APPLICATION OF THE LASAGNA™ SOIL REMEDIATION TECHNOLOGY AT THE U.S. DOE PADUCAH GASEOUS DIFFUSION PLANT

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ABSTRACT

The Lasagna™ technology uses electro-kinetics to clean up vadose-zone soil contaminated with organics and is especially suited to sites with low-permeability soils. This technology uses direct current that allows faster and more uniform water movement under low-permeability soil conditions than hydraulic methods. Electro-kinetics moves contaminants [e.g., trichloroethylene (TCE), a potential carcinogen] in soil-pore water through treatment zones comprised of iron filings, where the contaminants ultimately break down to basic chemical compounds. After three years of development in the lab, the Lasagna process was field tested at the Paducah Gaseous Diffusion Plant (PGDP), Paducah, Kentucky, in multiple phases.

> Phase I was a trial installation and field test of a 150-square-foot (13.94-square-meter) area selected for a 120-day run in 1995. Approximately 98% of the TCE was removed through this test.
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> Phase IIa was a commercial-scale demonstration test on a 600-ft^2 (55 m^2) site for one year. Completed in July 1997, this test removed 95% of the total volume of TCE down to a depth of 45 ft (13.72 m).
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> Phase IIb, a full-scale application, was the selected remedial alternative in the Record of Decision (ROD) for Solid Waste Management Unit (SWMU) 91. The technology was installed between August and December 1999. Operations began in December 1999. The treatment system was proposed to operate for two years, with an optional third year if the cleanup goal (an average of 5.6 milligrams of TCE per kilogram of soil) is not met in the first two years.

INTRODUCTION

The PGDP, owned by the U.S. Department of Energy (DOE), located in Paducah, Kentucky, has been enriching uranium since the early 1950s. The enrichment process uses several electrical and mechanical components that require periodic cleaning. Until its ban in the late 1980s, TCE was the primary cleaning agent used at the PGDP. Historical documentation indicates that TCE was also used with dry ice at PGDP for testing the integrity of steel cylinders used to store depleted uranium. It is believed that TCE contained in a belowground pit, and used during the integrity testing, contaminated the surrounding soil. This area, known as the Cylinder Drop Test Area, SWMU 91, is located in the northwest quadrant of the PGDP. Solid Waste Management Unit 91 is a 72- x 90-ft (21.95- x 27.43-m) area that encompasses the former drop test pad and the TCE pit used during the cylinder integrity drop tests.

From late 1964 until early 1965, cylinder drop tests were conducted in this area of the PGDP to test the structural integrity of steel cylinders used to store and transport depleted uranium hexafluoride (DUF_6). Before cylinders were tested, they were chilled in a pit containing TCE and dry ice. The cylinders were then lifted with a crane and dropped on a concrete and steel pad to test their integrity under worst-case accident conditions. After testing, the TCE was not removed from the pit and is believed to have eventually leaked into the surrounding soil and shallow groundwater.

In 1979, additional drop tests were initiated to document the structural integrity of these cylinders, entailing additional use of TCE. These tests were initiated in an effort to gain U.S. Department of Transportation approval for shipment of 10-ton (9072-kg) cylinders used to move DUF_6 on public roads.

The soil surrounding the test pad and pit at the PGDP cylinder drop test site is mostly clay with gravel and clay overburden and has been used as a truck road. Over the area of concern, the extent of TCE contamination ranges from 1 mg/kg to 1500 mg/kg. A level of 1500 mg/kg is a strong indication of the presence of dense nonaqueous phase liquid (DNAPL) in the area. Through soil boring samples, it was determined that the concentration of TCE was below detection limits at a depth of 30 to 35 ft (9.14 to 10.67 m).

A research consortium consisting of Monsanto, Dupont, and General Electric was formed to develop the Lasagna treatment technology. The consortium was supported by the DOE [the Office of Environmental Restoration (which became the Office of Site Closure in 1999) and the Office of Science and Technology] and the U.S. Environmental Protection Agency. As part of the DOE support, Lockheed Martin Energy Systems, Inc. (LMES) selected CDM Federal Programs Corporation to implement the consortium design under the LMES management and operations contract.

The consortium focused on cleaning up contaminated low-permeability soils. The direction was to use electro-kinetics to transport contaminants from the soil into treatment zones, where the contaminants would be removed and reduced from soil water by sorption, immobilization, or degradation. This process utilized electrode zones (anode and cathode) to transport water into the treatment zones. In 1994, SWMU 91 was selected for the demonstration of the Lasagna technology. The project began at bench level, but has been scaled to a fully functional system.

