United States Environmental Protection Agency

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.
- Used extensively in the manufacture of munitions. Accounts for a large part of the explosives contamination at active and former U.S. military installations.
- Easily migrates to groundwater and biodegrades very slowly in the presence of air.
- Not expected to persist for a long time in surface waters because of breakdown processes.
- Suggestive evidence of carcinogenicity.
- Can damage the nervous system if inhaled or ingested.
- Treatment technologies include composting, incineration, alkaline hydrolysis, solidification/ stabilization, DARAMEND® process, granular activated carbon treatment and ion exchange.

Introduction

This fact sheet, developed by EPA's Federal Facilities Restoration and Reuse Office (FFRRO), provides a summary of hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX). The fact sheet covers RDX's physical and chemical properties, environmental and health impacts, federal and state guidelines, detection and treatment methods, and additional sources of information. The fact sheet is for environmental professionals and the general public.

What is RDX?

RDX is a synthetic chemical used primarily as a military explosive (U.S Army 1984; EPA 2005). RDX accounts for a large part of the explosives contamination at active and former U.S. military installations (EPA 1999).

- 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. It belongs to a class of compounds known as explosive nitramines. Its Chemical Abstracts Service (CAS) number is 121-82-4 (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 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, 2012b).
- Production of RDX in the United States has been limited to U.S. Army ammunition plants (ATSDR 2012; NCBI 2020). The Holston Army Ammunition Plant in Kingsport, Tennessee, is the only active RDX 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).

Table 1 presents physical and chemical properties for RDX. For additional information, see the EPA Chemicals Dashboard.

Table 1: Physical and Chemical Properties for RDX

Property	Value
Chemical Abstracts Service (CAS) number	121-82-4
Physical description (physical state at room temperature)	White crystalline solid
Molecular weight	222.12 g/mol
Water solubility	2.69×10^{-4} mol/L (experimental average)
Octanol-water partition coefficient (log K_{ow})	0.87 (experimental average)
Soil adsorption coefficient (K_{oc})	45.1 L/kg (predicted average)
Boiling point	256°C to 747°C (predicted average: 452°C)
Melting point	205°C (experimental average)
Vapor pressure	4.10×10^{-9} mm Hg (experimental average)
Density	1.84 g/cm^3 (predicted average)
Henry's law constant	2.69×10^{-6} atm-m^3/mol (predicted average)

Notes:
g/mol = grams per mole
mol/L = moles per liter
L/kg = liters per kilogram
°C = degrees Celsius
mm Hg = millimeters of mercury
g/cm^3 = grams per cubic centimeter
atm-m^3/mol = atmosphere-cubic meters per mole

What are the potential health effects of RDX?

There is suggestive evidence of carcinogenic potential for RDX, specifically in the liver and lungs via oral exposure (EPA IRIS 2018). RDX affects the nervous system and can cause seizures, nausea and vomiting (ATSDR 2012; EPA 2005; NCBI 2020).

Cancer Effects (EPA IRIS 2018)
Level of confidence: suggestive


Liver


Lungs

Noncancer Effects (EPA IRIS 2018)


Nervous


Reproductive


Urinary

EPA considers risk to be the chance of harmful effects to human health or to ecological systems resulting from exposure to an environmental stressor. For a risk to exist, the following three factors must be present: 1) contamination; 2) pathways for that contaminant to reach surrounding populations; and 3) populations that may be exposed to the contaminant. If any of these factors are missing, little or no risk is present.

- There is suggestive evidence of carcinogenic potential for RDX based on evidence of benign and malignant tumors in the liver and lungs of rats (EPA IRIS 2018).

- Potential symptoms of exposure include eye and skin irritation, headache, irritability, fatigue, tremor, nausea, dizziness, vomiting, insomnia and convulsions (NCBI 2020; NIOSH 2016).
- In laboratory animal studies, RDX caused neurological symptoms (convulsions), reproductive effects (prostate inflammation or prostatitis) and kidney damage (medullary papillary necrosis).
- Limited information is available regarding the effects of long-term, low-level exposure in humans (ATSDR 2012).

Where is RDX found in the environment?

RDX contamination can be found where munitions have been used, manufactured or disposed of (ATSDR 2012). Due to its chemical properties, RDX contamination tends to be found in groundwater rather than soil (ATSDR 2012; EPA 2005).

