



## TECHNICAL FACT SHEET – RDX

### At a Glance

- ❖ Highly explosive, white crystalline solid.
- ❖ Synthetic product that does not occur naturally in the environment.
- ❖ Used extensively in the manufacture of munitions 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.
- ❖ Basic types of field screening methods include colorimetric and immunoassay.
- ❖ Primary laboratory analytical methods include liquid and gas chromatography.
- ❖ Potential treatment technologies include in situ bioremediation, granular activated carbon treatment, composting, phytoremediation and incineration.

### Introduction

This fact sheet, developed by the U.S. Environmental Protection Agency (EPA) Federal Facilities Restoration and Reuse Office (FFRRO), provides a 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 synthetic chemical used primarily as a military explosive. Major manufacturing of RDX began in the United States in 1943 during World War II with the rise in demand for improved explosives (U.S. Army 1984). RDX was combined with oils, waxes and other explosives, including 2,4,6-trinitrotoluene (TNT), to form usable compositions for military munitions (U.S. Army 1984; EPA 2005).

With its manufacturing impurities and environmental transformation products, RDX 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, Research Department 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 (U.S. Army 1984; USACE CRREL 2006; ATSDR 2012).
- ❖ RDX is a white crystalline solid that can be used alone as a base charge for detonators or mixed with other explosives such as TNT to form cyclotols, which produce a bursting charge for aerial bombs, mines and torpedoes (U.S. Army 1984; ATSDR 2012; DoD 2016).
- ❖ 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 2016).

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## Technical Fact Sheet – RDX

- RDX is commonly found at hand grenade ranges, antitank rocket ranges, bombing ranges, artillery ranges, munitions testing sites, explosives washout lagoons, demolition areas and open burn/open detonation sites (USACE CRREL 2006; EPA 2005, 2012c).
- Production of RDX in the United States has been limited to Army ammunition plants (ATSDR 2012; HSDB 2016). The Holston Army Ammunition Plant in Kingsport, Tennessee is the only active manufacturing facility in the United States (ATSDR 2012; EPA 2012a).
- RDX is not produced commercially in the United States; however, some U.S. companies import RDX from outside the United States for use in commercial applications (ATSDR 2012; EPA 2012a).

### Exhibit 1: Physical and Chemical Properties of RDX (USACE CRREL 2006; ATSDR 2012; HSDB 2016; NIOSH 2016)

Property	Value
Chemical Abstracts Service (CAS) number	121-82-4
Physical description (physical state at room temperature)	White crystalline solid
Molecular weight (g/mol)	222.26
Water solubility at 25°C (mg/L)	59.7
Octanol-water partition coefficient (Log $K_{ow}$ )	0.87
Soil organic carbon-water coefficient (Log $K_{oc}$ )	1.80
Boiling point (°C)	Decomposes
Melting point (°C)	204 to 206
Vapor pressure at 20°C (mm Hg)	$1.0 \times 10^{-9}$ (ATSDR 2012); $4.0 \times 10^{-9}$ (HSDB 2016)
Specific gravity at 20°C	1.82
Henry's law constant at 25°C (atm·m <sup>3</sup> /mol)	$2.0 \times 10^{-11}$

Abbreviations: g/mol – grams per mole; mg/L – milligrams per liter; °C – degrees Celsius; mm Hg – millimeters of mercury; atm·m<sup>3</sup>/mol – atmosphere - cubic meters per mole.

## Existence of RDX in the environment

- 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. RDX can also be released from manufacturing and munitions processing facilities (ATSDR 2012).
- As of 2016, RDX had been identified at 32 sites on the EPA National Priorities List (NPL) (EPA 2016b).
- In the atmosphere, RDX is expected to exist in the particulate phase and settles by wet or dry deposition (ATSDR 2012; HSDB 2016).
- Low soil sorption coefficient ( $K_{oc}$ ) values indicate that RDX is not significantly retained by most soils and can leach to groundwater from soil. However, the rate of migration depends on the composition of the soil (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 (USACE CRREL 2006; EPA 2012c).
- RDX has a slow rate of dissolution from the solid phase and does not evaporate from water readily as a result of its low vapor pressure (USACE CRREL 2006; EPA 2005).
- Based on its low octanol-water partition coefficient ( $K_{ow}$ ) and low experimental bioconcentration factor, RDX has a low bioconcentration potential in aquatic organisms (HSDB 2016; ATSDR 2012; 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 sunlit surface waters (ATSDR 2012; USACE CRREL 2006; HSDB 2016).
- Results from a study indicate that RDX may bioaccumulate in plants and could be a potential exposure route to herbivorous wildlife (USACE CRREL 2006; EPA 2005).
- RDX may biodegrade in water and soil under anaerobic conditions. Its biodegradation products include hexahydro-1-nitroso-3,5-dinitro-1,3,5-

triazine (MNX); 1,3-dinitroso-5-nitro-1,3,5-triazacyclohexane (DNX); hexahydro-1,3,5-trinitroso-1,3,5-triazine (TNX); hydrazine; 1,1-

dimethyl-hydrazine; 1,2-dimethyl-hydrazine; formaldehyde and methanol (ATSDR 2012; USACE CRREL 2006).