In July 1998, DOE issued the *Record of Decision for Remedial Action at Solid Waste Management Unit 91 of Waste Area Group 27 at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*. The ROD designated Lasagna as the selected remedial alternative for reducing the concentration of TCE in SWMU 91 to levels that would decrease the potential risk to groundwater, human health, and the environment at the point of exposure. Bechtel Jacobs Company LLC, acting as DOE's management and integration contractor, selected CDM Federal Programs Corporation to implement the full-scale test of Lasagna in accordance with the ROD. In addition, joint funding for phases I and II was provided by the Subsurface Contaminants Focus Area. The Lasagna technology received a research and development award in 1999 and was highlighted as one of DOE's Rapid Commercialization Initiative technologies.

LASAGNA PROCESS

The Lasagna process involves the combined operation of electro-kinetics with treatment technologies (e.g., activated carbon or iron filings). Electro-kinetics includes electro-osmosis (EO) and electro-migration induced by an applied direct-current electric field. Electro-osmosis has been used for dewatering clays, silts, and fine sands since the 1930s. In recent years, electro-kinetics has received increasing attention as an *in situ* remediation method. The mode of transport for organics is through the EO flow of soil-pore water from anode to cathode. Contaminants that are water-soluble are moved through treatment zones toward the cathode. The treatment zones can either capture the contaminant (e.g., with activated carbon) or chemically react (e.g., with iron filings) with the contaminant, thus removing the contamination from the soil.

Phase I

Phase I of the Lasagna project was an experimental installation and field test of a 150-ft^2 (13.94-m^2) area selected for a 120-day test run. This trial installation was an attempt to prove that contamination in low-permeability soils can be removed via *in situ* remediation.

The primary goal of the Phase I field experiment was to determine whether EO could be used to move TCE from the contaminated clay region into the carbon-filled treatment zones. The demonstration of TCE movement showed that EO could be used as an effective "pump" that, to date, had not been available for low-permeability clay soil such as those present at PGDP. The lack of an effective "pump" is one of the reasons that *in situ* methods available for remediating contaminated clay were limited.

Three important data were used to show effective TCE movement. The first two data were the TCE concentrations present in the clay before and after the field experiments. The third datum was the concentration of TCE in the carbon-filled wick drains, which served as treatment zones in the Phase I field test.

Pre-experiment core samples were collected in May 1994, and post-experiment core samples were collected in May 1995. Figure 1 is a plan view of the Phase I installation and sample collection locations. These samples were analyzed at 1-ft (0.305-m) intervals between 5 ft (1.52 m) and 15 ft (4.57 m) below ground surface. The experimental data, shown in Figure 2, indicated that TCE had been removed from the soil water and transferred to the treatment zones.

Also during Phase I, Monsanto performed lab-based experiments to test the feasibility of using zero-valent iron for treatment zones in the Lasagna process. The test cells were cylindrical columns with feed solution containing TCE.