- RDX can contaminate underlying groundwater, especially at the point of release where there are permeable soils, shallow groundwater and abundant rainfall (USACE CRREL 2006; EPA 2012b).
- RDX may bioaccumulate in plants, so plant-eating animals could be exposed (USACE CRREL 2006; EPA 2005).
- RDX is not expected to accumulate in aquatic organisms through bioconcentration (NCBI 2020; ATSDR 2012; EPA 2005).
- RDX is slow to evaporate from water (USACE CRREL 2006; EPA 2005).
- RDX may biodegrade in water and soil under low oxygen conditions (ATSDR 2012; USACE CRREL 2006).
- Sunlight breaks down RDX in water but not in soil (ATSDR 2012; USACE CRREL 2006; NCBI 2020).
- In the atmosphere, RDX is expected to exist in the particulate phase (ATSDR 2012; NCBI 2020).
- As of 2020, RDX had been identified at 37 sites on EPA's National Priorities List (NPL) (EPA 2020a).

What are the routes of exposure of RDX?

The most likely route of exposure at or near hazardous waste sites is drinking contaminated water or eating agricultural crops irrigated with contaminated water (ATSDR 2012). Potential exposure to RDX could also occur by skin contact or inhalation.

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

To determine potential risks of adverse health effects, the federal government has derived toxicity values based on available health studies, which can be combined with exposure data to calculate screening values and standards. Table 2 includes federal toxicity values derived for RDX. Table 3 includes federal and state advisories, screening values and standards established for RDX.

Table 2: Federal Human Health Toxicity Values

Parameter	Value	Source
Chronic oral reference dose (RfD)	4 x 10^{-3} milligrams per kilogram per day (mg/kg-day)	EPA IRIS 2018
Oral slope factor (OSF) for cancer risk	0.08 per mg/kg-day	EPA IRIS 2018
Minimal risk levels (MRLs) for oral exposure	0.2 mg/kg-day: acute duration (14 days or less) 0.1 mg/kg-day: intermediate duration (15 to 364 days) or chronic duration (365 days or more)	ATSDR 2012

- In 2020, EPA made a preliminary determination not to regulate RDX in drinking water due to its infrequent occurrence in public water systems at levels of public health concern (EPA 2020c), but the health advisories and screening levels will continue to be applied.
- EPA Region 3 derived ecological screening levels of 360 micrograms per liter (µg/L) for freshwater

and 0.013 mg/kg for freshwater sediment (EPA Region 3 2006).

- Some states have adopted screening values or cleanup goals for RDX in soil. The states' soil values, which are not included in Table 3, are wide-ranging in value, including 1 mg/kg to 170 mg/kg for residential areas (MADEP 2014; PADEP 2016) and 38 mg/kg to 830 mg/kg for industrial areas (NCDEQ 2020; PADEP 2016).
- 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; OWRB 2017).

Table 3: Federal and State Guidelines for RDX

Organization	Value	Medium[a]	Source
EPA	• 2 µg/L: lifetime health advisory • 30 µg/L: health advisory level (cancer risk of 10^{-4}) • 100 µg/L: 1-day and 10-day health advisory level for children	drinking water	EPA 2018
EPA	0.97 µg/L: tap water screening level	drinking water	EPA 2020b
EPA	• 8.3 mg/kg: residential screening level • 38 mg/kg: industrial screening level • 3.7 x 10^{-4} mg/kg: soil-to-groundwater screening level	soil	EPA 2020b
California	0.3 µg/L: notification level 30 µg/L: response level	drinking water	CalSWRCB 2020
Indiana	9.7 µg/L: residential screening level	groundwater (tap)	IDEM 2020
Maine	7 µg/L: residential remedial action guideline	groundwater	MEDEP 2018
Massachusetts	1 µg/L: standard for current or potential drinking water source	groundwater	MADEP 2014
Mississippi	0.609 µg/L: Tier 1 target remedial goal	groundwater	MDEQ 2002
Nebraska	0.7 µg/L: residential remediation goal	groundwater	NDEQ 2018
New Jersey	0.5 µg/L: quality standard	groundwater	NJDEP 2018
New Mexico	9.66 µg/L: tapwater screening level	drinking water	NMED 2019
Pennsylvania	2 µg/L: residential standard	groundwater	PADEP 2016
West Virginia	0.7 µg/L: residential remediation standard	groundwater	WVDEP 2020

Note:
a) Drinking water is generally what comes out of the tap. Groundwater can be a source of drinking water. When groundwater is a source of drinking water, standards for groundwater and drinking water are often the same.

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. 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, 2012b).
- RDX is commonly deposited unevenly in the environment. As described in SW-846 Method 8330B, proper sample collection and processing are required to obtain reliable soil data (EPA 2006b).
- Another method commonly used is EPA SW-846 Method 8095 for detection of explosives in water and soil (EPA 2005, 2007a, 2012b).
- EPA SW-846 Method 8321 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 2012b).

