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AN OVERVIEW OF IN SITU WASTE TREATMENT TECHNOLOGIES

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ABSTRACT

In situ technologies are becoming an attractive remedial alternative for eliminating environmental problems. In situ treatments typically reduce risks and costs associated with retrieving, packaging, and storing or disposing waste and are generally preferred over ex situ treatments. Each in situ technology has specific applications, and, in order to provide the most economical and practical solution to a waste problem, these applications must be understood.

This paper presents an overview of thirty different in situ remedial technologies for buried wastes or contaminated soil areas. The objective of this paper is to familiarize those involved in waste remediation activities with available and emerging in situ technologies so that they may consider these options in the remediation of hazardous and/or radioactive waste sites.

Several types of in situ technologies are discussed, including biological treatments, containment technologies, physical/chemical treatments, solidification/stabilization technologies, and thermal treatments. Each category of in situ technology is briefly examined in this paper. Specific treatments belonging to these categories are also reviewed. Much of the information on in situ treatment technologies in this paper was obtained directly from vendors and universities and this information has not been verified.

BIOLOGICAL TREATMENTS

Biological treatments utilize the natural activity of microorganisms (primarily bacteria, actinomycetes, or fungi) to remediate polluted soils and groundwater. While biological treatments often require a longer period for remediation than other treatment alternatives, they have the potential to completely destroy organic contaminants and are relatively inexpensive. Following is a summary of several biological treatments.

Bioremediation

The natural activity of microorganisms is used in the bioremediation process to decontaminate soils and groundwater polluted with organics.[1] Effective microorganisms are often found in small quantities at a contaminated site and,

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through nutrient enrichment, can be multiplied and encouraged to accelerate the natural degradation process. If the proper organisms are not already present, often they may be introduced. Bioremediation can be applied to chlorinated solvents and non-chlorinated organic contaminated water, soil, sludge, sediment, and other types of materials.[2]

Bioaccumulation

Biological techniques can also result in the precipitation and immobilization of metals. Metals such as Fe, Cu, Zn, and Pb can react with hydrogen sulfide produced by anaerobic microbial activity and form insoluble metal sulfides. Although the toxicity and volume of the metals will not be changed, insoluble metal sulfides will not dissolve and therefore the possibility of their migration will be significantly reduced. Bioaccumulation has been applied to metal-contaminated soils, groundwater, and surface water.

Dual Auger System

This technology uses a dual auger system to drill into contaminated soils and inject microorganism mixtures, water, and nutrients. This process is applicable to soils contaminated with organics. Soils at depths greater than 100 ft (30.48 m) can be treated.

CONTAINMENT TECHNOLOGIES

Containment technologies are used to reduce the mobility of contaminants. Containment may be used in conjunction with other in situ technologies to assist in the remediation of the site, or they may be used to control the migration of contaminants until an appropriate remediation technology is selected. However, containment does not treat the contaminants and contained sites still require monitoring.

Containment barriers usually include walls, floors, and caps composed of various types of materials. Barriers may be formed from numerous materials such as concrete, polymers, vitrified soil, and frozen soil.

Bottom Sealing

Using a horizontal or directional drilling method, bottom sealing involves grout injection techniques to place horizontal or curved barriers beneath a hazardous waste site to prevent downward migration of contaminants. Once in place, the barrier acts as a floor and seals the bottom of the waste site.

This technology has possible applications in all soils, including silts, clays, and weak rocks. It can be used with most contaminants including inorganics, organics, metals, mixed, high-level, low-level, and TRU waste. It is used in soils that are contaminated with liquid waste that have the potential of migrating downward.

Capping

The capping process is used to cover buried waste materials to prevent their contact with the surface environment and groundwater. Generally, capping is performed when extensive subsurface contamination at a site prevents excavation and removal of the wastes due to potential hazards and/or unrealistic costs.[3] Capping may be used for water, liquids other than water, gas, and/or soil contaminated with organics, inorganics, metals, and/or radionuclides.[4]

Polymer Concrete Barrier

This containment technology uses high strength, impervious polymer concrete to create an in situ barrier. Sealant materials are used that consolidate an earth/sand/gravel matrix into a high strength, impervious polymer concrete useful for the formation of barriers in the earth. These materials have very good chemical resistance and are typically two or three times stronger than structural concrete. This technology is effective for the containment of most contaminated waste. Residual risk from the untreated waste is greatly reduced once contained within a perimeter barrier with a sealant cap over the top (may also be composed of polymer concrete). This containment barrier could be used in conjunction with other in situ technologies.

