TITLE Cost Effectiveness Analysis of the SEAMISTTM Membrane System Technology

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COST-EFFECTIVENESS ANALYSIS OF THE SEAMIST™ MEMBRANE SYSTEM TECHNOLOGY

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ABSTRACT

This report describes the cost and performance characteristics of SEAMIST™, an innovative technology that facilitates measurements of contaminants in both vertical and horizontal vadose zone boreholes. This new technology consists of an airtight membrane liner that is pneumatically emplaced inside the borehole. The positive air pressure inside the liner maintains the integrity of the borehole structure. Sampling ports with attached tubing, absorbent collectors, or various in situ measuring devices can be fabricated into the liner and used for monitoring volatile organic compounds (VOCs), semivolatile organic compounds (SVOCs), pesticides, herbicides, polynuclear aromatic hydrocarbons, polychlorinated biphenyls, or radioactive substances. In addition, small instruments can be guided through the lined borehole and measurements taken inside at specified intervals.

The SEAMIST™ technology is simple in its concept and design. In some of its applications it replaces significantly more complicated and more costly methods of obtaining the same information. In other applications, SEAMIST™ performs tasks and obtains information in ways that have no simple baseline technology for comparison. The purpose of this study is to analyze the cost and performance effectiveness of this new technology. To do so, we constructed four hypothetical scenarios in which utilization of the SEAMIST™ system can address various needs of the Department of Energy's environmental remediation program. Two of the scenarios involve vertical boreholes (or vertical instrument configurations) and two involve horizontal boreholes (or horizontal instrument configurations). The four scenarios jointly address contamination by VOCs, SVOCs, various water-soluble toxic substances, and low-level radioactive waste. One of the scenarios involves towing an instrument through a borehole and taking measurements of moisture levels in the surrounding soil.

We determined that there are some characterization and/or monitoring situations in which the use of SEAMIST™ has definite performance advantages over the conventional alternative. For other situations, the use of SEAMIST™ may be the only alternative. For cases in which pore fluids are needed for analysis, SEAMIST™ coupled with absorbent wicking pads is more convenient, more effective, and has higher potential accuracy than traditional lysimeters. In situations where direct vertical access to the area of interest is not possible, the use of a SEAMIST™ membrane equipped with vapor monitoring ports and/or absorbent wicking pads in a horizontal borehole may be the only feasible method. However, the successful use of SEAMIST™ does require at least metastable borehole soil conditions. Unstable geology can preclude its use in certain situations.

We have also determined that there are some characterization and/or monitoring situations in which the use of SEAMIST™ is more cost effective than the conventional alternative. When the contamination is deep and hence can not be accessed by direct vertical punching, the use of SEAMIST™ in a drilled borehole to obtain VOC samples is 56% more cost-effective than constructing ports in conventional casing. On the other hand, when the contamination is shallow and direct vertical access is feasible, implanting conventional soil vapor probes is more cost effective than drilling horizontal boreholes and using SEAMIST™. The use of SEAMIST™ with absorbent wicking pads for obtaining pore fluid samples at various vertical depths is over three times more cost effective than the use of conventional lysimeters. In situations where the SEAMIST™ membrane serves as a substitute for conventional casing, cost savings on the membrane (versus casing) can be as high as 90%. The most cost- and performance-effective applications of SEAMIST™ occur when the requirements for more than one characterization technology are combined. Whereas several different characterization applications can be integrated into one SEAMIST™ system, the same is not usually true of the corresponding baseline technologies.

I. INTRODUCTION

The Department of Energy (DOE) and the Environmental Protection Agency (EPA) are presently faced with the massive task of cleaning up contaminated sites all over the United States. Over the next few decades, these sites will have to be identified, characterized, remediated, and then monitored. There is an urgent need for innovative technologies to assist in this effort, technologies that can do the job better, faster, and at less cost, while simultaneously posing minimal additional risk to human health and the environment.

Contaminants that leak or are disposed of at ground level diffuse outwardly in a pattern that depends on the characteristics of the soil. The resulting three-dimensional contaminant diffusion pattern is referred to as the "contaminant plume." The plume initially exists in the vadose zone, that region between the earth's surface and the saturated or groundwater-containing zone, but eventually can spread into the saturated zone and infiltrate the groundwater. It is critical to the success of any proposed remedial activities to accurately assess the extent of the contamination to the vadose zone. One of the most common tools used for this task is the vadose-zone borehole. Coupled with a wide variety of instrumental measurement techniques, a series of strategically placed boreholes facilitates vertical and horizontal delineation of the plume boundaries and also permits ongoing monitoring during and after the remediation process. Other techniques include soil vapor implants, cone penetrometer probes, and geophysical techniques.

Traditionally, boreholes are cased with polyvinyl chloride, Teflon®, stainless steel, and in some cases aluminum [11]. Borehole casing serves several purposes, including prevention of vertical cross-contamination and borehole collapse. Casing can also serve as a platform to position sampling devices such as vapor transport tubes or towing cables, or to vertically segment the borehole into discrete sampling zones. Some of the drawbacks of traditional borehole casing include its rigidity, its cost, contaminant leaching of some casing materials, and the fact that it is very expensive and time consuming to remove casing once it has been installed.

SEAMIST™ is an innovative technology that can function both as a borehole casing and as a support platform for sampling devices and instrumentation [5, 6, 8-10]. It is basically an impermeable membrane liner attached to a tether that is emplaced into a vadose zone borehole using a pneumatic pressure/canister system (see Figures 1-3). The liner is installed by progressive eversion; nothing is dragged over the surface of the borehole during the installation process. Positive pressure is supplied to maintain the integrity of the borehole once the liner is emplaced using either air, a filler material such as sand, or even grout.

SEAMIST™ can facilitate the sampling capability of the borehole system. It can act as a support structure for a series of absorbent wicking pads that directly contact the surface of the

Figure 1. SEAMIST™ system deployment sequence: a) canister placed on surface casing, b) membrane inverting into borehole under air pressure, and c) detail of the membrane inversion process.

Figure 2. Range of SEAMISTTM canister sizes. The largest is 30 in. tall.

Figure 3. A person using a 20 in. long SEAMIST canister to monitor a trench for gas.

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borehole or provide a platform for a series of volatile organic compound (VOC) monitoring ports or fiber optic sensors. The SEAMIST™ tether can be replaced by an electronic cable, which can then be used to tow an instrument through the borehole as the instrument takes measurements. For example, a neutron logging tool can be towed through a borehole while taking measurements of the moisture level of the surrounding soil at specified intervals. The SEAMIST™ membrane can also be custom-designed to facilitate gas permeability measurements.

SEAMIST™ was introduced at the 1990 National Ground Water Association *Outdoor Action Conference* in May of 1990 [6]. Since May of 1991, two SEAMIST™ membrane systems have been monitoring a tritium plume at the Lawrence Livermore National Laboratory in Livermore, California [10]. SEAMIST™ was demonstrated in April 1992 at the Los Alamos National Laboratory's TA-54 Area G in a horizontal borehole under a radioactive land disposal pit [8]. The borehole was 4-inches in diameter and 230 ft long. The Los Alamos system consisted of the following: a membrane equipped to collect gas and liquid samples, gas permeability measurement instruments, a connecting basepipe, an emplacement canister, and a 1/2 horsepower compressor. Since that time, SEAMIST™ has also been used at the Waste Isolation Pilot Project in Carlsbad, New Mexico; at Sandia National Laboratory in Albuquerque, New Mexico; at the Savannah River site in Aiken, South Carolina; at the Hanford site in Richland, Washington; and at several commercial sites [8]. Systems have also been built for future use at Oak Ridge National Laboratory in Oak Ridge, Tennessee.

The purpose of this report is to investigate and describe on the cost and performance effectiveness of the SEAMIST™ membrane and instrumentation emplacement technology by analyzing how it compares to existing methods designed to accomplish the same task or set of tasks. In this analysis, we attempt to describe SEAMIST™ in a sufficient number of different scenarios in order to adequately demonstrate the breadth of its capabilities. Each scenario emphasizes a different function or addresses a different need of the environmental remediation objectives of the Department of Energy. Because of the diversity of capabilities of this new technology, each scenario must use a different conventional technology as a baseline of comparison.

For purposes of this report, we constructed five different scenarios in which the SEAMIST™ system can be used. Two of the scenarios involve vertical boreholes or vertical sampling configurations and two involve horizontal boreholes or horizontal sampling configurations. Two of the scenarios involve determining the nature and levels of VOC contaminants, one scenario addresses semivolatile organic compounds and other nonvolatile toxic substances, and one scenario involves determining moisture levels in the soil immediately surrounding the borehole structure. The fifth scenario represents an integration of two of the previous scenarios. It was chosen because it demonstrates an especially valuable

characteristic of the SEAMIST™ technology, that is, its ability to combine more than one characterization technology within one membrane system. All of the applications in this study necessarily pertain to the vadose zone.

In Section I of this report, we describe the SEAMIST™ system and its component parts in detail. We also describe the general methodology that we use to evaluate new technologies such as SEAMIST™ [1]. This methodology is used to evaluate and assess the cost and performance effectiveness of this new technology in relation to some conventionally accepted baseline. The baseline is chosen so that both technologies effectively accomplish the same technical performance objectives. In Section II, the five different scenarios and the baseline technologies that will form the points of comparison are described in detail. One of the critical components of this section is the statement of assumptions about the operating conditions and the discussion of the correct applications and limitations of the results. In Section III, we compare the performance capabilities of the SEAMIST™ system to those of the four baselines within the scenario framework. We are particularly interested in the ability of each technology to achieve the comparable technical objectives. We are careful to present all caveats attached to the particular application and to the results so that misinterpretation of the data can be avoided. In Section IV, we compare the cost of accomplishing specific technical objectives using SEAMIST™ to the cost of accomplishing those same objectives using the baseline technology. We focus on those costs that differ between alternatives; however, all costs associated with implementing the systems and obtaining the desired information are taken into account to obtain a total system cost. In Section V, we present examples of cost-equivalent systems by showing graphically how much of each technology that can be "purchased" for the same dollars. Finally, the principal results of the study are summarized in Section VI.

A. Description of the SEAMIST™ Technology

The SEAMIST™ system consists of an airtight membrane, a tether to facilitate emplacement, a membrane emplacement/storage canister, a basepipe connection between the canister and the membrane, and a source of pneumatic pressure. Attached to the membrane is any instrumentation necessary to perform sampling and/or analysis (see Figures 1-3).

