INTERAGENCY DNAPL CONSORTIUM PROJECT

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ABSTRACT

The U.S. Department of Energy Office of Science and Technology (DOE-OST); U.S. Air Force Research Laboratory Air Base and Environmental Technology Division (AFRL/MLQ); U.S. Environmental Protection Agency National Risk Management Research Laboratory (EPA-NRMRL); National Aeronautics and Space Administration Kennedy Space Center (NASA-KSC); and the U.S. Air Force 45th Space Wing (45th Space Wing) have combined resources to form the Interagency Dense Nonaqueous-Phase Liquids (DNAPL) Consortium. From 1998 through 2001, the Interagency DNAPL Consortium (IDC) has been and will be conducting demonstrations of DNAPL remediation and monitoring technologies. The objective of the demonstrations is to evaluate and compare the cost and performance of in situ DNAPL remediation processes through concurrent testing under realistic, field-scale conditions and in similar geologic environments. Technical reports documenting the costs and performance of the demonstrated technologies will be provided to site owners and stakeholders so that informed decisions can be made regarding the economics and performance capabilities of DNAPL remediation technologies. The demonstrations are being conducted at Launch Complex 34 (LC34), Cape Canaveral Air Station (CCAS), Florida.

INTRODUCTION

Recently representatives of several federal agencies with common interests in DNAPL remediation formed the IDC to facilitate evaluation and deployment of mature DNAPL remediation technologies. IDC members include the DOE-OST, AFRL/MLQ, EPA-NRMRL, NASA-KSC, and 45th Space Wing. The Interagency DNAPL Source Remediation Project will compare the cost and performance of three technologies during side-by-side demonstrations at LC34, CCAS, Florida. This 4-year project began in fiscal year (FY) 1998 and will conclude during FY2001. First-year activities included characterization, site selection, technology selection, and design. FY1999 activities consisted of construction and initial operations of two demonstrations. Operation of the third demonstration is scheduled for FY2000. Cost and performance evaluations for the first two demonstrations are to be completed in FY2000; the evaluation of the third demonstration will be completed in FY2001.

THE CONSORTIUM

DNAPLs represent a major environmental problem at many DOE, U.S. Department of Defense (DoD), NASA, and private industry facilities. Chlorinated solvents were used by all of the agencies and released into the environment in massive quantities between 1950 and the early 1980s. The Office of Management and Budget estimates that the Federal Government will spend between $234 and $289 billion on environmental remediation over the next 75 years at sites owned by DoD, DOE, the U.S. Department of the Interior, the U.S. Department of Agriculture, private industry, and NASA (1). Although no specific data is available, we can expect that a significant portion of the budgets will be directed toward DNAPL sites.

The IDC is a strategic alliance of government agencies that seeks to maximize the strengths of each organization while minimizing duplication of effort, leveraging budgets, and expediting technology delivery to contaminated sites. The terms of this alliance are spelled out in a Memorandum of Agreement (MOA) entered into by the participating agencies on April 6, 1999.

In general, the responsibilities of the participating agencies are given below.

- NASA: Host and provide site support for demonstrations, regulatory compliance, utilities, and waste disposal.

- DOE: Contract with technology vendors, provide overall project and on-site coordination, technical evaluations through a Technical Advisory Group (TAG), preliminary site characterization, and cost analysis.

- DoD: Performance evaluation of demonstrated technologies, regulatory and readiness reviews, detailed site characterization.

- EPA: Independent verification of monitoring and performance data.

A core management team (CMT) has been assigned the responsibility of successfully carrying out the goals of the IDC. The CMT is comprised of representatives of the signatories to this MOA and is responsible for the overall funding, coordination, and management of the project. CMT members have accountability to their respective agencies in all matters related to project funding, schedules, and technical progress.

The IDC is supported by a TAG that consists of recognized experts covering the broad range of DNAPL remediation technologies. Each TAG member was selected by, and reports to, the CMT. The TAG provides the CMT with technical advice on technology selection, demonstration planning and execution, site characterization, performance assessment, and data evaluation requirements.

SITE CHARACTERIZATION AND SELECTION

The CMT defined initial site screening criteria (Table I) to ensure the greatest chance for success, both logistically and technically. Additionally, budget considerations required limiting the potential sites to relatively shallow, easily accessible, and well-characterized sites. In total, the project team evaluated approximately 20 sites. Although there was wide disparity among the amount and quality of available data, most sites could be excluded on the basis of undesirable infrastructure or general geologic conditions (e.g., the presence of fractured bedrock, an extensive vadose zone, or fine-grained sediments excluded a site from further consideration). The CMT also drew heavily on the experience of the Strategic Environmental Research and Development Program (SERDP), which had previously conducted an extensive search for a follow-up site to the Hill Air Force Base Demonstration Program. In some instances, the CMT conducted site visits to verify information at promising sites.

