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A Citizen's Guide to Phytoremediation

Technology Innovation Office

Technology Fact Sheet

What is phytoremediation?

Phytoremediation is the direct use of living green plants for *in situ*, or in place, risk reduction for contaminated soil, sludges, sediments, and ground water, through contaminant removal, degradation, or containment. Growing and, in some cases, harvesting plants on a contaminated site as a remediation method is an aesthetically pleasing, solar-energy driven, passive technique that can be used to clean up sites with shallow, low to moderate levels of contamination. This technique can be used along with or, in some cases, in place of mechanical cleanup methods.

Phytoremediation can be used to clean up metals, pesticides, solvents, explosives, crude oil, polyaromatic hydrocarbons, and landfill leachates.

Phytoremediation has been studied extensively in research and small scale demonstrations, but full-scale applications are currently limited to a small number of projects. Further development and research of the mechanisms described below likely will lead to wider acceptance and use of phytoremediation.

A Quick Look at Phytoremediation

- Is an aesthetically-pleasing, passive, solar-energy driven cleanup technique.
- Is most useful at sites with shallow, low levels of contamination.
- Is useful for treating a wide variety of environmental contaminants.

How does phytoremediation work?

How does phytoremediation work? Phytoremediation (the term *phyto-* means *plant*) is a general term for several ways in which plants are used to clean up, or *remediate*, sites by removing pollutants from soil and water. Plants can break down, or *degrade*, organic pollutants or contain and stabilize metal contaminants by acting as filters or traps. Some of the methods that are being tested are described in this fact sheet.

Treating Metal Contaminants

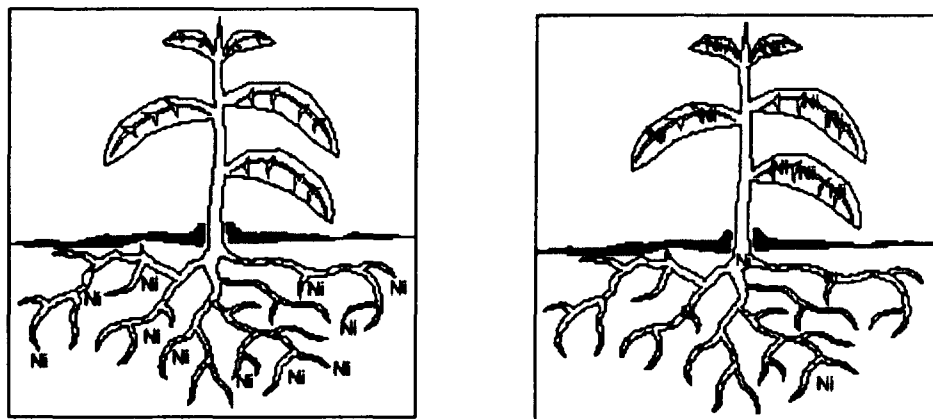
At sites contaminated with metals, plants are used to either stabilize or remove the metals from the soil and ground water through three mechanisms: *phytoextraction*, *rhizofiltration*, and *phytostabilization*.

Phytoextraction, also called *phytoaccumulation*, refers to the uptake and translocation of metal contaminants in the soil by plant roots into the aboveground portions of the plants (Figure 1). Certain plants, called *hyperaccumulators*, absorb unusually large amounts of metals in comparison to other plants. One or a combination of these plants is selected and planted at a particular site based on the type

of metals present and other site conditions. After the plants have been allowed to grow for some time, they are harvested and either incinerated or composted to recycle the metals. This procedure may be repeated as necessary to bring soil contaminant levels down to allowable limits. If plants are incinerated, the ash must be disposed of in a hazardous waste landfill, but the volume of ash will be less than 10% of the volume that would be created if the contaminated soil itself were dug up for treatment.

Metals such as nickel, zinc, and copper are the best candidates for removal by phytoextraction because it has been shown that they are preferred by a majority of the approximately 400 known plants that uptake and absorb unusually large amounts of metals. Plants that absorb lead and chromium are currently being studied and tested.

Figure 1. Uptake of Metals (Nickel) by Phytoextraction



Nickel is removed from soil by moving up into plant roots, stems, and leaves. The plant is then harvested and disposed of and the site replanted until the nickel in the soil is lowered to acceptable levels.

