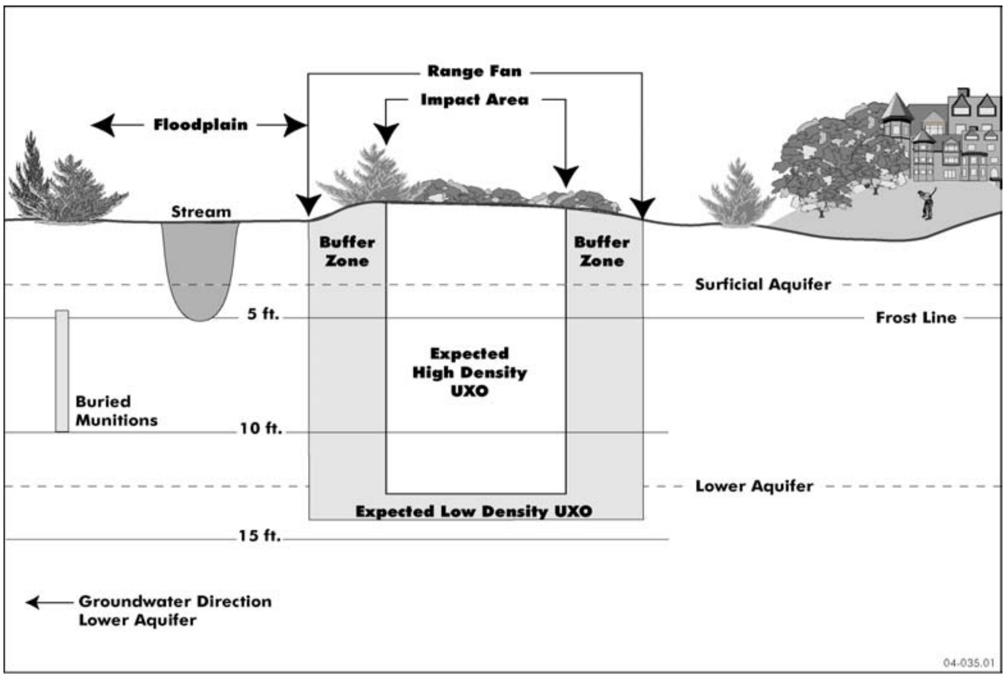

Figure 7-2. Conceptual Site Model: Vertical View

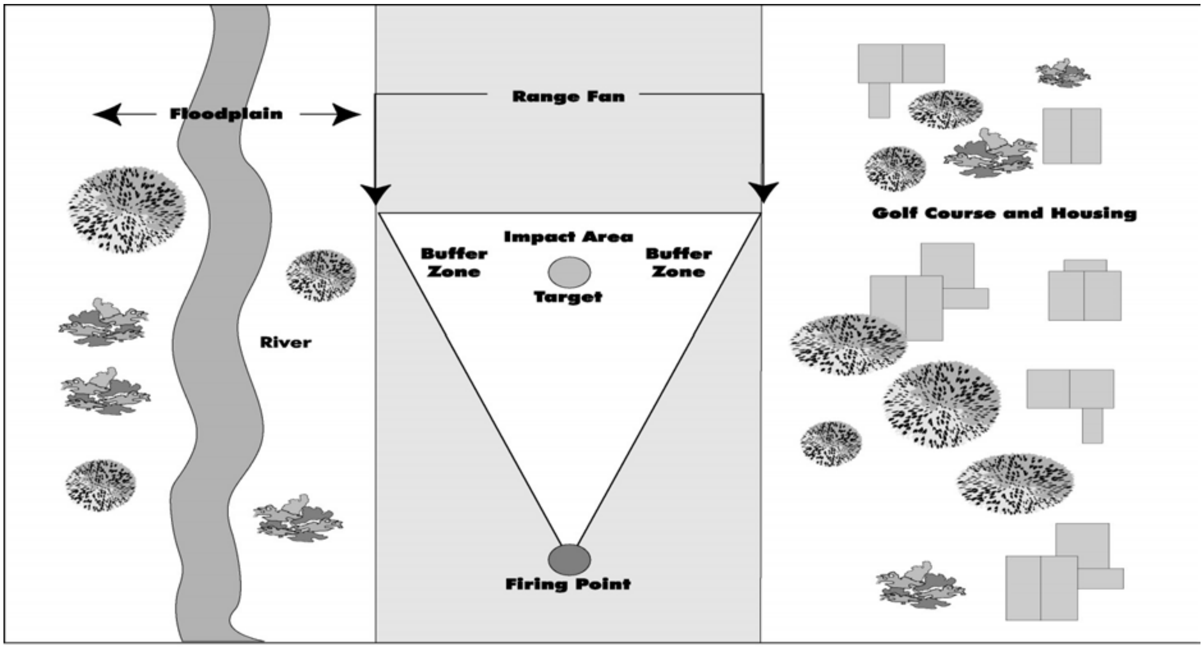

Figure 7-3. Conceptual Site Model: Plan View of a Range Investigation Area

A CSM for a closed munitions manufacturing area can be based on an operational analysis of historical operations and knowledge of site-specific information. The same concept should be applied when designing a sampling and analysis plan for the same area. The first step is to look at historical records and determine what operations were conducted there, what was manufactured, and where on the property the operations were located. Typically, explosives manufacturing areas manufactured TNT, RDX, and other explosives components. The chemicals of concern related to the manufacture of these products are TNT, toluene, nitric acid, sulfuric acid, and waste acids. For example, in a TNT manufacturing area, the CSM would focus the sampling and analysis for the COCs listed above on the operational areas in which these products are stored, transferred, handled, or disposed of, such as the following:

- Mono-, bi-, and tri-nitrating house
- Toluene and acid (sulfuric, nitric) storage areas
- Waste acid storage areas
- Finished product storage areas (e.g., bunkers or igloos for TNT)
- Burning grounds
- Yellow water and red water reservoirs
- Sewer lines and settling basins

Figure 7-4 shows what the plan view of a CSM would look like for a closed, World War II-era TNT manufacturing plant.

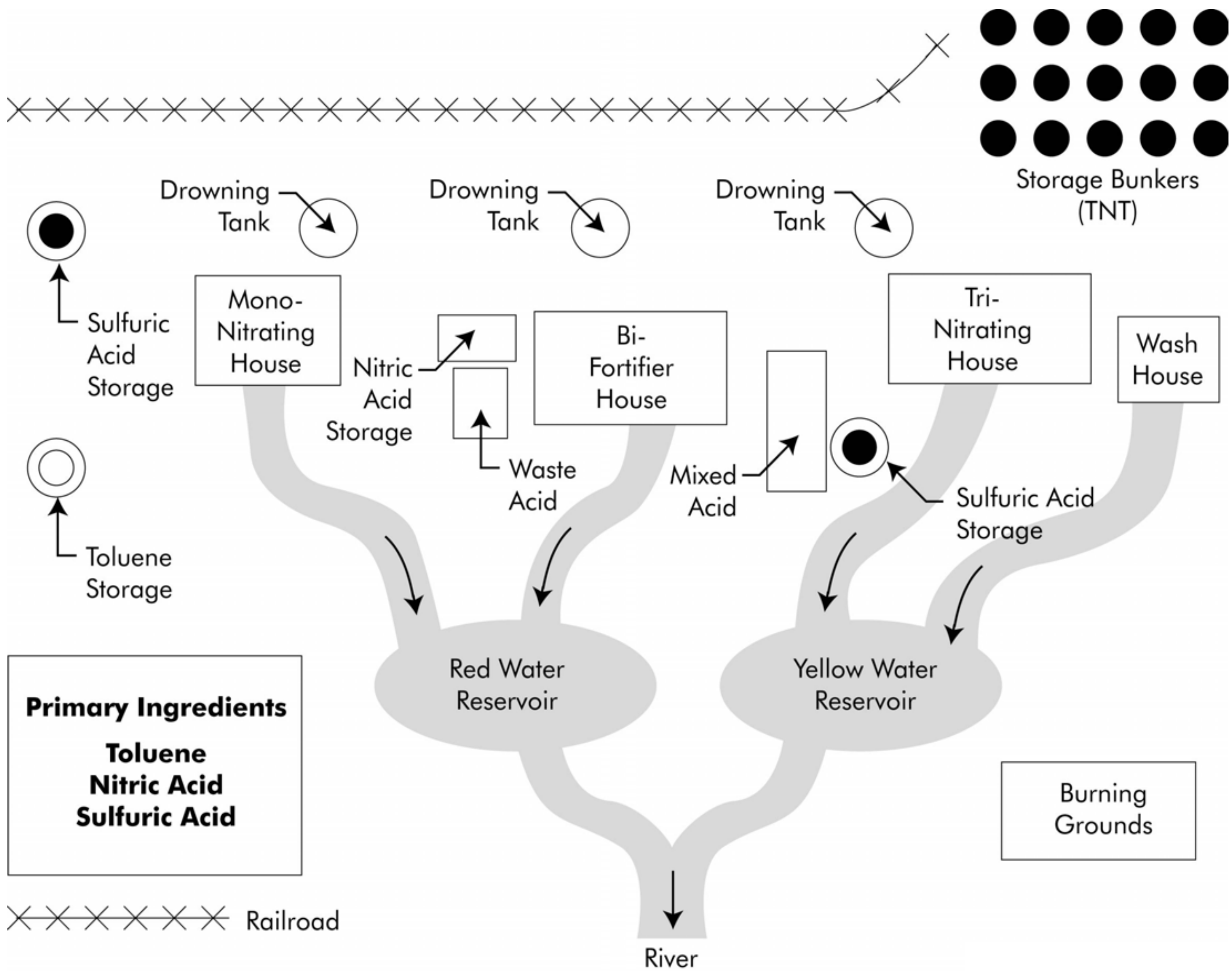

Figure 7-4. Conceptual Site Model: Plan View of a Closed TNT Manufacturing Plant

7.4.4 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 MEC 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, 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 MEC from the land area. Therefore, the PRGs will require that no MEC 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 MEC 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 MEC is present in the top 10 feet of the subsurface or above the frost line.

> **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.

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 the actual likely depth of the MEC, about environmental conditions that may cause movement of MEC, 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 munitions 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 MRSs 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

> **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.

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.[117] 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 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.[118]

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 MEC 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.[119] The text box below 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.

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

[118]Department of Defense. *Explosive Safety Submissions for Removal of Ordnance and Explosives (MEC) from Real Property*, Memorandum from DDESB Chairman, Col. W. Richard Wright, February 1998.

[119]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

7.4.5 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 MRA/MRSs)
- 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.")

7.4.5.1 *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 MEC
- Depth of MEC
- Anticipated sensitivity of MEC 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 to identify and classify anomalies. Data analysis can be conducted in real time during the investigation phase 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.

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 8.3.2.

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.

7.4.5.2 *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 pathways 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 munitions response 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 MEC 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.[120]

Important regulatory requirements that may affect both the investigation and the cleanup of the MRA 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.

7.4.6 <u>Identification of Remedial Objectives</u>

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 7.4.6). 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

[120] 40 CFR Section 300.400(g), National Oil and Hazardous Substances Pollution Contingency Plan.

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 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 MEC detection 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.

7.4.7 <u>The Data Quality Objectives of the Investigation</u>

7.4.7.1 *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 military range , are necessary to define the nature, quality, and quantity of information required to characterize each 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.

7.4.7.2 *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 MEC on an MRS. 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 MEC 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, and 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 related, 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. MEC 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 MEC 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, and 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 MEC 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.)

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. ***Standard Guide for Developing Conceptual Site Models for Contaminated Sites***. Guide E1689-95; 2001.

Interstate Technology and Regulatory Council, ***Technical/Regulatory Guidelines, Munitions Response Historical Records Review***, November 2003.

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/UXOCMEC**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.ddesb.pentagon.mil

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

Guidance Documents

U.S. Army Corps of Engineers. ***Conceptual Site Models for Ordnance and Explosives (MEC) and Hazardous, Toxic, and Radioactive Waste (HTRW) Projects***. Engineer Manual. EM 1110-1-1200, Feb. 3, 2003.

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

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

U.S. EPA (Environmental Protection Agency). ***Compliance with Other Laws (Vols 1 & 2)***. Aug. 8, 1988.

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

U.S. EPA. ***Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA***. Interim Final. NTIS No. PB89-184626; Oct. 1989.

Sources of Data for Historical Investigations

Air Photographics, Inc.
(aerial photographs)
Route 4, Box 500
Martinsburg, WV 25401
Tel: (800) 624-8993
Fax: (304) 267-0918
e-mail: info@airphotographics.com
http://www.airphotographics.com

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

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

National Exposure Research Laboratory
Environmental Photographic Interpretation Center (EPIC)
U.S. Environmental Protection Agency
Landscape Ecology Branch
12201 Sunrise Drive
555 National Center
Reston, VA 20192Tel: (703) 648-4288
Fax: (703) 648-4290
http://www.epa.gov/nerlesd1/land-sci/epic/aboutepic.htm

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.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/

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

U.S. 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

U.S. 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.7-28mil
http://www.dac.army.mil/esmam/default.htm

U.S. 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/

8.0 DEVISING INVESTIGATION AND RESPONSE STRATEGIES

The previous chapter provided a framework for organizing what is currently known about a site so that a project team can systematically identify the goals and objectives of an investigation. The focus of this chapter is to identify geophysical and munitions constituents sampling, analysis, and response strategies that will meet those goals and objectives.

The discussion that follows outlines major considerations in the development of your investigation and response plan. Keep in mind, however, that the foundation of your sampling and analysis plan rests on your conceptual site model (see Chapter 7).

Developing the geophysical investigation is often the most difficult part of the MEC investigation. Given the size of the ranges and the costs involved in investigating and removing MEC, 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 MEC on your MRS will come from several sources:

- Inadequacy of geophysical detection methods to locate and correctly identify anomalies that may be potential MEC
- Inappropriate extrapolation of the results of statistical geophysical sampling to larger areas
- Difficulty in collecting representative soil samples for munitions constituents
- Measurement errors introduced in laboratory analysis of soil samples (either on-site or off-site), including subsampling and analysis

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

- C Intrusive excavation of anomalies (usually to verify the results of geophysical investigations)
- C Soil sampling for potential munition constituents
- C 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:

- C Establishment of your desired level of confidence in the capabilities of subsurface detection techniques
- C How to phase the investigation so that data collected in one phase can be used to plan subsequent phases
- C Establishment of decision rules for addressing shifts in investigation techniques determined by field information
- C The degree to which statistical sampling methods are used to estimate potential future risks
- C How to verify data obtained through the application of statistical sampling approaches
- C The types of field analytical methods that should be used to test for explosive residues
- C The appropriate means of separating and storing waste from the investigation
- C 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 MEC impacts at the site. For example, if your project objective is to confirm that an area is "clean" (free from MEC), and you detect a MEC 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 geophysical data collection is necessary at that point.

Conversely, your objective may be to cleanup a target area that is expected to contain artillery items (e.g., 105 mm projectiles) using the combination of detection tools and data processing techniques deemed appropriate to the site and the objective specified by your project team. However, initial excavations reveal the presence of much smaller munitions (e.g., 40 mm anti-aircraft projectiles), in addition to the artillery items. You may have to modify your geophysical detection processes in order to address this unanticipated type of munition, which will be more difficult to detect.

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 MRA/MRSs under investigation safe for geophysical investigation. The 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 munitions 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 for sampling for munition constituents

8.1 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 includes 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 MEC detection
- The amount and quality of historical information available about the site
- The nature of the MEC 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 MEC 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. Measures of effectiveness include probability of detection, maximum depth of detection, false positive ("false alarm") rate, and sensor data characteristics such as signal and noise. The science of ordnance and explosives detection has improved significantly over the past decade; however, the limited ability to discriminate between ordnance and non-ordnance 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.

8.2 UXO Detection Methods

Until the Jefferson Proving Ground Technology Demonstration (JPGTD) Project was established in 1994 to advance the state of munition detection, classification, and removal, "Mag and Flag" had been the default MEC 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 the data from a Mag and Flag operation are not digitally recorded, it is more difficult to replicate and verify the data. This lack of digital recording also makes it difficult to assess whether an area has been completely surveyed using this technique. The certainty of the actual location of the anomaly is highly dependent on the operator's proficiency as well as on the systemic errors associated with the technique. 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 very difficult terrain (e.g., mountainous, densely forested), Mag and Flag may be the most cost-effective method for detecting UXO.

What Is the Effectiveness Rate of MEC 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 MEC, other metallic objects, and magnetic 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 overall effectiveness of a detection technology is intrinsically tied to the ability of the sensor to discriminate between munitions items and other subsurface anomalies. The more sensitive the detector, the more anomalies are found. Finding the balance between reducing false alarms and ensuring that hazardous items are found is the key to a cost effective investigation.

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.

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 discussion of different technologies is provided in Chapter 4.

Although many detection technologies do an adequate job of responding to the presence of metallic items below the ground surface, they may also (depending on site conditions and the type of detection technology) respond to geologic anomaly sources, such as ferrous rocks. One class of false positives is the response of sensors to nonmetallic sources. In addition, currently available technologies do not discriminate between metallic items of concern (i.e., UXO and buried munitions), fragmentation from exploded munitions, and non-ordnance-related metal waste. These false positive anomalies from geologic sources and non-ordnance related metallic items can greatly increase the number of anomaly excavations that must be undertaken during investigations and remedial responses, as well as during QA/QC of these activities. Development of reliable means of distinguishing between ordnance items and other subsurface anomaly sources will minimize false positives and, therefore, reduce the cost and time needed for a project.

In an attempt to address this issue, Phase IV of the JPGTD was initiated with the primary goal of improving the ability to distinguish between ordnance and nonordnance. Although 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, the number of false positives should be greatly reduced, thereby significantly reducing the costs of UXO investigations.

A number of data processing and modeling tools have been developed to screen munitions targets from raw detection data. These discrimination methods are typically based on one of two approaches. One approach is to rely on a comparison of the signatures of potential targets against a database of known UXO (with a variety of sizes, shapes, depths, and orientations) and clutter signatures. A more effective approach is to model the expected geophsysical signals based on the physics of the sensor and its expected response to the item being searched for. 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 used to verify the field data. Section 8.3.1.5 discusses anomaly reacquisition, and Section 4.2.3.1 describes the application of positioning technologies to geophysical data collection.

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.

8.3 Methodologies for Identifying Munitions Response Areas

The next key element of your investigation will be to select the quantity and location of samples. 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

Terms Used in MEC 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).

Discrimination – Distinguishing the presence of UXO from non-UXO from system responses or post-processing.

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).

excavation to make a decision at your site

Two methodologies have been developed to answer these questions – CSM-based and statistically based sampling. The two methods are discussed in the following sections. It is important to remember that the methods are not mutually exclusive, but can be used together to characterize the ordnance at your site.

8.3.1 CSM-Based Sampling Design

Your sampling design will be driven by your CSM (and the historical information gathered to support your CSM), the purpose of the investigation, and the terrain being investigated. In the simplest terms, two functional purposes affect the nature of your sampling design:

- Purpose 1— search for munitions response sites (e.g., a target area) to determine the possible location of munitions and the need for and location of further investigation.
- Purpose 2 — establish boundaries for and further characterize (e.g., ordnance type, depth) the sites where munitions have been located to guide the risk management decision that will lead to removal or remediation of the munitions.

Two types of geophysical survey patterns can be used to meet these two sampling purposes:

- Transects take a one-dimensional "slice" of a sampling area, the width of which is the width of the geophysical sensor.
- Grids, or 100% surveys, consist of overlapping, parallel transects that are used to create a two-dimensional map of a small, defined sampling area.

The following sections describe how and when these two patterns can be applied to accomplish the two different sampling purposes.

8.3.1.1 *Searching for Munitions Response Areas*

Regularly spaced parallel transects can be used to efficiently search a large area for evidence of concentrated areas of UXO. This approach can be especially useful to determine the location of target areas within a known or suspected firing range, and knowledge of the weapons systems used on the range can be used to determine appropriate search transect spacing. Field manuals for each weapon system are maintained and provide the expected high medium and low distribution of impact around targets under normal operating conditions. This information can be used to calculate spacing between parallel transects that will allow for less than 100 percent sampling and provide confidence that evidence of an impact area such as munitions fragments or UXO can be located. Figure 8-1 illustrates an example of a search using transect sampling.

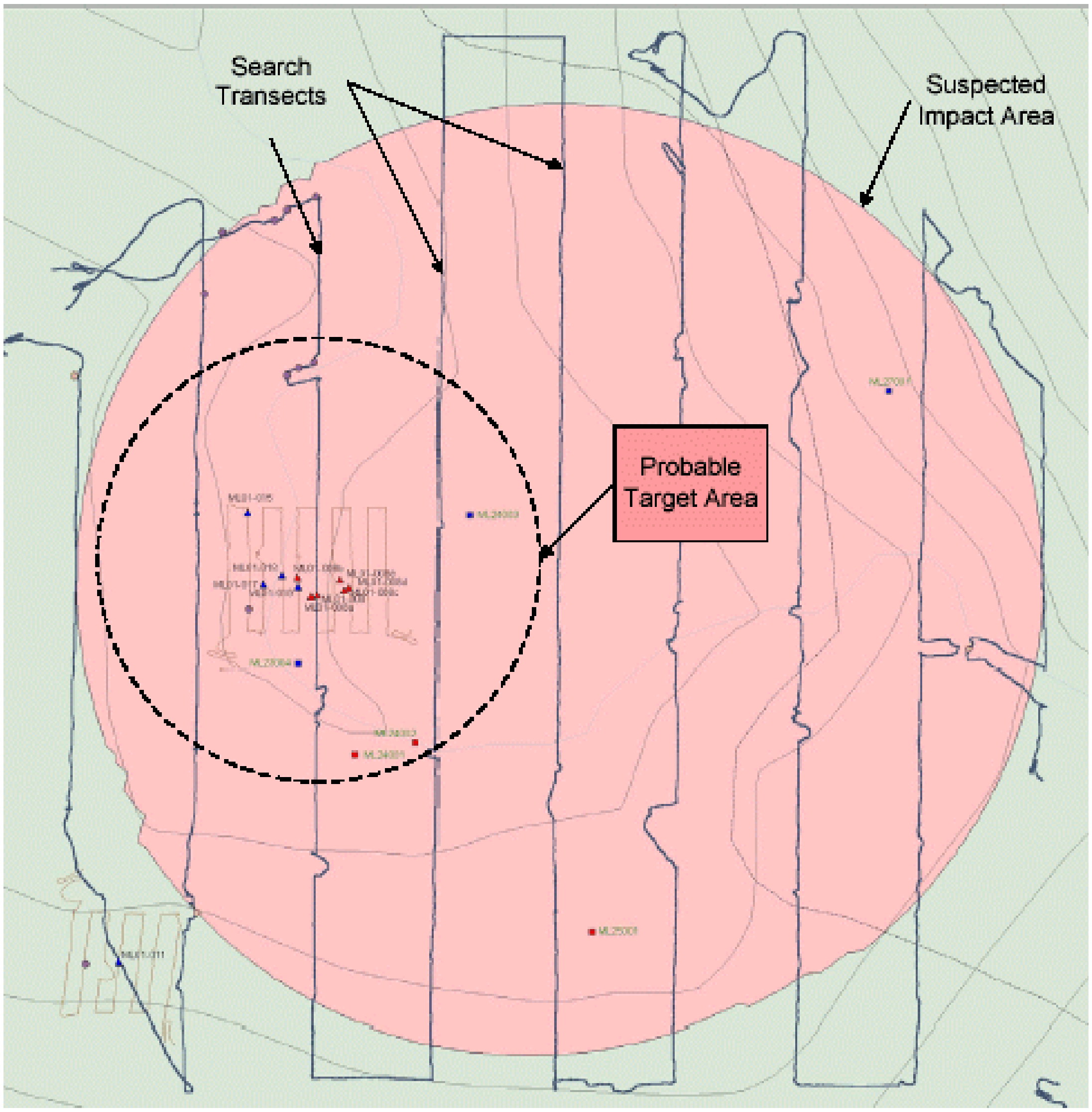

Figure 8-1. Example of Search Transects

Transect-Based Searches for Target Areas: Adak Island, Alaska

While planning the remedial investigation of Adak, the project team was faced with the issue of adequately investigating several large combat ranges (between approximately 3,400 and 6,800 acres). These areas were designated as combat ranges in June of 1943, during the time that much of Adak was in use as a training area for World War II troops preparing to retake the island of Kiska from the Japanese. Preliminary site investigation results provided evidence that at least some of the ranges had been used for live-fire 60 mm and 81 mm mortar training. The objective of the project team was to develop an investigation approach that would be cost-effective while still providing confidence that any target areas likely to contain UXO had been located.

The project team decided that a systematic search of the combat ranges using parallel transects would meet the investigation objectives. An operational analysis of the weapon systems of concern was undertaken to determine the spacing of these parallel transects. This analysis consisted of creating a "model" of the impacts that would result from small-scale target practice, based on information contained in Army field manuals for the weapon systems. Information from the field manuals was also used to determine the radius around an impact that would contain fragmentation of sufficient quantity to be detected by the geophysical sensor. This information was combined to estimate the minimum dimensions of potential target areas. The recommended spacing between the parallel transects was set at 75 percent of these minimum dimensions in order to obtain certainty that a transect would traverse any target areas.[1]

One of the key features of this approach was the agreement by the project team that fragmentation provided evidence of potential target areas and that areas in which fragmentation was located warranted further investigation, even if no UXO was found during the initial parallel transect search. This allowed the team to feel confident that the majority of the combat ranges could be designated for no further action upon the completion of the remedial investigation. The approach also located several previously unknown target areas, as well as an undocumented ordnance disposal area.

[1]Conceptual Site Model-Based Sampling Design, the UXO Countermine Forum 2001.

Use of a grid pattern when performing a search is appropriate when the primary release mechanism indicated by the CSM is loss/abandonment or unsanctioned burial (e.g., at firing points, bivouac/encampment areas, and transfer points), and the area of the search is relatively small (see Figure 8-2). In this case, the location and size of the grid should be determined from site reconnaissance information and knowledge of past ordnance activities (e.g., unsanctioned burials may have occurred near firing points). The lane spacing of the grid survey should be based on the sensor being used, the expected depth, and the size of the expected ordnance type, and should be influenced by the results of the geophysical prove-out.