- ❖ EPA SW-846 Method 3535A (Solid-Phase Extraction) can be used to prepare water samples to be analyzed for RDX (EPA 2007d).
- ❖ EPA Method 529 can be used to detect RDX in drinking water (EPA 2002; U.S. Army 2009).
- ❖ Specific field screening methods for RDX include EPA SW-846 Method 8510 to detect RDX and octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine (HMX) (U.S. Army 2009; EPA 2007c, 2012b; 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 detection is an emerging method for in situ RDX detection (Wang et al. 2016).

What technologies are being used to treat RDX?

As described by Craig (2020), a review of 24 remediation projects at 22 facilities indicates that the most common treatment technologies for explosives in soil is composting (46.5%), followed by incineration (32.1%). Groundwater contamination has been primarily treated by groundwater extraction and ex situ granular activated carbon (GAC) treatment. Based on promising results in pilot-scale treatability studies, in situ bioremediation could be employed more frequently in the future (Craig 2020). It is important to consider co-contaminants, such as metals and perchlorate, when selecting a treatment technology (EPA 1993). Table 4 summarizes treatment technologies for RDX.

Table 4: Cleanup Technologies for RDX

Cleanup Technology	Water	Soil
Composting		✓
Incineration (emissions may require treatment)		✓
Alkaline hydrolysis		✓
Solidification/stabilization (metals co-contaminants)		✓
DARAMEND® process of biological and chemical reduction		✓
Granular activated carbon (ex situ)	✓	
Ion exchange (ex situ) (perchlorate co-contaminant)	✓	
In situ bioremediation	Potential	Potential

Where can I find more information about RDX?

General

- ❖ EPA. 2005. “Handbook on the Management of Munitions Response Actions.” EPA 505-B-01-001. nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P100304J.txt
- ❖ EPA. 2006a. CLU-IN (Clean-Up Information): Explosives. clu-in.org/characterization/technologies/exp.cfm
- ❖ EPA. 2012a. ChemView. Manufacturing, Processing, Use and Release Data. www.epa.gov/assessing-and-managing-chemicals-under-tsca/introduction-chemview
- ❖ U.S. Army. 1984. Military Explosives, TM9-1300-214. Department of the Army Technical Manual. Headquarters Department of the Army, Washington, D.C.
- ❖ U.S. Department of Defense (DoD). 2016. The Basics: RDX. Emerging Chemical and Material Risks. Chemical and Material Risk Management Program. www.denix.osd.mil/cmrmp/ecmr/rdx/thebasics

Health Effects

- Agency for Toxic Substances and Disease Registry (ATSDR). 2012. "Toxicological Profile for RDX." www.atsdr.cdc.gov/toxprofiles/tp78.pdf
- EPA Integrated Risk Information System (IRIS). 2018. "Hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX) (CASRN 121-82-4)." cfpub.epa.gov/ncea/iris2/chemicalLanding.cfm?substance_nmbr=313
- National Institute for Occupational Safety and Health (NIOSH). 2016. NIOSH Pocket Guide to Chemical Hazards: Cyclonite. www.cdc.gov/niosh/npg/npgd0169.html

Existence in the Environment

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- National Center for Biotechnology Information (NCBI). 2020. PubChem Compound Summary for Cyclonite. pubchem.ncbi.nlm.nih.gov/compound/Cyclonite
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Guidelines and Standards

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- EPA. 2020c. Regulatory Determination 4. www.epa.gov/ccl/regulatory-determination-4
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- Indiana Department of Environmental Management (IDEM). 2020. "IDEM Screening and Closure Level Tables." www.in.gov/idem/cleanups/2392.htm
- Maine Department of Environmental Protection (MEDEP). 2018. "Remedial Action Guidelines (RAGs) for Sites Contaminated with Hazardous Substances." www.maine.gov/dep/spills/publications/guidance
- Massachusetts Department of Environmental Protection (MADEP). 2014. "Massachusetts Contingency Plan." 310 CMR 40.0000. www.mass.gov/lists/waste-site-cleanup-laws-and-regulations
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- Mississippi Department of Environmental Quality (MDEQ). 2002. "Risk Evaluation Procedures for Voluntary Cleanup and Redevelopment of Brownfield Sites." www.mdeq.ms.gov/wp-content/uploads/2017/05/Proced.pdf
- Nebraska Department of Environmental Quality (NDEQ). 2018. "Voluntary Cleanup Program Guidance Document." deq.ne.gov/Publica.nsf/pages/05-162
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- West Virginia Department of Environmental Protection (WVDEP). 2020. "Voluntary Remediation and Redevelopment Rule." dep.wv.gov/dlr/oer/brownfieldsection/technicalguidanceandtemplates/Pages/default.aspx

Detection Methods

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Cleanup Technologies

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Contact Information

If you have any questions or comments on this fact sheet, please contact FFRRO at www.epa.gov/fedfac/forms/contact-us-about-federal-facility-cleanups.