### What are the routes of exposure and the potential 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 or agricultural crops irrigated with contaminated water (ATSDR 2012).
- ❖ EPA has assigned RDX a weight-of-evidence carcinogenic classification of C (possible human carcinogen) based on the presence of hepatocellular adenomas and carcinomas in female mice that were exposed to RDX (EPA 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; HSDB 2016).
- ❖ Potential symptoms of overexposure include eye and skin irritation, headache, irritability, fatigue, tremor, nausea, dizziness, vomiting, insomnia and convulsions (HSDB 2016; NIOSH 2016).
- ❖ Animal studies found that the ingestion of RDX for 3 months or longer resulted in decreased body weight and slight liver and kidney damage in rats and mice (ATSDR 2012).
- ❖ Limited information is available regarding the effects of long-term, low-level exposure to RDX (ATSDR 2012).

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

- ❖ EPA assigned RDX a chronic oral reference dose (RfD) of  $3 \times 10^{-3}$  milligrams per kilogram per day (mg/kg/day) (EPA IRIS 1993).
- ❖ EPA has assigned an oral slope factor (OSF) for carcinogenic risk of 0.11 mg/kg/day, and the drinking water unit risk is  $3.1 \times 10^{-6}$  micrograms per liter ( $\mu\text{g/L}$ ) (EPA IRIS 1993).
- ❖ The Agency for Toxic Substances and Disease Registry (ATSDR) has established a minimal risk level (MRL) of 0.2 mg/kg/day 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).
- ❖ EPA risk assessments indicate that the drinking water concentration representing a  $1 \times 10^{-6}$  cancer risk level for RDX is 0.3  $\mu\text{g/L}$  (EPA IRIS 1993). EPA has established drinking water health advisories for RDX, which are drinking water-specific risk level concentrations for cancer ( $10^{-4}$  cancer risk) and concentrations of drinking water contaminants at which noncancer adverse health effects are not anticipated to occur over specific exposure durations (EPA 2012b).
  - EPA has established a lifetime health advisory guidance level of 2  $\mu\text{g/L}$  for RDX in drinking water. The health advisory for a cancer risk of  $10^{-4}$  is 30  $\mu\text{g/L}$ .
  - EPA also established a 1-day and 10-day health advisory of 100  $\mu\text{g/L}$  for RDX in drinking water for a 10-kilogram child.
- ❖ For RDX in tap water, EPA has calculated a screening level of 0.7  $\mu\text{g/L}$  (EPA 2017).
- ❖ EPA has calculated a residential soil screening level (SSL) of 6.1 milligrams per kilogram (mg/kg) and an industrial SSL of 28 mg/kg. The soil-to-groundwater risk-based SSL is  $2.7 \times 10^{-4}$  mg/kg (EPA 2017).
- ❖ EPA has not established an ambient air level standard or screening level for RDX (EPA 2017).
- ❖ EPA included RDX on the fourth Contaminant Candidate List (CCL). The CCL is a list of unregulated contaminants that are known to or may occur in drinking water and may require regulation under the Safe Drinking Water Act (EPA 2016a).
- ❖ The EPA Region III Biological Technical Assistance Group (BTAG) has established a freshwater screening benchmark of 360  $\mu\text{g/L}$  and a freshwater sediment screening benchmark of 0.013 mg/kg (EPA 2006).
- ❖ Some states have established soil guidelines and standards for RDX. Residential soil guidelines range from 1 mg/kg (Massachusetts) to 160 mg/kg (Pennsylvania) (MADEP 2014 and PADEP 2011). Industrial soil guidelines range from 28 mg/kg (North Carolina) to 3,664 mg/kg (New Mexico) (NCDENR 2016 and NMED 2017).

