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EPA A Citizen's Guide to Bioremediation

Technology Innovation Office

Technology Fact Sheet

What is bioremediation?

Bioremediation is a treatment process that uses naturally occurring microorganisms (yeast, fungi, or bacteria) to break down, or *degrade*, hazardous substances into less toxic or nontoxic substances. Microorganisms, just like humans, eat and digest organic substances for nutrients and energy. In chemical terms, "organic" compounds are those that contain carbon and hydrogen atoms. Certain microorganisms can digest organic substances such as fuels or solvents that are hazardous to humans. The microorganisms break down the organic contaminants into harmless products—mainly carbon dioxide and water (Figure 1). Once the contaminants are degraded, the microorganism population is reduced because they have used all of their food source. Dead microorganisms or small populations in the absence of food pose no contamination risk.

How does it work?

Microorganisms must be active and healthy in order for bioremediation to take place. Bioremediation technologies assist microorganisms' growth and increase microbial populations by creating optimum environmental conditions for them to detoxify the maximum amount of contaminants. The specific bioremediation technology used is determined by several factors, for instance, the type of microorganisms present, the site conditions, and the quantity and toxicity of contaminant chemicals. Different microorganisms degrade different types of compounds and survive under different conditions.

Indigenous microorganisms are those microorganisms that are found already living at a given site. To stimulate the growth of these indigenous microorganisms, the proper soil temperature, oxygen, and nutrient content may need to be provided.

If the biological activity needed to degrade a particular contaminant is *not* present in the soil at the site, microorganisms from other locations, whose effectiveness has been tested, can be added to the contaminated soil. These are called *exogenous* microorganisms. The soil conditions at the new site may need to be adjusted to ensure that the exogenous microorganisms will thrive.

Bioremediation can take place under *aerobic* and *anaerobic* conditions. In aerobic conditions, microorganisms use available atmospheric oxygen in order to function. With sufficient oxygen, microorganisms will convert many organic contaminants to carbon dioxide and water. *Anaerobic* conditions support biological activity in which no oxygen is present so the microorganisms break down chemical compounds in the soil to release the energy they need. Sometimes, during aerobic and anaerobic processes of breaking down the original contaminants, intermediate products that are less, equally, or more toxic than the original contaminants are created.

Bioremediation can be used as a cleanup method for contaminated soil and water. Bioremediation applications fall into two broad categories: *in situ* or *ex situ*. In situ bioremediation treats the contaminated soil or groundwater in the location in which it was found. Ex situ bioremediation processes require excavation of contaminated soil or pumping of groundwater before they can be treated.

A Quick Look at Bioremediation

- Uses naturally occurring microorganisms to break down hazardous substances into less toxic or nontoxic substances.
- A cost effective, natural process applicable to many common organic wastes.
- Many techniques can be conducted on-site.

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In Situ Bioremediation of Soil

In situ techniques do not require excavation of the contaminated soils so may be less expensive, create less dust, and cause less release of contaminants than ex situ techniques. Also, it is possible to treat a large volume of soil at once. In situ techniques, however, may be slower than ex situ techniques, may be difficult to manage, and are most effective at sites with *permeable* (sandy or uncompacted) soil.

The goal of aerobic in situ bioremediation is to supply oxygen and nutrients to the microorganisms in the soil. Aerobic in situ techniques can vary in the way they supply oxygen to the organisms that degrade the contaminants. Two such methods are **bioventing** and **injection of hydrogen peroxide.** Oxygen can be provided by pumping air into the soil above the water table (bioventing) or by delivering the oxygen in liquid form as hydrogen peroxide. In situ bioremediation may not work well in clays or in highly layered subsurface environments because oxygen cannot be evenly distributed throughout the treatment area. In situ remediation often requires years to reach cleanup goals, depending mainly on how biodegradable specific contaminants are. Less time may be required with easily degraded contaminants.

Bioventing. Bioventing systems deliver air from the atmosphere into the soil above the water table through injection wells placed in the ground where the contamination exists. The number, location, and depth of the wells depend on many geological factors and engineering considerations.

An air blower may be used to push or pull air into the soil through the injection wells. Air flows through the soil and the oxygen in it is used by the microorganisms. Nutrients may be pumped into the soil through the injection wells. Nitrogen and phosphorous may be added to increase the growth rate of the microorganisms.

Injection of Hydrogen Peroxide. This process delivers oxygen to stimulate the activity of naturally occurring microorganisms by circulating hydrogen peroxide through contaminated soils to speed the bioremediation of organic contaminants. Since it involves putting a chemical (hydrogen peroxide) into the ground (which may eventually seep into the groundwater), this process is used only at sites where the groundwater is already contaminated.

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.

A system of pipes or a sprinkler system is typically used to deliver hydrogen peroxide to shallow contaminated soils. Injection wells are used for deeper contaminated soils.

