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Soil Treatability Study

Energy Technology Engineering Center • U.S. Department of Energy

Soils Remediation Technology Screening Update
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Purpose

In response to requests to see more detailed information about the screening process that Sandia has undertaken, we have prepared a series of tables that reflect our progress thus far regarding soils remediation technology screening. The tables show the study boundaries and objectives, the technologies that have been eliminated and why, and the technologies that are still being considered.

Background

At the last STIG meeting we discussed the study boundaries, the study objectives, and the overall soil remediation treatment strategies that look most promising for meeting the boundaries and objectives. The study boundaries are shown in Table 1. The study objectives are shown in Table 2. The study boundaries have been crafted for general consistency with the requirements of the AOC. The overall treatment strategies are shown in Table 3 and Tables 4 through 12 show the eliminated technologies and the technologies still being considered, respectively.

Table 1. Study Boundaries

	Study Boundary
1	The goal of the chosen soil remediation alternatives will be to meet the established cleanup levels or reduce the contaminant concentrations/volume of soil to be excavated.
2	There will be no "leave in place" or on site burial/landfilling of contaminated soils.
3	Remediation alternatives will be in place by 2017.
4	Incineration (burning that forms an ash) will not be used as a remediation alternative.
5	Remediation alternatives will not exacerbate existing contamination issues or create new contamination problems.
6	Treatability studies being conducted for groundwater and unweathered bedrock are ongoing and will not be duplicated.
7	Plants that are not native or not naturalized to SSFL will not be considered as part of phytoremediation technologies. (native plants will be considered first as applicable)

Table 2. Study Objectives

	Study Objective
1	Dig and haul/excavation will be minimized as much as possible.
2	Remediation alternatives will be designed to consider the wild fires, native vegetation, and natural environment as much as possible.
3	Land and site disturbance will be minimized as much as possible.
4	Green and innovative/cutting edge technologies will be assessed as much as possible.

Table 3. Treatment Strategies

The following table presents the treatment strategies in their active and passive phases, where applicable, and how the two phases will most likely be paired.

Active Treatment	In-Situ Thermal (Less than 200°C)	Ex-Situ Thermal (Greater than 200°C)	In-Situ Bio-remediation	Phyto-remediation	In-Situ Nano	Ex-Situ Chemical and Biological Remediation
Potential Passive Treatment	Phyto-remediation	Engineered Barrier*	Phyto-remediation	Phyto-remediation	Phyto/Bio-remediation	Engineered Barrier*

*Only in cases where recontamination is possible

Screening Results Thus Far

Table 4 shows the technologies that have been eliminated from the Soil Treatability Study and why.

Table 5 shows the technologies being considered in In-Situ Thermal (200<°C) as active treatments.

Table 6 shows the technologies being considered in Ex-Situ Thermal (>200°C) as active treatments.

Table 7 shows the technologies being considered in In-Situ Bioremediation as active treatments.

Table 8 shows the technologies being considered in Phytoremediation as active treatments.

Table 9 shows the technologies being considered in In-Situ Nano as active treatments.

Table 10 shows the technologies being considered in Ex-Situ Chemical and Biological Remediation as active treatments.

Table 11 shows the technologies being considered in Phytoremediation as passive treatments.

Table 12 shows the technologies being considered in Engineered Barrier as passive treatments.