The tubular, impermeable membrane is the heart of the SEAMIST™ system. The choice of membrane material depends on the particular application. Possible applications include using the membrane as a vehicle to maintain the integrity of the borehole structure, as a platform to facilitate the use of instrumentation inside the borehole (e.g., a neutron logging tool or camera), or as a way to progressively isolate sections of a continuous horizontal borehole for taking local measurements. Another application would be monitoring a VOC plume by building ports into the membrane; the ports would have tubing to the surface for

transporting soil vapors. In some of these cases, ordinary tubular high density polyethylene (HDPE) is appropriate. It is inexpensive and relatively inert. For other applications, such as when a high degree of durability is necessary, tubular urethane-coated polyester may be used. It is lightweight, readily heat-welded, and extremely air tight. However, urethane-coated polyester may not be suitable for some chemical environments and it has low puncture resistance. Other membrane fabrics include vinyl-coated polyester, nylon film, and most recently, a polytetrafluoroethylene-coated polyester fabric manufactured by W. L. Gore and Associates. Advantages of these fabrics include the fact that nylon film is clear and can be used with a video or television camera; the fact that vinyl-coated polyester is durable, rugged, and cheap; and the fact that the Gore fabric is less chemically active and very slippery.

The tether is used to facilitate gradual, controlled emplacement of the membrane. The tether unwinds from the canister as the membrane is expanded with pneumatic pressure. Once the membrane is completely emplaced, the tether must be disconnected from the canister. If the tether is dropped in a vertical borehole during this process, it can only be retrieved by removing the membrane by hand; this would most likely ruin the membrane and render it unusable. Duplicate attachments of tether to the basepipe are therefore used as a precaution. Removal of the membrane from the borehole is accomplished by slowly rewinding the tether onto the canister. As the tether is rewound, the membrane reverses and leaves the borehole starting at the base, slowly reversing the emplacement process. For some applications, the tether can be replaced by a cable, which can then be used with a measuring device such as a neutron logging tool. The tool can be towed through the borehole on the cable during emplacement taking measurements and transmitting information at the desired intervals.

The canister system contains the membrane and the attached sampling equipment at the opening of the borehole and facilitates membrane emplacement (see Figures 2 and 3). The canister can even house a motor drive system for situations in which motorized (versus manual) emplacement is desirable. The size of the canister is dictated by both the size of the membrane and by the volume of attached sampling equipment. Canisters can accommodate membranes from 10 ft to 500 ft. They can be up to 39 inches high for large capacity jobs that include a lot of attached sampling equipment (see Figure 2) or less than a foot high for smaller, less complicated membrane systems. Some critical functional features of the canister design include large side-plate observation windows, capacity reels to contain the membrane, fittings at the base of the canister for relief valve and pressure gauge attachments, quick disconnect fittings, and aluminum construction.

The basepipe forms the airtight connection between the membrane and the canister. The complexity of the basepipe depends on the application. For membranes that have no attached tubing or only absorbent collectors, the basepipes are very simple. They consist of a large diameter, quick disconnect coupling; an oversize collar to protect the membrane from

dropping into the borehole; and a surface onto which the membrane is clamped. A pressure gauge, relief valve, and air pressure port are usually mounted on the side. For situations in which flexible tubing passes up through the center of the membrane, the basepipe is larger to accommodate that tubing while still maintaining the necessary air pressure levels.

The pressures necessary to evert the membrane during emplacement and to maintain continuous air pressure once emplacement is complete are generally less than five pounds per square inch (psi). The actual amount of pressure necessary is dictated by the nominal borehole diameter, by the desired diameter of the membrane relative to the nominal borehole diameter, by the desired emplacement speed, and by the presence or absence of additional instrumentation. Membrane emplacement rates at 3-4 psi have been as high as 30 ft per minute for a period of seven minutes. It is critical that the air pressure system be able to prevent overpressurization of the membrane during emplacement. It is also important that the air pressure system be rugged enough to withstand abusive field conditions.

The final component of the SEAMIST™ system is the attached sampling and/or analysis instrumentation. This includes any possible combination of vapor ports, gas permeability measuring equipment, absorbent collectors, fiber optic cables, tubing, or measurement devices. We discuss the sampling, measuring, and analysis aspect of the SEAMIST™ technology in detail in Section III.

B. Overview of the Cost-Effectiveness Analysis Methodology

The purpose of this analysis is to determine if certain tasks associated with environmental remediation can be done "better, faster, cheaper, and safer," by this new technology. Not only must SEAMIST™ be able to do the job for a lower total cost, but it must also perform at least as effectively as the conventional alternatives and without introducing any additional risks to the environment or human health. Being able to accomplish the job faster than the conventional alternative is also desirable.

To that end, we require a well-defined methodology that can be applied consistently in the evaluation of such new technologies. This methodology must take into consideration both the cost and performance attributes and compare these attributes to the competing conventional technologies. A detailed discussion of the methodology that we use is contained in Reference 1; however, we will outline the basic ideas here. The steps of the methodology are presented in Figure 4.

Probably the most difficult yet most critical aspect of the entire technology evaluation process is to perform the comparison on a truly even basis, that is, to not compare "apples and oranges." In the real world, no one technology is a perfect substitute for another; there will most often be some differences in capabilities which must be addressed in the analysis. One way to deal with this difficulty is to require that the *end result* of the use of the various

technologies be the same. For example, if the goal is to determine the identity and amount of VOCs leaking under a landfill, any technologies that can produce the correct information at the required level of detail are acceptable. In some other situation however, these same technologies may *not* be suitable substitutes.

To effect an equitable comparison that emphasizes the end result, we perform the comparison in the context of a scenario. Developing scenarios that adequately address the strengths and limitations of the various technologies requires accurately identifying the system and understanding the objectives. The scenarios are necessarily detailed, including the nature of the contamination, the geographic details of the contaminated area, the number of systems of each kind that are to be installed, the system performance requirements, and the sampling frequency. The scenarios are representative of where and how the new technology would be used in a real-world situation. We take a descriptive approach to presenting these scenarios, with emphasis on understanding the whole picture first, before details of the cost analysis are described.

Once the system is defined and the scenarios are constructed, we estimate the total costs associated with implementing the scenarios. It is critical to understand the exact details of the implementation so that the total cost can be determined as accurately as possible. Also, we must perform the comparison on an equitable basis with respect to the future as well as initial expenditures. For costs that span more than one year, the time value of money is then important issue. Since we are concerned with the *present* value of all those *future* costs, we obtain the present value by discounting.

The discount rate used to obtain the present value can be either real or nominal. A real discount rate only takes into account the effects of the time value of money; a nominal discount rate subsumes the effects of both inflation *and* the time value of money. All discount rates (and interest rates) used in this methodology are real rates; that is, the effects of inflation are ignored. This is a valid approach when the time duration of the comparison of the technologies is reasonably short and similar. In the case where discount rates and interest rates are real, any escalation applied reflects only true *relative* increases in cost, for example, true relative increases in raw materials costs for future years due to a projected decrease in supply. Once complete life-cycle costs are known and the present value calculated, the total cost can be expressed in terms of some standard quantity or event, e.g., per pound of VOCs removed or per sample analysis for a particular contaminant.

Within our set of hypothetical scenarios, we assumed a certain number of sample events per year, a certain number of ports per borehole, a specific length for the boreholes, etc. Suppose however, that instead of requiring boreholes that are 100 ft long (or deep), a site requires boreholes that are 50 ft deep or 200 ft deep? Suppose that the number of sample ports per borehole or lysimeters installed need not be ten because the vadose zone is only 50 ft deep? Such

costs most likely do *not* scale linearly. It is important and useful to be able to extrapolate some generalities about the behavior of costs and of cost savings from this very focused analysis.

We try to answer these questions through sensitivity analysis. Sensitivity analysis looks at the effect of varying one critical parameter on the total costs of the system. By treating the number of sample ports per borehole for example, as a variable parameter, a whole range of cost savings calculations can be made available. Graphical data can then be presented and discussed that show the range of cost savings. In this way, one specific scenario becomes a prototype from which we are able to demonstrate for a variety of situations the savings possible from using this new technology.

Another issue that arises in the evaluation of a new technology concerns the maturity level of the technology's production processes. A new technology that is only in the demonstration phase will have higher manufacturing and fabrication costs than a more mature technology that can take advantage of economies of scale and learning curve effects. The cost savings that *could* be realized at full-scale production must be addressed in the analysis so that the new technology is not unfairly penalized. Wherever it is necessary, the costs shown reflect estimates of manufacturing and fabrication costs that subsume reasonable (but not overly optimistic) assumptions about economies of scale and process knowledge. We obtain these costs by talking with technical and manufacturing personnel, by extrapolating historical information about the technology, and by consulting other experts in the area. We do not, however, use extrapolated or projected costs for the new technology that would require more sophisticated methods of production than are currently reasonably achievable.

After developing all the life-cycle costs associated with the alternatives, we characterize and assess relative technology performance. Quantitative performance characteristics or indicators include such things as accuracy, precision, sensitivity, lowest attainable concentration, and turnaround time. These indicators can and usually are specific to a particular technology and even to a particular scenario and they can be described objectively with numbers that permit ranking among the various alternatives. The goal is to develop a set of performance indicators that span the requirements of the remediation activity and emphasize the breadth of the technology's capabilities. A set of performance indicators is most useful when the reader is able to compare the two alternatives, to easily discern the strengths and limitations of each, and then to be able to determine situations in which the new technology would be an appropriate substitute. Sometimes, however, performance can only be discussed in qualitative terms, e.g., level of convenience. If we define a set of qualitative performance features, then the relative performance capabilities of the competing technologies can be compared within those categories.

The next step is to evaluate the cost effectiveness of the new technology and the expected savings if it is employed. For example, if a certain technology can save \$100 per sampling

event (in current-year dollars), and there is a need to perform 10,000 such analyses over the next 10 years, then the new technology can save \$1 million for the sponsoring agency (in current-year dollars). This estimate requires knowledge of the magnitude and extent of the contamination problem and of the potential use of the new technology to remedy it. Often, the most challenging aspect of determining the total cost savings possible from using a new technology is ascertaining how much the new technology might actually be used.

In summary, the steps of the cost-effectiveness analysis are 1) identify the new technology and suitable conventional substitutes, 2) identify the performance scenario or scenarios which provide a framework for the comparison, 3) develop the life-cycle costs of the alternatives, 4) characterize the performance of all alternatives within the context of the scenario(s), 5) evaluate the cost effectiveness of the new technology relative to the baseline, and 6) estimate the cost savings possible from implementation of the new technology. Together, these steps constitute a methodology and provide a consistent analytical framework in which we can assess the relative merits of emerging environmental technologies.

