APPENDIX F

PneuLog Test Standard Operating Procedure

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STANDARD OPERATING PROCEDURE - PNEULOG®

1. INTRODUCTION

This project will utilize a procedure combining site characterization and the collection of soil vapor extraction (SVE) data in vadose zone soils containing volatile organic compounds (VOCs). The procedure developed by PRAXIS Environmental Technologies, Inc. uses pneumatic well logging, known as PneuLog®, to measure the vertical air permeability and chemical concentration profiles in wells screened for SVE. The field procedures associated with PneuLog® are described in this attachment. All field activities will adhere to the procedures and specifications contained in the project Field Sampling Plan (FSP) and Quality Assurance Project Plan (QAPP) prepared as separate documents.

Pneumatic well logging is used to develop a detailed conceptual site model to aid in the design, optimization, or closure of SVE systems. The following data are collected in addition to lithologic logging and conventional sample analyses to build the conceptual site model:

- Flow and vacuum data from extraction wells,
- Vertical vapor concentration data from extraction wells, and
- Vertical air production profiles from extraction wells.

This attachment describes the PneuLog® technology and the collection of the data listed above.

2. TECHNOLOGY DESCRIPTION

This project will employ an expedited approach to vadose zone characterization with simultaneous collection of data for optimized SVE design and operation. For both vadose zone characterization and remedial design, Praxis has developed, field-tested and commercialized a pneumatic well logging process. Known as PneuLog®, the well logging is performed by simultaneously measuring the cumulative air flow and chemical vapor concentrations along the depth of an extraction well screen during active SVE. To make these measurements, a flow sensor is moved through the well during vapor extraction and soil gas samples are collected and analyzed continuously. Performing these measurements at a representative number of wells can yield a three-dimensional picture of the extent of chemicals in soils at a site as well as the soil permeability distribution. These measurements, in conjunction with traditional measurements, yield a thorough site evaluation.

The equipment for the pneumatic logging is illustrated in Figure 1. The Pneulog® instrumentation is attached to a cable, which passes through alignment pulleys and a vacuum-tight fitting at the wellhead. The instrumentation is raised or lowered by a motorized reel around which the cable is wound. The logging proceeds at roughly eight feet per minute along the screen in the SVE well. Sensors in the pulley assembly indicate the depth of the measurement. Electrical leads connect the flow sensor to a data acquisition system located on the motorized reel. A vapor sampling tube connects the sample port on the instrument to a vacuum pump, also on the reel. The sampling pump draws a continuous stream of air through the sampling tube to the surface where it is analyzed for VOCs and other compounds of interest (e.g., oxygen and carbon dioxide). A photoionization detector (PID) is used to provide a continuous reading of total VOC concentration. Canister samples can be collected for off-site gas chromatographic and mass spectrometer analyses to determine compound-specific concentrations at discrete depths and to calibrate the PID readings. Supplemental vapor samples can be collected and analyzed on-site with a field gas chromatograph.

