(HE, Order) Reference

APPENDIX C

GENERAL INFORMATION ABOUT EXPLOSIVES USED AT TA-12 AND TA-14

APPENDIX C GENERAL INFORMATION ABOUT EXPLOSIVES USED AT TA-12 AND TA-14

C.0 INTRODUCTION

Since their inception in about 1944, TA-12 (L-Site) and TA-14 (Q-Site) have been areas at which explosives and mixed explosive compositions have been test fired. Both sites are large, isolated land masses well suited for firing activities. Beginning in 1944, most of the research and development on energetic materials, done as part of the Manhattan Project, were performed by the Explosives (X) Division. At the height of the research, thousands of pounds of explosives were used each month. Many of these were engineered into explosives lenses, but others took different configurations (Rhodes 1886, 0664; Hawkins et al. 1983, 0850). Scrap explosives and explosive-contaminated materials such as rags and paper were either burned or destroyed by detonation (Department of the Army 1984, 1109). Thus, explosives and co-ingredients associated with their formulation, used and disposed of by detonation, are major contaminants in the soil at TA-12 and TA-14.

A minor but significant portion of the contamination comes from the initiating devices, detonators, and from fuel oil used in burning operations. Polynuclear aromatic hydrocarbons (PAHs), explosives, beryllium, uranium, and barium have been reported in soil samples taken from TA-14 and probably exist in the soil at TA-12 (LANL 1989, 0425).

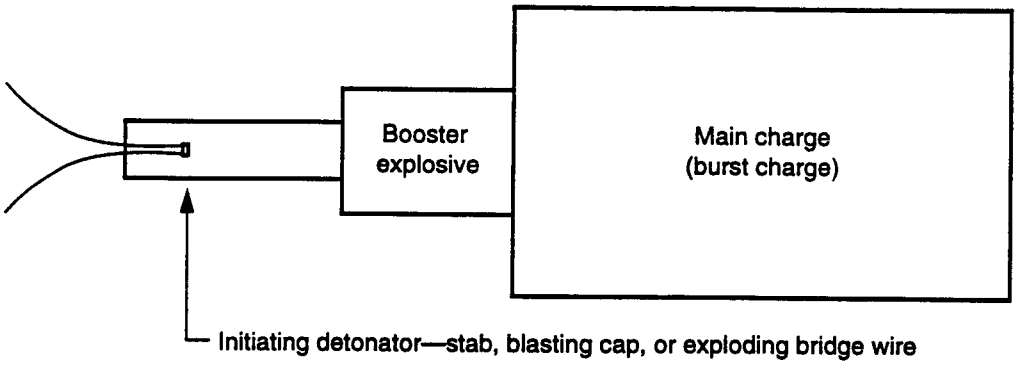
This appendix looks at the characteristics of the pure and formulated explosives fired at TA-12 and TA-14; possible effects of metal contamination; and the PAHs detected in some burning grounds.

C.1 Explosive Package of a Weapon System

The explosive package of a weapon system consist of an initiator, a booster, and a burst (main) charge (Figure C-1). The type of explosive used for each component in the explosive train depends upon the physical and chemical characteristic of the energetic material. Formulated explosive mixtures may have different characteristics and a different classification from the pure material.

C.2 Types of Explosives in Laboratory Weapon Systems

Explosives are classified based upon their sensitivity, such as primary or initiating explosives and secondary (booster or main charge) explosives. Also, the designations, sensitive and insensitive, are descriptive and meaningful for workers in the industry. Explosives may be classified according


Booster
explosive
Main charge
(burst charge)
Initiating detonator—stab, blasting cap, or exploding bridge wire

to the amount of potential (thermal) energy they possess or their ability to sustain a detonation wave: thus, high-energy explosives, high explosives (HE), or low-energy explosives. However, there is no known universal number for the thermal energy or the detonation velocity that would distinguish a borderline HE from a low-energy explosive. A working value of 500 meters per second (m/s) is acceptable among US scientists. Both classifications, secondary and HE, are used interchangeably in the industry (Department of the Army 1984, 1109). A more recent category of energetic material is the insensitive high-energy explosive (IHE).

C.3 Primary Explosives

Primary (initiating) explosives are energetic materials that are unstable and extremely sensitive to impact, sparks, heat, and many other outside influences. They are often used as initiators or in initiating devices such as detonators. Lead azide, mercury fulminate, and lead styphnate are examples of primary explosives (Table C-1).

C.4 Low-Energy Explosives

Low-energy explosives, such as black powder or smokeless powder, will undergo autocombustion (oxidation) reactions or decompositions at a rate that varies from a few centimeters per second to approximately 4.0 Km/s. They may be mixtures of more than one ingredient (Table C-2). Black powder is a mixture of either potassium or sodium nitrate, charcoal, and sulfur (6:1:1 wt %).