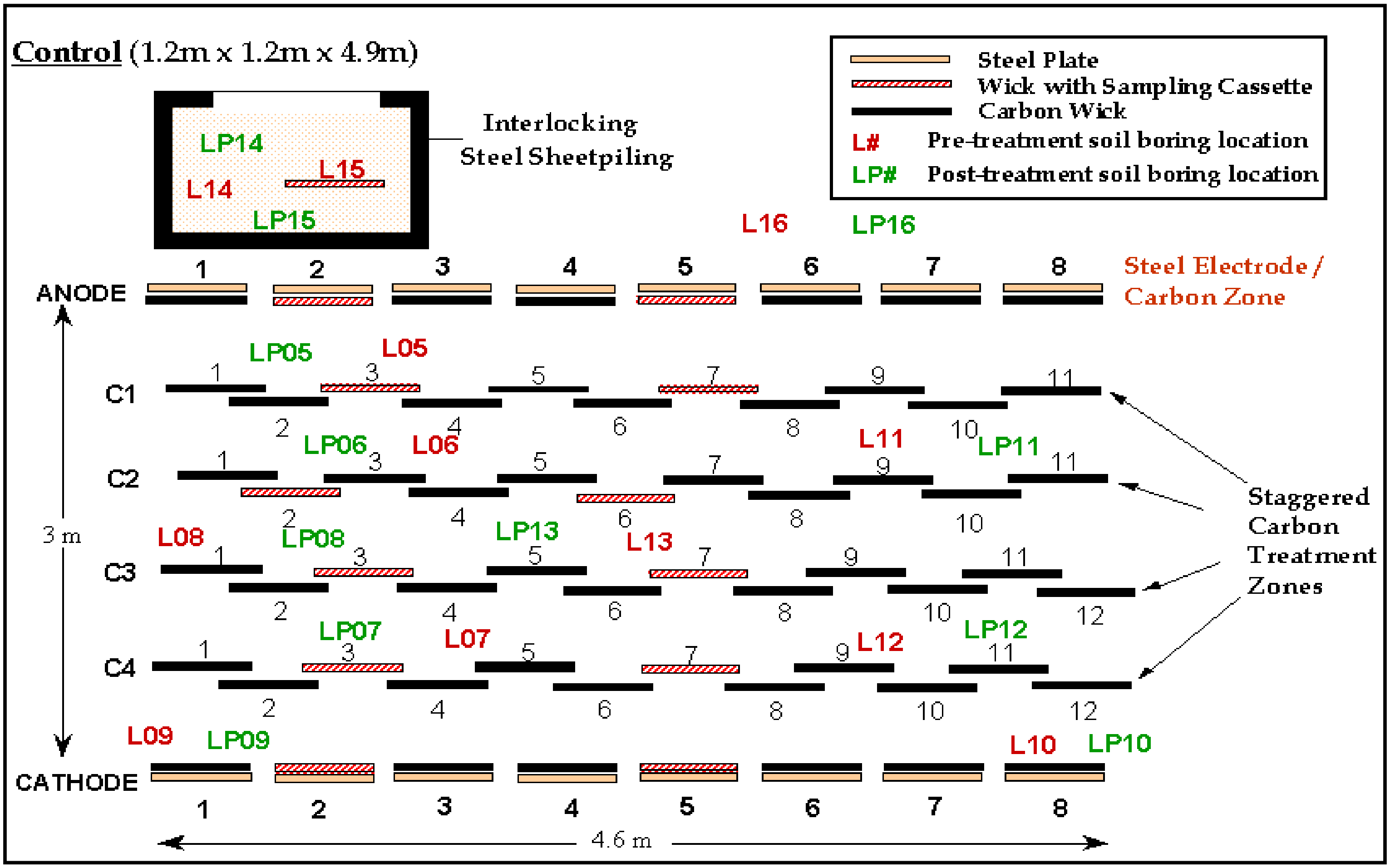

Figure 1. Phase I – Site layout and sampling locations

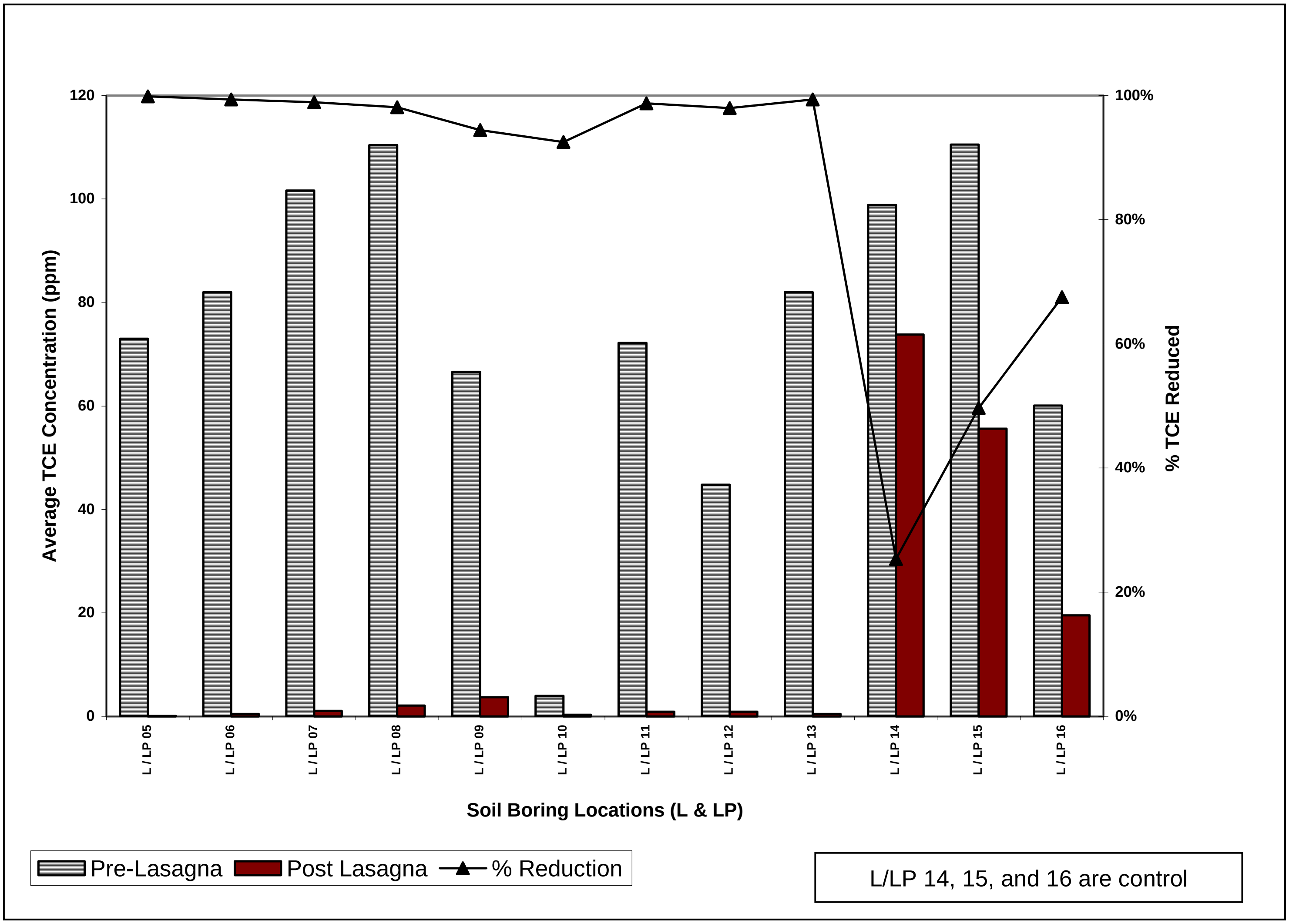

Fig. 2. Phase I – Reduction in TCE

The results from these lab experiments proved that the iron degraded the TCE as expected. The control sample also had 45% of the TCE collected in the effluent. The control sample had a large amount of volatilization due to hydrogen bubbles from the cathode, causing a lower TCE collection percentage. The iron zone sample had only 2% of the TCE collected in the effluent. Phase I concluded that EO was an effective “pump” to move contaminants in soil water and that iron could be used to degrade TCE.

Phase IIa

Phase IIa was approved on January 18, 1996. For this phase, a significantly larger plot was selected, measuring 21 x 30 ft (6.4 x 9.14 m) to a depth of 45 ft (13.72 m). Significant design changes were also implemented in the materials used to construct the electrodes and treatment zones. While Phase I was conducted to demonstrate the removal of TCE from the soil water in the treatment zones, Phase IIa was conducted to demonstrate a full-scale remediation of a section of the SWMU 91 site. Phase IIa used zero-valent iron in treatment zones that degraded TCE to light hydrocarbons and chloride ions. For this phase to be considered successful, the upper 95% confidence level of the mean soil sample population had to be less than 5.6 mg/kg TCE (the action level determined by LMES, DOE, and the Commonwealth of Kentucky, based on groundwater modeling calculations). If these conditions were met, the technology would be judged a viable option for the remediation of the *in situ* contamination at PGDP SWMU 91.