Cryogenic Barrier

This type of barrier is formed by installing freezing pipes around the circumference of a contaminated site. A refrigerant fluid is pumped down the outside pipe and returned through the inner pipe. The double wall design allows the entire volume between walls to freeze, thus containing the site. If necessary, another in situ treatment could then be applied with little risk of contaminant migration.

This technology can be used to isolate or contain all types of contamination and can be used on all media states in which freeze pipes can be installed. It appears to be more cost effective to use this technology for temporary rather than permanent containment because of the high operational costs. Under certain circumstances, containment for a relatively short period of time is sufficient in itself. Cryogenic barriers are compatible with most other in situ technologies.

Fluidized-Bed Zeolite System

This system utilizes zeolite and particulate/solution polymer based grouts for in situ stabilization and isolation of radioactive and hazardous chemical waste materials that have been disposed in or near underground waste disposal and containment structures. The fluidized-bed will provide chemical fixation by mechanically homogenizing and incorporating waste tank residuals (tank bottoms and sludges) with granular zeolite (or equivalent) materials. Then particulate and solution polymer-based materials are incorporated into the interstitial void volume of the granular zeolite and surrounding geologic media to provide chemical isolation and physical stabilization.

This system could be used for remediation of subsurface waste storage/disposal structures such as underground storage tanks, cribs, caissons, piping, and buried sites. This technology will produce a physically stable structure, wherein contaminated materials are anticipated to be isolated from the environment over hundreds to thousands of years.

Plasma Arc Glass Cap

This technology uses a plasma torch to generate a high heat flux in the vicinity of the disposal site surface, thereby vitrifying the surface soil to create an impermeable glass cap. Depending on how the torch is operated, the cap may be anywhere from 1-6 in. (2.54 to 15.24 cm) deep.

The mobility of the toxic contaminants will be greatly reduced by placing an impermeable glass cap over the site. Moisture from rain and snow melt will be shielded from the waste, eliminating leaching and downward migration of the contaminants. Contaminants will be constrained from migrating upward. This technology can be used with all contaminants and soils that can be vitrified.

Slurry Wall

Slurry walls are subsurface barriers that are used to reduce groundwater flow in unconsolidated earth materials. Slurry wall construction involves excavating a narrow vertical trench through pervious soils, and then backfilling the trench with an engineered material. The backfill material is usually a mixture of soil and bentonite or cement and bentonite. The cement-bentonite slurry initially provides trench support (also prevents high fluid losses to the surrounding soil) and then sets to form an impervious barrier. Some slurry walls also use geomembrane liners to help prevent the migration of contaminants.[4,5]

Slurry walls can be used to contain most contaminants with a few exceptions. Soil-bentonite slurry walls are not suitable for leachate or contaminated groundwater containing strong acids/bases and alcohols. Also, cement-bentonite slurry walls are not applicable for wastes or leachates containing chlorinated hydrocarbons, organic acids, or acid chlorides. Barrier walls are not totally impermeable to water and can only inhibit the spread of contaminants.

Soil/Cement Wall

The soil/cement wall technology involves fixation, stabilization, and solidification of contaminated soils. Solidification/stabilization agents are blended in situ with the contaminated soils by a multi-axis overlapping hollow stem auger. The product is a monolithic block that extends down to the treatment depth.

This technology is effective on soils that are contaminated with metals and semi-volatile organic compounds. This technology has been used on various construction applications, including soil stabilization and cutoff walls.[2]

Vitrified Barriers

In situ vitrification (ISV) is a thermal treatment technology in which a region of soil volume is melted. This process can also be used to produce vitrified barriers. Upon cooling, the resulting product is a glass and crystalline monolith resembling natural obsidian. The process involves creating a barrier by inserting electrodes in the ground and placing a conductive starter path between them. Soil is melted when an electric potential is applied to the electrodes causing the starter path to heat up above the melting point of the soil. Vitrified walls and floors can be joined as needed to isolate waste sites from transport mechanisms or to totally contain them, if necessary (e.g., for additional in situ treatment). The vitrified soil barrier is extremely leach resistant and possesses about ten times the strength of unreinforced concrete. It is predicted stable over geologic periods of time. It also results in significant volume reduction because no additives are required and the soil is densified in the melting process.

