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METALS IN SOILS
1998 TECHNOLOGY STATUS
REPORT

Soil Washing

And the Emerging Technologies of

Phytoremediation

Electrokinetics

In-situ Stabilization/Inplace Inactivation

-FINAL-

December 1998

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Prepared by
The Interstate Technology and Regulatory Cooperation
Work Group
Metals in Soils Work Team
Regulatory Guidance Project

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Established in 1995, the Interstate Technology & Regulatory Council (ITRC) is a state-led, national coalition of personnel from the environmental regulatory agencies of some 40 states and the District of Columbia; three federal agencies; tribes; and public and industry stakeholders. The organization is devoted to reducing barriers to, and speeding interstate deployment of, better, more cost-effective, innovative environmental techniques. ITRC operates as a committee of the Environmental Research Institute of the States (ERIS), a Section 501(c)(3) public charity that supports the Environmental Council of the States (ECOS) through its educational and research activities aimed at improving the environment in the United States and providing a forum for state environmental policy makers. More information about ITRC and its available products and services can be found on the Internet at **www.itrcweb.org**.

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EXECUTIVE SUMMARY

The Interstate Technology Regulatory Cooperation (ITRC) Work Group Metals in Soils Team published a series of technical documents in 1997. The two documents covering soil washing were, **Technical and Regulatory Guidelines for Soil Washing**, and **Fixed Facilities for Soil Washing A Regulatory Analysis**. Three documents on Emerging Technologies for the Remediation of Metals in Soils were published; **Phytoremediation**, **Electrokinetics**, and **In-Situ Stabilization/ Inplace Inactivation**. This report provides the 1998 updates for the five ITRC Metals in Soils Team documents published in 1997.

The *Technical and Regulatory Guidelines for Soil Washing* document was prepared for the regulators, vendors, site managers, and other interested groups. This document was designed to reduce the time required for reviews of permit applications, site investigations and remediation plans, allowing full-scale deployment of soil washing. The critical step in determining if soil washing is applicable is site characterization. If the soil at the site contains a large portion of sand (50-70%), soil washing may be cost competitive.

This report provides current updates of the ongoing projects using soil washing (Doe Run, Missouri, Astabula, Ohio, and Mt. Hope, New Jersey). There has been some progress in deploying new or upgraded soil washing techniques in the past year. The *Cost and Performance Report for Chemical Extraction for Uranium Contaminated Soil* for the Ashtabula site was published by DOE in July 1998. Discussions between the ITRC and California soil washing vendors illustrate how regulatory guidelines can affect the utilization of a technology.

Department of Energy facilities should have an interest in future uses of soil washing technology. The technology holds promise as one of the processes to remediate sites contaminated with radionuclides and/or organic chemicals. Soil washing continues to move at a steady pace in the remediation arena. Soil washing is a viable technology and is cost effective when site conditions are favorable. Data on site preparation, system design, setup cost, system operation and monitoring costs, waste handling, life cycle costs and system demobilization have been developed for many projects.

Phytoremediation is the term applied to biological; chemical and physical processes influenced by plants that aid in the cleanup of contaminated substances. Last year, the team prepared a status report on the phytoremediation of metals in soil. The team also identified both stakeholders and regulatory issues associated with the application of this technology. Phytoremediation is being applied at approximately 40 different sites within the USA to cleanup both soil and groundwater contaminated with metals, radionuclides, petroleum and organic chemicals. Phytoremediation involves a variety of biological mechanisms including direct uptake, release of exudates and metabolites and stimulation of the root-soil environment to enhance bacterial and fungal degradative processes.

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Data on site preparation, system design, setup costs, system operation and monitoring costs, waste handling, life cycle costs and system demobilization will be developed from the projects currently underway. ITRC may expand their activities on phytoremediation to other contaminants (e.g., organics) in soil and groundwater. State project managers need to become more familiar with the requirements of phytoremediation as a technology.

ITRC's Metals In Soils Team also prepared a technology status report on *Electrokinetics* for the *in situ* removal of heavy metals and radionuclides from contaminated soil. The process involves placing a series of electrodes (anodes and cathodes) in the soil. The application of a low voltage direct current creates a voltage gradient in a porous medium. The voltage gradient leads to transport of the contamination ions toward one of the electrodes. The report evaluated the status of the technology. Electrokinetic remediation has been used for a number of bench and pilot-scale tests. There have been problems with the premature precipitation of metal species close to the cathode. A field scale operation of this technology is currently underway at Point Mugu, California. There are studies underway using this technology for non-metal contaminants (organics) such as chlorinated solvents. The Lasagna demonstration in Paducah, Kentucky is testing the use of the technology on organic chemicals.

Electrokinetics is an emerging technology and the efficiency of the process must be evaluated. The cost effectiveness of this technology compared with other remediation technologies must be determined. Data on site preparation, system design, setup costs, system operation and monitoring costs, waste handling, life cycle costs and system demobilization needs to be developed from the projects currently underway. State project managers and other technology users will become more familiar with the requirements of electrokinetics as the technology matures. The ITRC may review the status of this technology once the above data are available.

In Situ stabilization/inplace inactivation is an emerging technology for site stabilization. This technique uses the application of soil amendments to alter the soil contaminant chemistry. Altering the soil chemistry makes the contaminants less soluble, less mobile, and less bioavailable. Inplace inactivation does not affect the total contaminant concentration, but reduces the risk of harm to target organisms (humans, animals, etc.) by reducing biological activity. The technology is being demonstrated/tested for a number of bench and pilot-scale studies around the world. More study is needed on this technology to determine the bioavailability of contaminants after the soil amendments have been applied. The USEPA has created the In-Place Inactivation and Natural Ecological Restoration Technologies (IINERT) Team to study and encourage the development of this technology. One of the sites the IINERT team is studying is the Joplin, Missouri site that is contaminated with lead.

In-Situ Stabilization is an emerging technology that merits continued study. The cost effectiveness of this technology compared with other remediation technologies must be determined. Data on site preparation, system design, setup costs and system operations are not yet available. The life cycle costs, requirements for reapplication of soil amendments and

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determination of bioavailability of the contaminants are of great interest to the ITRC, regulators and the public. The ITRC may review the status of this technology once the above data are available.

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METALS IN SOILS 1998 TECHNOLOGY STATUS REPORT

I. SOIL WASHING

1.0 INTRODUCTION

This section will provide an update to two documents: **Technical and Regulatory Guidelines for Soil Washing** and **Fixed Facilities for Soil Washing - A Regulatory Analysis** written in 1997. Over the past year, the Metals in Soils Team has continued contacting vendors, experts, and regulators and compiled the updated information for this 1998 report. Soil washing is a mature technology showing steady use. It has proven to be an effective technology from a scientific standpoint. Treatment costs for soil washing vary widely.

Soil washing is feasible for the treatment of a wide range of inorganic and organic contaminants including heavy metals, radionuclides, cyanides, polynuclear aromatic compounds, pesticides and PCBs. Soil washing is most appropriate when soils consist of at least 50 to 70 percent sands. Soil washing is not cost effective for soils with fines (silt/clay) content in excess of 30 to 50 percent. Onsite treatment of soils using soil washing requires at least 5000 tons of contaminated soil to be cost effective.

It is cost effective under appropriate site conditions when compared with other remediation options. Soil washing is one of the few permanent treatment alternatives for soils contaminated with metals and radionuclides. This technology shows promise for the removal of radionuclides from soils at Department of Energy sites.

2.0 TECHNOLOGY

The ITRC Metals in Soils Team has maintained contact with vendors and project managers to receive updates on new fixed facility soil washing projects. A new fixed facility, Soil Washing Technologies, Inc., built in San Diego illustrates regulatory differences between Northern and Southern California. Regulations in Southern California encourage the use of soil washing (NOTE: Dates in project descriptions are estimates). The vendors listed in this document are the ones that ITRC is aware of but others may be available.

2.1 Doe Run

The Doe Run Company and Alternative Remedial Technologies, Inc. (ART) have teamed up to remediate a new site, the Lake City Army Ammunition Plant near Kansas City, Missouri. The Lake City Ammunition site consists of more than 2,500 tons of soil contaminated with elements such as uranium, lead, and other heavy metals. Doe Run will use the TERRAMET technology (purchased from Cognis in 1997) to perform acid leaching. The process will implement

equipment that compliments the physical separation technology from ART. The TERRAMET process enables the use of acidic extraction to leach lead and other heavy metals from contaminated soils and to reuse the extracted lead in existing operations. The fines will be treated with a wide arrangement of processes, each of which is tailored for specific soil and contaminant parameters.

