IN-SITU THERMAL REMEDIATION OF TRICHLOROETHENE USING SIX-PHASE HEATING AT THE PADUCAH GASEOUS DIFFUSION PLANT, PADUCAH, KENTUCKY

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ABSTRACT

The Six-Phase Heating (SPH) treatability study was conducted under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). This treatability study has provided quantitative treatment and cost data to assess the feasibility of deploying electrical resistance heating technology as a part of the remedial action for the Groundwater Operable Unit at the Paducah Gaseous Diffusion Plant (PGDP). Operation of the system began on February 14, 2003 and the system was shut down September 6, 2003.

The SPH treatability study was implemented at the U.S. Department of Energy's PGDP located in Paducah, Kentucky. The primary objective of the treatability study was to demonstrate the implementation of this technology for the remediation of trichloroethene (TCE) and associated volatile organic compounds (VOC) in the unsaturated and saturated zones of the Upper Continental Recharge System (UCRS) and the groundwater of the Regional Gravel Aquifer (RGA). The presence of dense non-aqueous phase liquids in the groundwater are believed to be one of the major sources of TCE feeding the contaminated plume located beneath the site.

Execution of the SPH treatability study included the installation and operation of one SPH array. The single array consists of six power electrodes, a center neutral electrode, a power control unit, a steam and contaminant vapor recovery (VR) system, pressure and temperature monitoring systems, and contaminant vapor and water treatment systems. During operation, as the electrodes heat the subsurface, volatile organics and groundwater are converted to a vapor phase. The vapors migrate upward to be recovered by VR wells and steam vents constructed within the electrode borings and by the steam vents located in vacuum monitoring piezometer borings. Captured vapors and steam are evacuated to the surface where the steam is condensed and the vapors are adsorbed onto granulated carbon filters.

The removal of TCE in the groundwater of the RGA was assessed by a comparison of baseline groundwater sample results to post treatment groundwater sampling results. The post treatment groundwater sample results as compared to the baseline groundwater sample results indicate a 99 percent reduction in TCE concentration in groundwater.

The removal of TCE in the UCRS soil was also assessed by a comparison of the baseline soil sample results to the post treatment soil sample results. This comparison indicates an average TCE concentration reduction in soil of 98 percent.

INTRODUCTION

In August 1988, volatile organic compounds (VOC) and radionuclides were detected in residential wells near the U.S. Department of Energy's (DOE) Paducah Gaseous Diffusion Plant (PGDP). Between 1988 and the present, numerous groundwater investigations have been conducted to identify probable source areas. To address these source areas, a Groundwater Operable Unit (GWOU) Feasibility Study (FS) was issued August 2001 (DOE 2001b). The GWOU FS proposed that the effectiveness of certain treatment technologies being considered for full-scale use be evaluated (based on applicability to specific site conditions).

ENVIRONMENTAL SETTING

This Six-Phase Heating (SPH) treatability study was conducted at the southeast corner of the C-400 building (Figure 1) at the PGDP, which is a DOE leased uranium enrichment facility located west of Paducah, Kentucky. The primary activities associated with the C-400 building are cleaning machinery parts, disassembling and testing of cascade components, and laundering plant clothes. The building also has housed various other activities, including recovery of precious metals and enrichment of radionuclides.

The PGDP overlies the southern extent of an ancestral channel of the Tennessee River. Site stratigraphy is divided into three hydrogeologic units. In descending order, they are: the Upper Continental Recharge System (UCRS), the Regional Gravel Aquifer (RGA) both of Tertiary age, and the Upper Cretaceous McNairy (McNairy) Formation.

The UCRS consists primarily of sandy silts and clays, plus occasional gravel lenses and is often saturated with groundwater below 13 meters (m) [39 feet (ft)] below ground surface (bgs). Groundwater flows nearly vertically downward through the UCRS and serves as a recharge system for the underlying RGA. The RGA consists of sand and gravel with clay lenses. The top of the RGA is represented by a potentiometric surface at a depth of about 17 m (56 ft) bgs. The RGA is saturated throughout and is slightly artesian across the site. Hydraulic gradients beneath the site direct groundwater flow in the RGA to the north towards the Ohio River. Immediately underlying the RGA is the McNairy Formation of the Upper Cretaceous age. The top of the McNairy is about 28 m (91 ft) bgs. The upper McNairy consists of interbedded silts, sands and clay. The middle McNairy is a silty clay, while the lower portion is primarily sand with some silts and clay.

Previous site investigations have led to the identification of three groundwater contaminant plumes resulting from past activities at the PGDP. All three plumes are located in the RGA. Two of these plumes, currently identified as the Northwest Plume and the Northeast Plume, appear to have received considerable contaminant loading from contaminated areas surrounding the C-400 building.