Figure 4: Steps In Cost-Effectiveness Analysis

II. SCENARIOS FOR COMPARISON

We have defined the new technology and some general situations in which it could substitute for existing or baseline technologies. The next step is to construct some scenarios in which both the new and the baseline technologies are expected to accomplish the same technical goals, that is, to effect equivalent results. In order to limit the comparison to situations we can reasonably deal with, the scenarios are well-defined and very specific. There is naturally a resulting loss of generality, but the trade-off is worth it. It would clearly be a formidable task to perform a comparison for every conceivable variation on the use of the new technology.

We have developed five different scenarios for this study that characterize a variety of possible applications of the SEAMIST™ system. The scenarios involve a broad range of contaminant substances including volatile organic compounds, semivolatile and nonvolatile organic compounds, toxic substances like polychlorinated biphenyls (PCBs) and pesticides, and water-soluble radioactive substances such as tritium. Each of these different contaminants requires specific sampling processes which depend on whether the contamination is gaseous, whether it usually resides in the pore fluids, or whether it forms a non-aqueous phase liquid. As a result, three of the scenarios are designed to address these different sampling requirements and to demonstrate the versatility of the SEAMIST™ system in accommodating this variation. Because SEAMIST™ can also function as a platform for certain kinds of instrumentation, in addition to these three scenarios, the fourth scenario involves obtaining measurements of soil moisture content underneath a land disposal pit. The fifth scenario represents an integration of two of the previous scenarios. It was chosen because it demonstrates an especially valuable characteristic of the SEAMIST™ technology, that is, its ability to combine more than one characterization technology within one membrane system. A description of the scenarios for comparison, including both the SEAMIST™ application and the baseline, is contained in Table 1 and in Figures 5 and 6.

We must consider different spatial distributions of contamination in our analysis because the horizontal versus vertical distribution will dictate the optimal characterization methods. One of the scenarios therefore involves contamination that is distributed primarily in the horizontal direction in the vadose zone, and two scenarios involve contamination that is distributed more vertically. The horizontal distribution of contamination necessitates horizontal boreholes or a horizontal configuration of sampling devices; the vertical distribution necessitates vertical boreholes or a vertical distribution of sampling devices. In this report, we investigate the capability of SEAMIST™ to deal with both of these situations in a cost- and performance-effective manner.

One of the most advantageous features of SEAMIST™ is its ability to combine the capabilities of several conventional sampling technologies into one system. For example, two

TABLE 1. SCENARIOS FOR COMPARING SEAMIST™ TO A BASELINE TECHNOLOGY

<i>Scenario</i>	<i>SEAMIST™ Application</i>	<i>Baseline</i>
1 VAPOR SAMPLING VERTICAL	Twelve 100-ft vertical boreholes 4 inches inner diameter in the vadose zone at a site contaminated with VOCs. Each borehole is equipped with a SEAMIST™ liner. The liner has ten equally spaced ports with Teflon® tubes terminating to a ground-level sampling array. Boreholes are filled with sand for semi-permanent configuration. Each borehole array is sampled once per month for a twelve month period.	Twelve 100-ft vertical boreholes 4 inches inner diameter in the vadose zone at a site contaminated with VOCs. Each borehole is cased with PVC and outfitted with ten equally spaced, grouted, sealed ports with PVC tubes terminating to a ground-level sampling array. Each borehole array is sampled and analyzed once per month for a twelve month period.
2 VAPOR SAMPLING HORIZONTAL	Four 500-ft blind horizontal boreholes, 50 ft apart, 4 inches inner diameter, 25 ft below the surface, under a shallow VOC plume in the vadose zone. The plume measures approximately 200 ft wide by 500 ft long. Each borehole is equipped with a SEAMIST™ liner. Each liner has 10 equally spaced ports with Teflon® tubes terminating to an external sampling array. Each borehole array is sampled once per month for a twelve month period. During periods of inactivity, positive pressure is maintained with a solar-powered air pump system.	Forty soil vapor probes implanted 25 ft deep situated below a shallow VOC plume in the vadose zone. The plume measures approximately 200 ft wide by 500 ft long. The probes are implanted using a commercially available soil vapor probe system and are arranged in four rows of ten along the long axis of the plume. Each of the four rows is 50 ft apart and each probe is 50 ft from the nearest probe in the same row. Each probe is sampled once per month for a twelve month period.
3 PORE FLUID SAMPLING	Twelve 100-ft vertical boreholes 4 inches inner diameter in the vadose zone at a site contaminated with SVOCs, PCBs, pesticides, and/or PAHs. Each SEAMIST™ liner has 10 absorbent collectors down one side capable of wicking pore fluid from the soil matrix. Once a month the liner is removed, outfitted with fresh absorbent collectors, emplaced, allowed to collect fluid for analysis, removed to obtain the collectors, and then emplaced again. During periods of inactivity, positive pressure is maintained with a solar-powered air pump system.	Twelve vertical stacks of lysimeters in the vadose zone at a site contaminated with SVOCs, PCBs, pesticides, and/or PAHs. Each vertical stack consists of ten equally-spaced pressure-vacuum lysimeters spaced ten ft apart and grouted in place. Sampling pore fluids for analysis is performed one time per month on each lysimeter configuration. Successful implementation is dependent on the ability of the soil matrix to withstand the vacuum pressures necessary to effect the pore fluid extraction.
4 SOIL MOISTURE MEASUREMENTS	Four stable 250-ft blind horizontal boreholes 4 inches inner diameter 25 ft under the surface of a 20-ft deep radioactive land disposal pit. Desire measurements of moisture content of soil. A neutron logging tool and cable are attached to the SEAMIST™ system and guided through the borehole while taking a measurement every five ft. Tool is removed from the borehole uncontaminated and the liner is disposed of. Fifty measurements taken in each borehole. Air pressure will be provided for the one-day operation using a generator-powered air pump system.	Four 250-ft continuous horizontal boreholes 4 inches inner diameter cased with aluminum 25 ft under the surface of a 20 ft deep radioactive land disposal pit. Desire measurements of moisture content of soil. A neutron logging tool is towed through the borehole via cable that runs through the center of the casing. Fifty measurements taken in each borehole.

Table 1. Description of four scenarios constructed for comparing the cost and performance effectiveness of the SEAMIST™ technology to an appropriate baseline. Each scenario captures a different aspect of SEAMIST™ capabilities including vertical and horizontal sampling configurations and a variety of contamination situations (see Figures 5 and 6).

TABLE 2. INTEGRATION OF SCENARIOS 1 and 3 FOR COMPARING SEAMIST™ TO A BASELINE TECHNOLOGY

<i>Scenario</i>	<i>SEAMIST™ Application</i>	<i>Baseline</i>
5 INTEGRA- TION OF SCENARIOS 1 AND 3: VAPOR AND PORE FLUID SAMPLING	<p>Twelve 100-ft vertical boreholes 4 inches inner diameter in the vadose zone at a site contaminated with VOCs and SVOCs, PCBs, pesticides, and/or PAHs. Each borehole is equipped with a SEAMIST™ liner. The liner has ten equally spaced ports with Teflon® tubes terminating to a ground-level sampling array and 10 absorbent collectors down one side capable of wicking pore fluid containing the water-borne contaminants from the soil matrix. Each borehole Teflon® tube array is sampled once per month for a twelve month period. In addition, once a month the liner is removed, outfitted with fresh absorbent collectors, emplaced, allowed to collect fluid for analysis, removed to obtain the collectors, and then emplaced again. During periods of inactivity, each SEAMIST™ system is maintained at positive pressure using a solar-powered air pump system.</p>	<p>Twelve 100-ft vertical boreholes 4 inches inner diameter in the vadose zone at a site contaminated with VOCs and SVOCs, PCBs, pesticides, and/or PAHs. Each borehole is cased and outfitted with ten equally spaced, grouted, sealed ports with PVC tubes terminating to a ground-level sampling array. In addition, there are twelve vertical stacks of pressure-vacuum lysimeters. Each stack has ten lysimeters equally-spaced ten ft apart and grouted in place. Each borehole Teflon® tube array is sampled and analyzed once per month for a twelve month period and each lysimeter configuration is sampled for pore fluids one time per month.</p>

Table 2. Description of a scenario representing an integration of multiple characterization technologies into one SEAMIST™ membrane and instrumentation system for comparison to a combination of conventional technologies capable of accomplishing identical characterization goals. The integrated system is capable of sampling for VOCs (using multiple ports) as well as for SVOCs, pesticides, PAHs, PCBs, and even tritium (using absorbent wicking pads). The fact that several conventional technologies are simultaneously necessary to accomplish identical characterization goals means that integrated systems such as this are especially cost- and performance-efficient applications of the SEAMIST™ technology (see Figures 5 and 6).

SCENARIO 1

SCENARIO 2

Figure 5. Schematic of Scenarios 1 and 2 depicting both SEAMIST™ and the baselines of comparison. A detailed description of the scenarios is contained in Table 1.

SCENARIO 3

SCENARIO 4

Figure 6. Schematic of Scenarios 3 and 4 depicting both SEAMIST™ and the baselines of comparison. A detailed description of the scenarios is contained in Table 1.

separate systems would ordinarily be necessary to sample for both vapor-phase VOCs and for contaminants that are soluble in the pore fluids (e.g., PCBs or pesticides). SEAMIST™ can facilitate sampling for both classes of contaminants using just one membrane, thereby substantially decreasing the total costs associated with the sampling effort. To address this capability, we present and analyze a fifth scenario which represents a combination of two previously discussed scenarios, 1 and 3. Because it is often the case that multiple classes of contaminants are present at one site, it is important to consider this integrated scenario in order to adequately convey all of the advantages of the new technology. A description of Scenario 5 is presented in Table 2.

In the remainder of this section, we will describe each scenario in detail, including the specific conditions and assumptions as they relate to both the SEAMIST™ system and the corresponding baseline technology.

A. Description of Scenarios

Scenario 1 involves a VOC contamination plume in a geologic area where the vadose zone is at least 100 ft deep. Twelve vertical boreholes are needed to assess the horizontal and vertical extent of the plume. Since we desire a profile of the vertical distribution of the plume, it will be necessary to obtain vapor measurements at intervals within each borehole, in this case, every ten ft. Sampling will take place once per month during the period under consideration.

The assumptions that are implicit in this scenario concern the nature, texture, and stability of the soil. We assume the soil to be relatively free of large cobbles and rocks. As a result, the borehole drilling rig will encounter average drilling conditions as it drills and the SEAMIST™ membrane will not have to be installed over a rough surface. If the condition of the vadose zone were very rocky, the drilling costs would have to be reevaluated, the SEAMIST™ membrane fabric might have to be installed using special equipment (e.g., an external shield), or both. We also assume that the borehole is sufficiently stable once drilled to permit SEAMIST™ installation without collapse. This is a relatively valid assumption in the majority of cases.

