United States
Environmental Protection
Agency

# Technical Fact Sheet – Hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX)

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## At a Glance

- Highly explosive, white crystalline solid.
- Synthetic product that does not occur naturally in the environment.
- Has been used extensively in the manufacture of explosives and accounts for a large part of the explosives contamination at active and former U.S. military installations.
- Not significantly retained by most soils and biodegrades very slowly under aerobic conditions. As a result, it can easily migrate to groundwater.
- Not expected to persist for a long period of time in surface waters because of transformation processes.
- Classified as a Group C (possible human) carcinogen.
- Can damage the nervous system if inhaled or ingested.
- EPA plans to update its toxicity benchmarks and health risk assessment.
- Basic types of on-site analytical methods include colorimetric and EXPRAY.
- The primary laboratory methods include liquid and gas chromatography.
- Potential treatment technologies include in situ bioremediation, granular activated carbon treatment, composting, and incineration.

## Introduction

This fact sheet, developed by the U.S. Environmental Protection Agency (EPA) Federal Facilities Restoration and Reuse Office (FFRRO), provides a brief summary of hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX), including its physical and chemical properties; environmental and health impacts; existing federal and state guidelines; detection and treatment methods; and additional sources of information. This fact sheet is intended for use by site managers and field personnel who may address RDX contamination at cleanup sites or in drinking water supplies.

RDX is a secondary explosive that is used extensively by the U.S. military in manufacturing explosives. Major manufacturing of RDX began in the U.S. in 1943 during World War II and was produced in enormous quantities at the Government Owned-Contractor Operated (GOCO) Holston Army Ammunition Plant (AAP) in Kingsport, Tennessee, for use in military munitions in World War II and afterwards (AEHA 1985).

During the 1940s through the 1970s, Department of Defense (DoD) ammunitions plants and depots demilitarized off-specification, unserviceable, and obsolete munitions based on steam-out and melt-out processes to recover 2,4,6-trinitrotoluene (TNT) and TNT-containing explosive fillers such as Composition B (TNT/RDX mixture). These processes often generated significant quantities of explosives-contaminated wastewaters. The untreated wastewater was discharged into unlined impoundments, lagoons, ditches, and playas, which resulted in significant levels of soil and groundwater contamination. Groundwater contamination from RDX was first reported in the late 1980s (Spalding and Fulton 1988).

RDX is still widely used in U.S. military munitions and is present in munitions fillers such as Composition A, Composition B, Composition C, and Cyclotols. With its manufacturing impurities and environmental transformation products, this compound accounts for a large part of the explosives contamination at active and former U.S. military installations (EPA 1999).

## What is RDX?

- RDX, also known as Royal Demolition Explosive, cyclonite, hexogen, and T4, is a synthetic product that does not occur naturally in the environment and belongs to a class of compounds known as explosive nitramines (ATSDR 2012; CRREL 2006).
- Production of RDX in the U.S. is limited to Army ammunition plants. Currently, it is manufactured at one facility in the U.S., the Holston AAP GOCO facility in Kingsport, Tennessee, from 1943 to present (AEHA 1985; ATSDR 2012).

## What is RDX? (continued)

- RDX is not produced commercially in the U.S; however, RDX is used both in military and commercial applications (ATSDR 2012).
- RDX is one of the most powerful high explosives available and was widely used during World War II. It is present in more than 4,000 military items, from large bombs to very small igniters (DoD 2011).
- It is a highly explosive, white crystalline solid (in its pure form) that is often mixed with other explosives, oils, or waxes to make military munitions and other products (DoD 2011).
- It is commonly used as an ingredient in plastic explosives and has been used as explosive "fill" in most types of munitions compounds (DoD 2011; MMR 2001).
- RDX can be used alone as a base charge for detonators or mixed with other explosives such as TNT to form Torpex, Composition B, H6, and cyclotols, which produce a bursting charge for aerial bombs, mines, and torpedoes (ATSDR 2012).
- RDX is commonly found at hand grenade ranges, antitank rocket ranges, bombing ranges, munitions testing sites, explosives washout lagoons, and open burn/open detonation (OB/OD) sites (CRREL 2006; CRREL 2007).