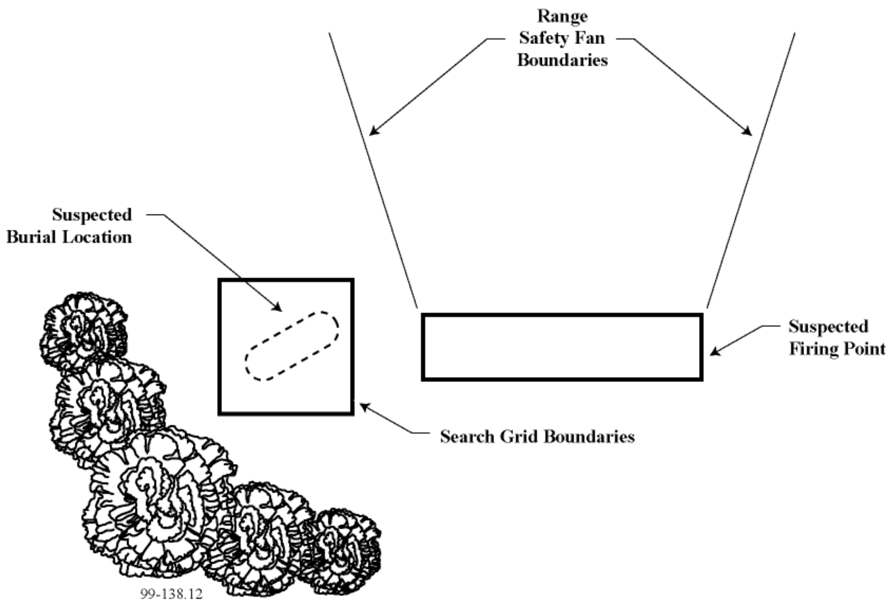

Figure 8-2. Example of a Sample Grid

8.3.1.2 *Boundary Delineation and Characterization of Munitions Response Areas*

Either parallel transects or the grid pattern may be used when the purpose of the sampling is to bound and characterize an area. For example, the boundaries of a target area may be estimated either from closely spaced transects (on the order of 5-15 meters), or from the geophysical map produced from a grid-based survey of the area. The selection of the pattern will depend, in part, on the terrain and vegetation of the area, the known or suspected types of ordnance in the sampling area, and the DQOs for the sampling effort.

8.3.1.3 *Site Conditions and Geophysical Sensor Capabilities*

In addition to the two sampling purposes discussed above, site conditions will also play a role in the selection of the sampling pattern. If the site terrain is open and relatively flat, a grid-based sampling pattern can be very effective. (If your purpose is to search for UXO, it may be more effective to start out with a transect-based design.) A transect-based design may also be more effective if the terrain is heavily wooded or sloping, (e.g., by reducing the need for brush clearing), regardless of the purpose of the sampling effort.

The site-specific capability of the geophysical sensor will also affect sample design. Site conditions that lead to greater uncertainty in the performance of the sensor (e.g., very rough terrain leading to noisy geophysical sensor data) may be a reason to increase the amount of surveying that is done, whether by decreasing the distance between parallel transects or by increasing the overlap between adjacent transects in a grid pattern.

8.3.1.4 *Anomaly Identification and Prioritization*

After the survey has been completed, the geophysical and positional data are processed and analyzed to identify and locate geophysical anomalies that may be MEC (see Chapter 4 for a discussion of the anomaly identification process). The outputs from this process, often called a "dig list," are the locations, signal amplitudes, and estimated depths of the sources of the anomalies. On many sites, the anomalies included on the dig list are prioritized based on the geophysical analyst's judgments about which anomalies are most likely to be caused by subsurface ordnance items. This prioritization process is often an ad hoc form of anomaly discrimination, based on the analyst's general and site-specific experience (see the discussion in Section 8.2). The effectiveness of this prioritization depends on whether or not information from a geophysical prove-out has been used successfully to inform the prioritization process, and whether the analyst is receiving and using feedback from the anomaly excavation results.

Use of a prioritized dig list can increase the efficiency of the anomaly excavation process by focusing the excavation efforts on the anomalies most likely to be of interest. However, a sample of all anomalies that meet threshold criteria for identification (even those judged not likely to be ordnance) should be excavated in order to provide information about the effectiveness of the prioritization process.

8.3.1.5 *Anomaly Reacquisition*

In general, before an anomaly is excavated, its location will be "reacquired" by the anomaly excavation team. The accuracy of anomaly locations entered on dig lists depends on both the survey pattern and the accuracy of the positioning system used during the geophysical survey. Therefore, the search radius used during anomaly reacquisition is another parameter that must be considered during the development of the sampling methodology.

In general, the locations of anomalies identified from a grid survey will be more accurate than those identified from a transect survey. This is because multiple passes of the geophysical detector over or near an anomaly source will give the analyst more data to use to estimate its location. And although differential global positioning system (DGPS) will provide the most accurate positional data, site conditions (especially dense tree canopy) may preclude the use of this system, and less accurate positioning methods may need to be used. All of these issues should be considered when specifying the search radius to be used during anomaly reacquisition.

The other factor to consider is the geophysical sensor used to reacquire the anomaly positions. Ideally, this will be the same device that was used to perform the original geophysical survey. However, logistical circumstances may not make it possible to use the same device (for example, the qualified geophysical survey personnel may have already left the site by the time anomaly excavation is undertaken). In this case, the excavation team may use a hand-held sensor to reacquire anomaly locations. It is important that this hand-held sensor be of the same type (magnetometer or electromagnetic) as the sensor originally used to perform the survey.

8.3.2 Use of Statistically Based Methodologies To Identify UXO

Given the variation in the size of the ranges investigated, a variety of statistical sampling approaches have also been used to investigate MRS/MRAs.

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.

8.3.2.1 *Rationale for Statistical 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. 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.

8.3.2.2 *Historical Use of 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.)

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.[121]

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 estimate the cost of 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).[122]

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

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

[122]U.S. Army Corps of Engineers. Ordnance and Explosives Cost Effectiveness Risk Tool (OECert), Final Report (Version E), Huntsville, AL: Ordnance and Explosives Mandatory Center for Excellence, 1995.

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.

Table 8-1 summarizes these two tools and their strengths and weaknesses. Table 8-2 identifies four survey patterns and summarizes their strengths, weaknesses, and applications.

Table 8-1. UXO Calculator and SiteStats/GridStats

Statistical Sampling Method	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 predications, 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 or 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 percent of a total site is investigated and 25 to 33 percent 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 percent of levels required by other techniques. Used by DoD to extrapolate results to larger area.

Table 8-2. General Summary of Statistical Geophysical Survey Patterns

Survey Patterns	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 percent) 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 survey patterns may include limited excavation of anomalies to verify findings.

8.3.2.3 *Regulator Concerns Regarding the Historical Use of Statistical Sampling Tools*

> **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 embedded within those analyses. Those assumptions, along with the intended uses of the analyses, should be communicated at the front end to the regulators 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.

The use of statistical sampling is a source of debate between the regulatory community (EPA and the States) and DoD.[123] Faced with large land areas requiring investigation, and the high costs of such investigation, DoD has used several statistical approaches to provide an estimate of the UXO density at a site as a basis for selecting remedies or making no-action decisions. Regulatory concerns have generally focused on four areas: (1) the inability of site personnel to demonstrate that the assumptions of statistical sampling have been met, (2) the extrapolation of statistical sampling results to a larger range area without confirmation or verification, (3) the use of the density estimates in risk algorithms to make management decisions regarding the acceptable future use of the area, and (4) 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:

- Historically, the use of statistical sampling tools has been 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 is known to ensure that the statistical sampling assumptions are met and the procedures used to test sector homogeneity are not effective enough to detect sector nonhomogeneity.
- Statistical procedures used in SiteStats/GridStats to determine when the sector has been sufficiently characterized and 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 this 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 munitions activities occurred is questionable.
- The capabilities of current statistical methods to identify hot spots are limited.
- A nonconforming distribution may not be identified by the program and thus not be adequately investigated.

[123] "Interim Guidance on the Use of SiteStats/GridStats and Other Army Corps of Engineers Statistical Techniques Used to Characterize Military Ranges." Memo from James E. Woolford, Director, EPA Federal Facilities Restoration and Reuse Office, to EPA Regional Superfund National Policy Managers, January 19, 2001.

- The 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 limitations 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.
- The levels of exposure risks developed by the OECert program have not been accepted by regulators or the public.

8.3.2.4 *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 MRAs, 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 and excavation 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

8.3.2.5 *Research and Development of New Statistical Sampling Tools*

The perceived ongoing need for statistical sampling has led the DoD's Strategic Environmental Research and Development Program (SERDP) to identify as high priority any projects that have the potential to develop "defensible statistical sampling schemes for bounding UXO contaminated areas." Three research projects in the MEC and UXO arena are currently under way.

Statistical Methods and Tools for UXO Site Characterization — This project will evaluate and develop statistical methods and tools that can be used for characterization and verification plans and data evaluation schemes. The development of the statistical sampling methods and tools will be consistent with the EPA's data quality objective (DQO) process. This process is used to plan any characterization activity to ensure that the right type, quantity, and quality of data are gathered to support confident decision-making. It is intended that the methods will strike an appropriate balance between the probability of missing UXO and the costs of characterization or unnecessary remediation (false positives). Statistical methods will be evaluated, adapted, or developed, and prototype tools will be developed and demonstrated. The methods will allow quick evaluation of trade-offs involving costs, risk of missing UXO, acceptable probabilities for decision errors, percentage of the site characterized or the number of swaths, false-positive error rates, grid sizes, etc. One statistical tool developed under this program is the Visual Sample Plan (VSP) software tool (developed by Pacific Northwest National Laboratory through a SERDP-sponsored project) for developing and visualizing transect survey design. The methods incorporate elements of the DQO approach for developing an optimal transect sampling design based on specified decision rules and tolerable decision error probabilities. Site-specific DQOs are specified and transect patterns (parallel, square, rectangular, or meandering) are identified and visually displayed using VSP. The VSP software is used to illustrate decision rules and associated transect sampling schemes that will provide the user's required high probability of traversing and detecting a target area of concern of specified size, shape, and anomaly (or UXO) density.

Bayesian Approach to UXO Site Characterization with Incorporation of Geophysical Information — The objective of this project is to develop a sampling protocol for estimating the intensity of UXO contamination across a site. This protocol uses an inherently Bayesian approach that allows for incorporation of historical information and geophysical data into the site characterization process. This protocol will use a sample optimization procedure to be incorporated to allow for straightforward field deployment of this characterization approach. A data worth framework will be used to optimize sampling locations and to determine when characterization is complete.

Statistical Spatial Models and Optimal Survey Design for Rapid Geophysical Characterization of UXO Sites — This project seeks to identify the mathematical foundations and statistical protocols in the domain of point process theory of spatial statistics by focusing on three objectives: (1) develop the statistical spatial models needed to produce the mathematical foundation for UXO distribution characterization, (2) develop optimal sampling strategies using experimental survey design, and (3) improve confidence levels for contamination estimates from measured data by improving discrimination techniques.

8.4 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 quality assurance and quality control (QA/QC) requirements for MEC investigations differ from other types of environmental investigations because of the unique characteristics of MEC and the tools available for characterizing MRSs. 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 by conducting tests of the technology on seeded areas representative of the range itself, 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 appropriately trained and qualified to work on the site using the detection system that will be used. What does not differ from other types of environmental investigations is the applicability of using a graded approach to the QA/QC of the investigation.

The resources dedicated to QA/QC should be appropriate to the kind of decision being made (e.g., preliminary screening vs. definitive determination of site response), as well as the size and complexity of the investigation. Specific QA/QC measures that could be taken include the following:

- **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 performance 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, the capability of the detection instruments to meet project-specific performance requirements is demonstrated in the field using geophysical prove-out sites in areas that have geology and topography similar to the area being investigated. The accuracy of this demonstration depends on the number, types, orientations, and depths of the test items buried in the prove-out site. Various metrics can be used to assess this capability, including probability of detection at a specified confidence level, maximum required detection depth, and geophsycial sensor signal and noise characteristics. Project goals may be based on any or all of these measures, and the geophysical prove-out design should support the assessment of the detection process performance against these metrics.
- **Geophysical qualification** — All members of the geophysical survey team are qualified by demonstrating their ability to meet prove-out performance results to ensure precision of geophysical data. An example of qualification 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 items planted collected is compared with the total number of items planted, 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 removed.
- **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.
- **Quality Control Program** — The contractor responsible for implementation of the investigation should have a comprehensive quality control program, including planned periodic surveillance of both field and data processing and analysis activities, as well as quality control acceptance sampling after the completion of fieldwork to confirm the adequacy of the work done.

8.5 Devising an Investigation Strategy for Munitions Constituents

This section introduces unique considerations in the design of an investigation strategy for determining the nature and extent of contamination from munitions constituents. Two aspects of the investigation strategy are discussed: the location and type of sample to be taken and methods for chemical analysis.

8.5.1 Sampling Strategy

As with a more routine hazardous waste site, the manner in which sampling is conducted represents the greatest potential for uncertainty and error to be introduced into the environmental decision process. However, increasing evidence from extensive studies by the Cold Regions Research and Engineering Laboratory (CRREL)[124] suggests that, given the extreme spatial heterogeneity of munition constituents, sampling of contaminated soils should be approached differently than the traditional hazardous waste investigation.

8.5.1.1 *Knowing Where To Sample*

A good sampling strategy should be based on a clear CSM that indicates all primary source and release mechanisms associated with each ordnance-related activity. The more you know about the ordnance activities on the site, the more representative the locations will be of ordnance-related contamination in that area of concern. Tables 7-1 through 7-6 in Chapter 7 show examples of ordnance-related activities and associated sources, release mechanisms, and expected MEC contamination. Thorough examination of historical records, aerial photographs, and base operational records will facilitate sufficient reconstruction of past ordnance-related operations. In many cases, however, design of an effective strategy for munitions constituents will depend on having the results of the MEC investigation. Confirming the location of target areas (and associated low-order detonations), firing points, and detonation areas will be a prerequisite for knowing where to sample.

[124]T.F. Jenkins, P.G. Thorne, S. Thiboutot, G. Ampleman, and T. Ranney. *Coping with Spatial Heterogeneity Effects on Sampling and Analysis at an HMX-Contaminated Antitank Firing Range*, Field Analytical Chemistry and Technology 3(1): 19-28, 1999.

8.5.1.2 ***Collecting Soil Samples***

Recent research by CRREL suggests that composite sampling provides a more accurate depiction of soil concentrations of MC. This same research also suggests that use of field analytical techniques is beneficial in a number of respects and has a high level of agreement with the use of off-site analytical methods for measuring MC. The use of field analytical methods also has the advantage of increasing sample density and, therefore, improving sample representativeness.

The traditional approach to collecting samples for chemical analysis uses large sampling grids and a small number of discrete samples. Usually, suspect areas of sites are divided into grids with dimensions ranging from tens to hundreds of meters. This approach involves the collection of a single core sample within a grid. The sample is divided into depth intervals, which are analyzed at an off-site commercial laboratory. Contaminant concentrations obtained from discrete sample analysis are then compared with background levels and action levels established for the site to determine the need for cleanup. This approach assumes that contaminant concentrations in the samples adequately represent the average concentrations within grid boundaries.

The problem with this approach in sampling for MC contamination is the spatial heterogeneity of munitions constituents. Concentrations of MC in adjacent soil samples may vary exponentially; therefore, you may miss the presence of MC altogether if too few samples are taken or the sampling locations are not correctly placed.

Sampling for any chemical residue is affected by the spatial heterogeneity of the residue. In traditional chemical residue sampling, the cause of the heterogeneity may be spills or leaks that occur in several locations, or hot spots. In addition, concentrations vary depending on the distance from the source and on the different fate and transport mechanisms that work on the particular chemicals of concern (e.g., the degree to which particular chemicals adsorb to soil, are taken up in plants, or are taken up in solution during rain events). However, in general, the traditional chemical release is expected to follow a pattern of concentration flow from the release point based on known characteristics of the chemical and its common fate and transport mechanisms.

In the case of explosive material, substantial research conducted by CRREL has demonstrated that the manner in which explosive residues are distributed when released by an explosive force results in such a heterogeneous distribution of material that soil samples taken right next to each other can show vastly different concentrations. One sample may be a nondetect, while another a few feet away may show concentrations above action levels. Conducting a traditional risk assessment using discrete samples may cause the risk assessment to erroneously report no risk, simply because the munitions constituents were missed.

Recent studies illustrated that compositing samples provides more representative data for characterization of an area suspected of being contaminated with explosive compounds than analyzing discrete samples does.[125,126] The following paragraphs present the results of the studies.

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[125]T.F. Jenkins, M.E. Walsh. *Field-Based Analytical Methods for Explosive Compounds.* USA Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory.

[126]T.F. Jenkins, C.L. Grant, G.S. Brar, P.G. Thorne, P.W. Schumacher, and T.A. Raney. *Sampling Error Associated with Collection and Analysis of Soil Samples at TNT Contaminated Sites*, Field Analytical Chemistry and Technology 1: 151-163 (1997).

In both studies, seven discrete samples were collected with a hand corer in a wheel pattern (radius 61 cm) and field analyzed for TNT, HMX, and RDX. The results of the discrete sampling over a very short distance indicate a wide range of concentrations. Figure 8-3 shows the sampling scheme and the results of the discrete samples. The resulting comparison of the composite sample analysis as compared with the mean of the discrete sample results is shown on Figure 8-4. Each of the sampling points are two feet apart.

Figure 8-4 shows that the resulting standard deviation is much lower with composite sampling. All duplicate samples were sent to an independent commercial laboratory for analysis with acetonitrile extraction and RP-HPLC-UX as described in EPA Method 8330. The results of the laboratory analysis are also presented in Figure 8-4.

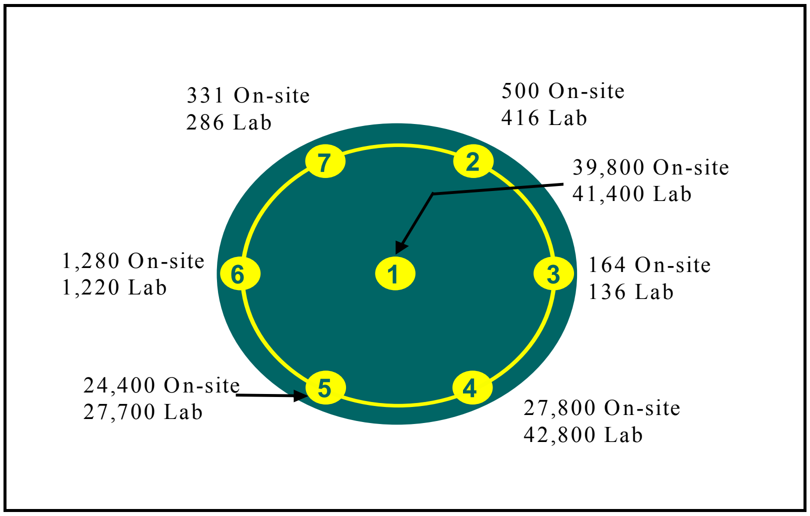

Figure 8-3. Sampling Scheme for Short-Range Heterogeneity Study: Monite Site, Sampling Location 1; Major Analyte: TNT (mg/kg)

			Discrete Samples			Composite Samples		
Sampling Location	**Major Analyte**	**Field or Lab**	**Mean**	**±**	**SD***	**Mean**	**±**	**SD**
Monite, location 1	TNT	F L	13,500 16,300	± ±	16,800 20,200	13,100 14,100	± ±	532 1,420
Monite, location 2	DNT	F L	16,100 34,800	± ±	11,700 42,200	23,800 33,600	± ±	3,140 2,390
Monite, location 3	TNT	F L	19.8 12.9	± ±	42.0 29.0	12.6 4.16	± ±	1.2 0.7
Hawthorne, location 4	TNT	F L	1,970 2,160	± ±	1,980 2,160	1,750 2,000	± ±	178 298
Hawthorne, location 5	TNT	F L	156 168	± ±	121 131	139 193	± ±	16.6 7.7
Hawthorne, location 6	Ammonium Picrate	F L	869 901	± ±	1,600 1,600	970 1,010	± ±	32 92

*The discrete sample standard deviations for locations 1, 2, 3, and 6 are larger than their corresponding means because the results from these locations are not distributed normally.

(Source: T.F. Jenkins, M.E. Walsh. *Field-Based Analytical Methods for Explosive Compounds.*)

Figure 8-4. Results of Composite and Discrete Samples: Soil Analyses: On-Site and Laboratory Methods, Monite Site and Hawthorne AAP (Source: Ibid.)

These findings reinforce the hypothesis that preparing a homogeneous and representative composite from a set of discrete samples is feasible and does not require sophisticated equipment nor exceptional time or effort. The use of composite samples also seems to effectively deal with the spatial heterogeneity associated with explosive residues.

In addition, the studies also indicate that distribution of explosive material within one field sample can vary so significantly that it can misrepresent the true concentration of explosive constituents in the area. To compound the matter even further, the traditional laboratory approach to soil sample preparation of a field sample usually involves taking a small amount of soil material from the top of the field sample container. This approach may miss explosive constituents altogether. For this reason, subsamples should be taken within a composite sample, with sample preparation consisting of mixing and grinding. CRREL studies have shown that mixing and grinding samples and subsamples can solve the problem.

There are many acceptable ways to collect and combine area-integrated samples into composite samples. The specific procedure chosen should be tailored to the conditions at the site to be characterized. By combining the ability to produce representative samples using on-site homogenization and compositing with the ability to obtain accurate analytical estimates with on-site methods, site investigators can minimize the problem of spatial heterogeneity for explosives-contaminated areas and the high costs normally associated with this sampling effort.

8.5.2 <u>Selecting Analytical Methodologies</u>

Two approaches may be used to determine the presence and concentration of munitions and munitions constituents 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. It has been thought in general that field analysis is less accurate than laboratory methods (especially near the quantitation limit), that the methods have lower selectivity when the samples contain mixtures of munitions constituents, and that they are subject to more interferences. For these reasons, it was common practice that a set percentage of samples, between 10 and 20 percent of the total samples, was sent to a laboratory for additional analysis. In addition, fixed laboratory methods offer greater specificity, as most field methods respond to classes of munitions constituents.

However, recent studies described in the previous section may cause the reevaluation of this common practice. These studies demonstrate that the use of composite sampling, combined with on-site sample analysis and appropriate representative confirmation of results at an off-site environmental laboratory, (less than the typical 10 to 20 percent described above) can significantly reduce costs while maintaining accuracy.

8.5.3 <u>Field Methods</u>

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.

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. Most on-site analytical methods have a detection range at or near 1 mg/kg for soil and 0.07 to 15 Fg/L for water.

Because TNT or RDX or both are usually present in explosives-contaminated soils, focusing on these two compounds during sampling can quickly identify areas of contamination. 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.[127,128] Another source reported that at least 95 percent of the soils contaminated with secondary explosive residues contained TNT and/or RDX.[129] Thus, the use of field methods for both of these compounds can be effective in characterizing explosives contamination at a site.

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 absorbency 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, the concentration that you determine will be influenced by the presence of the interfering compound.

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

[128] A.B. Crockett et al. *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.

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

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 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 8-3. In addition, TNT and RDX can be detected and measured in water samples using biosensor methods.

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 SW-846 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 SW-846 Method 8330.

DTECH Immunoassay Test Kits (EPA SW-846 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 SW-846 Method 8330.

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

Table 8-3. 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
Methyl-2,4,6-trinitrophenylnitramine (Tetryl)	X	

Table 8-3. Explosive Compounds Detectable by Common Field Analytical Methods (continued)

Compound	Colorimetric Test	Immunoassay Test
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	
Nitrocellulose	X	
Nitroglycerine	X	
Nitroguanidine	X	
PETN	X	

Figure 8-5 illustrates the results of regression analysis of the TNT results from the on-site colorimetric method compared with those of the laboratory HPLC method. The slope is very close to 1.0, which indicates that the on-site method provides essentially the same level of accuracy as the laboratory method. In addition, the correlation coefficient is high and the intercept value is low.

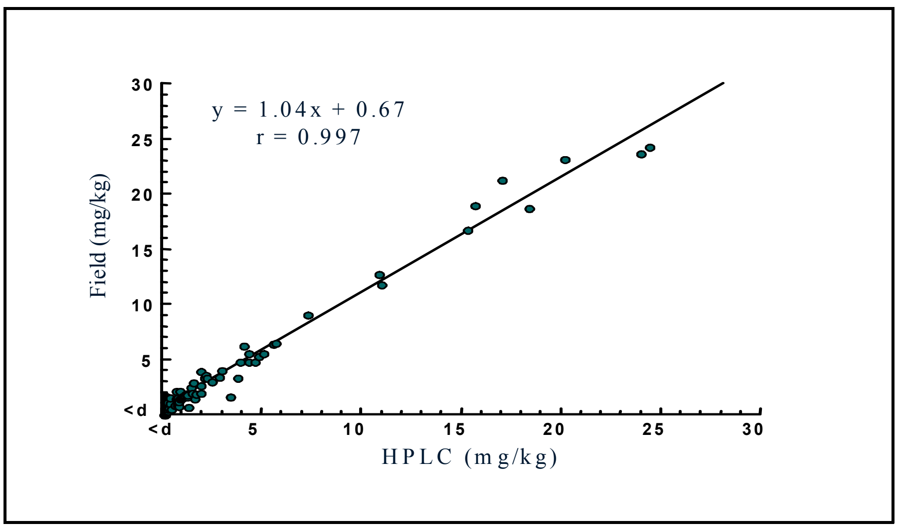

Figure 8-5. Comparison of Field and Fixed Laboratory Methods; Valcartier ATR: TNT Concentrations On-Site vs. Laboratory Results

8.5.4 Fixed Laboratory 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. Caution must be employed when using gas chromatography methods for the analysis of these compounds. Other problems exist when using gas chromatography due to the thermal lability and likelihood of degradation of certain compounds (e.g., HMX). These compounds are also very polar; thus, the use of the nonpolar solvents used in typical semivolatile analytical methods is not recommended.

8.5.4.1 *EPA Method 8330*

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.[130]

The compounds that can be detected and quantified by Method 8330 are listed in the text box to the right.

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 estimatedquantitation 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 Fg/L for low-level samples and 4.0 to 14.0 Fg/L for high-level samples. However, Method 8330 can give false positive results, especially at low concentrations. In such cases, the use of a liquid chromatography-mass spectrometry method, such as 8321, should be used for definitive confirmation. (See 8.5.4.3.)

Compounds That Can Be Detected and Quantified by SW-846 Method 8330 (EPA)

C 1,3-Dinitrobenzene (DNB)
C 1,3,5-Trinitrobenzene (TNB)
C 2-Amino-4,6-dinitrotoluene (2AmDNT)
C 2-Nitrotoluene
C 2,4-Dinitrotoluene (2,4-DNT)
C 2,4,6-Trinitrotoluene (TNT)
C 2,6-Dinitrotoluene (2,6-DNT)
C 3-Nitrotoluene
C 4-Amino-2,6-dinitrotoluene (4AmDNT)
C 4-Nitrotoluene
C Hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX)
C Methyl-2,4,6-trinitrophenylnitramine (Tetryl)
C Nitrobenzene
C Octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine (HMX)

8.5.4.2 *EPA Method 8095*

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 Method 8095 has been proposed as an alternative analytical method.[131] Method 8095 uses gas chromatography with electron capture detection (see text box). It can detect and quantify the same

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

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

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 chromatography 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. The major disadvantage of this method is the lack of commercial availability.

8.5.4.3 *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 and others 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.