TABLE I. SITE SELECTION CRITERIA

Groundwater within 20 feet of ground surface	Permeable (K≈1x10-4 cm/sec) with no cobbles
Saturated conditions	One acre minimum surface area
Lower confining unit with 40 feet of ground surface	Minimum underground utilities
Presence of DNAPL or a mix of organic contaminants	Presence of site infrastructure and logistical support
Unconsolidated	Federal Site
Easy access for equipment and researchers	Moderately well characterized

Based on this preliminary screening, the CMT narrowed its focus to LC34, at CCAS, Florida. Background data provided by NASA-KSC indicated trichlorethylene (TCE) concentrations up to 560,000 parts per billion (ppb) in groundwater. LC34 was a launch site for Saturn I and Saturn IB rockets in the 1960s, and solvents, primarily TCE, were used to clean rocket motors on the launch pad and in the adjacent Engineering Support Building

(ESB). The historical evidence and groundwater contamination levels strongly suggest DNAPL presence and were the basis for identifying LC34 as the primary demonstration site.

The IDC conducted further characterization during February 1998 to confirm and delineate the suspected DNAPL source zone(s). The results indicated a source zone northeast and adjacent to the ESB having the approximate dimensions of 125 feet by 50 feet and containing an estimated mass of 3,370 kilograms (kg) of TCE. TCE contamination appears limited to the upper 40 feet of subsurface where two clay layers apparently have prevented further downward migration. The highest soil concentration detected was 12,345 micrograms per gram (μg/g) at a depth of 37 feet below the edge of the ESB. Additionally, DNAPL also has accumulated near the top of an intermediate fine silt layer at a depth of approximately 25 feet.

The TAG reviewed the results of February sampling during a meeting in April 1998. Based on the recommendations of the TAG, the IDC conducted a final round of confirmatory sampling during June 1998. This sampling program consisted of collecting bulk sediment samples from 35 locations at LC34; 1,000 samples were analyzed for chlorinated organic compounds. The results of this sampling program confirmed that a large DNAPL source zone (approximately 225 feet by 100 feet) was present adjacent to and partially under the ESB. The total mass of TCE in this source zone was estimated to be approximately 34,000 kg with at least 21,000 kg present as separate-phase DNAPL.

The confirmation of a large DNAPL source zone at LC34 allowed the IDC to plan multiple technology demonstrations. The TAG reviewed the results of the June sampling program and agreed that three demonstration cells could be accommodated at the site, each being 50 feet by 75 feet in dimension, with a separation of 10 feet between the cells and each cell underlying the ESB by 15 feet.

TECHNOLOGY EVALUATION AND SELECTION

This project involves technology testing and evaluation under field-scale conditions with the ultimate goal of progressing to full-scale cleanup. Consequently, only relatively mature, commercially available technologies were considered for demonstration. The TAG objectively scored and ranked the applicable technologies and submitted a ranked list to the CMT for final technology selection and procurement. The criteria used for technology selection included:

- the technologies must be at the mature stage of development (e.g., tested at least at field scale);
- all technologies must be commercially available; and
- all technologies must be DNAPL remediation technologies.

The main technology types recommended by the TAG for consideration were in situ flushing, in situ oxidation, and thermal. In all, 20 technology vendors responded to an announcement published in the *Commerce Business Daily*. Through a multicriteria analysis, five vendors were selected to provide preliminary designs to be completed by October 1998. The TAG performed a thorough review of these designs and prioritized them for demonstration. The IDC reviewed this recommendation and selected three technologies: steam heating (Integrated Water Technologies), permanganate injection (IT Corporation), and Six-Phase Heating™ (SPH) (Current Environmental Solutions).

The SPH technology removes contaminants from soil and groundwater by passing an electrical current through the soil matrix. The passage of current generates heat due to electrical resistance within the soil. Heat is generated throughout the soil in the remediation area, and the temperature of the soil is increased to the boiling point of water. Soil moisture becomes steam that is captured by vapor recovery wells for removal. Soil contaminants are vaporized concurrently and are captured for ex situ treatment.

In situ oxidation using potassium permanganate is a potentially fast and low cost solution for the destruction of chlorinated ethylenes (TCE, perchloroethylene (PCE), etc.), BTEX (benzene, toluene, ethylbenzene, and xylene), and simple polycyclic aromatic hydrocarbons. In particular, potassium permanganate reacts effectively with the double bonds in chlorinated ethylenes such as TCE, PCE, dichloroethylene isomers, and vinyl chloride. It is effective for the remediation of DNAPL and adsorbed-phase and dissolved-phase contaminants and produces innocuous breakdown products such as carbon dioxide, chloride ions, and manganese dioxide. The permanganate solution typically is introduced into the contamination zone via injection wells at aqueous concentrations of from 1% to 3%.