In Situ Bioremediation of Groundwater

In situ bioremediation of groundwater speeds the natural biodegradation processes that take place in the water-soaked underground region that lies below the water table. For sites at which both the soil and groundwater are contaminated, this single technology is effective at treating both.

Generally, an in situ groundwater bioremediation system consists of an extraction well to remove groundwater from the ground, an above-ground water treatment system where nutrients and an oxygen source may be added to the contaminated groundwater, and injection wells to return the "conditioned" groundwater to the subsurface where the microorganisms degrade the contaminants.

One limitation of this technology is that differences in underground soil layering and density may cause reinjected conditioned groundwater to follow certain preferred flow paths. Consequently, the conditioned water may not reach some areas of contamination.

Another frequently used method of in situ groundwater treatment is *air sparging,* which means pumping air into the groundwater to help flush out contaminants. Air sparging is used in conjunction with a technology called soil vapor extraction and is described in detail in the document entitled *A Citizen's Guide to Soil Vapor Extraction and Air Sparging* (see page 4).

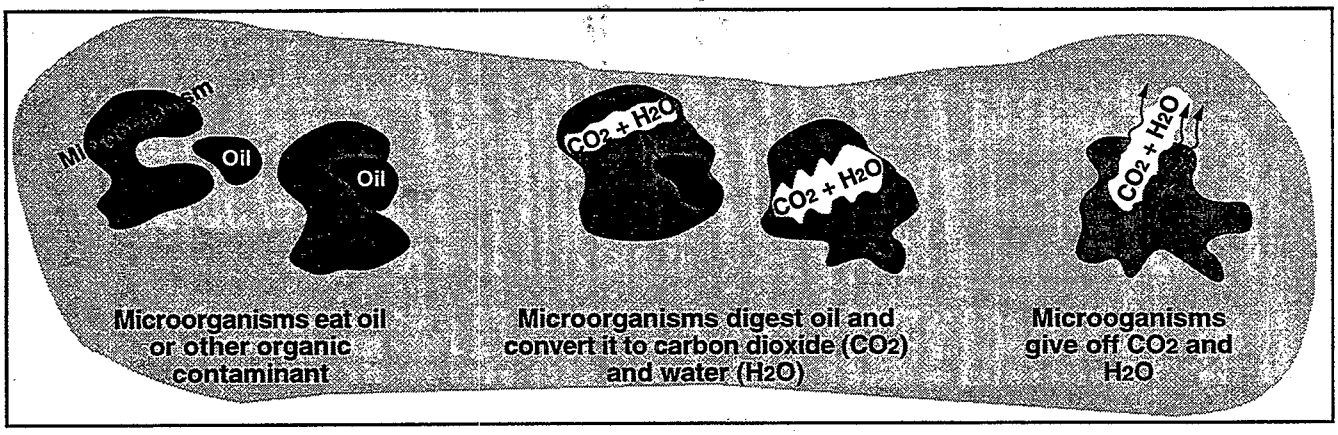
Ex Situ Bioremediation of Soil

Ex situ techniques can be faster, easier to control, and used to treat a wider range of contaminants and soil types than in situ techniques. However, they require excavation and treatment of the contaminated soil before and, sometimes, after the actual bioremediation step. Ex situ techniques include **slurry-phase bioremediation** and **solid-phase bioremediation.**

Slurry-phase bioremediation. Contaminated soil is combined with water and other additives in a large tank called a "bioreactor" and mixed to keep the microorganisms—which are already present in the soil—in contact with the contaminants in the soil. Nutrients and oxygen are added, and conditions in the bioreactor are controlled to create the optimum environment for the microorganisms to degrade the contaminants. Upon completion of the treatment, the water is removed from the solids, which are disposed of or treated further if they still contain pollutants.

Slurry-phase biological treatment can be a relatively rapid process compared to other biological treatment processes, particularly for contaminated clays. The success of the process is highly dependent on the specific soil and chemical properties of the contaminated material. This technology is particularly useful where rapid remediation is a high priority.

Figure 1
Schematic Diagram of Aerobic Biodegradation in Soil



Solid-phase bioremediation. Solid-phase bioremediation is a process that treats soils in above-ground treatment areas equipped with collection systems to prevent any contaminant from escaping the treatment. Moisture, heat, nutrients, or oxygen are controlled to enhance biodegradation for the application of this treatment. Solid-phase systems are relatively simple to operate and maintain, require a large amount of space, and cleanups require more time to complete than with slurry-phase processes. Solid-phase soil treatment processes include *landfarming, soil biopiles,* and *composting.*

Landfarming. In this relatively simple treatment method, contaminated soils are excavated and spread on a pad with a built-in system to collect any "leachate" or contaminated liquids that seep out of contaminant-soaked soil. The soils are periodically turned over to mix air into the waste. Moisture and nutrients are controlled to enhance bioremediation. The length of time for bioremediation to occur will be longer if nutrients, oxygen or temperature are not properly controlled. In some cases, reduction of contaminant concentrations actually may be attributed more to volatilization than biodegradation. When the process is conducted in enclosures controlling escaping volatile contaminants, volatilization losses are minimized.