Phase IIa represented a major step toward *in situ* treatment of TCE, also extending the depth of treatment needed for PGDP SWMU 91. Based on the consortium’s Phase I studies, zero-valent iron in the form of iron filings was chosen as the reagent to degrade TCE. With the larger scope of Phase IIa, new challenges had to be addressed. These challenges included the following: designing and installing electrodes and treatment zones to a depth of 45 ft (13.72 m); electrical effects (voltage, current, power, soil conductivity, etc.); long-term operation; and extent of soil cleanup as a function of treatment zone.

Designed for the Lasagna process, a mandrel tube system (20" wide x 2" thick x 55 ft long) (0.51 m wide x 0.05 m thick x 16.76 m long) was used to install electrode and treatment zones. The Phase I mandrel emplacement method was effectively adapted for the Lasagna process. Using a crane and vibratory hammer, the mandrel was driven 45 ft (13.72 m) into the ground. Along the 30-ft (9.14-m) length of SWMU 91, 24 drives were performed, creating a “planar curtain” of electrodes and treatment zones.

Treatment zones (3) measuring from the cathode end of the site were placed at 7 ft, 9 ft, and 14 ft (2.13 m, 2.74 m, and 4.27 m). A breakdown of the distances of the treatment zones is as follows:

- the distance from the cathode to the first treatment zone was 7 ft (2.13 m),
- the distance from the first treatment zone to the second treatment zone was 2 ft (0.61 m),
- the distance from the second treatment zone to the third treatment zone 5 ft (1.52 m), and
- the distance from the third treatment zone to the anode was 7 ft (2.13 m).

