



Remediation of Heavy Metal Contaminated Soil

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Metal pollution in soils is a widespread international problem resulting from mining and ore refinement, nuclear processing and the industrial manufacture of a variety of products including batteries, metal alloys and electrical components (Roane, et al. 1996). All industrialized countries have sites of high metal contamination as do nations hosting large military forces, such as countries in NATO. In Germany alone there are an estimated 143,252 sites with soil, water or both contaminated. There are approximately one million hectares contaminated in Germany which are located on old or current military sites. In addition to these military sites, there are 57,313 hectares of abandoned industrial sites and 85,939 hectares in abandoned waste disposal sites (Grimski, et al. 1996). Unfortunately, poor past waste disposal practices associated with industrialization have made air, soil and water contamination very common around the world. Many metal-contaminated sites occur worldwide that pose very serious health risks (Roane, et al. 1996).

Metals are naturally found in trace amounts in the soil around the world. Throughout the world, these trace amounts of metals are what help to foster good plant development and maturity. Without these trace amounts of metals, organisms would lack optimal development. Thus, plants would be small, have smaller yields, and be more susceptible to diseases (Roane, et al. 1996). Metals are also essential components of microbial cells. For example, sodium and potassium regulate gradients across the cell membrane and copper, iron and manganese are required for electron transport and photosynthesis (Roane, et al. 1996). However, metals at high concentrations can also be toxic to microorganisms, impacting microbial growth, morphology, and biochemical activities. The most toxic metals to the soil are the non-essential metals such as cadmium, lead and mercury (Roane, et al. 1996).

Soil highly contaminated with metals may disrupt the physical, chemical, and biological balance of the soil (Alloway, et al. 1990). Lead, mercury, arsenic, beryllium, boron, cadmium, chromium, copper, nickel, manganese, selenium, silver, tin, and zinc can be found in high concentrations in contaminated soils (Roane, et al. 1996). The type of soil characteristics such as pH, organic matter, particle size, permeability, soil moisture, and even particle density can drastically effect the rate of metal absorption (2.2.1 data Requirements for Soil, Sediment, and Sludge, 1999). Sand and gravel are the most favorable soil types for metal transport while clays are the least favorable. Another factor which effects the soil absorption rate of metals is the chemical interaction of the soil and metal (Alloway, et al. 1990).

Elevated metal concentrations in the environment also have wide ranging impacts on animals and plants. For example, human exposure to a verity of metals causes a wide range of medical problems such as heart disease, liver damage, cancer, neurological problems, and central nervous system damage. Metal toxicity in plants can cause shortening of roots, leaf scorch, nutrient deficiency and increased vulnerability to insect attack. Unless removed completely from the soil through intervention metal will persist indefinitely (Roane, et al. 1996).

Conventional methods of dealing with soils contaminated with heavy metals are solidification and removal. The most commonly used method is solidification. Solidification involves a process in which the contaminated matrix is stabilized, fixated or encapsulated into a solid material by the addition of a chemical compound such as cement. Although the metal contaminants are chemically and/or physically bound to the matrix, they are not destroyed (Alloway, et al. 1990). They are contained in such a way that leaching into the environment is prevented or reduced (Roane, et. al 1996). Removal is the process of physically removing the metal contaminated soil from the current site and discarding the waste into a designated contaminated site. The removal of the contaminated soil is not cost effective and environmentally safe (Grimski, et al. 1996).

Bioremediation, the use of microorganisms to control and destroy contaminants, is of increasing interest to minimize some of these problems, and is one of the fastest growing sector of hazardous waste cleanup and is expected to become a \$500 million dollar industry by the year 2000 (MacDonald, 1993). The main reason for choosing bioremediation is to accelerate biodegradation rates and minimize waste metals in the environment.

Enhanced bioremediation of soil typically involves an injection well or spray irrigation of ground water treated with microorganisms and hydrogen peroxide. Spray irrigation is typically used for shallow contaminated soils, and injection wells are used for deeper contaminated soils (4.2 Enhanced Bioremediation, 1999). As the microorganisms penetrate the soil, they can decrease metal toxicity in the soil by the oxidation or reduction of metals. Some microorganisms actively reduce the metals to decrease their bioavailability while others may oxidize metals to facilitate their removal from the environment. In some cases, metals are solubilized by microbes through oxidation to facilitate metal removal from a contaminated system. Specifically bacteria, algae, fungi and yeasts have all been found to absorb and breakdown metal compounds. (Roane, et al. 1996). Bacteria has been the most extensively studied. Complexation of metals by microorganisms occurs in two ways: the metals may be involved in nonspecific binding to the cell wall surfaces, the slime layer or the extracellular matrix, or they may be taken up intracellularly (Alloway et al, 1990). Studies have shown that both types of metal complexation are used to reduce metal toxicity and mobility. The complexation of the metal depends on the bacterium, the metal and the pH. It has been found that at a low pH, cationic metal complexation is reduced, however, the binding of anionic metals such as chromate is increased (Roane et al. 1996). The presence of soil complicates metal removal because soil absorbs metals strongly and can also affect the microbial-metal relationship.

