

1 Heavy flooding can loosen and displace soils, causing OE located on or beneath the ground  
2 surface to be moved or exposed. In flooded soils, OE could potentially be moved to the surface or  
3 to another location beneath the ground surface. Similarly, soil erosion due to high winds, flooding,  
4 or inadequate soil conservation could displace soils and expose OE, or it could cause OE to migrate  
5 to another location beneath the surface or up to the ground surface. Frost heaving is the movement  
6 of soils during the freeze-thaw cycle. Water expands as it freezes, creating uplift pressure. In  
7 nongranular soils, OE buried above the frost line may migrate with frost heaving. The effects of  
8 these and other geophysical processes on the movement of OE in the environment, while known to  
9 occur, are being studied more extensively by DoD.

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

#### 18 **3.3.4 Depth of OE**

19 The depth at which OE is located is a primary determinant of both potential human exposure  
20 and the cost of investigation and cleanup. In addition, the DoD Ammunition and Safety Standards  
21 require that an estimate of expected depth of OE be included in the site-specific analysis for  
22 determining response depth.<sup>47</sup> A wide variety of factors may affect the depth at which OE is found,  
23 including penetration depth — a function of munition size, shape, propellant charge used, soil  
24 characteristics, and other factors — as well as movement of OE due to frost heave or other factors,  
25 as discussed in Section 3.3.3.

26 There are several methods for estimating the ground penetration depths of ordnance. These  
27 methods vary in the level of detail required for data input (e.g., ordnance weight, geometry, angle  
28 of entry), the time and level of effort needed to conduct analysis, and the assumptions used to obtain  
29 results. Some of the specific soil characteristics that affect ordnance penetration depth include soil  
30 type (e.g., sand, loam, clay), whether vegetation is present, and soil moisture. Other factors affecting  
31 penetration depth include munition geometry, striking velocity and angle, relative location of firing  
32 point and striking point, topography between firing point and striking point, and angle of entry.  
33 Table 3-2 provides examples of the potential effects that different soil characteristics can have on  
34 penetration depth. These depths do not reflect the variety of other factors (e.g., different striking  
35 velocities and angles) that affect the actual depth at which the munition may be found. The depths  
36 provided in Table 3-2 are taken from a controlled study to determine munition penetration into earth.  
37 They are presented here to give the reader an understanding of the wide variability in the depths at  
38 which individual munitions may be found, based on soil characteristics alone.

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<sup>47</sup>*DoD Ammunition and Explosives Safety Standards*, DoD 6055.9-STD, Chapter 12, July 1999.

1 While Table 3-2 provides a few examples of penetration depths, it does not illustrate the  
 2 dramatic differences possible within ordnance categories. For example, rockets can penetrate sand  
 3 to depths of between 0.4 and 8.1 feet, and clay to depths of between 0.8 and 16.3 feet, depending  
 4 on the type of rocket and a host of site-specific conditions.<sup>48</sup>

5 **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

14 Sources: U.S. Army Corps of Engineers, *Ordnance and Explosives Response: Engineering and Design*, EM 1110-1-  
 15 4009, June 23, 2000; Ordata II, NAVIODTECHDIV, Version 1.0; and Crull Michelle et al., *Estimating Ordnance*  
 16 *Penetration Into Earth*, paper presented at UXO Forum 1999, May 1999.

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

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

### 28 **3.3.5 Environmental Factors Affecting Decomposition of OE**

29 Deteriorated OE can present serious explosive hazards. As the OE ages, the explosive  
 30 compound/mixtures in the OE can remain viable and could increase in sensitivity.<sup>49</sup>

31 The probability of corrosion of an intact OE item is highly site specific. OE can resist  
 32 corrosion under certain conditions. There are OE sites dating back to World War I in Europe that  
 33 contain subsurface OE that remains intact and does not appear to be releasing any munition  
 34 constituents. However, there are certain environments, such as OE exposed to seawater, that can

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<sup>48</sup>U.S. Army Corps of Engineers, *Interim Guidance for Conventional Ordnance and Explosives Removal Actions*, October 1998.

<sup>49</sup>U.S. Army Corps of Engineers, *Ordnance and Explosives (OE) Response Workshop*. Control #399, USACE Professional Development Support Center, FY01.

1 cause OE<sup>50</sup> to degrade. In addition, as OE casings degrade under certain environmental conditions,  
2 or if the casings were damaged upon impact, their fillers, propellants, and other constituents may  
3 leach into the surrounding soils and groundwater.