8.5.4.4 *EPA Method 7580*

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.[132] Two different extraction methods may be used for water samples. The first procedure provides a detection limit on the order of 0.01 Fg/L. It may be used to assess compliance with Federal water quality criteria. The second procedure provides fora detection limit of 0.1 Fg/L. The extraction method for solids provides a sensitivity of 1.0 Fg/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. Samples are extracted with either diethyl ether (low water method), isooctane (high water method), or degassed reagent water/isooctane (solids). The extracts are then injected into the gas chromatograph that has been calibrated with five standards.

8.5.4.5 *Perchlorate Analytical Methods*

One munitions constituent that has appeared on the scene in recent years is the perchlorate anion. Ammonium perchlorate is a major component of solid rocket fuel. Perchlorate compounds are also used in a variety of other items, including mines, torpedo warheads, smoke-generating

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[132]Method 7580, White Phosphorus (P_4) by Solvent Extraction and Gas Chromatography, U.S. Environmental Protection Agency, Revision 0, December 1996.

compounds, signal flares, parachute flares, star rounds for Very pistols, spotting charges for training rounds, thermite-type incendiaries, small arms tracers, fireworks, and airbags. As a result of various activities with these assorted items, including manufacturing, storage, weapons training, washout, burning, burial, and detonations, perchlorate contamination has become very widespread. It is believed to have migrated into the groundwater of at least 30 States. Most of the reported contamination in the United States ranges from 4 to 100 Fg/L.

The most controversial aspect of perchlorate contamination is the level at which perchlorate poses a human health risk. Some States have advocated a drinking water standard for perchlorate in the low parts per billion range. Though EPA currently does not officially regulate perchlorate, it is requiring monitoring for it under the Safe Drinking Water Act's Unregulated Contaminant Monitoring Rule (UCMR). Perchlorate in waste water may also be monitored under a National Pollutant Discharge Elimination System (NPDES) permit. Several States, including California, are issuing interim action levels that are close to the low end of the range.

The only analysis method for perchlorate approved by EPA is Method 314.0. This method was developed for use with drinking water and is required by the UCMR. Its use may also be required in individual NPDES permits. Method 314.0 uses ion chromatography with conductivity detection. The detector is nonspecific, that is, it does not measure perchlorate specifically. It only measures the change in the conductivity of the water eluting from the chromatography column. The identification of perchlorate is made based on the retention time for the ion in the chromatography column. Though the method requires calibration, the presence of unknown interferences and shifts in retention time caused by high total dissolved solids can result in erroneous data (false positives or false negatives), particularly at the low end of detection (about 4 Fg/L). These sources of interference are more common in non-drinking-water samples (e.g., groundwater or wastewater). DoD policy currently requires confirmation of positive detections made by Method 314.0 such as those using mass spectrometry.

Several methods for perchlorate analysis are under development. An improved method 314 that uses additional cleanup and a second confirmatory column is expected to be promulgated by the EPA Office of Water soon, as are methods that make use of mass spectrometry (MS) or MS/MS detectors and ion-pair ratio monitoring, with or without O^{18} spiking. Work has also been done on a method that uses an ion-specific electrode. The use of these newer methods as they come online will result in a higher level of confidence in the analytical data. In addition to the definitive methods described above, a number of field methods are in the process of development and testing.[133]

8.6 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 report 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

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[133]P.G. Thorn. *Field Screening Method for Perchlorate in Water and Soil*. Cold Regions Research and Engineering Laboratory. ERDC/CRREL TR-04-8. April 2004

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 MEC, the standard risk assessment process will be used.[134]

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

- Is any MEC present or potentially present that could pose a risk to human health or the environment?
- What is the appropriate **site response strategy** if MEC is present or potentially present? Three fundamental choices are evaluated:
  - Further investigation is required.
  - Response action is required (either an active response such as clearance or containment, or a limited response such as institutional controls and monitoring).
  - No action or no further action is required.

8.6.1 Assumptions of the Site Response Strategy

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

> **What Does "Unacceptable Risk" Mean**
>
> 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 MEC exposure below which you can definitively state that such potential exposure is acceptable. This is because exposure to only one MEC item can result in instantaneous physical trauma. In other words, if the MEC item has a potential for exposure, and a receptor comes into contact with it and the MEC item explodes, the result will be death or injury. Unlike noncarcinogenic chemicals, MEC 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 MEC. Therefore, no attempt is made to quantify the level of explosive risks.
- Once MEC is determined to be present or potentially present, a response action will

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

be necessary. This response action may involve removal, treatment, or containment of MEC, 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 MEC present or potentially present on-site after the action is complete, some kind of institutional controls will be required.[135]

EPA/DoD Interim Final Management Principles on Land Use and Clearance

- Because of technical impracticability, inordinately high costs, and other reasons, complete clearance of MRSs 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 MRS-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) or equivalent RCRA process. The decision will be 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 MEC 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).

8.6.2 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 MEC 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:

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[135]Institutional controls are nonengineered measures designed to limit exposure to hazardous substances, pollutants, or contaminants that have been left in place and that are above levels that support unrestricted use. They are sometimes referred to by the broader term "land use controls." The latter term encompasses engineered access controls such as fences, as well as the institutional or administrative mechanisms required to maintain the fence.

- The work plan for the next stage of work (if more investigation is necessary).
- The conclusion section of the RI or RFI (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 MEC is present, then it may not be necessary to conduct geophysical studies to detect MEC and determine the depth and boundaries of the MEC.
   - 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 MEC 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 MEC items 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 MEC, 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 8-6 provides an overview of the process of developing a site response strategy. It shows 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.

8.6.3 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.

8.6.3.1 *Determining the Presence of Munitions with Explosive Potential*

The central question addressed here is whether munitions 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 munition 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 munitions constituents such as lead, but such risks are addressed in a chemical risk assessment.) Larger munitions items (e.g., bombs, projectiles, or fuzes) will have an explosive risk if present or potentially present as MEC.

Establishing the Presence or Absence of MEC 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 MEC you would consider multiple sources of information, including historical information (see text 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 MEC.

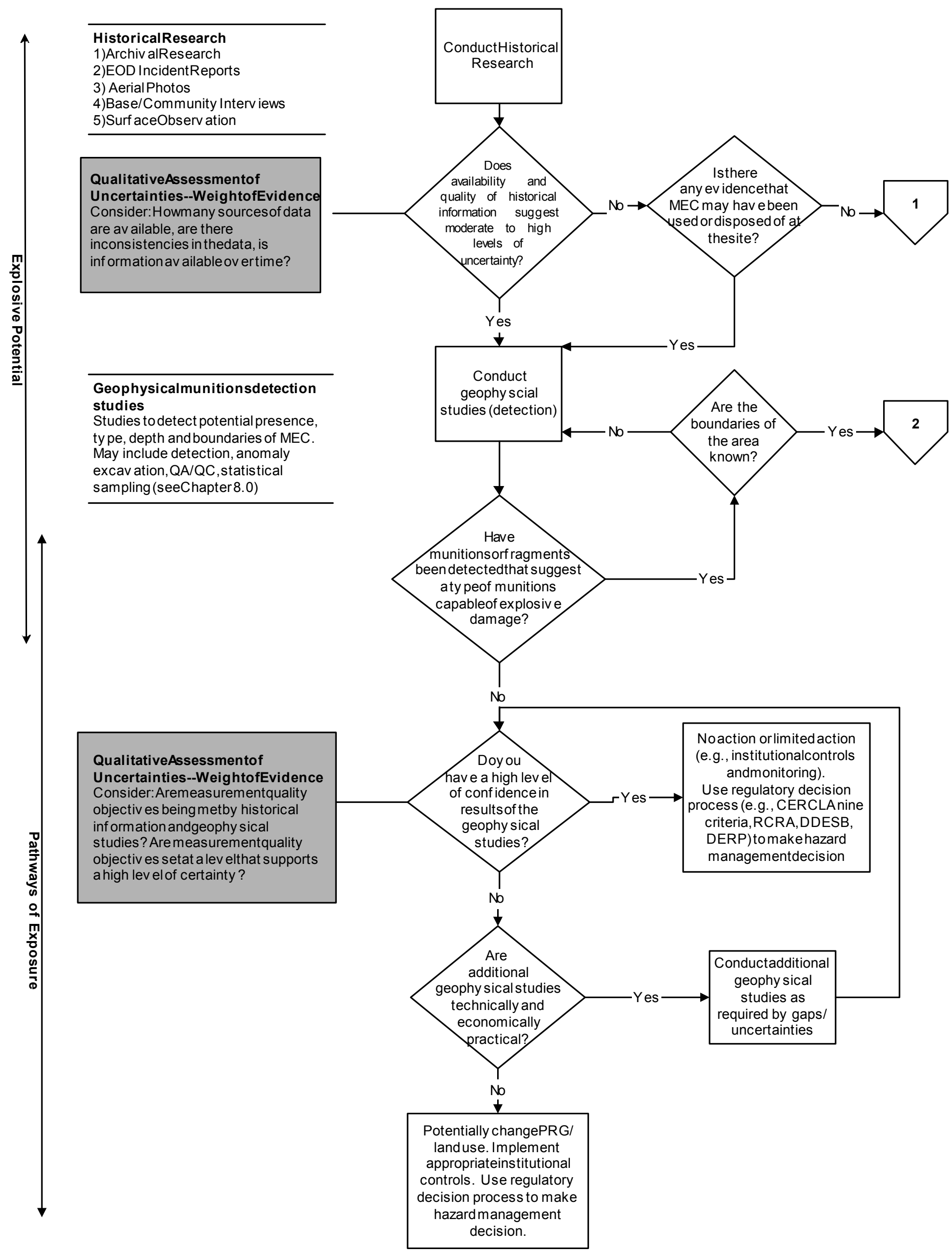

Figure 8-6. Developing a Site Response Strategy

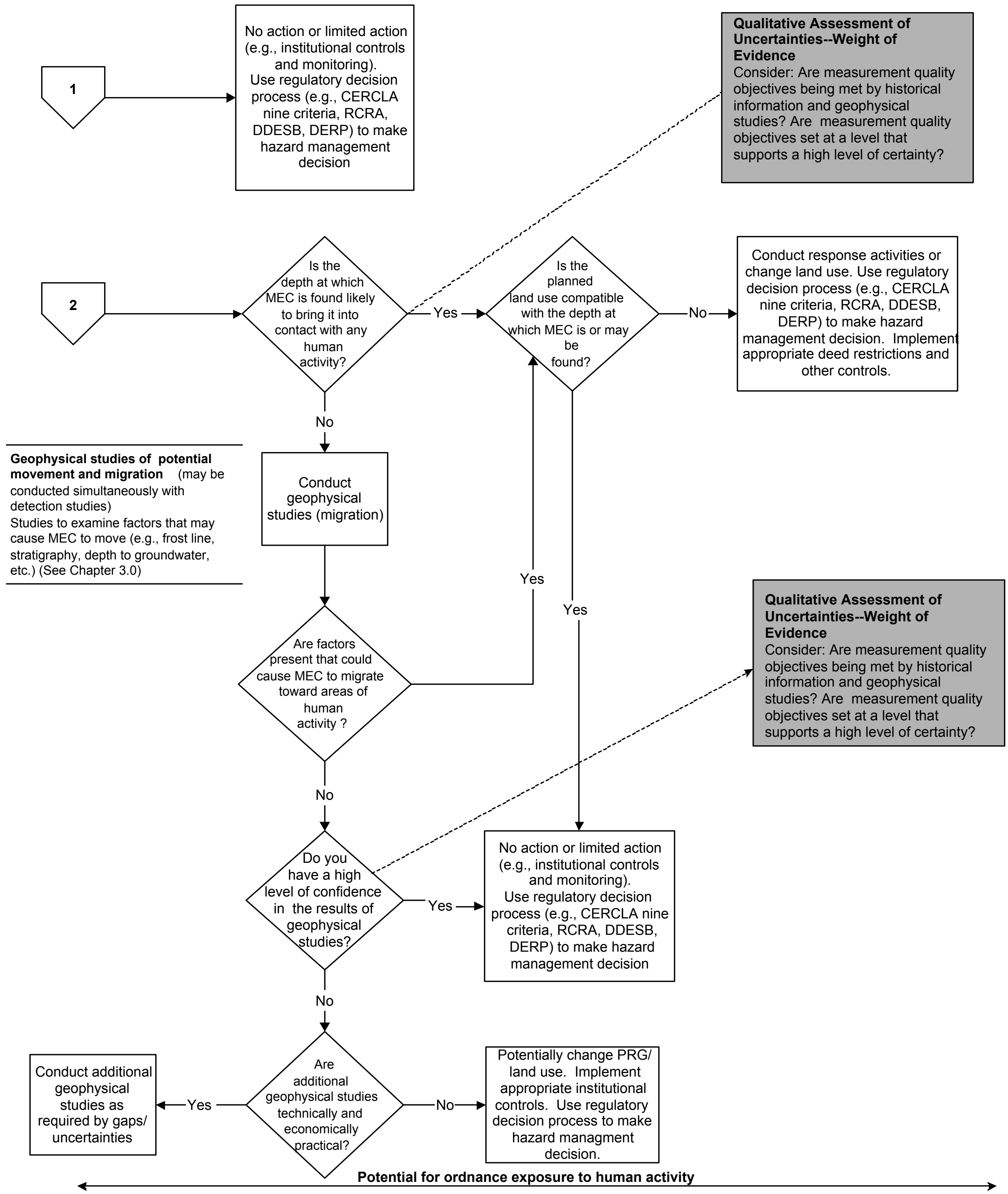

Figure 8-6. Developing a Site Response Strategy (continued)

8.6.3.2 *Identifying Potential Pathways of Exposure*

Once the actual or potential presence of MEC 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 MEC? (Is there munitions 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 MEC 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.

About Portability

The potential of exposure to MEC through human activity goes beyond the actual uses of ranges. Potential exposures to MEC can also occur as a result of human activity that causes MEC 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.

8.6.3.3 *Determining Potential for Human Exposure to MEC*

The potential for human exposure is assessed by looking at the types of human activities that might bring people into contact with MEC. Key issues for determining the potential of human receptors to come into contact with MEC include:

- Depth of ordnance MEC and exposure pathways of concern
- Potential for naturally caused migration to depths of concern

- Accessibility of areas where MEC is known or suspected to be present to workers, trespassers, etc.
- Potential for intrusive activity (e.g., construction in the MRS)
- 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 MEC (for potential human-caused migration off range)

During the final phase of the analysis, you should consider information and uncertainties from all phases of the investigation to determine whether there is a risk at the depth of concern. If the planned land use is not compatible with the depth at which ordnance is or may be found, then two options are possible:

- Remediate to a depth appropriate for the planned land use.
- Change the planned future land use to be consistent with the depth of cleanup.

Both of these decisions will be made during the risk management decision process under the applicable regulatory framework (e.g., CERCLA or RCRA). 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.

8.6.3.4 *Considering Uncertainty*

In every stage of site characterization, including the development of a site response strategy, a qualitative evaluation of uncertainty will help you decide the level of confidence you have in the information collected to determine your next steps. No single source is likely to provide the information required to assess the level of certainty or uncertainty associated with your analysis. Therefore, your qualitative uncertainty analysis will rely on *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 MRAs/MRSs.

8.7 Framework for 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 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.

8.8 Conclusion

The 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 design of the MEC investigation to the development of a site response strategy. As pointed out in the introduction, this chapter has focused primarily on MEC 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 MRAs. 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 MEC 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

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***. U.S. EPA, Federal Facilities Forum, Dec. 1996; EPA/540/S-97/501. Available at URL: http://www.epa.gov/nerlesd1/tsc/images/fld-smpl.pdf.

Crockett, A.B., H.D. Craig, and T.F. Jenkins. ***Field Sampling and Selecting On-site Analytical Methods for Explosives in Water***. U.S. EPA, Federal Facilities Forum, May 19, 1999; EPA/600/S-99/002.Available at URL: http://www.epa.gov/nerlesd1/tsc/images/water.pdf.

U.S. Army. ***Military Explosives***. Department of the Army Technical Manual. TM 9-1300-214. September 1984.

Wilcox, R.G. ***Institutional Controls for Ordnance Response***. Paper presented at UXO Forum 1997, 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
Engineering Research and Development Center
Cold Regions Research and Engineering Laboratory
72 Lyme Road
Hanover, NH 03755-1280
http://www.crrel.usace.army.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/

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

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, Aug. 1996.

U.S. Army Corps of Engineers. ***Requirements for the Preparation of Sampling and Analysis Plans***. Manual EM 200-1-3. February 1, 2001.

U.S. Army Corps of Engineers. ***Chemical Data Quality Management for Hazardous, Toxic, Radioactive Waste Remedial Activities***. ER 1110-1-263. April 30, 1998.

U.S. EPA. ***Guidance on Conducting Non-time-critical Removal Actions Under CERCLA***. NTIS No. PB93-963402; Aug. 1993.

U.S. EPA. ***Guidance for Data Usability in Risk Assessment (Part A)***. NTIS No. PB92-963356; Apr. 1992.

U.S. EPA. ***Guide to Preparing Superfund Proposed Plans, Records of Decision, and Other Remedy Selection Decision Documents***. NTIS No. PB98-963241; July 1999.

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

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

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

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

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 Final. Jan. 1998.

U.S. Navy. ***Environmental Compliance Sampling and Field Testing Procedures Manual***. NAVSEA T0300-AZ-PRO-0010; July 1997.

9.0 UNDERWATER MUNITIONS AND EXPLOSIVES OF CONCERN

Throughout this handbook, we have discussed a wide range of technical issues associated with MEC when it is found on land. All of the problems, issues, and concerns can be multiplied several times when MEC is found underwater. As with land-based MEC, the concerns involve risks to human health, the environment, and explosive hazards. However, the routes of exposure and the fate and transport for land-based and underwater ordnance can be different. There are a number of uncertainties that affect our decision-making regarding the management of MEC in the underwater environment. These include, but are not limited to, the following:

> **Snagging WWII Underwater Munitions**
>
> In July 1965, a fishing trawler off the coast of North Carolina snagged a World War II German torpedo in its nets. As the crew attempted to lift the torpedo clear of the water in heavy seas, the warhead hit the side of the trawler and detonated. Eight of the twelve crewmen died and the vessel sank.
>
> Source: A. Pedersen, *The Challenges of UXO in the Marine Environment,* Naval EOD Technology Division. Modified by written communication.

- Information on the fate and transport of munitions constituents in the underwater environment is lacking or not widely distributed.
- Finding underwater MEC offers additional complexities in detection, discrimination, and positioning.
- Safety issues can be magnified in the underwater environment.
- For reasons of personal safety, blowing in place (BIP) is (as it is on land) the common method for disposing of UXO unless the UXO item has been determined to be safe to move. (However, if conducting underwater BIP, the effects of underwater detonation to humans and the underwater ecosystem must be addressed.)

This chapter addresses what is known about the areas listed above, as well as the uncertainty in each area. The chapter is divided into four parts.

- Design of a conceptual site model for underwater ranges
- Detection of underwater MEC
- Safety
- Underwater response technologies

9.1 Conceptual Site Model for Underwater Environments

This section addresses the unique factors in designing a conceptual site model (CSM) for underwater MEC, including the following:

- The areas where underwater MEC is found,
- The potential for exposure to MEC,
- The environmental factors affecting decomposition of underwater MEC, resulting in potential for releases of munition constituents,
- The environmental fate and transport of munitions constituents, and
- The ecological and human health effects and toxicity of explosive compounds and other munitions constituents in the underwater environment.

9.1.1 Areas Where Underwater MEC Is Found

Much of the U.S. underwater MEC presence has occurred near military practice and test ranges. Activities at locations such as ammunition piers, coastal bombing ranges, and dredge spoil ponds, among others, have also resulted in a wide variety of MEC items. In addition, war, intentional dumping, and accidental dumping have contributed to the problem.

Some of the military activities that have historically resulted in underwater MEC contamination are described below:

- **Ammunition storage and transfer activities** – MEC may be deliberately or accidentally dumped near piers where ships load and unload munitions or materiel (mishandling/loss).
- **Weapons training and testing** – For some kinds of training, the underwater environment, particularly the deep ocean, may be target impact areas and areas where underwater munitions such as sea mines or torpedoes were used. These areas include ships that are used as practice targets. Other weapons training activities may have a range safety fan that includes a body of water where munitions that miss the target might land. MEC can include dud-fired munitions, low-order detonations, intact munitions, and dumped munitions (mishandling/loss).
- **Troop training areas** – Training areas may be on shorelines (near wetlands, ocean beaches, tidal wetland areas, etc.) or over rivers, lakes, or ponds. As in land-based training, unauthorized disposal, or loss of material, can result in MEC in underwater areas. Overshoots and undershoots on islands used as targets for aerial bombing, missiles, and naval artillery can also result in MEC in underwater areas. Examples of where such events have occurred include Nomans Land Island, Massachusetts, Kaho'olawe Island, Hawaii, and Adak, Alaska.
- **Disposal of MEC** – In the past, large- or small-scale dumping of military munitions occurred offshore.[135] In addition, disposal of underwater UXO may result in chunks of MEC released from low-order detonations. These disposal operations could have resulted in the introduction of munitions constituents to the aquatic environment.

9.1.2 Potential for Exposure to MEC

Potential human exposures to underwater MEC or UXO result from different factors than land-based exposures. Both land-based and underwater exposure can be from recreational and industrial uses, but other potential exposures are unique to the underwater environment (see Figure 9-1). Table 9-1 shows examples of activities and potential exposure. In addition, underwater MEC can migrate as a result of tides, surf, currents, floods, or other factors.

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[135] As used in this handbook, the term *offshore* refers to the area that is in the intertidal area and further out.

Table 9-1. Exposure Scenarios from Underwater MEC and UXO

Potential Receptor Activity	Exposure Pathway	MEC Hazard and Risk Type
Near-shore recreational use, (e.g., swimming, fishing)	Beaches, shorelines, river bottoms, sediments	Explosive hazard, munitions residue
Port and channel maintenance such as dredging and dredge spoil disposal	River bottoms, sediments	Explosive hazard, munitions residue
Commercial fishing, trawling for fish	Fishing activity that brings up unknown items	Explosive hazard
Deep sea recreational use such as diving	Coral reefs, other underwater formations, sunken ships	Explosive hazard
Consumption of seafood	Food chain	Munitions residue
Fish feeding areas, nurseries	Sediments, benthic organisms	Munitions residue

In addition to the potential receptor activities and related exposure pathways listed in the table, the disposal of ordnance in the underwater environment is another exposure pathway that may be difficult to control. As discussed in Chapter 5, blow-in-place is usually the preferred method for disposing of UXO because of safety considerations. This is true in underwater environments as well as on land. However, the underwater detonation of UXO may pose a significant risk to underwater ecological receptors and sensitive habitats, including wetlands, estuaries, coastal areas, and marine habitats such as coral reefs.

In the example presented below, one naval facility began the design of its conceptual site model by dividing the offshore area into four offshore clearance zones. These zones were based on likely human access due to water depth, with the flexibility to change a zone as appropriate. These offshore clearance zones were defined as follows:[136]

- Zone 1: The portion of the sea floor that is not covered by water most of the time and can be walked on during low tides — Intertidal zone
- Zone 2: The portion of the sea floor that is easily accessible by wading from the shore but is covered by water most of the time — Shallow subtidal zone
- Zone 3: The portion of the sea floor that is not accessible by wading but is accessible by skin diving from a boat or a pier — Intermediate subtidal zone
- Zone 4: The portion of the sea floor that is accessible only by self-contained underwater breathing apparatus (SCUBA) or surface-supplied-air diving — Deep subtidal zone

The offshore clearance zones and zone depths are shown in cross-section in Figure 9-1.

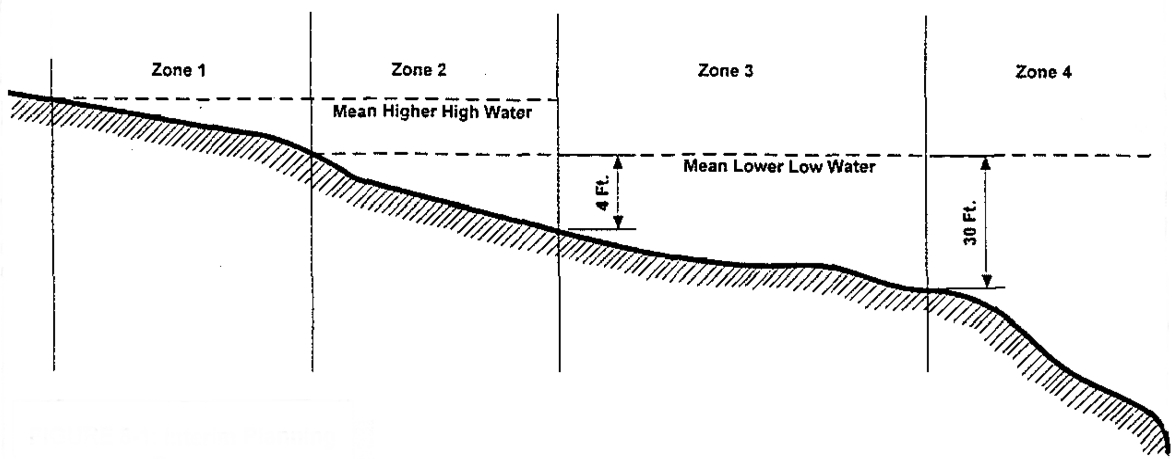

Figure 9-1. Example of Offshore Clearance Zones

9.1.3 Environmental Factors Affecting Decomposition of Underwater MEC Resulting in Releases of Munitions Constituents

A number of complex factors affect the fate and transport of munitions constituents released in the underwater environment. These factors include the nature of the delivery of the munition item to the underwater environment, its potential for corrosion, and associated releases.

Underwater releases of munition constituents can occur when casings deteriorate, (most notably from corrosion), rupture upon impact, or undergo a low-order detonation. Munitions

[136] Technical Memorandum for Offshore OE Clearance Model, OE Investigation and Response Actions, Former Mare Island Naval Shipyard (MINS). Prepared for Commander, Pacific Division, Naval Facilities Engineering Command, Pearl Harbor, HI. February 11, 1999.

constituents may be released immediately after impact or may be only partially contained within the remains of the delivery system. When UXO undergoes a low-order detonation or breaks apart upon impact, the munitions constituents, such as bulk explosives, can be scattered over the impact area.[137] (See Section 3.2.3). When the MEC remains relatively intact, munitions constituents can be released through pinhole cracks that develop over time as a result of corrosion or through the screw threads linking the fuze assembly to the main charge.

Corrosion of the iron and steel in MEC casings is a complex process that occurs in the presence of water and oxygen. The potential corrosivity of the local environment, such as a bay, harbor, lake, pond, or wetland, could vary greatly. Such variations can be caused by acid rain, industrial pollution, salinity, degree of oxygen saturation, or natural buffering caused by the presence of carbonate rocks or other minerals. Normally, the lower the pH of the environment, the higher its corrosive potential.