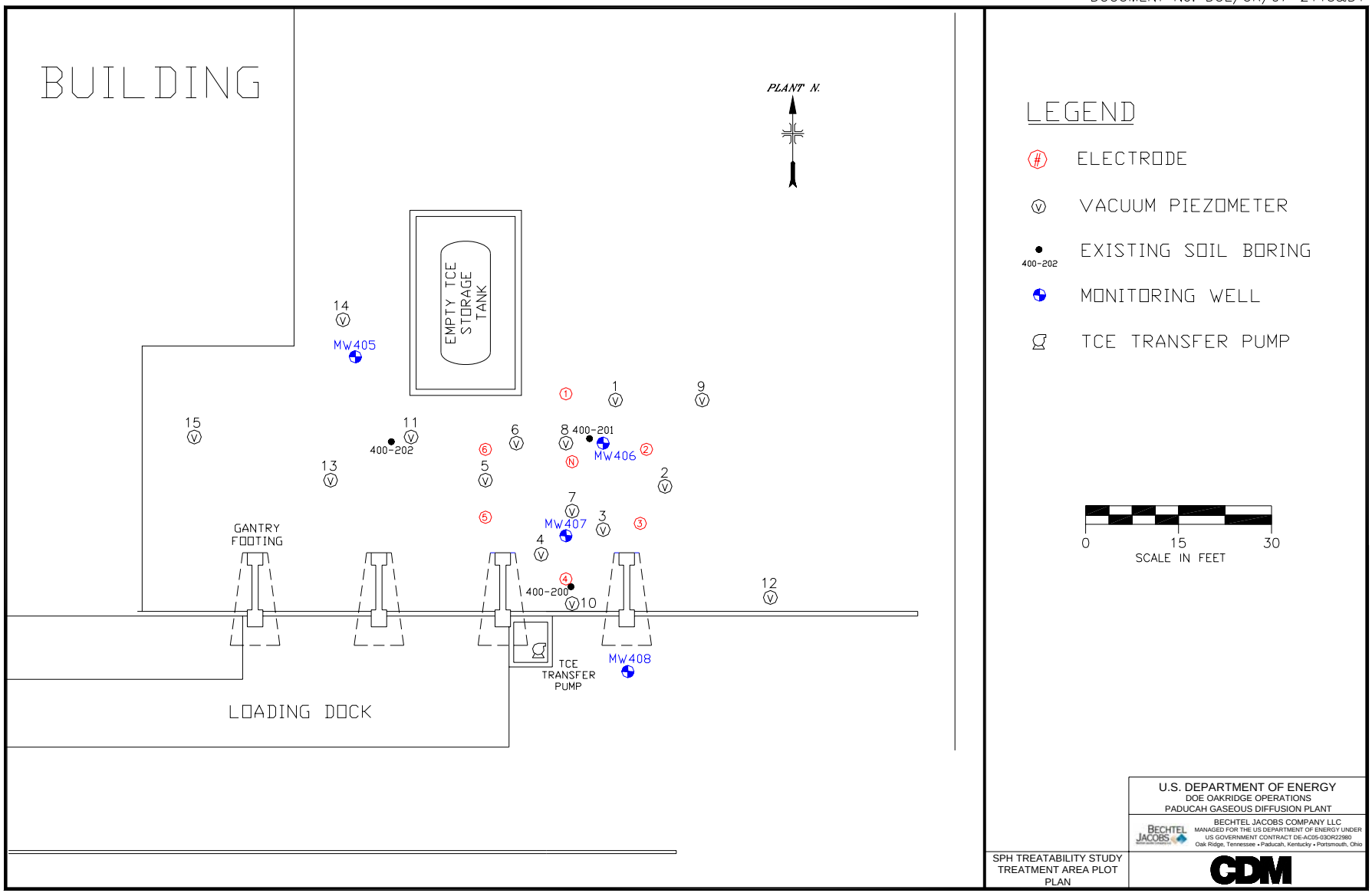

Fig. 1. Site Layout

TREATMENT TECHNOLOGY DESCRIPTION

The treatability study included the installation and operation of a single SPH array. The single array treatment system consisted of six power electrodes, a central neutral electrode, an electrical power control unit (PCU), a steam and contaminant recovery system, pressure and temperature monitoring systems, and contaminant vapor and water treatment systems. A total of 35 borings were installed for the project: 4 multi-port groundwater and soil temperature monitoring wells (MW); 7 electrode and co-located vapor recovery (VR) wells; 15 vacuum monitoring piezometers; and 9 post-test assessment borings as shown in Figure 1. The electrodes were constructed to a depth of 30 m (99 ft) bgs and consisted of six depth-discrete electrical resistance heating intervals covering the UCRS, the RGA, and the upper interbedded silt, sand, and clay layer of the McNairy formation.

As power was applied to the electrodes, the soil matrix became an electrical resistance heater, raising the temperature of the soil within the treatment area to a level that caused contaminated groundwater to boil and the target contaminants to be volatilized. The contaminants and steam were then removed from the subsurface using VR wells. The steam was condensed and the liquid and vapor waste streams were then treated separately.