C.5 Secondary Explosives

Secondary explosives compose another group of compounds that includes 2,4,6-trinitrotoluene (TNT) and nitroglycerine (NG). They have been found to sustain detonation reactions at rates from 1.0 to 8.5 Km/s. Such materials are known as high-energy explosives or HE (Table C-3). They are several magnitudes more stable and less sensitive to external physical factors than primary explosives. Properties of some secondary explosives are given in Table C-4. The secondary explosive can be an IHE such as TATB. Initiating explosives are generally required to "set off" or cause a reaction in secondary explosives. There is no known universal agreed-upon value for the detonation velocity or thermal energy that would distinguish the HE from the non-HE material or low-energy materials. A working value of 5.0 Km/s is used by US scientists.

Secondary explosives may be used as boosters or as main charges in the weapons explosive package, which is similar in design to the initiating device (Figure C-1). They may be pure explosives, thermal-cast mixtures, or plastic bonded mixtures (PBXs). Thus, single compounds

such as TNT, NG, hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX, cyclotrimethylene-trinitramine), 1,3,5,7-tetranitro-1,3,5,7-tetrazacycle-octane (HMX, cyclotetramethylenetetranitramine) nitroguanidine (NQ), 1,3,5-triamino-2,4,6-trinitrobenzene (TATB), and others that would sustain a detonation wave of 5.0 Km/s or greater would be considered high explosives (Tables C-3, C-4, and C-5). In addition, TATB would be better classified as an IHE, which means that it is several magnitudes more stable than most secondary explosives.

TABLE C-1

PRIMARY OR INITIATING EXPLOSIVES

NAME	FORMULA	YEAR	
		DISCOVERED	FIRST COMMONLY USED
Mercury fulminate	$C_2N_2O_2Hg$	~1700	1867
Lead azide	PbN_6	~1880	~1904
Lead styphnate hydrate	$C_6H_3N_3O_9Pb$	~1914	~1920
Diazodinitrophenol (DDNP)	$C_6H_2N_2O_5$	1860	1928
Lead dinitroresorcinate (LNPR)	$PbC_6H_2N_2O_6$	1882	~1925

TABLE C-2

LOW-ENERGY MIXED EXPLOSIVES

DESIGNATION	COMPOSITION (wt %)	NOMINAL WORKING DENSITY (g/cm^3)	DETONATION VELOCITY (Km/sec)	DETONATION PRESSURE (kbars)	CONSISTENCY
Dynamite					
Straight	50 NG/0.2 NC/34 SN/15.8 C	1.4	~5.8	~100	Powder
Ammonium	16 NG/0.1 NC/78.7 AN/6 F	1.3	~4.8		Powder
Ammonium gel	26 NG/0.6 NC/34 AN/28 SN/11.4 C	1.3	~5.4		Gel
ANFO	94 AN/6 FO	~0.8	~4.7	~40	Powder
Slurry and Gel					
SE-TNT	TNT/AN/SN/W/G			~100	Slurry or gel
SE-TNT/Al	39 AN-SN/20 TNT/25 Al/15 W/1 G	1.60	~3.5		Slurry or gel
SBA/Al	49 AN-SN/35 Al/15 W/1 G	1.45	<4.0	60	Slurry or gel

TABLE C-3

MORE COMMON SINGLE COMPOUND HIGH EXPLOSIVES

MATERIAL	SYMBOL	FORMULA	YEAR	
			DISCOVERED	FIRST COMMONLY USED
Ammonium nitrate	AN	$H_4N_2O_3$	1659	1867
Nitroglycerine	NG	$C_3H_5N_3O_9$	1847	1867
1,3,5-Trinitrotoluene	TNT	$C_7H_5N_3O_6$	1863	1901
Pentaerythritoltetranitrate	PETN	$C_5H_8N_4O_{12}$	1894	~1929
Cyclotrimethylenetrinitramine	RDX	$C_3H_6N_6O_6$	1899	~1940
Cyclotetramethylenetetranitramine	HMX	$C_4H_8N_8O_6$	~1940	~1950
Nitroguanidine	NQ	$CH_4N_4O_2$	1877	~1901
Triaminotrinitrobenzene	TATB	$C_6H_6N_6O_6$	1888	~1960

TABLE C-4

BASIC PROPERTIES OF COMMON SINGLE-COMPOUND HIGH EXPLOSIVES

MATERIAL	STATE	M. P. (°C)	COLOR	DENSITY (g/cm^3)	DETONATION VELOCITY (Km/sec)	DETONATION PRESSURE (kbars)
AN	Solid	170	White	1.75	—	—
NG	Liquid	13	Clear	1.60 at 20°C	7.580	~230
TNT	Solid	80	Yellow	1.65	6.930	190
PETN	Solid	140	White	1.70	7.980	300
RDX	Solid	204	White	1.80	8.750	347
HMX (b)	Solid	285	White	1.90	~9.100	393
NQ	Solid	~250	White	1.75	8.400	~260
TATB	Solid	>450	Yellow	1.90	~7.600	275
Explosive D	Solid		Yellow			