4 In general, the likelihood of OE deterioration depends on the integrity and thickness of the  
5 OE casing, as well as the environmental conditions in which the OE item is located and the degree  
6 of damage to the OE item after being initially fired. Most munitions are designed for safe transport  
7 and handling prior to use. However, if they fail to explode upon impact, undergo a low-order  
8 detonation, or are otherwise damaged, it is possible that the fillers, propellants, and other munition  
9 constituents may leach into surrounding soils and groundwater, potentially polluting the soil and  
10 groundwater and/or creating a mixture of explosives and their breakdown products. Anecdotal  
11 evidence at a number of facilities suggests adverse impacts to soil and groundwater from ordnance-  
12 related activities.

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

- 15 • Soil moisture
- 16 • Soil type
- 17 • Soil pH
- 18 • Buffering capacity
- 19 • Resistivity
- 20 • Electrochemical (redox) potential
- 21 • Oxygen
- 22 • Microbial corrosion
- 23

#### 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.

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

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

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

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

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<sup>50</sup>OE specifically designed for use in a marine environment, such as sea mines and torpedoes, would not be included in this scenario.

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

4 Another factor affecting the corrosive potential of soils is resistivity, or electrical  
5 conductivity, which is dependent on moisture content and is produced by the action of soil moisture  
6 on minerals. At high resistivity levels (greater than 20,000 ohm/cm) there is no significant impact  
7 on corrosion; however, corrosion can be extreme at very low resistivity levels (below 1,000  
8 ohm/cm). High electrochemical potential can also contribute significantly to OE casing corrosion.  
9 The electrochemical or “redox” potential is the ability of the soil to reduce or oxidize OE casings  
10 (the oxidation-reduction potential). Aerated soils have the necessary oxygen to oxidize metals.

### 11 **3.3.6 Explosives-Contaminated Soils**

12 A variety of situations can create conditions of contaminated and potentially reactive and/or  
13 ignitable soils, including the potential for low-order detonations, deterioration of the OE container  
14 and leaching of munition constituents into the environment, residual propellants ending up in soils,  
15 and OB/OD, which may disperse chunks of bulk explosives and munition constituents. Soils  
16 suspected of being contaminated with primary explosives may be very dangerous, and no work  
17 should be attempted until soil analysis has determined the extent of contamination and a detailed  
18 work procedure has been approved.<sup>51</sup> Soils with a 12 percent or greater concentration of secondary  
19 explosives, such as TNT and RDX, are capable of propagating (transmitting) a detonation if initiated  
20 by flame. Soils containing more than 15 percent secondary explosives by weight are susceptible to  
21 initiation by shock. In addition, chunks of bulk explosives in soils will detonate or burn if initiated,  
22 but a detonation will not move through the soil without a minimum explosive concentration of 12  
23 percent. To be safe, the U.S. Army Environmental Center considers all soils containing 10 percent  
24 or more of secondary explosives or mixtures of secondary explosives to be reactive or ignitable  
25 soil.<sup>52</sup>

### 26 **3.4 Toxicity and Human Health and Ecological Impacts of Explosives and Other Munition** 27 **Constituents**

28 The human health and environmental risks of other munition constituents from OE are  
29 caused by explosives or other chemical components, including lead and mercury, in munitions and  
30 from the compounds used in or produced during munitions operations. When exposed to some of  
31 these munition constituents, humans may potentially face long-term health problems, including  
32 cancer. Similarly, exposure of ecosystems may cause disturbance of habitat and development of  
33 health and behavioral problems in the exposed receptors. The adverse effects of munition  
34 constituents are dependent on the concentration of the chemicals and the pathways by which  
35 receptors become exposed. Understanding the human health and environmental risks of munition  
36 constituents and byproducts requires information about the inherent toxicity of these chemicals and

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<sup>51</sup>U.S. Army Corps of Engineers, *Ordnance and Explosives Response: Engineering Design*, EP 1110-1-18, April 2000.

<sup>52</sup>Federal Remediation Technologies Roundtable and USAEC, *ETL Ordnance and Explosives Response*, 1110-1-8153, May 14, 1999.

1 the manner in which they may migrate through soil and water toward potential human and  
 2 environmental receptors. This section provides an overview of some commonly found explosive  
 3 compounds and their potential health and ecological impacts.