The effects of immersion and corrosion on the release of munition constituents in various underwater environments depend on site conditions. Even though saltwater is potentially more corrosive the higher the salt saturation, exposure to oxygen is a key requirement for corrosive effects. In environments where wave action and tides cause mixing with the atmosphere, the oxygen content of the water, especially shallow water, can be at or near the saturation point, creating a high potential for oxidation. Likewise, repeated exposure of MEC items directly to the oxygen in the atmosphere through tidal movement can increase corrosion.

Recent studies have suggested that even corroded MEC does not necessarily result in the harmful release of munition constituents. A variety of factors in the underwater environment may either reduce the potential for corrosion, or affect the nature of the release from an MEC item releasing munition constituents. At higher pH levels, if the right conditions are present (e.g., CO_2 saturation, or temperature) submerged or buried metal may develop a coating of calcium carbonate, with a corresponding increase in corrosion resistance. In the absence of oxygen, such as the anaerobic conditions that can exist where there are large concentrations of unoxidized metals, or high content of organic matter, or in deeper, cold waters, corrosion in the underwater environment can be virtually stopped. It is also possible that submerged UXO and MEC can develop a coating consisting of biological materials that can seal the item off from the environment (as well as make it more difficult to locate.)[138]

Corrosion of steel casings can produce a complex local environment composed of intact steel and iron oxidation and reduction products through which the munition constituents must pass to enter the environment. Recent studies have shown that the presence of metallic iron can strongly affect the fate and transport of munition constituents in underwater environments. This process can lead to certain munition constituents, such as RDX, being removed from solution through chemical reduction unless a source, such as a ruptured casing, continues to release the constituents to the underwater environment. The effects of the presence of iron and steel on the fate and transport of

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[137] J.M. Brannon, et al. *Conceptual Model and Process Descriptor Formulations for Fate and Transport of UXO*. USACE WES, February 1999.

[138] Note that in deeper waters where residence time and turnover are measured in decades or centuries, anaerobic conditions exist that tend to preserve items.

munition constituents should be investigated further to determine the rate and extent of these effects on releases in an underwater environment.[139]

9.1.4 Environmental Fate and Transport of Munitions Constituents

The major pathways of concern for releases of munitions constituents in the underwater environment are the sediments that are found on the bottom of most rivers, lakes, ponds, wetlands, and other near-shore coastal environments. These sediments support biological communities that are the food for aquatic life. The main concerns include the following:

- The continued health of the biological community and its ability to support the ecosystem.
- Potential uptake of chemicals into the plants and sea life that ultimately form part of the food chain for people and marine life.
- Munitions constituents that may be suspended in water and potentially available to humans (through dermal contact as a result of recreational use, and ingestion of drinking water) and consumption of marine life.

As shown in Chapter 3, many munitions constituents (including the most common compounds, TNT, RDX, and HMX) have been shown to be potentially toxic to aquatic organisms. However, the potential for aquatic toxicity depends both on the fate and transport mechanism at work, and the dose exposure of aquatic organisms to these constituents. There is a mounting body of evidence that suggests that the potential for aquatic toxicity is not often realized in the open water environment where often the concentration of munitions constituents will not be detectable due to a variety of factors, including advection, dispersion, diffusion, photolysis, plant update, and biotic transformation.[140] In addition, there is increasing evidence that these compounds do not bioaccumulate in aquatic tissue.

When evaluating the fate and transport of the munitions constituents and the actual potential impact of releases of these constituents on both humans and aquatic life, a variety of complex interactions between the physical and chemical properties of these chemicals must be understood. Any of these compounds can release to the aquatic environment through the same release mechanisms as they release to land. As on land, complete detonations release compounds in such small quantities that the detection of constituents in sediments or in water is not likely. However, water in the immediate vicinity of a continuing source, such as constituents leaking from a cracked or leaking MEC casing or low-order detonation, can contain the munitions constituent in measurable quantities.[141] TNT is more water soluble than RDX and HMX and is therefore more likely to be found in small concentrations in water. Since RDX and HMX have a very low water solubility, they

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[139] J.M. Brannon, et al. *Conceptual Model and Process Descriptor Formulations for Fate and Transport of UXO*.

[140] Brannon, et al. *Conceptual Model and Process Descriptor Formulations for Fate and Transport of UXO*.

[141] M. Dock, M. Fisher, and C. Cumming. *Sensor for Real-Time Detection of Underwater Unexploded Ordnance.* Paper presented at the 2002 UXO/Countermine Forum, Orlando, FL, September 2002.

are much more likely to be dispersed as small particles by currents and unavailable either through sediments (and plant uptake), or ingestion, or dermal contact in the water column.[142]

Munitions constituents differ in how easily they bind to sediments, which may then act as a source of continuing release to water, or as a source for aquatic life uptake. Since TNT is more water soluble than RDX or HMX, it is less likely to bind to sediments, and more likely to be immediately absorbed into water. However, TNT also tends to be more susceptible to photodegredation and biotransformation, particularly in shallow water. TNT's amino biotransformation products will bind to the humic acids in sediments more strongly than RDX or HMX. This tendency to bind to sediment can reduce the overall concentration of TNT's biotransformation products in water, in spite of their relatively higher water solubility compared to RDX and HMX.[143]

Bio-uptake and bioaccumulation of munitions constituents into the food chain via aquatic plants and other organisms that grown in sediments is not well understood. Recent research on phytoremediation has shown that plants can take up munitions constituents such as TNT, RDX, and HMX. These munitions constituents will also undergo some biotransformation in the plants' tissues. The Waterways Experiments Station in Vicksburg, Mississippi, has conducted research into the uptake of TNT and RDX by aquatic plants. In these laboratory studies, TNT and its degradation products were not detected, but RDX was found to accumulate in a number of plant tissues.[144]

Biotransformation products and their properties are important factors in the fate and transport of munitions constituents. Additional research is needed on the toxicity and fate of these constituents' biotransformation products and the role sediments play in binding them. In one case, toxicological and chemical studies were performed with silty and sandy marine sediment spiked with 2,6-dinitrotoluene, tetryl, or picric acid. Whole sediment toxicity was analyzed for several invertebrate species. Tetryl was found to be the most toxic of the three spiked compounds. However, the study concluded that degradation products from the spiked compounds may have played a role in the observed toxicity.[145]

Many knowledge gaps exist, including the bioavailability of munitions constituents and their biotransformation and degradation products, how these compounds might move up the food chain, and the level at which these compounds produce harmful effects in exposed organisms, including humans. Additional research should be done to evaluate the potential for human exposure resulting from bioaccumulation in the food chain.

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[142]Personal communication with Thomas Jenkins, Ph.D, of USACOE ERDC/CRREL, on February 20, 2003.

[143]Personal communication with Thomas Jenkins, Ph.D., of USACOE ERDC/CRREL, on February 20, 2003.

[144]J.G. Burken. *Phytoremediation/Wetlands Treatment at the Iowa Army Ammunition Plant*. http://www.mhhe.com/biosci/pae/environmentalscience/casestudies/case12.html.

[145]M. Nipper, R.S. Carr, J.M. Biedenbach, R.L. Hooten, and K. Miller. *Toxicological and Chemical Assessment of Ordnance Compounds in Marine Sediments and Pore Water.* Marine Pollution Bulletin. February 12, 2002.

9.1.5 Ecological and Human Health Effects and Toxicity of Explosive Compounds and Other Munitions Constituents in the Underwater Environment

With the increased ability to detect MEC in water bodies near naval facilities, in harbors, and in water bodies adjacent to active and former ranges and training areas, concerns about the environmental contamination caused by munitions constituents and related compounds have grown.

Previous surveys that looked at munitions constituents, particularly in the sediments and pore water of Puget Sound in Washington, concluded that the studied munitions constituents were not the main cause for concern. Rather, other organic compounds, such as PAHs, PCBs, pesticides, and to a lesser extent metals, were the main causative agents of the observed toxicity.[146]

One laboratory study was undertaken to assess the potential for adverse biological effects of munitions constituents in marine sediments and pore waters. Toxicological and chemical characterizations were performed with two kinds of sediments with different grain-size distribution and organic carbon content. These sediments were spiked with munitions constituents whose selection was based on one of the following two criteria: elevated toxicity to marine organisms or presence in marine sediments near naval facilities. The study measured concentrations of munitions constituents in the spiked sediments and corresponding pore waters and, when possible, identified degradation products.[147]

A significant conclusion of this study was that the observed toxicity did not appear to be entirely the result of the spiked compounds. The data seemed to suggest that degradation products could have played a major role in the toxicity tests. The study concluded that the actual degradation products and their persistence in the underwater environment need to be studied further and identified.[148]

A review of a number of online toxicological databases (IRIS, ATSDR, CHPPM WTAs, TOXNET) provided some information regarding ecological toxicity of a number of munitions constituents. The information in these databases seems to be incomplete in a number of areas. For example, one study stated that it appeared RDX did not bioaccumulate in food crops or in deer or cattle. (However, see 9.1.4) Another study stated that it was not known if HMX accumulated in plants, fish, or animals in contaminated areas. It is clear that additional research is needed in this area. Additional toxicological information on a number of munitions constituents, including TNT, RDX, and HMX is found in Section 3.4.

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[146]R.S. Carr, R. Scott, and M. Nipper. *Development of Marine Sediment Toxicity Data for Ordnance Compounds and Toxicity Identification Evaluation Studies at Select Naval Facilities.* Naval Facilities Engineering Service Center, Port Hueneme, CA. February 26, 1999.

[147]Nipper et al. *Toxicological and Chemical Assessment of Ordnance Compounds in Marine Sediments and Pore Water.*

[148]Ibid.

9.1.6 An Example Conceptual Site Model

As discussed in Section 7.4, a CSM is needed in order to have a working hypothesis of the sources, pathways, and receptors at a site undergoing investigation. The CSM guides the investigation. An example of a CSM, created for the Southern Offshore Ordnance Sites, Former Mare Island Naval Shipyard, is provided in Figure 9-2.[149]

The Department of the Navy developed the CSM to examine historical site operations and previous investigations and to identify current data gaps. This CSM, which will form the basis for future MEC site investigations, covers the offshore areas of the South Shore and Ordnance Production areas located on the south and southeast end of Mare Island, respectively.

9.2 Detection of Underwater MEC

Everything is more difficult underwater!

The challenges of conducting an underwater munition detection survey include the properties of the water, the need to maintain safe working conditions, and the ability to accurately locate and retrieve the detected items. Saltwater is very corrosive, particularly in shallow water which has a higher oxygen content. Instruments exposed to the saltwater must be properly sealed. When the munition detection instrument is a hand-held detector, precautions must be taken to seal instruments by taping a plastic bag over the electronics and keeping the electronics above the water. Using instruments that are factory sealed and designed for the underwater environment, such as White's Surfmaster II and the Geonics EM-61 coils encased in epoxy with underwater connectors, is strongly recommended.[150]

Underwater munition survey work has typically required the use of divers, which presents safety problems not encountered on land. For example, blast impacts carry further underwater than they do on land for an equivalent amount of net explosive weight. The average safe distance from an underwater detonation can be over five times that of a land detonation.[151] Searching underwater for MEC is very time consuming as divers swim search patterns and mark any anomalies located. The use of more modern deployment systems on surface or submerged vehicles has its own difficulties. The issues include the potential increase in distance between the sensor and the anomaly as the water depth increases, as well as the constant movement occurring in the water environment. The variability in the depth at which MEC items may be located beneath the surface may cause an effective sensor system to become ineffective a few feet away, as the water depth increases, because of the sensor's decreased ability to detect an anomaly as the distance from sensor increases. The instability of the underwater environment, due to currents, tides, and wave action, can increase the difficulty in detecting anomalies. As on land, MEC items need to be located individually. However,

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[149] *Draft Conceptual Site Model for the Southern Offshore Ordnance Sites, Former Mare Island Naval Shipyard.* Prepared for: Department of the Navy, Commander, Pacific Division, Naval Facilities Engineering Command, Pearl Harbor, HI. July 17, 2002.

[150] Edwards, D. and R. Selfridge. *Munition Item Detection Systems Used By The U.S. Army Corps of Engineers in Shallow Water Environments.* U.S. Army Corps of Engineers, Huntsville Engineering and Support Center. February 12, 2003.

[151] The actual evacuation distance is based on the net explosive weight of the ordnance item.

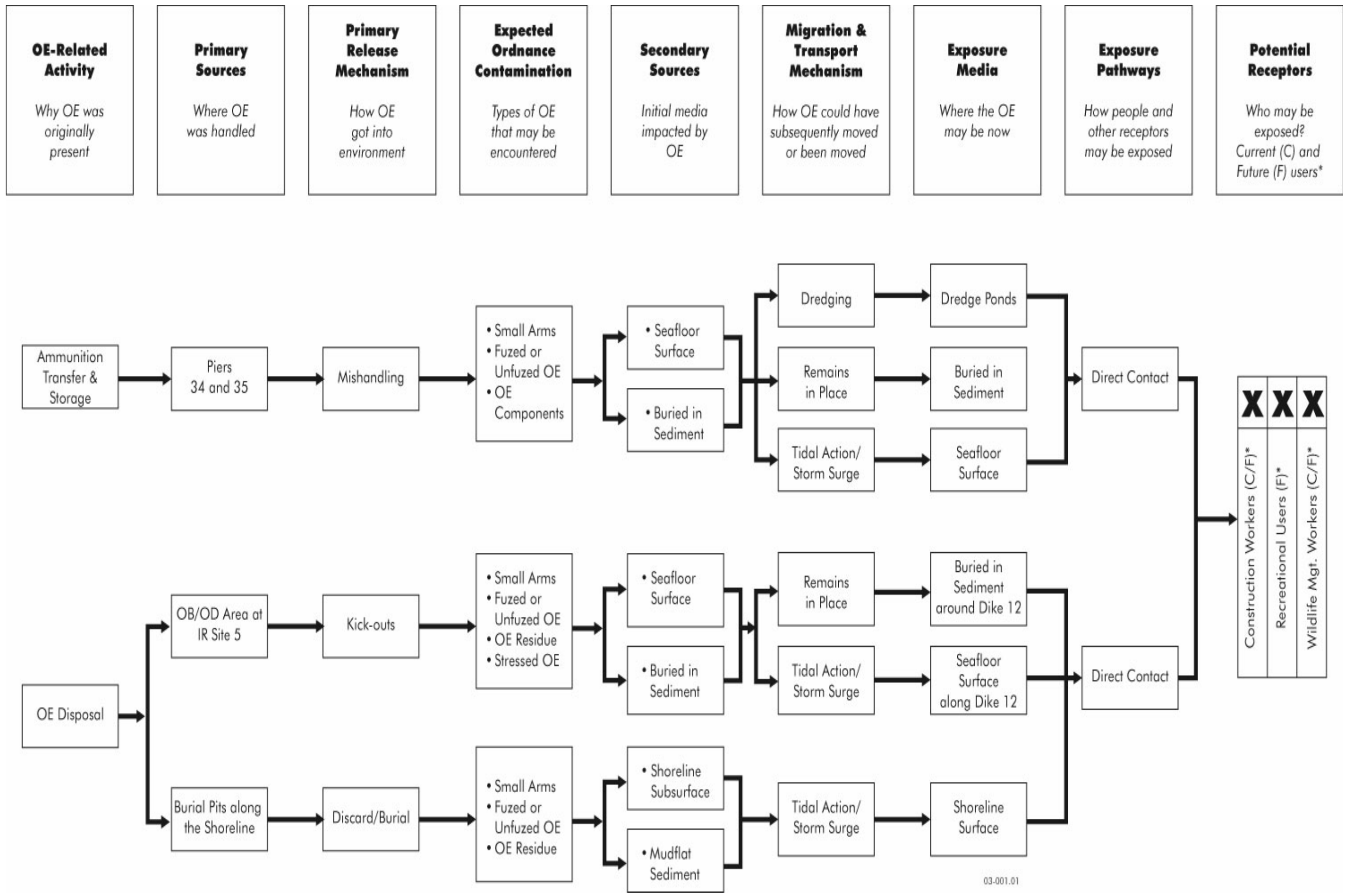

Figure 9-2. Example of a Conceptual Site Model

the underwater environment is more unstable because of the action of waves, tides, and currents. Low visibility, sedimentation, and biological and mineral coatings on the items of interest also make identifying MEC much harder. Boats and divers also have greater difficulty maintaining and marking their position. In spite of otherwise good weather conditions, work often must be stopped because of safety considerations related to wave action. In addition, underwater currents, wave action, and tides can cause underwater MEC to change location or become buried by sediment.

9.2.1 Detection Technologies

The two most common geophysical detection technologies are magnetometry and electromagnetic induction (EMI), as discussed in Chapter 4. Much of the technology used for land surveys can be adapted for underwater use. Various combinations of towed magnetometers, sidescan sonar, and underwater Geonics EM-61 can be used. (See below and the case studies in Section 9.2.4.1.) As on land, these technologies can be deployed on a variety of platforms. The selection of a particular technology, platform, data processing technique, and geolocation device for a given site often depends on the bottom conditions, the types of MEC or UXO expected, and the size of the area that is to be investigated. This is true with respect to the use of detection technologies in underwater environments.

For example, the Navy sponsored a test program at the former Mare Island Naval Shipyard (MINS) in Vallejo, California. The Naval Facilities Engineering Command, Pacific Division, contracted with a private company to perform a Validation of Detection Systems test program at MINS. The objective of the program was to identify, select, and validate detection equipment and technologies that could be used to locate and detect MEC at the four offshore sites at MINS that were suspected of containing MEC. The technical approaches included EMI and magnetometry (discussed in 4.2.1.1 and 4.2.1.2).[152]

Magnetometry is a reliable, proven technology for detecting ferrous MEC over land. With the need to detect underwater MEC increasing, a number of attempts have been made to adapt magnetometry for use underwater. An American company has developed and deployed several underwater platforms employing magnetometry in shallow water with magnetometers using a small boat as a platform. To date, they report that they have received few requests for underwater MEC exploration in the United States. Recent examples of work have included:

- Offshore sand burrows for beach replenishment on the East Coast
- Beach contamination from offshore UXO after storms on the East Coast
- Expansion and deepening of harbors in San Diego
- BRAC sites, such as at Mare Island, California
- Kaho'olawe Island, Hawaii
- Offshore pipeline routes in Hawaii[153]

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[152]Environmental Chemical Corporation (ECC). *Validation of Detection Systems (VDS) Test Program Final Report.* Burlingame, CA. July 7, 2000.

[153]R.J. Wold. *A Review of Underwater UXO Systems in Europe*. Paper presented at the 2002 UXO/Countermine Forum, Orlando, FL, September 2002.

With respect to EMI, operating a system underwater presents at least two basic challenges. The first is the presence of water itself, particularly saltwater, which is very corrosive, and second is the inherent difficulty of controlling and tracking a sensor array. The high electrical conductivity of saltwater limits the penetration of electrical and electromagnetic energy. There are also challenges in producing the primary field and measuring its decay. To detect objects underwater, it is necessary to reduce the distance to the target by submerging the sensor. The sensor is either dragged along the bottom or "flown" above the bottom. This creates the problem of knowing the location of a sensor that cannot be seen.[154]

Both magnotometry and electromagnetic induction have problems when deployed in the marine environment. For example, magnetometers are very sensitive to distortions in the earth's magnetic field caused by the iron and steel in MEC items. Magnetometers can sense these distortions to greater depths than other systems. They also can detect small anomalies. However, magnetometers are susceptible to the magnetic signature of non-MEC items, such as the hulls of passing ships and iron and steel debris such as discarded anchors, as well as geologic noise from certain mineral deposits. In addition, the corrosivity of the underwater environment, particularly in shallow saltwater where more oxygen is available, causes the iron and steel components of MEC to corrode, reducing the magnetic signature.

Electromagnetic induction systems also have a number of problems. The electrical conductivity of water limits the penetration of electrical and electromagnetic energy. In time-domain systems, such as the Geonics EM-61, the signal decay occurs at a slower rate than on land, and the time gates of the system must be adjusted accordingly. Operation in sea water, with its high salinity, can cause a high power draw, which makes a large supply of batteries necessary.[155]

9.2.2 Platform, Positioning, and Discrimination

The three common operational platforms for deploying MEC sensors are man-portable hand-held, towed-array, and airborne (see Section 4.2.3). The methods of underwater deployment are similar. Hand-held sensors are used by divers swimming along a search pattern. Towed arrays containing several magnetometers can be pulled along the bottom. Arrays can also be suspended from an underwater mast or other device and "flown" along, either at a fixed distance below the surface of the water or at a fixed distance above the bottom. In the near-shore areas, detectors can be affixed to floating platforms as well.[156]

Positioning techniques vary depending on the platform employed. The simplest means of identifying the position of an anomaly is similar to the land-based "Mag and Flag." The anomaly position is marked by or in relation to a buoy. Arrays employ differential global positioning system (DGPS) to mark the position of any anomaly. More sophisticated platforms will also use a high-frequency echo sounder to accurately record the distance between the sensors and the bottom.

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[154] P. Pehme, Q. Yarie, K. Penney, J. Greenhouse, and D. Parker. *Adapting the Geonics EM-61 for UXO Surveys in 0-20 Metres of Water.* Paper presented at the 2002 UXO/Countermine Forum, Orlando, FL, September 2002.

[155] Ibid.

[156] Wold. *A Review of Underwater UXO Systems in Europe*.

A number of factors affect the ability to discriminate between MEC and non-MEC. These include the instruments used, the platform, and the depth of the water over a target. For magnetometers, the apparent size of the anomaly depends on the elevation of the sensor above the anomaly. Thus, when interpreting the data, the depth of the anomaly must be taken into account. Two issues must be considered: (1) distance from the sensor to the sediment-water interface, and (2) distance of the anomaly below the sediment-water interface. The water depth above the sediment-water interface changes because of bottom topography, tides, and water level changes in rivers caused by floods and drought. For EMI, both the distance between the receiver coils and the anomaly and the separation between the transmitter and the receiver coils must be accounted for in the interpretation. In many cases, the instrument will not be able to determine the size or number of targets.

When the depth of the smallest object under investigation is within the detection limit of the sensor, the preferred platform is the surface of the water. In that situation, the attitude of the sensor is observable, the elevation of the sensor above the water bottom is known or can be determined, and the sensor position is easily measured using a GPS. However, wave action will significantly affect the attitude and the stability of the surface sensor and therefore the detectability of MEC. For anomalies approximately the size of a 12-pound MEC item, the depth limit (water depth and distance below the bottom sediments) is approximately 1.5 to 2 meters for a typical magnetometer or EMI instrument.[157]

At depths of approximately 2 to 4 meters, the geophysical sensors can be placed on a partly or fully submerged platform. This platform is rigidly linked to the watercraft, whose position is monitored by GPS. An alternative arrangement is to attach the GPS antenna to a bottom-holding system.[158]

At depths greater than 4 meters, controlling and measuring the depth and position of a submerged platform becomes more difficult. The depth to the bottom of a bottom-holding platform can be estimated by triangulation based on the measured water depth and the length of a towing cable. If the platform is flown above the bottom, controlling and monitoring the distance between the bottom and the platform's sensors are more difficult. The interpretation of an anomaly's size and depth can be strongly influenced by the indeterminate elevation of the platform sensors.[159]

Unlike land surveys that use various towed arrays, underwater surveys and equipment can be severely affected by the weather. Wave conditions, even on an otherwise good weather day, can cause serious safety concerns as well as place significant stress on a towed array. An array that is designed to handle the drag while being pulled in calm water can crumple under the additional stress created by waves.

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[157]Pehme, et al. *Adapting the Geonics EM-61 for UXO Surveys in 0-20 Metres of Water*.

[158]Ibid.

[159]Ibid.

9.2.3 Use of Divers for Detection

The oldest technology used to search for MEC underwater is manual searching using divers. Land-based searches involve technicians walking a search pattern and (usually) using a sensor. The only difference in the underwater environment is that the technician is a diver who conducts a visual and instrument-guided search. The instrument is normally hand-held. The search pattern is usually a grid marked out by a set of buoys or an expanding circle with a single buoy anchoring the center of the circle.

9.2.4 Other Technological Approaches for Detecting Underwater MEC and UXO

Magnetometers and EMI instruments can both be adapted for use in the underwater environment. For example, a variety of approaches have been developed to deploy cesium magnetometers for surveying harbors, lakes, rivers, swamps, and tidal regions. One German company is developing a system to tow a cesium sensor array in a 500-meter-deep lake to locate toxic gas containers and UXO.[160]

In the paper *A Review of Underwater UXO Systems in Europe*, presented at the 2002 UXO/Countermine Forum, it was noted that all groups that provide commercial underwater MEC/UXO surveys in Europe used arrays of magnetometers. The study did not report on any use of EMI sensors. Side-scan sonar often is used to map the bottom. Three approaches used for deployment of the magnetometer sensor arrays include suspending the array at a fixed depth, towing along the bottom, and maintaining a fixed distance above the water bottom or at a fixed depth. For data processing and analysis, visual interpretation of the data was shown to be the best way to detect UXO.[161]

The following section presents three case studies, one of an underwater towed-array magnetometer, the second of a modified Geonics EM-61, and the third of the test program. The case studies were conducted to survey underwater MEC/UXO under live conditions.

9.2.4.1 *Case Studies*

Case Study 1: Use of Hand-Held Detectors

A shallow-water procedure for USACE munition clearance projects is analogous to the "Mag-and-Flag" procedures used on land. Grids are set up and surveyed with a hand-held detector. Two projects where this process has been performed in shallow water of 3 feet or less are Buckroe Beach and the Former Erie Army Depot.[162]

In 1992, a UXO clearance was conducted at Buckroe Beach in Hampton, Virginia, along the beach and to a depth of 3 feet below the surface of the water. A systematic search of the surf zone used a procedure for laying out grids using weighted ropes and then sweeping the lanes. Five-man

[160]Wold. *A Review of Underwater UXO Systems in Europe*.

[161]Ibid.

[162]Edwards and Selfridge. *Munition Item Detection Systems.*

teams used underwater all-metal detectors to locate ordnance in the subsurface bottom to a depth of 6 to 12 inches. Using this search method, live projectiles and expended ordnance items were successfully detected and recovered.

In 2002, a beach and shallow-water area survey at the former Erie Army Depot along the shore of Lake Erie southeast of the mouth of the Toussaint River was conducted. A total of 29 grids along the beach were cleared. The grids were 200 feet wide and extended 200 feet toward the lake until 3 feet of water was reached. Hand-held magnetometers were used to identify potential munition items. After an item was identified, its position and identification data were loaded into a data logger. Fuzed items were remotely moved to the beach with ropes and pulleys.

Case Study 2: Use of a Towed-Array Magnetometer

In a presentation at the 2002 UXO/Countermine Forum, an American company reported on the efforts of several European companies conducting commercial UXO services in Europe.[163] One such effort was a survey of a harbor on the Gulf of Bothnia, where the ship channels and turnaround areas of the harbor were being deepened. At the beginning of the dredging project, it was discovered that a significant UXO problem existed. UXO ranging from 37 mm items to 500 kg bombs were found in the harbor bottom. In some cases, whole crates of munitions were found.