Scenario 2 also involves a VOC contamination plume, but one that is shallower than in Scenario 1. Characterization must therefore be conducted more horizontally than vertically using horizontal boreholes or a horizontal sampling configuration. The same assumptions as in Scenario 1 regarding the nature, texture, and stability of the soil apply. In particular, the fact that the horizontal borehole must be stable enough to permit installation of the SEAMIST™ liner without collapsing is critical. In both scenarios, sampling for VOCs will take place once per month during the period under consideration.

The baseline in Scenario 2 requires punching a soil vapor probe to a depth of 25 ft with a commercially available soil vapor probe system. We assume this is actually possible with the

given soil conditions. Soil that prevents easy implantation of the vapor probes would require an alternate drilling technology or could even necessitate changing the baseline to a cased horizontal borehole with soil vapor monitoring ports as in Scenario 1.

In Scenario 3, the contaminants of interest are water soluble and therefore primarily present in the pore fluids of the vadose zone. Example contaminants include such things as nonvolatile and semivolatile organic compounds, PCBs, polynuclear aromatic hydrocarbons (PAHs), trace metals, tritium, pesticides, and herbicides. Obtaining soil samples for analysis at various vertical depths can usually be done only at the time the conventional characterization and monitoring boreholes are actually being drilled. Therefore, soil analysis for these contaminants is destructive, does not lend itself to repeated analysis, and cannot provide any time profile of the contaminant concentration. In this scenario, we require a method that permits repeated sampling and analysis regularly over time because we desire such information as part of both the characterization and remediation processes.

In addition to the above-mentioned assumptions regarding the nature, texture, and stability of the soil, for the Scenario 3 baseline we must make the additional assumption that the soil will not collapse under the negative pressures necessary to effectively operate the lysimeters. This is not a trivial assumption and it must be valid in order to be able to use the baseline technology. In the arid soils of the southwest U.S., the assumption is not necessarily valid. These performance-related issues regarding the lysimeter systems and consequent performance advantages of SEAMIST™ are discussed in more detail in Section III.

Containment in specially-designed, excavated pits is a common method of handling the disposal of low-level radioactive waste. Radioactive waste that is strictly low level is suitable for such disposal. One way to verify containment of that waste, and to ascertain that leakage is not occurring, is to monitor the moisture level directly under the disposal area. Scenario 4 involves that particular activity. Monitoring the moisture level requires drilling horizontal boreholes directly under the pit, towing a neutron logging tool through the borehole, and taking neutron attenuation measurements at regular intervals. Abnormal moisture level readings can be interpreted as an indication that leakage is occurring. As before, the same requirements regarding the nature and stability of the borehole geology apply to Scenario 4. Because of the nature of the monitoring activities in this scenario, long-term hole stability is imperative. This is a consideration that may obviate the use of SEAMIST™ strictly by itself (i.e., without conventional casing).

The final scenario, number 5, represents a combination of two previously discussed scenarios. Because it is often the case that multiple classes of contaminants are present at one contaminated site, we often require the concurrent use of several technologies to adequately characterize the disposition of the situation. Scenario 5 combines volatile organic compounds with water-borne organic and/or inorganic contaminants. Its purpose is to demonstrate that

two separate SEAMIST™ characterization and monitoring systems are capable of being integrated into one membrane system. Since at least two separate baseline sampling systems (gas phase and liquid phase) would normally be necessary in this case, Scenario 5 demonstrates one of the most valuable cost- and performance-effective features of the SEAMIST™ technology.

B. Description of Technologies in the Scenarios

The SEAMIST™ system that is required for each scenario consists of the basic components discussed in Section I.A plus whatever sampling or analysis instrumentation is necessary to acquire the desired information. The baselines that will be used will be different for each scenario because there is no one single technology that can substitute for the SEAMIST™ system in all of these applications. Schematic representations of the scenarios are shown in Figures 5 and 6.

In Scenario 1, each SEAMIST™ membrane is outfitted with ten ports that are capable of collecting soil vapor for withdrawal via the Teflon® tubing at the surface. The ten tubes are configured in an external array at the surface convenient for monthly sampling. The SEAMIST™-lined boreholes are intended to be semipermanent, so they are filled with sand to maintain positive pressure against the borehole wall.

The baseline technology for Scenario 1 is a similar soil vapor port system, but is constructed in conventional PVC casing material. Vertical boreholes (identical to the ones used by the SEAMIST™ technology) are cased with ten-ft sections of 4-inch wide PVC pipe that contain specially constructed vapor monitoring ports [3]. More rigid narrow PVC tubing (instead of Teflon®) is used to transport the VOC vapors to the surface. The vapor transport tubing likewise terminates in an external sampling array.

Functionally the two systems are the same. Each system has an external sampling array from which to extract the soil vapors at the surface using a technique such as Tedlar™ bags or direct hookup to a suitable analytical instrument. The principal difference between the two systems is the method of casing the boreholes; SEAMIST™ uses the innovative membrane material and the baseline uses conventional PVC. Also, the SEAMIST™ system uses narrow Teflon® tubing and the baseline is better suited to more rigid PVC tubing. This naturally leads to differences in the method of port construction and to differences in total system cost. The system costs are addressed in detail in Section IV.

Scenario 2 is similar to Scenario 1 except that the VOC plume is more shallow, measuring about 500 ft long, 200 ft wide, and 20 ft deep. To conform the sampling system to these particular dimensions, four horizontal boreholes are drilled under the plume at a true vertical depth of 25 ft. Each borehole will have a SEAMIST™ liner equipped with ten soil vapor ports spaced fifty ft apart and each port will have a Teflon® tube leading to an external

sampling array. The boreholes will be maintained at positive pressure using a solar-powered air pump system.

The shallow nature of the VOC plume lends itself to a completely different baseline technology than borehole monitoring ports. Soil vapor probes with attached Teflon® tubing at a depth of 25 ft are a method of transporting VOC vapors to the surface for analysis. They can be implanted using a commercially available system. The implanted probes connected to the Teflon® tubing are grouted in place, and then the tubing is capped at the surface to form a series of soil vapor monitoring stations. The probe locations correspond exactly to the port locations in the SEAMIST™ arrangement.

Scenario 3 represents a change in the contaminants of interest—from vapor phase VOCs to substances that are soluble in the pore fluids. In this scenario, the contaminants are as deep as 100 ft in the vadose zone. Soil sampling for the water-borne contaminants is a destructive process and one-time incident that usually occurs at the time the borehole is being drilled. To facilitate a repeated pore-fluid sampling capability in this negative matric potential area, a SEAMIST™ membrane liner is equipped with absorbent pads at ten-ft intervals down one side of the membrane. The pads are capable of wicking pore fluid containing the contaminants. As needed during the period under consideration, the membrane can be withdrawn from the borehole, outfitted with new absorbent pads, emplaced, allowed to collect fluid, removed, and emplaced again. It will probably be necessary to remove the pads under the protection of a large windscreen.

A conventional substitute for the fluid collecting capability of the absorbent wicking pads is a system of lysimeters. Lysimeters effect pore fluid collection in negative matric potentials greater than 50 ft under the influence of alternating vacuum and positive pressure. To accurately mimic the SEAMIST™ system under consideration, the lysimeters must be installed in twelve columns of ten lysimeters per column. The ten lysimeters in each column must be spaced vertically ten ft apart. The lysimeter tubing can be configured as a sampling array at the surface similar to Scenarios 1 and 2. The successful use of any lysimeter system depends on the ability of the soil to withstand the pressures necessary to effect the removal of pore fluid. Furthermore, lysimeters cannot work with soil suctions greater than 0.7 bars, thus precluding their use in very dry soils.

Scenario 4 does not involve sampling for contaminants directly; instead it involves obtaining measurements of soil moisture content under a low-level radioactive waste land disposal pit. The process of acquiring the measurements requires towing a neutron logging tool through a set of horizontal boreholes underneath the pit and measuring neutron attenuation at various intervals. Both the SEAMIST™ technology and the conventional alternative require boreholes. The principal difference between the two systems concerns the structure of the boreholes and the casing. The SEAMIST™ boreholes are blind; that is, they

only have one open end. The baseline boreholes are continuous; that is, they have two open ends. These structural differences are dictated by the two technologies and this difference does affect the total cost. If the structure of the borehole is such that it will not readily collapse, then permanent casing can be replaced with a SEAMIST™ liner. In Scenario 4, the logging tool cable functions as the SEAMIST™ tether. The baseline horizontal boreholes are also equipped with the capability to tow the logging tool.

As was previously mentioned, one of the most advantageous features of SEAMIST™ is its ability to combine several characterization and monitoring technologies into one system. Scenario 5, which represents a combination of Scenarios 1 and 3, is a typical situation in which both vapor and water-borne contaminants are present at the same site. As a result, multiple technologies are necessary. The SEAMIST™ membrane in Scenario 5 accommodates both classes of contaminants using vapor monitoring ports and absorbent collectors. The baseline of comparison, however, is still two separate systems: boreholes with vapor monitoring ports and an arrangement of suction lysimeters. Even though we may not actually install a one-for-one arrangement of lysimeters for absorbent collectors as we have assumed, in this report we again present the cost of the one-for-one arrangement as the baseline of comparison.

III. PERFORMANCE COMPARISON

One of the most important performance attributes of SEAMIST™ is the fact that it can substitute for such a wide variety of conventional environmental technologies. In any given one-on-one comparison, SEAMIST™ may or may not be a preferable alternative to the conventional method, but the fact that SEAMIST™ is so versatile and has so many applications constitutes a large part of its value. Listed below are some of the uses of the SEAMIST™ membrane system to date.

- as a semipermanent, positive-pressure borehole liner
- for VOC plume monitoring
- for tritium plume monitoring
- for sampling of pore-fluid contaminants
- for fracture flow mapping
- to obtain gas permeability measurements
- as a platform for in-situ measurement devices e.g., fiber optic probes
- to measure brine flow at the Waste Isolation Pilot Project
- to transport logging tools and cameras
- as temporary casing support during steam injection remediation
- to isolate individual borehole segments for sampling purposes

In some situations, SEAMIST™ functions as a substitute for conventional borehole casing. The most obvious performance advantage in this role is that the SEAMIST™ liner is easily reusable, while the conventional borehole casing is not. In situations where the specific application permits, removing and reusing the same membrane would increase efficiency and save time compared to the time necessary to install traditional casing. Furthermore, abandonment of SEAMIST™-cased boreholes is significantly easier and cheaper than removing conventional, grouted-in casing. Scenario 4 represents a typical application in which SEAMIST™ functions as a casing substitute.