TABLE C-5

HIGH-ENERGY MIXED EXPLOSIVES

DESIGNATION	COMPOSITION (wt %)	NOMINAL WORKING DENSITY (g/cm^3)	DETONATION VELOCITY (Km/sec)	DETONATION PRESSURE (kbars)	CONSISTENCY
Plastic or Wax Bonded Mixtures					
Composition C-4	91 RDX/2.1 rubber/1.6 oil/5.3 plasticizer	1.0 to 1.6	8.0	255	Plastic
Sheet explosive	60-85 PETN/0-8 NC/rubber and plasticizer	~1.5	~7.0	185	Rubbery sheets
PB-HMX or RDX	80-95 RDX or HMX/ 20-5 various plastics or plastic and plasticizers	1.6 to 1.85	7.0 to 8.5	<275 to 375	Solid
Composition A	90 RDX/10wax	1.6	8.1	260	Solid
TNT Mixtures					
Ammatol	50 TNT/50 AN	1.55	6.3	—	Solid
Composition B	40 TNT/60 RDX	1.70	7.9	285	Solid
Cyclotol 75/25	25 TNT/75 RDX	1.75	8.2	320	Solid
Octol 75/25	25 TNT/75 HMX	1.82	8.4	340	Solid
Pentolite 50/50	50 TNT/50 PETN	1.67	7.4	245	Solid
Tritonal	80 TNT/20 Al	1.72	6.7	—	Solid

The energetic materials fired, burned, or disposed of at TA-12 and TA-14 were generally secondary explosives/HE. In 1944 through 1952, most of these were cast mixtures of TNT and other materials. Examples are torpex, pentolite, baratol, boracitol, and composition B.

The detonators used were based on pentaerythrite tetranitrate (PETN). These low-energy detonators are typical electric blasting caps referred to as exploding bridgewire detonators (Figure C-2).

C.5.1 Composition B

In 1945 Composition B, which had proven to be approximately 40% more powerful than TNT, was used extensively in weapons research. It was poured as a hot slurry of wax, molten TNT, and a noncrystalline powder RDX. The composition is approximately 60% RDX and 40% TNT. During World War II, HMX existed as an impurity in RDX which was not removed before formulation.

C.5.2 Baratol

Baratol was used frequently as the slow-burning component of weapons systems. Its formulation is a slurred barium nitrate, aluminum powder, TNT mixture that contains stearoxyacetic acid and nitrocellulose. Approximate composition is 76% barium nitrate and 24% TNT.

C.5.3 Pentolite

PETN was standardized during World War II. An equal weight mixture of PETN with TNT became known as pentolite. It was used as a burst (main) charge for grenades and as a booster-surround charge for weapons applications.

C.5.4 Torpex

This TNT composition was also standardized during World War II and used in bombs. It is 41% RDX, 41% TNT, and 18% aluminum. It is noted for its great blast effect.

C.5.5 Boracitol

Boracitol is another heavily used mixed explosive. It contains 60% boric acid and 40% TNT.

C.6 Mock HE

Mock HE is a compound used to simulate HE for engineering purposes and for the accumulation of test data. Cyanuric acid was a commonly used mock HE.

Figure C-2

C.7 Igniters and Detonators

There are two types of devices that are used to make an energetic material react; they are igniters and detonators. Igniters convey a flame to the explosive, causing it to burn, while detonators transmit, through a primary explosive, a sharp blow (shock) that causes the secondary explosive to disassociate, detonate, or burn with extreme rapidity (Harris 1987, 21-0055). The Laboratory used electric blasting cap detonators (exploding bridge wire) to initiate their devices (Figure D-2). Large volumes of detonators were used and destroyed at TA-12 and TA-14. PETN is the explosive component of those devices.

C.8 CONTAMINANTS OF CONCERN FROM EXPLOSIVES

Contaminants of concern from operations involving explosives at TA-12 and TA-14 are residual parent explosives and impurities, inorganic, metals, PAHs, nitroaromatics, partial detonation products, biodegradation products, and radionuclides such as uranium. Parent explosives include TNT, RDX, HMX, PETN, and possibly tetryl. Inorganic are nitrates, nitrites, and carbonates. Metals of concern are those found in weapon components and in bullet casings, Pb, Ba, Cr, Cd, and Hg. Derivatives of naphthalene, anthracene, benzopyrene, and fluoranthene, often referred to as PAHs, are found in burning ground soil. Some of these are carcinogens. Major impurities and degradation products from explosives are 2,4-dinitrotoluene (2,4-DNT), 2,6-Dinitrotoluene (2,6-DNT), 1,3,5-Trinitrobenzene (TNB), 1,3-Dinitrobenzene (1,3-DNB), and nitrates. A more complete listing of possible contaminants is iterated in Table C-6, but many of these have not been found in the soil at HE facilities. Many of the partial detonation products have not been identified nor characterized sufficiently.

