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Cost Effectiveness of In Situ Bioremediation 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 principal contaminant at the Savannah River Integrated Demonstration is trichloroethylene(TCE) a volatile organic compound (VOC),. A 384-day test run at Savannah River, sponsored by the U.S. Department of Energy (DOE), Office of Technology Development (EM-50), furnished information about the performance and applications of ISBR.

In situ bioremediation, as tested, is based on two distinct processes occurring simultaneously; the physical process of in situ air stripping and the biological process of bioremediation. Both processes have the potential to remediate some amount of contamination. A quantity of VOCs, directly measured from the extracted airstream, 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 these data, the cost effectiveness of this new technology can be evaluated.

INTRODUCTION

The purpose of this report is to study the cost effectiveness of ISBR with horizontal wells as tested at the 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 TCE. A 384-day test run at Savannah River furnished information about the performance and applications of ISBR.

- The overall cost effectiveness of 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 (or per kg) of VOCs remediated. The worst case scenario, ISBR + 0% addition costs \$29/lb (or per kg) of VOCs remediated, and is based solely on the vacuum component.
- The baseline pump-and-treat/soil vapor extraction system costs \$31/lb (or per kg) 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 airstream, 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 these 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 to determine how the overall cost of ISBR changes in regard to the performance of the biological component. By comparing the overall cost of this system and the price per pound (or per kg) of VOCs remediated against a conventional pump-and-treat/soil vapor extraction system, we can evaluate the overall cost effectiveness of the alternative technologies.

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 regard 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. 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 are used in the pump-and-treat/soil vapor extraction system, assuming that the equal flowrates 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 (91.4 m) long and 165 ft (50.3 m) deep (about 35 ft or 10.6 m below the water table). The second well is an extraction well, 175 ft (53 m) long and 75 ft (23 m) 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 airstream 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, TCE. For the conventional technologies used in Plan 2, four vertical soil vapor extraction (SVE) 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 the total cost is about \$354,000, with a total of 16,934 lb (7,681 kg) of VOCs destroyed by the vacuum component and biological component, giving a cost per pound (kg) of VOCs remediated of about \$21. The integrated pump-and-treat/soil vapor extraction with 4 vertical SVE wells costs about \$380,000. Assuming an equal vacuum extraction performance of 12,096 lb (5,487 kg) of VOCs removed, the integrated system has

a cost of about \$31 per lb (kg) of VOCs remediated. 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 that the baseline can perform at twice the expected time and clean 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. Because 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 worst 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.

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 lb (712 kg) of VOCs over the 12,096 lb (5,487 kg) 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 is in its ability to remediate VOCs in addition 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 (kg) as bioremediation increases. The \$38 per lb/kg of VOCs remediated with the pump-and-treat/soil vapor extraction remains constant because there is no equivalent biological addition.

PERSPECTIVES AND COST DRIVERS

The two largest categories in regard 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 that are incurred

each day of operation. Because 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 more 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.

Figure and Table Captions

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 5-year operation in comparison to percent addition.

FIGURE 1: Schematic diagram of the two processes involved in in situ bioremediation

