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Department of Energy sites suitable for electrokinetic remediation [1]

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Abstract

Department of Energy sites with contaminated soils that are likely to be responsive to electrokinetic remediation are identified, and conditions at 31 of these sites are summarized in a table. Features that make the soils good candidates for electroremediation include low hydraulic permeability and the presence of water-soluble contaminants. Included in the table are brief descriptions of site geology/hydrology; the types and approximate concentrations of contaminants; and telephone numbers of individuals having responsibility for the sites. © 1997 Elsevier Science B.V.

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1. Introduction

The US Department of Energy (DOE) is responsible for a number of sites that are known to have soils contaminated with radioactive and non-radioactive heavy metals, or waste materials from metal processing operations (including organic solvents), or wastes of unknown type, amount, or origin that have accumulated during 50 years of nuclear weapons and energy production. Over 3700 buried waste sites are known, with sizes varying from a few acres to several hundred acres. There are over 5000 sites of uranium mill tailings; several hundred thousand drums containing transuranic (TRU) waste; and several hundred tanks containing millions of gallons of high-level waste (HLW).

Because of the wide diversity of site conditions, contaminant identities and concentrations, and intended use of the reclaimed site, DOE has to have a variety of remediation

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Table 1
Potential DOE sites for electrokinetic remediation[a]

Location/Contact		Site area	Contamination	Problem	Site Characteristics
CA	Lawrence Berkeley Laboratory—Iraj Javendal, (510) 486-5686	Site wide	^{3}H (GW: 31 000 pCi l^{-1}, soil: 10 pCi g^{-1}); petroleum (GW: LNAPL present; soil: 1600 mg kg^{-1}); freon (9800 mg kg^{-1}) halogenated hydrocarbon (GW: 98 μg l^{-1}, soil: 5500 mg kg^{-1}) CA	Total of seven identified plumes on site. Off-site tritium plume (greatest public concern). LBL is in the middle of the stateland. Nuclear waste cannot be disposed here because it is safe not federal land	WT = 6–80 ft; there is an active fault next to the boundary. 90% of the site is low k, 10^{-7}–10^{-9} m s^{-1}. There are three main rock types: fractured shale and silstone (Great Valley); silts–stone, sandstone and mudstone (Orlinda); volcanics (Moraga)
CA	Stanford Linear Accelerator—Rich Fallejo (510) 637-1639	Site wide	VOCs, Pb, PCBs	Four sites with contaminated GW and two contaminated soil sites (over 200 000 cu.ft.) They have completed several interim removal actions of PCB contaminated soils.	Eocene and Miocene marine sedimentary sandstone, siltstone, and shale up to 4000 ft thick. Upper Pliocene and Pleistocene non-marine silts, sands and gravels up to 1000 ft thick. WT = 4–30 ft bgs. Most GW is in sedimentary rock. Soil is very low k
CO	Rulisan—Kevin Leary, (702) 295-0814	Storage pit	Metals and petroleum	Drilling mud storage pit contaminated with metals and petrolium hydrocarbon. Baseline technology is soil washing.	N/A
ID	Idaho National Engineering Laboratory Adam Owen (208) 526-9987	ICPP—WAG 3, OU3—13	^{90}Sr (GW: peak of 516 000 pCi l^{-1}), Np, Tc-99, tritium	Perched water contamination in sedimentary interbeds at 110 ft	Vadose zone:sandy loan (60 ft) over sand (90 ft) over silt (50 ft) over sand (200 ft)
IL	Argonne National Laboratory—Yvette Collazo	317 area/319 landfill	TCE, TCA, DCE, tritium and acetone	Contaminated groundwater exists in glacial till to a depth of at least 40 ft. DNAPLs and LNAPLs are suspected.	Low k layer (silty clay glacial till) overlaying high k zone (dolomite)
KS	Kansas City plant—D. Brown (816) 997 4034	ADS 1028	TCE, DCE, dichlorobenzene, petroleum, PCBs	Soil and contamination	WT = 7–15 ft. There is approximately 40 ft of unconsolidated clayey silt alluvium overlying shale and sandstone bedrock