**Exhibit 1: Physical and Chemical Properties of RDX**
(ATSDR 2012; Major et al. 2007)

| Property | Value |
|---|---|
| CAS Number | 121-82-4 |
| Physical Description (physical state at room temperature) | White Crystalline Solid |
| Molecular weight (g/mol) | 222 |
| Water solubility (mg/L at 20$^{o}$C) | 42 |
| Octanol-water partition coefficient ($K_{ow}$) | 0.87 |
| Soil organic carbon-water coefficient ($K_{oc}$) | 1.80 |
| Boiling point ($^{o}$C) | Decomposes |
| Melting point ($^{o}$C) | 206 |
| Vapor pressure at 25$^{o}$C (mm Hg) | 4.0 x$10^{-9}$ |
| Specific gravity | 1.816 |
| Henry's Law Constant at 25$^{o}$C (atm-$m^3$/mol) | 1.96 x$10^{-11}$ |

Abbreviations: g/mol – grams per mole; mg/L – milligrams per liter; $^{o}$C – degrees Celsius; mm Hg – millimeters of mercury; atm-$m^3$/mol – atmosphere time cubic meter per mole.

## What are the environmental impacts of RDX?

- RDX can be released to the environment through spills, firing of munitions, disposal of ordnance, open incineration and detonation of ordnance, leaching from inadequately sealed impoundments, and demilitarization of munitions. The compounds can also be released from manufacturing and munitions processing facilities (ATSDR 2010).
- RDX has been identified in at least 31 of the 1,699 hazardous waste sites that have been proposed for inclusion on the National Priorities List (NPL) (ATSDR 2012).
- In surface soils, RDX is biodegraded very slowly aerobically. It degrades most easily under anaerobic conditions (EPA 1999).
- Its biodegradation products include hexahydro-1-nitroso-3,5-dinitro-1,3,5-triazine (MNX), hexahydro-1,3-dinitroso-5-nitro-1,3,5-triazine (DNX), and hexahydro-1,3,5-trinitroso-1,3,5-triazine (TNX) (Army 2009; CRREL 2006).
- Low soil sorption coefficient ($K_{OC}$) values indicate that RDX is not significantly retained by most soils. However, the rate of migration depends on the soil composition (ATSDR 2012; EPA 2005).
- RDX can migrate through the vadose zone and contaminate underlying groundwater aquifers, especially at source areas that have permeable soils, a shallow groundwater table, and abundant rainfall (CRREL 2006).

## What are the environmental impacts of RDX? (continued)

- RDX dissolves slowly in water because of the slow rate of dissolution from the solid phase and does not evaporate from water readily as a result of its low vapor pressure (EPA 2005).
- Phototransformation of RDX in soil is not significant; however, it is the primary physical mechanism that degrades RDX in aqueous solutions. Consequently, RDX is not expected to persist for a long period of time in surface waters (ATSDR 2010; CRREL 2006).
- Based on its low octanol-water partition coefficient ($K_{OW}$) and low experimental bioconcentration factor, RDX has a low bioconcentration potential in aquatic organisms (ATSDR 2012; EPA 2005).

## What are the health effects of RDX?

- Potential exposure to RDX could occur by dermal contact or inhalation exposure; however, the most likely route of exposure at or near hazardous waste sites is ingestion of contaminated drinking water (MMR 2001).
- EPA has assigned RDX a weight-of-evidence carcinogenic classification of C (possible human carcinogen) (IRIS 1993; OSHA 2010).
- The oral slope factor for carcinogenic risk is 0.11 milligrams per kilogram per day (mg/kg/day) (IRIS 1993).
- EPA assigned RDX an oral reference dose (RfD) of 3 x $10^{-3}$ mg/kg/day (IRIS 1993).
- RDX targets the nervous system and can cause seizures in humans and animals when large amounts are inhaled or ingested. Human studies also revealed nausea and vomiting after inhalation or oral exposure to unknown levels of RDX (ATSDR 2012; EPA 2005).
- EPA is looking to update its toxicity benchmarks and health risk assessment for RDX in its database of chemical risk values, the Integrated Risk Information System (IRIS) (DoD 2011).
- Limited information is available regarding respiratory, reproductive, cardiovascular, or dermal exposure in humans after any route or duration of exposure to RDX (ATSDR 2012).