Results from both Phase I (pilot and lab experiments) and Phase IIa correlated well. The soil sampling in Phase IIa showed that using only two pore volumes of EO flow between adjacent treatment zones reduces TCE concentrations below 5.6 mg/kg. The sampling locations referenced in Figure 3 are listed as follows:

Sampling Point	Location
2A-01	Between Treatment Zone (TZ) 2 and TZ3
2A-02	Between TZ3 and the anode
2A-03	Between TZ1 and TZ2
2A-04	Between the cathode and TZ1
2A-05	Between the cathode and TZ1

The removal efficiency for one pore volume was 95% and for 2.6 pore volumes, more than 99%. Despite the complications of high DNAPL levels and complex hydrogeology, the Lasagna technology proved its flexibility and efficiency for *in situ* TCE-contaminated remediation. The Lasagna technology met its criterion and was deemed a suitable remediation process for the specific application at Paducah.

Phase IIb

The Lasagna technology was recommended and approved in the ROD as the selected remediation technology for SWMU 91. During Phase IIb, electrodes and treatment zones were installed at SWMU 91 in an area 72 x 90 ft (21.95 x 27.43 m) to a depth of 45 ft (13.72 m). They were installed using a vibrating pile driver and a mast/mandrel assembly supported by a large track hoe. This process introduced two anodes and one common cathode as shown in Figure 4.

Treatment zones contained a mixture of kaolin clay and cast iron particles and were inserted between the anodes and the cathode. It is expected that as soil water flows through the treatment zones, the TCE will degrade to non-toxic end products as the TCE comes in contact with the iron particles. As the process proceeds, the soil water "builds up" at the cathode. This water flows by gravity through polyvinyl chloride (PVC) pipes into a sump located in the ground at the south end of the cathode.

Thermocouples and voltage probes were installed at various locations in the treatment area to monitor the process. A water-level indicator/controller was installed in the sump. If the water level drops below a pre-set point, water will be added to the sump from a 1200-gallon (4542-liter) storage tank located near the sump. If water is not maintained in the sump, there will be no water recycled to the anodes and they will dry out. The lack of water would allow the temperature of the anode to rise and reduce the efficiency of the process. In this case, the anode eventually "burns up." If the power to the site is interrupted, or the level in the sump drops below or rises above pre-set levels, a computer used to capture process data shuts the system down. The computer also activates an automatic dialer so that a project team member may take appropriate action.