A company from Finland conducted a magnetometry survey of the harbor. The base configuration consisted of four cesium magnetometers spaced 1.8 meters horizontally. The conditions of the harbor bottom did not permit the magnetometer sensor array to be towed along the harbor bottom. Two approaches to suspend the magnetometer sensor array above the harbor bottom were tried. The first approach used a 3- by 4-meter raft to tow the magnetometer sensor array, which was fixed to an aluminum wing. This approach worked well and is still used when the depth of water does not exceed 20 meters.

A second approach involved the use of a 6- by 12-meter aluminum raft supporting the magnetometer sensor array on a cross piece connected to two plastic vertical supports. The magnetometer sensor array can be fixed to a maximum of 17 meters below the raft. An altimeter and x and y accelerometers are located in the center of the cross piece. Differential global positioning system track coverage is displayed for the operator and on the bridge of the raft. A magnetic base station and GPS reference station are operated onshore. The raft travels at 2 knots, and the magnetometers take 10 readings per second. The line spacing is 5 meters.

The magnetic data, coordinates from Differential global positioning system, and the high-frequency echo sounder data are recorded to a computer. Preliminary data processing is done in the field. The onshore magnetic base station is used to compensate for the natural variations of the Earth's magnetic field. The differential correction applied to the GPS data is done using the GPS base station data and Ashtech's PNAV program. GTK's own programs and Geosoft Oasis Montaj are used for data control and processing. The magnetic total field data are filtered by bandpass filter (1-30 or 3-30 m) to remove the effects of geological formations and measurement noise.

[163]Wold. *A Review of Underwater UXO Systems in Europe.*

The GTK survey reported that for detecting all MEC and UXO, visual interpretation proved best for evaluating the data. The magnetic profiles of the four sensors are studied simultaneously. To locate the targets, GTK technicians compared the measured anomalies with the results obtained from test bomb measurements. Since the size of the magnetic anomaly depends on the elevation of the magnetic sensor, the depth to target must be taken into account during interpretation. The report's conclusions did not discuss the actual success of the harbor survey.

Case Study 3: Use of Modified EM-61

In an EMI survey conducted offshore at Dartmouth, Nova Scotia, project technicians modified the Geonics EM61-MK2.[164] Peak transmitter power in the EM61-MK2 was increased to 288 watts from 81 watts in the standard system. In addition, the frequency of the transmitter pulse was doubled and made bipolar. The standard EM61-MK2 has a unipolar transmitter pulse. This combination results in a transmitter dipole moment of 1,248 Am^2 versus the standard 156 Am^2. This modification enabled the sensor to detect deeper objects. Another modification increased the dipole moment on the transmitter loop. Further modifications were considered in order to overcome the problem of detecting very deep anomalies.

To detect the very deep anomalies, it was necessary to get the receiver closer to them. Numerous designs were modeled and tested. These tests resulted in dropping the requirement that the receiver coil have a fixed offset from the transmitter coil. This change allowed the transmitter to be maintained on a stable surface platform while varying the receiver position to allow it to get as close as possible to the target anomalies. The advantage of this modification is that the transmitter at the surface is on a stable platform that could be accurately positioned. The disadvantages include the difficulty in knowing the position of the receiver and the variability of the distance between the transmitter and the receiver, making the comparison and analysis of anomalies more difficult. This modification could detect accumulated metal on the bottom but did poorly at resolving and interpreting individual anomalies.

A reconnaissance survey was conducted to outline the general distribution of UXO resulting from a 1945 fire and explosion at Rent Point, CFAD Bedford, Canada. This reconnaissance survey required the instrument to operate from the shoreline to a depth of greater than 15 meters. In water less than 2 meters deep, the survey used a simple configuration consisting of a standard high-power EM61-MK2 with modified time gates on a raft. Where the water depth was greater than 2 meters, the modification was as follows: The primary field was created by a 5- by 8-meter transmitter coil floating on the surface. A 1- by 1-meter receiver coil was suspended below the transmitter and at a depth approximately 2 meters above the bottom. The system was combined with a digital echo sounder on the towing boat and real-time GPS mounted on the transmitter coil for positioning.

The results of the reconnaissance survey were fairly good. The system for shallow water produced good detection capabilities. The deep-water system was able to detect small objects at intermediate depths and accumulations of objects at greater depths. Because the elevations of the transmitter and the receiver above the seabed could not be accurately controlled, no attempt was made to identify and compare the size of the targets based on the amplitude of their anomalies.

[164]Pehme, et al. *Adapting the Geonics EM-61 for UXO Surveys in 0-20 Metres of Water*.

However, additional research to improve anomaly discrimination and to better assess the size of the target is planned.

Case Study 4: Mare Island Naval Shipyard Validation of Detection Systems Test Program

The Department of the Navy identified seven sites (four offshore and three onshore) at the former Mare Island Naval Shipyard (MINS) in Vallejo, California, that potentially contained MEC. The Naval Facilities Engineering Command, Pacific Division, contracted with Environmental Chemical Corporation (ECC), Burlingame, California, to perform a Validation of Detection Systems (VDS) test program at MINS.[165]

The VDS test program was performed over a 5-week period beginning on August 30, 1999. The objective of the program was to identify, select, and validate detection equipment and technologies that could be used to locate and detect MEC at the four offshore sites at MINS. Secondary objectives of the VDS test program included the following:

- Determine which types and models of subsurface investigative instruments are successful underwater.
- Quantify the detection capacity of the equipment, attempting to obtain a 0.85 detection rate with a 90 percent confidence level.
- Quantify the false alarm ratio (FAR), attempting to minimize it.
- Determine the detection capabilities for each equipment type and system used, providing detection capabilities for each type and system in specific detection scenarios. Scenarios will exercise detection capabilities based on target composition, density mass, and depth below bottom surface.
- Determine the capabilities of the equipment to accurately match underwater geophysical anomaly data to physical reference points, either through DGPS or through other tracking and mapping techniques.
- Demonstrate that underwater anomaly data can be recorded for subsequent post-processing and analysis.
- Demonstrate that the anomaly data collected can be used to reacquire targets.

The program tested vendors' systems to determine which systems had a total probability of detection rate of at least 0.85 or higher with a 90 percent confidence level. Since more than 250 underwater targets would be required to establish a total confidence level of 90 percent, ECC decided to use only as many targets as necessary to establish the probability-of-detection goal of 0.85. The test program succeeded in evaluating and differentiating between technologies in order to determine the strengths and weaknesses of each. The VDS test results show that two vendors had the most success in detecting underwater targets. One vendor's detection system consisted of an underwater version of the Geonics EM-61 with a single coil. The second vendor's detection system was made up of two systems: a magnetic system using a four-sensor array consisting of Geometric G- 858 cesium vapor magnetometers that provide initial location data, and an electromagnetic system employing a single GEM-3 sensor that further characterizes the data set. The VDS results showed that the vendor using the Geonics EM-61 with a single coil was able to meet and exceed this

[165] ECC. *Validation of Detection Systems.*

goal with a detection rate of 0.99. The second vendor, using the combination system described above, barely missed this goal with a detection rate of 0.84.

Another objective of the test program was to minimize the FAR. The combination system with a FAR of 7 percent had the lowest of the five test participants. The Geonics EM-61 with a single coil was second, with a FAR of 18 percent. Both results show very strong detection capability.

Case Study 5: Use of a Helicopter

Airborne platforms can be successfully employed to detect underwater UXO under certain circumstances. One such effort was conducted in March 2002 using a helicopter geophysical survey to detect and map UXO at the site of the former Camp Wellfleet in Massachusetts.[166] The survey was done in an area that is now encompassed by the Cape Cod National Seashore. It was carried out with the Oak Ridge Airborne Geophysical System (ORAGS) Arrowhead magnetometer array. ORAGS consists of an eight-magnetometer array with sensors mounted in three booms (port, forward, and starboard). This arrangement is shown in Figure 9-3, has two sensors in each lateral boom and four sensors in the arrowhead-shaped forward boom. A fluxgate magnetometer is mounted in the forward boom to compensate for the magnetic signature of the aircraft. A GPS electronic Navigation system, using a satellite link, provided navigation for the survey. Differential post-processing produced more accurate positioning of the geophysical data. Altitude was measured with a laser altimeter. Over the beach and surf zone, where vegetation was low or absent, sensor heights of 1 to3 meters above ground level were regularly attained. Aircraft ground speed was maintained at approximately 12 meters per second, or 27 miles per hour. The GPS and diurnal monitor base stations were established at the airport in Hyannis, Massachusetts, at a known geodetic marker. Figure 9-4 is an orthophoto of the north beach area with targets indicated. Figure 9-5 is the corresponding magnetic map of the analytic signal.

Figure 9-3. Airborne Geophysical Survey Helicopter Platform (from Oak Ridge National Laboratory, 2002).

[166]Edwards and Selfridge. *Munition Item Detection Systems.*

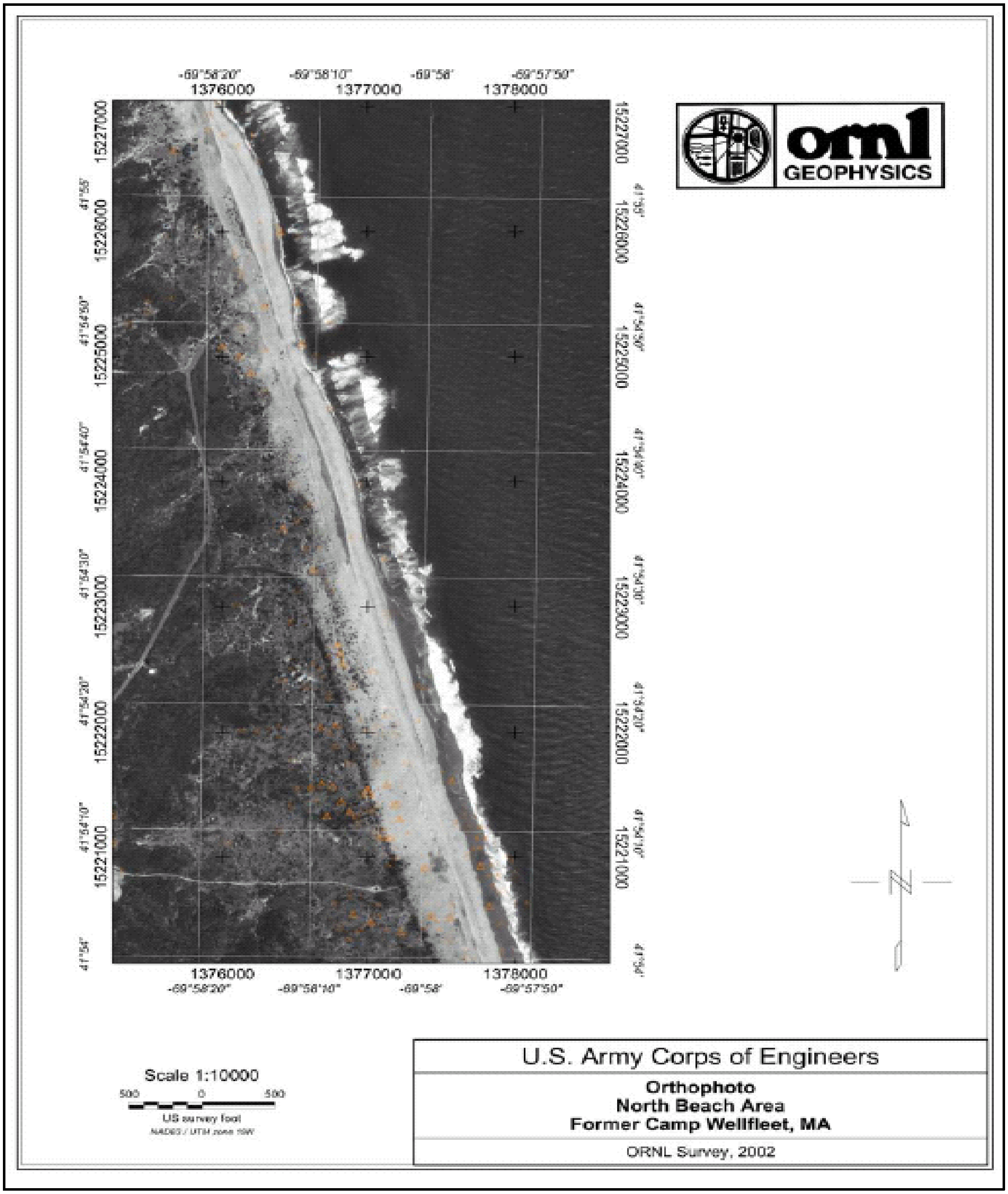

Figure 9-4. Orthophoto of North Beach Area, Former Camp Wellfleet, Massachusetts, with Detected Targets Indicated with Orange Triangles (from Oak Ridge National Laboratory, 2002)

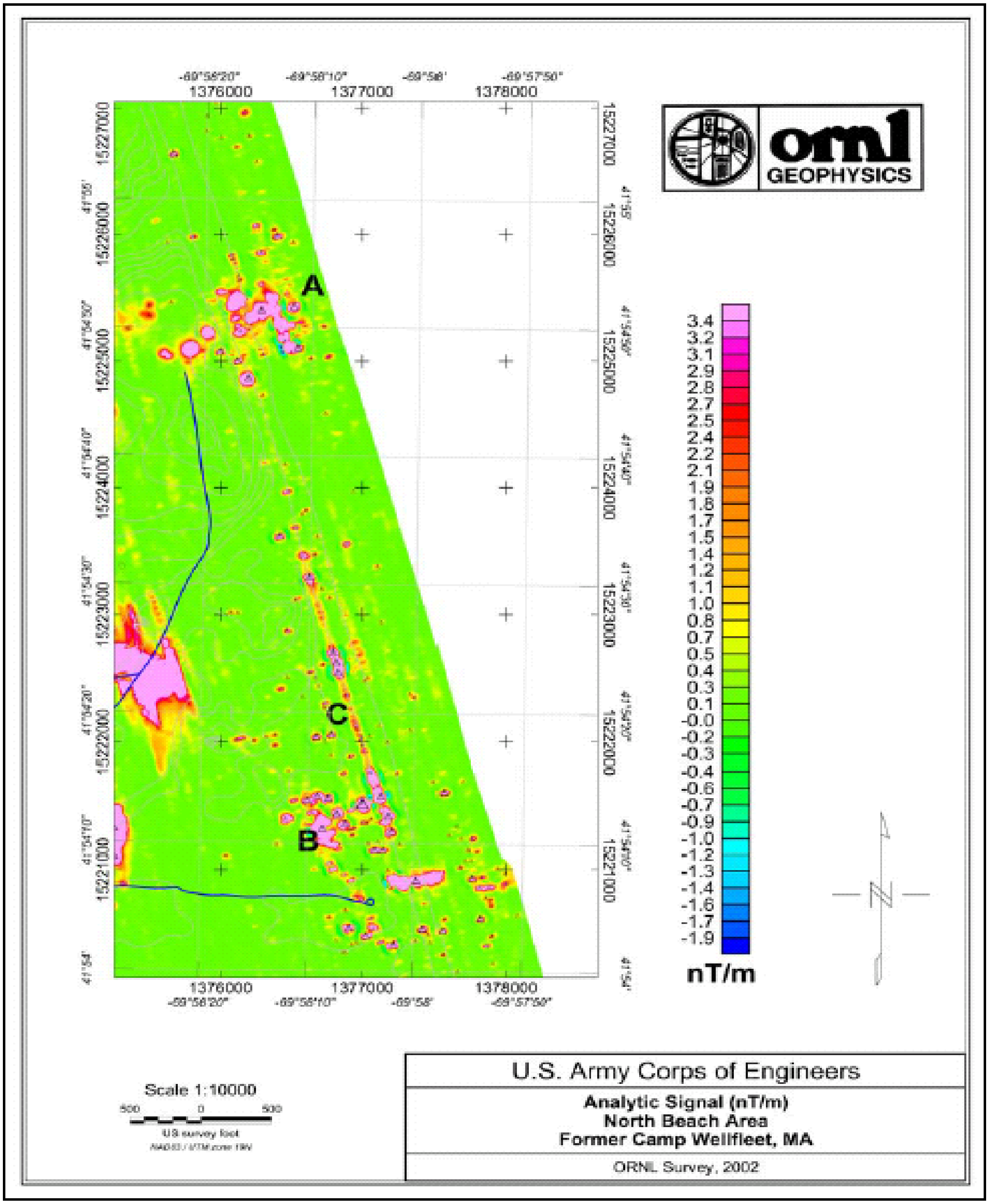

Figure 9-5. Map of the Analytic Signal of North Beach Area, Former Camp Wellfleet, Massachusetts (from Oak Ridge National Laboratory, 2002)

9.2.4.2 *Mobile Underwater Debris Survey System*

Among the potential detection technologies under development is the Mobile Underwater Debris Survey System (MUDSS), a Multisensor, towed, underwater MEC detection and identification system. MUDSS works by combining magnetic, sonar, trace chemical, and electro-optical identification sensor (EIS) technologies in a submersible, torpedolike vehicle that feeds high-speed data to a "mothership" through a fiber-optic cable.[167]

MUDSS was demonstrated during a UXO survey of a region of Choctawhatchee Bay in Florida that is adjacent to a World War II practice bombing range. The test, which was funded by the Strategic Environmental Research and Development Program (SERDP), was conducted during a 5-day period in November 1998. MUDSS was deployed from a surface vessel over a 2-square-mile shallow area (15- to 30-foot depth). Researchers traced a set of 92 parallel search tracks across the survey region. The search tracks were surveyed using a high-frequency/low-frequency (HF/LF) synthetic aperture sonar (SAS) sensor and a magnetic gradiometer array sensor to detect and locate the position of potential UXO targets. Potential targets were tagged with GPS coordinates. The MUDSS survey plan was to then reacquire nonburied targets and collect an EIS image of each target to determine whether the target was UXO. Buried targets were later investigated by divers using hand-held magnetic sensors. The divers also collected sediment samples near the confirmed buried targets to determine the presence of trace munition constituents.[168]

The MUDSS calibration tests on planted targets (ranging from a 60 mm mortar projectile to a 1,000-pound bomb) demonstrated that the HF/LF SAS, magnetic array, and EIS successfully detected and imaged calibration targets at ranges consistent with environmental conditions that included poor water clarity. MUDSS analysis of sonar and magnetic sensor survey data showed most bomblike targets were buried. Of the 492 buried magnetic targets detected, 135 targets had magnetic size and orientation consistent with UXO. This meant that MUDSS was able to eliminate 357 items as not being UXO. Eighteen of the 135 remaining targets were selected as the best targets for diver verification.[169] Using hand-held sensors, the divers were able to excavate and confirm that one target was a 500-pound bomb that was UXO and two targets were not UXO. The remaining anomalies investigated were not confirmed because of either the burial depth or the divers' inability to reacquire the anomalies using hand-held sensors.[170]

Only three suspected UXO targets had potential UXO-like acoustic signatures. Divers were unable to verify these as being UXO. The explanation offered was that the UXO bombs were buried too deeply in Choctawhatchee Bay for the sonar to detect them. Poor underwater visibility resulted in no UXO detection by the EIS.[171]

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[167]D.C. Summey. *MUDSS UXO Survey at Choctawhatchee Bay, FL.* Partners in Environmental Technology. Poster No. 80. Presented at the 2002 UXO/Countermine Forum, Orlando, FL, September 2002.

[168]Ibid.

[169]Ibid.

[170]D.C. Summey, J.F. McCormick, and P.J. Carroll. *Mobile Underwater Debris Survey System (MUDSS).* ND.

[171]Ibid.

The researchers presented the following conclusions:

- The Choctawhatchee Bay tests confirmed the need for the MUDSS multiple sensor approach. For very difficult underwater environments, the use of multiple sensors to evaluate potential UXO targets increases the potential for identifying UXO.
- MUDSS potentially reduces the time and resources required to survey unknown underwater sites that contain MEC.
- Additional analysis of the Choctawhatchee Bay data is needed to evaluate the effectiveness of MUDSS' full system capabilities, including the EIS.[172]

Additional testing and development of this system is expected to improve its ability to successfully locate submerged and buried MEC items.

9.2.4.3 *Chemical Sensors*

One of the problems associated with the use of magnetometry and EMI is the difficulty associated with distinguishing between iron-containing debris and actual MEC or UXO items. This situation can slow the remediation of an underwater UXO site because the identity and status of each anomaly must be confirmed. This procedure can be very time-consuming and cost-intensive. An experimental approach is being investigated that seeks to identify the chemical signature of individual munition constituents, such as TNT, underwater in real time.[173]

The source of munition constituents in underwater environments is either UXO or munitions items that have undergone low-order detonation, "bleed out" of intact or damaged munitions, or disposal of bulk material. The chemical signatures of individual munition constituents can be used to determine the presence and location of munition or UXO items. The chief problems associated with detecting the chemical signatures include dilution, the variety of naturally occurring substances, and particulate matter underwater. To overcome these problems, any sensor used must have very finely defined sensitivity to measure very low (< 1 ppb) concentrations and the ability to discriminate between the target munition constituent and other potentially interfering substances.[174]

9.3 Safety

Underwater environments magnify some of the problems identified in Section 6 ("Explosives Safety") with respect to both human and ecological receptors. The primary threat to safety is the increased danger posed by an underwater detonation. The average safe distance from an underwater detonation can be over five times that of a land detonation for an equivalent amount of an explosive mixture.[175] Whereas the dangers posed by a land detonation include fragmentation, debris, and the shock wave, the danger posed by an underwater detonation is primarily from the shock wave.

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[172] Ibid.

[173] Dock, et al. *Sensor for Real-Time Detection of Underwater Unexploded Ordnance.*

[174] Ibid.

[175] The actual evacuation distance is based on the net explosive weight of the ordnance item.

The underwater environment is generally more unstable to work in than on land because of the action of waves, tides, and currents. Low visibility, sedimentation, and biological and mineral coatings on MEC items also make identification much harder. For example, determining if a potential UXO item is fuzed and armed, or what type of fuze or fuzes are present, can be nearly impossible.

Because of the danger posed by an underwater detonation, divers must be out of the water before moving any MEC or UXO item or attempting to blow it in place. Current practices are costly and time-consuming. Technologies that rely much less on divers need to be developed so that underwater remediation is safer and more cost-effective.

9.4 Underwater Response Technologies

9.4.1 Blowing in Place

The most common technique for dealing with UXO is in-place open detonation, also known as blowing-in-place (BIP). However, BIP is hazardous to humans in the water and to aquatic life, as well as harmful to sensitive environments, such as wetlands and coastal marshes. It is necessary to coordinate with Federal, State, and local regulatory officials to obtain approval for BIP, as marine biota, such as sea turtles and marine mammals, may be affected at substantial distances from an underwater detonation.

The rapid shockwave pressures associated with underwater detonations can cause adverse biological effects. The primary blast injury in marine mammals and sea turtles, other than death as a result of the underwater detonation, has been shown to be to the auditory, respiratory, and gastrointestinal organs. Depending on water conditions, sound travels further underwater than the pressure wave generated by the detonation.[176]

> **Detonation Tools**
>
> Low-order detonation tools are designed to transmit sufficient energy to an MEC/UXO case to rupture it without causing a full detonation reaction in the explosive charge.

BIP may be necessary because of the hazardous nature of the UXO. One technique to mitigate the effects of BIP involves the use of low-order instead of high-order detonation. A low-order detonation is any explosive yield less than high order. Planning to conduct low-order detonations must include the possibility of a high-order detonation. The reduction in explosive yield depends on a number of factors, including but not limited to, the type of ordnance, explosive fill, detonation tool, and technique.

The availability of low-order detonation technologies has increased, providing potential alternatives to traditional BIP procedures for surface MEC. Low-order detonation tools are designed to transmit sufficient energy to an MEC case to rupture it without causing a full detonation reaction in the explosive charge. It is possible in some cases to reduce the explosive yield of a large MEC item by up to 90 percent. However, a consequence of low-order detonations may be the release of significant amounts of munition constituents into the underwater environment. These releases must

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[176] *Mitigation Options for Underwater Explosions.* Prepared for the Naval Undersea Warfare Center, Waianae, HI. September 19, 2000.

be accounted for and managed in underwater response activities. Research is being conducted in the application of low-order BIP as a response action that reduces the effect on underwater environments.[177]

One low-order detonation tool, called HL21, was developed in Germany. The HL21 uses a shaped charge to rupture the UXO casing and has been used successfully on surface UXO. Tests of the system were conducted in water-filled 55-gallon drums that contained 155 mm TNT-filled, nonfuzed projectiles. In five trials, the low-order detonation of 155 mm projectiles generated large fragments and small amounts of TNT.[178] Further testing is planned.

Another technique to mitigate BIP involves using physical barriers. Sandbags, concrete blocks, or other barriers can be used to surround the MEC item. The barrier can be formed to focus the sound and shock waves upward, reducing lateral effects. This technique is likely to work only in shallower water, as there are practical limits on the height of a barrier constructed underwater.

9.4.2 Dredging

Dredging can be a cost-effective and productive method for removing underwater MEC. Dredging excavates large areas and does not require detection or positioning of each MEC item. However, removing MEC by dredging is not necessarily a precise process and presents risks from both detonation of MEC and exposure to munition residues. Sediment turbidity inhibits visual verification of MEC removal, so monitoring the dredge discharge may be necessary. Dredging can also leave some MEC behind. Most of the MEC left behind will be on the newly dredged surface, and some of these MEC items can become mobile.[179] Additionally, dredging only transports potential MEC from one place to another. The dredge spoils potentially containing MEC may also require a munitions response action. Consideration should be given to offshore location and depth in determining whether MEC contained in offshore sediments pose a significant threat to human health and the environment.

Hydraulic and mechanical dredging methods vary in cost, effectiveness, and safety. Hydraulic dredging may be more productive and cost-effective for removing material that does not contain concentrated, highly sensitive, or large MEC items. Mechanical dredging is suitable for sensitive and large MEC items, and it may provide increased removal reliability. Engineering protective measures or the use of remotely operated equipment must be implemented to ensure worker safety. However, mechanical dredges are not appropriate for removing large areas of material because of their low productivity. A hybrid approach for removal of sensitive MEC items combines the benefits of the mechanical dredge's removal reliability and the hydraulic dredge's productivity. Therefore, the hydraulic dredge may be used to remove large volumes of material while rejecting or avoiding MEC. The mechanical dredge would then be used to collect the MEC from the bottom.[180]

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[177] A. Pedersen. *Low-Order Underwater Detonation.* Environmental Security Performance Report. November 2002.

[178] Ibid.

[179] Edwards and Selfridge. *Munition Item Detection Systems.*

[180] Ibid.

Dredging methods may have useful applications in UXO removal but to date have not been integrated with detection methods and means of separating metallic materials from nonmetallic materials.[181]

[181] Ibid.