The Doe Run plant currently operates as a fixed facility in Boss, Missouri. It can be mobilized for soil washing operations at other sites as needed. The plant will be mobilized and moved to the Lake

City, Missouri site in the spring of 1999.

2.2 Ashtabula

In Ohio, ART and RMI Environmental Services (RMIES) have teamed to construct a new fixed facility to wash uranium from clay soils. The U.S. Department of Energy (DOE) Ashtabula site was part of DOE weapons network for the previous 35 years. The pilot study is complete and construction of a full-scale design has begun at the Ashtabula site. Operation of the facility is anticipated in the spring of 1999.

Initial cleanup will use a carbonate extraction technology to treat 40,000 tons of the contaminated soil. The equipment at the site will continue to operate after the remediation is complete. The equipment will be operated as a fixed facility and treat soils from contaminated sites within a 300-mile radius. The equipment was not designed to be mobile; however, it can be operated as a mobile facility if needed. The operators of the Ashtabula site have the required permits to operate as a mobile or fixed facility. The Cost and Performance Report Chemical Extraction for Uranium Contaminated Soil for the Ashtabula site was published by DOE in July 1998.

The pilot plant results indicate uranium removal efficiencies of up to 94% (with an average of 82% in the pilot project) and an estimated volume reduction of contaminated soils for disposal of 95%. The free release standard of 30 pCi/g was met for most soils treated by the process. The projected total cost of a 10-ton/hr production plant (20,000-ton campaign) is \$565/ton. The projected cost for burial in an approved facility is \$857/ton. Soil remediation using chemical extraction offers an approximate \$300/ton cost advantage for this site. Based upon a 20,000-ton campaign, this system is expected to save DOE \$12.7 million over the life of the project.

2.3 Mt. Hope Rock Products and Recycling

Mt. Hope Rock Products Company is the parent company of Mt. Hope Recycling. Its New Jersey facility can process petroleum-contaminated soil and produce granite and bituminous concrete. The facility can ship materials to and from selected contaminated sites. The rock products and the recycling facilities are located in northern New Jersey at the site of a historic iron ore mine. While secluded, the site is within 20 miles of a major industrial area, with easy access to several major highways. The facility consists of two soil remediation plants, a

crushing plant, six asphalt plants, and a granite quarry. The site is the largest producer of granite, and the highest volume, single location producer of bituminous concrete in the USA. The soil remediation system uses low temperature thermal technology for the treatment of organic contaminants.

Mt. Hope found it difficult to reuse the treated soil because of stringent specifications set by the New Jersey Department of Transportation (DOT). Although the state had approved the soil

treatment operation and soil could be placed back on-site as clean fill, it could not be used in concrete or asphalt products for public road construction. The DOT has since overturned its decision

and is allowing the non hazardous soil to be used on an as needed basis. The new DOT decision allows project managers to use new materials or its equivalent (recycled media), for the construction of a road. Project Managers are not comfortable with the idea of using this material and there is little

widespread support for the use of recycled material in DOT projects. Project managers rarely use remediated soil and Mt. Hope has difficulty getting recycled soil used for road construction projects.

2.4 Soil Wash Technologies Inc. Remediation Center

Since 1994, Soil Wash Technologies Inc. (SWTI) Remediation Center has operated a soil washing fixed facility located in San Diego. SWTI specializes in the remediation, recycling, and transformation of hydrocarbon contaminated soil. The company uses physical separation to divide the soil types and clean the bigger particles with surfactants. For the silt and clay soil fines, SWTI uses a process that removes contaminants from the soil utilizing biodegradable surfactants and colloids. This procedure actually removes contaminants from soil by dissolving or suspending the contaminant within the wash solution.

SWTI operates a fixed facility, but has the capacity to provide mobile service through a scaled down version of the equipment mounted on two trucks. This unit is capable of traveling to any contaminated site accessible by road.

SWTI has been prospering in the San Diego area because regulations restrict the placement of hydrocarbon wastes into landfills. Northern California is a different situation because regulations currently allow these contaminated soils to be placed into the landfills. This regulatory difference explains why the soil washing market in Southern California is more robust. Soil washing companies are virtually non-existent in Northern California.

3.0 STATUS

3.1 New Technologies

The US Navy recently completed a large soil washing project at the Naval Air Station Coronado, California. PCBs were the contaminant of concern for this project. Soil washing was chosen for this project based upon cost and public acceptance. Other technologies considered for the project were incineration, in-situ stabilization and dig and haul.

In the past year, several new soil washing technologies have been deployed to clean soil contaminated with organics. Conor Pacific Environmental Services Inc. (Conor), an Edmonton, Canada based company, has recently purchased a wet oxidation technology from developers in Denmark. Conor will be the sole proprietor and marketer for this technology in the Western Hemisphere. This wet oxidation process is primarily used on polynuclear aromatic contaminants

that are used to treat wood. Wet oxidation is a low temperature process that controls oxygen content, temperature, and pressure to destroy organic molecules. The end product, clean soil, is a result of a combination of physical separation and wet oxidation. The physical separation process separates

and washes the larger particles while the fines are treated and cleaned using wet oxidation. The combination of these two technologies results in a large volume reduction.

Other new soil washing technologies involve recycling of the effluent to keep costs down in the existing soil washing processes. Electrode Assisted Soil Washing (EASW) is a promising technology to wash clays and silts. Boiling is nucleated on the soil particle surface by superheating the soil slurry with an electric current. The EASW technology has not yet completed a field study. Electrokinetics and ion exchange are the newest methods of recirculating water to keep a clean closed loop system (recycling of effluent). The quickest means of cleaning the effluent is through using ion-exchange resins to take metals and unwanted ions out of the water.

4.0 ISSUES

4.1 DOE Directives and Incentives

The Department of Energy (DOE), through the Accelerated Site Technology Demonstration (ASTD) program, will provide capital incentives to companies that develop useful remediation technologies. Soil washing is one of the technologies being used through the ASTD program. Technology proposals from companies are sent into the DOE and distributed to different focus areas. Each company's proposal will explain why its technology is deployable. Once the proposals have been reviewed, DOE will evaluate the technologies and determine the applicability for the technology's deployment at the various DOE focus sites. This program not only assists DOE in the remediation of its sites but also expands the market by fostering new innovative technologies and assists a technology to overcome funding and site obstacles for deployment.

The DOE initially produced a directive that called for a 10% annual reduction of secondary waste regeneration in relation to cleanup and stabilization activities, beginning in FY99.

Because of the difficulty identifying secondary wastes and quantifying the amount of reduction, the directive was changed. The DOE is now focusing on a 10% reduction in primary waste generated from environmental restoration activities.

The DOE is hoping project managers can incorporate some pollution prevention (P2) and waste minimization practices into remediation projects. The reduction of primary waste raises the concern of some contractors. There are contractors that have already built P2 waste minimization practices into their operations. These contractors believe they should not be expected to reduce wastes by another 10%.

The DOE is planning to implement a regulation to reduce cleanup waste in 1999. Details are still being worked out on how to quantify and qualify the reduction in waste in environmental remediation plans for all DOE sites. These regulations will call for a reduction in the allotted amount of soil waste to be placed in landfills (in some cases 90 to 95 percent reduction per project, depending on the type of soil and contamination).

4.2 Regulatory Issues

As of August 24, 1998, the USEPA officially changed the Land Disposal Regulation Universal Treatment Standards for metal-bearing forms of waste including soils. The USEPA changed these standards after some standards were gauged as unachievable while others were termed as "not stringent enough". The revised standards state "if a soil has a greater Toxicity Characteristic (TC) level than Universal Treatment Standard (UTS), the soil is deemed hazardous and must be treated to meet the new UTS level". The new UTS levels may be higher or lower than the previous TC level.

Toxicity Characteristics (TC) for metal hazardous wastes are RCRA listed wastes D004-D011, characteristic mineral processing wastes, or any hazardous waste required to meet the Land Disposal Regulations treatment standard for antimony, barium, beryllium, cadmium, chromium, lead, nickel, selenium, silver thallium vanadium, or zinc.

Table 1 lists the New Universal Treatment Standards affecting Non-Wastewater Metal Wastes. The Universal Treatment Standards will require some soil to be more thoroughly treated before it can be used as clean fill, some soil will require less treatment. The effect of the Universal Treatment Standards on soil washing is unknown at this time.