## Are there any federal and state guidelines and health standards for RDX?

- A minimal risk level (MRL) of 0.2 mg/kg/day has been derived for acute-duration oral exposure (14 days or less), 0.1 mg/kg/day for intermediate-duration oral exposure (15 to 364 days), and 0.1 mg/kg/day for chronic-duration oral exposure (365 days or more) to RDX (ATSDR 2012).
- The EPA has established a lifetime Health Advisory guidance level of 2 parts per billion (ppb) for RDX in drinking water. The health advisory for a cancer risk of $10^{-4}$ is 0.03 milligrams per liter (mg/L) (EPA 2011a).
- EPA has calculated a resident soil screening level of 5.6 milligrams per kilogram (mg/kg) and the industrial soil screening level of 24 mg/kg (EPA 2011b).
- EPA has not established an ambient air level standard for RDX (MMR 2001).
- RDX is on the EPA's Drinking Water Contaminant Candidate List (CCL) (DoD 2010).
- The Occupational Safety and Health Administration (OSHA) set a construction industry permissible exposure limit (PEL) of 1.5 milligrams per cubic meter ($mg/m^3$) of workplace air for an 8-hour workday for a 40-hour work week (OSHA 2010).
- The National Institute for Occupational Safety and Health (NIOSH) recommended exposure limit (REL) for RDX during an 8-hour workday, 40-hour work week is 1.5 $mg/m^3$ (OSHA 2010).
- The American Conference of Governmental Industrial Hygienists (ACGIH) has set a threshold limit value (TLV) of 0.5 $mg/m^3$ (OSHA 2010).
- Numerous states have established regulations on explosives for air quality control, solid waste disposal, storage, manufacture, and use. Tennessee is developing new regulatory standards for RDX and Massachusetts has established regulatory cleanup standards for RDX in soil and groundwater (DoD 2011; Mass DEP 2008).
- The Department of Transportation has many regulations on the transportation of RDX (DOT 1989).

## What detection and site characterization methods are available for RDX?

- RDX, manufactured in the U.S. by the Bachmann process at Holston AAP, contains High Melting Explosive (HMX) as a manufacturing impurity of RDX at a level of approximately 10 percent. Therefore, sites potentially containing RDX or RDX containing explosives fillers (such as Composition B) should be analyzed for HMX as well (AEHA 1985).
- Both RDX and HMX are analytes on U.S. EPA SW-846 Methods 8330B (high-performance liquid chromatography – ultraviolet [HPLC-UV]) and 8095 (gas chromatography–electron capture device [GC-ECD]).
- HPLC and high-resolution gas chromatography (HRGC) have been paired with several types of detectors, including mass spectrometry (MS), electrochemical detection (ED), ECD, and ultraviolet (UV) detector (ATSDR 2012).
- Laboratory Method 8330 is the most widely used analytical approach for detecting RDX in soil. The method specifies using HPLC with a UV detector. It has been used to detect RDX and some of its breakdown products at levels in the low ppb range (EPA 2006).
- Another method commonly used is Method 8095, which employs the same sample processing steps as Method 8330, but uses HRGC with an ECD for detection (EPA 2005).
- Specific field screening methods for RDX include SW4051 to detect RDX in soil by immunoassay and SW8510 to detect both RDX and HMX using a colorimetric screening procedure (Army 2009; USACE 2005).
- Colorimetric methods generally detect broad classes of compounds such as nitroaromatics or nitramines. As a result, these methods are able to detect the presence of the target analytes and also respond to many other similar compounds. Immunoassay methods are more compound specific (EPA 2005).
- The EXPRAY kit is a simple colorimetric screening kit that can be used to provide qualitative tests for soils. It is also useful for both surfaces and unknown soils. The tools detection limit is about 20 nanograms (USACE 2001).
- Prototype biosensor methods for RDX have been field tested and are emerging methods for explosives analysis in water (EPA 1999).
- Tested field-screening instruments for RDX include FAST 2000, which uses antibodies and fluorescence, and GC-IONSCAN, which uses ion mobility spectrometry (IMS) (EPA 2000a, b).

## What technologies are being used to treat RDX?

- Bioreactors, bioslurry treatments, and passive subsurface biobarriers have been proven successful in reducing RDX concentrations (CRREL 2006; EPA 2005; ESTCP 2010).
- Composting has been proven in achieving cleanup goals for RDX at field demonstrations (EPA 2005).
- In situ chemical remediation can also be used to treat RDX. Fenton oxidation and treatment with iron metal (FeO) has been used to remediate RDX-contaminated soil and water but has not been used as stand-alone, full-scale treatment technology (EPA 2005; NCER 2010).
- Other methods of treating waters contaminated with RDX include activated carbon, UV radiation and in situ bioremediation (ATSDR 2012).