Rhizofiltration (*rhizo-* means *root*) is the adsorption or precipitation onto plant roots or absorption into the roots of contaminants that are in solution surrounding the root zone. Rhizofiltration is similar to phytoextraction, but the plants are used primarily to address contaminated ground water rather than soil. The plants to be used for cleanup are raised in greenhouses with their roots in water rather than in soil. To acclimate the plants once a large root system has been developed, contaminated water is collected from a waste site and brought to the plants where it is substituted for their water source. The plants are then planted in the contaminated area where the roots take up the water and the contaminants along with it. As the roots become saturated with contaminants, they are harvested. For example, sunflowers were used successfully to remove radioactive contaminants from pond water in a test at Chernobyl, Ukraine.

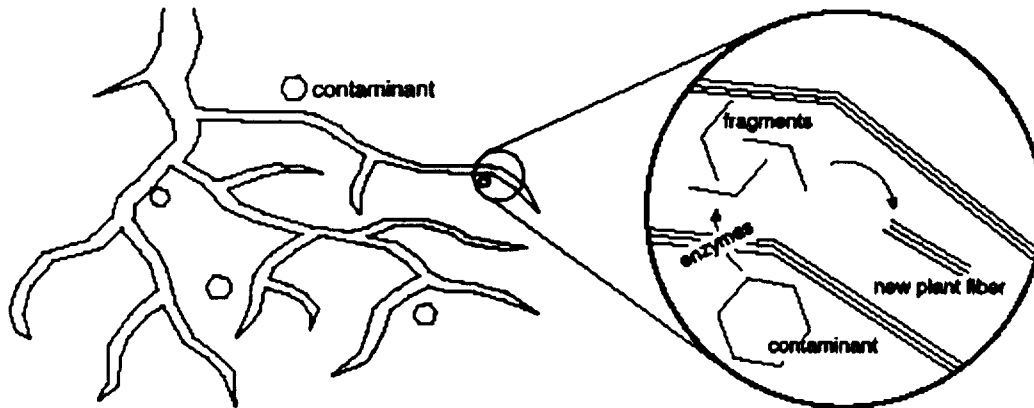
Phytostabilization is the use of certain plant species to immobilize contaminants in the soil and ground water through absorption and accumulation by roots, adsorption onto roots, or precipitation within the root zone of plants (*rhizosphere*). This process reduces the mobility of the contaminant and prevents migration to the ground water or air, and it reduces bioavailability for entry into the food chain. This technique can be used to reestablish a vegetative cover at sites where natural vegetation is lacking due to high metals concentrations in surface soils or physical disturbances to surficial materials. Metal-tolerant species can be used to restore vegetation to the sites, thereby decreasing the potential migration of contamination through wind erosion and transport of exposed surface soils and leaching of soil contamination to ground water.

Treating Organic Contaminants

Organic contaminants (those that contain carbon and hydrogen atoms) are common environmental pollutants. There are several ways plants can be used for the phytoremediation of these contaminants: *phytodegradation*, *rhizodegradation*, and *phytovolatilization*.

Phytodegradation, also called *phytotransformation*, is the breakdown of contaminants taken up by plants through metabolic processes within the plant, or the breakdown of contaminants external to the plant through the effect of compounds (such as enzymes) produced by the plants. Pollutants (complex organic molecules) are degraded into simpler molecules and are incorporated into the plant tissues to help the plant grow faster (Figure 2). Plants contain *enzymes*, complex chemical substances (proteins), that cause rapid chemical reactions to occur. Some enzymes breakdown and convert ammunition wastes, others degrade chlorinated solvents such as trichloroethylene (TCE), and others degrade herbicides.

Figure 2. Destruction of Organic Contaminants by Phytodegradation



Enzymes in plant roots break down (degrade) organic contaminants. The fragments are incorporated into new plant material.

Rhizodegradation, also called *enhanced rhizosphere biodegradation*, *phytostimulation*, or *planted-assisted bioremediation/degradation*, is the breakdown of contaminants in the soil through microbial activity that is enhanced by the presence of the root zone (the *rhizosphere*) and is a much slower process than phytodegradation. Microorganisms (yeast, fungi, or bacteria) consume and digest organic substances for nutrition and energy. Certain microorganisms can digest organic substances such as fuels or solvents that are hazardous to humans and break them down into harmless products in a process called biodegradation. Natural substances released by the plant roots—sugars, alcohols, and acids—contain organic carbon that provides food for soil microorganisms and the additional nutrients enhance their activity. Biodegradation is also aided by the way plants loosen the soil and transport water to the area. The fact sheet entitled *A Citizen's Guide to Bioremediation* describes the biodegradation process in detail (see "For More Information" at the end of this guide).