Other issues involving soil washing technologies are raised when radionuclides are recovered as a secondary waste. At this time, recycling facilities will not take uranium or plutonium enriched soils when there is a radionuclide concentration of > 1% of the total volume. It is difficult and costly to dispose of radionuclide waste.

Table 1

New Universal Treatment Standards Affecting Non-Wastewater Metal Wastes as of August 24, 1998

METAL CONSTITUENT	TC Level mg/L	Existing UTS Level mg/L TCLP	New UTS Level mg/L TCLP
Barium	100	7.6	21
Cadmium	1	0.19	0.11
Chromium	5	0.86	0.6
Lead	5	0.37	0.75
Mercury	0.2	0.025	0.025
Selenium	1	0.16	5.7
Silver	5	0.3	0.14
Antimony		2.1	1.15
Beryllium		0.014	1.22
Nickel		5	11
Thallium		0.078	0.2
Vanadium		0.23	1.6
Zinc		5.3	4.3

5.0 FUTURE DIRECTION

The progress of soil washing has been steady in the past year. Most soil washing technologies are directed at the physical separation of lead, hydrocarbons and organics in contaminated media. There have been advances in the technical and regulatory aspects of soil washing. It is difficult to predict how the innovative technologies (promulgated by the ASTD) and the new USEPA Universal Treatment Standards will affect the market.

The controlling factor in the success of soil washing is proper site assessment. It is not cost effective to use soil washing if the soil contains 30-50% silt and clay. When the site has economic value, and site conditions are favorable, soil washing is a treatment option. The ITRC publication *Technical and Regulatory Guidelines for Soil Washing* detail the site conditions that favor soil washing.

When site conditions do not favor soil washing, the site owner will lobby to cap the site and save money. If the contaminant concentration is high enough to require treatment, a decision is usually made between remediation or Adig and haul@land filling. When landfills can accept the soil, this low cost alternative is usually chosen. The future success of soil washing hinges on the technology being cost competitive.

Soil washing may be more competitive for marginal sites through cost avoidance, process refinement, recycling the effluent and reducing the generation of hazardous wastes.

Regulations changing the landfill requirements for contaminated soil could spur this technology.

The DOE's ASTD program may bring technologies that are more effective to the market, and more importantly, enable new technologies to overcome obstacles to deployment. The incentive to reduce waste by 10% per project should aid soil washing technologies by increasing the number of opportunities available in the field.

Department of Energy facilities should have an interest in future uses of soil washing technology. Soil washing is a promising technology to remediate DOE sites contaminated with radionuclides and/or organic chemicals. Remediation of contaminated sites using soil washing continues at a steady pace. When soil washing is used under proper site conditions it is very cost competitive with other remediation technologies.

II. PHYTOREMEDIATION

1.0 INTRODUCTION

In 1997, the Metals in Soils Team concentrated on several remediation technologies for the treatment of metals contamination in soil. The technologies considered were soil washing, phytoremediation, electrokinetics, and in-situ stabilization. Soil washing is recognized as a mature technology, and the Metals in Soils Team produced a technical/regulatory document for ITRC acceptance. This technical/regulatory document was designed to enable faster; more thorough reviews by state agencies of permit applications, and site investigation and remediation plans for full-scale deployment of soil washing. Use of this document should also foster greater consistency of reviews from state to state.

The other technologies that the Metals In Soils Team reviewed were not as mature, lacking field validation or commercial application. In these cases, the team identified these technologies as "emerging", and wrote technology overview documents to describe their current status.

This document will provide an update to the Emerging Technologies document on phytoremediation. Over the past year, the Metals In Soils Team has continued contacting phytoremediation experts throughout the country and compiling information to update the 1997 document.

2.0 TECHNOLOGY

Soils, aqueous waste streams, and groundwater contaminated with metals pose an environmental and human health hazard. Bioremediation, the use of living organisms to treat contaminants, is increasingly favored by both the public and private sectors as an alternative method for waste treatment due to its low costs and minimal secondary environmental impact.

Phyto- (or green plant based) remediation technology is being developed to improve upon traditional remedial efforts.

Phytoremediation is the treatment of contaminated soils, sediments, and groundwater by plants. The technology involves a variety of biological mechanisms including direct uptake, release of exudates and metabolites and stimulation of the root-soil environment (rhizosphere) to enhance bacterial and fungal degradative processes. Phytoremediation applies to all biological, chemical, and physical processes that are influenced by plants and that aid in the cleanup of contaminated substances.

Phytoremediation is applied in different ways for environmental cleanups, and can be classified into different types: 1) rhizofiltration, a water remediation technique involves the uptake of contaminants by plant roots; 2) phytoextraction, for treatment of organic compounds and metals involves the uptake of the contaminants from the soil into the plant; 3) Phytovolatilization is the process of the plant turning the absorbed contaminant (organic or metal) into gases; 4) phytotransformation, applicable to both soil and water, involves the degradation of contaminants through plant metabolism; 5) phytostabilization uses plants to reduce the mobility and migration potential of contaminants in soil; 6) rhizodegradation, or plant assisted bioremediation, used for water and soil, involves the stimulation of microbial biodegradation through the activities of plants in the root zone.

3.0 STATUS

Phytoremediation should still be considered an emerging technology for the remediation of metals in soils. As of this writing, no field demonstrations have been completed. Research continues to identify hyperaccumulating plants, particularly plants that will uptake metal other than lead. Research is also focusing on the processes that occur in these plants, with the emphasis on maximizing the plants ability to concentrate contaminants.

3.1 Projects

The work at the Magic Marker site in Trenton, NJ continues into its fourth year. Phytotech anticipates that the lead contamination at the site will be below residential standards by the end of the 1998-growing season. The USEPA SITE evaluation should also be completed this year. Phytotech has also reported working with the Department of Defense on several small arms firing ranges. This work is particularly exciting for the Metals In Soil Team, since the proposed work has married two technologies. Components of soil washing have been incorporated in the remediation plan to remove gross particulates from the soil before phytoextraction is used to remove the remaining lead. Work is planned at Fort Dix, NJ in the spring of 1999. Funding for other sites is anticipated with the next federal budget.

Phytotech has several other sites where work is progressing. Recently, work has begun at a Fortune 10 company in North Carolina with low concentrations of uranium in soil. An *ex situ* system has been designed to aggressively mobilize the uranium. Any contaminants not extracted by the plants are collected in a leachate collection system that is then treated by rhizofiltration. A full scale clean up of two sites containing lead in soil has begun this summer in Detroit and Connecticut.

Phytoworks, Inc., of Pennsylvania, has been working with Dr. Richard Meagher at the Genetics Department of the University of Georgia to create genetically engineered plants that thrive in soil with heavy metal concentrations considered toxic by other plants. Their research has revolved around mercury contamination in soil. The plants can extract highly toxic mercury ions, reduce them to relatively harmless elemental mercury, and retain them in aboveground parts of the plant, and/or release elemental mercury vapor at levels well below USEPA standards. It is hypothesized that the same genes, or modified versions, may be used to treat other metals such as arsenic, copper, nickel, cadmium, and cobalt.

Table 2, (Phytoremediation Handbook for Site Managers, Draft, USEPA 1998) shows how phytoremediation technologies are applicable to different types of contaminants. Currently, more work has been completed and released on phytoremediation of non-metals. Remediation of

organic contaminants using phytoremediation technology is the most actively studied among all the contaminants of concern. Table 2 also shows the status of this technology demonstration/research. Table 3, shows 13 Superfund sites using phytoremediation or engaging in a technology demonstration. Table 4, lists the major sites in the United States where phytoremediation is being applied.

Table 2
Phytoremediation Technologies Applicable to Different Types of Contaminants^a

Technology Media	Phytoextraction		Rhizofiltration	Phytostabilization	Rhizodegradation	Phytodegradation	Phytovolatilization
	Soil	Water	Water	Soil	Soil	Soil/Water	Soil/Water
Petroleum hydrocarbons	T				F	G	T
PAHs					F		
PCBs					T		
Pesticides					F	F	T
PCP					G		
Chlorinated Solvents	T				F	G/G	T/T
Munitions					G	G/F	
Metals ^b	F	F	F	F			T (Hg)
Metalloids	T	F (Se)		T			G/F (Se)
Nonmetals	T						
Radionuclides ^c	G	F	F	G			
Nutrients			F ^d		G	F/F	
Surfactants					T		

^a The applicability of a particular method of phytoremediation to each contaminant type has been judged by the current state or stage of the application. This is indicated in the table by the following designations:

T - The application is at the theoretical stage.