KS	Kansas City plant—D. Brown, (816) 997-4034	Plating building petrolium	TCE, PCE, DCE, PCBs,	DNAPLs are suspected at this site	WT = 7–15 ft. There is approximately 40 ft of unconsolidated clayeysilt alluvium overlying shale and sandstone bedrock
KS	Kansas City plant—Joe Baker, (816) 997-7332	ADS 1038	TCE, DCE, jet/diesel fuel, PCBs	Chlorinated solvents contaminate both soil and groundwater, others only are found in soil	WT = 7–15 ft. There is approximately 40 ft of unconsolidated clayey silt alluvium overlying shale and sandstone bedrock
KS	Kansas City plant—Joe Baker, (816) 997-7332	ADS 1046 zene,	TCE, DCE, chloroethene, ben- TCA, petroleum, PCE, Toluene, PCBs	Contaminantsexist in multiple hotspots due to nemerous spills/leaks	WT = 7–15 ft. There is appro- namely 40 ft of unconsolidated clayey silt alluvuim overlying shale and sandstone bedrock
KS	Kansas City plant—Mike Stites, (816)997-7192	ADS 1048	TCE, DCE, chloroethene, petroleum	Contamination of soil and groundwater beneath and adjacent to a building	WT = 7–15 ft. There is approximately 40 ft of unconsolidated clayey silt alluvium overlying shale and sandstone bedrock
KS	Kansas City plant—Mike Stites, (816) 997-7192	Department 26	TCE, DCE, PCBs, petroleum	Contamination present in soil beneath a building	WT = 7–15 ft. There is approximately 40 ft of unconsolidated clayey silt alluvium overlying shale and sandstone bedrock
KY	Paducah—Ross Miller, (502) 441-5088)	Northeast plume	TCE, ^{99}Tc	Seven tentative sources for the NE plume have been identified, including spills associated with the C400 building. DNAPLs are confirmed within both the vadose and saturated zones at the C400 building	Hydrogeologic units listed in descending order (Unit 1—surface, Unit 5—at depth). Unit 1: loess (5 ft); Unit 2: clayey silt (15 ft); Unit 3: sand and gravel lenses (5 ft); Unit 4: clayey silt (25 ft); Unit 5: gravel (30 ft)
KY	Paducah—Ross Miller, (502)441-5088	Northwest plume plume	TCE, ^{99}Tc	DNAPLs: sources of this plume are believe to be WAGs 7 and 30 and Building C400	Hydrogeologic units listed in descending order (Unit 1—surface, Unit 5—at depth). Unit 1: loess (5 ft); Unit 2: clayey silt (15 ft); Unit 3: sand and gravel lenses (5 ft); Unit 4: clayey silt (25 ft); Unit 5: gravel (30 ft)

Table 1 (continued)

Location/Contact	Site area	Contamination	Problem	Site Characteristics
NM Sandia National Laboratory—Cynthia Ardito (505) 246-1600	Chemical waste landfill	TCE (up to 1000 ppm), PCBs, chromium	DNAPLs (TCE, PCBs) are present at this site. Chromium plume extends down to 75 ft and TCE to below 485 ft	Low to high k zone complicated by fault blocks. Very deep vadose zone, WT = 485 ft
NV Nevada test site—John Hall, (702) 295-5855		Large variety of radionuclides		Low to high k zone overlying high k zone (carbonate)
NY West Valley—Herman Moore, (716) 942-4814	Site wide	^{90}Sr	^{90}Sr has contaminated a shallow alluvial aquifer to a depth of 20 ft and an extent of 8-9acres.	Shallow water table. Unit 1: sand and gravel alluvium 10–50 ft thick; Unit 2: Lavery till, silty clay unit that ranges up to 80 ft thick and is an effective low k aquitard
OH Fernald—Robert Janke, (513) 648-3214	OU 5	Uranium (up to 10 000 mg kg^{-1} in soils), Th	Need technology to treat soils with concentrations above the waste acceptance criteria (1030 ppm)for on site disposal	Glacial overburden is 0–50 ft of clay-rich till material with discontinuous lenses of coarser-grained material within the fine-grained matrix
OH Mound—Ron (513) 865-3548	Miami–Erie Canal—OU 4	^{238}Pu (max. 4000 pCi g^{-1})	In 1969, as a result of heavy rainfall, runoff water containing significant quantities of Pu was discharged into the Miami–Erie Canal. App. 25 000 yds of soil located within the sides and bottom along a 1 mile reach of the canal was contaminated with Pu	The Miami-Erie Canal is located in the floodplain of the Miami River. When constructed 200 years ago, the base of the canal was covered with clay layer several feet thick (where the Pu is concentrated)
OH Mound—Gary Coons, (513) 865-3867	SM/PP Hill and 'New' property area—OU 5	^{238}Pu, Th	Soil contamination is a result of surface spills and leaks. > 1 million cu ft of contminated soils in in OU 5 and 6	Contaminated soils (clay?) overlie interbedded limestone and shale
OH Mound—Joe Geneczko, (513) 865-3677	Soil under D&D sites—OU 6	^{238}Pu, Th	Soil contamination associated with buildings that will be undergoing D&D	Contaminated soils (clay?) overlie interbedded limestone and shale

