



TECHNICAL FACT SHEET – 2,4,6-TNT

At a Glance

- ❖ 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.
- ❖ Sorbed by most soils, limiting its migration to water.
- ❖ Not expected to persist for a long period in surface waters because of transformation processes.
- ❖ 1,3,5-Trinitrobenzene (1,3,5-TNB) is one of the primary photodegradation products of TNT in environmental systems.
- ❖ Classified as a Group C (possible human) carcinogen.
- ❖ Primarily damages the liver and blood systems if inhaled or ingested.
- ❖ The primary laboratory methods for analysis 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 summary of 2,4,6-trinitrotoluene (TNT), 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 TNT contamination at cleanup sites or in drinking water supplies.

Major manufacturing of TNT began in the United States in 1916 at the beginning of World War I. Production increased between World War I and World War II. TNT was produced and used in enormous quantities during World War II (EPA 2005). In demilitarization operations conducted up to the 1970s, explosives were removed from munitions with jets of hot water. The effluent flowed into settling basins and the remaining water was disposed of in unlined lagoons or pits. The effluent from TNT manufacturing and demilitarization acted as a major source of munitions contamination in soils and groundwater at munition plants (EPA 2005).

TNT is still widely used in U.S. military munitions and accounts for a large portion of the explosives-related contamination at active and former U.S. military installations. With its manufacturing impurities and environmental transformation products, TNT presents various health and environmental concerns.

What is TNT?

- ❖ TNT is a yellow, odorless solid that does not occur naturally in the environment. It is made by combining toluene with a mixture of nitric and sulfuric acids (ATSDR 1995).
- ❖ It is a single-ring nitroaromatic compound that is a crystalline solid at room temperature (CRREL 2006).
- ❖ TNT is one of the most widely used military explosives, partly because of its insensitivity to shock and friction. It has been used extensively in the manufacture of explosives since the beginning of the 20th century and is used in military shells, bombs and grenades (ATSDR 1995; Cal/EPA 2010).

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- ❖ It has been used either as a pure explosive or in binary mixtures. The most common binary mixtures of TNT are cyclotols (mixtures with RDX) and octols (mixtures with octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine [HMX]) (ATSDR 1995).
- ❖ In addition to military use, small amounts of TNT are used for industrial explosive applications, such as deep well and underwater blasting. Other industrial uses include chemical manufacturing as an intermediate in the production of dyestuffs and photographic chemicals (HSDB 2012).
- ❖ TNT is commonly found at hand grenade ranges, antitank rocket ranges, artillery ranges, bombing ranges, munitions testing sites and open burn/open detonation (OB/OD) sites (CRREL 2006, 2007b; EPA 2012c).
- ❖ Production of TNT in the United States is currently limited to military arsenals; however, it may be imported into the United States for industrial applications (Cal/EPA 2010; HSDB 2012).
- ❖ Effluent from TNT manufacturing is a major source of munitions constituent contamination in soils and groundwater at military ammunition plants (EPA 2005).

Exhibit 1: Physical and Chemical Properties of TNT
(ATSDR 1995; HSDB 2012; Ware 1999)

Property	Value
Chemical Abstracts Service (CAS) number	118-96-7
Physical description (physical state at room temperature)	Yellow, odorless solid
Molecular weight (g/mol)	227.13
Water solubility at 20°C (mg/L)	130
Octanol-water partition coefficient (Log K _{ow})	1.6 (measured)
Soil organic carbon-water coefficient (K _{oc})	300 (estimated)
Boiling point (°C)	240 (explodes)
Melting point (°C)	80.1
Vapor pressure at 20°C (mm Hg)	1.99 x 10 ⁻⁴
Specific gravity at 20°C	1.654
Henry's law constant (atm·m ³ /mol at 20°C)	4.57 x 10 ⁻⁷

Abbreviations: g/mol – grams per mole; mg/L – milligrams per liter; °C – degrees Celsius; mm Hg – millimeters of mercury; atm·m³/mol – atmosphere ·cubic meters per mole.

