# Heat-Enhanced In Situ Degradation for Treatment of Energetic Compounds Impacting Groundwater

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**Background/Objectives.** The Department of Defense (DoD) has extensively used energetic compounds including both explosives such as 2,4,6-trinitrotoluene (TNT), 1,3,5-hexahydro-1,3,5-trinitrotriazine (RDX), oxtahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine (HMX), and propellants such as perchlorate. Residual energetics (free product) in soil released can act as long-term sources of contamination to groundwater. Movement of energetics from solid residuals to groundwater is determined by the relative dissolution (mass transfer) rate of the constituent, with the point source size of the residual as the primary controlling variable. In addition, physical, chemical, and biological attenuation processes dictate fate and transport of energetics. A novel in situ treatment process, heat-enhanced treatment of energetic compounds (HETEC), has been developed to treat energetic compounds using enhanced biotic and abiotic degradation for high-rate, in situ treatment of contaminated soil, sediment and water. The technology relies on low-temperature heating (i.e., <100°C) and application of amendments to enhance in situ destruction of chemicals through a variety of biotic and abiotic pathways. In addition, the technology enhances mass transfer (dissolution and desorption) of chemicals from source mass (e.g., energetic solid particles), sediment and/or soil to the aqueous phase where it is available for degradation reactions.

**Approach/Activities.** Experiments were conducted to demonstrate and further elucidate mechanisms and conditions to accelerate treatment of energetic compounds, RDX and HMX, using HETEC technology. Meso-scale microcosm studies were constructed with a silty sand spiked with 50 milligrams per kilogram (mg/kg) each of the energetic compounds RDX and HMX. Each microcosm experiment first consisted of saturating the soil with a rainwater control or various biostimulation (enrichment) solutions comprised of sodium acetate, corn steep liquor powder, urea or ammonium sulfate, and/or unsulfured molasses over approximately 29 days. Microcosms were then incubated at either 20°C or 40°C. Results of the experiments were evaluated by assessing RDX and HMX concentrations, geochemical parameters, metagenomics for fungi and bacteria, and degradation byproducts in soil and leachate before, during and/or after treatment. The negative controls were used as the basis for comparison to both the microcosms treated with amendments at ambient temperature and treated with amendments at elevated temperature.

**Results/Lessons Learned.** The column treated with amendments at 40°C observed a 99-100% reduction in RDX mass over the 4-week study compared to the 20°C at 89-91% and the negative control at 20°C (49%) and at 40°C (78%). The total HMX mass was degraded 92-96% at 40°C compared with a 69-73% reduction at 20°C and 17%-37% reduction in the controls. Soil pH in some cases exceeding pH indicating potential for alkaline hydrolysis. In addition, significant increases in fungal and bacterial populations capable of biodegrading energetics were observed with the metagenomics. Significant increases in the rate and extent of RDX and HMX degradation in soils at 40°C compared to 20°C and the controls was demonstrated. The degradation is likely due to a combination of biotic degradation by bacterial and fungal microbes, alkaline hydrolysis and enhanced mass transfer due to increased temperature.