OH	Portsmouth—Frank Anderson, (614) 987-2241	X-231B source and plume	TCE (1.8 $mg\,l^{-1}$), ^{99}Tc (57 $pCi\,l^{-1}$), DCE, U, TCA, BTX, and metals	Site is requesting in-situ treatment methods for contaminated clay soil in both saturated conditions saturated conditions	Hydrogeologic units listed in descending order (Unit 1—surface, Unit 5—at depth). Unit 1: silty lay, 25 ft thick; Unit 2: clayey sand, 3–5 ft thick; Unit 3: fractured shale, competent at base 10 ft thick; Unit 4: sandstone; Unit 5: shale
OH	Portsmouth—Frank Anderson, (614) 897-2241	X-701B pond source and plume	TCE (800 $\mu g\,l^{-1}$), ^{99}Tc (450 $pCi\,l^{-1}$), PCBs (200 $mg\,l^{-1}$)	X-701B holding pond received discharges from a number of facilities. Leachate from the pond has contaminated the Galia at a depth of 30 ft and created a plume that migrates toward a stream near the boundary of the plant. DNAPL is TCE,PCB	Hydrogeologic units listed in descending order (Unit 16surface, Unit 5—at depth). Unit 1: silty clay, 25 ft thick; Unit 2: clayey sand, 3–5 ft thick; Unit 3: fractured shale, competent at base 10 ft thick; Unit 4: sandstone; Unit 5 shale
OH	Portsmouth—Frank Anderson, (614) 897-2241	X-749 landfill groundwater plume	TCE (4 $mg\,l^{-1}$), other VOCs, ^{99}Tc (633 $pCi\,l^{-1}$), metals	Site is requesting groundwater ma-manipulation and treatment methods with a focus on thin aquifers of low hydraulic conductivity contaminated with VOCs and rads. The plume at this site is ~ 70 acres	Hydrogeologic units listed in descending order (Unit—surface, Unit 5—at depth). Unit 1: silty clay, 25 ft thick;Unit 2: clayey sand, 3–5 ft thick; Unit 3: fractured shale, competent at base 10 ft thick; Unit 4: sandstone; Unit 5: shale
SC	Savannah River site—J. Horvath (813) 644-6853	A/M ground water	TCE, PCE, TCA, oils, PCBs	Four DNAPL sources located, large plume extends over 2 miles	Heterogeneous geology, sandy aquifers with thick clay confining units
SC	Savannah River site—Guy 644-6788	TNX area Standard (813)	TCE, CCl_4, Hg and low levels of radionuclides	Includes a number of basins: Met Lab, Old TNX, and New TNX	Heterogenous geology, sandy aquifers with thick clay confining units
TN	K-25—Gary Bodenstein, (423)576-9429	Site wide	TCE, PCBs, U, ^{99}Tc	DNAPLs and LNAPLs are present at this site. Three plumes present at this site; plume sources are the K-1070 CD landfill, a gas station and the K-1420 decon facility	Disturbed geology. site was leveled to ease construction (Unit 1 —surface, Unit3—at depth). Unit 1: 40 ft of clayey soil; Unit 2: 10 ft of competent bedrock; Unit 3: high flow karst system

Table 1 (continued)

Location/Contact		Site area	Contamination	Problem	Site Characteristics
TN	Oak Ridge—David Page, (423) 576-1357	Lower East Fork of Poplar Creek	Mercuric sulfide (2–2000 ppm)	This creek flows into the Clinch River. It has been a problem because of mercury contamination which is in the floodplain soil from Upper East Fork of Poplar Creek and Y-12. The Hg is not in the GW	Floodplain sediments
TN	Y-12—Steve Hasse, (423) 241-5258	Ash disposal basin—OU 2	Heavy metals and U	Site consists of a filled coal ash pond that may impact surface and groundwater and stream sediments	Vadose zone consists of silty and clay-like soil underlain by fracured dolomite
TN	Y-12—Steve Hasse, (423) 241-5258	Chestnut Ridge security pits—	Acids, Be, biological material, heavy metals, inorganics, organ	Site consists of 30–40 pits contain -ing 3950 tons of waste material. 1988. VOCS have reached groundwater but metals, rads, Be and PCBs are still near the pits	Vadose zone consists of silty and clay-like soil underlain by fractured dolomite
TN	Y-12—Donna Bennett, (423) 574-5839	Poplar Creek watershed	Hg,organics, nitrates, heavy metals and U	Site consists of multiple sources and is underlain by a very difficult hydrogeologic setting. Current opinions are that complete remediation is intractable and economically infeasible	Contamination is in the lower permeability sediments (less than 100 ft) and in deep (500 ft) karst carbonate deposits
TX	Pantex plant—Johnny eems (806) 477-6856	HE/rad sites in Zones 11 and 12	U, and possibly other rads, high explosive residues	Depleted uranium and possibly other radionuclides are present in surface and near-surface soils. Soil contamination from these activities occurs in the testing areas but also occurs in Playa #1 and associated ditches	The uppermost geologic unit is a clayey siltwhich is up to 100 ft thick