SOURCES AND RESOURCES

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

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U.S. EPA. *Health Advisory for Octahydro-1,3,5,7-Tetranitro-1,3,5,7-Tetrazocine (HMX)*. Criteria and Standards Division, Office of Drinking Water, Washington, DC. November 1988.

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10.0 CHEMICAL MUNITIONS AND AGENTS

10.1 Introduction to Chemical Munitions and Agents

Chemical munitions and agents are defined by the Department of Defense Explosives Safety Board (DDESB) as:

> *An agent or munition that, through its chemical properties, produces lethal or other damaging effects to human beings, except that such term does not include riot control agents, chemical herbicides, smoke or other obscuration materials.*[182]

The presence of chemical agents can add significantly to the complexity of an MRS site investigation. Risks include potentially lethal contamination by releases of liquid or vapor forms of the chemicals, in addition to the explosive hazards of fuses, boosters, bursters, or propellants that may exist within munitions. The presence of chemical agents and/or their degradation products may pose a threat to soil and groundwater.

The majority of the chemical weapons in this country are considered stockpile chemical weapons.[183] Stockpile weapons are weapons and bulk agents that could be used in a retaliatory strike against an opponent or could serve as a deterrent to such a strike. **Stockpile items are made up of chemical agents and munitions that have been maintained under proper storage and accounting procedures since their manufacture.** Under the Chemical Weapons Convention, all stockpile weapons in the United States must be destroyed by April 29, 2007, unless an extension of up to 5 years is given.

The Chemicals in This Chapter

The lists of chemical warfare agents described in this chapter are taken from the *Convention in the Prohibition of the Development, Production, Stockpiling and Use of Chemical Weapons*, Annex on Chemicals. This list does not include all of the chemicals contained in that Annex, but rather focuses on those most commonly tested in the United States.

In addition to agreeing to destroy the chemical weapons stockpile, the United States also agreed to dispose of all other chemical weapons-related materiel, which are considered non-stockpile materiel. Non-stockpile chemical warfare materiel (NSCWM) consists of five categories: (1) binary chemical weapons,[184] (2) former chemical weapons production facilities, (3) unfilled munitions and devices, and chemical samples, as defined by the Chemical Weapons Convention, (4) chemical weapons already recovered from pre-1969 land disposal sites, and (5) buried CWM yet to be recovered. Such materiel exists at hundreds of locations as a result of routine disposal by burial that was conducted prior to the 1969 changes in public laws. Since it is reasonably expected that only non-stockpile chemical materiel would be found at MRSs and other defense sites, this chapter addresses only non-stockpile chemical materiel.

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

[183]This chapter does not address chemical weapons of foreign origin.

[184]*Binary chemical weapons* refers to the concept of developing nontoxic precursors that can be loaded in munitions. Once deployed, the precursors mix and develop the nerve agent.

Chemical agents achieve their effects through chemical actions rather than through blast, fragments, projectiles, or heat, which are normally associated with explosives. Chemical agents are characterized by the potential human health effects, which range from incapacitation to lethality. The actual effects of exposure vary with the type and concentration of the agent, form (gaseous, liquid), dose and pathway, and susceptibility of the exposed individual. Chemical agents are classified as nerve, blister, blood, choking, tear gas, and vomiting agents. Definitions for each of the classifications and their relative toxicities are discussed in Section 10.4.

Because of the overlap of detection methods, remediation techniques, and safety considerations for chemical and conventional explosive munitions, this chapter focuses on those issues that differentiate chemical munitions from conventional explosive munitions.

10.2 Where Chemical Munitions and Agents Are Found

10.2.1 Background

Chemical agents can be found in most types of munitions, including grenades, artillery projectiles, bombs, mines, and rockets. Chemical agents also are found in various storage containers, such as one-ton containers, PIGS and Chemical Agent Identification Sets (CAIS), that might be found at burial sites. CAIS have been routinely used in personnel training since World War I and are considered chemical warfare materiel (CWM). These may be found on any military facility where troop training was conducted. CAIS come in three principal types that contain real chemical agent in bottles or vials to be used in different types of training exercises. CAIS were used from 1928 to 1969 and were widely distributed during World War II. During the World War II era they were frequently disposed of by burial.

Containers of Chemical Agent

One-ton containers:

- Bulk cylindrical steel containers
- Hold 170 gallons of materiel
- 101.5 inches long, 30.5 inches in diameter
- Three types (A, D, and E)

PIGS:

- Cylindrical forged steel shipping container
- Used to transport and store Chemical Agent Identification Sets (CAIS) and laboratory standards
- 38 inches long

CAIS:

- Used for field training
- Kits contain glass tubes/vials of different chemical agents such as:
  - mustard (H)
  - lewisite (L)
  - phosgene (CG)
  - chlorpicrin (PS)

Seven different configurations of CAIS kits were made by the Army and Navy over a period of close to 50 years. Three principal varieties of these are still found today: (1) toxic gas sets (100 ml bottles of mustard), (2) gas identification sets (40 ml heat-sealed vials with dilute agents except for pure phosgene), and (3) Navy or sniff sets (filled with charcoal on which 25 ml of agent was placed). They were intended for use by troops during training so that different chemical agents could be properly identified and decontaminated in combat. Complete sets contained from 2 to 48 bottles or vials, depending on the type of set. Some complete sets contain small quantities of agent, while others contain as much chemical agent as is normally found in large projectiles.

Many munitions of the World War II era, such as 4.2 inch mortars, M47 and M70 bombs, Livens projectiles, 75 mm projectiles, 4 inch Stokes mortars, and others, had both lethal chemical fills and smoke and/or incendiary fills, all of which are liquid. In addition, some industrial compounds were used to produce lethal effects. These include phosgene, hydrogen cyanide, and cyanogen chloride.

10.2.2 Stockpile and Non-stockpile CWM Sites

There are two basic categories of sites containing CWM and agents which are designated on the basis of how the materiel was stored: stockpile and non-stockpile CWM sites.

Stockpile CWM sites are those locations in the United States where all chemical agents and munitions that were available for use on the battlefield (including those assembled in weapons and in bulk one-ton containers) are stored. There are currently eight locations that the United States has control of where stockpile CWM is found: Umatilla Depot, Oregon; Tooele Army Depot, Utah; Pueblo Depot, Colorado; Newport Army Munition Plant, Indiana; Aberdeen Proving Ground, Maryland; Lexington Blue Grass Army Depot, Kentucky; Anniston Army Depot, Alabama; and Pine Bluff Arsenal, Arkansas. (Destruction of CWM at Johnston Atoll has been completed.)

In 1985, the U.S. Congress passed Public Law 99-145, which requires the destruction of the stockpile of lethal chemical warfare agents and munitions in the United States. A 1997 decision to ratify the Chemical Weapons Convention required the destruction, by 2007, of all stockpiled CWM, and all non-stockpile CWM known at the time of the signing. The United States and other signatories are in the process of moving aggressively to meet this requirement. However, the United States has acknowledged difficulty in achieving this goal and has requested the allowed 5-year extension.

Non-stockpile Chemical Materiel

Non-stockpile chemical materiel includes the following categories, all of which could be located at MRSs:

- **Buried chemical materiel** – materiel that was buried between World War I and at least the late 1950s, during which time burial was considered to be a final disposal solution for obsolete chemical weapons.
- **Binary chemical weapons** – munitions designed to use two relatively nontoxic chemicals that combine during functioning of the weapons system to produce a chemical agent for release on target. (These weapons were neither widely produced nor tested in the United States.)
- **Recovered chemical weapons** – those weapons retrieved from range-clearing operations, research and test sites, and burial sites.
- **Former chemical weapons production facilities** – facilities that produced chemical agents and other components for chemical weapons.
- **Other miscellaneous chemical warfare material** – includes unfilled munitions and devices; samples; and research, development, testing, and evaluation materials that were used for the development of chemical weapons.

According to the Army's Program Manager for Chemical Destruction, as of June 8, 2003, 26 percent of the original stockpile of chemical agent in the United States had been destroyed, and 39 percent of chemical munitions had been destroyed. More information can be found on their website: http://www.pmcd.army.mil.

The second category of CWM and agents is referred to as non-stockpile chemical materiel (NSCM). This is a diverse category that includes all other chemical weapon-related items, such as lethal wastes from past disposal efforts, unserviceable munitions, and chemically contaminated containers; chemical production facilities; newly located chemical munitions; known sites containing significant quantities of buried chemical weapons and waste; and binary weapons and components.

According to the National Research Council,[185] as of 1996, the Army identified 168 potential burial sites in 31 States and several territories (including the District of Columbia). Most are current or former military facilities. The majority of sites are thought to include small quantities of material. The information reported as of 1996 is updated regularly and maintained by the Product Manager for the Non- Stockpile Chemical Warfare Materiel (NSCWM) program.

NSCWM can be found in a range of different areas. It may be found at any site that manufactured or conducted testing of chemical agent and/or weapons, stored such materials as they were prepared for shipment overseas, or provided training to troops who used CAIS kits to identify chemical agent. Since development and testing of chemical weapons took place as early as the World War 1 era, and many military test sites have either changed uses over time or have been transferred out of military ownership, such locations are not always obvious. The National Research Council has asserted that "a major uncertainty for the non-stockpile program is the extent to which suspected burial sites will be excavated and what items will be found and recovered."[186] Sites that have been transferred out of military ownership (formerly used defense sites – FUDS) may represent a particular challenge. For example, in the World War 1 era, a test site owned by American University was the location of significant testing of chemical agent material by the military. That location is now in residential use. Non-stockpile material has been recovered and destroyed in ongoing investigations and cleanup activities likely to go on for a number of years.

NSCWM in Residential Delaware

On July 19, 2004, Explosive Ordnance Disposal (EOD) personnel from Dover AFB recovered an explosive munition embedded in a driveway made of clamshell paving material. This material was dredged off the Mid-Atlantic coast. The EOD team detonated the munition with a shaped charge whereupon a black tar-like substance began to ooze from the munition. Mustard agent (HD) was detected in the tar-like substance. The next day, 3 members of the EOD team were stricken with HD-related blisters. Army records indicate that 1,700 mustard filled rounds were dumped off the coast of Cape May, NJ in 1964.

10.3 Regulatory Requirements

The regulatory authorities for managing recovered CWM (RCWM) include all of the regulations that apply to explosive munitions, as described in Chapter 2. In addition, 50 USC 1512-1521 provide specific guidance to DoD on transporting, testing, and/or disposing of lethal chemical agent. The principal regulatory programs under which cleanup of RCWM at MRSs is conducted include CERCLA, RCRA, the Defense Environmental Restoration Program (DERP), and the safety standards of the DDESB. In addition, the Army, as the single manager for conventional

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[185]Systems and Technologies for the Treatment of Non-stockpile Chemical Warfare Materiel, National Research Council, Board on Army Science and Technology, National Research Council, National Academy Press, 2003.

[186]Ibid.

munitions (which includes chemical agents), has developed a number of regulations and guidance documents designed to specifically address the management of chemical agents.[187]

AR 50-6 outlines the policies, procedures, and responsibilities for the Army Chemical Surety Program, which is designed to provide tools to facilitate safe and secure operations involving chemical agents. AR 50-6 describes the policies for the safe storage, handling, maintenance, transportation, inventory, treatment, and disposal of CWM. The policy also provides safety and security control measures to ensure the safe conduct of chemical agent operations and personnel safeguards for the recovery of CWM discovered during environmental remediation activities or by chance. AR 385-61 establishes policies and responsibilities for the Army's chemical agent safety program, and DA PAM 385-61 describes the safety criteria and standards for processing, handling, storing, transporting, disposal, and decontamination of chemical agents. These chemical munitions-specific safety regulations are discussed again in Section 10.7.) Additional regulations are listed in "Sources and Resources" at the end of this chapter. In addition to U.S. regulations, disposal of CWM must also comply with the notification requirements of the CWC.

10.4 Classifications and Acute Effects of Chemical Agents

Chemical agents, such as blister, blood, choking, incapacitating, lacrimator (tear gas), vomiting, and nerve agents, are typically classified by the type of physiological action caused by exposure. A wide variety of chemical agents can be found on MRSs, either in their original form or in some deteriorated form.

The effects of these chemical agents include long-term chronic effects such as cancer or nerve damage and acute effects ranging from incapacitation to lethality. Effects vary with the type of agent, concentration, form, duration and route of exposure, and condition of the person exposed (e.g., elderly, children). All of these agents can cause death, some more quickly than others. When certain chemical agents are used in combination with each other, the speed and likelihood of lethality increases. The following sections provide an overview of the acute health effects of the different categories of chemical agents. Subsequent sections provide more detail related to chronic health effects and toxicity.

- **Blister agents** (vesicants) – work by destroying individual cells that come in contact with the agent. Blister agents, as the name implies, cause tissue damage, including blisters, on the skin and produce severe effects in the eyes and lungs (if inhaled). Compared with some of the other chemical agents, blister agents take longer to produce effects (4-24 hours) and are intended to cause incapacitation casualties for a longer duration (36 hours to several days). The following are considered blister agents:

  – Lewisite / L
  – Mustard-Lewisite Mixture / HL
  – Nitrogen Mustard / HN-1

[187]DoD Directive 5160.65, Single Manager for Conventional Ammunition, March 8, 1995. Many Army policies also are addressed in Army Regulation (AR) 50-6, *Chemical Surety*, February 1, 1995; AR 385-61, *Army Chemical Agent Safety Program*, February 28, 1997; and Department of the Army Pamphlet (DA PAM) 385-61, *Toxic Chemical Agent Safety Standards*, March 31, 1997.

- Nitrogen Mustard / HN-2
- Nitrogen Mustard / HN-3
- Sulfur Mustard Agent / H, HD or HS
- Mustard- T Mixture / Sulfur Mustard Agent / HT
- Phenyldichloroarsine / PD
- Ethyldichloroarsine / ED
- Methyldichloroarsine / MD
- Phosgene Oxime / CX

C **Blood agents** – affect bodily functions through action on an enzyme, resulting in the inability of cells to use oxygen normally. This interaction leads to rapid damage to body tissues. Blood agents are absorbed into the body through inhalation. The following are considered blood agents:

- Hydrogen Cyanide /Prussic Acid / AC
- Cyanogen Chloride / CK
- Arsine / SA

C **Choking agents** – damage the respiratory tract, especially the lungs. Affected cells in the respiratory tract become filled with liquid, and an oxygen deficiency results in choking and asphyxia. The following are considered choking agents:

- Phosgene / CG
- Diphosgene / DP

C **Nerve agents** – encompass a variety of compounds that have the capacity to inactivate the enzyme acetylcholinesterase (AChE). They generally are divided into two families, the G agents and the V agents. The Germans developed the G agents (tabun [GA], GB, and GD) during World War II. They are volatile compounds that pose mainly an inhalation hazard. The nerve agent GB is quick acting (5-10 minutes to onset of symptoms after inhalation), and very low doses may incapacitate a person for 1-5 days. The effects of higher doses include muscle contractions, suffocation, and death. V agents, which were developed later, are approximately 10 times more toxic than GB and are considered persistent agents, which means that they can remain on surfaces for long periods. The consistency of V agents is oily, thus they mainly pose a contact hazard. A highly toxic nerve agent, VX, acts by absorption through the skin and causes muscle contractions, suffocation, and death. The following are considered nerve agents:

- Tabun / GA
- Sarin / GB
- Soman / GD
- V-Agent / VX
- Cyclo-sarin / GF

- **Tear gas**[188] – irritates skin and eyes, causing short-term incapacitation. Prolonged exposure, such as in an indoor situation, can cause illness and death. The duration of incapacitation is approximately 10 minutes. Symptoms of exposure include burning eyes, tearing, and irritation of the respiratory tract. The following are considered tear gas agents:

  – Chloroacetophenone / CN
  – Chloropicrin / PS
  – Chloroacetophenone and chloropicrin in chloroform /CNS
  – Chloroacetophenone in benzene and carbon tetrachloride / CNB
  – Bromobenzylcyanide / CA
  – O-Chlorobenzylidene / CS *also* CS1 and CS2

- **Incapacitation agents** – block the action of acetylcholine both peripherally and centrally. The agent BZ, the only known incapacitation agent that is a central nervous system depressant, disturbs integrative functions of memory, problem-solving, and comprehension.

- **Vomiting agents** – induce nausea and vomiting. Physiological actions of vomiting agents include eye irritation, mucous discharge from the nose, severe headache, acute pain and tightness in the chest, nausea and vomiting. The following are considered vomiting agents:

  – Diphenylchloroarsine / DA
  – Adamsite / DM
  – Diphenylcyanoarsine / DC

10.4.1 Chronic Human Health Effects of Chemical Agents

Although CWM is most commonly thought of in relation to acute effects, chronic health effects are also significant. For example, if an exposure occurs outside the range of acute toxicity during an exposure event, or if a low level of exposure occurs due to the presence of small amounts of a particular chemical, then chronic effects such as cancer can occur.

Table 10-1 lists some of the common chemical agents and known chronic health effects. The table is organized by major category of chemical agent. Where no information on the chronic effects of a particular agent was found in readily available literature, it is noted as "not available."

Table 10-1. Chemical Agents and Their Potential Chronic Effects

Common Name	Chemical Name /Formula/CAS#	Potential Chronic Effects
Blister Agents/Vesicants		
Lewisite/L	Dichloro-(2-chlorovinyl)arsine	Chronic respiratory and eye conditions may

[188] Tear Gas is listed as a CWM when used in warfare. The U.S. implementing legislation exempts Tear gas from reporting requirements when found in concentrations of less than 80 percent.

Table 10-1. Chemical Agents and Their Potential Chronic Effects (continued)

Common Name	Chemical Name /Formula/CAS#	Potential Chronic Effects
	$C_2H_2AsCl_3$ CAS# 541-25-3	persist. Arsenical poisoning possible.
Mustard-Lewisite Mixture/HL	Not applicable (mix of components)	Chronic respiratory and eye conditions and arsenical poisoning. May produce respiratory and skin cancer.
Nitrogen Mustard/HN-1	2,2'-dichlorotriethylamine $C_6H_{13}Cl_2N$ CAS# 538-07-8	Possible human carcinogen. Chronic respiratory and eye conditions may persist. May decrease fertility.
Nitrogen Mustard/HN-2	2,2'-dichloro-N-methyldiethylamine $C_5H_{11}Cl_2N$ CAS# 51-75-2	Possible human carcinogen. Chronic respiratory and eye conditions may persist. May decrease fertility.
Nitrogen Mustard/HN-3	2,2',2"-trichlorotriethylamine $C_6H_{12}Cl_3N$ CAS# 555-77-1	Possible human carcinogen. Chronic respiratory and eye conditions may persist. May decrease fertility.
Sulfur Mustard Agent/H, HD or HS	Bis(2-chloroethyl) sulfide $C_4H_8Cl_2S$ CAS# 505-60-2	Carcinogenic to humans. May cause cancer of the upper respiratory tract, skin, mouth, throat, and leukemia. Chronic respiratory and eye conditions may persist. May cause skin sensitization. Potential teratogen.
Mustard-T Mixture/Sulfur Mustard Agent/HT	60% HD and 40% sulfur and chlorine compound CAS# 6392-89-8	Not Available
Phenyldichloroarsine/PD	Phenyldichloroarsine $C_6H_5AsCl_2$ CAS# 696-28-6	Similar properties and toxicities as lewisite.
Ethyldichloroarsine/ED	Ethyldichloroarsine $C_2H_5AsCl_2$ CAS# 598-14-1	Similar properties and toxicities as lewisite.
Methyldichloroarsine/MD	Methyldichloroarsine CH_3AsCl_2 CAS# 593-89-5	Similar properties and toxicities as lewisite.
Phosgene Oxime/CX	Dichloroformoxime $CHCl_2NO$ CAS# 1794-86-1	Not Available
Blood Agents		
Hydrogen Cyanide/Prussic Acid/AC	Hydrogen cyanide HCN CAS# 74-90-8	Similar to acute effects. Skin conditions have been reported. Long-term exposures have produced thyroid changes. Occasionally: chronic eye conditions.
Cyanogen Chloride/CK	Chlorine cyanide ClCN CAS# 506-77-4	Long-term exposures will cause dermatitis, loss of appetite, headache, and upper respiratory irritation in humans.
Arsine/SA	Arsenic trihydride AsH_3 CAS# 7784-42-1	Human carcinogen. May cause skin or lung cancer. Chronic arsenic exposure can affect skin, respiratory tract, heart, liver, kidneys, blood and blood-producing organs, and the nervous system.

Table 10-1. Chemical Agents and Their Potential Chronic Effects (continued)

Common Name	Chemical Name /Formula/CAS#	Potential Chronic Effects
Choking Agents		
Phosgene/CG	Dichloroformaldehyde Carbonyl chloride CCl_2O CAS# 75-44-5	Chronic exposure may cause emphysema, fibrosis, skin, and eye conditions.
Diphosgene/DP	Trichloromethyl chloroformate $C_2Cl_4O_2$ CAS# 503-38-8	Not Available
Nerve Agents		
Tabun/GA	Ethyl N,N-dimethylphosphoramidocyanidate $C_5H_{11}N_2O_2P$ CAS# 77-81-6	Weakness of skeletal musculature. In severe cases: disabling condition (muscle weakness and paralysis).
Sarin/GB	Isopropylmethyl-phosphonofluoridate $C_4H_{10}FO_2P$ CAS# 107-44-8	Weakness of skeletal musculature. In severe cases: disabling condition (muscle weakness and paralysis).
Soman/GD	Pinacolyl methyl-phosphonofluoridate $C_7H_{16}FO_2P$ CAS# 96-64-0	Weakness of skeletal musculature. In severe cases: disabling condition (muscle weakness and paralysis).
V-Agent/VX	O-ethyl S-[2-(disopropylamine)ethyl] methylphosphonothiolate $C_{11}H_{26}NO_2PS$ CAS# 50782-69-9	Weakness of skeletal musculature. In severe cases: disabling condition (muscle weakness and paralysis).
Cyclo-sarin/GF	$CH_3PO(F)OC_6H_{11}$	Not Available
Incapacitating Agents		
Agent BZ	3-Quinuclidinyl benzilate $C_{21}H_{23}NO_3$ CAS# 6581-06-2	Not Available
Lacrimators/Tear Gases*		
Chloroacetophenone/CN	2-Chloroacetophenone $C_6H_5COCH_2Cl$ CAS# 532-27-4	Repeated or prolonged contact may cause chronic skin conditions.
Chloropicrin/PS	Chloropicrin CCl_3NO_2 CAS# 76-06-2	Not Available
Chloroacetophenone and chloropicrin in chloroform/CNS	Mixture of CN, PS, and chloroform na	No known long-term effects
Chloroacetophenone in benzene and carbon tetrachloride/CNB	Mixture of CN, carbon tetrachloride, and benzene	Not Available
Bromobenzylcyanide/CA	Bromobenzylcyanide C_8H_6BrN CAS# 5798-79-8	Not Available

Table 10-1. Chemical Agents and Their Potential Chronic Effects (continued)

Common Name	Chemical Name /Formula/CAS#	Potential Chronic Effects
O-Chlorobenzylidene/CS *also* CS1 and CS2	O-chlorobenzylidene malononitrile $C_{10}H_5ClN_2$ CAS# 2698-41-1	Not Available
Vomiting Agents		
Diphenylchloroarsine/DA	Diphenylchloroarsine $C_{12}H_{10}AsCl$ CAS# 712-48-1	Not Available
Adamsite/DM	Diphenylaminechloroarsine $C_{12}H_9AsClN$ CAS# 578-94-9	Not Available
Diphenylcyanoarsine/DC	Diphenylcyanoarsine $C_{13}H_{10}AsN$ CAS# 23525-22-6	Not Available

*The U.S. CWC implementing legislation exempts these chemicals (which appear in schedule 3 of the CWC Chemical Annex) from reporting requirements if found in concentrations of less than 80 percent.

Sources:
U.S. Army Field Manual FM 3-9 and the 1956 version of TM 3-215.
Agency for Toxic Substances and Disease Registry (ATSDR). *Medical Management Guidelines (MMGs) for Blister Agents*.
Mitretek Systems. Toxicological Properties of Vesicants; Toxicological Properties of Nerve Agents. Last Revised on May 15, 2003. http://www.mitretek.org/home.nsf/HomelandSecurity/ChemBioDefense.
U.S. Army Soldier and Biological Chemical Command (SBCCOM). Material Safety Data Sheet: Distilled Mustard (HD).
U.S. Army Center for Health Promotion and Preventive Medicine (USACHPPM). *Detailed Facts About Blood Agent Cyanogen Cyanide (CK); Detailed Facts About Choking Agent Phosgene (CG)*. Last Revised on July 23, 1998.
U.S. National Library of Medicine, Specialized Information Services. Hazardous Substances Data Bank (HSDB).
University of Oklahoma College of Pharmacy. Arsine Fact Sheet. 2001-2002.
Deployment Health Clinical Center (DHCC). Blister Agent Fact Sheet. Last Updated on May 21, 2003.

10.4.2 Persistence of Chemical Agents

The persistence of chemical agents is determined by their rate of vaporization. Nonpersistent compounds vaporize quickly and produce high-density clouds of chemical agent that evaporate rapidly. The hazards of these non-persistent agents result from brief contact with the clouds or from inhalation of vapors. The information on the persistence in the environment of the CW agent compounds is scattered and fragmentary. With the exception of the sulfur mustards, CW agents are generally not considered highly persistent due to the action of various degradation processes such as hydrolysis, microbial degradation, oxidation, and photolysis. However, certain degradation products may themselves be highly persistent and/or toxic. Those persistent degradation products that are not highly toxic may be important as an indicator of the former use of the site.[189]

Table 10-2 features data regarding the persistence of CWM on the battlefield. The data were derived by United States Army Center for Health Promotion and Preventative Medicine (USACHPPM) from material safety data sheets. Although the language used to describe persistence of CWM relates to the battlefield, Table 10-2 may be helpful in obtaining an initial understanding of persistence of certain chemicals in the environment. There is no data from the USACHPPM document for chemicals listed in Table 10-1 that do not appear in Table 10-2.

Persistent chemical agents are liquids that vaporize slowly or viscous materials that adhere and do not spread or flow easily. The hazards posed by persistent compounds result either from contact with the liquids or from contact with or inhalation of vapors, which persist longer than the non-persistent compounds. Persistent chemicals include mustard, lewisite, blister agents, and V-class nerve agents (VX).

Table 10-2 Persistence in the Environment of CW Agents

Common Name	Persistence
Blister Agents/Vesicants	
Lewisite/L	Somewhat shorter than for HD (sulfur mustard agent); very short duration under humid conditions.
Mustard-Lewisite Mixture/HL	Depends on munitions used and the weather. Somewhat shorter than that of HD, heavily splashed liquid of which persists 1 to 2 days under average weather conditions, and a week or more under very cold conditions.
Nitrogen Mustard/HN-1	Depends on munitions used and weather; somewhat shorter duration of effectiveness for HD, heavily splashed liquid of which persists 1 to 2 days under average weather conditions, and a week or more under very cold conditions.
Nitrogen Mustard/HN-2	Depends on munitions used and weather; somewhat shorter duration of effectiveness for HD, heavily splashed liquid of which persists 1 to 2 days under average weather conditions, and a week or more under very cold conditions.
Nitrogen Mustard/HN-3	Considerably longer than HD. HN-3 use is emphasized for terrain denial. It can be approximately 2x or 3x the persistence of HD and adheres well to equipment and personnel, especially in cold weather.
Sulfur Mustard Agent/H, HD or HS	Depends on munition used and weather; heavily splashed liquid persists 1 to 2 days in concentration to provide casualties of military significance under average weather conditions, and a week to months under very cold conditions.