The treatment process for the vapor waste stream consisted of two 12,500 lb granular activated carbon (GAC) beds configured in series. The primary and secondary configuration allowed for the secondary vessel to capture any TCE that may have "broken through" the primary vessel. The effluent of the secondary vessel was continuously monitored during project operations using an Innova Model 1314 photoacoustic analyzer (photoacoustic analyzer). The analyzer was configured to monitor for four contaminants (TCE, cis-1, 2-Dichloroethene, trans-1, 2-Dichloroethene, and vinyl chloride (VC)). The analyzer was designed to alarm and shut down the SPH system if the effluent of the secondary vessel was measured above the alarm set points. The alarm set points were 19 parts per million by volume (ppmv) TCE; 20 ppmv VC; 25 ppmv cis-1, 2-Dichloroethene; and 25 ppmv trans-1, 2-Dichloroethene.

The treatment process for the liquid waste stream passed through an ion exchange resin vessel to capture any ^{99}Tc that may have been collected. The liquid waste stream also passed through liquid GAC vessels, two 150-lb carbon drums placed in parallel, to remove TCE. The GAC vessels were placed in parallel to allow sufficient volume to flow through the vessels once silt began to collect within the original vessel.

The SPH treatability study was scheduled to operate for 130 days. However, a 45-day extension was implemented due to positive TCE extraction and the desire to determine if an increase in temperatures at the base of the RGA could be achieved. Upon completion of the study, the remedial effectiveness of the system in the UCRS was verified by collecting post-treatment soil samples from new borings adjacent to selected baseline borings. Post-treatment groundwater samples were collected from the multi-port monitoring wells, and the data compared to the baseline data to determine the treatment system effectiveness.

For this treatability study, the SPH array treatment area was 9 m (30 ft) in diameter, heating a subsurface treatment area measuring 13 m (43 ft) in diameter.

OPERATING FEATURES

The following are examples of operational features that were included in the SPH treatment system design to conduct the treatability study safely and efficiently at PGDP:

The exhaust of the treated vapor stream was continuously monitored by a photoacoustic analyzer. The photoacoustic analyzer measured the contaminant concentrations approximately every 63 seconds. If the vapor stream exceeded the alarm set points, the analyzer would trigger an alarm and the SPH system would automatically shut down and operators would be notified through an automated auto-dialer system.

The vapor treatment process was maintained at a slight vacuum (negative pressure); in the event of a leak, outside air would be drawn into the piping and vessels instead of releasing TCE vapors to the atmosphere prior to treatment.

A negative pressure vapor treatment process also provided the ability to dilute the vapor stream for optimal loading of the GAC vessels to prevent an excessive GAC temperature rise through heat adsorption.

A total of 15 vacuum piezometers were installed within and around the treatability study area. The piezometers were used to monitor temperature increases and steam migration along the UCRS and RGA interface. The piezometers within the treatment area contained screens and were connected to the VR system to collect any potential steam migration before it exited the treatment area.

OPERATIONAL PARAMETERS

The following paragraph discusses the operational parameters that were evaluated to determine the effectiveness of the system and the impact of the SPH technology on current PGDP operations.

Steam and Temperature Decay Rates

The steam and temperature decay rates of the treatment area are based on three data points collected since the conclusion of active heating on September 6, 2003. The rate of heat loss varied between the UCRS and the upper McNairy formation. The upper unsaturated zone of the UCRS, which lost heat faster than the lower saturated UCRS, is likely experienced the impact of ambient air moving through the pore spaces of the formation. The saturated UCRS and upper McNairy formation cooled slower than the other depth zones due to the insulating effect of the saturated soil and the relatively slow movement of groundwater flow. As expected, the saturated zone of the RGA cooled faster than all other depth zones in the treatment area. The rapid movement of

groundwater through the treatment area is the mechanism that removed more heat than other depth intervals.

The rate of heat loss since the conclusion of active heating has been consistent with the temperature changes observed during the SPH application. The retention of heat by the subsurface has no detrimental effects on a full-scale application of the SPH technology and is also consistent with the rate of heat loss seen at many other SPH applications. The heat loss in the RGA further asserts the need for a full-scale electrode design that can compensate for the rapidly moving groundwater of the formation.

Temperature Gradients throughout the Test Cell

The criterion used to evaluate temperature gradient was the uniform heating of the treatment area to the boiling point of water at depth inside the electrode treatment area. This goal was achieved in the UCRS and shallow RGA from 1.5 to 23 m (5 to 75 ft) bgs but not in the deep RGA from 23 to 29 m (75 to 95 ft) bgs. The technology has the ability to heat the subsurface at the southeast corner of the C-400 building but did not fully reach the temperature goal due to electrode malfunctions as described later in this paper. However, the treatment system did heat the treatment region to above the boiling point of TCE dense non-aqueous phase liquid (DNAPL).