Table 4. Technologies that have been Eliminated from the Soil Treatability Study

Process	Technology Description	Reason for Elimination
Physiochemical Technologies Eliminated		
Air Sparging	In-situ groundwater and soil remediation technology that involves the injection of a gas under pressure into a well in saturated zone.	This is a soils treatability study and is not intended to be a groundwater treatability study. Other treatability studies for SSFL groundwater are ongoing and will not be duplicated with this study.
In-Situ Flushing	Injection or infiltration of an aqueous solution into a zone of contaminated soil/groundwater, followed by down gradient extraction of groundwater and elutriate and aboveground treatment and discharge or re-injection.	Study Boundary 5: Remediation alternatives will not exacerbate existing contamination issues or create new contamination problems.
In-Situ Oxidation	In-situ chemical oxidation involves the introduction of strong oxidants in the subsurface where they can destroy in-situ the contaminants of concern.	Study Boundary 5: Remediation alternatives will not exacerbate existing contamination issues or create new contamination problems.
In-Well Vapor Stripping	In-well vapor stripping technology involves the creation of a ground-water circulation pattern and simultaneous aeration within the stripping well to volatilize VOCs from the circulating ground water. Air-lift pumping is used to lift ground water and strip it of contaminants. Contaminated vapors may be drawn off for aboveground treatment or released to the vadose zone for biodegradation.	This is a soils treatability study and is not intended to be a groundwater treatability study. Other treatability studies for SSFL groundwater are ongoing and will not be duplicated with this study.
Thermal Technologies Eliminated		
Incineration	Combustion of waste where the resulting end product is ash.	Study Boundary 4: Incineration (burning that forms an ash) will not be used as a remediation alternative.
Vitrification	Media is subjected to temperatures in excess of 1200°C to form stable glass or glass crystalline materials. Organics are destroyed and radionuclides are bound in a less soluble and leachable form. An off-gas hood or HEPA filters are used to collect gases and particulates, respectively.	Study Boundary 2. There will be no "leave in place" or on site burial/landfilling of contaminated soils.
Bio Technologies Eliminated		
Biosorption	The use of microorganism metabolism to remove contaminants from soils, water and other materials; physiochemical binding of metals to non-viable biomass.	Study Boundary 2: There will be no "leave in place" or on site burial/landfilling of contaminated soils.
Phytoremediation Technologies Eliminated		
Stress Induced Phytoremediation	The use of plant stressors such as a micronutrient deficiency or acidic conditions to instigate phytoaccumulation in plants.	Study Boundary 5. Remediation alternatives will not exacerbate existing contamination issues or create new contamination problems.

Process	Technology Description	Reason for Elimination
Phytoaccumulator +Chlorocomplexes	The use of salinity and Cl forming metal complexes such as CdCl as a means to improve the phytoaccumulation abilities of certain plants.	Study Boundary 5. Remediation alternatives will not exacerbate existing contamination issues or create new contamination problems.
Nano Technologies Eliminated		
SAMMS™	Nanoporous ceramic substrate or material coated with a mono (single) layer of functional nanoparticles tailored to preferentially bind to target contaminant are introduced into the contaminated soils.	Study Boundary 2. There will be no "leave in place" or on site burial/landfilling of contaminated soils.
SOMS (syn: Osorb; e.g. Iron - Osorb & Palladium - Osorb)	Hydrophobic or water adverse organically modified silica that swells on contact with and captures small molecule organic compounds, and may capture up to eight-times its volume in organic compounds, is introduced into contaminated soils to sorb contaminants.	Study Boundary 2. There will be no "leave in place" or on site burial/landfilling of contaminated soils.
Other Technologies Eliminated		
MT2 ECOBOND	Chemical treatment process for the remediation of heavy metals; achieved via MT2's (a remediation vendor) process under the brand name ECOBOND®.	Study Boundary 2. There will be no "leave in place" or on site burial/landfilling of contaminated soils.