G - The application has been researched in the greenhouse or laboratory.

F - The application has been researched using field plots or has been applied in full-scale systems.

^b Reeves and Brooks 1983; Baker 1995, Salt et al. 1995; Nanda Kumar et al. 1995; Cornish et al. 1995.

^c Salt et al. 1995; Nanda Kumar et al. 1995; Cornish et al. 1995.

^d In constructed wetlands. All contaminants can be controlled using vegetative caps. The vegetative cap, riparian corridors, buffer strips, and hydraulic control are not included in the table because they can be considered combinations of the other phytoremediation technologies.

Table 3
Superfund Sites Using Phytoremediation for Remediation or Demonstration

<u>Site Name, State</u>	<u>Date Initiated</u>	<u>Plant</u>	<u>Contaminant/Matrix</u>
ORGANICS			
Former Carswell Air Base, TX	Spring 1996	Eastern Cottonwood Tree	TCE/Groundwater at 4-12 feet
Aberdeen Proving Grounds, MD	Spring 1996	Hybrid Poplar Tree	TCE/Groundwater
Edward Sears Site, NJ	Fall 1996	Hybrid Poplar Tree	TCE/Groundwater at 8 feet
Ammunition Army Depot, IA	Spring 1997	Wetland and Terrestrial Plants	TNT/soil and pond water
Fort Wainwright, AK	Spring 1997	Felt Leaf Pillow	Pesticides/soil and groundwater
Kaufman & Minter, NJ	Spring 1997	Hybrid Poplar Tree	PCE/groundwater
Calhoun Park, SC	Spring 1998	Local Landscaping Plants	PAH/groundwater at 1-4 feet
SRS, CT	Spring 1998	Hybrid Poplar Tree	Mixed solvents/groundwater
Del Monte, HI	Koa Hoale	Pesticides/soil and	
Keyport, WA	Spring 1998	Hybrid Poplar Tree	Chlorinated Solvents
Industrial Excess Landfill, OH	Proposed	Hybrid Poplar Tree	Mixed waste ^a
Lexington County Landfill, SC	Proposed	Hybrid Poplar Tree	Mixed waste
Woodlawn Landfill, MD	Proposed	Hybrid Poplar Tree	Mixed waste

^a Mixed waste refers to municipal waste that contains or may contain hazardous waste.

Table 4
Sites Around the United States Using Phytoremediation

<u>Project ID</u>	<u>Project Name</u>	<u>Principal Investigator</u>	<u>Site Location</u>
1	Chevron Fuel Terminal	Ari M. Ferro (801) 750-0985	Ogden, Utah
2	Crainey Island Fuel Terminal, US Navy	M. K. Banks	Portsmouth, Virginia
3	Milan Army Ammunition Plant (MAAP)	Darlene Bader	Milan, Tennessee
4	Aberdeen Proving Grounds J-Field Toxic Pits Site	Harry Compton (732) 321-6751	Edgewood, Maryland
5	McCormick and Baxter Superfund Site	Ari M. Ferro (801) 750-0985	Portland, Oregon
6	Metal Plating	Mike Blaylock	Findley, Ohio
7	Magic Marker Site	Mike Blaylock (Phytotech)	Trenton, New Jersey
8	Ashtabula, Ohio DOE Facility	Dev Vasudev, B. Ensley (Phytotech)	Ashtabula, Ohio
9	Brookhaven National Laboratory (BNL) OUI		Upton, New York
10	Carswell AFB (former), Fort Worth, Texas	Steve Rock, Greg Harvey (USAF) (937) 255-7716	Fort Worth, Texas
11	Edward Sears Site (Superfund)	George Prince (USEPA-ERT) (732) 321-6649	New Gretna, New Jersey
12	Iowa Army Ammunition Depot	J. Schnoor (319) 335-3333	Middletown, Iowa
13	Fort Wainwright	W. Schnabel	Fort Wainwright, Alaska
14	Calhoun Park	T. Tanner (Regulatory Contact), Steve Rock	Calhoun Park, South Carolina
15	SRS-CN	Ari M. Ferro (801) 750-0985	Unknown
16	Industrial Excess Landfill	(Gerety Miller) Scott Potter, Tim Bend (PRP)	Uniontown, Ohio
17	Lexington County Landfill	Greg Richardson	South Carolina
18	Woodlawn Landfill	(Gerety Miller) Scott Potter, Tim Bend (PRP)	Cecil County, Maryland
19	Northeast Site	M. K. Banks	Unknown
20	Gulfcoast Site	M. K. Banks	Unknown
21	Chevron Site	Lucinda Jackson	Richmond, California
22	Palmerton, PA	S. L. Brown; Rufus Chaney USDA (301) 504-6511	Palmerton, Pennsylvania
23	Upper Silesia, Poland	Anna Chlopecka	Upper Silesia, Poland

24	Dearing, Kansas (Cherokee County)	G. Pierzynski	Dearing, Kansas
25	Bayonne		Bayonne, New Jersey
26	Iowa		Iowa
27	Rothamsted	Alan J. Baker (011) (441) 14282-4626	Rothamsted, United Kingdom
28	Los Banos	Gary Banuelos, USDA	Los Banos, California
29	Unknown	C. R. Cothorn	Pennsylvania, New Jersey
30	Thiokol Corp.	B. Lucas	Unknown
31	Childerburg	Darlene Bader	Childerburg, Alabama
32	Poppy Lane, Alaska		Poppy Lane, Alaska
33	Paper Industry	Eric Carman, Ed Gatliff	Unknown
34	Lakeside Reclamation Landfill	Dr. Louis A. Licht, Ecolotree (319) 358-9753	Beaverton, Oregon
35	City of Woodburn WWTP	Dr. Louis A. Licht, Ecolotree (319) 358-9753	Woodburn, Oregon

4.0 ISSUES

The issues identified in the 1997 document are still pertinent. With each project data set, more information becomes available concerning the fate of chelating agents in the soil. Adequate site characterization and sampling strategies have been developed to demonstrate metal removal efficiency.

5.0 FUTURE DIRECTION

Each of the technology vendors that the team has worked with continues to expand their respective markets. As with the case of other remediation technologies, the regulatory arena is not a driving force. The vendors do claim that this will work to their advantage since phytoremediation has been shown to be cheaper than other remediation technologies. The combining of phytoremediation with other technologies, such as soil washing, will also serve to increase the potential number of sites where phytoremediation is appropriate.

The successful completion of the SITE evaluation, (anticipated late 1998) along with the continued completion of full-scale phytoremediation projects, will greatly enhance the future of phytoremediation. Currently, there is more research and focus being placed on phytoremediation of non-metals. Remediation of organic contaminants using phytoremediation is far more common than the use of phytoremediation for metals remediation. ITRC may expand its phytoremediation focus to include organic contaminants in both soil and groundwater.

The Remediation Technologies Development Forum (RTDF) established the Phytoremediation of Organics Action Team in 1997. Among the goals of this team is validation of phytoremediation technologies and determining the appropriate uses of phytoremediation. The ITRC works closely with RTDF and many members of the Metals in Soil team are members of the RTDF Phytoremediation of Organics Action Team. The CRC Press is now publishing a quarterly International Journal of Phytoremediation devoted to laboratory and field research describing the use of plant systems to remediate contaminated environments.

III. ELECTROKINETICS

1.0 INTRODUCTION

Electrokinetics is a process that involves placing a series of electrodes (anodes and cathodes) in the soil. A low voltage current is applied across the electrodes creating a voltage gradient and a current flow. As a result of the applied electric field, four phenomena occur: electromigration, electro-osmosis, electrophoresis, and pH depression across the electrodes. Electrokinetics is one of the emerging technologies that ITRC's Metals In Soil Team selected to review for its application as an environmental remediation tool for the cleanup of metals in soil. The FY97 report contains the detailed description of this technology and examples of bench and pilot-scale demonstration studies. This report identifies the current status of this technology with information about ongoing/planned demonstrations. The report briefly describes the future direction of activities the ITRC will follow.

2.0 TECHNOLOGY

Electrokinetic soil remediation technology is attractive for *in situ* removal of heavy metals from soil. The process creates little or no environmental impact, requires minimal chemical application and has been demonstrated in lab/bench tests and a few pilot-scale studies. The technology is more cost effective on a per ton or per cubic meter basis than the conventional treatment methods (e.g., soil flushing or acid washing). The process has a high potential for public acceptance because it is visually unobtrusive and is an environmentally benign technology.