[189] Munro, Nancy B. et al., "The Sources, Fate and Toxicity of Chemical Warfare Agent Degradation Products," Environmental Health Perspectives, Vol 107, Number 12, 1999.

Table 10-2 Persistence in the Environment of CW Agents (continued)

Common Name	Persistence
Mustard-T Mixture/Sulfur Mustard Agent/HT	Depends on munitions used and the weather; heavily splashed liquid persists 1 to 2 days in concentration to provide casualties of military significance under average weather conditions, and a week to months under very cold conditions.
Blood Agents	
Hydrogen Cyanide/Prussic Acid/AC	Short; the agent is highly volatile, and in the gaseous state it dissipates quickly in the air.
Cyanogen Chloride/CK	Short; vapor may persist in the jungle for some time under suitable weather conditions.
Arsine/SA	No information from source document
Choking Agents	
Phosgene/CG	Short; however, vapor may persist for some time in low places under calm of light winds and stable atmospheric conditions (inversion).
Diphosgene/DP	No information from source document
Nerve Agents	
Tabun/GA	The persistency will depend upon munitions used and the weather. Heavily splashed liquid persists 1 to 2 days under average weather conditions.
Sarin/GB	Evaporates at approximately the same rate as water; depends upon munitions used and the weather.
Soman/GD	Depends upon the munitions used and the weather. Heavily splashed liquid persists 1 to 2 days under average weather conditions.
V-Agent/VX	Depends upon munitions used and the weather. Heavily splashed liquid persists for long periods of time under average weather conditions.
Incapacitating Agents	
Agent BZ	No information from source document
Lacrimators/Tear Gases	
Chloroacetophenone/CN	Short because the compounds are disseminated as an aerosol.
Chloropicrin/PS	Short.
Chloroacetophenone and chloropicrin in chloroform/CNS	Short.
Chloroacetophenone in benzene and carbon tetrachloride/CNB	Short.
Bromobenzylcyanide/CA	Depends on munitions used and the weather; heavily splashed liquid persists one or two days under average weather conditions.
Vomiting Agents	
Adamsite/DM	Short, because compounds are disseminated as an aerosol. Soil - persistent. Surface (wood, metal, masonry, rubber, paint) - persistent. Water - persistent; when material is covered with water, an insoluble film forms which prevents further hydrolysis.

Source:

U.S. Army Center for Health Promotion and Preventative Medicine (UCACHPPM). Detailed and General Facts About Chemical Agents, TG 218.

10.4.3 Acute Toxicity of Persistent Chemical Agents

Acute toxicity values are useful in understanding the risk associated with exposure to chemical agents. *Acute toxicity* is defined as toxicity that results from short-term exposure to a toxicant. The acute toxicity of a chemical is commonly quantified as the LD50 (lethal dose that kills 50 percent of the exposed population) or LCt50 (lethal concentration that kills 50 percent of the exposed population in a specified period of time). These values provide statistically sound and reproducible measures of the relative acute toxicity of chemicals.

Table 10-3 shows acute human toxicity data (LD50 and LCt50) for oral, dermal, and inhalational routes of exposure for the chemical warfare agents listed in Table 10-1. In cases when human toxicity data were not available, data on exposure of laboratory animals (e.g., rats) to the agent(s) were substituted. Caution should be used in extrapolating this data to humans.

Table 10-3. Acute Human Toxicity Data for Chemical Warfare Agents

Chemical Agent	**LD50**	**LCt50**
Blister Agents/Vesicants		
Lewisite/L	50 mg/kg (oral, rat)	100,000 mg-min/m^3 (dermal, human)
	24 mg/kg (dermal, rat)	1,200 to 2,500* mg-min/m^3 (inhalation, human)
Mustard-Lewisite Mixture/HL	Not Available	about 10,000 mg-min/m^3 (dermal, human)
		about 1,500 mg-min/m^3 (inhalation, human)
Nitrogen Mustard/HN-1	2.5 mg/kg (oral, rat)	20,000 mg-min/m^3 (dermal, human)
	17 mg/kg (dermal, rat)	1,500 mg-min/m^3 (inhalation, human)
Nitrogen Mustard/HN-2	10 mg/kg (oral, rat)	3,000 mg-min/m^3 (inhalation, human)
	12 mg/kg (dermal, rat)	
Nitrogen Mustard/HN-3	5 mg/kg (oral, rat)	10,000 mg-min/m^3 (dermal, human)
	2 mg/kg (dermal, rat)	1,500 mg-min/m^3 (inhalation, human)
Sulfur Mustard Agent/H, HD or HS	0.7 mg/kg (oral, human)	5,000 to 10,000* mg-min/m^3 (dermal, human)
	20 to 100* mg/kg (dermal, human)	900 to 1,500* mg-min/m^3 (inhalation, human)
Mustard-T Mixture/Sulfur Mustard Agent / HT	Not Available	
Phenyldichloroarsine / PD	16 mg/kg (dermal, rat)	2,600 mg-min/m^3 (inhalation, human)

Table 10-3. Acute Human Toxicity Data for Chemical Warfare Agents

Chemical Agent	LD50	LCt50
Ethyldichloroarsine/ED	Not Available	1,555 mg/m^3 for 10 min (inhalation, mouse)
Methyldichloroarsine/ MD	Not Available	
Phosgene Oxime/CX	Not Available	3,200 mg-min/m^3 (estimated)(human)
Blood Agents		
Hydrogen Cyanide/ Prussic Acid/AC	100 mg/kg (dermal, human)	2,000 mg/m^3 for 0.5 min (inhalation, human)
		20,600 mg/m^3 for 30 min (inhalation, human)
Cyanogen Chloride/CK	6 mg/kg (oral, cat)	11,000 mg-min/m^3 (human)
Arsine/SA	Not Available	390 mg/m^3 for 10 min (inhalation, rat)
Choking Agents		
Phosgene/CG	Not Available	3,200 mg/m^3 (inhalation, human)
Diphosgene/DP	Not Available	
Nerve Agents		
Tabun/GA	3.7 mg/kg (oral, rat)	135 mg/m^3 for 0.5-2.0 min at RMV of 15 L/min (inhalation, human)
	14 to 15 mg/kg (dermal, human)	200 mg/m^3 for 0.5-2.0 min at RMV of 10 L/min (inhalation, human)
Sarin/GB	0.55 mg/kg (oral, rat)	70 mg-min/m^3 at 15 L/min (inhalation, human)
	24 mg/kg (dermal, human)	
Soman/GD	5 mg/kg (dermal, human)	70 mg-min/m^3 at 15 L/min (inhalation, human)
V-Agent/VX	0.142 mg/kg (dermal, human)	30 mg-min/m^3 at 15 L/min (inhalation, human)
Incapacitating Agents		
Agent BZ	Not Available	200,000 mg-min/m^3 (estimated)(human)
Lacrimators/Tear Gases		
Chloroacetophenone/CN	50 to 1,820* mg/kg (oral, rat)	7,000 mg-min/m^3 from solvent (human)
		14,000 mg-min/m^3 from grenade (human)
Chloropicrin/PS	250 mg/kg (oral, rat)	2,000 mg-min/m^3 (human)

Table 10-3. Acute Human Toxicity Data for Chemical Warfare Agents

Chemical Agent	LD50	LCt50
Chloroacetophenone & Chloropicrin in Chloroform/CNS	Not Available	11,400 mg-min/m^3 (human)
Chloroacetophenone in Benzene & Carbon tetrachloride/CNB	Not Available	11,000 mg-min/m^3 (human)
Bromobenzylcyanide	Not Available	8,000 mg-min/m^3 (estimated)(human)
O-Chlorobenzylidene/CS also CS1and CS2	178 mg/kg (oral, rat)	61,000 mg-min/m^3 (human)
Vomiting Agents		
Diphenylchloroarsine	Not Available	
Adamsite/DM	Not Available	variable, average 11,000 mg-min/m^3 (human)
Diphenylcyanoarsine	Not Available	

*value varies depending on source.

Notes:

In cases where data on human exposure were not available, data on exposure of laboratory rats to the agent(s) were substituted. Caution should be used in extrapolating this data to humans.

RMV – respiratory minute volume

LD50 – dose which kills 50% of the exposed population; typically expressed in units of mg/kg body weight

LCt50 – concentration which kills 50% of the exposed population in a specified period of time; typically expressed as product of the chemical's concentration in air (mg/m3) and the duration of exposure (min)

Dermal – absorption through the skin

Oral – intake via mouth

Inhalation – intake via the lungs

Sources:

Mitretek Systems. *Toxicological Properties of Vesicants; Toxicological Properties of Nerve Agents*. Last Revised on May 15, 2003. http://www.mitretek.org/home.nsf/HomelandSecurity/ChemBioDefense

U.S. Army Soldier and Biological Chemical Command (SBCCOM). Material Safety Data Sheet: Distilled Mustard (HD); Lethal Nerve Agent (GD); Lethal Nerve Agent (GB).

U.S. Army Center for Health Promotion and Preventive Medicine (USACHPPM). *Detailed Facts About Blood Agent Cyanogen Cyanide (CK), Hydrogen Cyanide (AC); Blister Agent Phosgene Oxime (CX), Mustard-Lewisite Mixture (HL), Nitrogen Mustard (HN-1), (HN-2), (HN-3), Lewisite (L), Sulfur* ***Mustard Agents H and HD; Nerve Agent VX, Nerve Agent GA; Psychedelic Agent 3-Quinuclidinyl Benzilate (BZ); Tear*** *Agent 2-Chloroacetophenone (CN), Chloropicrin (PS), Chloroacetophenone and Chloropicrin in Chloroform (CNS), Chloroacetophenone in Benzene and Carbon Tetrachloride (CNB), a-Bromobenzylcyanide (CA), o-Chlorobenzylidene Malonitrile (CS); Vomiting Agent Adamsite (DM)*. Last Revised on July 23, 1998.

U.S. Army Chemical Biological Defense Command Edgewood. Material Safety Data Sheet: Lewisite.

National Toxicology Program (NTP). NTP Chemical Repository. Last revised on June 3, 2003.

U.S. Department of Labor. Occupational Safety & Health Administration. Occupational Safety and Health Guidelines. The Regisry of Toxic Effects of Chemical Substances (RTECS).

U.S. National Library of Medicine, Specialized Information Services. Hazardous Substances Data Bank (HSDB).

10.4.4 Degradation Products of Chemical Munitions and Agents

Many chemical agents are broken down by weathering processes into both hazardous and nonhazardous materials. The weathering effects of sun, rain, and wind will dissipate, evaporate, or decompose chemical agents. Specifically, sunlight causes catalytic decomposition and evaporation, rain or dew causes hydrolysis, and wind accelerates the natural process of evaporation.

When addressing the hazards of CWM at a site, special attention should be paid to the decomposition products that often pose risks to human health and the environment as a result of their toxicity and persistence. While a number of degradation products exist, only a few of them are persistent and highly toxic.[190]

The following text describes examples of some common chemical agent decomposition products of CWM and an overview of their persistence in the environment and toxicity. The environmental conditions and the length of time that an agent has been exposed to the environment will determine the extent of the degradation and whether some or all of the degradation products and subsequent daughter products (described in the following sections) will be present. Table 10-4 provides more detail on toxicity of these degradation products.

- **Sarin (GB)** – reacts with water (hydrolyzes) under acidic conditions to form hydrofluoric acid, isopropyl methylphosphonic acid (IMPA), which slowly hydrolyzes to methylphonic acid (MPA). IMPA, although environmentally persistent has been shown to present low acute oral toxicity to rats and mice. MPA is essentially nontoxic to mammalian and aquatic organisms.[8] Hydrofluoric acid is an extremely corrosive material that must be handled with extreme caution unless copiously diluted. Sarin will hydrolyze under alkaline (basic) conditions to form sodium (or other metallic) isomethyl phosphonate salt.

- **Tabun (GA)** – produces a variety of hydrolysis products under acidic, basic, and neutral conditions, including hydrogen cyanide, ethylphosphoryl cyanidate, organic acids and esters, ethyl alcohol, dimethylamine, ethyl N,N-dimethylamido phosphoric acid and phosphoric acid.

- **VX** – forms a variety of degradation products. The most persistent products in weathered soil samples are bis(2-diisopropylaminoethyl)disulfide (EA 4196) and MPA. The most toxic is S-(2-diisopropylaminoethyl) methylphosphonothioic acid (EA 2192). The intermediate VX hydrolysis product EA 2192 may be stable in water but is degraded rapidly in soil. It is nearly as toxic as VX. EMPA and MPA are final degradation products that exhibit relatively low toxicity to mammalian species.Other less toxic degradation products include phosphorus-containing organic acids, sulfur-containing compounds, organic phosphorus-containing esters, and ethyl alcohol.[8]

- **Soman (GD)** – hydrolyzes to form primarily pinacolyl methylphosphonic acid, which has

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[190] Munro, N.B. et al., *The Sources, Fate, and Toxicity of Chemical Warfare Agent Degradation Products,* Environmental Health Perspectives, Vol. 107, No. 12, December 1999.

a similar structure to IMPA. IMPA has even been shown to exhibit low mammalian toxicity. GD also slowly hydrolyzes to MPA.[8]

- **Mustard (HD)** – hydrolyzes to form hydrochloric acid (a strong mineral acid), thiodiglycol (TDG) and 1,4-oxathiane. The most persistent degradation product is TDG but it is suseptible to microbial degradation and has been demonstrated to be low toxicity to mammalic and aquatic species. At burial sites, a commonly found breakdown product is 1,4-dithiane.

- **Lewisite** – hydrolyzes under acidic conditions to form hydrochloric acid and the nonvolatile (solid) compound chlorovinylarsenious oxide (lewisite oxide). Although this compound is a much weaker blistering agent than Lewisite it is still highly toxic and has vesicant properties. Hydrolysis in basic conditions, such as decontamination with alcoholic caustic or carbonate solution, produces acetylene, a very flammable gas, and trisodium arsenate. Therefore, the decontamination solution would contain a toxic form of arsenic.[191]

Table 10-4 summarizes chemical agent degradation products that are known to have significant environmental persistence and toxicity. *Environmental persistence* refers to chemicals that resist degradative processes and remain in the environment for very long periods of time. Significant persistence refers to compounds that are stable in the environment for months to years.

Table 10-4. Summary of Known Persistent or Toxic Chemical Agent Degradation Products

Chemical Agent	Degradation Process	Degradation Products	Persistence	Relevant Routes of Exposure	Toxicity, LD50 (mg/kg)
Sulfur mustard (HD)	Hydrolysis	Thiodiglycol $C_4H_{10}O_2S$ CAS# 111-48-8 Dithiane $C_4H_8S_2$ CAS# 505-23-7	Moderate	Oral	Rat oral: 6,610 guinea pig oral: 3,960
Lewisite (L)	Hydrolysis, dehydration	2-Chlorovinyl arsenous oxide (Lewisite oxide) C_2H_2AsClO CAS# 3088-37-7 Arsenic AS CAS# 7440-38-2	High	Dermal	Unknown
V-Agent (VX) O-ethyl-S-[2-diisopro-pylaminoethyl]methyl-phosphonothionate	Hydrolysis	S-(Diisopropylaminoethyl) methyl phosphonothionate (EA 2192)	Moderate	Oral	Rat oral LD50: 0.63

[191]Materiel Safety Data Sheets, Edgewood Chemical Biological Center (ECBC), Department of the Army.

Table 10-4. Summary of Known Persistent or Toxic Chemical Agent Degradation Products (continued)

Chemical Agent	Degradation Process	Degradation Products	Persistence	Relevant Routes of Exposure	Toxicity, LD50 (mg/kg)
		Ethyl methylphosphonic acid (EMPA) C3H9O3P CAS# 1832-53-7	Moderate	Oral	No data
	Formed from EMPA	Methylphosphonic acid (MPA) CH_5O_3P CAS# 993-13-5	High	Oral	Rat oral LD50: 5,000
Sarin (GB) Isopropyl methyl-phosphonofluoridate	Hydrolysis	Isopropyl methylphosphonic acid (IMPA) $C_4H_{11}O_3P$ CAS#1832-54-8	High	Oral	Rat oral LD50: 6,070
		Methylphosphonic acid (MPA) CH_5O_3P CAS# 993-13-5	High	Oral	Rat oral LD50: 5,000
	Impurity	Diisopropyl methylphosphonate (DIMP) C7H17PO3 CAS# 1445-75-6	High	Oral	Rat oral LD50: 826
Soman (GD) Ethyl N,N-dimethyl-phosphoroamido-cyanidate	Hydrolysis	Methylphosphonic acid (MPA) CH_5O_3P CAS# 993-13-5	High	Oral	Rat oral LD50: 5,000

Source:
Munro, N.B.et. Al., The Sources, Fate, and Toxicity of Chemical Warfare Agent Degradation Products, *Environmental Health Perspectives,* Vol, 107. No.12, December 1999.

10.5 Detection of CWM

Techniques for locating buried chemical munitions and containers are the same as those for the detection of conventional munitions. The appropriate geophysical detection technology should be selected based on the container's material (e.g., steel vs. glass). Chapter 4 described the variables associated with the selection of geophysical detection technologies. Once the presence of CWM or chemical agent(s) are suspected, they must be identified. Several methods for detecting and identifying chemical agents exist. Some of the more common methods are discussed in Table 10-5. Each detection method has strengths and weaknesses that will need to be weighed against the conditions and the chemicals suspected at individual sites.[192]

[192]The term detection is used in two ways in this section. The first discussion refers to locating discrete metallic items through geophysical investigation. The second use refers to finding and identifying the chemical agent itself. The detection tools for locating discrete metallic items are discussed in Chapter 4.

Table 10-5. Common Methods for Monitoring for and Sensing Chemical Agents

Detection Types	Description	Advantages and Disadvantages
Chemical Agent Monitor (CAM™)	Used as a monitor for chemical agents. Area reconnaissance is accomplished by moving the CAM through the area of concern. The CAM is usually used in conjunction with other detection methods. The CAM can detect nerve and blister agents at moderately low levels that could affect personnel over a short time.	C Sensitivity – False alarms have been a problem with CAM, such as false alarms caused by the presence of aromatic vapors from materials such as perfumes, food flavorings, cleaning compounds, disinfectants, and smoke and fumes in exhaust from rocket motors and munitions. C Detector uses a radiation source that could be a problem when moving the detector to different States. C Operates in nerve agent or mustard mode. C Quick response time.
Individual Chemical Agent Detector (ICAD)	Uses two electrochemical sensors: one sensor is sensitive to nerve agents, blood agents, and choking agents; the second sensor detects blister agents. When preset threshold levels are reached, an alarm is activated.	C Detector can be worn on outside of clothing. C Quick response time – less than 2 minutes for GA, GB, BD, and HD. Shorter alarm times for higher concentrations and other agents.
Chemical Agent Detector Paper (ABC-M8)	Used to detect liquid chemical agents. The paper turns different colors according to the type of agent to which it is exposed. V-type nerve agents turn it green, G-type nerve agents turn it yellow, blister agents turn it red.	C Paper must be examined in white light (which could be a problem in night operations). C Detection thresholds are high. C Subject to false alarms from other chemicals and from rubbing the paper on surface instead of blotting. C Easy to use, minimal training required.
Chemical Agent Detector Paper (M9)	M9 is the most widely used detector for liquid chemical agents and is more sensitive and reacts more rapidly than ABC-M8 paper. M9 paper reacts to chemical agents by turning a red or reddish brown color. Detection of a chemical agent by the M9 paper should be confirmed with the M256 kit.	C High detection thresholds. C Subject to false alarms from exposure to petroleum products. C Easy to use, minimal training required.

Table 10-5. Common Methods for Monitoring for and Sensing Chemical Agents (continued)

Detection Types	Description	Advantages and Disadvantages
M256 Chemical Agent Detector Kit	Can detect chemical agent in liquid or vapor forms. The M256 kit is usually used to confirm chemical agent presence after an alarm and to identify the type of agent present. It is not used to monitor for the presence of a chemical agent. Kit contains vials of liquid reagents that are combined and exposed in a specific sequence to indicate presence of chemical agent vapors. Use of the kit entails manual manipulation of the kit contents.	C Proceeding through the full series of tests requires 20-25 minutes. C Step-by-step instructions are provided with each kit to avoid misuse and consequent misinterpretation.
M272 Water Testing Kit	Used to detect chemical agents in raw or treated water. Detects mustard agent (HD), cyanide (AC), Lewisite (L), and nerve agents (G and V series).	C Capable of detecting agents at levels safe for human use. C Portable.
MINICAD	Hand-held chemical agent detector kit that simultaneously detects trace levels of nerve and blister agents.	C No false alarms resulting from other chemical vapors. C Provides a data record. C Small, easy to carry – weighs only 1 pound.
APD 2000 (Sabre)	Hand-held detector of GA, GB, GD, VX, HD, HN, Lewisite, pepper spray, and mace.	C Superior interference resistance. C Has a data logger option. C Small, easy to carry – weighs 6 pounds.
Portable GC/MS	Gas chromatograph/mass spectrometer	C Detects and quantifies most chemicals. C Sampling and analysis time is longer than for instruments designed as detectors. C Requires a technician operator. C Analyzes industrial chemicals as well as chemical agents.

Table 10-5. Common Methods for Monitoring for and Sensing Chemical Agents (continued)

Detection Types	Description	Advantages and Disadvantages
MINICAMS (Miniature Chemical Agent Monitoring System)	Portable monitoring unit available with flame ionization detector (FID) or flame-photometric detector (FPD). Provides near real time information. Various versions of MINICAMS can detect some chemical agents and other air pollutants depending on the detector and the sampling module that is installed. Sampling module may be a plug-in flow-through module, loop-sampling plug-in module, or sorbent sampling plug-in module. MINICAMS7 includes a gas chromatograph, which the manufacturer claims can detect chemical agent vapors in air to meet the Surgeon General's 8-hour TWA standard.	C Portability of unit that can be used to monitor areas or specific point. C Programmable to sequentially sample from a number of sample points.
JCAD	Hand-held detector that uses an advanced surface acoustic wave (SAW) technology. Capable of detecting the presence of nerve agents (G and V series), blister agents (HD, HN3, L), blood agents (AC, CK), and toxic industrial chemicals.	C Compact size provides real advantage for portability and use in the field. C Has multiagent detection capability. C Can be mounted in a fixed location and linked to RS 232 communications port for feedback from remote locations.
SAW MINICAD mk II	Lightweight, solid-state detector, using surface acoustical wave sensor technology. Capable of simultaneous detection of trace levels of nerve and blister agents.	C Sensor is selective to the chemical agents and does not give false alarms due to other chemical vapors. C Unit is battery operated, can store data from detection sensor, is fully automatic, and is lightweight.
Portable Isotopic Neutron Spectrometer (PINS)	Nondestructive chemical assay tool that can identify previously cataloged contents of munitions and chemical- storage containers use of special fingerprinting algorithms.	C Portable C Easy to use C Rugged enough for military or civil defense use C Assay times: 100 to 1,000 seconds

Table 10-5. Common Methods for Monitoring for and Sensing Chemical Agents (continued)

Detection Types	Description	Advantages and Disadvantages
Digital Radiography/ Computed Tomography (DRCT)	Creates high-clarity X-rays of a munition's interior. The DRCT system is used when information on the contents, configuration, or condition of the munition is conflicting or unknown.	C X-rays are so clear that analysts can often determine the condition of the bomb's firing mechanisms and whether it has been damaged from years of storage or burial.
Mobile Munitions Assessment Systems (MMAS)	Includes equipment for nonintrusively identifying munitions and for assessing the condition and stability of fuzes, firing trains, and other potential safety hazards. The Phase II MMAS is currently being tested and qualified for use by the INEEL and the Army. The Phase II system contains several new assessment systems that significantly enhance the ability to assess CWM.	C The system provides a self-contained, integrated command post, including an on-board computer system, communications equipment, video and photographic equipment, weather monitoring equipment, and miscellaneous safety-related equipment.

Market Survey and Literature Search of Monitoring Technologies; July 22, 1996; U.S. Army Program Manager for Chemical Demilitarization
Site Monitoring Concept Study; September 15, 1993; U.S. Army Chemical Destruction Agency
U.S. Army Field Manual (FM) 3-4 NBC Protection
Department of the Army (DA) Pamphlet 385-61 Toxic Chemical Agent Safety Standards
U.S. Army Technical Manual (TM) 43-0001-26-1 Army Equipment Data Sheets: Chemical Defense Equipment
U.S. Army Technical Manual (TM) 3-6665-225-12 Operator's and Organizational Maintenance Manual: Alarm, Chemical Agent, Automatic: Portable, Manpack M8
U.S. Army Technical Manual (TM) 3-6665-254-12 Operator's and Organizational Maintenance Manual: Detector Kit, Chemical Agent, ABC-M18A2
U.S. Army Technical Manual (TM) 3-6665-307-10 Operator's Manual for Detector Kit, Chemical Agent, M256 and M256A1
U.S. Army Technical Manual (TM) 3-6665-311-10 Operator's Manual for Paper, Chemical Agent Detector: M9
U.S. Army Technical Manual (TM) 3-6665-312-12andP Operator's and Organization Maintenance Manual for the M8A1 Automatic Chemical Agent Alarm

The most effective tool for determining the presence of CWM inside a suspected chemical munition or container is the Portable Isotopic Neutron Spectrometer (PINS). The PINS beams neutrons into an enclosed container, yielding a spectrum that is collected and stored. The PINS Analysis software analyzes the spectrum and determines the contents of the container. Another useful instrument is the Digital Radiography/Computed Tomography (DRCT) unit. A DRCT can effectively produce a CAT scan of a munition or container. Both of these tools have been placed on mobile platforms called Mobile Munitions Assessment Systems (MMAS) for identifying suspected chemical weapons materials. The MMAS units are available from the U.S. Army Technical Escort Unit, Aberdeen Proving Ground, Maryland.

In addition, the Army uses more sophisticated air-monitoring equipment on its mobile treatment systems that achieves near real time monitoring results. An example of this equipment is the Miniature Chemical Agent Monitoring System (MINICAMS), which is a device capable of monitoring for blister, nerve, and some other agents to well below their required acceptable exposure limits (AELs). Devices such as MINICAMS are typically used in areas where excavations are ongoing or where mobile destruction equipment is being operated.