This technology can be used to isolate or contain all contaminant types and can be used on all media states. It can be used to permanently contain a waste site or to temporarily contain a waste site while another method of in situ remediation is applied. There may be a concern in the presence of acids and salts (see discussion of in situ vitrification).

PHYSICAL/CHEMICAL TREATMENT

Physical/chemical treatments involve physical (heat, freezing, etc.) and/or chemical manipulation of a waste in order to reduce the toxicity and/or volume of the waste. In situ physical/chemical treatments can be used on soils, sludges, slurries, gases, sediments, and water. Contaminants may include metals, organics, radioactive contaminants, inorganics, acids, or bases. Following is a discussion on several physical/chemical treatments, including: dechlorination; electroacoustics; electrokinetics; neutralization; oxidation/reduction; precipitation/flocculation; soil flushing; in situ steam/air stripping; simultaneous injection, extraction, and recharge; and vacuum extraction.

Dechlorination

This process is based on the affinity of alkali metals for chlorine. Polyethylene glycol and some other hazardous chemicals can be used as catalysts for the reaction. The reagent reacts with the chlorinated organic by displacing a chlorine molecule. This chlorine displacement produces a lower toxicity, water soluble material. The reagent can be recovered and recycled after the reaction is complete. For in situ dechlorination, the mixture is typically heated by radio frequency heating or microwave heating to reduce the viscosity of the reagent.[4]

Alkali metal dechlorination is used on contaminated oils and liquid wastes to displace chlorine from chlorinated organic compounds such as polychlorinated biphenyls (PCBs) and dioxins. In situ dechlorination should be used for shallow, uniformly contaminated soils. Conventional agricultural equipment is used to mix the soil and the reagent. If the contaminated soil is deeper than 1 to 2 ft (.3 to .61 m), or if high concentrations are apparent, the soil should be excavated and dechlorinated after it is made into a slurry.[4]

Electroacoustics

Electroacoustic decontamination is used to remediate soils by applying electrical and acoustical fields. The electrical field is used to transport liquids through soils. The acoustic field can enhance the dewatering or leaching of waste such as sludges. Electroacoustic decontamination is effective on soils contaminated by inorganic, organic, and/or heavy metal liquids. Because this technology depends on surface charge to be effective, fine-grained clay soils are an ideal medium for application.[2,4]

Electrokinetics

This process is a separation/ removal technique for extracting heavy metals and/or organic contaminants from soils and sediments. Electrokinetic soil processing uses electricity to remove/separate organic and inorganic contaminants and radionuclides from the soil. A low direct current is run between an anode and a cathode inserted in a soil mass saturated with deionized water. This results in an acid front at the anode and a base front at the cathode. The acid front advances toward the cathode and eventually flushes across the soil and neutralizes the base. The movement of the front results in desorption of contaminants from the soil. The concurrent mobility of the ions and the advection of pore fluid under the electrical gradients supplies the method to flush contaminants from the soil.[6]

Neutralization

The in situ neutralization process is performed by injecting dilute acids or bases into the ground in order to optimize pH for further treatment, or to neutralize plumes that do not require further treatment. Neutralization is used on liquids, sludges, slurries, and gases contaminated by acidic or alkaline wastes.[4]

Oxidation/Reduction

This process takes advantage of the reactant's oxidation state and chemically transforms it by reduction-oxidation (REDOX). By raising one reactant's oxidation state while lowering the other, the toxicity of many organics and heavy metals can be reduced or destroyed using REDOX reactions. Decreased permeability of soils (due to hydroxide precipitation) or loss of adsorption (due to oxidation/reduction of soil organics) may affect in situ soil treatment. Violent reactions may occur with in situ methods because subsurface injection of reagents and water is required.[4]

This process can be used in situ on soils that are contaminated with cyanide, aldehyde, mercaptans, phenols, benzidine, unsaturated acids, pesticides, benzene, organics, arsenic, iron, manganese, chromium VI, mercury, lead, silver, chlorinated organics, or unsaturated hydrocarbons. Oxidation/reduction may also be used ex situ on water, slurries, and sludges.[4]

Precipitation/Flocculation

Precipitation is a treatment technique that transforms a substance in solution to a solid phase by physical/chemical mechanisms. It involves alteration of the ionic equilibrium to produce insoluble precipitates that can be easily removed by sedimentation or filtration. Typically, flocculating agents are added to cause the precipitate to become agglomerated. The solubility of metal hydroxides and sulfides is greatly affected by pH.[4]