TABLE C-6

EXPLOSIVE CONSTITUENTS OF POTENTIAL CONCERN IN THE ENVIRONMENT

PRINCIPAL TYPE OF EXPLOSIVE	PARENT EXPLOSIVE (production impurities)	PRODUCTS OF INCOMPLETE DETONATION AND/OR PRODUCTS OF INCOMPLETE COMBUSTION	PRODUCTS OF ENVIRONMENTAL DEGRADATION	CONSTITUENTS DETECTED IN THE ENVIRONMENT
HMX	RDX, aliphatic and cyclic nitro-compounds (a)	Barium, lead, friable asbestos, PAHs (b)	Nitrate ions, nitrite ions, ammonia, formaldehyde, organic nitro-compounds, hydrogen cyanide (a), mono-, di-, and trinitroso-RDX analogues, hydrazine, 1,1-dimethylhydrazine, 1,2-dimethylhydrazine, methanol (a)	Parent explosive (HMX, RDX, aliphatic and cyclic nitro-compounds), inorganics, metals, products of incomplete detonation and products of incomplete combustion (lead, friable asbestos, PAHs) (a)
RDX	HMX, aliphatic and cyclic nitro-compounds (a)	Barium, lead, friable asbestos, PAHs (b)	Similar to those of HMX (a)	Parent explosive (RDX, HMX, aliphatic and cyclic nitro-compounds), inorganics, metals, products of incomplete detonation and products of incomplete combustion (lead, friable asbestos, PAHs) (a)
TNT	2,4-DNT, 2,6-DNT, 1,3-DNB, 1,3,5-TNB (a)	Barium, TNT, 2,4-DNT, 2,6-DNT, 1,3,5-TNB, 1,3-DNB, lead, friable asbestos, PAHs (b)	1,3,5-TNB, TNBOH, TNBAL, TNBA, anthranils (e.g., 2,6-dinitroanthranil), nitriles (e.g., 2,4,6-trinitrobenzonitrile), amines (2-amino-4,6-DNT, 4-amino-2,6-DNT, 3,5-dinitrophenol, 2-amino-4,6-dinitrobenzoic acid) (a)	Parent explosive (TNT, 2,4-DNT, 2,6-DNT, 1,3-DNB, 1,3,5-TNB), inorganics, metals, products of incomplete detonation and products of incomplete combustion (lead, friable asbestos, PAHs), environmental degradation products (2-amino-4,6-DNT, 4-amino-2,6-DNT) (a)
PETN	PE-tri-N, dipentaerythritol hexanitrate, tripentaerythritol acetonitrate (a)	Lead, friable asbestos, PAHs (b)	Pentaerythritol (PE or Pe-tri-N) (a)	Parent explosive, inorganics, metals, products of incomplete detonation and products of incomplete combustion (lead, friable asbestos, PAHs), environmental degradation products (a)
Tetryl	No production impurities of consequence (a)	Lead, friable asbestos, PAHs (b)	N-methylpicramide, picric acid, methylnitramine (a)	Parent explosive, inorganics, metals, products of incomplete detonation and Products of incomplete combustion (lead, friable asbestos PAHs) (a)

Legend:

2-amino-4,6-DNT 2-amino-4,6-dinitrotoluene
4-amino-2,6-DNT 4-amino-2,6-dinitrotoluene
1,3-DNB 1,3-dinitrobenzene
2,4-DNT 2,4-dinitrotoluene
2,6-DNT 2,6-dinitrotoluene
1,3,5-TNB 1,3,5-trinitrobenzene
HMX cyclotetramethylenetetranitramine
PE-tri-N pentaerythritol
PETN pentaerythritol tetranitrate
PAH polycyclic aromatic hydrocarbon
RDX cyclonitrite, cyclortrimethylenetrinitramine
TNBA 2,4,6-trinitrobenzoic acid
TNBAL 2,4,6-trinitrobenzaldehyde
TNBOH 2,4,6-trinitrobenzyl alcohol
TNT 2,4,6-trinitrotoluene

Footnotes:

(a) Layton et al 1987, 15-16-447
(b) USATHMA 1986, 15-16-457

C.8.1 Cyanuric Acid (Mock HE)

As a pure compound, cyanuric acid poses few hazards to humans; however, it will react violently with ethanol and acetonitrile. Upon decomposition, hydrogen cyanide (HCN) can be formed. Under the proper conditions, the cyanide radical will biodegrade to harmless materials such as ammonia, nitrates, and/or gaseous nitrogen. Mock HE was fired at both TA-12 and TA-14.

