TEST PLAN AND TECHNICAL PROTOCOL FOR A FIELD TREATABILITY TEST FOR POL FREE PRODUCT RECOVERY -

EVALUATING THE FEASIBILITY OF TRADITIONAL AND BIOSLURPING TECHNOLOGIES

DRAFT

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OFFICE OF THE ASSISTANT SECRETARY

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MEMORANDUM FOR REMEDIAL PROJECT MANAGERS AND PROJECT TEAMS

SUBJECT: Test Plan and Technical Protocol for a Field Treatability Test for POL Free Product Recovery - Evaluating the Feasibility of Traditional and Bioslurping Technologies

This test plan is a tool that provides a low-cost, field-based method of determining the feasibility of petroleum, oils, and lubricant (POL) free product recovery and supplies critical design information.

In accordance with the Air Force Center for Environmental Excellence Technology Transfer Division (AFCEE/ERT) Risk-based Approach Initiative, the primary goal of free product recovery is to aggressively reduce the load of mobile, risk-based constituents [e.g., benzene, toluene, ethylbenzene, xylenes (BTEX)] down to levels where natural processes provide appropriate contaminant containment and destruction.

This testing regime includes the evaluation of traditional gravity-driven skimmer and dual pump technologies, but also focuses on a more aggressive innovative approach called bioslurping. Bioslurping utilizes a strong vacuum to provide a driving force that greatly exceeds the force of gravity. This technology combines vacuum-enhanced recovery of free product and soil aeration (a.k.a. bioventing) of unsaturated zone soils. We believe that this technology is the most aggressive approach. Thus, if free product recovery is not feasible using bioslurping, significant recovery may not be possible with traditional technologies.

The AFCEE Technology Transfer Division has launched a nationwide (36 sites) Bioslurper Initiative to evaluate the cost and performance of traditional and bioslurper technologies under a large variety of site/contaminant conditions. We believe that these data will be invaluable to the DOD and that this test plan should be implemented prior to any commitment to initiate free product recovery or system design

This publication is the result of a cooperative effort with AFCEE and Battelle Memorial Institute, Columbus, OH. We invite your comments and suggestions. Please contact Mr. Patrick Haas or Lt Col Ross Miller, AFCEE/ERT, 8001 Arnold Drive, Brooks AFB, TX 78235-5357, DSN 240-4331, commercial (210) 536-4331.

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to

U.S. Air Force

Brooks AFB, TX 78235

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1.0 OBJECTIVE

This Test Plan and Technical Protocol has been written to describe the activities to be conducted as part of the Bioslurper Initiative and the methods for conducting a field treatability test for bioslurping. This project is funded and managed by the U.S. Air Force Center for Environmental Excellence. The objective of this study is to develop procedures for evaluating, the potential for recovering free-phase light, nonaqueous-phase liquid (LNAPL) present at petroleum-contaminated sites. The test methods to be employed include initial evaluation of site variables followed by conduct of a bioslurper LNAPL recovery test. The intent of the field testing is to determine the predictability of LNAPL recovery efficiency, and to evaluate the applicability, cost, and performance of the bioslurping technology for removal of free product and remediation of the contaminated site. The specific test objectives are described in the following sections.

This Test Plan and Technical Protocol was developed as overall guidance to support preparation of site-specific plans for each of the more than 35 sites where short-term field tests will be conducted. The overall protocol contains details on the general materials and methods for the bioslurper testing. Describing the aspects of testing applicable to all sites in one protocol will increase the consistency and efficiency of the overall effort. The protocol is a source for basic information to ensure that site-specific plans are prepared using common materials and methods. The site-specific test plans will incorporate details such as test equipment setup, calibration, and use of bioslurper well design by reference, thus avoiding duplication of information that is not dependent on site conditions. The bioslurper protocol was developed from a similar protocol for bioventing (Hinchee et al., 1992).