## Where can I find more information about RDX?


- Agency for Toxic Substances and Disease Registry (ATSDR). 2012. Toxicological Profile for RDX. www.atsdr.cdc.gov/toxprofiles/tp78.pdf
- Cold Regions Research and Engineering Laboratory (CRREL). 2006. Conceptual Model for the Transport of Energetic Residues from Surface Soil to Groundwater by Range Activities. ERDC/CRREL TR-06-18. www.dtic.mil/cgi-bin/GetTRDoc?Location=U2&doc=GetTRDoc.pdf&AD=ADA472270
- CRREL. 2007. Protocols for Collection of Surface Soil Samples at Military Training and Testing Ranges for the Characterization of Energetic Munitions Constituents. ERDC/CRREL TR-07-10. www.dtic.mil/cgi-bin/GetTRDoc?Location=U2&doc=GetTRDoc.pdf&AD=ADA471045.
- Environmental Security Technology Certification Program (ESTCP). 2010. Passive Biobarrier for Treating Comingled Perchlorate and RDX in Groundwater at an Active Range (ER-1028).

## Where can I find more information about RDX? (continued)


- Massachusetts Department of Environmental Protection (Mass DEP). 2008. Massachusetts Contingency Plan. 310 CMR 40.0000. www.mass.gov/dep/cleanup/laws/mcptoc.htm
- Massachusetts Military Reservation (MMR) 2001. Impact Area Groundwater Study Program. Chemical Fact Sheet – RDX. Fact Sheet 2001-04. http://imc2.army.mil/wastewater/community/facts/rdx.pdf
- Major, M., Reddy, G., and Leach, G. 2007 Reevaluation of the toxicity and carcinogenicity of RDX within the guidelines of modern risk assessment. Health Effects Research Program. 2007 JSEM Conference.
- Occupational Safety & Health Administration (OSHA). 2010. Cyclonite (RDX). www.osha.gov/dts/chemicalsampling/data/CH_231075.html
- Spalding, R. and J. Fulton. 1988. Groundwater Munition Residues and Nitrate near Grand Island, Nebraska, USA. Journal of Contaminant Hydrology. Volume 2 (2), Pages 139-153.
- U.S. Army. 2009. Military Munitions Response Program. Munitions Response Remedial Investigation/Feasibility Study Guidance.
- U.S. Army Corps of Engineers (USACE). 2001. Field-Based Analytical Methods for Explosive Compounds. Clu-In Seminar. August 28, 2001. http://www.clu-in.org/conf/tio/explosives_082801/prez/aug01BW.pdf
- USACE. 2005. Military Munitions Center of Expertise. Technical Update. Munitions Constituent (MC) Sampling. www.hnd.usace.army.mil/oew/MMTechUpdates/MC_Tech_Update_Final.pdf
- U.S. Army Environmental Hygiene Agency (AEHA). 1985. Water Pollution Aspects of Explosive Manufacturing. Technical Guide No. 140.
- U.S. Department of Defense (DoD). 2011. Emerging Chemical & Material Risks. www.denix.osd.mil/portal/page/portal/CMRMD/ECMR
- U.S. Department of Transportation (DOT). 1989. Hazardous materials table and hazardous materials communications regulations. Code of Federal Regulations. 49 CFR 172.101.
- U.S. Environmental Protection Agency (EPA). 1999. Office of Research and Development. Federal Facilities Forum Issue. Field Sampling and Selecting On-site Analytical Methods for Explosives in Water. EPA-600-S-99-002.
- EPA. 2000a. Office of Research and Development. Barringer Instruments. GC-IONSCAN. Environmental Technology Verification Report. EPA/600/R-00/046.
- EPA. 2000b. Office of Research and Development. Research International, Inc. FAST 2000. Environmental Technology Verification Report. EPA 600-R-00-045EPA. 2005.
- EPA Handbook on the Management of Munitions Response Actions. EPA 505-B-01-001 http://nepis.epa.gov/EPA/html/DLwait.htm?url=/Adobe/PDF/P100304J.PDF
- EPA. 2006. 8330b. Nitroaromatics, Nitramines, and Nitrate esters by High Performance Liquid Chromatography (HPLC) Revision 2.
- EPA. 2011a. 2011 Edition of the Drinking Water Standards and Health Advisories. http://water.epa.gov/action/advisories/drinking/upload/dwstandards2011.pdf
- EPA. 2011b. Regions 3,6, and 9. Regional Screening Levels Table. www.epa.gov/reg3hwmd/risk/human/index.htm
- EPA. Integrated Risk Information System (IRIS). 1993. Hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX) (CASRN 121-82-4). Last Revised 1993. www.epa.gov/IRIS/subst/0313.htm
- EPA. National Center for Environmental Research (NCER). 2010. Final Report: Fate and Transport of Munitions Residues in Contaminated Soil. http://cfpub.epa.gov/ncer_abstracts/index.cfm/fuseaction/display.abstractDetail/abstract/5251/report/F


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