- ❖ Few states have established surface water guidelines and water quality standards for RDX. Surface water guidelines and standards range from 5.8 µg/L (protective of human health, Michigan) to 2,591.5 µg/L (acute exposure, protective of fish and wildlife propagation, Oklahoma) (Michigan DEQ 2006 and OWRB 2014).
- ❖ Various states have established groundwater or drinking water standards and guidelines for RDX including the following:

State	Standard or Guideline (µg/L)	Source
California	0.3/30 <sup>a</sup>	CalSWRCB 2005
Indiana	7	IDEM 2016
Maine	3	MEDEP 2016
Massachusetts	1	MADEP 2014
Mississippi	0.609	MDEQ 2002
Nebraska	0.61	NDEQ 2012
New Jersey	0.5	NJDEP 2011
New Mexico	7.02	NMED 2017
Pennsylvania	2	PADEP 2011
West Virginia	0.61	WVDEP 2014
a) The first value is the California State Water Resources Control Board, Division of Drinking Water notification level; the second value is the response level.		

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

- ❖ EPA SW-846 Method 8330 is the most widely used analytical approach for detecting RDX in water, soil and sediment. The method specifies using high-performance liquid chromatography (HPLC) with an ultraviolet (UV) detector. It has been used to detect RDX and some of its breakdown products at levels in the low parts per billion (ppb) range in water, soil and sediment (EPA 2005, 2007b, 2012c).
- ❖ RDX is commonly deposited in the environment as discrete particles with strongly heterogeneous spatial distributions. As described in SW-846 Method 8330B, proper sample collection (using an incremental field sampling approach), sample processing (which includes grinding) and incremental subsampling are required to obtain reliable soil data (EPA 2006).
- ❖ Another method commonly used is EPA SW-846 Method 8095, which employs the same sample processing steps as EPA SW-846 Method 8330, but uses capillary column gas chromatography with an electron capture detector (GC/ECD) for detection of explosives in water and soil (EPA 2005, 2007a, 2012c).
- ❖ EPA SW-846 Method 8321, which uses HPLC-mass spectrometry (MS), may be modified for the determination of RDX in soil. Since RDX is not a target analyte for this method and the sample processing steps are not appropriate for use with energetic compounds, this method is commonly modified for RDX to employ different sample processing steps, such as those identified in Method 8330 (EPA 2012c).
- ❖ EPA Method 529 used solid phase extraction and capillary column GC and MS for the detection of RDX in drinking water (EPA 2002, U.S. Army 2009).
- ❖ Specific field screening methods for RDX include EPA SW-846 Method 4051 to detect RDX in soil by immunoassay and EPA SW-846 Method 8510 to detect RDX and octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine (HMX) using a colorimetric screening procedure (U.S. Army 2009; EPA 2007c; USACE 2005). Other screening techniques may be used for identification purposes (USACE CRREL 2007).
- ❖ Prototype biosensor methods for RDX have been field-tested and are emerging methods for explosives analysis in water (EPA 1999).
- ❖ Fluorescence spot (fluo-spot) detection is an emerging method for in situ RDX detection (Wang et al 2016).

### What technologies are being used to treat RDX?

- ❖ Ex situ methods for treating waters contaminated with RDX include granular activated carbon and UV irradiation (ATSDR 2012; USACE ERDC 2013).

- ❖ In situ bioremediation utilizing various substrates can be used to treat groundwater contaminated with explosives, including RDX (EPA 2005; DoD ESTCP 2012; ATSDR 2012).
- ❖ Bioaugmentation with aerobic explosive degrading bacteria may be a viable treatment technology for remediating RDX-contaminated groundwater (DoD SERDP 2012; Fuller and others 2015).
- ❖ In situ chemical remediation can also be used to treat RDX. Fenton oxidation and treatment with iron metal (Fe<sup>0</sup>) has been used to remediate RDX-contaminated soil and water but has not been used as a stand-alone, full-scale treatment technology (EPA 2005; EPA NCER 2013).
- ❖ Bioreactors, bioslurry treatments and passive subsurface biobarriers have proven successful in reducing RDX concentrations in soil (USACE CRREL 2006; EPA 2005; DoD ESTCP 2008 and 2010).
- ❖ Composting has been successful in achieving cleanup goals for RDX in soil at field demonstrations (EPA 2005).
- ❖ Incineration is a proven and widely-available method to treat RDX-contaminated soil and debris; however, resulting incinerator stack emissions may require treatment (EPA 2005).
- ❖ Phytoremediation of RDX-contaminated water and soil is being evaluated as a potential treatment technology (Lamichhane and others 2012; Panz and Miksch 2012; USACE CRREL 2013; Srivastava 2015).

### Where can I find more information about RDX?

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

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## Contact Information

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If you have any questions or comments on this fact sheet, please contact: Mary Cooke, FFRRO, at [cooke.maryt@epa.gov](mailto:cooke.maryt@epa.gov).