Table 5. Technologies Being Considered in In-Situ Thermal (<200°C) as Active Treatments

In-situ thermal technologies can be utilized to remediate dioxins, N-nitrosodimethylamine (NDMA), poly-aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs) (partially), polychlorinated triphenyls (PCTs) (partially), pesticides/herbicides (type dependent), semi-volatile organic compounds (SVOCs), total petroleum hydrocarbons (TPHs), and volatile organic compounds (VOCs).	
Process	**Technology Description**
In-Situ Thermal Technologies Under Consideration	
Hot Air/Steam Injection Generally with Soil Vapor Extraction (SVE)	Hot air or steam is injected into the contaminated underground formation or zone to enhance release of contaminants from the formation. Technology is used to enhance SVE by increasing volatilization of contaminants.
Multi/Dual-Phase Extraction	This technology uses a high vacuum system to remove various combinations of contaminated ground water, separate-phase petroleum product, and hydrocarbon vapor from the subsurface. Extracted liquids and vapor are treated and collected for disposal, or re-injected to the subsurface (where permissible under applicable state laws). (Synonyms: Dual-phase extraction, vacuum-enhanced extraction, bioslurping, free product recovery, liquid-liquid extraction.)
Radiofrequency or Microwave Heating	Radiofrequency (RF) is used to heat a target area. Generally heats soil to less than 100°C and is used to increase effectiveness of SVE.
Soil Vapor Extraction	Soil vapor extraction (SVE) is an in-situ process for soil remediation where contamination is removed from soil by carrying it out through a medium such as air or steam. The extracted soil vapors are separated into liquids and vapors and each stream is treated as necessary.
SVE - Solar Detoxification	Used with SVE, condensed contaminants are mixed with water and a catalyst, which is activated by ultraviolet light to break down organics into non-hazardous components.
Thermal Blanket (ISTD) In-Situ Thermal Desorption	Thermal blanket heats soil to temperatures up to 200°C to desorb or destroy organics. A negative pressure off gas system is used to capture and treat vapors (afterburner, condenser, carbon, etc).
Vertical Thermal Well, Resistivity Heating/High Temperature Thermal Conduction/In-Situ Thermal Desorption and Destruction (ISTD)	Soil is heated by resistive electrical heating elements in a closely-spaced well network. Wells are under a vacuum to move contaminants, organics are oxidized/pyrolysized in the well, and remaining contaminants are treated at the surface. Soil temperatures can reach 200°C.

Table 6. Technologies Being Considered in Ex-Situ Thermal (>200°C) as Active Treatments

Ex-situ thermal technologies can be utilized to remediate dioxins, mercury, N-nitrosodimethylamine (NDMA), poly-aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), polychlorinated triphenyls (PCTs), perchlorate, pesticides/herbicides (type dependent), semi-volatile organic compounds (SVOCs), total petroleum hydrocarbons (TPHs), and volatile organic compounds (VOCs)	
Process	**Technology Description**
Ex-Situ Thermal Technologies Under Consideration	
Advanced Electric Reactor	A type of pyrolysis system where electrically heated carbon electrodes are used for radiant heating of a porous reactor core. Nitrogen dioxide is pumped through the porous core isolating it from the waste in the reactor chamber. An off-gas system is used to capture and treat the resultant byproducts.
Electric Arc Pyrolysis	Consumable electrodes produce an arc that is used to heat waste in a reaction chamber. Temperatures can reach 1450-1800°C. An off-gas treatment is necessary for vaporized metals and other byproducts.
High Temperature Thermal Desorption	Thermal desorption uses temperatures that facilitate pyrolysis of the non-volatile organics or all organics (750°C). Can use carrier gas or vacuum. An off gas/particulate system is a necessary component of the system.
Low Temperature Thermal Desorption (LTTD) and Low Temperature Thermal Stripping	Soil remediation techniques that remove low temperature volatiles (hydrocarbons) by heating in a closed system to between 90 and 320°C. May use afterburner or condenser.
Low Temperature Thermal Treatment	Treatment technology volatilizes the contaminants from the soil (200°C) and volatiles are generally condensed. System uses low flow, low oxygen closed system such that the contaminants are removed from the soils without combustion or decomposition. Results in treated soil, fabric filter dust, treated condensate, and treated stack gas.
Molten Salt Reactor	A heated liquefied salt is injected with waste (pyrolysis), a secondary reactor may be used to combust generated gases or an off-gas system can be used to capture byproducts. Specific salts can be used in the process that will react with the decomposition products, effectively trapping these elements in the salt.
Plasma Arc Pyrolysis	A plasma arc (torch) is used in a low pressure, low oxygen chamber to decompose waste at temperatures approaching 10,000°C. Liquid is sprayed through the arc and into the furnace chamber (1,000°C reactor/mixing zone). Off-gas system removes byproducts.
Steam Reformers	Reduction of organics with steam produces combustible gases that are further combusted or captured. Pyrolysis with lower oxidation and reduction, and less off gas, than that of other processes.
Supercritical Water Oxidation	Water and waste are processed at a temperature and pressure above the critical point of water. At this point, water is soluble to many organics allowing these compounds to oxidize. Salts also precipitate and can be separated. Process temperatures are between 400 and 650°C.