C.8.2 Polynuclear Aromatic Hydrocarbons (PAHs)

PAHs are produced when organic materials such as fuel oils are burned at temperatures above 500°C. Both 3,4-benzopyrene and 3,4-benzofluoranthene are included in the products from incineration, and both are carcinogenic to animals. Some of the metabolites of PAHs are known to cause cancer. The most studied is 7,8-diol-9,10-epoxide, a metabolite of benzo(a)pyrene; it has two steroisomers that are potent mutagens (Manahan 1989, 1112). In the past, when scrap/waste explosives and explosive-contaminated materials were disposed of by incineration, excelsior (wood product) and fuel oil were a part of the process. Therefore, PAHs present in fuel oil become a part of the soil at burning grounds and have been identified in TA-14 soil samples. PAHs are not rapidly broken down by the microbes in the soil and could remain for a number of years.

The manner in which individual PAHs behave in the soil is linked directly to the molecular weight of each PAH. Research has shown that the higher the molecular weight the less volatile the PAH. Therefore, less volatile compounds would remain in the soil for a longer period of time (Clement International Corporation 1990, 0873). In addition, sorption of the PAHs to the soil is dependent upon the soil type. Soils rich in organic matter tend to bind the high molecular weight PAHs, more strongly to their surfaces than low molecular weight PAHs, with water partition coefficient, K_{OC}, values of 10^{+5} to 10^{+6}. These strongly-bound compounds will be transported in water absorbed onto particulate whereas low molecular weight PAHs will volatilize. Again, PAHs are not degraded by microbes to any great extent in water nor in soil.

C.8.3 Metals

The concentrations of several metals in the soil at TA-12 and TA-14 are increased as a result of past and present firing activities. Moisture content and soil pH are important factors in determining the mobility of the unbound metal, which are generally more mobile in acidic media. Lead is an exception, as it is mobile under both acidic and basic media. Some metals can have adverse health effects if ingested or absorbed into the body at significantly high concentrations (The Handbook of Chemistry and Physics; The Handbook on Toxic and Inorganic Compounds; Hazardous and Toxic Effects of Industrial Chemicals).

C.8.3.1 Lead (Pb)

Lead can be found in nearly all parts of OU 1085. Lead used in bullets tested at TA-14 typically is an alloy containing 8-12% antimony and up to 0.25% tin to increase hardness.

The presence of lead and lead compounds in the environment does not necessarily result in exposure to the workers. The lead must be inhaled, ingested, or absorbed through the skin in measurable quantities to cause an exposure.

When lead is inhaled, it is easily absorbed from the respiratory tract and symptoms of lead poisoning tend to develop immediately, whereas most of the ingested lead passes through the body and is eliminated in the feces. Absorbed lead is caught in the liver and excreted, in part, through the bile. Absorption of organic lead compounds through the skin is more effective in causing lead poisoning than the absorption of inorganic compounds.

C.8.3.2 Barium (Ba)

Barium nitrate is a compound used in explosive formulation and has become a significant contaminant in the environment at weapon facilities. Its toxic effect to humans and the environment is low but still of concern.

C.8.3.3 Beryllium (Be)

Beryllium was used extensively in weapons designs during World War II. Beryllium and its salts are highly toxic and the soil contaminated with this metal should be handled with the greatest of care. Entrance into the body is by inhalation.

C.8.3.4 Chromium (Cr)

Chromium is a toxic metal. Its routes of entry are percutaneous absorption, inhalation, and ingestion. Chromium compounds in the +3 oxidation state are of low order of toxicity. In the +6 oxidation state, chromium compounds are irritants and corrosive.

C.8.3.5 Uranium (U)

Uranium is a radioactive, toxic, heavy, silvery- white, malleable, ductile metal softer than stainless steel. It is also a carcinogen. Natural uranium consists of 238-U and 234-U in radioactive equilibrium, plus 0.7% of 235-U. Enriched uranium has an increased percentage of the lighter isotopes, 234-U and 235-U: its specific activity and its radiation hazards are correspondingly increased.

Isotope 235 U decays to radioactive thorium (231-Th) via 4.3 to 4.6 MeV alpha particles. Isotope 238-U decays to radioactive 234-Th via 4.2 MeV alpha particles.

C.9 FATE AND TRANSPORT OF EXPLOSIVES AND EXPLOSIVES BY-PRODUCTS

In addition to environmental degradation, other factors affect the potential fate and migration of PCOCs in the environment. These include the physical and chemical properties of the constituents and their degradation products as well as the physical and geochemical characteristics of the sediments and soils on site. Factors such as soil pH, soil cation-exchange-capacity (CEC), water infiltration rate, soil porosity, along with chemical-specific factors [e.g., octanol water partition coefficient (Koc), and soil retention factors (K_d)] are key to understanding the potential migration patterns of these constituents. A summary of aspects of the environmental fate of explosives is presented in Table C-7.

Layton et al. (1987, 15-16-447) provide a detailed discussion of the distribution of HE in environmental media. They calculate the distribution of a number of HE, including TNT, HMX, RDX, and HE by-products including DNT and DNB, in reference landscapes using the program GEOTOX. They also summarize existing data confirming HE and HE by-products at open burn/open detonation sites nationwide.