Precipitation may be used as an in situ process to treat aqueous wastes in surface impoundments. In this type of application, lime and flocculants are added directly to the lagoon and mixing, flocculation, and sedimentation occur within the lagoon. Wind and pumping action can provide the energy for mixing in some cases.[3] Contaminants that may be affected by this treatment include zinc, cadmium, chromium, copper, lead, manganese, mercury, phosphate, sulfate, fluoride, arsenic, iron, nickel, and organic fatty acids.[4]

Soil Flushing

The use of soil flushing to remove soil contaminants involves the elutriation of inorganic constituents from soil for recovery and treatment. The site is flooded with the appropriate washing solution, and the elutriate is collected in a series of shallow wellpoints or subsurface drains. The elutriate is then treated and/or recycled back into the site. The technology can introduce potential toxins into the soil system. An effective collection system is required to prevent contaminant migration. Flushing solutions may include water, acidic solutions, basic solutions, chelating agents, and surfactants. Water can be used to extract water-soluble or water-mobile constituents.[1,3]

Soil flushing and elutriate recovery may be appropriate in situations where chemical oxidizing or reducing agents are used to degrade waste constituents and results in the production of large amounts of oxygenated, mobile, degradated products. In situ soil flushing is effective on sludges, soils, sediments, and other solids contaminated with inorganic corrosives, organic corrosives, oxidizers, halogenated nonvolatiles, halogenated volatiles, nonvolatile metals, volatile metals, organic cyanides, inorganic cyanides, nonhalogenated volatiles, nonhalogenated nonvolatiles, PCBs, pesticides, dioxins/furans, oxidizers, and reducers.[7] Chelation is used on liquids and soils contaminated by metals.[4]

In Situ Steam/Air Stripping

Steam/air stripping involves injecting steam or air into the soil beneath a contaminated zone to volatilize and strip organic contaminants. A transportable treatment unit for detoxification is used with this technology and consists of two main components--the process tower and process train. Hot air and steam carry the contaminants to the surface where a metal shroud collects the vapors for off-gas treatment and ducts them to the process train for treatment.[1]

In situ steam/air stripping system is effective in reducing the toxicity of soil by removing contaminated organics, such as hydrocarbons and solvents. This system is also commonly used to remove VOCs from ground or surface waters for the purpose of reinjection (for ground water) or discharge. Soil particle size, initial porosity, chemical concentration, and viscosity do not limit the technology. The compound's vapor pressure and polarity are important in determining how effectively this technology will remove the contaminants.[1,2,4]

Simultaneous Injection, Extraction, and Recharge

This process involves the remediation of unsaturated soils by injection of a medium to strip and transport contaminants to an extraction well(s). Water and steam are commonly used media. In unsaturated soil, steam will condense at some distance from the injection point and form a diffuse front consisting of a transient saturated zone with soil permeated by condensing steam on one side and relatively cool, unsaturated soil on the other side. This front is a region of radical contrasts in electromagnetic properties. The placement of injection points and extraction wells are designed to allow injection fronts to consolidate and move the contaminant to strategically located extraction wells. After being transported to the extraction wells, the contaminants are removed and treated.

This technology removes contaminants that can be mobilized by steam or water from unsaturated soil. Highly soluble or volatile contaminants in transmissive soils will be the best application for this technique, and these contaminants are expected to be removed very rapidly.

Vacuum Extraction

Vacuum extraction systems involve the extraction of contaminants from unsaturated soils through air injection. Clean air is injected into the contaminated soil, and a vacuum apparatus is used to extract the air filled with VOCs from recovery or extraction wells. The established air flows are a function of the equipment used and soil characteristics. Spent carbon and contaminated water are residuals of this treatment and further treatment of these residuals is necessary.[1 2 7]

Vacuum extraction is used for the treatment of soils, sediments, sludges, and ground water contaminated with volatile or semivolatile organic compounds (VOCs or SVOCs) at ambient temperatures. This technology is effective on VOC and SVOC total concentrations ranging from 10 ppb to 100,000 ppm by weight. For effective removal, contaminants should have a Henry's constant of 0.001 or higher. The use of vapor extraction systems is typically limited to permeable unsaturated soils such as sands, gravels, and coarse silts; diffusion rates through dense soils, such as compacted clays, are much lower than through sandy soils. Clayey soils usually lack the conductivity necessary for effective vapor extraction, unless they are first fractured.[1 2 7]

SOLIDIFICATION AND STABILIZATION

Solidification and stabilization are treatment processes designed to accomplish one or more of the following: (a) improve the handling and physical characteristics of the waste by producing a solid from a liquid or semi-liquid waste, (b) reduce the solubility of the contaminants in the treated waste, or (c) decrease the exposed surface area across which transfer or loss of contaminants may occur.