TCE Removal Rates as a Function of Operational Time and Energy Consumption

The TCE removal rate was quantified by two different sampling methods during treatability study operations, daily photoacoustic analyzer readings and weekly measurements with summa canisters configured to collect a 24-hour integrated sample. The vapor recovery system extracted a baseline TCE concentration of 130 ppmv from the non-heated treatment area prior to active heating. The trending of the daily photoacoustic analyzer readings shows a sharp increase in vapor waste stream concentration to approximately 1,700 ppmv on March 20, 2003. The analytical results from the summa canister collected on March 19, 2003 show a similar peak in concentration of 1,800 ppmv. The TCE concentration decreases by both measurement techniques over the next three weeks yet still averaged approximately 600 ppmv. The vapor waste stream decreased further around April 20, 2003 and did not consistently return to greater than 400 ppmv for the remainder of active heating. These data, combined with the results of the 60 percent groundwater-sampling event starting on May 3, 2003, indicate that a significant amount of the TCE contamination was removed during the first 60 percent of energy application.

The amount of energy input to the subsurface was closely aligned with the original estimate for the treatability study operation. A total of 2,283,850 kilowatt-hours were input into the subsurface during 175 days of operation. The original estimate was 1,927,000 kilowatt-hours for remediation of the treatment area over a 130-day operational period.

TCE concentrations were measured daily at the influent of the primary GAC vessel using a photoacoustic analyzer. The vapor waste stream velocity was also measured daily using a hand-held flow meter. The resulting measurements were then used to calculate the approximate TCE loading for each GAC vessel. The following formula and

assumption was used to calculate that an estimated 23,000 lbs of TCE were removed from the vapor waste stream during SPH operations.

Formula: TCE (lbs/day) = (velocity x pipe cross-sectional area) x (TCE concentration/186) x 0.0898

TCE and velocity were measured once per weekday using the photoacoustic analyzer with the rate of loading per day applied to each GAC vessel until the next sample was taken (i.e., Saturday and Sunday).

Air samples were also collected weekly from the influent of the primary GAC using summa canisters. The summa canisters were configured to collect a 24-hour integrated sample. The air samples were sent offsite for laboratory analysis using analytical method TO-14A.

Construction and Operation Costs as a Function of TCE Mass Removed or Destroyed (Cost-Effectiveness)

An estimated 22,856 lbs of TCE was removed from the vapor waste stream during SPH operations. Using a unit weight for TCE of 12.11 lbs per gallon, a total of 1,887 gallons were removed. Using an estimated cost for the treatability study of $6.3 million would relate to a cost of $3,338 per gallon of TCE removed.

Effect of the SPH System on Adjacent Utilities and Facilities

Air samples were collected at four separate subsurface locations adjacent to the SPH treatability study site. Samples were collected to ensure and document that workers in adjacent facilities were not being exposed to vagrant VOC contaminants generated by SPH operations.

During the first 30 days of system operation, air samples were collected daily from the C 400 building basement and from three locations in a tunnel located just east of the SPH site. The samples were collected using gas indicator tubes designed to identify TCE and VC. Neither contaminant was detected during the initial 30-day time period. Therefore, the sampling frequency was reduced to weekly. Gas indicator tubes indicated no detections of TCE or VC for the duration of SPH operations. The detection limits were 2 parts per million (ppm) for TCE and 0.5 ppm for VC.

Additionally, for the first 10 weeks of SPH operations, air samples were collected weekly at the same four locations using summa canisters configured to collect a 24-hour integrated sample. Summa canisters were analyzed for VOCs with detection limits of 0.5 ppmv. During the week of March 17, 2003, TCE was detected at 2.8 ppmv in the summa canister sample collected from the C-400 basement. The positive TCE result was evaluated and determined to have originated from seep water in the sump surrounding an abandoned TCE storage tank located in the C-400 building. However, as a precaution, and for the remainder of the project, one of the summa canister sample locations was changed from the tunnel to the office area of the C-400 building. Additionally, sample collection was reduced from weekly to bi-weekly for the remainder of the project. All results from samples collected in the C-400 building office area were non-detect.

LESSONS LEARNED AND RECOMMENDATIONS

The following are lessons learned from this treatability study that offer a solution for future implementation of this technology.

Heated Groundwater Mitigation

Heated groundwater may have migrated from the treatment area. Thermocouples located in the borings of monitoring wells MW405 and MW408 outside the treatment area indicated that heated groundwater may have migrated from the treatment area during the treatability study, particularly near the middle of the RGA at approximately 23 m (75 ft) bgs. However, the heated groundwater did not appear to carry significant TCE mass because the VOC concentrations in MW405 and MW408 decreased as the heated groundwater encroached upon them.

A hydraulic control system could be incorporated into a full-scale design to prevent the spread of heated groundwater; however, the cost of such a system may not be justified because of the lack of detrimental effects shown during the treatability study. Edge effects, including hot groundwater spreading, become relatively less important as the treatment area increases.

