PHYTOREMEDIATION TECHNOLOGY AT THE DOE PORTSMOUTH GASEOUS DIFFUSION PLANT

A. C. Lewis, D. R. Baird
CDM Federal Programs
P.O. Box 789, Piketon, OH 45661

S. Burton
DKM Construction, Inc.
P.O. Box 340, Piketon, OH 45661

ABSTRACT

The Portsmouth Gaseous Diffusion Plant (PORTS), owned and operated by the U.S. Department of Energy (DOE), has produced enriched uranium since the early 1950s. The X-120 Goodyear Training Facility has been operated since plant construction as a machine shop, paint shop, and warehouse space. It is highly probable that the machine and metal shops used solvents and degreasers while in operation. The past disposal procedures for these substances are unknown. The X-120 facilities were demolished and removed in the late-1970s, prior to the more recent construction of the Gas Centrifuge Enrichment Plant. Several remedial investigations, however, have identified various VOCs (volatile organic compounds), primarily TCE (trichloroethylene), at detectable levels in the groundwater.

Phytoremediation technology is based on the ability of certain plant species and their associated rhizospheric microorganisms to remove, degrade, or contain chemical contaminants located in the soil, sediment, surface water, groundwater, and possibly even the atmosphere. Plant species are chosen for phytoremediation based on their potential for rapid absorption of water through evapotranspiration, the degradative enzymes they produce, their growth rate and yield, the depth of their root zone, and their ability to bioaccumulate contaminants.

Phytoremediation has been chosen as a remedial option for treatment of the groundwater in the X-749/X-120 area. The hybrid poplar tree (*Populus sp.)* was chosen for the application as a result of its high growth rate and yield, high evapotranspiration rates, root zone depth, long life span, and ease of growth. The phytoremediation system of 2,640 poplar trees has been planted in seven areas/zones to manage the volatile organic compound (VOC) contaminant plume. Currently the groundwater contains levels of TCE that are above the targeted risk level. The objective of this task is to remove contamination from the groundwater, and prevent further migration of contaminants from the X-749 Landfill. The goal of the remediation procedure is to achieve a completely mature and functional phytoremediation system within two years of the initial planting of the hybrid poplar trees.

Phytoremediation is a promising clean-up solution for a wide variety of pollutants and sites. Phytoremediation is a passive technology producing no waste during tree installation or during remediation. Mature trees can consume up to 3,000 gallons of groundwater per acre per day. Organic compounds are captured in the trees' root systems. These organic compounds are degraded by ultraviolet light as they are transpired along with the water vapor through the leaves of the trees. Phytoremediation is an *in situ* technology that produces an aesthetically pleasing environment, and is entirely solar driven, which provides high public acceptance. The plants are normally sold for profit after project completion and the soil remains in place and is reusable following treatment. Phytoremediation is 10% to 20% less costly than mechanical treatments, regarding overall operating costs.

INTRODUCTION

The Portsmouth Gaseous Diffusion Plant (PORTS), owned by the Department of Energy (DOE), has been enriching uranium since the early 1950s. During plant construction the X-120 Goodyear Training Facility operated as a machine shop, paint shop, and two warehouses. It is highly probable that the machine and metal shops used solvents and degreasers while in operation. The disposal procedures concerning these substances are unknown. The X-120 facilities have since been demolished and removed during construction activities of the Gas Centrifuge Enrichment Plant. Several investigations, however, have identified various VOCs (volatile organic compounds), primarily TCE (trichloroethylene), at detectable levels in the groundwater.

Phytoremediation has been chosen as a remedial option for treatment of the groundwater in the X-749/X-120 area. The selection was based on the application of the technology to the site geology, contaminants of concern, and the operating life cycle costs. The site geology consists of slow-moving shallow groundwater ideal for a remedial phytoremediation system. TCE, the contaminant of concern, is a dense non-aqueous-phase liquid (DNAPL), meaning it is denser than water and therefore tends to accumulate in the bottom of the aquifer. This characteristic makes it difficult to treat TCE by typical pump-and-treat methods. The pump-and-treat methods are only capable of treating TCE in the aqueous phase, which leaves the non-aqueous phase untreated. This can lead to a continuous cycle of TCE being pulled from the non-aqueous phase to the aqueous phase, which could take many years and large amounts of energy to treat. A functional phytoremediation system, however, can remove TCE in both the aqueous and non-aqueous phases.