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

### 12 **3.4.1 Human Health Affects**

13  
 14 Table 3-3 lists common munition constituents and their uses. Many compounds  
 15 have multiple uses, such as white phosphorus, which is used both in pyrotechnics and  
 16 incendiaries. The list of classifications on Table 3-3 is not intended to be all-inclusive but to  
 17 provide a summary of some of the more common uses for various explosive materials.  
 18  
 19  
 20  
 21

#### **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.

22 **Table 3-3. Primary Uses of Explosive Materials**

23 <b>Compound</b>	<b>Propellant</b>	<b>Primary or Initiator</b>	<b>Booster</b>	<b>Burster Charge</b>	<b>Pyrotechnics</b>	<b>Incendiary</b>
24 TNT						
25 RDX						
26 HMX						
27 PETN						
28 Tetryl						
29 Picric acid						
30 Explosive D						
31 Tetrazene						
32 DEGDN						
33 Nitrocellulose						

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

Compound	Propellant	Primary or Initiator	Booster	Burster Charge	Pyrotechnics	Incendiary
2,4-Dinitrotoluene						
2,6-Dinitrotoluene						
Ammonium nitrate						
Nitroglycerine						
Lead azide						
Lead styphnate						
Mercury fulminate						
White phosphorus						
Perchlorates						
Hydrazine						
Nitroguanidine						

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 <sub>7</sub> H <sub>5</sub> N <sub>3</sub> O <sub>6</sub>	Possible human carcinogen, targets liver, skin irritations, cataracts.
RDX	Hexahydro-1,3,5-trinitro-1,3,5-triazine C <sub>3</sub> H <sub>6</sub> N <sub>6</sub> O <sub>6</sub>	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 <sub>4</sub> H <sub>8</sub> N <sub>8</sub> O <sub>8</sub>	Animal studies suggest potential liver and central nervous system damage.

**Table 3-4. Potential Toxic Effects of Explosive Chemicals and Compounds on Human Receptors (continued)**

	<b>Contaminant</b>	<b>Chemical Composition</b>	<b>Potential Toxicity/Effects</b>
1	PETN	Pentaerythritol tetranitrate $C_5H_8N_4O_{12}$	Irritation to eyes and skin; inhalation causes headaches, weakness, and drop in blood pressure.
2	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.
3	Picric acid	2,4,6-Trinitrophenol $C_6H_3N_3O_7$	Headache, vertigo, blood cell damage, gastroenteritis, acute hepatitis, nausea, vomiting, diarrhea, abdominal pain, skin eruptions, and serious dysfunction of the central nervous system.
4	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.
5	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.
6	DEGDN	Diethylene glycol dinitrate $(C_2H_4NO_3)_2O$	Targets the kidneys; nausea, dizziness, and pain in the kidney area. Causes acute renal failure.
7	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.
8	2,6-Dinitrotoluene	$C_7H_7N_2O_4$	Exposure can cause methemoglobinemia, anemia, leukopenia, and liver necrosis.
9	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.
10	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.
11	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.

**Table 3-4. Potential Toxic Effects of Explosive Chemicals and Compounds on Human Receptors (continued)**

	<b>Contaminant</b>	<b>Chemical Composition</b>	<b>Potential Toxicity/Effects</b>
1	Ammonium nitrate	$\text{NH}_4\text{NO}_3$	Prompt fall in blood pressure; roaring sound in the ears with headache and associated vertigo; nausea and vomiting; collapse and coma.
2 3	Nitroglycerine (Glycerol trinitrate)	$\text{C}_3\text{H}_5\text{N}_3\text{O}_9$	Eye irritation, potential cardiovascular system effects including blood pressure drop and circulatory collapse.
4	Lead azide	$\text{N}_6\text{Pb}$	Headache, irritability, reduced memory, sleep disturbance, potential kidney and brain damage, anemia.
5	Lead styphnate	$\text{PbC}_6\text{HN}_3\text{O}_8 \cdot \text{H}_2\text{O}$	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.
6	Mercury fulminate	$\text{Hg}(\text{OCN})_2$	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.
7	White phosphorus	$\text{P}_4$	Reproductive effects. Liver, heart, or kidney damage; death; skin burns, irritation of throat and lungs, vomiting, stomach cramps, drowsiness.
8	Perchlorates	$\text{ClO}_4^-$	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.
9	Hydrazine	$\text{N}_2\text{H}_4$	Possible human carcinogen; liver, pulmonary, CNS, and respiratory damage; death.
10	Nitroguanidine	$\text{CH}_4\text{N}_4\text{O}_2$	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.<sup>53</sup> 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 munition constituents has been varied and fragmented. Conservative screening levels of the most common munition 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.<sup>54</sup> In addition USCHPPM (U.S. Army Center for Health Promotion and Preventive Munitions) has

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<sup>53</sup>U.S. EPA, Office of Research and Development. *Wildlife Exposure Factors Handbook*, EPA/600/R-93/187, December 1993.

<sup>54</sup>S. Talmage, D. Opreko, 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.

1 developed Wildlife Toxicity Assessments (WTAs) for military compounds such as TNT, RDX, and  
 2 HMX.