Phytovolatilization is the uptake and transpiration of a contaminant by a plant, with release of the contaminant or a modified form of the contaminant to the atmosphere from the plant. Phytovolatilization occurs as growing trees and other plants take up water and the organic contaminants. Some of these contaminants can pass through the plants to the leaves and evaporate, or *volatilize*, into the atmosphere. Poplar trees at one particular study site have been shown to volatilize 90% of the TCE they take up.

Hydraulic Control of Contaminants

Plants can act as **hydraulic pumps** when their roots reach down toward the water table and establish a dense root mass that takes up large quantities of water. Poplar trees, for example, can transpire between 50 and 300 gallons of water per day out of the ground. The water consumption by the plants decreases the tendency of surface contaminants to move towards ground water and into drinking water. The use of plants to rapidly uptake large volumes of water to contain or control the migration of subsurface water is known as *hydraulic control*. There are several applications that use plants for this purpose, such as *riparian corridors/buffer strips* and *vegetative caps*.

Riparian corridors (the term *riparian* means *located on the bank of a river*) or **buffer strips** are applications of phytoremediation that also may incorporate aspects of phytodegradation,

phytovolatilization, and rhizodegradation to control, intercept, or remediate contamination entering a river or ground-water plume. Riparian corridor refers to plants that may be applied along a stream or river bank, while buffer strips may be applied around the perimeter of landfills. Applications of these systems prevent contamination from spreading into surface water and/or ground water.

Vegetative cover is a long-term, self-sustaining cap composed of soil and plants growing in and/or over waste in a landfill. This type of cover is an alternative to composite clay or plastic layer caps. Plants control erosion and minimize seepage of water that could otherwise percolate through the landfill and form contaminated leachate. In addition, vegetative caps can be designed not only to control erosion and seepage of water, but to enhance the degradation of underlying materials in the landfill.

Does phytoremediation work at every site?

Phytoremediation has been used to clean up metals, pesticides, solvents, explosives, crude oil, polyaromatic hydrocarbons, and landfill leachates. Phytoremediation can be used in combination with other cleanup approaches as a "finishing" or "polishing" step. Although some phytoremediation applications are slower than mechanical methods and are limited to the depths that are within the reach of the plant roots.

Generally, the use of phytoremediation is limited to sites with low to medium contaminant concentrations and contamination in shallow soils, streams, and ground water. Researchers are finding that the use of trees (rather than smaller plants) allows them to treat deeper contamination because tree roots penetrate more deeply into the ground. Very deep lying contaminated ground water may be treated by pumping the water out of the ground and using plants to treat the contamination.

Further research is needed to study the effects on the food chain that could occur if insects and small rodents eat the plants that are collecting contaminants and are then eaten by larger mammals. Also, scientists still need to establish whether contaminants can collect in the leaves and wood of trees used for phytoremediation and be released when the leaves fall in the autumn or when firewood or mulch from the trees is used.

Where has it been used?

Phytoremediation has been successfully tested in many locations, but full-scale applications are still limited. In Maryland at a U.S. Army testing facility, hybrid poplar trees were planted in a one acre area over a shallow ground water plume contaminated with organics from several toxic disposal pits. The poplar trees act as hydraulic pumps to prevent the spread of contaminants to a nearby marsh. In addition to hydraulic control, researchers have determined that phytovolatilization and rhizofiltration are other mechanisms by which the system is treating the contaminated plume. After the second growing season, the trees are successfully containing the contaminated ground water plume with rates estimated at 2-10 gallons of water per day for each tree. In addition, preliminary results have indicated that the poplar trees are degrading the contaminants in the ground water plume. Table 1 lists some other phytoremediation projects.

