LA-UR-95- 698

Conf-950216--73

TITLE: **In Situ Bioremediation: Cost Effectiveness of a Remediation Technology Field Tested at the Savannah River**

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MAR 10 1995
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SUBMITTED TO: WM Symposia, Inc., 245 South Plumer, Suite #19, Tucson, AZ 85719, February 27-March 2, 1995

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In Situ Bioremediation: Cost Effectiveness of a Remediation Technology Field Tested at Savannah River

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ABSTRACT

In Situ Bioremediation (ISBR) is an innovative new remediation technology for the removal of chlorinated solvents from contaminated soils and groundwater. The prinicpal contaminant at the SRID is the volatile organic compound (VOC), tricloroetylene(TCE). A 384 day test run at Savannah River, sponsored by the U.S. Department of Energy, Office of Technology Development (EM-50), furnished information about the performance and applications of ISBR.

In Situ Bioremediation, as testd, is based on two distinct processes occcurring simultaneously; the physical process of in situ air stripping and the biolgoical process of bioremediation. Both processes have the potential to remediate some amount of contamination. A quantity of VOCs, directly measured from the extracted air stream, was removed from the test area by the physical process of air stripping. The biological process is difficult to examine. However, the results of several tests performed at the SRID and independent numerical modeling determined that the biological process remediated an additional 40% above the physical process. Given this data, the cost effectiveness of this new technology can be evaluated.

INTRODUCTION

The purpose of this report is to study the cost effectiveness of In Situ Bioremediation (ISBR) with horizontal wells as tested at the Savannah River Integrated Demonstration (SRID) site in Aiken, South Carolina. ISBR is an innovative new remediation technology for the removal of chlorinated solvents from contaminated soils and groundwater. The principal contaminant at the SRID is the volatile organic compound (VOC), trichloroethylene (TCE). A 384 day test run at Savannah River, sponsored by the U.S. Department of Energy, Office of Technology Development (EM-50), furnished information about the performance and applications of ISBR.

- The overall cost effectiveness of In Situ Bioremediation (ISBR) is based on the cost sensitivity of the biological component; as the biological addition increases, the cost per pound of VOCs remediated decreases.

- The short-term cost of ISBR with a biological addition of 40% above the vacuum component is $21 per pound of VOCs remediated. The worse case scenario, ISBR + 0% addition costs $29/lb of VOCs remediated, and is based solely on the vacuum component.

- The baseline pump and treat/soil vapor extraction system costs $31/lb in the short-term and has no possibility of a biological addition.

- Life-cycle analysis shows that ISBR is more cost effective than the baseline pump and treat/soil vapor extraction system.
- As demonstrated, ISBR has a possible savings of $1 million at the SRID site alone.

In Situ Bioremediation is based on two distinct processes occurring simultaneously: the physical process of in situ air stripping and the biological process of bioremediation (see Figure 1). Both processes have the potential to remediate some amount of contamination. A quantity of VOCs, directly measured from the extracted air stream, was removed from the test area by the physical process of air stripping. The biological process is difficult to examine. However, the results of several tests performed at the SRID and independent numerical modeling determined that the biological process remediated an additional 40% above the physical process. Given this data, the cost effectiveness of this new technology can be evaluated. In addition to calculating the cost effectiveness on the ISBR demonstration at the SRID, sensitivity analysis is conducted in order to determine how the overall cost of ISBR changes in regards to the performance of the biological component. By comparing the overall cost of this system and the price per pound of VOCs remediated against a conventional pump and treat/soil vapor extraction system, we can evaluate the overall cost effectiveness of the alternative technologies. **(place Figure 1 here)**

SYSTEM CAVEATS

The ISBR demonstration at the SRID was set up to address a "hot spot" of an overall larger VOC contaminant plume. The pump and treat/soil vapor extraction system is engineer designed and presumed to perform optimally. Both pump and treat and soil vapor extraction systems have been tested at the SRID. The baseline system (a combination of pump and treat/soil vapor extraction apparatus) is integrated to avoid overlapping of equipment and materials, and is located in an area exactly like the ISBR demonstration in regards to all necessary site characteristics, including overall concentration of contaminants. By designing both the baseline and the innovative systems to handle equal flow and assuming equal vacuum extraction performance, a level playing field for a cost comparison is created.