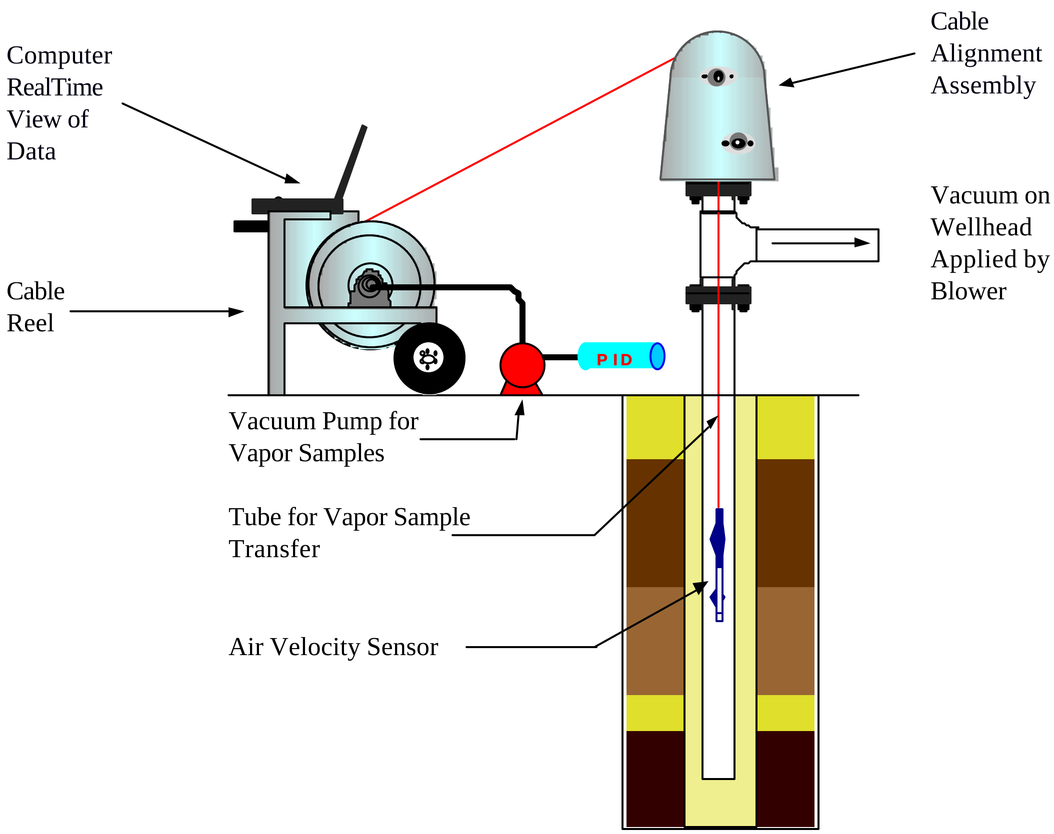

Figure 1. Schematic of Pneumatic Well Logging Equipment

The airflow from each soil layer is related to the cumulative airflow by a simple mass balance. To determine the airflow from a given soil layer, the cumulative airflow measured below the soil layer is subtracted from the cumulative airflow measured above the soil layer. The soil permeability of the interval is then determined from Darcy's law. The data and the analyses appear similar to output from borehole flowmeter testing in water wells (Molz et al., 1989). A typical cumulative airflow measurement from PneuLog® is provided in Figure 2a. In this example, the well is screened from 12 to 32 feet below the ground surface (bgs). The screen interval is indicated by the green (dark) and yellow (light) blocks together. As shown, the airflow from the bottom half of the well is practically zero. The airflow increases steadily from 0 to 28 standard cubic feet per minute (scfm) between 23 and 16.5 feet bgs as the instrument is raised through the screen. The steady flow increase indicates this soil interval has a relatively uniform permeability to air. From 16.5 to 15 feet, only 2.5 scfm of soil gas are added. 15 scfm are then added in the next 1.5-foot interval up to 13.5 feet. The top 1.5 feet of the screen adds only one scfm to the total.