There are some performance limitations associated with SEAMIST™ that must be considered. The most serious in practice has been that the membrane can tear when being emplaced in an extremely rocky or jagged borehole environment. This can be counteracted by using a different, stronger membrane fabric or by using an additional protective liner. Membranes can also be subject to leakage. However, adequate quality control measures during fabrication minimize this problem. A necessary condition for successful membrane installation is that the borehole be sufficiently stable. A certain amount of time passes between completion of borehole drilling, removal of the drilling equipment, and emplacement of the membrane. If during that time the borehole structure collapses, membrane emplacement will not be possible. In some areas of the country collapse is not a problem, but it is a consideration that many times obviates the use of SEAMIST™ by itself (i.e., without conventional casing).

A. Scenario 1

In Scenario 1, the SEAMIST™ setup and the baseline are functionally identical (see Figure 5). Both systems consist of something to “case” the borehole (a membrane versus standard PVC casing) and a series of vapor monitoring ports constructed in the casing [3,8]. Individual tubes attached to the monitoring ports transport the vapors to a sampling array at the surface. The SEAMIST™ system uses Teflon® tubing because it is flexible enough to be wound inside the canister. The baseline system uses PVC tubing because it is more rigid. The baseline could use Teflon® if the chemical properties of PVC were an issue; however, the more rigid PVC tubing is preferred. Each of the twelve boreholes has ten of the monitoring ports spaced ten ft apart. In both SEAMIST™ and the baseline, sampling procedures are identical, and therefore sampling is not a difference that needs to be addressed. One of the advantages of the SEAMIST™ system over the baseline monitoring ports is that the SEAMIST™ system can be removed and inserted at intermediate points in the borehole. The result is that measurements of VOC vapors can be taken very easily *in between* the ten-ft spacings simply by offsetting the membrane by five ft.

B. Scenario 2

The two technologies being compared in Scenario 2 have the same purpose, but they are not the same types of systems. The purpose is to transport VOC vapors from the shallow contaminated area to the surface for monthly sampling (see Figure 5). The SEAMIST™ system in this scenario is similar to that of Scenario 1, except that the boreholes are horizontal instead of vertical and positive pressure is maintained with a solar-powered air pump system. The baseline in Scenario 2, however, does *not* require boreholes; the shallow depth of the contamination permits vertical installation of soil vapor probes. The baseline setup in this scenario is contingent on the ability of the soil vapor probe equipment to actually punch to the vertical depth of 25 ft. If the contaminated area is impenetrable, which would be the case if the contaminated area were a landfill or an equipment dump, then soil vapor probes could not be implanted directly and the use of horizontal boreholes underneath the contaminated area would be the only alternative.

There are several performance issues that are relevant when comparing these two alternatives. The differing lengths of the transport tubing may have an impact on the quality of the data obtained. While in principal it is possible to vacuum extract VOC vapors the distance required in the SEAMIST™ arrangement, long distance vacuum extraction is affected by problems related to adsorption. This can be compensated for by proper calibration. As was the case in Scenario 1, the SEAMIST™ membrane can be offset by the required number of ft to facilitate taking data in between the predetermined usual locations; the vapor probes once implanted can not be moved around to intermediate locations. Note that there are only four convenient sampling arrays with ten tubes apiece for SEAMIST™, whereas there are forty separate locations for the baseline each consisting of one capped Teflon® tube.

C. Scenario 3

The collection of pore fluids in the vadose zone for analysis of water-borne contaminants is traditionally done by suction lysimeters. At depths exceeding 50 ft, pressure-vacuum lysimeters become necessary [14]. The SEAMIST™ innovation for sampling pore fluids utilizes absorbent materials attached to the side of the liner that are capable of wicking the pore fluids from the borehole wall (see Figure 6). There is a subtle difference in the mechanics of the process of vacuum extraction versus wicking. Those pore fluids that are actually extracted are directly related to the relative sizes of the pores. The natural tendency is to extract fluid from the largest pores first. Furthermore, the composition of the fluid extracted actually may be dependent on the magnitude of the applied vacuum. As a result, the extracted fluid may or may not be representative of the relative and absolute levels of the various contaminants. Wicking, on the other hand, has the potential to extract pore fluid at a more representative composition. This subtle dissimilarity can result in different levels of

accuracy between the two alternatives.

In addition to this performance consideration, successful implementation of suction lysimetry is dependent on the ability of the soil matrix to withstand the vacuum pressures necessary to effect the extraction. This is a particularly vexing problem for certain areas of the southwest, where the dry, noncompacted vadose zone is not readily amenable to this suction technique. As stated before, lysimeters cannot work with soil suctions greater than 0.7 bar. However, the SEAMIST™ absorbent pad system has been tested and works up to 10 bars. The other limitation of using lysimeters is that the installation process may be difficult or impossible if the vadose zone is rocky or cobbly. Drilling rigs are better able to contend with these conditions. Also, as in Scenarios 1 and 2, the SEAMIST™ membrane can be offset by the required number of ft to facilitate measurements in between the predetermined usual locations; the lysimeters once implanted and grouted in place can not be easily moved.

Sampling for these two alternatives is very different. The SEAMIST™ sampling process consists of removing the liner, installing absorbent pads, emplacing the liner for some specific length of time, removing the liner, removing the absorbent pads under a protective windscreen, and then reinstalling the liner. The sampling process for the lysimeters consists of attaching a vacuum for the necessary length of time (dependent on the moisture level of the soil) and then applying positive pressure to effect removal of the pore fluid. Not only is the baseline more unpredictable, but it is also more time-consuming and significantly less convenient. Time must elapse between sampling events for lysimeters because the vacuum acts to deplete the soil of moisture and it is only with time that the soil returns to a state of equilibrium.

D. Scenario 4

Some differences between the two alternatives in Scenario 4 is that for the baseline the horizontal borehole is continuous and cased, whereas with SEAMIST™ the borehole is blind and not cased (see Figure 6). The actual process of towing the neutron logging tool through the borehole is the same in both situations, but the way in which the towing cable assembly is anchored at the base of the borehole may differ. This does not impact the process of taking measurements. There are advantages to having the borehole cased if any remediation efforts are to take place at a later time. On the other hand, if this is to be a monitoring operation only and if the borehole is stable, there are very few advantages to permanent casing. One additional consideration for SEAMIST™ is that the membrane must be disposed of properly because of radioactive contamination.

One of the notable advantages of using a removable liner system for this operation is that the liner can be simultaneously equipped with absorbent wicking pads, as in Scenario 3. Should any suspect readings occur during data acquisition, the absorbent pads can be pulled

and analyzed for an immediate assessment of the situation. This would not be possible with the cased borehole.

E. Scenario 5

Scenario 5 represents a combination of Scenarios 1 and 3. The critical feature of this scenario is the fact that the two separate SEAMIST™ systems can be fabricated into one membrane, but that the two conventional technologies can not be similarly combined. This synergy is especially important with respect to cost. It is also important because it is more convenient and increases efficiency.

The single SEAMIST™ membrane incorporates both borehole monitoring ports for soil vapors and the absorbent pads for pore fluids. The baseline of this combination scenario consists of separate borehole monitoring port and lysimeter systems. Very few economies of scale or scope are possible with the baselines. The fact that several conventional technologies are simultaneously necessary to accomplish the same characterization goals possible with one SEAMIST™ system means that integrated systems such as this are especially cost- and performance-efficient applications of the SEAMIST™ technology. As in Scenario 3, the SEAMIST™ liner must be maintained at positive pressure with air so that it can be removed as necessary to retrieve the absorbent pads. There are no other consequential performance differences between the separate scenarios versus the combination that must be addressed.

IV. COST COMPARISON

In this section, we present and discuss the costs of installing and using the various technologies in each scenario to obtain the required information. We include the cost of purchasing or renting the necessary equipment, the cost of labor to install the system, the cost of materials and supplies, the cost to obtain samples if sampling procedures vary between alternatives (i.e., SEAMIST™ versus the baseline), and where necessary, the cost of disposal. Whether the equipment is treated as purchased or rented depends on what we determined to be the generally accepted practice. The total costs associated with installing and operating the various technologies for a period of one year are presented at a summary level in Tables 3 through 7. A more detailed listing of costs by vendor is available in the appendix.

We determined that the required capital to install the various technologies could usually be rented from the commercial company that marketed the equipment or that the company was able to provide installation for a fee. Either of these alternatives appeared to be preferred by the site investigators as opposed to actually purchasing the required equipment themselves. Because very little investment will be made up front, we need not consider the

distribution over time of any initial capital costs to make a meaningful comparison between technologies.

We considered the total costs of operating the equipment over the one-year period. We also included a cost for monthly sampling if the sampling procedures vary between the two alternatives. In order to not bias the results in favor of the new technology, judgments about cost estimates were always made in favor of the baseline. For example, if the amount of labor used to install some component of the baseline technology can range from three man-hours to six man-hours, we chose a lower value within that range.

The cost of the labor used to manufacture the SEAMIST™ membrane includes salary and fringe only; general and administrative expenses (G&A) and manufacturing overhead are shown as a separate item in the cost estimate. Contracted labor used to install the system or to otherwise work in the field is quoted at the fully burdened rate. The fully burdened labor rate includes salary, fringe, G&A, and other overhead. Contracted labor is usually quoted at the fully burdened rate because that is what the user pays. All labor rates were arrived at with due consideration to the level of expertise required and by taking into account the applicable health and safety regulations.

In the remainder of this section, we discuss each scenario individually. We are interested in the total costs that contribute to installing and operating both SEAMIST™ and baseline, in the absolute difference, and in the important cost drivers. We are also interested in understanding the kinds of modifications to the scenario that might have a significant impact on the total system cost.

A. Scenario 1

Total installation and operating costs over a period of one year for the vertical monitoring port system in Scenario 1 are estimated at \$52k for the SEAMIST™ setup and \$118k for the baseline (see Table 3). This represents a cost savings of 56% for the new technology. The principal cost driver for the SEAMIST™ system is the membrane. It comprises almost 25% of the total cost. The other major contribution is the cost of drilling the boreholes. This cost, however, is the identical for both alternatives. The principal cost driver for the baseline is the cost of constructing the built-in monitoring ports in the PVC casing; that cost is significantly higher than fabricating ports in the SEAMIST™ membrane. If the chemical properties of the PVC soil vapor transport tubing are an issue, Teflon® could be substituted; however, the more rigid PVC tubing is preferred.