The technology needs more full-scale demonstrations and testing to determine its success under a variety of site soil and contaminant conditions. Proper site evaluation is critical for the success of electrokinetics. The transference number (fraction of current carried by the contaminant of concern given all of the other ions in the system) of the contaminant of concern is critical. The transference number should be greater than 0.1% if a site is to be considered for electrokinetic remediation. Data on critical cost elements such as site preparation, system design, setup cost, system operation and monitoring cost, waste handling, life cycle cost, system demobilization, etc. are estimates and have yet to be available from full scale field demonstrations.

The technology has undergone a number of bench and pilot- scale tests. Premature precipitation of metal species close to the cathode has been a bottleneck for this process. Acetic acid depolarization techniques and other depolarization schemes have been developed to circumvent this problem. A field scale demonstration at Point Mugu, California is currently underway (Technology Demonstration Plan Electrokinetic Demonstration at Naval Air Station Point Mugu, California). The site demonstration at Naval Air Weapons Station Point Mugu is jointly funded by the Environmental Security Technology Certification Program (ESTCP) and the Naval Facilities Engineering Command-Southwest Division. The US Army Environmental Center (USACE) and US Army Engineering Waterways Experiment Station (USAEWES) are conducting the demonstration. This is the only field demonstration with a detailed site remediation plan that the ITRC is aware of. A more detailed description of this work plan is described in the Case Study (Section 6.0)

After approximately 3 months of operation (end of May 1998) the USAEC, WES, Lynntech, Inc. and Advancia, Inc. reviewed the field and lab study data for the Point Mugu project. The field data review indicated that the electrokinetic process had no effect in test cell number 1. No pH effect or mobilized metal ions were detected in the Advancia monitoring piezometer wells located within the treatment zone. Also, Lynntech's process control monitoring, which consisted of electrolyte sampling in the anode and cathode wells, piezometer well and soil sampling in a defined process control zone, provided no indication of pH front development or mobilized metal ions. The process control zone is an area between the electrodes to monitor process development. Although pH suppression was achieved in the electrode wells and an electric field had been established in the treatment zone between the electrode arrays as expected, no treatment had occurred.

The review of WES lab results from recently completed analyses of 5 and 10 foot test cells conflicted with data collected from earlier WES treatability studies that were conducted in 10 centimeter (cm) test cells using Point Mugu soil. No significant metal migration was detected in the 5 and 10 foot test cells after 7 months of operation. Significant metals migration had been detected in the earlier 10-cm test cell studies that had been operated for a 2 month period. The differing results had not been observed in earlier laboratory, bench and pilot scale field tests conducted at other sites.

Laboratory tests conducted by Lynntech showed excellent metal movement and extraction over a 6-month period. However, their laboratory results were found to have little correlation with field tests. The operation of the lab test cells were not representative of the design and operation of the system in the field. The Lynntech laboratory tests were operated with uncontrolled electro-osmotic flow, continuous pH controlled acid addition, constant amperage (as opposed to constant voltage in the field), a current density 23 times higher than that initially applied in the field, lower soil pH than planned for field implementation, and a different well design than that implemented in the field.

A detailed review of the field and laboratory data, and a cause and effect analyses are currently in progress. The success of this project will be a major milestone for future full-scale implementation of the technology at other sites. The details of the project are found in the Case Study.

Previously, the Metals In Soil Team reported the status of the Ft. Polk, Louisiana site. Electrokinetics Inc. conducted lab and bench-scale studies to remove lead from the contaminated soil. The full-scale field demonstration has not begun and USEPA is expected to conduct an independent evaluation of the demonstration study through the SITE program.

Other notable studies involving lab/bench/pilot scale studies on metals include:

Electrokinetic demonstration at Sandia National Laboratory, Albuquerque, New Mexico

Conducted by: Sandia National Laboratory

Contaminants: chromium

(More information is found in the 1997 ITRC Publication *Emerging Technologies for the Remediation of Metals in Soils Electrokinetics*)

Electrokinetic demonstration at Radford Army Ammunition Plant, Radford, Virginia.

Conducted by: Lynntech Inc.

Contaminants: lead, zinc, copper, cadmium and chromium

Electrokinetic demonstration at Camp Stanley storage activity, Boerne, Texas

Conducted by: Lynntech inc.

Contaminants: chromium, cadmium, along with organic contaminants.

FINAL -

The Final reports on these projects will provide needed data on the cost and effectiveness of the technology.

3.0 STATUS

Electrokinetic extraction of metals from soils has undergone bench-scale testing and pilot-scale testing. A theoretical model has been developed and its numerical implementation has been completed. The critical factor in evaluating the use of electrokinetics is the transference number for the contaminants of concern. After proper site evaluation, the model gives good predictive results with pilot scale studies. Electrokinetic remediation may offer an alternative at sites contaminated with inorganic species when other remediation options are prohibited by cost or technical requirements.

Several demonstrations are complete on non-metal contaminants - notably on chlorinated solvents. The most notable demonstration is the Lasagna Eletrokinetic Soil Remediation in Paducah, Kentucky. A consortium of industry (Monsanto, DuPont and General Electric) developed the process with support from Lockheed Martin Energy System, US Department of Energy and the USEPA. The contaminant of concern is trichloroethylene. The demonstration was successful and the final full-scale remedial plans are underway for the implementation of the technology through a record of decision. More information on this technology and its application to sites contaminated with inorganics and organics will be available in the future.

The electrokinetics technology is a long-term process when compared to dig and haul. It usually takes several months for complete removal of contaminants. The solubility and desorption of contaminants from the soil matrix may limit the success of the technology.

4.0 ISSUES

The efficiency of the electrokinetic process must be evaluated especially when the target ion concentration is low and the non-target ion concentration (background) is high. Evaluation of the following factors is needed:

The effects of non-conducting pore fluids. While no hard evidence exists, it is suspected that electro-osmosis will transport these due to the bulk movement of water.

The effect of geological heterogeneity or anomalies found at sites, such as submerged foundations, rubble, boulders etc.

The effect of fluctuating water table and perched water conditions.

Effect of large amounts of certain elements (e.g., iron) in the soil.

FINAL -

5.0 FUTURE DIRECTION

It is clear electrokinetics is an emerging technology that requires further studies and full-scale field demonstrations. The overall success of the process under a variety of geological conditions must be determined. More detailed information on cost and duration of the remediation is needed. Data on critical cost elements such as site preparation, system design, setup cost, system operation and monitoring cost, waste handling, life cycle cost, system demobilization, etc. are not available from any successful full scale field demonstration. States should come forward with sites for treatability tests and full-scale demonstrations. As more data become available from these sites, ITRC will develop technical and regulatory guidance documents for states= approval and implementation. Vendors and academic institutions need to develop an understanding of the technology under a variety of geological conditions and engineering parameters.