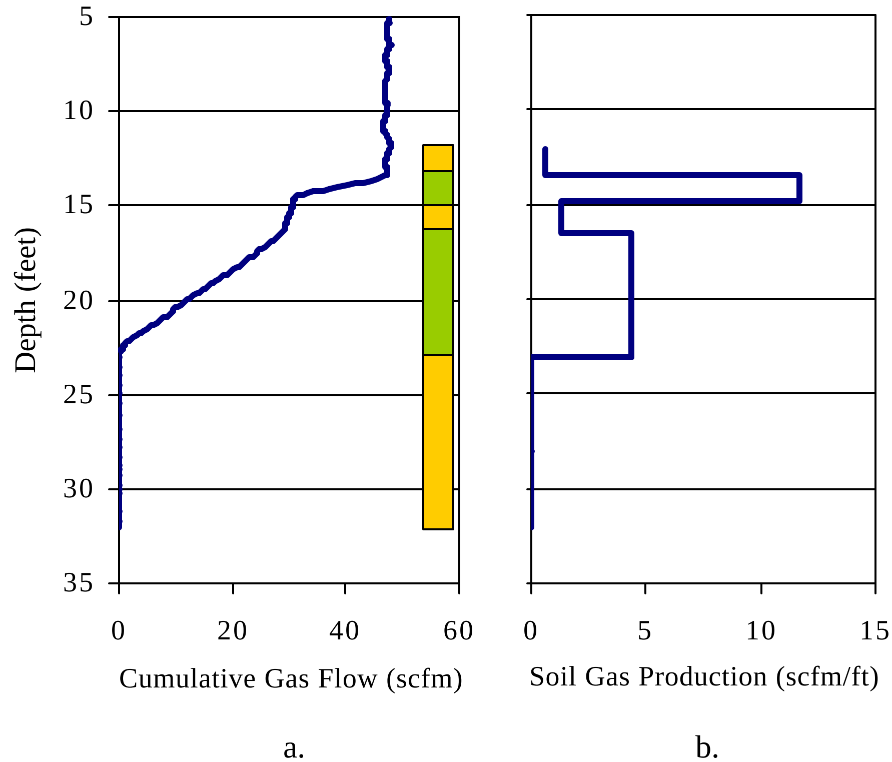

Figure 2. Example Pneumatic Well Logging Results for Soil Permeability to Air

Figure 2b presents an interpretation of the cumulative flow measurements as soil gas production. An effective air permeability profile can be generated using the soil gas production profile with multi-dimensional analytical or numerical airflow models. The permeability of an interval is proportional to the change in flow across the interval, its thickness, its depth below the surface and the well vacuum according to Darcy's law. Figure 2b reveals roughly five soil strata along the screen. The stratum intersected by the bottom half of the screen has a relatively low permeability since no measurable soil gas was produced. The geologist characterized the soils of this interval as silts. The soil intervals from

16.5 to 23 feet and 13.5 to 15 feet have air productions indicative of coarse sands. These two sand intervals are separated by a 1.5-foot-thick silt interval. The soil at the top of the screen would also be characterized as silt. This characterization of the physical properties is superior to a geological log and a typical air permeability test. The PneuLog® results were qualitatively consistent with the geological log; however, the geological log provided little indication of air permeability. Without the pneumatic logging data, the permeability determined by typical testing would be averaged over the screen interval and dominant features of the subsurface flow during SVE would not be quantified.

The characterizations of zones containing chemicals and soil gas concentrations result from the measurement of VOC concentrations along the well screen. An example concentration log, which was collected simultaneously with the previously discussed air flow log, is presented in Figure 3a. This concentration profile was obtained from a continuous PID reading which was calibrated to trichloroethylene (TCE) concentrations with on-site and off-site gas chromatographic analyses of vapor samples from discrete depths and the wellhead. The measured vapor concentration is lowest near the bottom of the screen and increases slightly up to a depth of about 28 feet. As the instrumentation is raised higher in the well, the concentration increases sharply to a maximum and remains relatively steady into the soil gas production interval starting at 23 feet. The concentration then decreases steadily from 22 to 15 feet bgs. Between 15 feet and the top of the screen, the concentration increases very slightly.