Table 7. Technologies Being Considered in In-situ Bioremediation as Active Treatments

In-situ bioremediation technologies can be utilized to remediate dioxins, N-nitrosodimethylamine (NDMA), poly-aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), polychlorinated triphenyls (PCTs), perchlorate, pesticides/herbicides (type dependent), semi-volatile organic compounds (SVOCs), total petroleum hydrocarbons (TPHs), and volatile organic compounds (VOCs).

Process	Technology Description
Biological Technologies Under Consideration	
Bioaugmentation	The use of microorganism metabolism to remove contaminants from soils, water and other materials through the introduction of microbes to the contaminated soil.
Biostimulation-CO2 Source	Stimulation of natural microorganisms by injection of a carbon dioxide source into the subsurface. Bacteria can then proliferate and degrade contaminants.
Bioventing	Stimulation of natural in-situ biodegradation of any aerobically degradable contaminants in the soil by providing oxygen to existing soil microorganisms.
Monitored Natural Attenuation	Monitored Natural Attenuation (MNA) is a technique used to monitor or test the progress of the attenuation process. It may be used with other remediation processes as a finishing option or as the only remediation process. Natural processes can mitigate the remaining amount of pollution, and regular monitoring of the soil and ground water can track those reductions. MNA is increasingly used in cleanup actions.

Table 8. Technologies Being Considered in Phytoremediation as Active Treatments

Phytoremediation technologies can be utilized to remediate dioxins, metals (excluding mercury), N-nitrosodimethylamine (NDMA), poly-aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), polychlorinated triphenyls (PCTs), perchlorate, pesticides/herbicides (type dependent), radioactive elements, semi-volatile organic compounds (SVOCs), total petroleum hydrocarbons (TPHs), and volatile organic compounds (VOCs).	
Process	**Technology Description**
Phytoremediation (Active) Technologies Under Consideration	
Bacteria Assisted Phytoaccumulation	Process by which plant growth-promoting bacteria are used to protect plants from toxicity of contaminants.
Phytoextraction, Hyperaccumulation	Process by which plants hyper-accumulate contaminants through their roots and store them in the tissues of plant. Contaminants are not necessarily degraded but are removed from the environment when the plants are harvested. In some cases, the metals/contaminants can be harvested for reuse by incinerating the plants (phyto-mining).
Rhizodegredation	Process by which plant exudates stimulate rhizosphere bacteria to enhance biodegradation of soil contaminants (happens in the soil directly surrounding the plant roots).
Rhizodegredation/ Accumulation	Process by which plant exudates stimulate rhizosphere bacteria to enhance biodegradation of soil contaminants (happens in the soil directly surrounding the plant roots), and increase accumulation capabilities.
Rhizodegredation/ Phytoextraction	Process by which plant exudates stimulate rhizosphere bacteria to enhance biodegradation of soil contaminants (happens in the soil directly surrounding the plant roots), and also increases the solubility of the metals so that they are more bioavailable to the plant.
Phytoaccumulator+Chelator	The use of chelators such as ethylenediaminetetraactetic acid (EDTA) to improve the phytoaccumulation abilities of certain plants.
Phytochelatins	Process by which plants produce phytochelatins which are enzymatically synthesized cysteine-rich peptides to protect the plant from heavy metal toxicity.
Phytovolatilization	Process where plants intake volatile compounds through their roots, and transpire the same compound or its metabolite(s) into the atmosphere through the leaves. This will be contaminant dependent and will not be utilized for certain constituents.