B. Scenario 2

Total installation and operating costs over a period of one year of the SEAMIST™ horizontal monitoring port system in Scenario 2 are estimated at \$173k. This includes the cost

of drilling the horizontal boreholes. The baseline configuration of soil vapor probes is estimated to cost \$28k (see Table 4). If the cost of drilling the horizontal boreholes is not included with the SEAMIST™ estimate, which would be the case if the holes already existed, then the cost decreases to \$55k. Even if the cost of drilling the horizontal boreholes is not included, the SEAMIST™ horizontal monitoring port system is still approximately twice as expensive as the functionally equivalent system of soil vapor probes.

The principal cost drivers of the SEAMIST™ alternative in Scenario 2 are the membrane and tubing costs and the cost of drilling the horizontal boreholes. The cost of the boreholes makes the use of SEAMIST™ impractical in this particular scenario. But there are situations, however, in which horizontal boreholes and SEAMIST™ might be the only alternative, such as when the area of interest is under a building or an equipment dump, or when vertical access to the contamination is otherwise impossible. The cost of the horizontal boreholes could also be shared by a future long-term remediation effort. Being able to allocate a large portion of the cost of the boreholes over a remediation effort would make the use of SEAMIST™ more economical and more attractive. The principal cost driver for the baseline in this scenario is the cost of the hole-punch equipment.

C. Scenario 3

Total installation and operating costs over a period of one year for the two pore fluid sampling systems described in Scenario 3 are estimated at \$84k for the SEAMIST™ arrangement and \$272k for the baseline (see Table 5). The baseline in this scenario are configured identically to the SEAMIST™ absorbent pads, but it costs more than three times as much to obtain the same information using the conventional lysimeters. It is important to note that in Scenario 3, the method of sampling differs between the two alternatives. Therefore, the cost of sample acquisition is explicitly considered in the total cost.

The membrane is the largest material cost for SEAMIST™ in Scenario 3. The labor and materials used to install and retrieve the absorbent pads are also a large part of the total cost. For the baseline, the cost of the lysimeters, the Teflon® tubing, and sampling of the lysimeters account for a substantial difference. The lysimeters and the Teflon® tubing comprise almost 30% of the total cost. Another 45% is attributable to the lysimeter sampling process due to the fact that pore fluid extraction is a very labor intensive effort. Even though we have made the assumption favoring the baseline that one technician could simultaneously monitor five vacuum instruments (with two technicians then, all ten lysimeters could be sampled at one time), the total cost is still significantly more than that of using SEAMIST™.

D. Scenario 4

Total installation and operation over a period of one year of the neutron logging tool

towing system in Scenario 4 is estimated to cost \$124k for SEAMIST™ and \$147k for the baseline (see Table 6). This represents a cost savings of 16%. There are two sources of the cost savings in the scenario: the use of the more economical HDPE membrane to replace traditional aluminum casing and the fact that the horizontal boreholes need not be continuous for SEAMIST™ to accommodate the logging tool pulley mechanism. In this scenario, the SEAMIST™ liner functions primarily as a replacement for conventional borehole casing, but at a cost of approximately 90% less. The only additional cost incurred for using the HDPE liner is that it must be properly disposed of at the end of each of the monthly data-gathering exercises because of possible low level radioactive contamination. The cost of proper disposal is included in the estimate. If a pulley system could be configured for the baseline that permitted towing of the logging tool through a blind borehole, the "blind versus continuous" cost difference would disappear.

E. Scenario 5

Total installation and operation over a period of one year of the combined vapor monitoring ports and pore fluid sampling system of Scenario 5 was estimated to cost \$99k for SEAMIST™ and \$390k for the sum total of the two baselines (see Table 7). The point of including the combination scenario in this report is to demonstrate the *additional* cost savings that are possible (above and beyond those already discussed) which result from *integrating* two separate sampling systems into one SEAMIST™ membrane. The combined cost estimated at \$99k is 27% less than the sum of the separate costs of Scenarios 1 and 3 (\$136k). This same kind of cost-reducing synergy is not possible for the baseline because the two conventional technologies can not be combined in any similar fashion. This capability represents one of the most beneficial aspects of the new technology.

TABLE 3. COST OF SAMPLING FOR VOCs IN A VERTICAL BOREHOLE : SCENARIO 1

SEAMIST™		BASELINE	
MATERIALS & SUPPLIES		MATERIALS & SUPPLIES	
Membrane	12,600	PVC casing	4,850
Teflon® tubing	6,600	Bentonite/seals	2,600
Ports	1,080	Port assemblies	390
Basepipe assembly w/ tether	1,800	PVC tubing	9,600
Sand	60	Sand packing	1,360
		Well vaults	9,600
		Sampling array w/ valves	6,000
MANUFACTURING LABOR		INSTALLATION & SET-UP	
Technician*	3,020	Drill boreholes incl. mobilization/demob	18,000
INDIRECT COSTS		Labor* to construct and install port systems and casing, and set up	<u>65,300</u>
Manufacturing overhead/G&A**	6,290		
INSTALLATION & SET-UP		TOTAL COSTS	117,700
Drill boreholes incl. mobilization/demob	18,000		
Labor*** to install and set up	2,400		
Equipment rental: air pump, generator, canister	<u>150</u>		
TOTAL COSTS	<u>52,000</u>		
* Rate includes salary and fringe benefits		* Fully burdened: includes salary, fringe, overhead, G&A	
** 25% of total manufacturing costs			
*** Fully burdened: includes salary, fringe, overhead, G&A			

Table 3. Costs associated with acquiring, installing, and setting up a SEAMIST™ system and a comparable conventional technology to obtain VOC samples from twelve 100-ft vadose-zone boreholes. Each borehole VOC sampling system consists of ten equally-spaced sampling ports connected to tubes which terminate to an external sampling array. Details of this scenario are provided in Table 1 and Figure 5; details of the materials and costs are provided in the appendix. Costs reflected in this table are rounded to a logical number of significant figures.

TABLE 4. COST OF SAMPLING FOR VOCs UNDERNEATH A SHALLOW PLUME: SCENARIO 2

SEAMIST™		BASELINE	
MATERIALS & SUPPLIES		MATERIALS & SUPPLIES	
Membrane	25,200	Vapor probe systems	
Teflon® tubing	13,000	Punch system w/ shaft sections	16,900
Ports	360	Gas connector	20
Basepipe assembly w/ tether	600	Vapor probes and anchors	360
		Teflon® tubing	3,600
MANUFACTURING LABOR		Packing sand	30
Technician*	1,000	Surface cap assemblies	480
		Bentonite	30
INDIRECT COSTS		INSTALLATION & SET-UP	
Manufacturing overhead/G&A**	10,040	Labor* to install and set up	<u>6,400</u>
INSTALLATION & SET-UP			
Drill boreholes incl. mobilization/demob	117,800		
Labor*** to install and set up	1,600		
Equipment rental: air pump, generator, canister	100		
Solar-powered air pump system	3,260		
TOTAL COSTS	<u>172,960</u>	TOTAL COSTS	<u>27,820</u>
* Rate includes salary and fringe benefits			
** 25% of total manufacturing costs			
*** Fully burdened: includes salary, fringe, overhead, G&A		* Fully burdened: includes salary, fringe, overhead, G&A	

Table 4. Costs associated with acquiring, installing, and setting up a SEAMIST™ system and a comparable conventional technology to obtain VOC samples underneath a shallow contaminant plume in the vadose zone. There are forty sampling port locations in the SEAMIST™ system that correlate to vapor probe locations in the baseline. Details of this scenario are provided in Table 1 and Figure 5; details of the materials and costs are provided in the appendix. Costs reflected in this table are rounded to a logical number of significant figures.

TABLE 5. COST OF SAMPLING FOR NON-VOLATILE CONTAMINANTS IN SUBSURFACE PORE FLUIDS: SCENARIO 3

SEAMIST™		BASELINE	
MATERIALS & SUPPLIES		MATERIALS & SUPPLIES	
Membrane	12,600	Lysimeters	35,400
Absorber assemblies and pads	3,600	Bentonite/seals	1,450
Basepipe assembly w/ tether	1,200	Teflon® tubing	43,200
		Clamps	170
MANUFACTURING LABOR		Sampling array w/ valves	6,000
Engineer*	530	Well vaults	9,600
Technician*	340	Vacuum equipment w/ battery (x10)	5,750
INDIRECT COSTS		INSTALLATION & SET-UP	
Manufacturing overhead/G&A**	4,600	Labor* and equipment to install and set up	49,550
INSTALLATION & SET-UP		SAMPLING**	
Drill boreholes incl. mobilization/demob	18,000	Mobil/demobilize 2 technicians	14,520
Labor*** to install and set up	1,600	Sampling lysimeters	<u>106,560</u>
Equipment rental: air pump, generator, canister	100		
Solar-powered air pump system	3,260		
SAMPLING****		TOTAL COSTS	
Windscreen	2,000		272,200
Labor***	23,000		
Materials	<u>12,960</u>		
TOTAL COSTS			
	83,790		
* Rate includes salary and fringe benefits		* Fully burdened: includes salary, fringe, overhead, G&A	
** 25% of total manufacturing costs		** Sampling rate is once per month for one year; included because sampling varies between alternatives	
*** Fully burdened: includes salary, fringe, overhead, G&A			
**** Sampling rate is once per month for one year			

Table 5. Costs associated with acquiring, installing, and setting up a SEAMIST™ system and a comparable conventional technology for obtaining samples of nonvolatile contaminants from pore fluids in the vadose zone. There are twelve 100-ft vertical boreholes consisting of ten equally-spaced absorbent wicking pads in the SEAMIST™ system versus ten equally-spaced lysimeter stacks for the baseline. Details of this scenario are provided in Table 1 and Figure 6; details of the materials and costs are provided in the appendix. Costs reflected in this table are rounded to a logical number of significant figures.