Electrode Failure

Electrodes failed to heat six discrete intervals. The treatability study electrodes were designed to include six independent electrically conductive elements at various depths. Steel shot was used as an electrode backfill. During electrode installation, the high density of the steel shot column potentially displaced the electrical insulating materials (bentonite) that separated the six elements and, therefore, caused each electrode to function as a single element with no vertical differentiation. The high backfill density and structural instability could have disconnected the two deepest electrode intervals and prevented sufficient power from reaching these depths for active water boiling.

The electrode design should be adapted in a full-scale application to prevent the electrical connection, settling, and weight issues discovered during the SPH treatability study. The density of the conductive backfill material could be lowered by using a combination of steel and graphite backfill to reduce the electrode's ability to shift within an unstable RGA formation. The cable that supplies power to the individual electrode intervals should have one electrical connection and one structural connection that will absorb the stress of any movement or settling. A simpler electrode design would incorporate three electrode elements (one each in the UCRS, the RGA, and the upper McNairy formation) rather than the six intervals used during the treatability study. The electrodes were not able to create a thermal barrier or "hot floor" as designed, but no evidence suggests that DNAPL migrated down to the McNairy Formation during the treatability study and the use of a thermal barrier may not be warranted in a full scale application. The electrode element isolators should be made of cement grout or sand to prevent dissipation and failure; bentonite should not be used in a weight bearing application.

Clogging of System Components

Influx of sediments into the treatment system clogged system components. The shallow vapor recovery screens located from 1.5 to 2 m (5 to 7 ft) bgs were pulling sediments into the condenser knockout pots. Periods of rain would saturate the surface soil and lower the permeability of the shallow soil of the treatment area, which would then begin to act as a vacuum cap. The vacuum inside the treatment area would increase due to the lack of airflow through the soil. The elevated vacuum in the shallow soil created air channels to the surface around the electrode's concrete surface seal. The velocity of the ambient air stream moving through a small channel transported a high volume of sediments into the vapor recovery wells and into the condenser. These sediments accumulated in the knockout pots and eventually clogged the liquid GAC vessels resulting in system shutdown.

The air channels were filled with concrete and the electrode seals were extended horizontally away from the electrodes to provide better surface isolation. A 6-millimeter Visqueen™ cap was installed over the treatment area to help maintain stable soil permeability. Additionally, the vacuum applied to the treatment area was decreased. These changes drastically reduced the amount of sediment collected in the condenser components during remaining operations. The design of a full-scale application should incorporate a treatment area cap where shallow vapor recovery is necessary. The cap should be constructed of plastic sheeting, concrete, or asphalt to maintain stable permeability. Particulate filters should be installed prior to the condensate water treatment system to aid in capturing any fine sediment that may be pulled into the condenser by the vapor recovery system.

VOCs in the Breathing Zone

Higher than expected VOC readings where observed in the breathing zone during subsurface installation. Photoionization detector (PID) readings indicated VOCs in ambient air in the vicinity of the borings during drilling, sample collection, and other installation activities. Based on historical data and process knowledge, VOCs measured in the ambient air during installation activities were probably vapors from the volatilization of TCE. However, due to the detection of larger quantities of VOCs and an elevated PID reading in the breathing zone of an employee (>300 ppmv), the presence of TCE degradation byproducts (specifically VC) became a concern.

Two summa canister grab samples were collected from the open boring of Electrode #4 at two depths. One sample was collected at approximately 6 m (20 ft) bgs and the other sample collected at approximately 15 m (50 ft) bgs. Results from these samples estimated the presence of small quantities of VC in the boring (16,000 and 14,000 parts per billion by volume [ppbv]). However, the presence of extremely high levels of TCE (380,000 ppbv) resulted in high detection limits and VC sample results could not be validated to a high degree of certainty. Area monitoring was conducted for a period of 10 working days to confirm the presence of VC in the work area. Monitoring was performed in conjunction with the use of Level B PPE and feasible engineering controls. The monitoring consisted of the continuous collection of carbon tube samples in the breathing

zone of workers when the potential existed for worker exposure to VC. The sample media were changed every 15 minutes in order to obtain a 15 minute Time Weighted Average (TWA). The sampling was conducted in accordance with National Institute for Occupational Safety and Health (NIOSH) Method 1007 to obtain a 95 percent confidence level for VC concentrations.

The VC charcoal tube samples were shipped to an American Conference for Governmental Industrial Hygienists (ACGIH) accredited industrial hygiene laboratory for analysis. All laboratory sample results for the VC samples were non-detect at 0.25 ppm with regulatory limits of 1 ppm TWA and a 5-ppm ceiling. As a result, PPE requirements were downgraded from Level B to Level C.