Thermal remediation by steam injection and recovery uses a process called dynamic underground stripping to recover volatile contaminants for ex situ treatment and hydrous pyrolysis/oxidation that causes in situ destruction of some of the contaminants. The dynamic underground stripping system uses boilers to generate steam that is then pumped into injection wells that surround the contaminants. The steam front volatilizes and mobilizes the contaminants as it pushes the resulting steam front toward a central network of extraction wells where it is vacuumed to the surface. In some cases, direct electrical heating of clays and fine-grained sediments can be used to cause trapped water and contaminants not readily available to the steam to vaporize and force them into steam zones where vacuum extraction then removes them.

COST AND PERFORMANCE EVALUATION

To develop a meaningful comparison of the demonstrated technologies, a detailed predemonstration evaluation of each treatment cell is conducted. The findings of these assessments are then compared to post-demonstration conditions to determine the overall performance of the technologies. Costs and operating parameters are regularly reported during the course of the demonstrations. The objectives of the performance and cost assessment are to:

- verify the mass of TCE destroyed or removed with the performance targets being 90% mass reduction and residual 3 ppb in groundwater;
- verify that TCE is not migrating to surrounding regions;
- evaluate the soil and groundwater quality before and after demonstrations;
- verify there are no cross-influences between treatment plots; and
- verify the system operating requirements and costs.

Battelle and EPA-NRMRL collaboratively developed the quality assurance project plans for the demonstrations. Battelle is responsible for defining and collecting the process monitoring data that is not directly related to performance assessment (e.g., monitoring between test cells to determine the impact, if any, of the demonstrations beyond their assigned areas). EPA-NRMRL, using their established protocol developed for technology evaluation, defines and oversees the collection, verification, and validation of performance assessment data. In addition, each individual remediation contractor installs and operates performance-monitoring systems as appropriate.

Technology vendors are required to submit detailed demonstration cost reports during the duration of the project. Costs are broken down into detailed capital and annual operating and maintenance costs at the fourth level according to the *Guide to Documenting Cost and Performance for Remediation Projects* (2). Costs are reported following the *Interagency Hazardous, Toxic, and Radioactive Waste Work Breakdown Structure* (3). All associated technology demonstration costs including bidding, design, permitting, construction, mobilization, demobilization, operations and maintenance, monitoring, disposal, reporting, and project management are documented, broken down, and reported. These requirements are also binding on all lower level subcontracts.

The vendors are also required to assist the IDC with the preparation of a scalable cost and performance model. The models are refined during the demonstration and then finalized after the demonstration is complete. The models must calculate unit cost estimates for a given level of performance. The cost and performance models must be able to account for uncertainty factors such as site size, spill size, geological conditions, and performance impacts on remediation times. These cost and performance models will allow the participating agencies to better estimate the cost for employing the technologies at other DNAPL sites.

Predemonstration sampling was performed in June 1999 for the permanganate oxidation and SPH cells; 12 cores were collected from each of the cells with the coring locations systematically determined using an unaligned systematic sampling design. Core was sampled at every 2-foot interval and analyzed for volatile organic compounds using a modified EPA Method 8021. Groundwater samples were also collected from two well clusters inside each treatment cell.

The results of the predemonstration sampling showed significantly higher amounts of TCE present in both treatment cells. Total TCE mass in the permanganate oxidation cell was estimated to be 6,122 kg with 5,039 kg present as DNAPL. Total TCE mass in the SPH cell was estimated to be 11,313 kg with 10,490 kg present as DNAPL.

INSTALLATION AND OPERATIONS TO DATE

SPH operations were initiated on August 30, 1999. The system operated until mid-October, when the process was well underway. Heating had started volatilizing DNAPL, and TCE vapors had been lifted almost to the top of the water table. These TCE vapors were about to break through the groundwater table, move into the vadose zone, and be captured by the extraction wells. In short, TCE removal was proceeding according to the design plan.

In mid-September 1999, Hurricane Floyd passed close to the Florida peninsula, causing heavy precipitation and raising the groundwater table under the SPH demonstration cell from 8 feet below ground surface (bgs) to less than 1 foot bgs. This high level of groundwater rendered the vertical vapor-extraction wells in the SPH plot inoperative. Current Environmental Solutions installed a surface plenum and horizontal vapor extraction system to overcome this problem. Then, in mid-October 1999, Hurricane Irene damaged the SPH transformer, and over 6-inches of rain fell on the site. Because the SPH cell occupies a topographic low spot, surface runoff from Hurricane Irene flushed through the cell and washed near-surface groundwater from beneath the cell and toward an adjacent drainage ditch. Subsequent sampling of the drainage ditch revealed elevated concentrations of TCE.