6.0 CASE STUDY

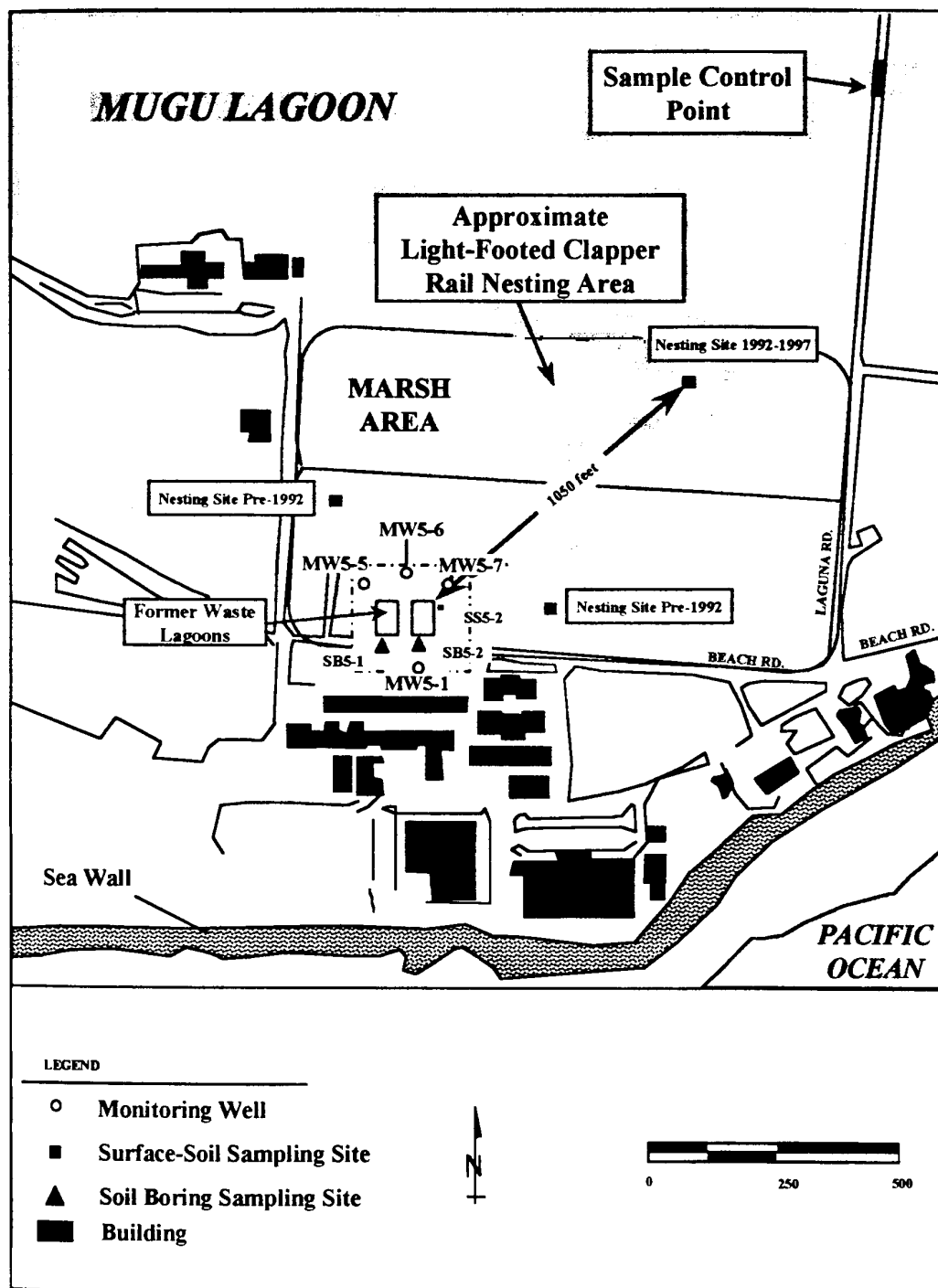
Electrokinetic Demonstration at Naval Air Weapons Station (NAWS) Point Mugu, California

6.1 Introduction

NAWS Point Mugu site is located in Ventura County, California approximately 50 miles northwest of Los Angeles (Figure 1). Military and industrial operations at NAWS Point Mugu have contaminated large tracts of land. The Electrokinetics demonstration is conducted in and around two former wastewater lagoons at NAWS Point Mugu, Site 5 Old Area Shops (Figure 2). The waste pits were in use between 1948-1978 and received a variety of waste materials including an estimated 95 million gallons of plating rinse water, up to 60,000 gallons of waste photo-voltaic fixer solution, and small quantities of organic solvents and rocket fuels. Tidal salt marsh areas and wetlands surround these lagoons (Figure 3). Seawater is extremely electrically conductive and could affect the electrokinetic process. The primary contaminants of concern are chromium, cadmium, silver, nickel and copper. This report briefly describes the objectives of the demonstration and some of the results.



2. Assess the performance of electrokinetic remediation of metal contaminated soil including:



FINAL -

- a)** Determine the ability of the electrokinetics process to reduce metal-contaminant soil to levels below federal regulatory action levels for concentration and toxicity as measured by Toxic Characteristic Leachate Procedure (TCLP), California state Total Threshold Limit Concentration (TTLC), and Soluble Threshold Limit Concentration (STLC) levels.
 - b)** Determine the ability of the electrokinetic process to achieve remediation goals that are based on human health risk and site background levels. The contaminant reductions will be compared to established Modified USEPA Region IX Preliminary Remediation Goals (PRG). These goals are based on human health risk assessments and established site background levels. Lowering the contaminant concentrations in the test cells to target levels protective of human health should result in ground water and surface water levels below current USEPA Marine Ambient Water Quality Criteria (AWQC).
 - c)** Determine the ability to control the effects of the electrokinetic process in both an artificially confined and an unconfined treatment area. For this study an artificially confined treatment area is defined as an area around which a barrier wall has been installed to mitigate the influences of ground water flow and tidal effects on the electrokinetic remediation process. Unconfined treatment is open to groundwater and tidal effects. The electrokinetics process will be monitored to verify control and containment of the electric field effects and control of contaminant migration and emissions. Process dynamics will be assessed using surface water, groundwater, and soil background levels measured prior to and during system operation.
 - d)** Identify off gas emissions resulting from the operation of the electrokinetic process.
 - e)** Monitor and report the effects of the electrokinetics process on organic contaminants in the soil. No effects are anticipated due to the low levels of organic contaminants present in the test areas.
 - f)** Identify biota impacts resulting from the use of the electrokinetics process.
 - g)** Determine if the waste material generated by the electrokinetic process has the potential to be recycled.
 - h)** Identify site characteristics that have an effect on treatment performance. Lynntech Inc. and USAEWES will qualify the assessment, highlighting site conditions with the largest impacts.
- 3.** Quantify the costs associated with the use of electrokinetic technology for the remediation of metal-contaminated soil including:
- a)** Determine the capital cost associated with electrokinetic remediation.

- ### 6.3 Approach

A) The contaminants and the contaminant profiles are different in each test cell.

B) The geologic and hydrogeologic conditions are different for each test cell.

If the TC #1 results do not indicate that positive control of the process is being maintained, then Test Cell #2 (TC #2) will not be placed in operation. When adequate process control has been proven, operation of the electrokinetics system in TC #2 will be initiated. The electrokinetic system will not be turned on in TC #2 until and unless the system in TC #1 has proven to successfully contain horizontal contaminant movement by electrokinetic processes. Figure 4 shows the electrode array in Test Cell 1 and 2.

