# Technical Fact Sheet – 2,4,6-Trinitrotoluene (TNT)

**January 2014**



## At a Glance

- ❖ Highly explosive, yellow odorless solid.
- ❖ Synthetic product that does not occur naturally in the environment.
- ❖ Has been 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.
- ❖ Classified as a Group C (possible human) carcinogen.
- ❖ Primarily damages the liver and blood systems if inhaled or ingested.
- ❖ Specific field screening methods for TNT include EPA SW-846 Method 8515 to detect TNT by a colorimetric screening method and EPA SW-846 Method 4050 to detect TNT by immunoassay.
- ❖ 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. It was produced in enormous quantities both commercially and at government ammunition plants for use in military munitions in World War I and World War II (Steen 2006). During the 1940s through the 1970s, Department of Defense (DoD) ammunition plants and depots demilitarized off-specification, unserviceable and obsolete munitions using steam-out and melt-out processes to recover TNT and TNT-containing explosive fillers such as Composition B (TNT/hexahydro-1,3,5-trinitro-1,3,5-triazine [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 TNT was first reported in the late 1980s (Spalding and Fulton 1988).

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 highly explosive, single-ring nitroaromatic compound that is a crystalline solid at room temperature (CRREL 2006).



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## What is TNT? (continued)

- Effluent from TNT manufacturing is a major source of munitions constituent contamination in soils, groundwater and occasionally surrounding surface water and sediment at Army ammunition plants. (EPA 2005).
- TNT is one of the most widely used military high 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 20$^{th}$ century and is used in military cartridge casings, bombs and grenades (ATSDR 1995; Cal/EPA 2008).
- 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; Gibbs and Popolato 1980).
- 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; MMR 2001).
- 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 2008; HSDB 2012).

**Exhibit 1: Physical and Chemical Properties of TNT**
(ATSDR 1995; HSDB 2012; NIOSH 2010)

| 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$^{o}$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 ($^{o}$C) | 240 (explodes) |
| Melting point ($^{o}$C) | 80.1 |
| Vapor pressure at 20$^{o}$C (mm Hg) | 1.99 x10$^{-4}$ |
| Specific gravity | 1.654 |
| Henry's Law Constant (atm-m$^3$/mol at 20$^{o}$C) | 4.57 x10$^{-7}$ |

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 -cubic meters per mole.

## What are the environmental impacts of TNT?

- TNT can be released to the environment through spills, firing of munitions, 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 2013, TNT had been identified at more than 30 sites on the EPA National Priorities List (NPL) (EPA 2013c).
- TNT is a crystalline solid at room temperature and TNT's water solubility (approximately 130 milligrams per liter [mg/L] at 20$^{o}$C) and vapor pressure are relatively low, but greater than those of RDX and HMX (ATSDR 1995; CRREL 2006).
- 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 (CRREL 2006; Price and others 1997; USACE 1997).

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

- The majority of 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; CRREL 2006; EPA 2012c).
- Products of photolysis of TNT have been observed as a coating on TNT particles and as a fine powdered residue surrounding TNT particles on ranges that receive limited rainfall (CRREL 2007a).
- Generally, dissolved-phase TNT is broken down by biodegradation in water but at rates much slower than photolysis (ATSDR 1995; CRREL 2006).
- 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; 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 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; Bodeau 1993).
- 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 necrosis and aplastic anemia (ATSDR 1995; HSDB 2012).
- The highest exposures to TNT have been found in areas around Army ammunition plants where these explosives are manufactured, packed, loaded or released through demilitarization of munitions (ATSDR 1995).
- Potential exposure to TNT could occur by dermal contact or inhalation, and the likely route is exposure to contaminated soils. However, exposure to contaminated groundwater is also likely at sites with high infiltration rates, such as washout lagoons or OB/OD areas (ATSDR 1995; HSDB 2012).
- There is limited evidence regarding the carcinogenicity of TNT to humans; however, urinary bladder carcinoma has been observed in female rats (EPA IRIS 1993, Cal/EPA 2008).
- EPA has assigned TNT a weight-of-evidence carcinogenic classification of C (possible human carcinogen) (EPA IRIS 1993).
- On December 19, 2008, the California Office of Environmental Health Hazard Assessment listed TNT as a chemical known to cause cancer for purposes of the Safe Drinking Water and Toxic Enforcement Act of 1986 (Cal/EPA 2013).
- Animal study results indicate that inhalation or ingestion of high levels of TNT may cause liver, blood, immune system and reproductive damage (EPA 2005; MMR 2001).
- When TNT reaches the liver, it breaks down into several different substances. Not all of these substances have been identified. Several metabolites have been identified in human urine including 4-aminodinitrotoluene, 2-aminodinitrotoluene, 2,4-diatnino-6-nitrotoluene, 4-hydroxylamino-2,6-dinitrotoluene and amino-nitrocresol proteins. Studies indicate that one possible mechanism of toxicity of TNT and some of the metabolic intermediates is the generation of reactive oxygen species that cause injury of the lens to form cataracts and lipid peroxidation in the liver (Army 1986; ATSDR 1995; Liu and others 1992).
- 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; MMR 2001).
- There is no information indicating that TNT causes birth defects in humans. However, male rats treated with high doses of TNT have developed serious reproductive system effects (ATSDR 1995; HSDB 2012).

