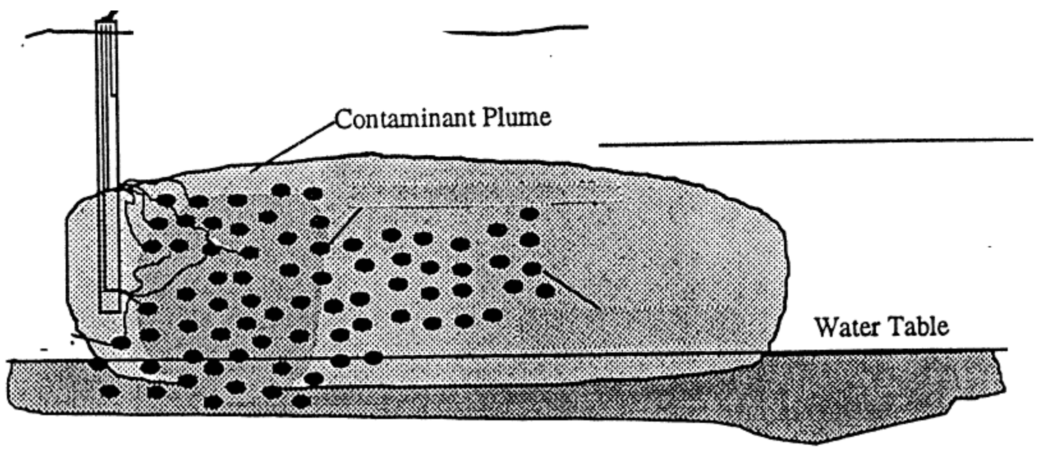
Beyond the Bioremediation Black Box...

Successful Continuous, Real-Time Monitoring of Biological Treatment Technologies



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A. Identification and Significance of the Problem or Opportunity

The majority of the DOE sites slated for remediation are contaminated with volatile organic compounds (VOCs), ranging from the lighter hydrocarbons such as gasoline, acetone, and toluene to the heavier chlorinated hydrocarbons like trichloroethylene (TCE). Sites located in the vadose zone (above the water table) wili typically be remediated by soil washing (excavation and ex-situ treatment), biodegradation, soil vapor extraction (to remove volatiles), or thermally enhanced extraction processes such as steam stripping. Also, naturally occurring bioremediation (sometimes called bioattenuation) is both an available, and in many cases unavoidable, process that can be utilized at certain sites as a low cost, low involvement remediation alternative.

Monitoring of soil contaminants during the remediation process is required to assure that they are being controlled and that the remediation effort itself is not increasing undesirable contaminant movement at the site or creating dangerous by-products. An example includes the creation of vinyl chloride as a by-product of arrested TCE bioremediation (natural or planned). The effectiveness (and completeness) of a remediation effort must also be determined, since small amounts of residual contamination will remain in the soil. The monitoring methods currently in use are highly varied and depend on site, process, and project manager characteristics. In many cases soil samples are removed for laboratory analysis or soil gas samples are drawn and analyzed with field portable analytical instruments. Microbial counts are taken and certain parameters are closely monitored such as temperature, pH, salinity, dissolved oxygen, and oxidation-reduction (redox) potential. This approach is time consuming, expensive, and does not provide a continuous, real-time picture of subsurface biological processes. The **“black box’~** remains intact and corrections or adjustments to the remediation system that may need to occur immediately can be delayed days to weeks.

This situation could be greatly improved by taking a step back and identifying key bioremediation parameters. First is the need for real-time contaminant plume monitoring at multiple subsurface locations. In many cases, part per million or even part per thousand accuracy will suffice if real-time, continuous, unattended operation can be achieved. Second is the ability to open the subsurface black box of biological processes. Biodegradation would benefit from knowledge of subsurface processes such as the creation of dangerous by-products, oxygen levels available to microbes, carbon dioxide concentration (an indicator of biological activity), etc. Third is the variety and complexity of the monitoring technologies currently available to meet these demands. Many are adaptations of complex, comprehensive laboratory techniques. The use of these technologies may be appropriate to fulfill regulatory requirements, to gain a deeper understanding of the specific process, or to obtain extremely accurate results, but are generally unnecessary for many of the day-to-day decisions involved in running a successful bioremediation program. This is where a **modular, integrated, real-time, stand-alone** multipoint soil vapor sampling and analysis system can provide the flexibility and cost savings that would allow a system such as this to literally pay for itself. **The key to this approach** is the realization that processes generally have “signature” attributes. While these attributes may not completely characterize a process, they can provide the information necessary to quickly “get a handle on the process’ and the determination of the values of these attributes can in turn be used to momtor and control the process more efficiently. For environmental applications, soil gas composition is one signature attribute and is extensively utilized in this approach to provide an efficient, practical solution to the advanced remediation analysis technology need.