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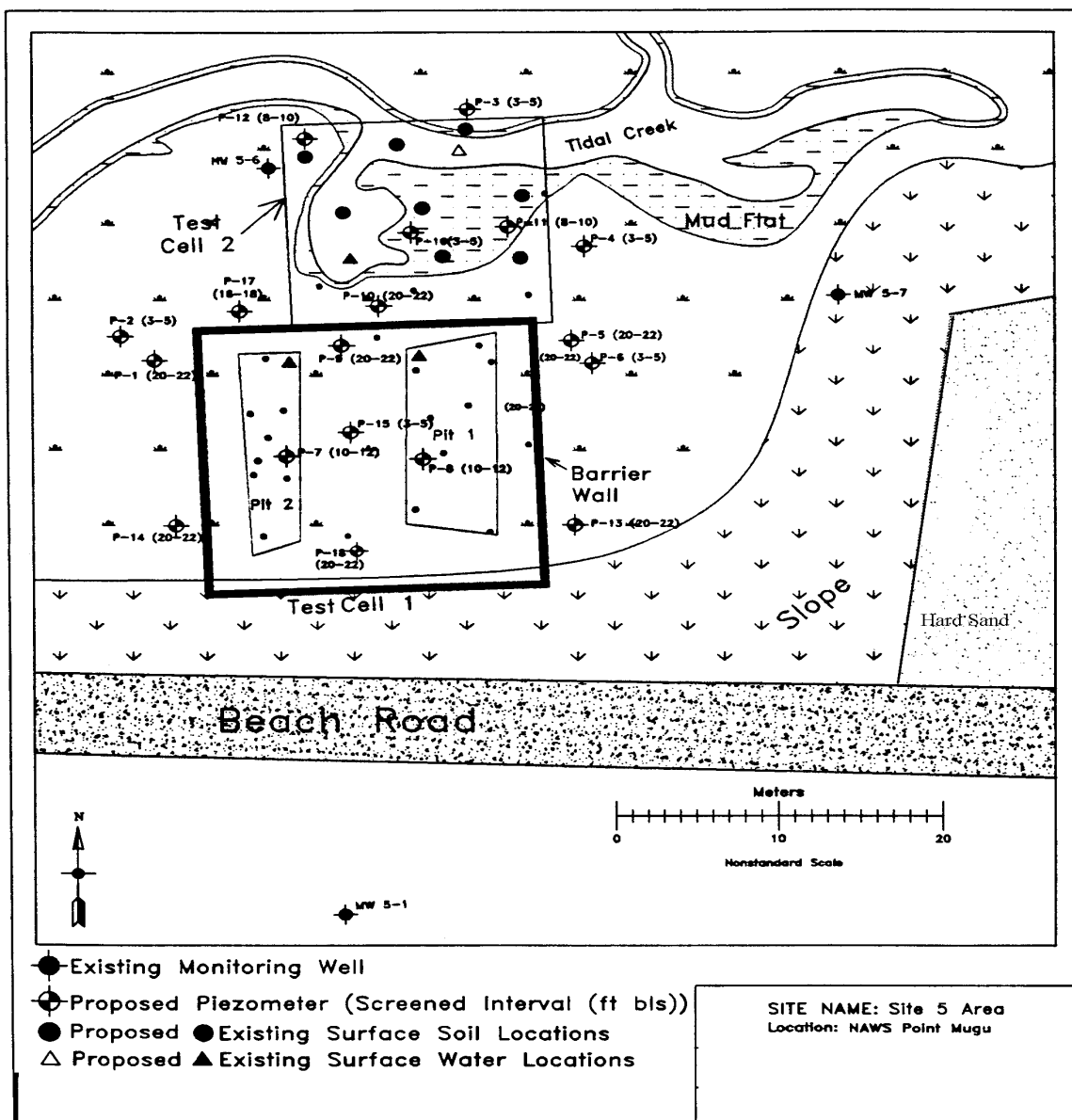
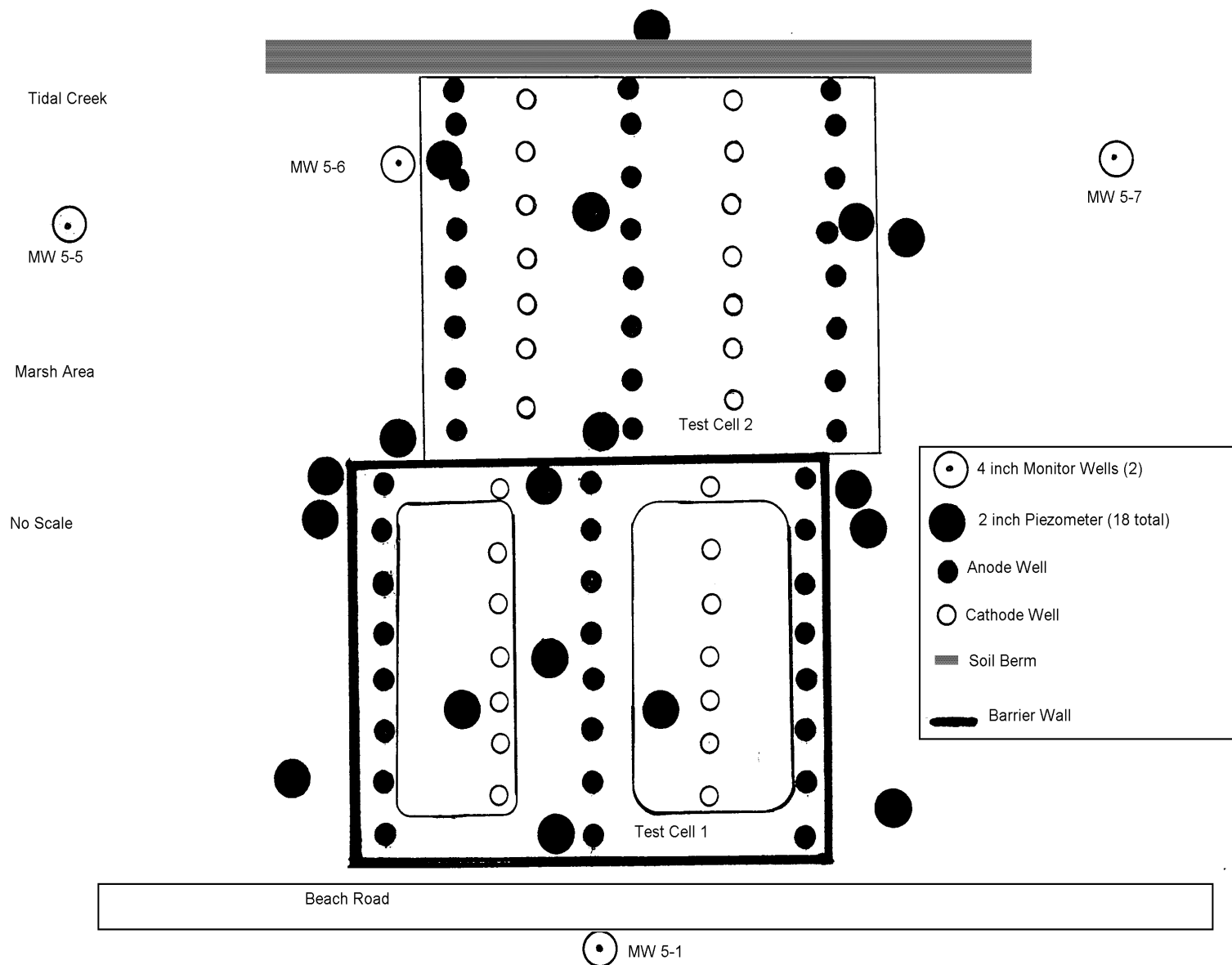


Figure 3. Proposed Sample Locations

**Figure 4. Test Cells for Electrokinetic Demonstration**

The required equipment and structures for the technology demonstration were:

- \$ Installation of non-conductive barrier wall
- \$ Installation of piezometers
- \$ Utility routing and installation
- \$ Installation of temporary test cell enclosures
- \$ Setup and installation of the electrokinetics system.

6.4 Preliminary Test Results

After a few months of operation, the data collected (end of May 1998) indicated the electrokinetic process is having no effect in the treatment zone of Treatment Cell number 1 (TC#1). All data were reviewed to determine why the system in TC#1 produced no results. Following are the highlights of the review:

- \$ Monitoring data of the piezometer wells inside and outside the treatment cell shows no indication of pH change or buildup of mobilized metal ions.

Data received from recently completed analyses of the 5 and 10-foot test cells conflicts with the data received from earlier treatability tests. No metal migration was detected in either test cell. The differing results were not observed in earlier laboratory, bench, and pilot scale field tests conducted at other sites. Lynntech's laboratory test cells results showed excellent metal movement and extraction. However, their lab results were found to have no correlation to the field tests because the operation of these lab test cells was not representative of the design and operation system in the field. Other significant differences between the lab tests and field operations were: the lab test operated with uncontrolled electro osmotic flow, continuous pH control by acid addition, constant amperage (as opposed to constant voltage in the field), lower soil pH than planned for field implementation, and a different well design than the one implemented in the field. A detailed review of the field and lab data, and cause and effect analyses are currently in progress. The success or failure of this project will have a major impact on the future of this technology.

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IV. IN SITU STABILIZATION OF SOILS

1.0 INTRODUCTION

In situ stabilization/inplace inactivation can chemically and physically inactivate soil metals. The solubility and bioavailability of the metals in the soil complex are reduced without the need for excavation and removal of the soil. *In situ* introduction of various chemicals and materials such as phosphates, mineral fertilizers, iron oxyhydroxides, biosolids and limestone can change the molecular species of a metal. Incorporating an inactivation strategy in soil does not actually reduce the pollutant concentration. Health and environmental risks are reduced to acceptable levels by physically and/or chemically manipulating site conditions. The change of species reduces the metals water solubility, bioavailability and potential toxicity to humans and the environment.

Growing a plant cover physically stabilizes the soil and its contaminants in place, which minimizes soil erosion and off-site movement of soil and the metals it contains. Plant roots absorb metals and toxins further preventing off-site migration.

There are areas of concern with this technology including longevity of treatments, assessing bioavailability, restrictions on land use, cost of implementing the technology, mitigating dust from tillage operations, and eliminating any potential environmental effects of the material added. The innovative nature of this technology will continue to raise concerns with stakeholders and regulators.

2.0 TECHNOLOGY

There is a need to determine the bioavailable portion of the contaminants in the soil/waste complex. Risk analysts and assessors can use this information for individual waste sites to more accurately estimate the health risks from soil ingestion. It is difficult to determine the bioavailability of a toxicant because the matrix that binds the toxicant to the soil or components in the soil alters the availability of the toxicant. The discussion that follows is specific to lead.

Animal dosing studies such as swine and rat studies are the preferred method of measuring the bioavailability of metals and toxicants. These dosing studies are expensive, complex and time consuming. The Physiologically Based Extraction Test (PBET) is a quick chemical extraction that is being developed to serve as an alternative to animal studies. An acceptable test that models the bioavailability of metals in soil is needed.