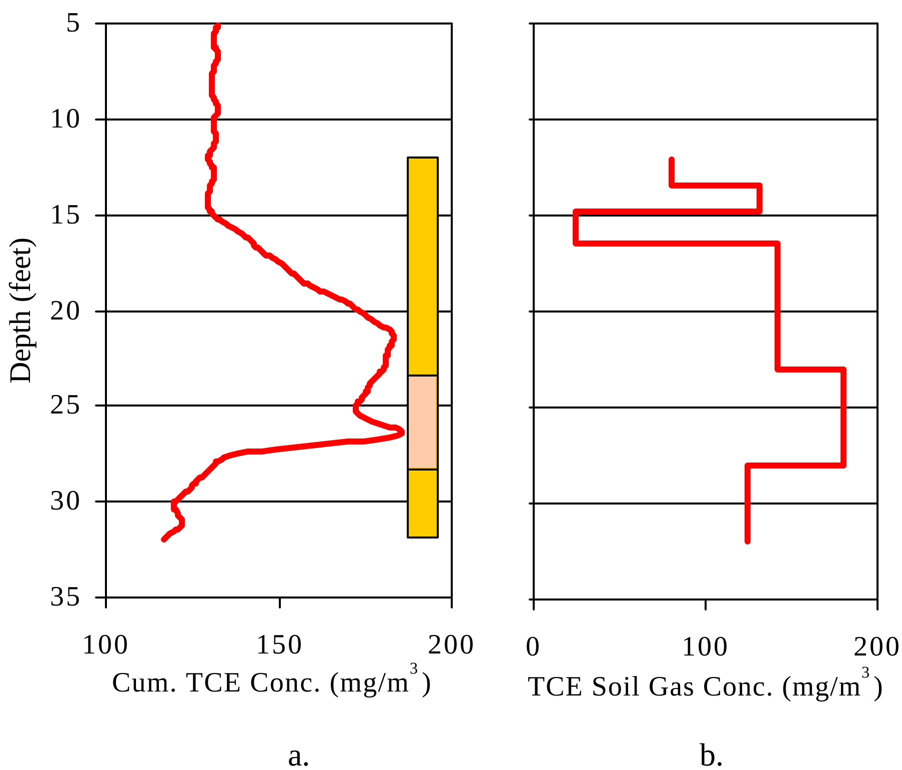

Figure 3. Sample Pneumatic Well Logging Results

The observed increases and decreases in concentration can be combined with the depth-specific air production in a mass balance to estimate depth-specific soil gas concentrations. The PneuLog® device simultaneously measures the flow rate and concentration versus depth. The change in the product of these two variables over a specified depth interval divided by the flow change is equal to the chemical vapor concentration in the soils of that depth interval. Application of this relationship to the data shown in Figures 2a and 3a yields the chemical vapor concentration profile presented in Figure 3b. The highest concentration occurs in the low permeability material underlying the deep sand interval. This high concentration indicates the low permeability interval creates a mass transfer constraint to SVE. Compounds must migrate slowly out of this interval into the flow interval above. The silt interval at 15 feet does not appear to be a barrier to chemical migration between the sands.

As illustrated by this example, pneumatic logging provides a more thorough and appropriate site characterization than traditional methods alone. Repeating the process in a representative number of wells can generate a three-dimensional description of the physical and chemical subsurface by correlating between locations. The technique also provides data to more effectively design and optimize an SVE system. Soil strata near or below cleanup goals are quickly identified and the extraction flow rate can be lowered or terminated from these layers. The operation can then be focused on strata remaining above cleanup goals. This optimization could lead to cost savings by accelerating cleanup and lowering operation & maintenance costs.

3. FIELD TASKS AND PROCEDURES

This section describes the field activities and procedures to collect data for site characterization and SVE design using PneuLog®. The activities adhere to the procedures and specifications contained in the project Field Sampling Plan (FSP) and Quality Assurance Project Plan (QAPP) prepared as separate documents. Site evaluation includes measurements of flow and vacuum in extraction and monitoring wells during pneumatic logging. Concentrations during the tests are monitored with a PID and two samples from each screen interval are collected and analyzed for VOCs. During the testing, vacuum responses are monitored in other available screens to aid in the calculation of permeabilities at the site. Vacuum responses depend on the soil properties and well spacing and may not be measurable in all monitored screen intervals.

The PneuLog® technique was described in detail in Section 2. During the pneumatic logging, a small flow of air is extracted through the Teflon® tubing attached to the flow instrument in the well. The total organic compound concentration in this air flow will be measured with a calibrated photoionization detector (PID) to yield the chemical concentration in soil gases extracted along the well screen depth. The pneumatic log will then be repeated and the instrument will be paused at a depth of major change in flow or concentration, generally at the maximum concentration. At this discrete depth, a sample of the soil gas may be collected in a canister or Tedlar® bag. A second canister or Tedlar® sample will be collected at the top of the well. Canisters will be packaged and shipped to a state-certified, off-site laboratory for analysis by GC/MS. The flow data from the pneumatic well log will immediately be analyzed to yield an air production profile along the well screen and the concentration log will be analyzed to indicate the intervals with the highest chemical concentrations. In wells with lower concentrations, a meaningful maximum concentration along the screen may not be identified. In these screens, a vapor sample will be collected from the bottom of the screen.