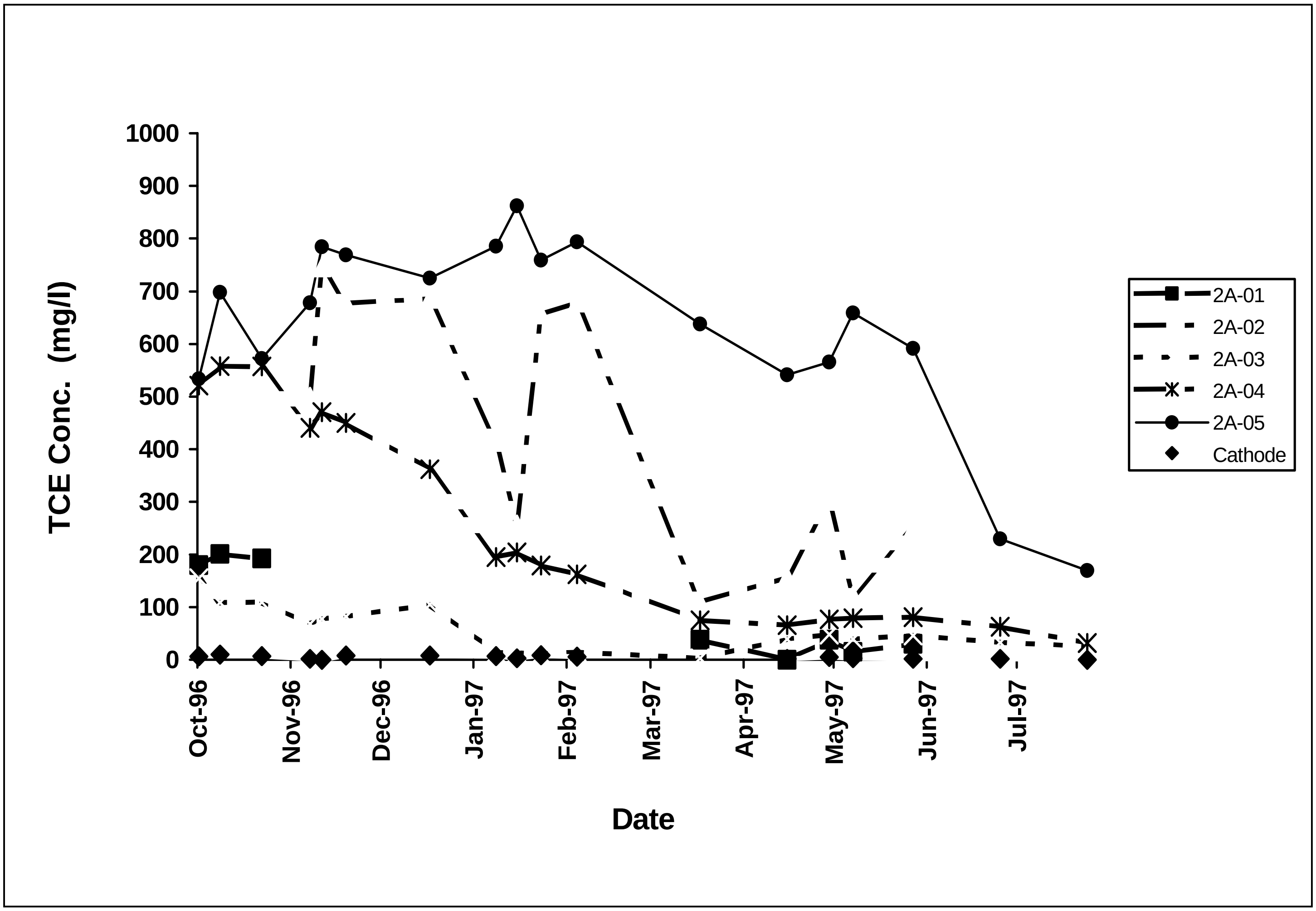

Fig. 3. Lasagna Phase IIa – TCE concentration trends

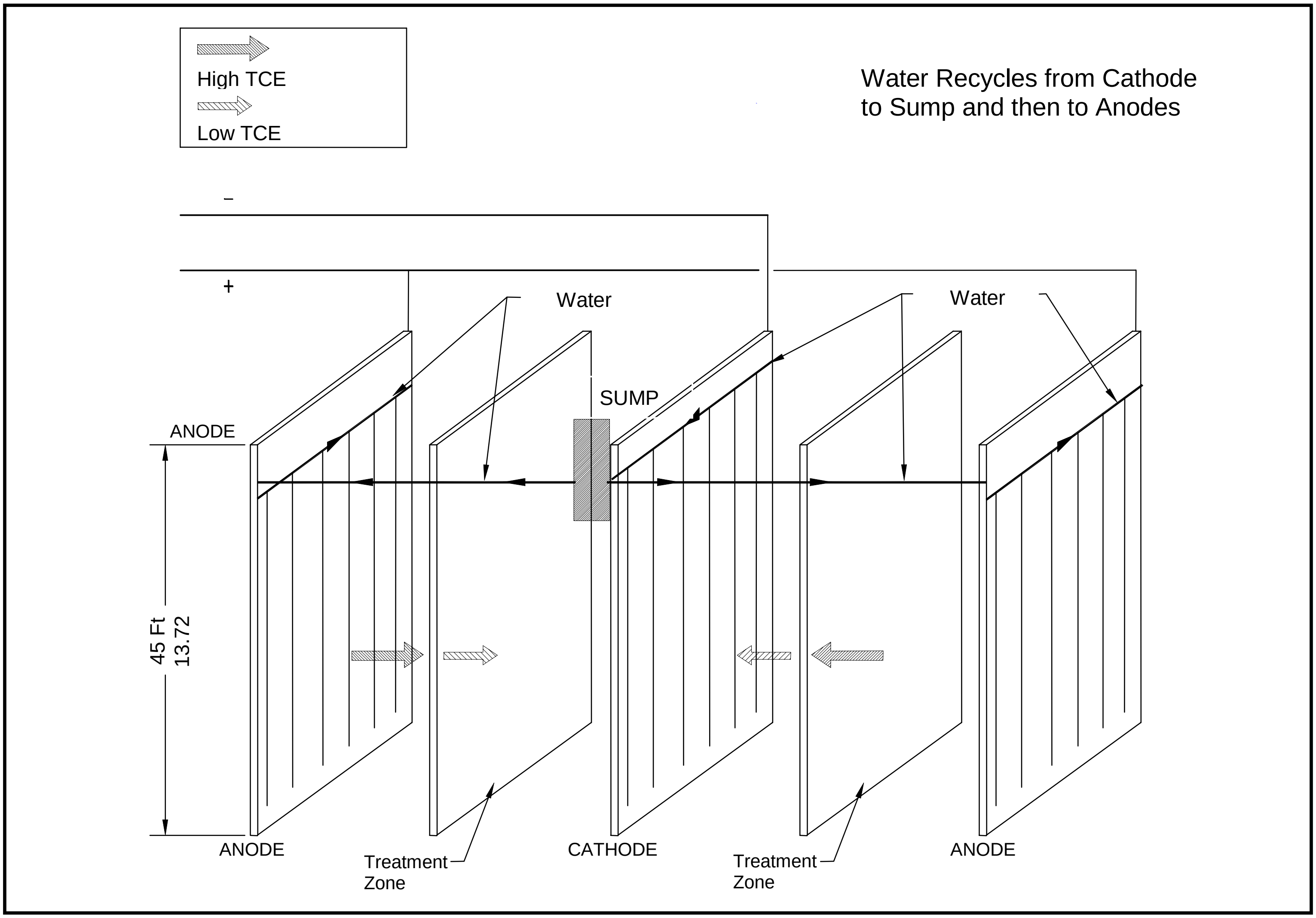

Fig. 4. Phase IIb – Model of Lasagna operation

Construction included removal of the belowground pit materials, installation of electric power, installation of treatment zones, installation of electrode zones, and installation of the water handling system.

During phases I and IIa, the boundaries of the pit (constructed of metal and concrete) were determined. Based on the information collected, the pit was excavated, demolished, removed, and disposed of in accordance with requirements.

Overhead electric utility lines, power transformers, an electrical switching center, and associated equipment were installed to meet the Lasagna power requirements. In addition, to locating power near SWMU 91, electricians cad welded one end of the power supply lines to the electrodes and the other end was connected to the rectifier.

The same mast/mandrel assembly used to install the Phase IIa system was used for insertion of the treatment zones during this phase. The treatment zones were composed of a mixture of 60% by weight iron particles in kaolin clay slurry that was approximately 40% by weight kaolin clay and 60% by weight water. The kaolin clay was added to keep the cast iron particles from settling in the water. The treatment zones were installed by driving a hollow mandrel (as described in Phase IIa) into the ground using a vibrating pile driver.