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

5 **Table 3-5. Potential Effects of Explosive Chemicals and Compounds on Ecological**  
 6 **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. <sup>a</sup> Screening benchmarks of toxicity for mammalian and bird wildlife species have been developed by ORNL <sup>b</sup> and CHPPM. <sup>c</sup>
RDX	ATSDR studies conclude that RDX does not build up in fish or in people. <sup>a</sup> 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. <sup>d</sup> 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. <sup>b,c</sup>
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. <sup>a</sup> Screening benchmarks of toxicity for mammalian wildlife species have been developed by ORNL and CHPPM. <sup>b,c</sup>
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. <sup>c</sup>
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. <sup>a</sup> Screening benchmarks of toxicity for mammalian wildlife species have been developed by ORNL and are in preparation by CHPPM. <sup>b</sup>
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. <sup>a</sup> 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. <sup>c</sup>
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. <sup>a</sup> Screening benchmarks of toxicity for wildlife species are being prepared by CHPPM.

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

Contaminant	Potential Toxicity and Ecological Effects
<b>2,6-Dinitrotoluene</b>	The ATSDR profile states that 2,6-DNT has the same effect as 2,4-DNT on biota. <sup>a</sup> Screening benchmarks of toxicity for wildlife species are in preparation by CHPPM.
<b>Diphenylamine</b>	Unavailable
<b>N-Nitrosodiphenylamine</b>	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. <sup>a</sup>
<b>Phthalates</b>	Unavailable
<b>Ammonium nitrate</b>	Unavailable
<b>Nitroglycerine (Glycerol trinitrate)</b>	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. <sup>c</sup>
<b>Lead azide</b>	Unavailable
<b>Lead styphnate</b>	Unavailable
<b>Mercury fulminate</b>	Unavailable
<b>White phosphorus</b>	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. <sup>a,e,f</sup>
<b>Perchlorates</b>	Unavailable
<b>Hydrazine</b>	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. <sup>a</sup>
<b>Nitroguanidine</b>	Unavailable

Notes:

<sup>a</sup>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.

<sup>b</sup>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.

<sup>c</sup>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.

<sup>d</sup>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.

<sup>e</sup>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.

<sup>f</sup>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**

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

### 3 ***White Phosphorus***

4 One of the most frequently used pyrotechnics is white phosphorus, which is used for  
5 “spotting” or marking an area. White phosphorus burns rapidly when exposed to oxygen. In soils  
6 with low oxygen, unreacted white phosphorus can lie dormant for years, but as soon as it is exposed  
7 to oxygen, it may react. If ingested, white phosphorus can cause reproductive, liver, heart, or kidney  
8 damage, or death. Skin contact can burn the skin or cause organ damage. White phosphorus has  
9 been found in fish caught in contaminated water and in game birds from contaminated areas.<sup>55</sup>  
10 Research conducted by CRREL has shown that an unusually high mortality of migratory waterfowl,  
11 particularly dabbling species such as ducks and swans, is attributable to the ingestion of elemental  
12 white phosphorus particles in the salt marsh sediments at Eagle River Flats, Alaska. Between 1982  
13 and 1988, field and air surveys of the area were conducted. Nearly 1000 dead waterfowl were  
14 counted. The highest species-specific numbers included over 200 Northern pintail and over 150  
15 Mallard ducks. Because of its use as an artillery training impact area (with nearly 7000 rounds of  
16 high-explosive white phosphorus fired in 1989), munitions contamination was suspected as the  
17 cause. Tissue studies of gizzard contents, fat tissue, liver, and kidneys found white phosphorus  
18 content in all field collected ducks and swans analyzed. Behavior of exposed birds prior to death  
19 included increased thirst, head rolling, and violent convulsions.<sup>56, 57</sup>

### 20 ***Trinitrotoluene (TNT)***

21 TNT is soluble and mobile in surface water and groundwater. It is rapidly broken down into  
22 other chemical compounds by sunlight, and is broken down more slowly by microorganisms in  
23 water and sediments. TNT is not expected to bioaccumulate under normal environmental  
24 conditions. Human exposure to TNT may result from breathing air contaminated with TNT and  
25 TNT-contaminated soil particles stirred up by wind or construction activities. Workers in explosive  
26 manufacturing who are exposed to high concentrations of TNT in workplace air experience a variety  
27 of organ and immune system problems, as well as skin irritations and cataracts. Both EPA and  
28 ATSDR have identified TNT as a possible human carcinogen.  
29

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<sup>55</sup>ATSDR. Toxicological Profile for White Phosphorous. Atlanta, GA: U.S. Department of Health and Human Services, Public Health Service, 1997.