ANALYSIS

The data used in these analyses have a "field demonstration" level of confidence and are based on an actual field demonstration. The performance comparison consists of **Plan 1**, which is based on the new ISBR technology as demonstrated at the SRID, and **Plan 2**, which is based on "equivalent" conventional technologies, pump and treat/soil vapor extraction, necessary to remediate the contamination problems addressed by ISBR. Plan 2 is constructed so that it remediates the same conditions treated by ISBR at the SRID. In order to be fair to both technologies, equal physical process performance is forced from both Plan 1 and Plan 2. Plan 1 and Plan 2 are compared based on what it costs to operate them over equal periods of time. Performance data indicate that the vacuum component of ISBR destroyed 12,096 pounds of VOCs in 384 days, and an additional 40% above the vacuum component was destroyed by bioremediation. The vacuum component data is used in the pump and treat/soil vapor extraction system, assuming that the equal flow rates will remove the same quantity in an equal amount of time.

The ISBR system, as tested, uses two horizontal wells. The first well is an injection well, 300 ft long and 165 ft deep (about 35 ft below the water table). The second well is an extraction well, 175 ft long and 75 ft below the surface (in the vadose zone). A concentration of methane (between 1% and 4%) and any necessary chemical nutrients (nitrogen in the form of nitrous oxide and phosphorus in the form of triethyl phosphate) are blended into the injected air stream to create a biological element for remediation. The methane provides the necessary material substrate for the indigenous microorganism to produce the enzyme methane monooxygenase which, in turn, degrades the principal contaminant, trichloroethylene (TCE). For the conventional technologies used in Plan 2, four vertical SVE extraction wells are assumed to be equal in area influenced to the one horizontal extraction well of ISBR. One vertical pump and treat well is also used. Volatilized contaminants from both remediation systems are sent to a catalytic oxidation off-gas system where they are destroyed.

Economic comparisons for short-term costs are made by relying on actual field data and using cost sensitivity analysis; life-cycle costs are estimated in relation to possible time to achieve cleanup. The first economic comparison is a calculation of the short-term costs in relation to performance. Short term costs are those expenses incurred during the immediate field test demonstration of the technologies compared (generally about a year). The equipment capital costs are amortized yearly over the useful life of the equipment, which is assumed to be 10 years. All short-term equipment costs are amortized at 7%, which is the interest on the loan.

For ISBR there is a total cost of about $354,000 with total 16,934 pounds of VOCs being destroyed by the vacuum component and biological component, giving a cost per pound of VOCs remediated at about $21. The integrated pump and treat/soil vapor extraction with 4 vertical SVE wells has a total cost of about $380,000. Assuming an equal vacuum extraction performance of 12,096 pounds of VOCs removed, the integrated system has a cost per pound of VOCs remediated at about $31. A ratio of ISBR to the baseline shows that ISBR is 32% less expensive than the baseline.

Next, an analysis of life-cycle cost is conducted. A real discount rate of 2.3% is used to calculate the present value. ISBR, with its combination of vacuum component and bioremediation, costs $1 million and remediates the site in only 3 years. The baseline takes 10 years to remediate the site and costs $2 million. ISBR, therefore, saves $1 million and 7 years of remediation. Even when we assume the baseline can perform at twice the expected time and cleans the site in only 5 years, it still costs $1.4 million. ISBR still beats the baseline by $400,000 and 2 years remediation time.