Phosphorous, iron oxyhydroxides, some aluminum silicates, steel shot, biosolids and zeolites have been proposed as an *in situ* alternative to soil removal for lead, cadmium and other heavy

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metal contaminated soils. Using *in situ* stabilization of metals has shown promise in reducing the bioavailability of these metals to the receptor of concern, the human child.

Conversion of cadmium, copper, lead, and zinc into complexes that are much less soluble or insoluble changes the bioavailability of these heavy metals. The long term efficacy, the effect of the chemicals on other metals of concern, the appropriate molar ratio, control of soil pH, methods for estimating reductions in metal bioavailability and the impacts on ecological risk are issues to be resolved with this technology. The total extractable concentration of a contaminant present in the soil is not the best estimator of exposure.

Studies indicate the amount of lead and other heavy metals present in soil and dust (environmental concentrations) may not accurately represent the amount of the contaminant actually available for human exposure. Many researchers have found that high concentrations of lead in the blood levels of humans can be associated with high environmental concentrations of this pollutant. However, other studies have found low concentrations of lead in the blood levels in humans despite similarly high environmental concentrations of this pollutant. A Harvard School of Public Health study found the relationship between the concentration of metals in soil and effective exposure is very complicated. Studies are ongoing to determine the reasons a metal is more or less bioavailable.

3.0 STATUS

State regulators and the ITRC are waiting for a full-scale field test of this technology. There are numerous bench and pilot-scale projects taking place at facilities around the world. These tests should provide the data required for a full-scale test. The USEPA is interested in this technology and is supporting further development.

3.1 In-Place Inactivation and Natural Ecological Restoration Technologies (IINERT)

The Remediation Technologies Development Forum (RTDF) was created by the USEPA in 1992 to foster collaboration between the public and private sectors in developing innovative solutions to mutual hazardous waste problems. The In-Place Inactivation and Natural Ecological Restoration Technologies (IINERT) Soils-Metals Action Team was established in 1995 as one of seven action teams under the RTDF. The IINERT Soils-Metals Action Team includes representatives from industry and government who share an interest in further developing and validating *in situ* techniques as viable technologies for eliminating the hazards of metals in soil and surficial materials.

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Studies are attempting to address the hazards of *in situ* soil stabilization of metals. Items requiring study include understanding the mechanisms of the technology, developing methodologies and testing protocols and improving predictive capabilities.

The mission of the IINERT Team is to develop and demonstrate in-place inactivation and natural ecological restoration technologies that eliminate the risks to human health and the environment of metals/metaloids in soil and to achieve regulatory and public acceptance of these technologies.

3.2 Field Studies

Field studies have been completed or are ongoing which will provide information and data. Numerous groups are conducting the field studies.

The IINERT Team under the USEPA RTDF, the US Department of Agriculture (USDA), and the Missouri Department of Natural Resources (MDNR) are conducting a field study in Joplin, MO. The approximate one-half acre site (roughly one city block) is contaminated with lead from mining and smelting operations. Lead concentrations range from 500 to 6000 mg/Kg. The USEPA has established a goal of treating the soil in place. The USEPA applied agricultural-grade phosphoric acid (1 percent) via three different application methods (i.e. rototilling, pressure injection and surface aeration). Studies are underway to determine the most effective method of application.

The May 1998 RTDF Update stated analysis of grass collected from the Joplin site six months after treatment indicates that in-place lead inactivation technologies are able to reduce plant lead concentrations over control levels by 80 percent. In vitro results of bench-treated soil showed a 78 percent reduction in bioaccessibility. In vivo tests (on swine) were run on both bench and field treated soils. Blood, liver, kidney, and bone lead measurements revealed significant reductions in bioavailability for both field and bench amendments.

Bioavailability studies are being conducted at Trail, British Columbia and the Bunker Hill, Idaho Superfund Site but the results have not been published. Bench-scale studies on stabilizing heavy metals in soil have been conducted in Europe, Taiwan and Russia. The results of these studies may provide useful information for the studies being conducted by the IINERT Team and others.

3.3 In Vitro and In Vivo Studies

The total extractable concentration of a contaminant present in the soil is not the best estimator of exposure since the human digestive system does not have the capacity to extract all of the

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contaminant from a soil matrix. It is difficult to obtain an accurate assessment of the internal dose. There is a lack of scientific information on the degree to which a contaminant will accumulate in bodily fluids and be made available for migration across the membranes within the digestive system.

The Solubility Bioavailability Research Consortium (SBRC) is developing an in vitro test to determine the bioavailability of metals in soil samples. There is a strong desire to develop an in vitro test to determine the bioavailability of metals in soil. The USEPA is part of the SBRC consortium and is attempting to validate the model.

Researchers are developing and testing an in vitro method that relates to in vivo tests on swine and rats. The correlation between in vitro and in vivo results is being evaluated and the method is being refined. Validating an in vitro method would be cost effective. An in vivo study on swine, rats or monkeys costs an order of magnitude more than in vitro test.

4.0 ISSUES

There is a need to establish an in vitro test that is acceptable to the USEPA. Current in vivo tests on swine and rats are costly and time consuming. There are conflicting conclusions about the usefulness of current in vitro tests of bioavailability. The test works well for lead but more data are needed on other metals of concern. The Toxicology Excellence for Risk Assessment (TERA) Group has reviewed the glycine-based gastric test developed by the SBRC. The TERA Group review is available on the Internet (website www.tera.org).

The USEPA has correlated the SBRC in vitro method with the swine in vivo results for lead only. The USEPA is reviewing data and study results in an attempt to quantify the current status of in vitro tests for other metals. It is unlikely that a conclusion will be reached in 1998.

The USEPA is interested in determining how much the bioavailability of lead changes across the Midwest. Since the bioavailability significantly affects cleanup levels, an assessment of how bioavailability changes in different geological settings and across each site is needed. At the Big River site the Integrated Exposure and Uptake Biokinetic (IUBK) model indicates that the concentrations of lead found in residential yards should cause 25-30% of the population to have blood lead levels exceeding 10 mg/deciliter. However, only 17% of the population show elevated blood levels. Based on the large sample size the bioavailability of the soil appears to be affecting the blood levels.

5.0 FUTURE DIRECTION

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In situ stabilization/inplace inactivation shows promise as a remediation technology. The technology has not been widely deployed to date. The regulatory community and the public are not likely to approve widespread use of this technology until some research and development problems are solved. The public and regulatory community must be convinced the technology is mature enough to deploy on a full-scale level.

There is a great deal of ongoing research on this subject around the world. Continued work on the Joplin, MO site provides information on the technology and its development. Work by the IINERT Team on this site by the regulatory, research, and commercial sectors of the remediation may serve as the model for future use of this technology.

In situ stabilization is an emerging technology that merits continued study. The ITRC will closely follow the results of the field studies and reports from the IINERT team. The cost effectiveness of this technology compared with other remediation technologies must be determined. Data on site preparation, system design, setup costs, and system operations are not yet available. The life cycle costs, requirements for reapplication of soil amendments and determination of bioavailability of the contaminants are of great interest to the ITRC, regulators and the public.

APPENDIX A

Acronyms

ACRONYMS

ART	Alternative Remedial Technologies Inc.
ASTD	Accelerated Site Technology Demonstration
DOE	Department of Energy
DOT	Department of Transportation
EASW	Electrode Assisted Soil Washing
ESTCP	Environmental Security Technology Certification Program
IEUBK	Integrated Exposure and Uptake Biokinetic model
IINERT	In-Place Inactivation and Natural Ecological Restoration Technology
TRC	Interstate Technology Regulatory Cooperation
MDNR	Missouri Department of Natural Resources
P2	Pollution Prevention
PBET	Physiologically Based Extraction Test
ppm	parts per million
RMIES	RMI Environmental Services
RTDF	Remediation Technologies Development Forum
SBRC	Solubility Bioavailability Research Consortium
SITE	Superfund Innovative Technology Forum
SWTI	Soil Wash Technologies Inc.
TC	Toxicity Characteristic
TERA	Toxicology Excellence for Risk Assessment
USACE	United States Army Environmental Center
USAEWES	United States Army Engineering Waterways Experiment Station
USDA	United States Department of Agriculture
USEPA	United States Environmental Protection Agency
UTS	Universal Treatment Standards

APPENDIX B

ITRC Contacts, Information and User Survey

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For more Information, feel free to contact the following people:

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