Table 1. Examples of Sites Demonstrating Phytoremediation*

| Location | Application | Contaminants | Medium | Plant(s) |
|-----------------------|--|-------------------------------|----------------------|--|
| Edgewood, MD | phytovolatilization rhizofiltration hydraulic control | chlorinated solvents | ground water | hybrid poplar |
| Fort Worth, TX | phytodegradation phytovolatilization rhizodegradation hydraulic control | chlorinated solvents | ground water | eastern cottonwood |
| New Gretna, NJ | phytodegradation hydraulic control | chlorinated solvents | ground water | hybrid poplar |
| Ogden, UT | phytoextraction rhizodegradation | petroleum hydrocarbons | soil ground water | alfalfa poplar juniper fescue |
| Portsmouth, VA | phytodegradation rhizodegradation | petroleum | soil | grasses clover |
| Portland, OR | phytodegradation | PCP PAHs | soil | ryegrass |
| Trenton, NJ | phytoextraction | heavy metals radionuclides | soil | indian mustard |
| Anderson, SC | phytostabilization | heavy metals | soil | hybrid poplar grasses |
| Chernobyl, Ukraine | rhizofiltration | radionuclides | ground water | sunflowers |
| Ashtabula, OH | rhizofiltration | radionuclides | ground water | sunflowers |
| Upton, NY | phytoextraction | radionuclides | soil | indian mustard cabbage |
| Milan, TN | phytodegradation | explosives wastes | ground water | duckweed parrotfeather |
| Beaverton, OR | vegetative cover | metals nitrates BOD | not applicable | cottonwood |
| Texas City, TX | vegetative cover rhizodegradation | PAHs | soil | mulberry |
| Amana, IA | riparian corridor phytodegradation | nitrates | ground water | hybrid poplar |

** Not all waste types and site conditions are comparable. Each site must be individually investigated and tested. Engineering and scientific judgment must be used to determine if a technology is appropriate for a site.*

What Is An Innovative Treatment Technology?

Treatment technologies are processes applied to the treatment of hazardous waste or contaminated materials to permanently alter their condition through chemical, biological, or physical means.

Innovative treatment technologies are those that have been tested, selected or used for treatment of hazardous waste or contaminated materials but lack well-documented cost and performance data under a variety of operating conditions.

For More Information

The publications listed below can be ordered free of charge by faxing your request to NCEPI at 513-489-8695. If NCEPI is out of stock of a document, you may be directed to other sources. If you choose, you may write to NCEPI at:

National Center for Environmental Publications and Information (NCEPI)
P.O. Box 42419
Cincinnati, OH 45242

- Recent Developments for *In Situ* Treatment of Metal Contaminated Soils, March 1997, EPA 542-R-97-004.
- A Citizen's Guide to Bioremediation, April 1996, EPA 542-F-96-007.
- Soil Stabilization Action Team, April 1996, EPA 542-F-96-010d.
- Phytoremediation Handbook, prepared by EPA (in Draft).

The following references are not available through NCEPI:

- Phytoremediation Bibliography, prepared by the EPA Phytoremediation Handbook Team in conjunction with the RTDF Phytoremediation of Organics Action Team, updated April 1998.
<http://www.rtdf.org/phytobib.htm>
- Phytoremediation of TCE in Groundwater by Jonathan Chappell, EPA NNEMS Fellow, February 1998.
<http://clu-in.com/phytotce.htm>
- Phytoremediation Technology Evaluation Report, prepared by Jerry Schnoor for GWRTAC, October 1997, TE-98-01.
http://www.gwrtac.org/html/tech_eval.html
- Development of a Phytoremediation Handbook: Considerations for Enhancing Microbial Degradation in the Rhizosphere by Todd A. Anderson, AAAS/EPA Environmental Science and Engineering Fellow, August 1997.
Claudia Sturges, 202-326-6700, science_polict@aaas.org
- Phytoremediation Technology Overview Report, prepared by Ralinda R. Miller for GWRTAC, October 1996, TO-96-03.
http://www.gwrtac.org/html/tech_over.html
- Soil & Groundwater Cleanup, February/March 1998.
- "Phytoremediation: A new technology gets ready to bloom," by Jim Bishop in Environmental Solutions Magazine, May/June 1997.
- "Mother Nature's Pump and Treat," by Kalle Matso in Civil Engineering, October 1995, pages 46-49.
- "The Green Clean," by Kathryn Brown Sargeant in BioScience, October 1995, pages 579-582.

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