The hybrid poplar tree was chosen due to several positive factors such as; high growth rate and yield, high transpiration rates, depth of their root zone, long life span, and ease of growth. The phytoremediation system of trees has been planted in seven areas/zones to manage the volatile organic compound (VOC) contaminant plume. Currently the groundwater contains levels of TCE that are above the targeted risk level. The objective of this task is to remove contamination from the groundwater, and prevent any further movement of contaminants from the X-749 Landfill. The intention of the remediation procedure is to achieve a completely mature and functional phytoremediation system within two years of the initial planting of the hybrid poplar trees.

HISTORY

During plant construction in the 1950s the X-120 Goodyear Training Facility operated as a machine shop, paint shop, metal shop, and two warehouses. It is believed that the machine and metal shops used solvents and degreasers while in operation, but the disposal procedures concerning these substances are unknown. In 1977 the X-120 facilities were demolished and removed during construction activities of the Gas Centrifuge Enrichment Plant.

Located approximately 500 feet to the southeast of the X-120 Goodyear Training Facility is the X-749 Landfill. The X-749 Landfill is comprised of both northern and southern segments. The northern segment was utilized from 1955 to 1989; it is approximately 7.5 acres in size. The northern segment was used for the disposal of equipment and materials. This waste was contaminated with low-level radioactivity, chlorinated solvents, metal hydroxide sludge, and waste oils. The southern segment was utilized from 1986 to 1989; it is approximately 4 acres in size. The southern segment was used for the disposal of a variety of demolition debris and scrap metals. This waste was contaminated with low-level radioactivity, alumina, sodium fluoride, incinerator ash, and asbestos.

The X-749 Landfill is currently treated as a single unit due to the groundwater plume which lies under both segments of the landfill. The 11.5-acre landfill underwent closure under the Resource Conservation and Recovery Act (RCRA) in 1989. This closure activity included the installation of slurry walls along the north and west sides of the landfill as well as the installation of groundwater trenches along the east and southwest sides of the landfill. These installed features operate, as a source control for groundwater contamination. In addition, a multi-layered landfill cap was installed over the complete facility. The captured contaminated groundwater is treated at an on-site groundwater treatment facility.

The X-120 facilities are no longer considered a source of contamination. It is extremely probable, however, that the X-749 Landfill is a continuing source of contamination to the groundwater. Currently at the X-749/X-120 area the TCE levels in the groundwater are above the targeted risk level of 1×10^{-6}. Phytoremediation has been chosen as a remediation option for the X-749/X-120 area due to the contaminant of concern and the location of the contaminated area.

PROCESS

Phytoremediation is the use of specific plants to remove, degrade, or contain contaminants in soil, sediment, and groundwater. Phytoremediation can be used to treat numerous contaminants, including crude oil, polyaromatic hydrocarbons (PAHs), chlorinated solvents, metals, radionuclides, and explosives. The phytoremediation process occurs naturally in the environment as inorganic and organic constituents cycle through vegetation. Phytoremediation is an extended version of the natural process.

The phytoremediation process can be utilized to restore soil, sediment, or groundwater to its natural state by removing contamination in numerous ways:

- Plant degradation: Natural chemical processes within the plant are absorbed and broken down into non-toxic molecules.
- Extraction: The roots of plants remove contaminants from the sites and transport them to leaves and stems for harvesting and disposal.
- Microorganism stimulation: Plants excrete and provide natural enzymes which stimulate the growth of microorganisms such as fungi and bacteria. The organic contaminants are then metabolized buy the microorganisms in the root zone.
- Volatilization: Volatilization is the release of non-toxic gases through plants into the environment. The gases are absorbed by plant roots and then transported to the leaves.
- Stabilization: The growth of plants reduces contaminant migration by reducing runoff, surface erosion, and groundwater flow rates.