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

- The EPA assigned TNT an oral reference dose (RfD) of 5 $\times 10^{-4}$ milligrams per kilogram per day (mg/kg/day) (EPA IRIS 1993).
- The Agency for Toxic Substances and Disease Registry (ATSDR) has established a minimal risk level (MRL) of 0.0005 mg/kg/day for intermediate oral exposure (15 to 364 days) to TNT (ATSDR 2013).
- The EPA assigned an oral slope factor for carcinogenic risk of 3 x $10^{-2}$ mg/kg/day, and the drinking water unit risk is 9.0 $\times 10^{-7}$ micrograms per liter (µg/L) (EPA IRIS 1993).
- EPA risk assessments indicate that the drinking water concentration representing a 1 x $10^{-6}$ cancer risk level for TNT is 1.0 µg/L (EPA IRIS 1993).
- The 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).
  - The 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 screening level of 2.2 µg/L (EPA 2013b).[1,2]
- EPA has calculated a residential soil screening level (SSL) of 19 milligrams per kilogram (mg/kg) and an industrial SSL of 79 mg/kg. The soil-to-groundwater risk-based SSL is 1.3 $\times 10^{-2}$ mg/kg (EPA 2013b).
- The EPA has not established an ambient air level standard or screening level for TNT (EPA 2013b).
- 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).
- The Occupational Safety and Health Administration (OSHA) set a general industry permissible exposure limit of 1.5 milligrams per cubic meter (mg/m$^3$) as the time-weighted average (TWA) over an 8-hour workday for airborne exposure to TNT (OSHA 2013).
- The National Institute for Occupational Safety and Health (NIOSH) established a recommended exposure limit of 0.5 mg/m$^3$ as the TWA over a 10-hour workday for airborne exposure to TNT (NIOSH 2010).
- NIOSH has also established an immediately dangerous to life or health value of 500 mg/m$^3$ for TNT (NIOSH 2010)
- The American Conference of Governmental Industrial Hygienists (ACGIH) has set a threshold limit value (TLV) of 0.1 mg/m$^3$ as the TWA over an 8-hour workday for airborne exposure to TNT (ACGIH 2008).
- TNT in bulk and in cased munitions is a United Nations Hazard Division 1.1 Explosive (not a flammable solid), and an EPA Resource Conservation and Recovery Act (RCRA) D003 (reactive) waste for waste military munitions containing TNT (DOT 1989; EPA 2013a).
- Numerous states have established regulations on explosives for air quality control, solid waste disposal, storage, manufacture and use (ATSDR 1995).

[1] Screening Levels are developed using risk assessment guidance from the EPA Superfund program. These risk-based concentrations are derived from standardized equations combining exposure information assumptions with EPA toxicity data. These calculated screening levels are generic and not enforceable cleanup standards but provide a useful gauge of relative toxicity.

[2] Tap water screening levels differ from the Integrated Risk Information System (IRIS) drinking water concentrations because the tap water screening levels account for dermal, inhalation and ingestion exposure routes; age-adjust the intake rates for children and adults based on body weight; and time-adjust for exposure duration or days per year. The IRIS drinking water concentrations consider only the ingestion route, account only for adult-intake rates and do not time-adjust for exposure duration or days per year.

## 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 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 (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 2007b, 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 2007a, 2012c).
- EPA SW-846 Method 8321, which uses HPLC-MS, may be modified for the determination of TNT in soil. Since TNT 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 to employ different sample processing steps such as those identified in SW-846 Method 8830 when analyzing for TNT (EPA 2012c).
- EPA Method 529 uses solid phase extraction and capillary column GC and MS for the detection of TNT in drinking water (EPA 2002).
- 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).
- Prototype biosensor methods for TNT have been field tested for explosives analysis in water (EPA 1999).
- 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, 2001).
- Recent laboratory studies are investigating the use of 1,2-ethylenediamine (EDA) gold nanoparticles for the ultrasensitive and trace detection of TNT in all environmental samples (Lin and others 2012).

## 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 the most common ex situ method to treat explosives-contaminated groundwater and wastewaters (FRTR 2007). Ultrafiltration and resin adsorption have not been used at full scale to treat groundwater contaminated with TNT or related explosive co-contaminants such as 1,3,5-TNB, dinitrotoluene (DNT), tetryl, RDX or HMX.
- 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 but has not been used as stand-alone, full-scale treatment technology (EPA 2005, EPA NCER 2013).

## What technologies are being used to treat TNT? (continued)

- Phytoremediation of TNT-contaminated water and soil is being evaluated as a potential treatment technology (HSDB 2012; Zhu and others 2012).
- Results from a Department of Defense Strategic Environmental Research and Development Program (SERDP) project indicated the potential use of transgenic plants for phytoremediation of TNT at contaminated military training ranges. In this laboratory study, plants engineered to express a bacterial gene, nitroreductase (NR) from the bacterium *Enterobacter cloacae*, were shown to detoxify and degrade TNT in soil and water (DoD SERDP 2009).

## Where can I find more information about TNT?


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