The most important result of the modeling is that all of the HE and HE by-products are calculated to be distributed into both surface soils (A soil horizons) and subsurface soils (B soil horizons). In the western ecoregion models TNT, DNT, and RDX were all predicted to favor subsurface over surface soils. This modeling may not be directly relevant to TA-12 and TA-14 because a near-surface groundwater reservoir was included in the models.

The compiled data on concentrations of HE and HE by-products for a wide variety of facilities also suggest that HE is distributed in surface and subsurface soils (Layton et al. 1987, 15-16-447). In general, the actual field data suggest greater concentrations of HE in surface soils than predicted by the GEOTOX modeling.

The implication of these data for TA-12 and TA-14 is that subsurface sampling for HE will be necessary at those sites where HE contamination is likely. However, the lack of evidence for decoupling of surface and subsurface HE suggests that surface screening can be used to locate subsurface HE contamination.

The Explosives, Testing, and Safety Group monitoring records show both surface and subsurface contamination of HE at TA-14 and surface chunks of HE at TA-12 firing areas (Haywood 1993, 21-0082).

Table C-7
Environmental Fate of Explosives and HE By-Products

CONSTITUENT OF POTENTIAL CONCERN	WATER SOLUBILITY (mg/L)	Log K_{oc}	HENRY'S CONSTANT (atm-m^3/mol)	ENVIRONMENTAL FATE	PRIMARY LOCATION IN ENVIRONMENT
2-amino-4,6-DNT	2 800 (a)	0.15 (a)	~4 E-9 (a)	Gradual movement through soils and groundwater, should bind to humic acids and other organic matter (a)	Subsurface soils and groundwater (a)
4-amino-2,6-DNT	2 800 (a)	0.26 (a)	~1 E-9 (a)	Gradual movement through soils and groundwater, should bind to humic acids and other organic matter (a)	Subsurface soils and groundwater (a)
1,3-DNB	533 (b)	1.56 (b)	1.8 E-7 (b)	Gradual movement through soils and groundwater (a)	Subsurface soils and groundwater (a)
2,4-DNT	280 (b)	2.4 (b)	1.86 E-7 (b)	Gradual movement through soils and groundwater, diffusion of both vapor and aqueous phases through soil in soils receiving limited water infiltration (a)	Subsurface soils and groundwater (a)
2,6-DNT	206 (b)	1.89 (b)	4.86 E-7 (b)	Gradual movement through soils and groundwater, diffusion of both vapor and aqueous phases through soil in soils receiving limited water infiltration (a)	Subsurface soils and groundwater (a)
HMX	2.6 (a) or 5.0 (a)	2.11 (a)	1 E-16 (a)	Leaching through soils	Subsurface soils and groundwater (a)
PETN	2 (a) or 32 (a)	1.83 (a)	4 E-10 (a)	Leaching through soils	Subsurface soils and groundwater (a)
PE-tri-N	Very soluble (a)	N/A	N/A	Very stable in sunlight, resistant to microbial degradation (a)	Subsurface soils and groundwater (a)
RDX	42.2 (a)	0.89 to 2.43 (a)	6.58 E-12 (a)	RDX does not strongly adsorb to soils and sediments, soil adsorption affects RDX migration only in soils with an organic content >0.25 wt % (a)	Subsurface soils and groundwater (a)
Tetryl	75 (a)	2.43 (a)	2.0 E-12 (a)	Leaching through soils (a)	Subsurface soils and groundwater (a)
1,3,5-TNB	385 (b)	2.82 (b)	9 E-8 (b)	Gradual movement through soils and groundwater (a)	Subsurface soils and groundwater (a)
TNT	123 (a)	2.67 to 3.2 (a)	2.6 E-9 (a)	Migration of TNT is affected in soils with a cation exchange capacity (CAC) >10 meg/100 g; vapor-phase diffusion only important in soils where water infiltration is low (a)	Subsurface soils and groundwater (a)

(a) Layton et al. 1987, 15-16-447
(b) Burrows et al. 1989, 15-16-455

C.10.0 TOXICITY OF HE CONSTITUENTS

Several of the explosives, co-constituents, degradation products of the explosives, and associated experimental materials are carcinogens and/or systemic toxicants. Nearly all of the potential contaminants may exert their toxic effect (i.e., either carcinogenic and/or systemic effect) through any of the direct routes of exposure (i.e., inhalation, incidental soil ingestion, ingestion of water, and dermal exposure). The exceptions to this include the carcinogenic metals (cadmium, chromium VI, and nickel) and the carcinogenic mineral asbestos, which are considered by the US Environmental Protection Agency (EPA) to be carcinogenic only through the inhalation route of exposure.

Table C-8 lists the potential inorganic contaminants considered by the EPA to be carcinogenic only through the inhalation route of exposure (EPA 1992, 0830). They are placed in order of highest carcinogenicity to lowest carcinogenicity. The class of carcinogen refers to the evidence used to support the carcinogenic classification. For example, the evidence supporting the carcinogenic classification of A for a potential contaminant is stronger than that for a constituent with a carcinogenic classification of B.