SAMPLING AND ANALYSIS

The overall sampling strategy for the SPH treatability study focused on the soils in the UCRS and groundwater in the RGA. Sampling for the SPH treatability study consisted of groundwater and soil sampling as described below.

Groundwater in the RGA

Four multi-port monitoring wells were installed to collect groundwater samples. One of the groundwater monitoring wells was placed upgradient of the treatment area, two of the monitoring wells were placed within the treatment area, and one monitoring well was placed downgradient of the treatment area Figure 1. Each multi-port monitoring well has seven sampling ports, which made each well equivalent to a multi-well cluster. Each of the four multi-port monitoring wells contains seven independent sampling ports. The shallowest port located in the lower UCRS 11 m (36 ft) bgs never yielded groundwater. Five ports were located in the RGA formation 20 to 27 m (66 to 89 ft) bgs, and the deepest port was located in the McNairy formation at 32 m (105 ft) bgs.

Groundwater sampling of the four multi-port monitoring wells was conducted at baseline, 60 percent completion, 87 percent completion, post-treatment, two-week post treatment and four-week post treatment. The groundwater contaminant removal efficiency criterion for the treatment area was a reduction in TCE to less than 1 percent of its solubility limit in water (1 percent is approximately 11,000 ppb). The sample ports within the treatment area (MW406 and MW407) area ranged from a 98.3 percent to 99.9 percent reduction in TCE concentration and also met the removal efficiency criteria of less than 1percent solubility limit of TCE goal for the project. A graph depicting groundwater-sampling results for MW406 and MW407 is located in Figure 2.

During the treatability study, groundwater TCE contamination outside of the treatment area (MW 405 and MW 408) was monitored at the same frequency as the groundwater inside the treatment area. The region outside the treatment area had levels of TCE contamination similar to those inside the treatment area during the baseline-sampling event. No removal efficiency criteria were established for groundwater sample analysis outside of the treatment area although the surrounding data could be used to confirm contamination was removed from the treatment area instead of moving out of the

treatment area. A graph depicting groundwater-sampling results for MW405 and MW408 is located in Figure 3.

During the 87 percent completion and post-heating groundwater sample events, DNAPL was removed through the sample port in the 31 to 32 m (102 to 105 ft) bgs of MW408. There was little temperature influence at MW408, which indicates the absence of a driving force to move DNAPL out of the treatment area and into the vicinity of MW408. The thermocouple installed at the 32 m (105 ft) bgs interval did not function properly after installation, but the interval above 29 m (95 ft) bgs only increased 10°C above the normal ambient temperature. The subsurface temperatures at MW408 are similar to subsurface temperatures recorded in MW405. The TCE concentrations in the RGA and McNairy formation were near the solubility limit at baseline and indicated that DNAPL was most likely present around MW408 before the treatability study began. During well installation of MW408 the thin confining layer that established the RGA/McNairy formation interface was not identified during drilling of MW408. The absence of a confining layer in this location could allow DNAPL to flow into the McNairy formation from the RGA above.

Additional groundwater sampling events were performed after the post treatment groundwater-sampling event to assess and quantify the amount of contaminant rebound. The two-week post treatment groundwater-sampling event was initiated on September 22, 2003. The four-week post treatment groundwater-sampling event began on October 7, 2003. The original post treatment sampling event yielded a reduction of 99.1 percent in TCE concentration. The two-week post treatment sampling event shows 99.2 percent reduction, and the four-week post treatment sampling event shows a 99.0 percent TCE reduction. The maximum concentration found in the latest sampling events is 10,090 ppb, which remains below the target of 11,000 ppb.