[a] Data and information contained in this table were compiled from refs. [1–3].

technologies to choose from, and these technologies need to be well understood in terms of their applicability, effectiveness, and cost. DOE is interested in technologies that will economically and effectively clean up waste sites in such a manner that these problems will not have to be revisited.

An emerging remediation technology that may be useful at certain DOE sites involves application of direct current between electrodes inserted in the soil, and the consequent effects on soil contaminants. These 'electrokinetic' effects include electroosmosis (the movement of pore water through the soil by virtue of the applied electric field); electrolytic conduction of ions ('electromigration'); and the generation of chemical species by the electrode reactions, particularly H^+(aq.) or OH^-(aq.), that can affect the solubility and speciation of contaminants and other soil constituents.

The technology is particularly well suited for removing contaminants from soils of low hydraulic conductivity, e.g. clay and silty clay. Electroosmosis and electromigration are properties that are independent of hydraulic conductivity; these mechanisms can therefore transport water and ions through soils that are practically impermeable to hydraulic transport. Conversely, the electric field will have a negligible impact on water flow through coarse sand where hydraulic resistance is low; highly permeable media are more efficiently cleaned by hydraulic flushing than by electrokinetics, and the electric field will not be able to control hydraulic leakage of contaminants from very permeable media to regions outside the treatment zone.

Soils that may be responsive to in-situ cleanup by electrokinetics have the following characteristics:

- low hydraulic conductivity;
- water-soluble contaminants (poorly soluble contaminants may require addition of reagents to enhance solubility, e.g., carbonate for uranium, or surfactants for free-phase organics);
- relatively low concentrations of ionic materials in the water (essential for electroosmosis; needed for good efficiency of power use for electromigration).

DOE sites and contaminants have been identified in a database from which a candidate list of sites for electrokinetic remediation can be inferred. Characterization of these sites is often incomplete, however, and further evaluation of site geology as well as contaminant distributions and concentrations will often be required. This is especially true for sites having heterogeneous media and/or multiple contaminants.

Soils of low permeability are prevalent at the following DOE locations: Fernald, OH; Kansas City, MO; Mound, OH; Oak Ridge, TN; Portsmouth, OH; and Paducah, KY.

Discrete layers or isolated pockets of low-permeability soil can be found at DOE sites near: Albuquerque, NM; Idaho Falls, ID; Berkeley, CA; West Valley, NY; Livermore, CA; Savannah River (Aiken), SC; Los Alamos, NM; and Pantex (Amarillo), TX.

Notably absent from these lists is the Hanford site near Richland, WA. High transmissivity and permeability characterize the soil and subsurface in all but a few rare (and small) locales of the Hanford site. Soil washing (an ex-situ process) would presumably clean soil faster and more cost effectively than electrokinetics, and without risk of spreading the contamination through hydraulic leakage.

Information is compiled in Table 1 for DOE sites that appear to be good candidates for in-situ electrokinetic remediation. The data include brief descriptions of site geology and hydrology, the types and approximate concentrations of contaminants, the extent of pollution, and telephone numbers of individuals having responsibility for that site. Some sites may have remediation plans already in place, or are under regulatory pressure to finalize their choice of cleanup technology and schedule.

Innovative technologies such as electrokinetics have to be backed by convincing cost and performance data in order to compete effectively in the remediation marketplace. DOE has sponsored a number of technology development projects in electrokinetic remediation, and two different in-situ field demonstrations took place at DOE sites in 1996:

- Paducah, KY, gaseous diffusion plant: LASAGNA™ remediation of TCE plume (Monsanto, DuPont, and General Electric);
- Sandia chemical waste landfill, Albuquerque, NM: chromate plume in arid soil (Sandia National Laboratory).

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