Table C-9 lists the potential inorganic and organic contaminants that are explosives' components considered by the EPA to be carcinogenic through all direct routes of exposure (EPA 1992, 0830). The target organs identified are for the oral route of exposure. These potential contaminants are placed in decreasing order of carcinogenicity within each class of chemical (i.e., inorganics and organics).

All of the aforementioned constituents have the potential to exert a systemic toxic effect through all direct routes of exposure. However, systemic health criteria have not been developed for all of these constituents. Tables C-10 and C-11 list the constituents, oral target organ designation, and oral reference criteria [i.e., reference dose (RfD) in mg/kg-day] available from the EPA. An RfD is the highest dose that an individual may receive throughout his lifetime without experiencing an adverse health effect. The more toxic systemic constituents have the lowest RfDs. These constituents are placed in decreasing order of systemic toxicity within each class of chemical (i.e., inorganics and organics).

The high-energy explosives used during the 1940s and 1950s were mixtures of TNT and RDX with other components playing a minor role. Later, HMX became available and was used in a mixture with TNT. Although plastic-bonded explosives were researched in the 1940s, they were not mass-produced until the 1950s (Layton 1987, 1060l; Rickert 1985, XXXX). The toxicity data herein should not be used without close scrutiny of the methods used and the results obtained.

Also, it is not feasible to extrapolate from bacteria or animals to humans, but one can use laboratory data as a warning tool in assessing potential hazards.

TABLE C-8
CARCINOGENIC INORGANICS VIA INHALATION – HE DEVICE CONSTITUENTS

CONSTITUENT	CLASS OF CARCINOGEN	TARGET ORGAN
Chromium (VI)	A	Lung
Cadmium	B1	Respiratory tract

TABLE C-9
CARCINOGENIC CONSTITUENTS VIA ALL ROUTES OF EXPOSURE – HE AND BY-PRODUCTS

CONSTITUENT	CLASS OF CARCINOGEN	TARGET ORGAN FOR ORAL ROUTE
Inorganics		
Beryllium	B2	Multiple organs
Organics		
PAHs (i.e., benzo[a]pyrene)	B2	Stomach
2,4-DNT	B2	Liver
2,6-DNT	B2	Liver
RDX	C	Liver
TNT	C	Bladder

TABLE C-10

ORGANIC SYSTEMIC TOXICS – HE AND BY-PRODUCTS

CONSTITUENT	ORAL RfD (mg/kg/day)	TARGET ORGAN OR EFFECT
1,3,5-TNB	5.00E-5	Spleen
1,3-DNB	1.0E-4	Spleen weight
Nitrobenzene	5.00E-4	Liver, kidney
2,4,6-TNT	5.00E-4	Liver
2,4-DNT	2.00E-3	Neurotoxic
RDX	3.00D-3	Prostate
Tetryl	1.00E-2	Liver, kidney, spleen
HMX	5.00E-2	Liver

TABLE C-11

INORGANIC SYSTEMIC TOXICS – HE DEVICE COMPONENTS

CONSTITUENT	ORAL RfD (mg/kg/day)	TARGET ORGAN OR EFFECT
Lead	10 ug/dl (blood) [a]	Central nervous system
Cadmium	5.00E-4	Kidney
Uranium	3.00E-3	Kidney
Beryllium	5.00E-3	Not available
Chromium VI	5.00E-3	Central nervous system
Vanadium	7.00E-3	Not available
Cyanide	2.00E-2	Myelin degradation
Nickel	2.00E-2	Decreased body weight
Barium	7.00E-2	Blood pressure
Boron	9.00E-2	Testicular effects
Manganese	1.00E-1	Central nervous system
Nitrite	1.00E-1	Methemoglobemia
Zinc	2.00E-1	Anemia
Copper	1.30E+0	GI irritation
Nitrate	1.60E+0	Methemoglobemia

[a] The blood lead level of 10 ug/dl has been selected as a cutoff for intervention. Lead does not have an RfD because lead does not have a known threshold for the induction of systemic effects (EPA 1990, 15-16-456).

C.10.1 1,3,5-Trinitrotoluene (TNT)

TNT is one of the most widely used and the most extensively studied of the eight basic HE. It was the base compound in many of the mixed formulations used in World War II, and has been shown to be resistant to most types of biodegradation with the exception of ultraviolet light and certain types of microbes. TNT can enter the body by absorption through the skin, inhalation, or through the gastrointestinal tract. Like many of its degradation products (2,4-DNT, 2,6-DNT, 1,3,5-TNB, etc.), it can be harmful to workers. TNT causes what is known as yellow jaundice.

When fed to live animals, TNT was shown to cause cancer, but there are no corresponding data for the effects of TNT in humans. However, TNT poisoning in humans has been extensively documented.