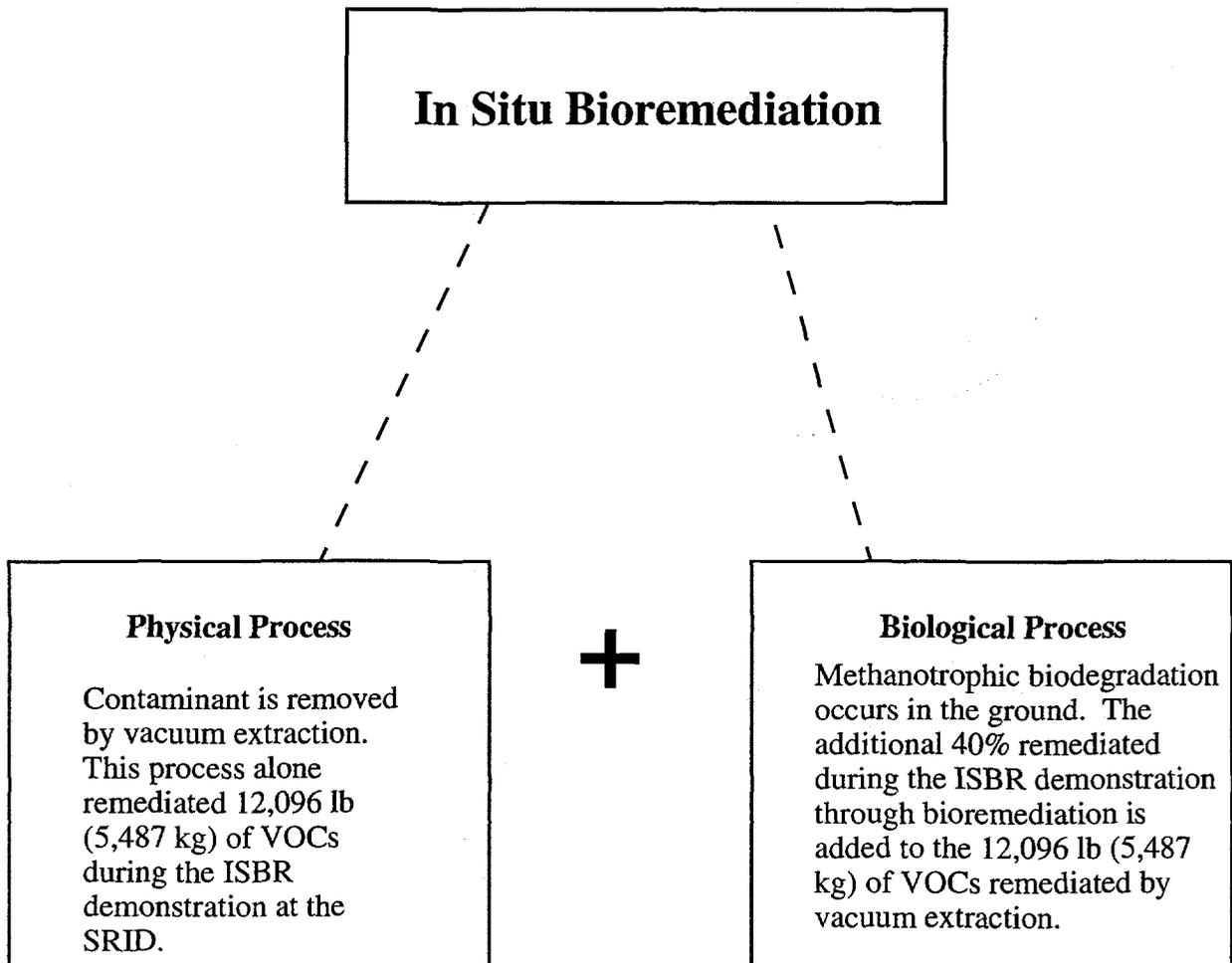


FIGURE 2: Comparison of short-term costs with various biological additions

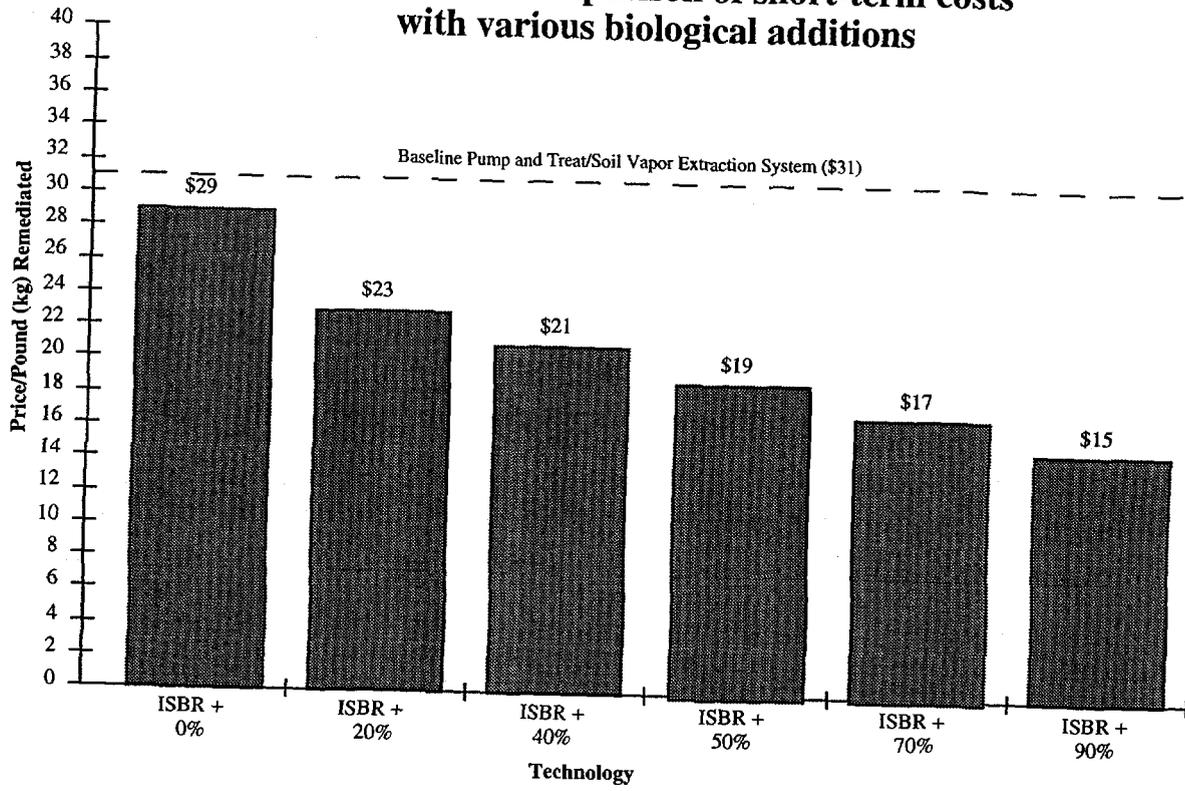


Table 1: Life-Cycle Cost of ISBR over Five Year Operation in Comparison to Percent Addition

Hypothetical percent addition	Physical component from life-cycle costs (lb)	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

KEY WORDS

ISBR

VOC

TCE

SRID

Methane Monooxygenase

In Situ Bioremediation

Volatile Organic Compound

Trichloroethylene

Savannah River Integrated Demonstration

Enzyme which degrades the TCE