Soil biopiles. Contaminated soil is piled in heaps several meters high over an air distribution system. Aeration is provided by pulling air through the heap with a vacuum pump. Moisture and nutrient levels are maintained at levels that maximize bioremediation. The soil heaps can be placed in enclosures. Volatile contaminants are easily controlled since they are usually part of the air stream being pulled through the pile.

Composting. Biodegradable waste is mixed with a bulking agent such as straw, hay, or corn cobs to make it easier to deliver the optimum levels of air and water to the microorganisms. Three common designs are *static pile composting* (compost is formed into piles and aerated with blowers or vacuum pumps), *mechanically agitated in-vessel composting* (compost is placed in a treatment vessel where it is mixed and aerated), and *windrow composting* (compost is placed in long piles known as windrows and periodically mixed by tractors or similar equipment).

Will it work at every site?

Biodegradation is useful for many types of organic wastes and is a cost-effective, natural process. Many techniques can be conducted on-site, eliminating the need to transport hazardous materials.

The extent of biodegradation is highly dependent on the toxicity and initial concentrations of the contaminants, their biodegradability, the properties of the contaminated soil, and the particular treatment system selected.

Contaminants targeted for biodegradation treatment are non-halogenated volatile and semi-volatile organics and fuels. The effectiveness of bioremediation is limited at sites with high concentrations of metals, highly chlorinated organics, or inorganic salts because these compounds are toxic to the microorganisms.

Where has it been used?

At the Scott Lumber Company Superfund site in Missouri, 16,000 tons of soils contaminated with polyaromatic hydrocarbons (PAHs) were biologically treated using land treatment application. PAH concentrations were reduced by 70%.

At the French Ltd. Superfund site in Texas, slurry-phase bioremediation was used to treat 300,000 tons of lagoon sediment and tar-like sludge contaminated with volatile organic compounds, semi-volatile organic compounds, metals, and pentachlorophenol. Over a period of 11 months, the treatment system was able to meet the cleanup goals set by EPA.

Some additional examples of Superfund sites where different types of bioremediation have been selected as a treatment method are listed in Table 1 on page 4.

Table 1
Examples of Superfund Sites Using Bioremediation Technologies*

Name of Site	Treatment	Contaminants
Applied Environmental Services, NY	Bioventing	Volatile organic compounds (VOCs), semi-volatile organic compounds (SVOCs)
Onalaska Municipal Landfill, WI	Bioventing	VOCs, polyaromatic hydrocarbons (PAHs)
Eielson Air Force Base, AK	Bioventing	VOCs, SVOCs, PAHs
Brown Wood Preserving, FL	Land treatment	PAHs
Vogel Paint & Wax, IA	Land treatment	VOCs
Broderick Wood Products, CO	Land treatment/Bioventing	SVOCs, PAHs, dioxins
Burlington Northern (Somers), MT	Land treatment/ In Situ Bioremediation	SVOCs, PAHs

For a listing of Superfund sites at which innovative treatment technologies have been used or selected for use, contact NCEPI at the address in the box below for a copy of the document entitled ***Innovative Treatment Technologies: Annual Status Report (7th Ed.),*** **EPA 542-R-95-008.** Additional information about the sites listed in the Annual Status Report is available in database format. The database can be downloaded free of charge from EPA's Cleanup Information bulletin board (CLU-IN). Call CLU-IN at 301-589-8366 (modem). CLU-IN's help line is 301-589-8368. The database also is available for purchase on diskettes. Contact NCEPI for details.

** 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.*

For More Information

The publications listed below can be ordered free of charge by calling NCEPI at 513-489-8190 or faxing your request to 513-489-8695. If NCEPI is out of stock of a document, you may be directed to other sources. Write to NCEPI at:

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

- *Selected Alternative and Innovative Treatment Technologies for Corrective Action and Site Remediation: A Bibliography of EPA Information Sources*, January 1995, EPA 542-B-95-001. **A bibliography of EPA publications about innovative treatment technologies.**
- *Bioremediation Resource Guide*, September 1993, EPA 542-B-93-004. **A bibliography of publications and other sources of information about bioremediation technologies.**
- *A Citizen's Guide to Soil Vapor Extraction and Air Sparging*, EPA 542-F-96-008
- *Engineering Bulletin: In Situ Biodegradation Treatment*, April 1994, EPA 540-S-94-502.
- *Engineering Bulletin: Slurry Biodegradation*, September 1990, EPA 540-2-90-016.
- *Abstracts of Remediation Case Studies*, March 1995, EPA 542-R-95-001.
- *WASTECH® Monograph on Bioremediation*, ISBN #1-883767-01-6. Available for $49.95 from the American Academy of Environmental Engineers, 130 Holiday Court, Annapolis, MD 21401. Telephone 410-266-3311.

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