



Research Brief #13

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Phytoremediation of TNT-Contaminated Soils: Integrated Laboratory and Field Studies

Introduction

Phytoremediation, the use of aquatic plants to assimilate and detoxify hazardous substances, is one of the promising cleanup methods for TNT-contaminated sites under consideration by the HSRC/South & Southwest, Environmental Protection Agency, and the Department of Defense. To remediate TNT, military remediation teams can first remove contaminated soils, then place them in a containment facility with aquatic plants known for their ability to break down and assimilate the contaminant. Once hazardous constituents are released from the soil and dissolved in water, they can be transformed chemically and assimilated by aquatic plants.

At the Georgia Institute of Technology, researchers in the School of Civil and Environmental Engineering and

the Georgia Tech Research Institute have conducted research that confirms the strong potential of phytoremediation to clean up TNT-contaminated sites. After extensive research, the Georgia Tech group has:

- identified numerous aquatic plants that effectively remediate TNT;
- made advances in understanding how plants make TNT nontoxic and nonexplosive while assimilating it into plant tissues;
- made advances in understanding how certain key physical and chemical environmental conditions affect TNT phytoremediation;
- established fundamental kinetic-rate relationships for TNT removal and transformation;
- designed a reactor that simulates TNT phytoremediation in field conditions;
- built an experimental TNT remediation system and began

continued on back



Parrot feather (Myriophyllum aquaticum) — one of the plants with TNT transforming capabilities

Summary of the Problem

Researchers at Georgia Institute of Technology, Louisiana State University, and Rice University are investigating the effectiveness of aquatic plants as a means of cleaning soils contaminated with trinitrotoluene (TNT). An explosive compound used in munitions, TNT is found in soil at many ammunition plants and military bases in the United States. The ability of aquatic-plant enzymes to reduce and assimilate TNT and convert it into nonhazardous plant mass has been investigated in bench-scale and pilot-scale studies with aquatic plants and natural organic matter in soils and sediments. Researchers have developed and investigated a working hypothesis in which TNT is initially transformed to aminated intermediates which are then conjugated and assimilated into plant mass.

Rice University is conducting fundamental studies of plant transformations and pathways. Georgia Tech is studying whole-plant biochemical processes, as well as the physicochemical processes that affect the fate of biochemical intermediates produced by the remediative plant/soil system. Georgia Tech researchers also conducted pilot-scale studies aimed at placing (and testing) the plant remediation system in the field. Louisiana State University characterized the transport of TNT in contaminated soils from soil to water, and are developing models of TNT transport for use in investigating an enhanced-flow TNT-treatment system.

The three-university project on phytoremediation of TNT was managed by HSRC/S&SW Co-Director F.M. Saunders at Georgia Tech. This fact sheet focuses on Georgia Tech's phase of the project.

pilot-scale testing in expectation of field deployment of this innovative technology.

Plant Identification

The researchers performed a variety of laboratory procedures on candidate aquatic plants, testing approximately 20 plants in both monocultures and polycultures. Results indicate that opportunistic aquatic-plant species such as *Elodea*, *Myrophylum aquaticum* and *Spyrogyra* are excellent candidates as remediation species.

Biochemical Transformation

In the working hypothesis for phytoremediation of TNT with aquatic plants, the nitro groups of TNT are reduced to form a series of amino-nitrotoluenes. This process is rapid, taking just several hours to complete. The next process in the working hypothesis is conjugation, in which the plant attaches biochemical metabolites, such as glucose, to the contaminant. Conjugation facilitates detoxification, cellular transport, and cellular storage of TNT and its transformation products. This process acts in concert with plant growth processes. The final key process is the assimilation of TNT constituents into the plant tissues. These remediation processes conform to the plant's life cycle, but they take place faster than contaminant degradation provided by microbial systems.

The transformation of TNT by the cyanobacterium, *Anabaena spiroides*, was also investigated. Repetitive additions of TNT to batch cultures resulted in disappearance of TNT within 10 hours, with no inhibitory effects. The formation and subsequent disappearance from the solution of azoxytoluene isomers were also observed. Significantly lower TNT transformation rates were achieved in light-deprived cultures than in illuminated ones. This was more pronounced with subsequent TNT additions, demonstrating that TNT transformation was a photosynthesis-driven process. The transformation of TNT by *Anabaena* was also demonstrated with continuous-flow cultures

and continuous input of TNT.

Georgia Tech researchers found that breakdown of the TNT contaminant does not appear to occur in soils and sediments at rates of any significance, but instead occurs in the plant. Some of the resulting amino-nitrotoluenes leak into the surrounding water, then are taken back up into the plant and assimilated.

Impact of Chemical/Physical Processes

Chemical and physical processes other than phytoremediation may have an impact on TNT transformation. The research team examined the extent of sorption of TNT reaction intermediates to soil and the ability of sunlight to catalyze photochemical transformations of TNT reaction intermediates.

Sorption of TNT reaction intermediates to soil particles can potentially slow their complete breakdown by aquatic plants. The organic content of the soil is a key variable in determining the magnitude of sorption.

Georgia Tech researchers found that, in systems exposed to direct sunlight, photocatalyzed transformation processes can significantly affect the fate of TNT reaction intermediates. Phototransformation, which is strongly affected by the presence of natural organic matter, follows different pathways and yields products different from those in phytotransformation processes.

Field Studies

Based on the laboratory studies, the research team built an experimental lagoon on the Georgia Tech campus. The aquatic vegetation planted in this reactor has been continually fed soluble TNT. This work is described in detail in *Research Brief #14*.

The knowledge gained on this project and others has resulted in initiation of a field demonstration at an Army ammunition plant by the US Army.



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