OR01SS13 - Novel Hotpoint Detector for In Situ DNAPL Analysis

2001 Mid-Year Review
Technical Summary

The targeted problem for this project is the characterization of sites with Dense Non-Aqueous Phase Liquid (DNAPL) contamination in unsaturated soil or rock; four Site Technology Coordination Groups have expressed the need for better DNAPL detection capability and eighteen of these specific needs are listed in the Technical Task Plan for this project. Present technologies for measuring concentrations and the spatial distribution of common DNAPL contaminants [trichloroethylene (TCE), per(or tetra)chloroethylene (PCE), and, occasionally, carbon tetrachloride] have significant limitations, particularly for in situ assay and characterization. At ambient soil and groundwater temperatures (5-20°C), the solubility and vapor pressure of TCE are both so extremely low that in situ analysis of the soil gas phase for TCE is inherently limited to the soil in direct proximity to a penetrometer probe sampler port. Thus, significant amounts of TCE, which may be near an in situ sampling probe, can easily remain undetected resulting in low confidence in the sensitivity and accuracy of in situ CPT soil gas sampling. However, attempts to overcome this limitation by heating soil around a probe to sample from a larger soil volume have also met with limited success because of the difficulty of transferring heat imposed by the low thermal conductivity of soil. This hotpoint DNAPL detector project is attempting to overcome both of these limitations of sampling and heating a large volume of soil around a CPT sampling point by broadcasting radio-frequency radiation from the probe into the surrounding soil to heat it in situ; a significant volume of soil (i.e., 10-20 L) is targeted for heating to at least 85°C so that most of any contained TCE can be presented to the probe's sampling port at high concentration in the gas phase. In FY01, our objective is to establish a proof-of-principle that this10-20 L volume of soil can be heated from ambient temperature to 85°C in a relatively short interval (2-10 min) so that a complete in situ soil profile (i.e., 0-30 ft) of TCE concentration can be obtained during CPT characterization in a single day. This capability will provide both the spatial resolution and sampling of adequate soil volume per sampling interval to overcome the difficulties of present CPT techniques for in situ TCE measurement.

There is no short-cut method to add the heat required to raise the temperature of a 20 L volume of soil from ambient to 85°C; it requires significant amounts of heat (58 calories/L of soil at typical bulk density and field moisture capacity) to be generated in situ and, thus, the transmission and adsorption of significant amounts of RF energy. Radio- and microwave-frequency heating is an established method to heat materials in situ where moisture and its characteristic conductance is responsible for most of the radiation adsorption. However, the selection of a specific frequency or band of frequencies to broadcast into the soil determines the volume of soil in which this energy will be attenuated. There is a trade-off in the design of such in situ heating systems; if RF penetration is too far because the frequency selected is too small, then a large volume will be heated but, at a given power level, this could take a long time. Such a scenario may be ideal for in situ striping of TCE from a large soil volume during a remedial action but would be extremely time consuming (expensive) during CPT site characterization. If the frequency selected is too large (e.g., microwave), then penetration into the soil will be shallow and too small a volume will be heated (and, since the energy will be adsorbed near the probe, the probe could be overheated). We are currently performing electric and magnetic field attenuation measurements around a small dipole antenna designed to fit on a CPT drill rod train. Frequencies between 1 and 500 MHz are being examined using dry and field-saturated soil to determine an optimum frequency for this design trade-off between penetration and heated volume. In addition, the impedance of this antenna-soil geometry has been determined over the same range of frequency and soil moisture so that a variable impedance-matching circuit can be constructed to adjust the impedance of the soil-antenna to the 50-ohm impedance of standard RF power supplies and coaxial cables which must be used to conduct RF radiation from the ground surface to the CPT probe down in the soil; otherwise, variable and unknown RF power reflection could occur during transmission resulting in inefficient soil heating and probable probe overheating. By the end of April we should have an optimum frequency selected for our targeted 20-L soil volume and have initiated in situ heating tests at that scale to measure heating by transmitting 2-10 kW of RF power. This will be compared to a "baseline" using a contact resistance heater applying as much power as the soil can accept as limited by its thermal conductance (typically, 0.15 W/m-^{o}K). After the heating configuration is optimized and tested, similar configurations, containing TCE at various distances from the probe, will be tested to demonstrate this technology's enhanced sampling capability.

User Relevance and Technology Maturity Summary

This site characterization technology has not been reviewed for advancement through a gate; as initially proposed, we placed this technology into Stages 4-6, Advanced Development and Demonstration. After 12-months from the start of this project (i.e., in November 2002), a decision point has been proposed for initiation of a field test (pass Gate 5). At the end of the second year, the technology is proposed for transfer and deployment (pass Gate 6 into Stage 7, Deployment and Implementation). Understandably because of the highly developmental stage of the technology, we do not yet have a commitment from an end-user to implement the hotpoint detector although we have interest from one (OR-221 - Y-12 Remedial Action) and we have contracted for technical support with our probe design with Applied Research Associates, Inc., an experienced CPT designer and operator at DOE and DOD sites. A technical peer review of this project has been completed by the ASME Review Panel; the five review recommendations of this panel have been understood and incorporated into our research plan although no formal document changes were deemed necessary at this time. It is presently difficult to perform a cost-benefit analysis for this technology because the baseline technology to which it must be compared (in situ gas sampling without heating) is so poor (i.e., costly) that few end users are even contemplating implementing it; site characterization of the spatial distribution of TCE contamination remains a very difficult problem to address. It is too early to determine if this technology will meet current E, S,& H protection levels compared to the baseline although a more robust, accurate, and confident TCE spatial distribution during site characterization must work in favor of safer remedial actions as well as cost reductions. A Technology Safety Data Sheet will be prepared prior to the field demonstration in the second year. A NEPA Action Review for this project has been completed and it is covered by an existing DOE Categorical Exclusion; the project has also been reviewed following our organization's E, S, & H project review procedure. Intellectual property issues have been addressed with a patent idea disclosure submitted during the initiation of this project. Our contract with Applied Research Associates (ARA), Inc., is designed to get this technology into a field demonstration during its second year;

ARA can vend this technology using its present and former clients and familiarity with their sites.