Another bioremediation approach is phytoremediation. Phytoremediation is defined as the use of green plants to remove heavy metals and contaminants from the soil. The heavy metals most commonly associated with phytoremediation are lead, cadmium, zinc, nickel, or radioactive isotopes such as uranium or cobalt (Comis, 1996). The use of plants in metal contaminated soils has been used only since the 1970s (Cunningham, et al. 1995). The plants take up the toxic metals or isotopes through their roots and transport them to the stems or leaves. Researchers are hoping that one day these metal-scavenging plants, called hyperaccumulators , could be grown in contaminated soils and harvested like hay. The metal could then be recovered and recycled when burned and the ash is collected (Comis, 1996).

There are plants that tolerate excessive concentrations of metals in soils by absorbing, translocating and storing the metals in a nontoxic way. Many of these plants have evolved on metal-rich soils. Research over the last two decades has shown that certain specialized plants have the ability to accumulate up to 3% (by dry weight) of heavy metals and up to 25% (by dry weight) in sap/latex with no apparent damage to the plant. Researchers have found plants in numerous countries of the world including United Kingdom, Germany, Switzerland, Spain, France, and Italy. Almost all of these plants have been found on metalliferous soils. These soils are either natural or man made soils. The accumulation of metals is dependent on the plant, metal and environmental conditions (Cunningham, et al. 1995). Most types of ragweed and *Thlaspi rotundifolium* can be used for lead removal while alpine pennycress (*Thlaspi caerulescens*) can be used for the removal of zinc and cadmium. The pennycress is a wild herb found in many countries with soils contaminated with zinc and nickel. It has been used in Europe by prospectors as signs of the presence of metal ore (Comis, 1996).

Even though these plants are being used for phytoremediation, they are not as efficient and practical as researchers would like them to be. The pennycress specifically is inefficient in the metal uptake as well as being a low-growing and scrawny plant. Experimental plants are currently being tested and as well as the search for hyperaccumulator genes (Comis, 1996). Once the responsible gene is found, the goal is to insert them into high-yielding plants such as hay-type canola or Indian mustard. Another option is to use established breeding to produce pennycress plants which grow faster and taller (Comis, 1996). Currently, most varieties of pennycress grow only eight to twelve inches. Researchers are collecting the seeds of this plant from all over the world. They have found plants which accumulate 20 to 30 times more zinc than other hyperaccumulators and still grow in contaminated sites (Comis, 1996).

Phytoremediation promises a new level of bioremediation to clean up sites that are contaminated with heavy metals. Even though there is high potential for this newly evolving remediation technique it still cost between \$600,000 to \$3,000,000 to clean a hectare depending on the type and intensity of the pollutant (Thompson, 1995). As of this time there are plants that will hyperaccumulate only one or two different metals at a time. Thus, multiple types of hyperaccumulating plants are needed at a single site to remove more than one heavy metal from the soil. Having to plant and harvest multiple plants greatly increases the total cost and efficiency of removing heavy metals from a contaminated site.

Having to plant hyperaccumulator plants in an area more than an hectare is very expensive, time consuming, and requires lots of maintenance and care to keep the plants alive. Just having maintenance such as watering and adding iron to the plants in the remedied area requires lots of labor hours over a period of several years as the plants grow (Cunningham, et al. 1995). Additional costs are created when supplementary remediation techniques are used in conjunction with phytoremediation. Hyperaccumulating plants normally have roots that remove heavy metals from the top one meter. Any removal of heavy metals from the soil deeper than one meter needs an additional remediation technique. Thus, techniques such as phytoremediation, *situ* bioremediation, and other common remediation practices such as; solidification and soil removal, are used in conjunction to remove and stabilize heavy metals in the soil.

As of yet there has been no single cure-all technology to remove heavy metals from the soil. Phytoremediation and situ bioremediation are two of the best ways to remove heavy metals from the soil. Even though both technologies are not fast, they are cheaper and more environmentally friendly than conventional practices. Having to dig up and remove soil contaminated with heavy metals is relatively expensive. Digging up soil disturbs both the site being worked on as well as the new site the soil is being relocated on. There are fewer chances of recontamination, leaching, and other environmental problems when situ bioremediation and phytoremediation are used. Both techniques take longer time to work, as well as require more maintenance than dig-and-remove techniques. Overall more and more contaminated sites are being remedied by situ bioremediation and phytoremediation techniques. Both techniques will become more and more accepted and used in the impending years to come as they are better researched and studied. Both situ bioremediation and phytoremediation will have an important roll in the upcoming years as alternatives to traditional cleanup techniques; as traditional techniques become more expensive and less friendly to our environment.

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