Where ISBR has the potential to exceed the baseline technologies is its ability to remediate a portion of the contamination *in situ*, thereby eliminating the need to physically remove the contaminant and process it. Since ISBR relies heavily on the biological component to achieve greater performance, sensitivity analysis is conducted to compare the cost per pound of VOCs remediated versus the performance of the biological component. Of particular interest is ISBR + 0% addition. This is a **worse case** scenario based on a 0% addition from the biological component. It assumes that all the necessary materials are added to stimulate the biological addition, but no additional remediation occurs. In this situation, ISBR still costs slightly less than the baseline, $29 versus $31, respectively. By adding a percent addition of pounds of VOCs destroyed by bioremediation in addition to that removed via the vacuum component, we can examine how the cost per pound changes with respect to the biological component. Six hypothetical percentages are used to account for the bioremediation levels: 0%, 20%, 40%, 50%, 70%, and 90%. Figure 2 shows the various hypothetical additions and the decrease in cost per pound of VOCs remediated. **(place Figure 2 here)**

The baseline technologies in Plan 2 have a constant price per pound of VOCs remediated of $31 because there is no biological component. As the biological addition of

ISBR increases, the price per pound of VOCs decreases. So, even in the worse case scenario where no bioremediation occurs, ISBR breaks even with the baseline. There is, therefore, no cost risk to run ISBR over the baseline system. The savings, however, are quite substantial when the biological component is stimulated. In order for the biological component to occur, it is necessary to inject methane and nutrients into the system. Without this material, only the physical, vacuum component of ISBR is possible. Because the cost of the biological component is so inexpensive, ISBR only has to remediate an additional 1,570 lbs of VOCs over the 12,096 lbs of VOCs remediated with the vacuum component in order for the system to completely pay for the cost of the methane injection. Any additional remediation is achieved at no extra cost and increases the cost savings of ISBR over the baseline technologies.

Next, the total present value cost for operating each plan for five years, including all necessary equipment, is computed. The total equipment costs are included in the first year so that no amortization is needed. As with the short-term cost, the potential cost-savings for ISBR lie with its ability to remediate VOCs in additon to the physical process, thereby lowering the cost per pound and increasing the total amount remediated over equal time. The same hypothetical percent additions of 0%, 20%, 40%, 50%, 70%, and 90% are used. Table 1 shows the decrease in price per pound as bioremediation increases. The $38 per pound of VOCs remediated with the pump and treat/soil vapor extraction remains constant because there is no equivalent biological addition.

(place Table 1 here)

PERSPECTIVES AND COST DRIVERS

The two largest categories in regards to cost for both ISBR and the baseline system are the costs of consumables and labor. The labor and consumables are greater than 85% of the overall operating costs; therefore, if the overall remediation time of the project is shortened, the cost will drop. This is due to the nature of the labor and consumables which are incurred each day of operation. Since ISBR can significantly decrease operation time, ISBR lowers the overall cost of the remediation effort.

APPLICABILITY

ISBR can be very effective in settings where some interbedded thin and/or discontinuous clays are present. ISBR should prove even move successful than in situ air stripping alone because ISBR contains a biological component as well as the physical air stripping process. A potential concern with the use of ISBR is the possible lateral spread of the contaminant plume. If the geology constricts vertical flow, the injection process can push the dissolved contamination concentrically from the injection point. Thus, it may be advisable in heterogeneous formations to use ISBR in conjunction with a surrounding pump and treat system that provides hydraulic control at the site. Note that the limitations on applicable geologic settings described above also apply to soil vapor extraction and pump and treat systems.

REFERENCES

Saaty, R.P., W.E. Showalter, and S.R. Booth. 1994. "In Situ Bioremediation: Cost Effectiveness of a Remediation Technology Field Tested at the Savannah River Integrated Demonstration Site." Los Alamos National Laboratory report No. LA-UR-94-1714 (November 1994).