10.5.1 Laboratory Analysis of CWM

When environmental samples from sites contaminated with CWM are sent to laboratories for analysis, those samples may pose a threat to the laboratories that analyze them. For this reason, only a few commercial laboratories are authorized for the analysis of CWM. All environmental samples must be sent to approved laboratories.

10.6 Response, Treatment, and Decontamination of Chemical Agents and Residues of CWM

Because of the dual hazards of explosive capability and potential lethality, CWM poses significant response, treatment, remediation and decontamination challenges. This section addresses these components.

> **Decontamination**
>
> Decontamination is the process by which any person, object, or area is made safe through the absorption, destruction, neutralization, rendering harmless, or removal of chemical or biological material, or the removal of radioactive material clinging to or around the materials.

10.6.1 Response

Because of both the explosive and the chemical hazards, Army guidance specifies a hierarchy for conducting response actions at sites containing CWM alone or both CWM and conventional munitions. This hierarchy calls for explosive hazards to be addressed and mitigated first, followed by non-stockpile CWM hazards.[193]

At any site where chemical contamination is known or suspected, the Army Technical Escort Unit (TEU), a division of the U.S. Army Soldier and Biological Chemical Command (SBCCOM), must be called in to assess the CWM and determine how it can be handled. One of the ways in which CWM is handled is destruction.

Procedures for the destruction of chemical weapons under controlled conditions are spelled out in detailed, case-by-case plans developed by the Army and submitted to State regulatory officials. The destruction of chemical weapons frequently involves the use of mobile equipment tested by the Army and permitted by each State for exactly that purpose.

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[193] Interim Guidance for Biological Warfare Materiel (BWM) and Non-Stockpile Chemical Warfare Materiel (CWM) Response Activities, Department of the Army, 13 April 1998.

10.6.2 Treatment

In 2003, the National Research Council, Board of Army Science and Technology, published the results of their review of ***Systems and Technologies for the Treatment of Non-Stockpile Chemical Warfare Material.*** They concluded that the Army has or will shortly have a number of options for the destruction and/or treatment of chemical agent, including the use of fixed facilities and mobile systems that can use one or a number of combinations of individual treatment technologies. Like mobile systems, individual treatment technologies may be incorporated into a larger entity such as a fixed facility or mobile systems that are transported to the site of a find.

Table 10-6 represents an overview of facilities, mobile treatment systems, and individual treatment technologies that were reviewed by the National Research Council committee. Because of the safety concerns associated with movement of CWM, Army guidance (based on 50 U.S.C. 1512-1521) expresses a preference for on-site treatment of CWM. However, if on-site treatment is not an option, such as at a heavily populated FUDS, the Army preference is for on-site storage or storage at the nearest military facility within the State until the CWM or agent-contaminated material can be treated. Out-of-State storage is the Army's least preferred option. The committee presented what their recommendations were from the review regarding the uses of these treatment options.[194]

The treatment options identified in Table 10-6 are not all currently in use for NSCWM. For example, the table lists treatment options for non-stockpile items that the Army has historically used to effectively destroy stockpiled items. However, all were reviewed for their potential use as recent legislation specifically allowed the use of stockpile facilities to destroy non-stockpile CWM. A few of the key recommendations of the NRC are summarized below:

- Treatment facilities developed for the stockpile program may be very appropriate for treatment of NSCWM, if regulatory agencies and other stakeholders can support this.
- The Rapid Response System for the destruction of CAIS PIGS and large numbers of loose CAIS vials and bottles is an expensive but adequate treatment for these items.
- The Explosive Destruction System (EDS) developed as a transportable system for the destruction of chemical munitions in the field has performed well for its intended uses and should be further developed for additional uses. However, given the amount of potential NSCWM that may be buried in various sites around the country, it may not have sufficient throughput to be efficient in the future.
- The development and testing of the tent and foam system for controlling on-site detonation of unstable munitions should continue to be explored as an alternative to open detonation.
- The Donovan Blast Chamber (developed for conventional munitions) is currently being tested for CWM in Belgian. "If results are encouraging and it appears that the DBC can

[194]Ibid. Systems and Technologies for the Treatment of Non-stockpile Chemical Warfare Materiel, Board on Army Science and Technology, National Research Council, National Academy Press, 2002.

be permitted in the United States, it should be considered for use at sites where prompt disposal of large numbers of munitions is required."[195]

The table is organized into three categories: facilities, mobile treatment systems, and individual treatment technologies. The following sections provide a review of these categories.

Table 10-6. Potential Treatment Facilities for NSCWM

Treatment Option	Description
Facilities	
Non-stockpile facilities Pine Bluff Non-Stockpile Facility (PBNSF) (in final design)	Designed to use chemical neutralization and associated technologies to address the recovered non-stockpile items stored at Pine Bluff Arsenal, Arkansas.
Munitions Assessment and Processing System (MAPS) (under construction)	Designed to use chemical neutralization and associated technologies to address the recovered non-stockpile items found at Aberdeen Proving Ground, Maryland.
Use of stockpile destruction facilities for disposal of non-stockpile materiel	Equipped to open stockpile chemical munitions, drain and incinerate agent, and destroy energetics.
Research and development facilities Chemical Transfer Facility (CTF)	Research facility at Aberdeen Proving Ground, Maryland, capable of destroying stockpile and non-stockpile agents.
Chemical Agent Munitions Disposal System (CAMDS)	Research facility at Tooele, Utah, capable of destroying non-stockpile munitions that contain agent fills not easily accommodated at other facilities (eg., lewisite).
Treatment, storage, and disposal facilities	Capable of high-temperature incineration of secondary waste streams produced by the RRS, EDS, and other systems.

[195]Ibid.

Table 10-6. Potential Treatment Facilities for NSCWM (continued)

Treatment Option	Description
Mobile Treatment Systems	**Facilities**
Rapid Response System (RRS)	Non-stockpile facilities Pine Bluff Non-Stockpile Facility (PBNSF) (in final design)
Single CAIS Accessing and Neutralization System (SCANS) (in design)	Munitions Assessment and Processing System (MAPS) (under construction)
Explosive Destruction System (EDS)	Use of stockpile destruction facilities for disposal of non-stockpile materiel
Donovan Blast Chamber (DBC) (in testing for use with CWM)	Research and development facilities Chemical Transfer Facility (CTF)
	Chemical Agent Munitions Disposal System (CAMDS)
	Treatment, storage, and disposal facilities
Individual Treatment Technologies	
Plasma arc	High-temperature technology for direct destruction of agent or for destruction of secondary waste streams produced by the RRS, EDS, and other systems.
Chemical oxidation	Low-temperature technology potentially applicable to destruction of liquid secondary waste streams produced by the RRS, EDS, and other systems.
Wet air oxidation	Moderate-temperature technology potentially applicable to the destruction of liquid secondary waste streams produced by the RRS, EDS, and other systems.
Batch supercritical water oxidation (SCWO)	High-temperature technology potentially applicable to the destruction of liquid secondary waste streams produced by the RRS, EDS, and other systems.
Neutralization (chemcial hydrolysis)	Low-temperature technology for hydrolysis of neat chemical agents and binary precursors.
Open burning/open detonation (OB/OD)	Historic blow-in-place method for destroying dangerous munitions.
Tent and foam	Partially contained blow-in-place method for destroying dangerous munitions.

10.6.2.1 *Non-stockpile Facilities*

Non-stockpile facilities are designed to destroy large quantity of dissimilar CWM and stockpile facilities are constructed to destroy large quantities of similar CWM.

The Munitions Assessment and Processing System (MAPs) mentioned in the table as a fixed facility was under construction during the National Research Council's (NRC) review. It was designed to handle explosively configured chemical munitions and smoke rounds to be recovered during the Installation Restoration Program at APG.

The Pine Bluff non-stockpile facility is designed to process RCWM binary chemical weapons components CAIS and chemical samples at PBA.

10.6.2.2 *Research and Development Facilities*

The Army has two R&D facilities in the United States; the Chemical Transfer Facility (CTF) at Aberdeen Proving Ground (APG) and the Chemical Agent Munitions Disposal System (CAMDS) at Desert Chemical Depot to destroy items containing Lewisite. The CT facility handles CWM recovered from APG.

10.6.2.3 *Treatment, Storage, and Disposal Facilities*

A fourth type of fixed facility (treatment, storage, and disposal facilities, or TSDFs) differs from the rest in that commercial TSDFs cannot be used to treat CWM. They can accept secondary waste generated by either mobile systems or individual treatment technologies if the waste no longer contains agent (except at de minimis levels).

10.6.2.4 *Mobile Treatment Facilities*

Table 10-5 lists four mobile treatment systems. The Explosive Destruction System (EDS) and the Rapid Response System (RRS) are the primary systems used. The EDS is designed to treat munitions that contain chemical agents with energetics equivalent to 3 pounds of TNT. These are considered too unstable to be transported and stored. The RRS is designed to treat recovered CAIS, which contain small amounts of various industrial SCANS (Single CAIS Accessing and Neutralization System) is under development to treat individual CAIS vials or bottles. The Donovan Blast Chamber (DBC), originally designed to treat conventional explosive munitions, was modified to treat explosively configured CWM and offers a higher rate of throughput than the EDS. It is not yet approved for use with CWM, by DDESB, but its' use is under evaluation.

10.6.2.5 *Individual Treatment Facilities*

The treatment facilities and systems discussed involve a combination of technologies, including the preparation of the agent for processing, agent accessing, agent destruction, and treatment of secondary waste materials. There are individual treatment technologies that can be used on their own or integrated into the systems and facilities to accomplish specific tasks. These technologies such as plasma arc and chemical oxidation are listed and described in table 10-6. It is important to note that at the time of the NRC's study, some of these technologies were still considered experimental and had not been demonstrated to have met EPA and state requirements. It is important to note that the use of OD in a field environment necessities ideal conditions in which the area can withstand a significant high-order detonation so that all chemical munitions are consumed and there are no personnel or property located in the downwind hazard area. The disadvantages of this method are many, including noise impacts, limit on the quantity that can be destroyed at one time, and the need for regulatory and public approval. This is also the case with other technologies that may create air emissions such as incineration.

10.6.3 Technical Aspects of CWM Remediation Decontamination

At sites where deterioration of CWM has occurred as a result of weathering (see 10.4.3), the breakdown products are often remediated using techniques for hazardous chemical soil remediation. Occasionally, until the TEU can make arrangements for decontaminating the chemical agents, they will construct either a cap made of soil or foam to restrict the absorption and volatilization of chemical agents. However, after some time, such temporary caps will allow vapors to seep through. These temporary sealing techniques protect potential receptors until a more permanent remedy can be conducted.

Chemical Decontamination

In February 2001, at the Rocky Mountain Arsenal, Army experts completed the destruction of eight Sarin bomblets using an explosive destruction system. This transportable explosives destruction system was designed to dispose of CWM in a safe and environmentally sound manner. The device functions by first detonating the chemical munitions to expose the chemical agent filler in the containment vessel. Next, reagents are pumped into the vessel to react with the chemical agent filling. The resulting compound is then drained into drums for shipment to a hazardous waste treatment facility, and the air from the device is vented through a carbon filter to remove all chemical agents from the

As a result of CWM response, there is a need to remediate any residual chemical agent that may be on equipment or PPE. All procedures for the emergency field decontamination of chemical agents must follow standard operating procedures (SOPs) based on Army Field Manual 3-7.[196] These are techniques (especially physical removal) that are typically employed in a field environment. Two commonly used decontamination methods are described below:

- **Physical removal** – washing or flushing of the surface with water, steam, or solvents. Soap and boiling water or steam are often practical and effective methods for decontaminating smaller objects such as personal protective equipment (PPE) and equipment. Water will hydrolyze most chemical agents, but large quantities of water and sufficient pressure are required to make this method practical. During any decontamination operation, appropriate personal protective equipment (PPE) must be used to ensure safety of the workers, and all downwind hazards must be analyzed and minimized in order to reduce exposure to the surrounding community and environment. All water and waste water that are generated from the decontamination operation must be properly handled and disposed of in accordance with appropriate

[196] NBC Field Handbook, Department of the Army Field Manual, FM 3-7, September 1994.

regulations. This is explained in more detail in the following section.

- **Chemical neutralization** – triggers a chemical reaction between the chemical agent and the decontaminant, usually resulting in the formation of a new compound that may be remediated using a RCRA-permitted incinerator. Generally, a chlorinated bleach, such as supertropical bleach, chlorinated lime, bleaching powder, or chloride of lime, is used for this purpose. Except under emergency situations, chemical neutralization is conducted only in contained areas.

10.7 Safety Considerations at Sites Containing Chemical Agents

10.7.1 <u>DoD Chemical Safety Requirements in the DoD Ammunition and Explosives Safety Standards</u>

The DoD Ammunition and Explosives Safety Standards (DoD 6055.9-STD, July 1999) contain strict safety requirements for properties currently or formerly owned by DoD that are contaminated with CWM and require that all means possible be used to protect the public. Chapter 11 of the DoD Explosives Safety Standard specifically addresses safety standards for chemical agents while acknowledging the explosive hazards accompanying CWM. Chapter 11 does not apply in emergency situations when disposal or decontamination needs are immediate and when delay will increase the risk to human life or health.

In the event that an item is discovered that is suspected of containing CWM, the Army, as well as each branch of military service, has specific reporting and emergency response procedures that need to be followed in order to ensure the safety of everyone in the vicinity of the possible contaminant. The first response is always to leave the area immediately, without touching or disturbing the item, and to notify the agency indicated by the branch of service that has jurisdiction over the range. The Technical Escort Unit out of Aberdeen, Maryland, responds to all reports of possible CWM.

The safety requirements for CWM at MRSs are essentially the same as those for explosives safety, with some modifications to address the unique safety considerations of chemical agents:

- Hazard Zone Determination - As required by the DoD Explosives Safety Standard, hazard zone calculations, or quantity-distance data, enable site planners to estimate damage or injury potential based on a maximum credible event (MCE). Planners consider the propagation characteristics of the ammunition, the amount of agent that could potentially be released, and the nature of the potential release (evaporation or aerosolization). For agent-filled ammunition without explosives, the MCE factors should address the number of items likely to be involved, the quantity of agent likely to be released in such an event, and the percentage of that agent that would be disseminated in an event. For combined chemical and explosive components, the MCE should be based on the detonation of the explosive components that will produce the maximum release of chemical agent.
- The DDESB must review and approve the chemical safety aspects of all plans for leasing, transferring, excessing, disposing of, or remediating DoD real property when chemical agent contamination exists or is suspected to exist.
- The DDESB must review plans to remediate FUDS at which chemical agent

contamination exists or is suspected to exist.

- Significant worker safety requirements should be followed to prevent exposure to chemical agent, including measuring AELs, controlling exposures, and using protective equipment and clothing in areas known to contain or suspected of containing CWM.
- Medical surveillance, including annual health assessments, must be provided for employees at sites where CWM is or is thought to be located.
- Personnel safety training must be provided to those who work with chemical agents and ammunition, including agent workers, firefighters, and medical and security personnel, to maintain a safe working environment.
- Labeling and posting of hazards is required to warn personnel of potential hazards at sites containing or thought to contain CWM.
- Procedures for decontaminating protective equipment and clothing in the event of spills must be outlined.
- Transportation requirements for bulk chemical agent and materials contaminated with chemical agents must be followed.

10.7.2 Chemical Safety Requirements

In addition to the DoD Explosives Safety Standards, several other guidance documents and manuals contain requirements for managing CWM at MRSs. These documents include Army Regulation 385-61, the *Army Chemical Agent Safety Program*, and Department of the Army Pamphlet 385-61, *Toxic Chemical Agent Safety Standards.* All procedures for the decontamination of chemical agents must follow SOPs based on Army Field Manual 3-7.[197,198]

When CWM is found or suspected at any MRS, the Army Technical Escort Unit (TEU), a division of the U.S. Army Soldier and Biological Chemical Command (SBCCOM), will assess any recovered non-stockpile CWM to determine if the materiel is explosive, whether it is fuzed, what its chemical composition is, and whether it is safe for movement, storage, treatment, or disposal. For each recovered munition, data are developed from systems such as the PINS and the DRCT (see Table 10-5). Data also are captured from any markings on the munition, the historical context of the find (World War I, World War II, Korean war era, etc.) and any eyewitness information. The data are then referred to a Materiel Assessment Review Board (MARB), chaired by the Commander of TEU. The MARB is responsible for evaluating available assessment data on suspect recovered CWM and making a final expert determination as to its explosive configuration and chemical fill.

10.7.2.1 *Preoperational Safety Surveys*

Before a chemical agent investigation or decontamination activity can begin, a preoperational safety survey is required in order to ensure that all safety aspects of the activity will be achieved. During the survey, all facilities, equipment, and procedures are certified, and operator proficiency in performing SOPs is demonstrated. This survey is conducted by the major command (MACOM)

[197] NBC Field Handbook, Department of the Army Field Manual (FM) 3-7, September 1994.

[198] Toxic Chemical Agent Safety Standards, Department of the Army Pamphlet (DA PAM) 385-61, March 31, 1997.

or its designee, often the Army Technical Center for Explosives Safety (USATCES) Toxic Chemical Agent Team in the Chemical Safety and Data Division. The survey consists of a simulation of the planned activity by the operational personnel and their first line supervisor using dummy (inert) material. All Army regulations and provisions of the site plan and safety submission must be complied with during the survey.[199]

10.7.2.2 *Personnel Protective Equipment*

The DoD safety standard requires the use of administrative and engineering controls to minimize the personnel protective equipment (PPE) requirements (for example, the construction of a temporary seal over soils contaminated with chemical agents to reduce or eliminate the exposure potential to personnel). It is impossible to eliminate the need for PPE at all chemical agent sites. The level and types of PPE required should be specified in the health and safety plan.

In order to protect workers who may be exposed to chemical agents and to determine the appropriate level and type of PPE, the Army has set certain limits of chemical agent that a worker can be exposed to in 8-hour and 72-hour time-weighted shifts. AR 385-61 and the DoD Ammunition and Explosives Safety Standards (DoD 6055.9-STD) define these limits as the maximum permissible concentrations of chemical agent also known as the Airborne Exposure Limits (AELs), as established by the Army Surgeon General.

The levels of protection are identified in the regulatory requirements are as Levels A through F., with Level A is used for the most hazardous situations and Level F used in the most benign situations. Level A PPE involves wearing the maximum level of protection, which includes a toxicological agent protective (TAP) suit with a self-contained breathing apparatus, TAP boots, a hood, and gloves. Level F specifies that personnel carry a mask if they may be moving through clean storage or operating areas. Intermediate levels E through B require progressively more protection. These protection levels are designed by the Army and are specific to chemical agents. They do not match EPA's A-D levels of protection for hazardous waste. For more information on the Army's designation of PPE levels A through F see DA PAM 385-61.

10.7.3 Managing Chemical Agent Safety

Procedures for managing chemical safety require documentation of site safety and health plans and site safety submissions. Site safety submissions for chemical agent sites follow the same process as the explosives safety submission (ESS) review and approval process described in Chapter 6. However, because the Army is the lead agency for chemical safety, all safety submissions must be prepared or formally endorsed by the installation safety director and sent to the U.S. Army Technical Center for Explosive Safety (USATCES), which reviews, approves, and facilitates final approval by the DDESB.

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[199]Ibid.

10.8 Conclusion

In accordance with the Chemical Weapons Convention, all stockpile chemical weapons and non-stockpile chemical warfare material and identified at the time of the ratification of the CWC and located in the United States must be destroyed by 2012. Although the United States is in the process of destroying all known stockpile and non-stockpile CWM, because of past disposal practices (e.g., burial) it is possible that CWM may still be present at former ranges, test areas and other sites. The presence of this materiel may present acute and chronic risks to human health and the environment.

When considering appropriate methods for detection, destruction and treatment of CWM, there are unique challenges that are encountered. Although the most common and effective method for remediation of CWM is item separation and incineration, this method has been publicly opposed because of possible health risks from emissions. The safety hazards imposed by the chemical agents and the explosive safety risks from the munition itself pose additional challenges. Safety requirements and common sense dictate that the explosive hazards be mitigated before the CWM is addressed.

As a result, the Army has developed a number of safety requirements and protocols that dictate how explosives CWM and RCWM are to be handled in order to minimize the risk to human health and the environment and have established a national program to tackle the problem of eliminating chemical weapons by 2012 and in so doing reducing the risks to human health and the environment.

Additionally, each service has regulatory requirements that follow the guidance provided to them by DoD's chemical and biological directives.

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

CBRNE – Nerve Agents, Binary: GB2, VX2, Velez-Daubon, Larissa I., MD, Fernando L Benitez, MD. eMedicine Journal 3:1, January 2002. 3:1, http://www.emedicine.com/emerg/topic900.htm.

Chemical Agent Data Sheets, Volumes I and II, Edgewood Arsenal Special Report No. EO-SR-74001, December 1974. Available through Defense Technical Information Center, DTIC No. AD B028222.

Hartman, H.M. ***Evaluation of Risk Assessment Guideline Levels for the Chemical Warfare Agents Mustard, GB, and VX.*** Regulatory Toxicology and Pharmacology, 35, pp. 347-356, 2002.

Munro, N.B. et al. ***The Sources, Fate, and Toxicity of Chemical Warfare Agent Degradation Products.*** Environmental Health Perspectives, Vol. 107, No. 12, December 1999.

Munro, N.B. et al. ***Toxicity of the Organophosphate Chemical Warfare Agents GA, GB, and VX: Implications for Public Protection.*** Environmental Health Perspectives, Vol. 102, No. 1, January 1994.

NAP (National Academy Press). ***Review of Acute Human-Toxicty Estimates for Selected Chemical-Warfare Agents.*** National Research Council, National Academy Press, 1997.

NAP. ***Review of the U.S. Army's Health Risk Assessments for Oral Exposure to Six Chemical Warfare Agents.*** National Research Council, National Academy Press, 2000.

NAP. ***Systems and Technologies for the Treatment of Non-Stockpile Chemical Warfare Agents.*** National Research Council, National Academy Press, 2002.

NAP. ***Veterans at Risk: The Health Effects of Mustard Gas and Lewisite.*** Institute of Medicine, National Academy Press, 1993.

Roberts, W.C., and W.R. Hartley. ***Drinking Water Health Advisory: Munitions.*** CRC Press, Boca Raton, FL, 1992.

Somani, S.M., and J. Romano, ***Chemical Warfare Agents: Toxicity at Low Levels.*** CRC Press, Boca Raton, FL, 2001.

U.S. Army. ***Non-Stockpile Chemical-Material Program, Survey and Analysis Report.*** U.S. Army Chemical Materiel Destruction Agency, November 1993.

U.S. Army Armament, Munitions and Chemical Command Chemical Research, Development and Engineering Center. Material Safety Data Sheet: Lethal Nerve Agent Tabun (GA).

U.S. Army Center for Health Promotion and Preventive Medicine (USACHPPM). ***Detailed and***

General Facts About Chemical Agents, TG 218.

U.S. Army Chemical Biological Defense Command Edgewood. Material Safety Data Sheet: Lewisite. Last Technical Review on May 5, 1999.

U.S. Army Corps of Engineers. ***Safety and Health Requirements Manual.*** EM 385-1-1, Washington, D.C., September 3, 1996.

U.S. Army Soldier and Biological Chemical Command (SBCCOM). Material Safety Data Sheets. Revised on August 13, 2001.

Information Sources

Agency for Toxic Substances and Disease Registry (ATSDR)
ATSDR Region 1
1 Congress Street
Suite 1100 HBT
Boston, MA 02114
(617) 918-1494
http://www.atsdr.cdc.gov/mmg.html

Deployment Health Clinical Center (DHCC)
Blister Agent Fact Sheet
http://pdhealth.mil/wot/chemical.asp

International Programme on Chemical Safety (IPCS INCHEM)
World Health Organization (WHO)
20 Avenue Appia
1211 Geneva, Switzerland
http://www.inchem.org/pages/icsc.html

Mitretek Systems
3150 Fairview Park Drive
Falls Church, VA 22042-4519
(703) 610-2002
http://mitretek.org/home.nsf/homelandsecurity/chembiodefense

National Institute for Occupational Safety and Health (NIOSH)
(800) 35-NIOSH
http://www.cdc.gov/niosh/homepage.html

National Toxicology Program (NTP)
P.O. Box 12233, MD EC-03
Research Triangle Park, NC 27709
(919) 541-3419
http://ntp-server.niehs.nih.gov/

Organization for the Prohibition of Chemical Weapons, Chemical Weapons Convention
http://www.opcw.org/html/db/cwc/eng/cwc_frameset.html

University of Oklahoma, College of Pharmacy
1110 N. Stonewall Avenue
Oklahoma City, OK 73117
(405) 271-6484
http://www.oklahomapoison,org/prevention/arsine.asp

U.S. Army Center for Explosives Safety (USATCES)
1 Tree Road, Building 35
McAlester, OK 74501
http://www.dac.army.mil/es/

U.S. Army Center for Health Promotion and Preventive Medicine (CHPPM)
5158 Blackhawk Road
Aberdeen Proving Ground, MD 21010
(800) 222-9698
http://chppm-www.apgea.army.mil/

U.S. Army Chemical Materials Agency Headquarters
Public Affairs
AMSCM-SSP
5183 Blackhawk Road
Aberdeen Proving Ground-Edgewood Area, MD 21010-5424
(800) 488-0648
http://www.cma.army.mil/home.aspx

U.S. Department of Labor, Occupational, Safety and Health Administration (OSHA)
200 Constitution Avenue
Washington, D.C. 20210
1-800-321-OSHA
http://www.osha.gov

U.S. Army Engineering and Support Center, Huntsville
Directorate of Chemical Demilitarization
ATTN: CEHNC-CD
P.O. Box 1600
Huntsville, AL 35807-4301
(256) 895-1370
http://www.hnd.usace.army.mil/chemde/index.asp

U.S. National Library of Medicine, Specialized Information Services
2 Democracy Plaza
Suite 510 6707 Democracy Boulevard, MSC 5467
Bethesda, MD 20892
(301) 496-1131
http://sis.nlm.nih.gov/

Guidance Documents

Chemical Accident or Incident Response and Assistance (CAIRA) Operations. DA PAM 50-6, Headquarters, Department of the Army, Washington, D.C., May 1991.

U.S. Army. Army Chemical Safety Program, AR 385-61, Headquarters, Department of the Army, Washington, D.C., February 1997.

U.S. Army. Chemical Surety, Army Regulation 50-6, Headquarters, Department of the Army, Washington, D.C., February 1995.

U.S. Army. ***DoD Ammunition and Explosives Safety Standards.*** DoD 6055.9-STD.

U.S. Army. ***Military Chemistry and Chemical Compounds.*** Army Field Manual (FM) 3-9, Air Force AFR 355-7, Headquarters, Department of the Army, October 1975.

U.S. Army. NBC Field Handbook, Field Manual (FM) 3-7, Headquarters, Department of the Army, Washington, D.C., September 29, 1994.

U.S. Marine Corps. NBC Decontamination, FM 3-5, Headquarters, Department of the Army, MCWP 3-37.3, Commandant, Washington, D.C., July 28, 2000.