While solidification and stabilization reduce the mobility of a contaminant, the volume of the waste increases slightly, and there is only an incidental effect on toxicity. In addition, the effectiveness of the binders in incorporating organics and acid salts is questionable.

With proper recipe and additives, solidification and stabilization can be applied to virtually all contaminants including organics, inorganics, heavy metals, mixed wastes, and all classes of radioactive wastes. Solidification and stabilization can be applied to refuse, sediment, sludge/slurry, soil, structures, and water.

Waste solidification/stabilization systems discussed below include the DETOXIFIER™ system, lime-fly ash pozzolan systems, organic binding, pozzolan-portland cement systems, sorption, and thermoplastic microencapsulation.

Lime-fly Ash Pozzolan Systems

Lime-fly ash pozzolanic processes use a finely divided, noncrystalline silica in fly ash and the calcium in lime to produce low-strength cement. The solidification/stabilization of the waste is produced by microencapsulation in the pozzolan concrete matrix.[1]

With proper recipe and additives, the lime-fly ash pozzolan process can be applied to inorganics, metals, mixed, low-level, and TRU radioactive wastes; specifically refuse, sediment, sludge/slurry, soil, structures, and water mediums.[4]

Organic Binding

Modified clays can be used to immobilize organic contaminants. Clay particles are platy-shaped minerals that have negative charges on their surfaces as a result of isomorphous substitution. To achieve neutrality in their structure, clay particles attract cationic metals such as Li, Na, Ca, and Mg on their surfaces. Introduction of these organic cations into clays increases the interplanar distance between the clay particles and provides more suitable conditions for bonding of organic contaminants. Other organic binder types are epoxy, polyesters, asphalt, polyolefins, and urea-formaldehyde.[1] Organic binding is useful for soils or sludges contaminated with organic materials.

Pozzolan-Portland Cement Systems

In this process, portland cement and pozzolan materials (i.e., fly ash) are combined to create a high-strength waste and concrete matrix, where solidification/stabilization is achieved through the physical entrapment of waste particles. Fly ash or another pozzolan is often added to the cement to react with free calcium hydroxide and thus improve the strength and chemical resistance of the solidified product. The types of cement used for the solidification can be selected specifically to emphasize a particular cementing reaction, or to enhance cementation (such as sulfate resistance).[1,4]

Hazardous/toxic waste sites effectively treated by the pozzolan-portland cement process include: (1) heavy metals in metallic or cationic forms, (2) inorganics in anionic form, (3) water-soluble organics, and (4) water-insoluble organics. The wastes that can be treated include aqueous solutions, sludges, and contaminated soils.[8]

Sorption

Sorption is the addition of solid adsorbents to soak up and prevent the loss of drainable liquids through the mechanisms of capillary action, surface wetting, and chemical reaction. To prevent undesirable reactions, the absorbent material must be matched to the waste. Zeolite, kaolite, vermiculite, calcite, amorphous entonites silicates, acidic and basic fly ash, and kiln dust are all typical adsorbents. There are also synthetic adsorbents available. Adsorbents can be spiked with scavengers to bind trade metals, flocculating agents, and agents to improve subsequent solidification (cementing) processes.[1,4]

Sorption can be used to solidify any contaminants in water, liquids other than water, or sludges/slurries. For in situ treatment, the waste can be in the groundwater, surface water, saturated soil, or source term.[4]

Thermoplastic Microencapsulation

Thermoplastic microencapsulation involves blending fine particulate waste with melted asphalt or other matrix. Liquid and volatile phases associated with the wastes are driven off, and the wastes are isolated in a mass of cool hardened asphalt.[1]

THERMAL TREATMENTS

Thermal technologies elevate the temperature of the soil to volatilize certain contaminants. Volatilized contaminants are captured at the surface, thereby reducing the toxicity of the soil. Thermal treatment can be used to treat most contaminants and can be used in most media states.