Table 9. Technologies Being Considered in In-Situ Nano as Active Treatments

Process	Technology Description
In-situ nanotechnologies can be utilized to remediate dioxins, N-nitrosodimethylamine (NDMA), poly-aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), polychlorinated triphenyls (PCTs), perchlorate, pesticides/herbicides (type dependent), semi-volatile organic compounds (SVOCs), total petroleum hydrocarbons (TPHs), and volatile organic compounds (VOCs).	
In-Situ Nano Technologies Under Consideration	
Bimetallic Nanoscale Particles (BNPs)	Particles of elemental iron or other metals in conjunction with a metal catalyst, such as platinum, gold, nickel, and palladium, used for contaminant degradation.
Dendrimers	Hyper-branched, well-organized polymer (molecule made from joining small molecules) molecules with three components: core, branches, and end groups. Dendrimer (repetitively branched molecules) surfaces terminate in several functional groups that can be modified to enhance specific chemical activity.
Emulsified Zero-Valent Iron (EZVI)	Nano- or microscale ZVI surrounded by an emulsion membrane that facilitates treatment of chlorinated hydrocarbons.
Ferritin	An iron storage protein that has been shown to reduce the toxicity of contaminants.
Metalloporphyrinogens (e.g. hemoglobin and vitamin B12)	Complexes of metals and naturally occurring, organic porphyrin (group of compounds containing the porphin structure) molecules that are redox catalysts and exhibit characteristics effective for remediation of certain contaminant groups.
Nanoscale Zero-Valent Iron (nZVI)	Particles ranging from 10 to 100 nanometers in diameter or slightly larger. Shown to be effective for treating groundwater contaminants within permeable reactive barriers (PRBs) through adsorption but could apply to soils.
Nanotubes	Electrically insulating, highly electronegative, and easily polymerizable engineered molecules most frequently made from carbon or titanium dioxide (TiO_2) and have demonstrated the potential for use as a photocatalytic (uses light or electromagnetic radiation to alter the rate of a chemical reaction) degrader of chlorinated compounds.

Table 10. Technologies Being Considered in Ex-Situ Chemical and Biological Remediation as Active Treatments

Ex-situ chemical and biological technologies can be utilized to remediate dioxins, metals, N-nitrosodimethylamine (NDMA), poly-aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), polychlorinated triphenyls (PCTs), perchlorate, pesticides/herbicides (type dependent), radioactive elements, semi-volatile organic compounds (SVOCs), total petroleum hydrocarbons (TPHs), and volatile organic compounds (VOCs).	
Process	**Technology Description**
Ex-Situ Chemical and Biological Remediation Technologies Under Consideration	
Biomining	Extraction of specific metals through biological means, usually bacteria.
Biopiles	Excavated soils are mixed with soil amendments and placed on a treatment area that includes leachate collection systems and some form of aeration.
Composting	Controlled biological process by which organic contaminants (e.g., PAHs) are converted by microorganisms (under aerobic and anaerobic conditions) to innocuous, stabilized byproducts.
Electrokinetic Separation	A dc electric field can be applied across electrode pairs utilized as part of a soil washing process. The contaminants in the liquid phase are moved under the action of the field, by electromigration and/or electroosmosis, where they are then removed.
Fluidized Bed Reactors	Fixed-film bioreactors that rely on immobilization on a hydraulically fluidized bed of media particles, and can facilitate conditions required to promote degradation of energetic compounds.
Landfarming	Incorporates liners and other methods to control leaching of contaminants, which requires excavation and placement of contaminated soils, sediments, or sludges. Contaminated media is applied into lined beds and periodically turned over or tilled to aerate the waste.
Lasagna	Layered configuration that combines eletrokinetics with in-situ bioremediation technologies.
Slurry Phase (Slurry Biodegradation)	Controlled treatment of excavated soil in a bioreactor. Soil is mixed with water to a predetermined concentration dependent upon the concentration of the contaminants, the rate of biodegradation, and the physical nature of the soils.
Soil Washing	Soil washing “scrubs” soil to remove and separate the portion of the soil that is most polluted. This reduces the amount of soil needing further cleanup. Soil washing alone may not be enough to clean polluted soil. Therefore, most often it is used with other methods that finish the cleanup.
Wet Oxidation - Catalytic Aqueous Process	Wet Oxidation process with iron chloride (FeCL3) and hydrogen chloride (HCl) using 200°C and up to 200 pounds/square inch gauge (psig).