1.1 Conduct Site Characterization

Initial site characterization activities will be conducted to evaluate site variables that may affect LNAPL recovery efficiency, and to determine the bioventing potential of the sites. These activities will include estimating the persistence of LNAPL in site monitoring wells (baildown tests), soil sampling to determine physical/chemical site characteristics, determining soil gas permeability to estimate the well's radius of influence, and in situ respiration testing to evaluate site microbial activity. Results from the baildown tests will be used to select the bioslurper pilot test well. The site characterization approach will be aimed at providing the environmental manager with a stepwise procedure for determining the feasibility of product recovery as well as aid in the design of the pilot or full-scale system.

1.2 Conduct Bioslurper Pilot Test

Following the site characterization activities, a short-term bioslurper pilot test will be conducted. A bioslurper system will be installed on a single selected well and will be operated for a period of 9 days. The bioslurper system will be operated as follows: 2 days in the skimmer mode (no vacuum); 4 days in the bioslurper mode (vacuum-mediated); 1 day in the skimmer mode (follow-up repeatability test); and 2 days in the groundwater depression mode. Measurements of the extracted soil gas composition, free product thickness, and groundwater level will be made during the test. The mass of extracted free product, groundwater, and soil gas will be quantified over time. These measurements will be used to evaluate the long-term effectiveness of bioslurping.

1.3 Use Existing Monitoring Wells

The U.S. Air Force has already installed monitoring points or other wells at many sites that will be suitable for use in this study. In keeping with the objective of developing a cost-effective program for site remediation, every effort will be made to use existing wells and to minimize drilling costs.

2.0 INTRODUCTION TO LNAPL RECOVERY AND BIOSLURPING

Historic handling practices and past spills and leaks have caused petroleum releases to the environment to occur at most industrial and government fuels-handling facilities. When a fuel release occurs, the contaminants may be present in any or all of three phases in the geologic media:

1. sorbed to the soils in the vadose zone,
2. in free-phase form floating on the water table, and/or
3. in solution phase dissolved in the groundwater.

Of the three phases, dissolved petroleum contaminants in the groundwater are considered to be of greatest concern due to the risk of humans being exposed to the contaminants through drinking water. However, the liquid- and sorbed-phase hydrocarbons act as feedstocks for groundwater contamination, so any remedial technology aimed at reducing groundwater contamination must address these sources of contamination.

At many contaminated sites, petroleum contamination is present as free product in both the vadose zone and the capillary fringe. Regulatory guidelines generally require that free-product recovery (FPR) take precedence over other remediation technologies. One significant point is that product often is not recoverable, especially when conventional gravity-driven recovery technologies are used. Also, the conventional wisdom has been to complete free-product removal activities prior to initiating vadose zone remediation. This "phased" approach to site remediation is costly and slow because conventional free-product recovery technologies have little or no effect on soil contamination; when LNAPL recovery is complete, a second remediation system must be installed, operated, and maintained to treat residual soil contamination.

2.1 Subsurface Distribution of Hydrocarbons

When a fuel spill occurs, the fuel is adsorbed onto the soil matrix and collects on the water table. The contaminants partition through the in situ environment. Fluids can move through the subsurface via various mechanisms. Advection and diffusion are two of the dominant mechanisms.

Advection results from a spatial difference in the fluid total potential, which is the sum of the fluid pressure and gravitational potentials. Diffusion results from a spatial difference in chemical concentrations. Both of these mechanisms and fluid content-pressure relationships govern the distribution of chemicals and fluid phases in the subsurface.

Before light, nonaqueous-phase liquids (LNAPLs) are introduced into the subsurface, a single-phase fluid system exists below the capillary fringe (i.e., a water-saturated system), and a two-phase fluid system exists above the capillary fringe (i.e., an air-water system). Chemicals in the aqueous phase can migrate through the subsurface in response to a gradient in the aqueous-phase total potential (i.e., advection) or by a difference in their aqueous-phase chemical concentrations. Chemicals in the aqueous phase also may partition into the gaseous phase, depending on their vapor pressures for the existing temperature and pressure regime. Once in the gaseous phase, these chemicals can migrate in response to advection and diffusion, which may occur at significantly different rates than in the aqueous phase because the aqueous and gaseous phases may be contained in contrasting pore sizes.