B. Background, Technical Approach, and Potential Uses

1. Background and Technical Approach

This effort proposes to build on our experience with multi-point soil vapor sampling and analysis by developing a methodology to fulfill the practical monitoring needs of biological treatment technologies. This approach will be validated using a small suite of highly focused laboratory tests. It will be utilized in Phase II in conjunction with a system currently used to monitor soil vapor extraction processes. This is not simply an improvement to an existing technical capability, but an organized, systematic research and development effort designed to provide technology implementers with a practical, real-time window on the day-to-day status of traditionally “closed” biological processes. The current multi-point soil vapor extraction monitoring system was initially designed for Sandia National Laboratories (SNL) to collect only subsurface pressure data to determine the effects of barometric pressure changes on contaminant movement in the vadose zone. It was subsequently enhanced to study the same phenomenon through the real-time analysis of soil gas samples taken from an area injected with an inert tracer gas. Recently, it has been upgraded for Los Alamos National Laboratories (LANL) to monitor the radius of influence of a soil vapor extraction system. This real-time, long-term unattended operation is achieved by utilizing a Bruel and Kjaer (B&K) Model 1302 photoacoustic soil gas analyzer controlled by a palmtop computer. The system is designed to modularly accommodate 16 to 64 discrete vapor sampling points and can be interfaced to additional sensors to monitor oxygen concentration, subsurface pressure, or to obtain more accurate measurement of other specific compounds. Each of these enhancements required significant research and development to create a robust, easily adaptable monitoring system. As a result of this, the system was later utilized for additional, originally unanticipated, testing at each site. At SNL, the system was used to monitor thermally enhanced remediation at a nearby site. At LANL, the system was used to conduct several additional vapor movement tests including monitoring barometric pressure effects, vapor extraction influence, and yearly cyclic subsurface pressure changes.

There are several areas that must be examined before a successful monitoring system can be deployed. First, a better understanding of the "signature" (core) attributes of bioremediation must be established. For bioremediation, several factors *seem* important such as oxygen content, carbon dioxide, methane, and water, to name a few. These factors depend on the dominant process occurring, but as can be seen from Figure 1, there are commonalties between many of the pathways. Which of the inputs, intermediate products, and outputs of biological processes most accurately characterize the progress of an in-situ bioremediation project and most accurately can immediately determine or predict its needs?