Any point or non-point discharge to air generally requires review and permission from the local air board. This includes any process that volatilizes materials from the ground (e.g., soil vapor extraction) or uses volatilization as a means of disposal for unwanted materials or constituents. The SVE aspect of this fieldwork will require the extraction of contaminated air from the subsurface. The SVE discharge from each well will be treated with existing vapor abatement equipment on each site.

4. VAPOR SAMPLING AND ANALYSES

This section summarizes the procedures for collecting and analyzing vapor samples during the field tests. The equipment that will be used to collect vapor samples is also described. The sample locations, frequencies, and procedures presented are subject to change based on site-specific conditions.

Vapor concentrations will be monitored continuously during extraction periods with a calibrated PID as described in Section 3. Vapor samples will be collected in Summa® canisters for off-site analysis via method TO-14 (VOCs) or TO-15 (VOCs), and/or method TO-3 (total volatile petroleum hydrocarbons) at a state-certified laboratory or in Tedlar bags for on-site analyses of VOCs using a modified EPA Method 18. Approximately 2 samples will be collected during the pneumatic log of each screen in each well location. Samples will be collected through the pneumatic logging instrumentation and will provide depth-specific concentrations from inside the extraction wells. One sample will be collected from above the screen interval and one sample from the depth in the screen yielding the highest concentration or the bottom.

Depth-specific samples will be drawn by a small, oilless diaphragm pump through a Teflon® tube attached to the flow instrumentation for pneumatic logging. The vapor sample will be monitored by a PID on the surface and collected near the discharge of the Teflon® tube in a stainless steel SUMMA® canister or Tedlar® bag. The majority of samples collected in Tedlar bags will be analyzed on-site with a portable GC. Canisters will also be used to directly collect vapor samples at the wellhead to validate on-site analyses. The canisters will be submitted for offsite chemical analysis. Samples will be collected following the guidance offered in EPA's *"Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air,"* EPA 4-84-041-April 1984. The specific methods to be used are TO-14, "Determination of Volatile Organic Compounds (VOCs) in Ambient Air Using SUMMA Passivated Canister Sampling and Gas Chromatography Analysis" or TO-15 and/or TO-3 for total volatile petroleum hydrocarbons. The canisters will be used and samples collected in the vacuum mode. The vacuum in the clean canister (near 30 inches Hg) will be sufficient to pull the sample out of the gas line. A slow flow rate into the canister will be controlled manually by slightly cracking open its valve.

The rate is checked by monitoring the canister vacuum gauge and comparing the value to the elapsed time and the wellhead vacuum. The final canister vacuum will be approximately equal to the vacuum in the vapor extraction line. The final vacuum will be recorded on the chain-of-custody and then measured at the laboratory after shipment and before analysis. The two recorded vacuums will be approximately equal if the canister has not leaked. Each canister will be cleaned in the laboratory before delivery.

The purpose of a field quality control program is to provide a measure of data quality. QA samples to be collected include field duplicates, equipment blanks, trip blanks, ambient condition blanks, and material for matrix spike/matrix spike duplicate (MS/MSD) analyses. Collection of the QA samples during the project is described in the project Work Plan. A summary of the quality control sampling for vapor sampling during PneuLog® is provided in Table 1. The sample handling, preservation and shipment procedures are described in the Work Plan along with sample custody and decontamination procedures.

TABLE 1
QUALITY CONTROL SAMPLES

Sample Matrix Analysis	Analysis Level	Number of Samples						
		Primary	Duplicate	Ambient Blank	Trip Blank	Equipment Blank	Matrix Spike /MSD	Total
Soil Vapor								
VOCs (Offsite TO-14)	III	TBD[1]	1 per 10	0	0	0	0	TBD[1]
VOCs (Offsite TO-15)	III	TBD[1]	1 per 10	0	0	0	0	TBD[1]
VOCs (Onsite TO-18)	I	2 per well	1 per 10	1 per 10	0	1 per 10	0	13 per 5 wells
TVPH (Offsite TO-3)	III	TBD[1]	1 per 10	0	0	0	0	TBD[1]

[1] TBD = To Be Determined

5. DATA MANAGEMENT

The data to be collected during PneuLog® include:

- Soil vapor concentrations,
- Extraction air flowrates,
- Wellhead vacuums,
- Vertical air flow profiles, and
- Vertical concentration profiles.