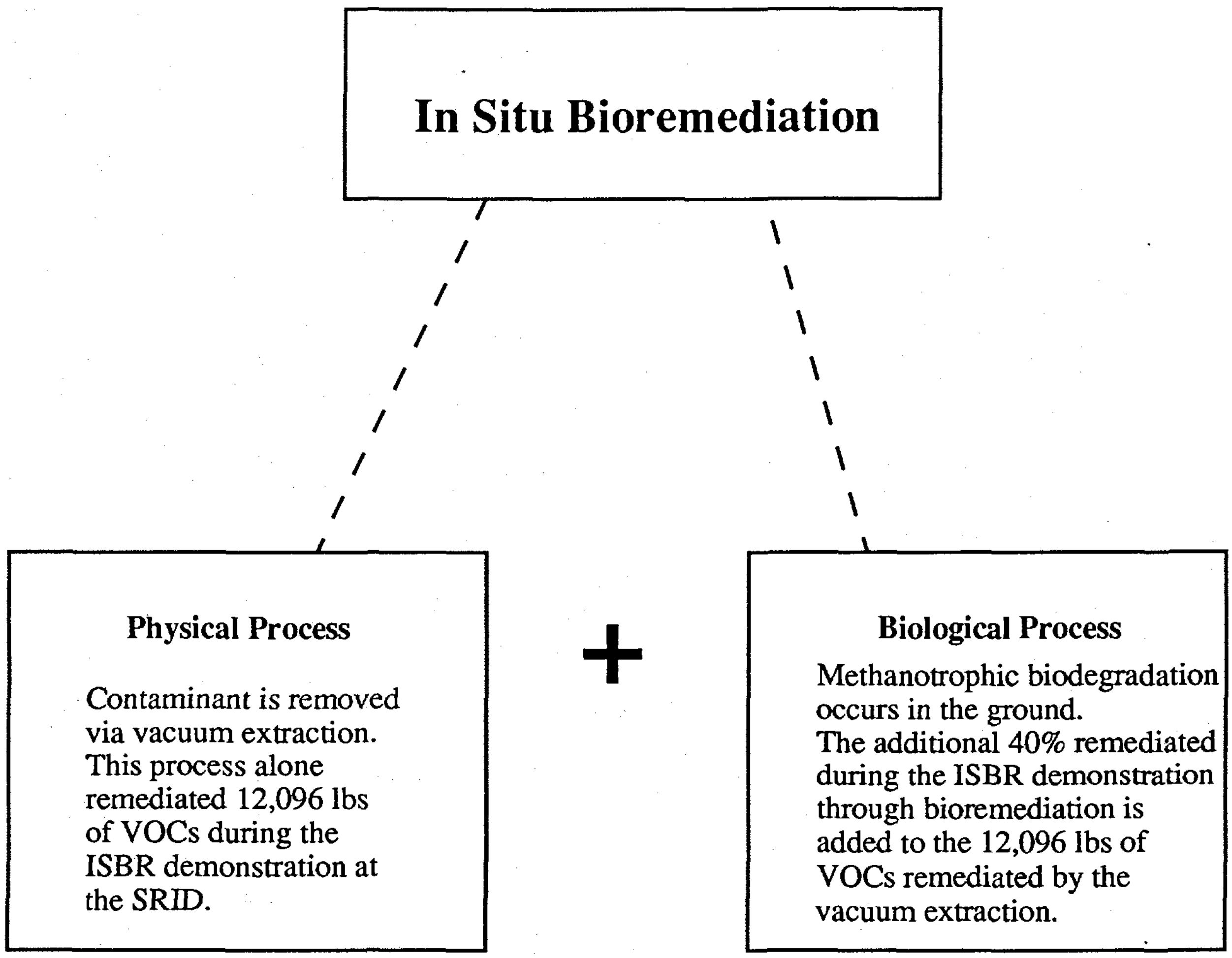

Figure 1: Schematic Diagram of the Two Processes Involved in In Situ Bioremediation