Because near-surface groundwater from beneath the SPH cell contained elevated levels of TCE from the heating process, this unique scenario of events represents a plausible transportation mechanism for the movement of dissolved-phase TCE from within the SPH cell to the immediately adjacent ditch. It is difficult to assess how much TCE mass may have been moved from the SPH cell or the significance of the migration as it is unclear how impacted the ditch area was prior to the start of the SPH demonstration. However, it is important to note that elevated levels of TCE in groundwater were widely present at LC34 prior to the start of SPH operations.

The 45th Space Wing Regulatory Partnering Team reviewed the site conditions after the presence of TCE in the drainage ditch was discovered. Based on that review, Current Environmental Solutions installed additional pressure, temperature, and vacuum monitoring points in and around the SPH treatment cell. Operations were restarted in mid-December 1999, and significant TCE recovery was noted in mid-January 2000.

An initial permanganate injection was performed at one location during the period of August 12 through August 14, 1999. The permanganate injection was conducted concurrently with the injection of a conservative tracer, sodium fluoride, to assist in verifying the design parameters for the full cell injection. Approximately 1,375 pounds of permanganate were injected over a 10-foot interval in the one injection point. The results of the test determined that the injection method, without groundwater pumping, was adequate to transport the injected fluid over a radius of influence greater than or equal to the design basis. Other design parameters, such as flow rate and pressure, were confirmed by this test.

Full cell-wide injection was initiated on September 8, 1999, and completed on October 29, 1999; 32 days of injection were completed during the first injection phase. Injection was completed at 11 locations from a depth of 15 to 45 feet below grade; a total of 64,100 pounds of permanganate were injected. The amount of permanganate injected in Zone A, the upper sand unit, was 13,361 pounds. The amount injected in Zone B, the middle fine-grained unit, was 18,661 pounds. Zone C, the lower sand unit, received 30,654 pounds. The concentration of permanganate injected ranged from 0.2% to 3%, and the flow rates per injection point ranged from 0.8 to 5.8 gallons per minute (gpm) at injection wellhead pressures of 15 to 45 pounds per square inch gauge (psig).

A second injection phase was initiated on November 17, 1999, and completed on November 24, 1999. The primary goal of this phase was to inject within areas unaffected by the first injection. Eight days of injection were completed during the second phase, and injection was completed at 4 to 11 locations, depending upon the injection depth, which ranged from 15 to 29 feet below grade. The second injection included the upper sand unit and the upper 4 feet of the middle fine-grained unit. A total of 13,825 pounds of permanganate were injected during the second phase: 10,854 pounds in Zone A and 2,971 pounds in Zone B. Concentrations injected during this phase ranged from 1.9% to 2.8%. The flow rates per point ranged from 0.1 to 6.1 gpm at injection wellhead pressures of 36 to 55 psig.

At the completion of the first injection (week 7), groundwater samples were collected for laboratory analysis from each of the zones. Color was also used to assist in evaluating the effects of the permanganate injection. In Zone A six wells showed > 99% reduction in TCE. The groundwater from all of these wells exhibited a purple color. An additional well indicated a purple color but only showed a 19% TCE reduction. This well is located in the northeast section of the cell, which appears to contain more mass than calculated and which did not show as much TCE reduction. The results from Zone B indicate that five wells showed > 99% TCE reduction. The northeast corner of the cell and the portion along and under the ESB indicate that additional treatment is needed in these areas. The results from Zone C showed two wells with > 99% TCE reduction, which also showed a purple color. All wells within the cell showed some TCE reduction except in the northeast corner.

No analytical data is available to evaluate the effectiveness of the second injection. Visual observation of color in the cell monitoring wells was performed 1 week after this injection. The color data from Zone A indicates that either purple or brown color was observed in almost every well within Zone A. Groundwater and soil analytical data will be needed to confirm if the treatment is complete. The results from Zone B show an increase in brown color across the cell from the first injection. The edges of the cell and area around ML-1 may still need some additional treatment. No injection was performed in the lower sand unit; therefore, based upon the first injection results, additional treatment is still needed. The changes in color indicate that the injected permanganate continues to be mobile and reactive; consequently, it is difficult to determine the amount of TCE mass reduction without additional soil sampling.

REFERENCES

1. *Soil and Groundwater*, August/September 1997.
2. U.S. EPA, *Guide to Documenting Cost and Performance for Remediation Projects*, EPA-542-B-95-002, 1995.
3. U.S. Army Corps of Engineers, U.S. Navy, U.S. Air Force, U.S. EPA, and U.S. DOE, *Interagency Hazardous, Toxic, and Radioactive Waste Work Breakdown Structure*, 1996.

ACKNOWLEDGMENT

Work was conducted through the DOE-OST under DOE Contract Number DE-AC22-96EW96405.