Chemicals in the aqueous phase also may partition onto inorganic and organic solids. The chemical adsorption and desorption may be considered to be instantaneous or may be considered to be controlled by kinetics, i.e., the chemical adsorption and desorption rates may be significantly different. If chemical adsorption and desorption are not instantaneous, then the migration of some chemicals may be retarded, which may affect subsequent remediation strategies. Because many subsurface solids are preferentially wetted by water, the adsorption and desorption of chemicals will occur in association with the aqueous phase. For chemicals to be adsorbed onto solids from the gaseous phase, they must first partition into the aqueous phase.

After nonaqueous-phase liquids (NAPLs) are present in the subsurface, another fluid phase must be considered in which chemicals can migrate by advection and diffusion. Compounds that constitute a NAPL can migrate in response to a spatial gradient in the NAPL total potential. These compounds also may partition into the aqueous and gaseous phases and be transported independently of the NAPL total potential. Therefore, the migration of NAPL compounds through the subsurface occurs via the gaseous, NAPL, and aqueous phases. The proportion of NAPL compounds that is transported via the gaseous and aqueous phases is a function of the NAPL vapor pressures; aqueous-phase NAPL solubilities; and the spatial differences in gaseous-, NAPL-, and aqueous-phase pressures. As compounds partition into other fluid phases, changes in fluid densities and viscosities must be considered to accurately determine fluid flow rates.

The distribution of fluids in the pore spaces is governed by differences in the fluid pressures at the interfaces between two contiguous fluid phases, termed capillary pressures. For an air-NAPL-water fluid system, the water content is a function of the difference between the NAPL and aqueousphase pressures, i.e., the NAPL-water capillary pressure. The total liquid content is a function of the difference between the gaseous and NAPL pressures, i.e., the air-NAPL capillary pressure. For air-NAPL-water fluid systems in water-wet subsurface materials, water will occupy the smallest pore spaces, gas will occupy the largest pore spaces, and the NAPL will occupy intermediate-sized pores. The distribution of fluid phases in the pore spaces governs the ability of a porous medium to transmit a fluid phase and can affect how a NAPL migrates below the water-saturated capillary fringe.

NAPLs less dense than water (i.e., LNAPLs) are likely to migrate through unsaturated subsurface materials rather uniformly until they encounter the water-saturated capillary fringe. The present of NAPL will lower the interfacial tension and the water-saturated fringe. A LNAPL will not penetrate the water-saturated region unless a critical entry capillary pressure is exceeded, which is a function of the porous medium pore sizes. NAPLs more dense than water (DNAPLs), also are likely to migrate through the unsaturated subsurface uniformly', provided the DNAPL flux rate is not high. Otherwise, very distinct pathways for DNAPL movement may occur. Because NAPLs typically are a nonwetting fluid with respect to water, they prefer to migrate in the larger pore sizes. When DNAPLs approach a water-saturated region, they will move selectively within the largest pore spaces. As a consequence, DNAPLs do not appear to be retarded by the presence of a water-saturated region because significant pressures can occur in these larger pores that exceed the critical entry capillary pressure of those pores. Hence, DNAPLs are likely to migrate in the water-saturated region in what appears to be a chaotic manner; however, the migration pattern is based on physics. Therefore, predicting DNAPL movement below a water table is likely to be challenging because the distribution pattern of the larger pore spaces seldom is known in sufficient detail.