Phytoremediation is a promising technology for the clean up of a variety of pollutants and areas. As with any system there are advantages and disadvantages as listed below:

Advantages	Disadvantages
♦ *In situ* technology	Limited to shallow soils, streams, and groundwater. Also, remediation rate and effectiveness is temperature dependent, nutrient dependent, dependent on climate, and soil fertility.
♦ Solar driven	Mass transfer limitations
♦ Passive system	High concentrations of certain materials can be toxic to plants
♦ Works on a variety of organic and inorganic compounds	May take several years to remediate

♦ High public acceptance	Toxicity of degradation products is unknown
♦ Generate less secondary wastes, soils remain in place and are reusable	Potential contamination of food chain, dependent upon contaminant type and chosen plant species
♦ Easy to implement and maintain	Dependent on climatic conditions
♦ Fewer air and water emissions	Unfamiliar to many regulators
♦ Costs 10% to 20% of mechanical treatments	Slower than mechanical treatments

All aspects of phytoremediation technology should be investigated before the selection of the innovative process.

DESIGN

The species of hybrid poplar trees that were chosen for the X-749/X-120 phytoremediation project are a cross between the European black poplar and an Asian balsam poplar. The species is *NM-6*, *Populus nigra x Populus maximowiczi*. This species of hybrid poplar was developed in the 1970s and is a vigorous grower even into late autumn. This species can grow in excess of 60 feet in length and is more likely than most other species to grow under harsher soil conditions.

The design for the X-749/X-120 phytoremediation area is divided into two phases. The first phase, which was completed in 2002, utilized data from a previous phytoremediation project located on-site at the Portsmouth Gaseous Diffusion Plant. Based on this data, the Quadrant I groundwater plume model, the flow direction of groundwater, and the density and water uptake per tree per day, the proposed remediation system should be entirely sufficient to remediate the volume of contaminated groundwater.

Although the final design phase of the X-749/X-120 area is based on the initial design, the final phase incorporates approximately 41 acres not included in the initial phase. The phytoremediation system includes hybrid poplar trees planted in rows perpendicular to groundwater flow. A sand stack and trenching/boring design was implemented throughout the 41 acres of the X-749/X-120 area. The trees were planted in rows typically 10-30 feet apart, with 10 feet between each row of trees. Prior to the installation of the trenches, borings 8 inches in diameter were drilled to the bedrock, approximately 38 feet below ground surface (bgs). Each boring was positioned to be between two adjoining trees in the same row. After reaching the bedrock, the borings were filled with coarse sand to ground surface. The sand stacks will allow the flow of water upward to the tree planting trenches. Trenches were installed to 12-15 feet bgs and above the sand-filled borings. Coarse sand was then placed in the bottom of each trench one foot thick. Excavated soils from the trench installation were combined with fertilizer, lime, coarse sand, and peat moss to create an environment in which the trees will thrive. The trees were planted in the trench backfill material along the length of the trench, alternating between the sand stack locations. The final phase was completed in 2003. A total of 2,640 trees were planted within a 6-month time frame. This design structure and planting scheme will ensure an effective groundwater remediation system.

CONCLUSION

Phytoremediation is a promising clean-up solution for a wide variety of pollutants and sites. Phytoremediation is a passive technology producing no waste during tree installation or during remediation. Mature trees can consume up to 3,000 gallons of groundwater per day per acre. Organic compounds are captured in the trees’ root systems. These organic compounds are degraded by ultraviolet light as they are transpired along with the water vapor through the leaves of the trees. Phytoremediation is entirely an *in situ* technology. Phytoremediation offers an aesthetically pleasing environment and is entirely solar driven, which provides high public acceptance. The plants are normally sold for profit after project completion and the soil remains in place and is reusable following treatment. Phytoremediation is 10% to 20% less costly than mechanical treatments, regarding overall operating costs. A pump-and-treat facility would cost approximately $2 million to build and $1 million a year for 30 years to operate versus approximately $1.5 million for total costs of the project.

Currently, the groundwater at the X-749/X-120 area contains levels of TCE that are above the targeted risk level. The objective of this project is to remove contamination from the groundwater, and to prevent any further movement of contaminants from the X-749 Landfill. The intention of the remediation procedure is to achieve a completely mature and functional phytoremediation system within two years of the initial planting of the hybrid poplar trees and to reduce the extent of the X-749/X-120 area groundwater TCE plume.

REFERENCES

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