Existence of TNT in the environment

- ❖ TNT can be released to the environment through spills, disposal of ordnance, OB/OD of ordnance, leaching from inadequately sealed impoundments and demilitarization of munitions. The compound can also be released from manufacturing and munitions processing facilities (ATSDR 1995).
- ❖ As of 2016, TNT had been identified at 30 sites on the EPA National Priorities List (NPL) (EPA 2016).
- ❖ Based on the partition coefficients identified by most investigators, soils have a high capacity for rapid sorption of TNT. Under anaerobic conditions, TNT that is not sorbed by the soil is usually transformed rapidly into its degradation by-products (Price and others 1997; USACE 1997).
- ❖ Most TNT may be degraded in the surface soil at impact areas; however, small quantities can reach shallow groundwater (CRREL 2006).
- ❖ Once released to surface water, TNT undergoes rapid photolysis to a number of degradation products. 1,3,5-Trinitrobenzene (1,3,5-TNB) is one of the primary photodegradation products of TNT in environmental systems (ATSDR 1995; EPA 2012c).
- ❖ Generally, TNT is broken down by biodegradation in water but at rates much slower than photolysis. In surface waters, TNT is degraded by photolysis and has a half-life of 0.5 to many hours. The biological half-life of TNT is much longer, ranging from several weeks to 6 months (CRREL 2006; EPA 1999).
- ❖ Biological degradation products of TNT in water, soil, or sediments include 2-amino-4,6-dinitrotoluene, 2,6-diamino-4-nitrotoluene, 4-amino-2,6-dinitrotoluene and 2,4-diamino-6-nitrotoluene (EPA 1999).
- ❖ TNT does not seem to bioaccumulate in animals, but may be taken up and metabolized by plants, including garden, aquatic and wetland plants, and some tree species (CRREL 2006, EPA 2005).
- ❖ Soils contaminated with TNT and TNT primary degradation products have been found to be toxic to certain soil invertebrates, such as earthworms (HSDB 2012).

- ❖ Based on its low octanol-water partition coefficient (K_{ow}) and low experimental bioconcentration factor, TNT is not expected to bioconcentrate to

high levels in the tissues of exposed aquatic organisms and plants (ATSDR 1995; HSDB 2012).

What are the routes of exposure and the potential health effects of TNT?

- ❖ The toxicity of TNT to humans was well documented in the 20th century, with more than 17,000 cases of TNT poisoning resulting in more than 475 fatalities from manufacturing operations during World War I (ATSDR 1995).
- ❖ The primary routes of exposure in manufacturing environments are inhalation of dust and ingestion and dermal sorption of TNT particulates; significant health effects can include liver atrophy and aplastic anemia (ATSDR 1995; HSDB 2012).
- ❖ There is limited evidence regarding the carcinogenicity of TNT to humans; however, urinary bladder papilloma and carcinoma were observed in female rats. EPA has assigned TNT a weight-of-evidence carcinogenic classification of C (possible human carcinogen) (EPA IRIS 2002).
- ❖ The California Office of Environmental Health Hazard Assessment lists TNT as a chemical known to cause cancer for purposes of the Safe Drinking Water and Toxic Enforcement Act of 1986 (Cal/EPA 2016).
- ❖ Animal study results indicate male test animals treated with high doses of TNT developed serious reproductive system effects (EPA 2005; HSDB 2012).
- ❖ When TNT reaches the liver, it breaks down into several different substances. Not all of these substances have been identified. Most of these substances travel in the blood to the kidneys and leave the body in urine within 24 hours (ATSDR 1995).
- ❖ At high levels in air, workers involved in the production of TNT experienced anemia and liver function abnormalities. After long-term exposure to skin and eyes, some people experienced skin irritation and developed cataracts (ATSDR 1995).

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

- ❖ EPA assigned TNT an oral reference dose (RfD) of 5×10^{-4} milligrams per kilogram per day (mg/kg/day) (EPA IRIS 2002).
- ❖ EPA assigned an oral slope factor for carcinogenic risk of 3×10^{-2} mg/kg/day, and the drinking water unit risk is 9.0×10^{-7} micrograms per liter ($\mu\text{g/L}$) (EPA IRIS 2002).
- ❖ EPA risk assessments indicate that the drinking water concentration representing a 1×10^{-6} cancer risk level for TNT is $1.0 \mu\text{g/L}$ (EPA IRIS 2002).
- ❖ EPA has established drinking water health advisories for TNT, 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 2012a).
 - EPA established a lifetime health advisory guidance level of 0.002 milligrams per liter (mg/L) for TNT in drinking water. The health advisory for a cancer risk of 10^{-4} is 0.1 mg/L.
 - EPA also established a 1-day and 10-day health advisory of 0.02 mg/L for TNT in drinking water for a 10-kilogram child.
- ❖ For TNT in tap water, EPA has calculated a risk-based carcinogenic screening level of $2.5 \mu\text{g/L}$ (EPA 2017).
- ❖ EPA has calculated a residential soil screening level (SSL) of 21 milligrams per kilogram (mg/kg) and an industrial SSL of 96 mg/kg. The soil-to-groundwater risk-based SSL is 1.5×10^{-2} mg/kg (EPA 2017).
- ❖ EPA has not established an ambient air level standard or screening level for TNT (EPA 2017).
- ❖ Since TNT is explosive, flammable and toxic, EPA has designated it as a hazardous waste once it becomes a solid waste, and EPA regulations for disposal must be followed (EPA 2012b).
- ❖ Various states have established groundwater standards including the following:

State	Guideline ($\mu\text{g/L}$)	Source
Indiana	9.8	IDEM 2016
Mississippi	2.23	MDEQ 2002
Missouri	2	MDNR 2014
Nebraska	2.2	NDEQ 2012
New Mexico	18.3	NMED 2012
Pennsylvania	2	PDEP 2011
Texas	0.012	TCEQ 2016
West Virginia	2.2	WVDEP 2014

- ❖ Some states have established soil guidelines. Residential soil standards range from 7.2 mg/kg

(North Carolina) to 110 mg/kg (Pennsylvania) (NCDENR 2016 and PDEP 2011). Industrial soil standards range from 96 mg/kg (North Carolina) to

1,400 mg/kg (Pennsylvania) (NCDENR 2016 and PDEP 2011).

What detection and site characterization methods are available for TNT?

- ❖ TNT is commonly deposited in the environment as discrete particles with strongly heterogeneous spatial distributions. Unless precautions are taken, this distribution causes highly variable soil data, which can lead to confusing or contradictory conclusions about the location and degree of contamination. As described in SW-846 Method 8330B, proper sample collection (using an incremental field sampling approach), sample processing (which includes grinding) and multi-incremental subsampling are required to obtain reliable soil data (EPA 2006).
- ❖ High performance liquid chromatography (HPLC) and high-resolution gas chromatography (HRGC) have been paired with several types of detectors, including mass spectrometry (MS), electrochemical detection (ED), electron capture detectors (ECD) and ultraviolet (UV) detectors to detect TNT in water (ATSDR 1995).
- ❖ EPA SW-846 Method 8330 is the most widely used analytical approach for detecting TNT in soil. The method specifies using HPLC with a UV detector. It has been used to detect TNT and some of its breakdown products at levels in the low parts per billion (ppb) range in water, soil and sediment (EPA 2006, 2012c).
- ❖ Another method commonly used is EPA SW-846 Method 8095, which employs the same sample-processing steps as Method 8330 but uses capillary-column gas chromatography (GC) with an ECD to analyze for explosives in water and soil (EPA 2007, 2012c).
- ❖ Specific field screening methods for TNT include EPA SW-846 Method 8515 to detect TNT in soil by a colorimetric screening method and EPA SW-846 Method 4050 to detect TNT in soil by immunoassay (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 is a simple colorimetric screening kit that can support qualitative tests for TNT in soils. It is also useful for screening surfaces. The tool's detection limit is about 20 nanograms (EPA 2005).
- ❖ Tested field-screening instruments for TNT include GC-IONSCAN, which uses ion mobility spectrometry, for the detection of TNT in water and soil, and the Spreeta Sensor, which uses surface plasma resonance (SPR) for the detection of TNT in soil (EPA 2000; EPA 2001).
- ❖ Recent experiments have reported rapid and ultrasensitive TNT detection in the field using gold nanoparticles and spectroscopy in all environmental samples (Lin and others 2012; Yang and others 2014; and Jamil and others 2015).

What technologies are being used to treat TNT?

- ❖ In situ bioremediation is an emerging technology for treatment of groundwater contaminated with explosives, including TNT (EPA 2005; DoD ESTCP 2012).
- ❖ Biological treatment methods such as bioreactors, bioslurry treatment and passive subsurface biobarriers have proven successful in reducing TNT concentrations (EPA 2005; DoD ESTCP 2010).
- ❖ Composting has proven successful in achieving cleanup goals for TNT in soil at field demonstrations (EPA 2005; FRTR 2007).
- ❖ Incineration can be used on soil containing low concentrations of TNT (EPA 2005; FRTR 2007). Granular activated carbon (GAC) is a common ex situ method to treat explosives-contaminated groundwater (FRTR 2007).
- ❖ In situ chemical oxidation can also be used to treat TNT. Fenton oxidation and treatment with iron metal (FeO) has been used to remediate TNT-contaminated soil and water (EPA 2005, EPA NCER 2016).
- ❖ Pine bark has been used as a substitute for GAC treatment in experimental batches (Chusova and others 2014).
- ❖ Phytoremediation of TNT-contaminated water and soil is being evaluated as a potential treatment technology. Studies indicate phytoremediation has the potential to be a suitable remediation strategy for TNT contaminated sites (DoD SERDP 2009; HSDB 2012; Zhu and others 2012).
- ❖ In a laboratory scale study, TNT biodegraded under anaerobic reduction with whey as a substrate (Innemanova and others 2015).

- ❖ In a 28-day laboratory experiment, a combination of bioaugmentation-biostimulation coupled with

phytoremediation revealed significant decreases in TNT concentrations (Nolvak and others 2013).

Where can I find more information about TNT?

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Where can I find more information about TNT? (continued)

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