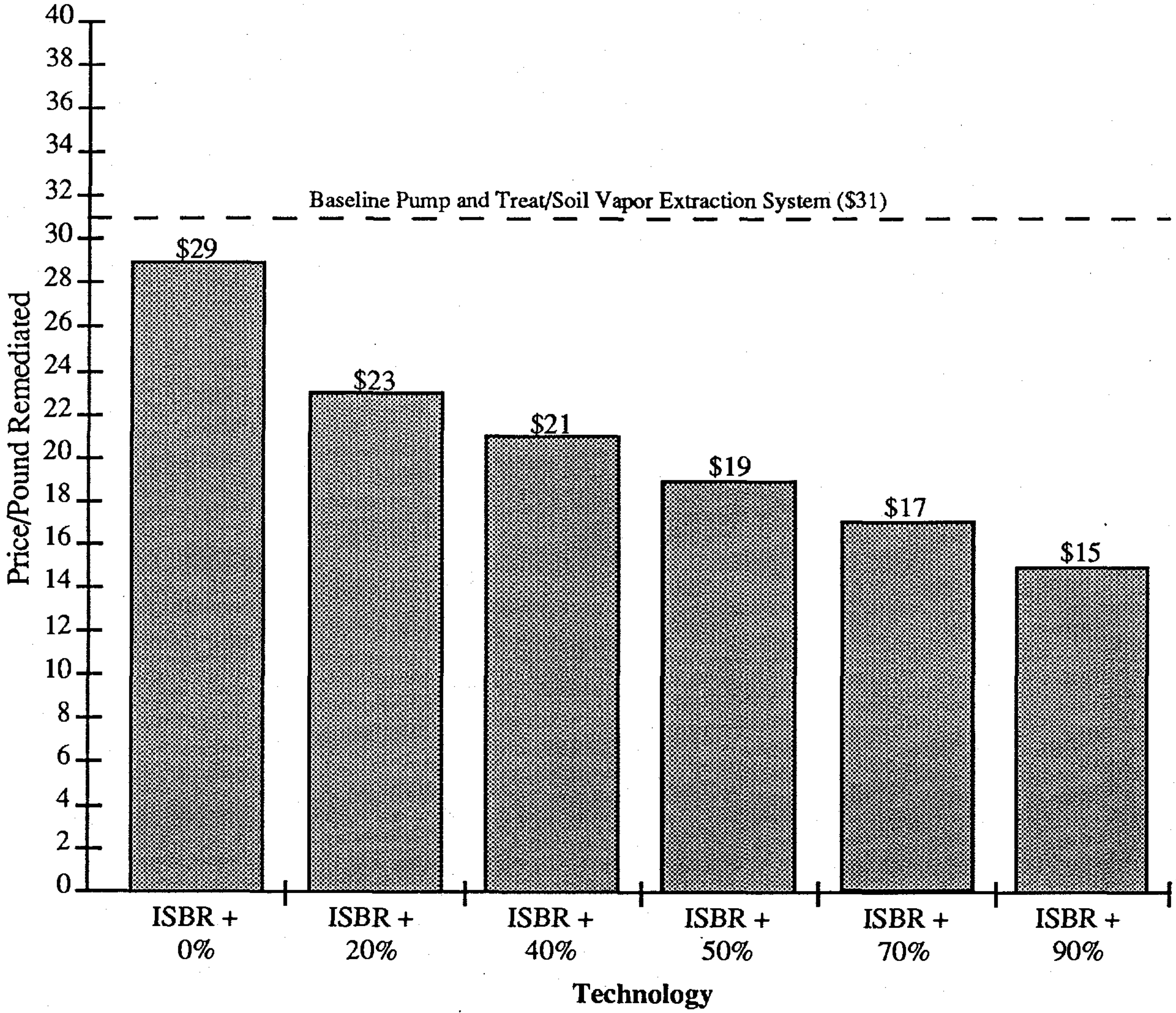

Figure 2: Comparison of Short Term Costs with Various Biological Additions

Table 1: Life-Cycle Cost of ISBR over Five Year Operation in Comparison to Percent Addition

Hypothetical percent addition	Physical component from Life cycle costs (lbs)	Additional Pounds remediated via biological component	New Total pounds VOCs remediated	Price per pound VOC remediated
0%	37,375	0	37,375	$38
20%	37,375	7,475	44,850	$31
40%	37,375	14,950	52,325	$27
50%	37,375	18,688	56,063	$25
70%	37,375	26,162	63,537	$22
90%	37,375	33,638	71,013	$20