Table 11. Technologies Being Considered in Phytoremediation as Passive Treatments

Phytoremediation technologies can be utilized to remediate dioxins, metals (excluding mercury), N-nitrosodimethylamine (NDMA), poly-aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), polychlorinated triphenyls (PCTs), perchlorate, pesticides/herbicides (type dependent), radioactive elements, semi-volatile organic compounds (SVOCs), total petroleum hydrocarbons (TPHs), and volatile organic compounds (VOCs).	
Process	**Technology Description**
Phytoremediation (Passive) Technologies Under Consideration	
Bacteria Assisted Phytoaccumulation	Process by which plant growth-promoting bacteria are used to protect plants from toxicity of contaminants.
Phytoextraction, Hyperaccumulation	Process by which plants hyper-accumulate contaminants through their roots and store them in the tissues of plant. Contaminants are not necessarily degraded but are removed from the environment when the plants are harvested. In some cases, the metals/contaminants can be harvested for reuse by incinerating the plants (phyto-mining).
Rhizodegredation	Process by which plant exudates stimulate rhizosphere bacteria to enhance biodegradation of soil contaminants (happens in the soil directly surrounding the plant roots).
Rhizodegredation/ Accumulation	Process by which plant exudates stimulate rhizosphere bacteria to enhance biodegradation of soil contaminants (happens in the soil directly surrounding the plant roots), and increase accumulation capabilities.
Rhizodegredation/ Phytoextraction	Process by which plant exudates stimulate rhizosphere bacteria to enhance biodegradation of soil contaminants (happens in the soil directly surrounding the plant roots), and also increases the solubility of the metals so that they are more bioavailable to the plant.
Phytochelatins	Process by which plants produce phytochelatins which are enzymatically synthesized cysteine-rich peptides to protect the plant from heavy metal toxicity.
Phytovolatilization	Process where plants intake volatile compounds through their roots, and transpire the same compound or its metabolite(s) into the atmosphere through the leaves. This will be contaminant dependent and will not be utilized for certain constituents.

Table 12. Technologies Being Considered in Engineered Barrier as Passive Treatments

Engineered barriers can be utilized to remediate dioxins, metals (excluding mercury), N-nitrosodimethylamine (NDMA), poly-aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), polychlorinated triphenyls (PCTs), perchlorate, pesticides/herbicides (type dependent), radioactive elements, semi-volatile organic compounds (SVOCs), total petroleum hydrocarbons (TPHs), and volatile organic compounds (VOCs).	
Process	**Technology Description**
Engineered Barrier Technologies Under Consideration	
Permeable Reactive Barriers	A permeable reaction barrier is installed across the flow path of a contaminant plume, allowing passage of water while prohibiting the movement of contaminants by employing such agents as zero-valent metals, chelators (ligands selected for their specificity for a given metal), sorbents, microbes, and others. The walls are typically installed in a vertical form, but a horizontal design may be considered.

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