TABLE 6. COST OF OBTAINING SOIL MOISTURE MEASUREMENTS UNDERNEATH A LOW-LEVEL RADIOACTIVE LAND DISPOSAL PIT: SCENARIO 4

SEAMIST™		BASELINE	
MATERIALS & SUPPLIES		MATERIALS & SUPPLIES	
Membrane	480	Aluminum casing	18,240
Basepipe assembly w/ cable attachment	100	Neutron logging tool	4,300
Neutron logging tool	4,300	Cable-350 ft. w/ markings & collar	1,380
Cable-350 ft. w/ markings	1,300	Laptop computer w/ accessories	4,000
Laptop computer w/ accessories	4,000	Battery pack, charger & cable	230
Battery pack, charger & cable	230		
INDIRECT COSTS		INSTALLATION & SET-UP	
Manufacturing overhead/G&A*	150	Drill cont. boreholes incl. mob/demob	109,500
		Labor* to obtain measurements**	9,600
INSTALLATION & SET-UP			
Drill blind boreholes incl. mob/demob	102,650		
Labor** to obtain measurements***	9,600		
Equipment rental: air pump, generator, canister	50		
Membrane disposal	1,040		
		TOTAL COSTS	147,250
TOTAL COSTS	123,900		
* Rate includes salary and fringe benefits		* Fully burdened: includes salary, fringe, overhead, G&A	
* Fully burdened: includes salary, fringe, overhead, G&A		** Measurements taken once per month for one year	
*** Measurements taken once per month for one year			

Table 6. Costs associated with acquiring, installing, and setting up both a SEAMIST™ system and a comparable conventional technology to obtain measurements of soil moisture underneath a shallow low-level radioactive land disposal pit. A neutron logging tool is towed through four horizontal boreholes and moisture measurements recorded every five ft. Details of this scenario are provided in Table 1 and Figure 6; details of the materials and costs are provided in the appendix. Costs reflected in this table are rounded to a logical number of significant figures.

TABLE 7. COST OF COMBINATION OF SCENARIOS 1 AND 3: SCENARIO 5

SEAMIST™		BASELINE	
MATERIALS & SUPPLIES		MATERIALS & SUPPLIES: Scenario 1	
Membrane	12,600	PVC casing	4,850
Teflon® tubing	6,600	Bentonite/seals	2,600
Ports	1,080	Port assemblies	390
Absorber assemblies and pads	3,600	PVC tubing	9,600
Basepipe assembly w/ tether	1,800	Sand packing	1,360
		Well vault	9,600
		Sampling array w/ valves	6,000
MANUFACTURING LABOR		INSTALLATION & SET-UP	
Engineer*	530	Drill boreholes incl. mobilization/demob	18,000
Technician*	3,360	Labor to construct and install system	65,300
INDIRECT COSTS		MATERIALS & SUPPLIES: Scenario 3	
Manufacturing overhead/G&A**	7,400	Lysimeters	35,400
INSTALLATION & SET-UP		Bentonite/seals	1,450
Drill boreholes incl. mobilization/demob	18,000	Tubing	43,200
Labor*** to install & sample on site	2,400	Clamps	170
Equipment rental: air pump, generator, canister	100	Sampling array w/ valves	6,000
Solar-powered air pump system	3,260	Well vault	9,600
		Vacuum equipment w/ battery (x2)	5,750
SAMPLING		INSTALLATION & SET-UP	
Absorber pad system sampling	<u>37,960</u>	Labor to install and set up	49,500
TOTAL COSTS		SAMPLING	
	<u>98,690</u>	Lysimeter systems only	<u>121,080</u>
		TOTAL COSTS	
			<u>389,850</u>

* Rate includes salary and fringe benefits
 ** 25% of total manufacturing costs
 *** Fully burdened: includes salary, fringe, overhead, G&A

Table 7. Costs associated with a scenario that integrates the sampling requirements for VOCs in Scenario 1 with the sampling requirements for the nonvolatile, water-borne contaminants of Scenario 3. The same SEAMIST™ membrane can be used to support both sampling systems; however, the conventional approach necessitates two entirely *separate* systems. Details of this scenario are provided in Tables 1 and 2 and Figures 5 and 6; details of the materials and costs are provided in the appendix. Costs reflected in this table are rounded to a logical number of significant figures.

V. RESULTS

The information presented in this report demonstrates that in certain situations the innovative SEAMIST™ technology has definite performance advantages over analogous conventional technologies *and* that it can also realize substantial cost savings for the Department of Energy. To demonstrate cost savings, it is convenient to compute the number of performance units of the baseline technology that are equivalent in cost to a specific number of SEAMIST™ performance units, e.g., the number of stacked lysimeters equivalent in cost to ten absorbent pads contained in one SEAMIST™ membrane.

A. Cost-Equivalent Systems

Figures 7 through 9 indicate the number of functional units of the baseline versus the number of functional units of SEAMIST™ *that have identical costs*. Figure 7 indicates that it is possible to get almost three times as many VOC vapor monitoring ports with SEAMIST™ than are possible for the same cost by constructing such ports in conventional PVC casing at a site where there are twelve borehole locations. Figure 8 indicates that at a site where there are twelve sampling locations, for every ten absorbent wicking pads that can be installed in one SEAMIST™ membrane, it is only possible for the same cost to stack between two and three pressure-vacuum suction lysimeters. Figure 9 shows the number of SEAMIST™ HDPE liner systems that can be purchased for use over a one-year period equal in price to one round of aluminum casing. A description of how these relationships were determined is contained in the figure captions.

B. Cost Savings

The cost savings possible from utilizing this innovative technology depend directly on the number of contaminated sites, on the geology and location of the sites, and on the specific nature and distribution of the contamination. When data regarding projected need are available, estimates can be made of the potential cost savings possible from using SEAMIST™ instead of a more expensive, existing technology.

FIGURE 7. NUMBER OF BASELINE MONITORING PORTS PER BOREHOLE EQUIVALENT IN COST TO TEN SEAMIST™ PORTS

Figure 7. Graph of the number of baseline borehole monitoring ports that is equivalent in cost to ten SEAMIST™ monitoring ports at a site containing twelve boreholes. The baseline cost equivalency point was determined by categorizing the costs in Table 3 as either “fixed” or “variable” and then deriving a simple linear equation that can predict total cost as a function of the number of ports per borehole. The cost relationship for the baseline in this particular scenario is $TC = \$10.1X + \17.1 where TC is the total system cost and X is the number of baseline vapor monitoring ports per borehole.

FIGURE 8. NUMBER OF STACKED LYSIMETERS EQUIVALENT IN COST TO TEN SEAMIST™ ABSORBENT PADS

Figure 8. Graph of the number of lysimeters per vertical stack that is equivalent in cost to ten SEAMIST™ absorbent wicking pads per borehole at a site containing twelve stack or borehole locations. The baseline cost equivalency point was determined by categorizing the costs in Table 5 as either “fixed” or “variable” and then deriving a simple linear equation that can predict total cost as a function of the number of lysimeters per stack. The cost relationship for the baseline in this particular scenario is $TC = \$24.3X + \29.4 , where TC is the total system cost and X is the number of lysimeters per stack.

FIGURE 9. NUMBER OF ALUMINUM CASINGS EQUIVALENT IN COST TO TEN SEAMIST™ HDPE LINERS

Figure 9. Graph showing the number of SEAMIST™ HDPE liner systems that can be purchased equal in price to one round of aluminum casing for use in obtaining soil moisture measurements in four 250-ft horizontal boreholes underneath a low-level radioactive land disposal pit. The “number” of HDPE liners includes the use of one liner per month, all the liner supplies, and proper disposal for a period of one year. The cost of using HDPE liners is an order of magnitude less than the cost of using conventional casing.

VI. SUMMARY and CONCLUSION

This report describes the cost and performance characteristics of SEAMIST™, an innovative technology that facilitates measurements of contamination in both vertical and horizontal vadose zone boreholes. SEAMIST™ consists of an airtight membrane liner that is pneumatically emplaced inside the borehole. The positive air pressure inside the liner maintains the integrity of the borehole structure. Various sampling and measuring devices can be attached to the membrane including vapor monitoring ports, absorbent pads, and fiber optic probes. Small instruments such as neutron logging tools or cameras can be towed through the borehole as the membrane is emplaced and take measurements or photographs at intervals.

The purpose of this report has been to analyze the cost and performance effectiveness of this new technology in comparison to currently used technologies that accomplish equivalent objectives. To perform a realistic comparison, we devised five scenarios that are typical of situations the Department of Energy might encounter in its environmental remediation programs. We developed the total costs associated with implementing and using both the innovative and conventional technologies and then compared the two alternatives to determine in which situations the new technology would be more cost or performance effective or both.

Scenario 1 involved constructing soil vapor monitoring ports in the SEAMIST™ liner for use in a 100-ft vertical borehole and then comparing that cost to the cost of constructing similar ports in conventional PVC casing. For a series of twelve vertical boreholes each with ten ports, the SEAMIST™ system turned out to be 56% more cost effective. The performance of both systems is equivalent; the only difference is in the kind of tubing to the surface which could be changed if necessary. The primary caveat on the use of the SEAMIST™ system in this scenario (and in all scenarios) is that the borehole remain stable until the liner is emplaced.

Scenario 2 is similar to Scenario 1 except that the VOC contamination is very shallow and therefore the boreholes are drilled horizontally. The baseline of comparison in this scenario is a series of soil vapor probes placed in locations analogous to the SEAMIST™ soil vapor monitoring ports. There was no cost advantage for the new technology demonstrated in this scenario due primarily to the fact that the shallow nature of the plume permitted direct vertical access. Implanted soil vapor probes are more cost effective than drilling horizontal boreholes. However, in situations where direct vertical access is not possible, the use of SEAMIST™ may be the only feasible alternative. In that case, the relative cost becomes less of an issue than being able to acquire the necessary information.

Scenario 3 involves obtaining pore fluid from the vadose zone to analyze for water-

borne contaminants such as nonvolatile organic compounds, PCBs, PAHs, pesticides, metals, and even tritium. The SEAMIST™ setup consists of absorbent wicking pads attached to the side of the membrane which are in direct contact with the borehole soil. There are twelve 100-ft vertical boreholes and each one has ten absorbent pads spaced 10 ft apart. The baseline of comparison is a series of vertically stacked, analogously placed, pressure-vacuum suction lysimeters. The SEAMIST™ system was found to be more cost effective than the baseline by a factor of three. In addition, SEAMIST™ was found to have significant performance advantages compared to the use of suction lysimeters. These performance advantages could potentially impact the accuracy of the analysis results.

Scenario 4 involves the use of a neutron logging tool to obtain measurements of soil moisture under a low-level radioactive land disposal pit. Four horizontal boreholes are drilled underneath the land disposal pit. A SEAMIST™ liner is everted in the borehole as the neutron logging tool is simultaneously towed through it while taking neutron attenuation measurements at 5-ft intervals. The baseline consists of permanently casing the boreholes with aluminum and similarly towing the logging tool using a pulley system. The primary caveat on the use of the SEAMIST™ system in this scenario is, again, that the borehole must remain stable for the duration of its use, which in this case could be months. In some areas of the country, borehole collapse is not a problem, but it is a consideration that many times obviates the use of SEAMIST™ by itself (i.e., without conventional casing). A definite performance advantage of SEAMIST™ is the capability to simultaneously acquire pore fluid samples for investigating anomalous data readings.