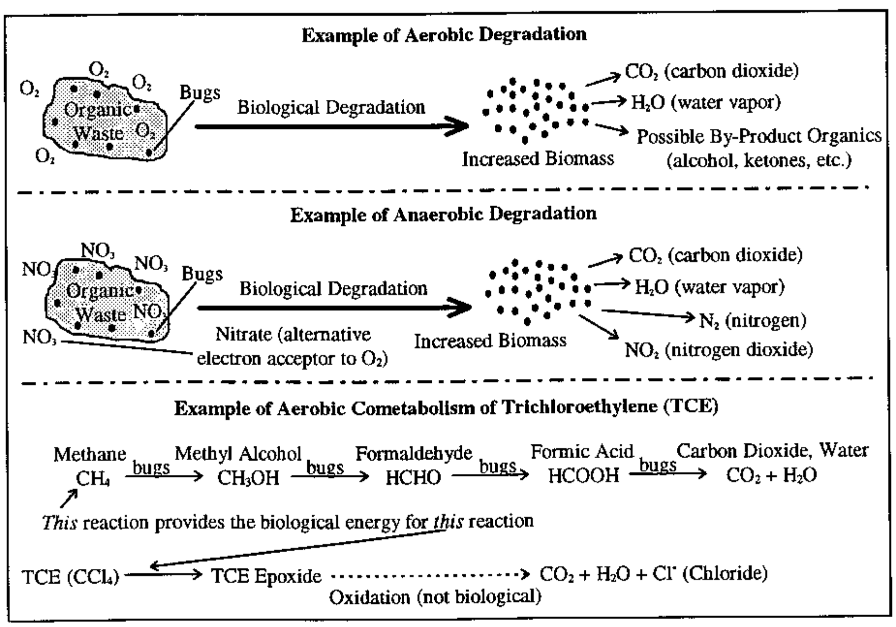

Figure 1. Three Characteristic Microbial Degradation Pathways

Second, the ability to effectively monitor these attributes must be evaluated. Can the B&K photoacoustic gas analyzer be used to measure some of these attributes? Can carbon dioxide from biological processes be differentiated from naturally produced carbon dioxide? If not, would another signature attribute be more practical? Can an inexpensive electrolytic oxygen sensor be used to monitor soil gas oxygen levels? This evaluation will be done in three main ways:

working closely with a B&K applications engineer to determine detectability of soil gases of interest, correlating various sensor specifications with remaining gases, and by looking at detection issues (such as interference and transport).

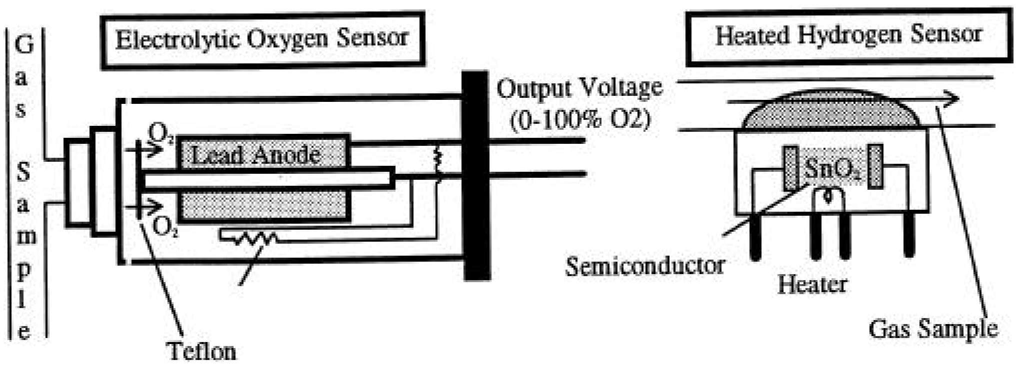

Figure 2. Typical Candidate Sensors for Integration

Third, the areas mentioned above must be validated in bench scale laboratory tests. These tests will range from simple “yes or no” detection tests to more elaborate soil column testing for process evaluation in actual biological environments. Fourth, data reduction and representation issues must be examined. The most technically advanced, autonomous, efficient monitoring system is worthless if the data cannot easily be converted into a form usable by humans. This is especially an issue in real-time monitoring where the amount of data that can be collected can easily overwhelm the ability to meaningfully represent it.

There is an extremely high probability of success with this approach due to the built-in flexibility of the underlying concepts and measurement techniques. The basic multi-point onitoring system has been validated through three years of testing at SNL The gas analysis capability has been thoroughly tested during tracer tests at SNL and during a State of New Mexico mandated sampling program at LANL. Most recently the upgrade of the system for monitoring of soil vapor extraction at LANL has resulted in the usage of a Hewlett Packard palmtop computer to achieve a high degree of programming flexibility (by utilizing standard personal computer software) and autonomy. The system is now modular to allow a variety of sensors to be integrated into the gas stream and into the electronics. Finally, the photoacoustic gas analyzer by B&K has several key advantages over currently available field gas analyzers. It is based on infrared bsorption spectroscopy, a technique that is well established in over 30 years of application. However, it does not actually interpret a spectrum, it calculates gas composition and concentration through the use a combination of acoustic response of gas to intense, pulsed infrared light, a comprehensive cross-compensation scheme, and calibrations that take into account individual unit roperties. In short, it combines the best aspects of infrared absorption spectroscopy into an extremely robust, accurate analyzer with well understood limitations. B&K has created a real-time, standalone device where up to five gases can be analyzed simultaneously, total control through a senal interface is possible, power requirements are such that it can be run off a small trailer mounted solar power system, and that requires no carrier gases, special pumps, or valving. These five gases can be chosen from over 230 compounds that have been successfully measured by B&K with this analyzer.