The treatment zone contained the iron particles and kaolin clay slurry, which were mixed off-site and transported to the Lasagna site in a cement mixer truck. The slurry was transferred from the cement mixer truck into a bucket designed to pour concrete in limited access locations. The bucket was raised with a forklift to the height of the hopper on the mandrel and emptied. The mandrel was vibrated and withdrawn from the ground, leaving the slurry mixture beside the previous one. The process was repeated until all treatment zones were completed.

The amount of insertions depended upon the location of the zone. The more highly contaminated the zone, the closer the treatment zones were to one another. Twenty-seven treatment zones were installed, requiring approximately 1000 drives. During the installation, a hard geologic formation was discovered at a depth of 35 ft (10.67 m) on the southern portion of the 72- x 90-ft (21.95- x 27.43-m) treatment area. In some areas it was not possible to penetrate the formation to the desired 45-ft (13.72-m) depth. In these cases, the treatment zones were installed at the maximum viable depth.

The electrode zones were constructed using a 10"- (25.4-centimeter) wide x 40-ft- (12.19-m) long, ¼"- (0.635-cm) carbon steel plate, a 4"- (10.16-cm) wide section of ¼"- (0.635-cm) wick drain, and granular carbon all wrapped with geotextile. The wick drains were thin, hollow plastic meshes installed in each electrode assembly, allowing the recycled water from the cathode via the sump to keep the steel plate “wetted.” The carbon steel plate had a length of #10 insulated copper wire cad welded to the top of the plate. There were approximately 86 of these assemblies in each anode, and all 86 copper wires were attached to a #00 insulated cable, which was connected to the positive terminal of the rectifier. The 86 copper wires from the center cathode were attached to a second #00 insulated cable, which was connected to the negative terminal of the rectifier.