The thermal treatments covered below include a high energy corona, radiofrequency and electromagnetic heating, and in situ vitrification.

High Energy Corona

Use of a high energy corona is an innovative thermal treatment process that does not require high temperatures or additives. Electrodes/vents are placed in the contaminated soil. Peripheral electrodes/vents are used as air inlets, while a center electrode/vent is used as an off-gas vent. A form of corona develops at higher voltages to generate energetic electrons and robust oxidants from soil gases.[4] The high energy corona technology is used to treat organic contaminated soils, sludges, slurries, and sediments.[4]

Radio Frequency and Electromagnetic Heating

In situ radio frequency (RF) heating is a rapid process that uniformly heats soil without excavation or digging. This process uses electromagnetic wave energy in the range of 45 Hz to well over 10 GHz to heat soil. Exciter and guard electrodes are placed in the ground, and the temperature rise occurs due to ohmic or dielectric heating mechanisms. The RF technology is capable of heating soils to temperatures in excess of 212°F (100°C) (boiling point of water). The gases and vapors formed in the soil are recovered at the surface or through vented electrodes used for the heating process. A vapor containment cover collects volatilized organics for incineration or carbon absorption. This process is also referred to as electromagnetic (EM) heating. The only major difference between RF and EM is in the choice of frequency of the applied power. The EM technology is suitable for heating soils only to the boiling point of water.[4]

RF and EM heating processes are used to treat sludges, solids, soils, and sediments contaminated with volatile and semivolatile dioxins/furans, pesticides, halogenated volatiles, halogenated nonvolatiles, radioactive materials, PCBs, nonvolatile metals, volatile metals, nonhalogenated nonvolatiles, and nonhalogenated volatiles. This technology can be used in saturated or unsaturated soil. Both of these technologies have the potential for economic and efficient remediation of soils at hazardous waste sites contaminated with organic compounds.[4,7]

In Situ Vitrification

In situ vitrification (ISV) involves the electric melting of contaminated soils in place. ISV uses an electrical network typically consisting of four electrodes placed in a square pattern and at the desired depth, to electrically heat and melt contaminated soils and solids at temperatures of 2900 to 3600°F (1600 to 2000°C). ISV destroys organic pollutants by pyrolysis. Inorganic pollutants are immobilized within the vitrified mass, which has properties of glass. Both the organic and inorganic airborne pyrolysis by-products are captured in a hood, which draws the contaminants into an off-gas treatment system that removes particulates and other pollutants of concern.[1,2,4]

ISV is effective on aqueous media, organic liquids, sediments, soils, and sludges contaminated with halogenated volatiles, halogenated nonvolatiles, nonhalogenated volatiles, nonhalogenated nonvolatiles, pesticides, dioxins/furans, organic cyanides, organic corrosives, volatile metals, nonvolatile metals, and PCBs.[7]

On saturated soils or sludges, the initial application of the electric current is needed to reduce the moisture content before the vitrification process can begin. This increases energy consumption and associated costs. Also, sludges must contain a sufficient amount of glass-forming material (nonvolatile, nondestructible solids) to produce a molten mass that will destroy or remove organic and immobilize inorganic pollutants. The ISV process, however, has the following limitations: (a) individual void volumes in excess of 150 ft^3 (4.25 m^3); (b) buried metals in excess of 5% of the melt weight or continuous metal occupying 90% of the distance between two electrodes; (c) rubble in excess of 10% by weight; and (d) the amount and concentration of combustible organics in the soil or sludge. These limitations must be addressed for each site.[2]

Acids and salts in the soil can also be a concern when using this technology. Acids and salts can cause the soil to have an abnormally high electrical conductivity (hence, a low electrical resistance), which is generally more pronounced as the moisture content of the soil increases. This low resistance will require the application of more electrical energy to the treatment area in order to achieve a vitrified melt. This may also result in a much higher melt temperature.

SUMMARY

In situ treatment technologies should be considered as a remedial alternative for eliminating or reducing many environmental problems. The in situ technologies reviewed in this paper included biological treatments, containment methods, physical/chemical treatments, solidification/stabilization techniques, and thermal treatments. The overview of these technologies should have familiarized those involved in remediation activities with a broad spectrum of in situ remedial alternatives for buried waste and contaminated soils.

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