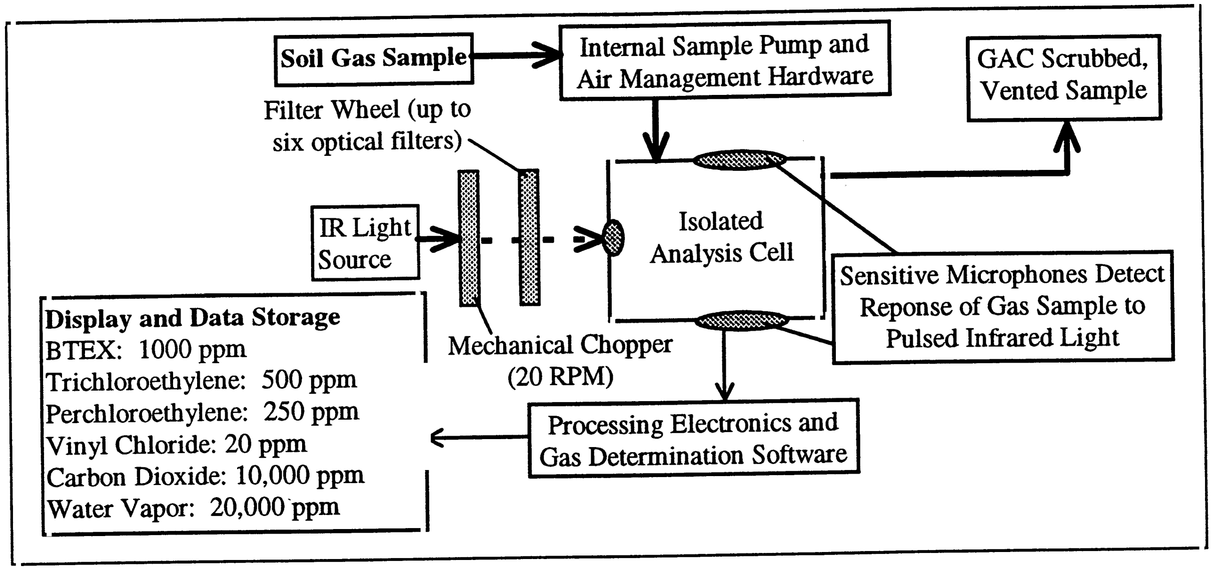

Figure 3. Bruel and Kjaer 1302 (Stand-alone, Continuous, Real-Time Gas Analysis

2. Anticipated Results of the Approach and Commercialization Potential

Successful implementation of this approach would result in a single, modular system that would provide a real-time viewport on subsurface biological processes occurring in the vadose zone and, indirectly, in the upper portions of the water table. Monitoring that has traditionally not been done due to cost and difficulty could now be done on a continuous basis, furthering the biological remediation knowledge base. Safety issues can also be addressed by this system. For example, the detection of dangerous vinyl chloride as a result of incomplete biological breakdown of TCE is a large DOE issue. This breakdown can result from either planned/arrested biological treatment or natural processes and can create a worse problem that initially present. Also, this system could provide a cost-effective first step for site feasibility studies. Initial continuous monitoring could be conducted to determine whether a site is a candidate for natural bioremediation or possibly minimal action to stimulate natural processes (such as bioventing). The interest in commercialization of this system is high. Based on initial applications of the system for barometric pumping at SNL, several new areas of opportunity have arisen including tracer gas diffusion studies at SNL, in-situ barrier validation testing at SNL, and soil vapor extraction monitoring at LANL. Informal interest has arisen to utilize this system at the LANL Airport Landfill bioremediation site through a joint project with Daniel B. Stephens and Associates. A first step in this effort will be the analysis of soil gas samples (taken using SummaTM canisters) by both a laboratory Gas Chromatograph (GC) and by the B&K to validate feasibility of this approach for this specific project. Section F of this proposal, Related Research or R&D, also contains a discussion of the shortcomings of many techniques currently in use and cites several recent articles and books that express a need for this type of system.

3. Significance of the Phase I Effort

Phase I will demonstrate the practicality and efficiency of the approach and provide the basic design parameters for the system to be built in Phase II. These parameters are derived from the signature attributes of bioremediation and include gases of interest to be analyzed, analysis