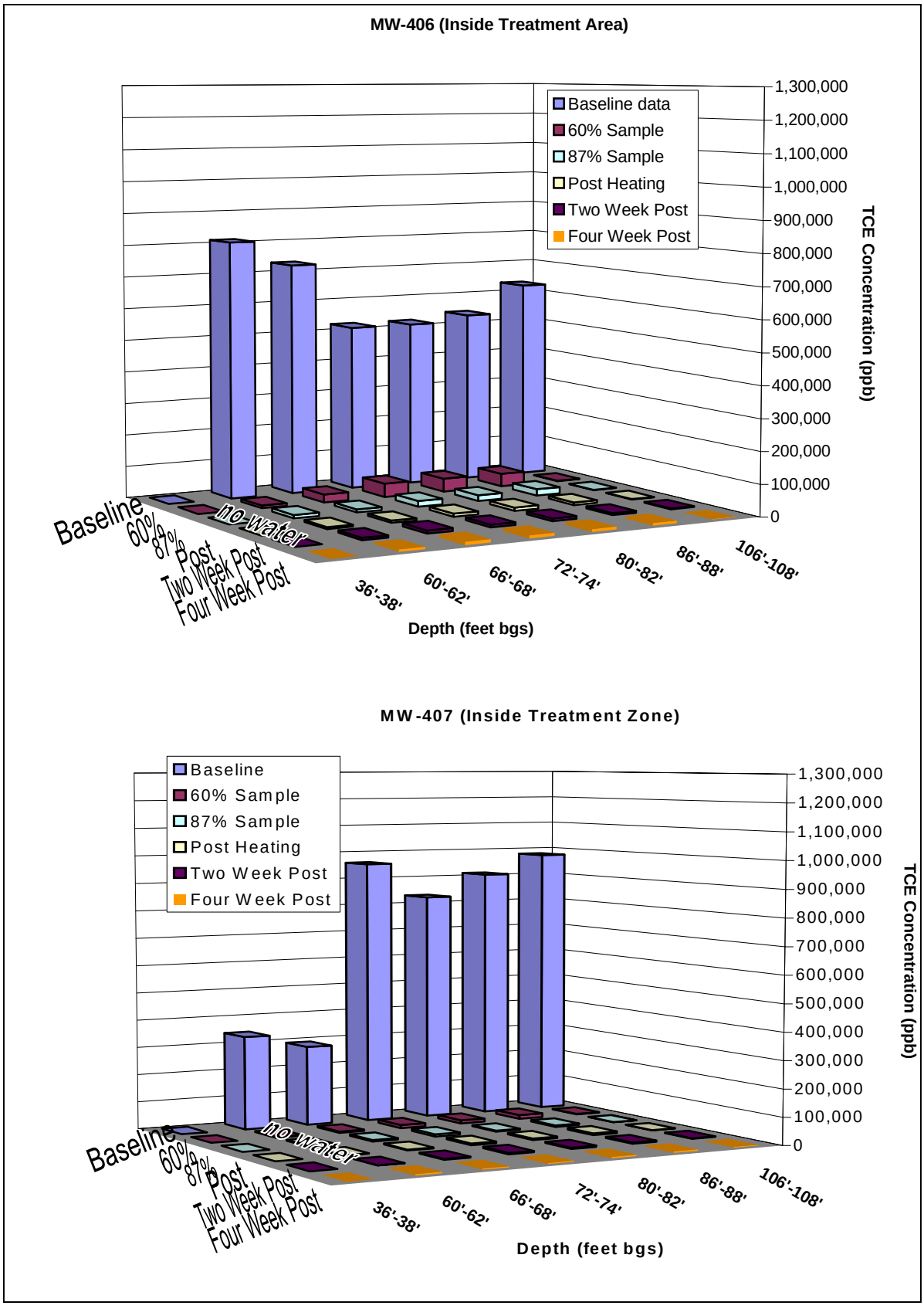

Fig. 2. Groundwater Concentrations Inside the Treatment Area.