The final scenario represents a combination of the sampling requirements of Scenarios 1 and 3. The purpose of this scenario is to demonstrate the economies of scope that can be achieved with SEAMIST™ that are not possible with most conventional technologies. The combination of vapor sampling ports and absorbent wicking pads in one membrane produces an *additional* 27% savings over the sum of the two separate SEAMIST™ system costs. This results in a 74% savings of the combined SEAMIST™ system over the sum of the costs of the two baseline technologies. This integration capability is by far the most advantageous cost and performance advantage of SEAMIST™.

The choice of any technology is very complex, and that the choice depends on both the geologic circumstances in which the technology is to be used *and* on the future as well as present remediation technology needs. The optimal choice of technologies requires knowing and understanding the situation and the requirements thoroughly. Usually the best approach is to have a problem first, to outline the requirements of that problem, and then to choose a technology that meets those requirements. Determining the cost effectiveness of the available choices requires knowledge of some technique or methodology. The real benefit of this paper is twofold: first, it presents an analysis of a specific technology with respect to other available

options; and second, it presents a framework in which to do other analyses in which similar situations and questions may arise.

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APPENDIX: Cost Detail

SCENARIO 1

<i>Company</i>	<i>Item</i>	<i>\$/Unit</i>	<i># Units</i>	<i>Price</i>
	SEAMIST™			
	Materials			
W. L. Gore & Assoc.	Urethane-coated polyester	10.50/H	1,200	12,600
Harrington Plastics	Teflon® tubing - 1/8" od	1/H	6,600	6,600
Science & Engineering	Stainless steel ports w/ dust screens	@ 9	120	1,080
Assoc., Inc.	Basepipe assemblies w/ tether	@ 150	12	1,800
R&J Crushing, Inc.	Sand	11.80/cub yd	5	59
	Manufacturing Labor			
Eastman Cherrington	Technician	21/hr *	144	3,024
	Installation			
Beylik Drilling, Inc.	Drill boreholes - hollow stem auger	Contract for 12		18,000
Eastman Cherrington	Installation and set up: Engineer	60/hr **	24	1,440
Eastman Cherrington	Technician	40/hr **	24	960
* Includes salary and fringe only; manufacturing overhead and G&A noted separately				
** Fully burdened: includes salary, fringe, overhead, and G&A				
	BASELINE			
	Materials			
Beylik Drilling, Inc.	4" diam PVC casing - 10' lengths	4.04/H	1,200	4,848
Harrington Plastics	1/4" diam brass st. elbows w/bnut	@ 3.25	120	390
Harrington Plastics	1/4" diam sch 80 PVC tubing	1.23/H	7,800	9,594
R.S. Means data	1/4" diam tube sampling array w/valves	@ 500 parts	12	6,000
Pumps, Inc.	Bentonite/sand seal	15.12/bag	172	2,600
R&J Crushing, Inc.	10/20 silica sand	11.80/cub yd	115	1,357
R.S. Means data	Flush mount well vault	@ 800	12	9,600
	Labor			
Beylik Drilling, Inc.	Drill boreholes - hollow stem auger	Contract for 12		18,000
See below*	Cut, prepare, & install casings	4.00/ft	1,200	4,800
	Construct ports in casing	@ 180	12	14,178
	Construct sampling array stand w/valves	@ 180	12	2,160
	Install sand, bentonite & seals	3197.5	12	38,370
	Install flush mount vaults	480	12	5,760
* Fully burdened labor rates used. Estimates based on discussions w/ Daniel B. Stephens & Assoc., Inc.				

SCENARIO 2

<i>Company</i>	<i>Item</i>	<i>\$/Unit</i>	<i># Units</i>	<i>Price</i>
	SEAMIST™			
	<i>Materials</i>			
W. L. Gore & Assoc.	Urethane-coated polyester	10.5/lb	2,400	25,200
Harrington Plastics	Teflon® tubing - 1/8" od	1/lb	13,000	13,000
Science & Engineering Assoc., Inc.	Stainless steel ports w/ dust screens	⑨ 9	4	360
	Basepipe assemblies w/ tether	⑨ 150	4	600
	<i>Manufacturing Labor</i>			
Eastman Cherrington	Technician	21/hr *	48	1,008
	<i>Installation</i>			
Drilex	Drill boreholes including mob/demob	Contract for 4		117,839
Eastman Cherrington	Installation and set up: Engineer	60/hr **	16	960
Eastman Cherrington	Technician	40/hr **	16	640
Remote Power, Inc.	Solar-powered air pump system: 2 panels			3,260
Air Dimensions, Inc.	4 pumps, 12 switches, labor			
Air Logic				
* Includes salary and fringe only; manufacturing overhead and G&A noted separately				
** Fully burdened: Includes salary, fringe, overhead, and G&A				
BASELINE				
	<i>Materials</i>			
K-V Assoc., Inc.	Porta-Punch™ System	⑨ 13,400	1	13,400
K-V Assoc., Inc.	Rod kit w/ 21 feet of shafts	⑨ 2,860	1	2,860
K-V Assoc., Inc.	Additional shaft sections	255/3 lb	2	510
K-V Assoc., Inc.	Shieldpoint adapter	⑨ 140	1	140
K-V Assoc., Inc.	Gas connector	⑨ 20	1	20
K-V Assoc., Inc.	Vapor probes w/ anchors	⑨ 9	40	360
Harrington Plastics	Teflon® tubing - 3/16" od	3/lb	1,200	3,600
R&J Crushing, Inc.	Packing sand	11.80/cub yd	2	24
K-V Assoc., Inc.	Surface cap assemblies	⑨ 12	40	480
Pumps, Inc.	Bentonite	15/bag	2	30
	<i>Labor</i>			
K-V Assoc., Inc.*	2 technicians installing	40	160	6,400
	4 systems/day @ \$40/hr*			
* Rates from ICF Kaiser Engineering; time estimate based on discussion with K-V Associates, Inc.				

SCENARIO 3

<i>Company</i>	<i>Item</i>	<i>\$/Unit</i>	<i># Units</i>	<i>Price</i>
	SEAMIST™			
	<i>Materials</i>			
W. L. Gore & Assoc.	Urethane-coated polyester	10.50/H	1,200	12,600
Science & Engineering Assoc., Inc.	Absorber assemblies and pads	30	120	3,600
	Basepipe assemblies w/ tether	100	12	1,200
	<i>Manufacturing Labor</i>			
Eastman Cherrington	Engineer	33/hr *	16	528
Eastman Cherrington	Technician	21/hr *	16	336
	<i>Installation</i>			
Beylik Drilling, Inc.	Drill boreholes including mob/demob	Contract for 12		18,000
Eastman Cherrington	Installation and set up: Engineer	60/hr **	16	960
Eastman Cherrington	Technician	40/hr **	16	640
Remote Power, Inc.	Solar-powered air pump system: 2 panels			3,260
Air Dimensions, Inc.	4 pumps, 12 switches, labor			
Air Logic				
	<i>Sampling ***</i>			
Eastman Cherrington	Technician	40/hr	576	23,040
Rader Awning	Windscreen - 21 ft. x 30 ft.	2,000	1	2,000
Eastman Cherrington	Absorbers	5	1,440	7,200
Wheaton	Collection bottles	4	1,440	5,760
* Includes salary and fringe only; manufacturing overhead and G&A noted separately				
** Fully burdened: includes salary, fringe, overhead, and G&A				
*** Sampling rate is once per month for one year				
BASELINE				
	<i>Materials</i>			
Soil Measurement Systems	Stainless steel suction lysimeters	295	120	35,400
Pumps, Inc.	Bentonite/seals	15.12/bag	63	953
Pumps, Inc.	Silica sand	11.80/cub yd	42	495
Harrington Plastics	Teflon® tubing - 1/4" id	3/ft	14,400	43,200
Granger	Clamps	.35	480	168
R.S. Means data	1/4" id tube sampling array stand w/ valves	500	12	6,000
R.S. Means data	Flush mount well vaults	800	12	9,600
Soil Measurement Systems	Vacuum equipment w/ battery	575	10	5,750
	<i>Labor</i>			
See below *	Install lysimeters	120	120	14,400
	Prepare tubing	0.75	14,400	10,800
	Construct sampling array stand	180	12	2,160

SCENARIO 3 (cont'd)

	Install clamps	5.00	480	2,400
	Install sand, bentonite & seals	1,169	12	14,028
	Install flush mount well vaults	480	12	5,760
	<i>Sampling **</i>			
Soil Measurement Systems	Mobilize/demobilize - 2 techs	1,210	12	14,520
Soil Measurement Systems	Sampling - labor	2,880	12	34,560
	materials	6,000	12	72,000
* Fully burdened labor rates used. Estimate of time based of discussions w/ Soil Measurement Systems				
** Sampling rate is once per month for one year				

SCENARIO 4

<i>Company</i>	<i>Item</i>	<i>\$/Unit</i>	<i># Units</i>	<i>Price</i>
	SEAMIST™			
	<i>Materials</i>			
M&Q Packaging Materials	High density disposable polyethylene	0.10/lb	400x12	480
Science & Eng. Assoc., Inc.	Basepipe assemblies w/ tether	@ 100	1	100
CPN	Neutron logging tool	@ 4,300	1	4,300
CPN	350 ft cable			1,210
CPN	Cable markings	1.25	60	88
CPN	Battery pack, charger & cable			224
	Laptop computer w/ accessories			4,000
	<i>Installation & Measurements</i>			
Drilex	Mobilization /demobilization of drilling equipment			45,679
Drilex	Four blind boreholes - 250' horiz. 25' TVD			56,980
Eastman Cherrington	Obtain measurements*: Engineer	60/hr **	96	5,760
Eastman Cherrington	Technician	40/hr **	96	3,840
Medical Compliance Service	Membrane disposal	86.25	12	1,035
* Measurements taken once per month for one year				
** Fully burdened: includes salary, fringe, overhead, and G&A				
	BASELINE			
	<i>Materials</i>			
Drilex	4" id aluminum casing	8/ft	2,280	18,240
CPN	Neutron logging tool	@ 4,300	1	4,300
CPN	350 ft cable			1,210
CPN	Cable markings	1.25	60	88
CPN	Collar	80	1	80
CPN	Battery pack, charger & cable			224
	Laptop computer w/ accessories			4,000
	<i>Installation</i>			
Drilex	Mobilization /demobilization of drilling equipment			45,679
Drilex	Four continuous boreholes - 250' horizontal 25' TVD			63,840
	<i>Measurements</i>			
Labor estimate: ICF Kaiser Engineering	Obtain measurements*: Engineer	60/hr **	96	5,760
	Technician	40/hr **	96	3,840
* Measurements taken once per month for one year				
** Fully burdened: includes salary, fringe, overhead, and G&A				

END

**DATE
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12/27/93