These data can be used to define the vertical and horizontal extent of chemicals at the various sites if a sufficient number of representative wells are logged. The data will also yield the disposition of the chemicals (e.g., found primarily in low permeability soil, found near the groundwater, suspected non-aqueous phase liquid present, etc.). The pneumatic logging data, combined with historical data can provide information on optimal SVE system operation and possibly the optimal locations for new SVE wells.

A general chronicle of field activities and personnel on site will be recorded daily. The following information shall be recorded for all field activities: (1) location, (2) date and time, and (3) identity of people performing activity. The information shall be recorded in a field notebook or on data logging sheets. These records shall be archived in an easily accessible form and made available to the Air Force upon request.

The collection of soil vapor samples will be documented in a field notebook or on appropriate data logging sheets. These records shall be archived in an easily accessible form and made available to the Air Force or its contractors upon request. The following additional information shall be recorded for all sampling activities: (1) sample type and sampling method, (2) the identity of each sample including location and depth(s), where applicable, from which it was collected, (3) the date and time of collection, (4) the amount of each sample or sample container volume, (5) sample description (e.g., color, odor, clarity), and (6) identification of conditions that might affect the representativeness of a sample (e.g., refueling operations, damaged casing).

Field measurements will be recorded on data sheets specific to each measurement (e.g., air flow rates and wellhead vacuums). For each field instrument the following shall also be recorded: (1) the numerical value and units of each measurement, and (2) calibration results

6. HEALTH AND SAFETY

The health and safety plan for the fieldwork is prepared separately and is adhered to during all field activities.

7. MANAGEMENT AND STAFFING

Key staff from PRAXIS assigned to the project are shown in Table 2 with their responsibilities. Team members include:

Ms. Mary Scarpetti is the President of PRAXIS. She is responsible for the administrative, contractual and fiscal aspects of all PRAXIS projects. All significant changes in scope or cost must have her approval. Ms. Scarpetti received her law degree from the University of San Francisco in 1990 and is a member of the California Bar Association. Ms. Scarpetti has seven years of experience in the operations and financing of small firms and, in particular, government contracting and accounting. She worked in the securities industry prior to law school.

Dr. Lloyd “Bo” Stewart is the Principal Engineer for the pneumatic well logging and a Vice President of PRAXIS. Dr. Stewart has ten years of experience overseeing the development and implementation of innovative technologies for the remediation and characterization of hazardous waste sites. Dr. Stewart also develops and implements computer models for risk assessments and cleanup actions. Remedial technologies under development at Praxis include steam injection combined with vacuum extraction, dual-phase extraction, and hydraulic fracturing. Dr. Stewart received his Ph.D. in Mechanical Engineering from the University of California Berkeley in 1989.

Mr. Mike Chendorain in the Soil Hydrologist for the subsurface investigation, data analysis, and modeling. Mr. Chendorain received an MS in Soil and Environmental Sciences from the University of California at Riverside. He received a BS in Environmental Sciences from Virginia Institute of Technology. He has three years of experience in modeling the fate and transport of chemicals in the subsurface. While working on his MS, he also worked as a teaching assistant and as a research assistant.

Table 2
PRAXIS Project Team Members

Responsibility	Team Member
Program Manager / Contracts	Mary Scarpetti
Project Manager / Principal Engineer	Bo Stewart
Subsurface Modeling/Data Analysis	Mike Chendorain
Equipment Installation & Maintenance	Steven Scarpetti

8. REFERENCES

Molz, F.J., R. H. Morin, A. E. Hess, J. G. Melville, and O. Guven, 1989, "The Impeller Meter for Measuring Aquifer Permeability Variations: Evaluation and Comparison with Other Tests," *Water Resources Research*, Vol. 25, No. 7, pp. 1677-1683.