<sup>56</sup>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.

<sup>57</sup>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.

1  
2 **Toxicological Profiles of RDX and TNT**

3 The EPA's IRIS uses a weight-of-evidence classification for carcinogenicity that characterizes the extent to which  
4 the available data support the hypothesis that an agent causes cancer in humans. IRIS classifies carcinogenicity  
5 alphabetically from A through E, with Group A being known human carcinogens and Group E being agents with  
6 evidence of noncarcinogenicity. IRIS classifies both TNT and RDX as Group C, possible human carcinogens, and  
7 provides a narrative explanation of the basis for these classifications.<sup>58</sup>

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

11 The ATSDR has developed toxicological profiles for RDX and TNT to document the health effects of exposure to  
12 these substances. The ATSDR has identified both TNT and RDX as possible human carcinogens.<sup>59</sup>

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

16 Research has concluded that RDX, TNT, and other nitroaromatic compounds can be  
17 accumulated by plants from contaminated soils and could be a potential exposure route for  
18 herbivorous wildlife. Plant studies conducted using TNT-contaminated soil taken from ammunition  
19 sites found a direct correlation between concentrations in soil and plants. Large-scale uptake of  
20 TNT was found to take place in plants, including edible varieties such as lettuce, beans, and carrots.  
21 Studies suggest that because of the prevalence of TNT-contaminated sites, risk assessors should  
22 consider the hazard posed to organisms higher in the food chain, including humans and wildlife,  
23 which could also be affected by exposure. In addition, seed germination and growth studies  
24 conducted on terrestrial higher plants found varied thresholds for phytotoxicity. Some plants (e.g.,  
25 oat plants) have shown such high tolerances for TNT that they have been considered potential  
26 bioremediation species.<sup>60</sup>  
27

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<sup>58</sup>*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.

<sup>59</sup>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.

<sup>60</sup>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.

## ***Royal Demolition Explosive (RDX)***

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

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

### **3.5 Other Sources of Conventional Munition Constituents**

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

#### **3.5.1 Open Burning/Open Detonation (OB/OD)**

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

Incomplete combustion of munitions and energetic materials can leave uncombusted TNT, RDX, HMX, PETN, and other explosives. These materials can possibly be spread beyond the immediate vicinity of the OB/OD operation by the kick-out these operations generate and can contribute to potentially adverse human health and ecological effects.

### 3.5.2 Explosives Manufacturing and Demilitarization

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

#### **Demilitarization of Munitions**

Demilitarization is the processing of munitions so they are no longer suitable for military use.

Demilitarization of munitions involves several techniques, including both destructive and nondestructive methods. Destructive methods include OB/OD and incineration. Nondestructive methods include the physical removal of explosive components from munitions. Munitions are generally demilitarized because they are obsolete or their chemical components are deteriorated.

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

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

### **3.6 Conclusions**

The potential for explosive damage by different types of OE, including buried munitions, UXO, and munition constituents, depends on many different factors. These factors include the magnitude of the potential explosion, the sensitivity of the explosive compounds and their breakdown products, fuze sensitivity, the potential for deflagration or detonation, the potential for OE deterioration, and the likelihood that the item will be disturbed, which depends on environmental and human activities.

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

## SOURCES AND RESOURCES

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

### **Publications**

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

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**Information Sources**

**Department of Defense Explosives Safety Board (DDESB)**

2461 Eisenhower Avenue  
Alexandria, VA 22331-0600  
Fax: (703) 325-6227  
<http://www.hqda.army.mil/ddesb/esb.html>

**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](mailto: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](mailto: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 UXO throughout this chapter.) Proper selection and use of these technologies is an important part of the site investigation, which often takes place on ranges or parts of ranges that cover many acres. Since excavating all the land to depth is usually not practical, UXO detection technologies are used to locate anomalies that are subsequently verified as UXO or non-UXO. Given the high cost of UXO excavation (due to both range size and safety considerations), the challenge of most UXO investigations is the accurate and appropriate deployment of nonintrusive geophysical detection technologies to maximize probability of detection and minimize false alarms.

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

#### **False Alarms**

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

It should be noted that a particular technology or combination of technologies will never have the highest effectiveness, best implementability, and lowest cost at every site. In other words, there is no “silver bullet” detection technology. It is also important to note that no existing technology or combination of existing technologies can guarantee that a site is completely UXO-free. As discussed in Section 4.2 below and in Chapter 7, a combination of information from a variety of sources (including historical data, results of previous environmental data collection, and knowledge of field and terrain conditions) will be used to make decisions about the detection system to be used, including the particular sensor(s), the platform on which it is deployed, and data