The electrodes were installed by driving the hollow mandrel into the ground using a vibrating pile driver. Electrodes were assembled at 9" wide x 40 ft long (22.86 cm x 12.19 m), with a 4"-wide x 45-ft-long (10.16-cm x 13.72-m) wick drain and lowered into the hollow mandrel. The mandrel was withdrawn, leaving the electrode zone in the ground. The mandrel was moved next to the previous drive location and the process repeated. Three electrode zones were installed, each 72 ft long (21.95 m). The installation required 260 drives. As with the treatment zones, the hard geological formation was encountered during electrode installation. The installation was handled in the same manner, achieving maximum viable depth. During the removal of the first few electrodes, the amount of iron within the geotextile fabric was reduced. This reduction was necessary to prevent binding inside the mandrel. To counterbalance the reduction in iron material, an additional 4"-wide x 30-ft-long x ¼"-thick (10.16-cm x 9.14-m x 0.635-cm) steel plate was welded to the steel electrode.

After the treatment and electrode zones were installed, a 1-ft-wide x 4-ft-deep (0.305- x 1.22-m) trench was dug above each electrode for the installation of a water management system. The management system included PVC piping, a collection sump, and a 400-gallon (1514-L) storage tank. After a survey of the water management system site, it was determined that the natural site grade was from south to north. The decision was made to relocate the sump from the southwest end to the northwest end of the site. The sump depth was approximately 4 ft (1.22 m), while the recycle lines were 2 ft to 3 ft (0.605 m to 0.914 m) in depth.

In addition to fitting the natural site grade, the northwest site also allowed easier access to refill the makeup water tank. The makeup water tank was fitted with 0.375"- (0.953-cm) braided metal lifting cables, anchored to 4000-pound (1814-kg) concrete barriers. This fitting was performed to prevent buoyancy during heavy rainfall. When the process was energized, water began to flow from the anodes to the cathode.

As part of the system, a perforated PVC pipe was installed above the cathode 4 ft (1.22 m) below the surface in the "red gravel" layer. Tests indicated this red gravel layer was void of TCE contamination. The PVC pipe was installed at a slight grade that allowed the water collected at the cathode to flow into a sump placed into the ground at the south end of the cathode. The water that collected in the sump from the cathode entered additional PVC pipes that carried the recycled water to each anode. The anode pipes were installed on a slight grade, with the high end being at the sump. The top of the geotextile of each component of the anode was placed into this pipe. The geotextile conducted water down to the anodes. The level in the sump was controlled to allow additional water to be added to maintain a level above the discharge point to the anode. The sump maintained a water level to allow the anodes to stay "wet" during the process.

As discussed earlier, the objective of the remedial action was to reduce the soil water TCE contamination to less than 5.6 mg/kg. The system has been operational for one year with minimal support during normal operations. Operations personnel have conducted weekly inspections and routine maintenance at the SWMU 91 site.

Key process parameters have been monitored and operations personnel have been automatically notified if any monitored parameters were measured outside the pre-set operating ranges. Nine temperature and voltage probes have monitored temperature and voltage levels near the electrodes and in the center of the treatment areas. Voltage and current levels have been monitored at the rectifier. Water levels in the sump have been monitored using high and low water-level sensors. Data captured by the sensors and probes have been stored in an on-site personal computer. In addition, junction boxes that monitored voltage and temperature measurements were installed at the fence perimeter.

Operations personnel conducted weekly equipment and system checks of key process variables to record operational data and ensure effective and safe system operation. The weekly site inspections included verifying the operation of the water recycling system and that the sump had sufficient water to keep the anodes "wetted."

CONCLUSION AND SUMMARY

Phases I and IIa have demonstrated that the use of EO is a viable option to move and degrade contaminants in low-permeability soils. The Lasagna technology has demonstrated the capability to effectively remediate TCE *in situ* to a depth of 45 ft (13.72 m). In addition, iron filings have shown to be effective in degrading TCE. The emplacement method has been refined through the experience gained in phases I, IIa, and IIb. The Lasagna remediation technology is an option to other traditional methods to remediate contaminated low-permeability soils. The Phase IIb has been operating for a year. The final remedial action report is expected to be available in 2002.

REFERENCES

1. *Operations and Maintenance Plan for the Lasagna™ Phase IIb In-Situ Remediation of Solid Waste Management Unit 91 at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, DOE/OR/07-1814&D1, U.S. Department of Energy, 1999.

2. HO, SA V., Et Al., *Development of an Integrated In-Situ Remediation Technology*, Monsanto, 1996.

3. *Remedial Design Report-90%, Remedial Action Work Plan, and Construction Quality Control Plan for Remedial Action at Solid Waste Management Unit 91 Waste Area Group 27 at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, DOE/OR/07-1811&AD1, U.S. Department of Energy, 1997.

FOOTNOTES

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