C.10.2 1,3,5-Hexahydro-1,3,5-trinitrotriazine (RDX)

The carcinogenicity of RDX is controversial. Studies with rats showed that females are more readily affected than males, and the results are much more dose-dependent. The conclusions are that RDX is noncarcinogenic. Acute RDX toxicity has been observed in humans and primarily affects the central nervous system. This includes hyper-irritability, muscle twitching, generalized epileptiform, seizures, prolonged confusion, and amnesia.

C.10.3 1,3,5,7-Tetranitro-1,3,5,7-tetraazocyclooctane (HMX)

HMX is a by-product in the synthesis of RDX and is structurally similar. Although one would expect that the carcinogenic and reproductive effects and toxicity would be similar to RDX, these have not been adequately evaluated in animals. Reports of organ toxicity following exposure has showed that HMX can reach the heart, central nervous system, liver, and kidneys. The route of entry seems to be important in the results obtained. HMX was found not to be mutagenic with or without metabolic activation.

C.10.4 Pentaerthritol-tetranitrate (PETN)

PETN is a most sensitive secondary explosive. It is used in primer formulation, as a vasodilator in the treatment of angina in which a decrease in systolic and diastolic blood pressure is observed. It has been evaluated in low-dose animal tests, but no long-term data are available. In the short term, therapeutic treatments are infrequent-reversible effects such as headaches, nausea, and skin allergies. PETN was found not to be mutagenic.

C.10.5 2,4,6-Trinitrophenylmethyl-nitramine (Tetryl)

Tetryl is a booster explosive that is known to cause dermal and respiratory irritation. It will stain the skin, hands, neck, and hair yellow. Tetryl is a potential mutagen in humans, but no conclusive evidence exists on its carcinogenic nature.

C.10.6 Ammonium Picrate (Explosive D)

Explosive D has been shown to hydrolyze to picric acid in aqueous solutions. It is readily absorbed through the skin and lungs. Workers exposed to the dust of this explosive have shown skin and nasal cavity staining, and granular deposits (picrate) in the blood, kidney, thyroid, and adrenal gland. Also, picric acid is known to severely affect the central nervous system and to cause jaundice in workers, as well as causing dermatitis. Explosive D can cause chromosomal damage.

C.10.7 Lead

Lead is a cumulative poison and the early effects are nonspecific: except by laboratory testing, they are difficult to distinguish from the symptoms of minor seasonal illnesses. The individual who has lead poisoning will have decreased physical fitness, increased fatigue, sleep disturbance, headaches, aching bones and muscles, digestive symptoms, abdominal pain, and a decrease in appetite.

C.10.8 Barium

Barium's toxic effect to humans is low, but still of concern.

C.10.9 Beryllium

Beryllium and its salts are highly toxic, and soil contaminated with this metal should be handled with the greatest of care. Entrance into the body is via inhalation. Symptoms of Be poisoning are nonproductive coughs, substernal pain, moderate shortness of breath, and some weight loss. Soluble beryllium salts are cutaneous sensitizers as well as primary irritants. If a crystal of beryllium salt becomes imbedded in an open cut in the skin, it may cause granulomatous lesions that must be surgically removed. The maximum allowable concentration of beryllium dust in an eight-hour day is recommended to be 2 ug/cu meter in the work area.

C.10.10 Cadmium

Cadmium and solutions of its compounds are toxic. Acute toxicity is caused by inhalation of cadmium fumes or dust. Symptoms include severe pulmonary infection, chest pains, dyspnea, coughs, and general weakness.

C.10.11 Chromium

Exposure to dust and fumes can cause coughing, wheezing, headaches, fever, loss of weight, and dyspnea.

C.10.12 Mercury

Mercury, an acute toxic silvery liquid metallic element, is a very dangerous health hazard to humans. When heated, it emits highly toxic fumes. When at equilibrium with the supply of mercury, the vapor concentration of this element, even at room temperature, can exceed 200 times the allowable limit.

Mercury can be absorbed through the respiratory tract following the inhalation of the vapor or finely divided dust, or through the skin or the alimentary tract. Organic compounds of mercury are easily absorbed through the skin.

Acute mercury poisoning results in damage to the kidneys, whereas chronic mercury poisoning damages the nervous system. This damage is serious and may be permanently disabling.

C.10.13 Uranium

Radioactive uranium, with direct exposure to cells and tissue, causes injuries such as skin damage or erythema, shortening of the life span of blood-forming organs, nonspecific shortening of life span, induction of cancer or cataracts, and impaired fertility. With excessive exposure to ionizing radiation, all of these effects are irreversible.

Uranium is an alpha emitter and can penetrate the clothing or dead cells of the epidermis. Uranium is both an internal and external hazard. In the case of a large acute dose or continued chronic overexposure, there is the possibility that nonreversible damage will occur. The high rates of leukemia among radiologists, bone cancer among radium dial painters, and lung cancer among miners in Czechoslovakia, Germany, and the US all point to radiation as the causative agent.

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