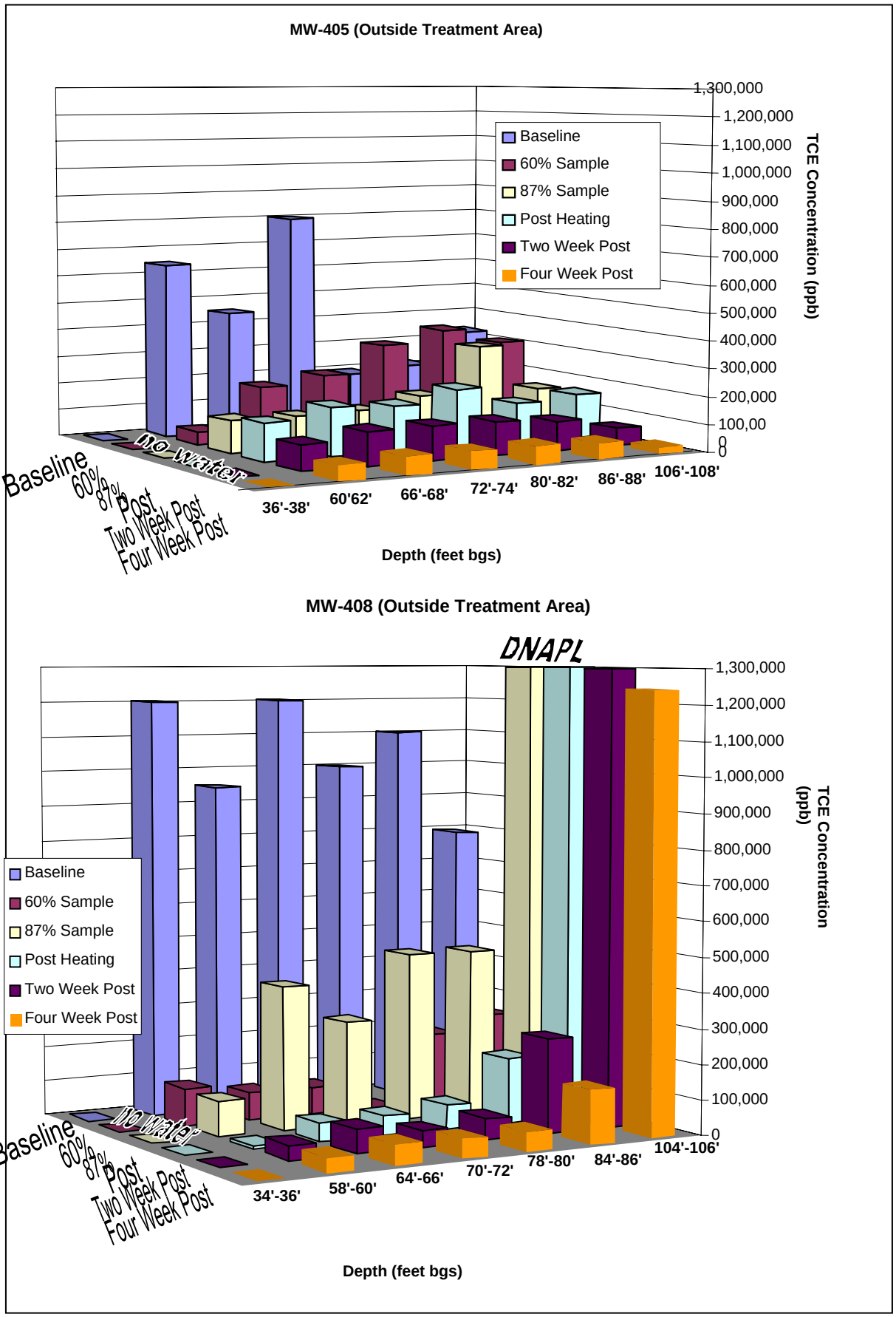

Fig. 3. Groundwater Concentrations Outside the Treatment Area.

Soil Sampling in the UCRS

Soil sampling was conducted during the subsurface installation phase of the treatability study to quantify the amount of TCE in the UCRS prior to remediation. Soil samples were taken at piezometer locations VP-1 through VP-8 inside the treatment area and piezometer locations VP-9 through VP-11 surrounding the treatment area Figure 1. Samples were collected in 2- ft intervals from the surface to 58 ft bgs.

At the conclusion of heating, nine soil borings were installed to measure soil residual contamination concentrations after applying the technology. These borings were located adjacent to piezometer locations (VP-1 through VP-8 and VP-10) where baseline soil samples were collected to establish pre-test contaminant levels. The soil samples were collected from the same depths as the baseline samples and analyzed for the same analytes and parameters tested for in the baseline soil samples. Post treatment soil sampling results show an average reduction in TCE concentration of 98 percent, which is significantly higher than the target reduction of 75 percent. The average TCE concentration was reduced from a pre-test level of 125,459 ppb to a post treatment average of 2,485 ppb.

In each of the monitoring well installation borings that extend to the base of the RGA, a soil sample was collected across the RGA/McNairy formation interface, or within the uppermost McNairy formation, to aid in determining the presence of pooled DNAPL. Field analysis of this soil sample, based on readings of a PID and visual observations, were used to assess the local presence of a DNAPL pool. No significant thickness of pooled DNAPL was identified in any of the soil samples. No recovery was obtained in the attempt to collect a soil sample from the interface at MW408.

CONCLUSION

The primary objective of the treatability study as described in the Treatability Study Work Plan for Six-Phase Heating, Groundwater Operable Unit, at Paducah Gaseous Diffusion Plant, Paducah, Kentucky Treatability (DOE 2001a) was to demonstrate the implementability of the SPH technology for the unsaturated and saturated areas of the UCRS and for the groundwater of the RGA. A successful implementation would heat the soils and groundwater in both the UCRS and RGA to a temperature that allows steam and vapors containing the TCE to rise and be moved by the VR wells are treated by the vapor treatment system.

Removal efficiency criteria were outlined in the Six-Phase Heating Technology Assessment (GEO 2003). The criteria for evaluating the success of the SPH treatability study are the assessment of removal efficiency using co-located soil and groundwater sampling. The criteria for success included a greater than 75 percent reduction of TCE soil concentrations in the UCRS and a reduction of TCE groundwater concentrations to less than 1 percent solubility (11,000 ppb) in the RGA. These efficiency criteria were

met during this treatability study indicating this is a viable remedial alternative for treating TCE plumes of this magnitude.

The removal efficiency of TCE in the UCRS soils was assessed by a comparison of baseline soil sampling results to post treatment soil sampling results. Post treatment soil sample results indicate that this goal was achieved based on comparison of the data that indicates an average reduction in soil of 98 percent

The removal efficiency of TCE in the groundwater of the RGA was assessed by a comparison of baseline groundwater sampling results to post treatment groundwater sampling results. Post treatment groundwater sample results indicate that this goal was achieved based on comparison of the data that indicates an average reduction in groundwater of 99.1 percent at the end of active heating, 99.2 percent at two-week post treatment, and 99.0 percent at four-week post treatment.