NAPL compounds, when in the subsurface, are subject to chemical and microbiological transformations. Depending on the specific compound, the transformations can occur via various pathways. For example, aliphatic hydrocarbons in fuel oils can serve as substrates for a variety of microorganisms and can be chemically altered by both aerobic and anaerobic bacteria. When oxygen is present, longer-chained alkanes are degraded by converting them to longer-chained fatty acids, which are then degraded by beta-oxidation for subsequent complete oxidation. The pathway for anaerobic biodegradation of aliphatic hydrocarbons, however, has not been as well elucidated as for aerobic degradation. Many microorganisms also have evolved biochemical degradation pathways for degrading aromatic hydrocarbons. Benzene rings can be aerobically transformed into organic acids that can be further degraded to carbon dioxide. The microbiological degradation of BTEX compounds has been widely studied, and the specific biochemical pathways have been well characterized. Benzene rings also can be degraded by anaerobic bacteria, but the pathways have not been as well studied as for aerobic pathways.

In summary, LNAPL and DNAPL components can partition from a NAPL into the gaseous and aqueous phases. The amount of NAPL found in a given fluid phase is a function of vapor pressure and chemical solubility. Once in the gaseous and aqueous phases, NAPLs can migrate through the subsurface in response to diffusive and advective processes. The components also may migrate in the subsurface as a NAPL by advection. The distribution of NAPLs in the pore spaces of a porous medium is a function of differences in the gaseous, aqueous, and NAPL pressures, i.e., the capillary pressures. For porous media containing gas, NAPL, and water, the NAPL will occupy pore sizes larger than those containing water, but smaller than those containing gas. For porous media containing only NAPL and water, the NAPL will occupy the largest pore spaces. LNAPL and DNAPL components also can adsorb onto inorganic or organic solids and can be chemically transformed by microorganisms. The subsurface fate of NAPLs is very complex and depends on many environmental factors.

2.2 Overview of Free-Product Pumping Technologies

There are two basic LNAPL recovery collection systems: (1) interceptor trenches and drains; and (2) recovery wells (API, 1989). Interceptor trenches and drains can be used at LNAPL contaminated sites with shallow water tables. These systems require excavation of a trench to a depth below the lowest seasonal water table fluctuation. The trench is installed downgradient of the LNAPL plume to intercept migrating free-phase fuel. Either LNAPL migrates to the trench with natural groundwater movement, or flow of LNAPL and water can be enhanced by using a pump to draw down the water table in the trench to increase the hydraulic gradient. LNAPL is collected in the trench and periodically pumped to the surface.

The greatest advantage to trench recovery systems is that the full geologic cross section is intersected by the LNAPL collection system. This is particularly useful at sites with discontinuous interbedded sands and clays. However, there are some drawbacks and limitations to the trench/drain approach. First, the trench must intersect the water table, so depth is a limitation and stabilization often is problematic. Second, the excavation will result in contaminated soils being brought to the surface, where treatment and disposal requirements must be addressed. Finally, installation of a trench recovery system requires a great deal of site disruption and may be incompatible with site activities.

Compared to trench collection systems, recovery well LNAPL collection system are adaptable to a much wider range of site conditions. Recovery well LNAPL collection system consist of a vertically installed well, or array of wells, in the LNAPL plume.

There are two types of LNAPL recovery technologies: (1) passive technologies (skimmer systems), which rely on the passive movement of LNAPL into a collection system; and (2) active technologies (pump drawdown and vacuum-enhanced system), which actively, physically induce flow of LNAPL into a collection system. Conventional skimmer and pumping methods are compared in Figure 1.

2.2.1 Skimmer Technologies

Skimmer LNAPL recovery systems are designed to remove LNAPL from the groundwater surface in a recovery well or trench collection system (right side of Figure 1). These systems can consist of a variety of pump types and configurations, but the basic operation is the same. Skimmer recovery systems rely on the passive movement of LNAPL into the product recovery system. These systems are designed to remove LNAPL only and pump very little groundwater, reducing operation and maintenance costs.

Skimmer system are very popular because of ease of use. The main limitation to skimmer systems is that they have a very small radius of influence. Because skimmer pumps cause little or no drawdown of the water table, they do little to cause preferential migration of LNAPL to the recovery

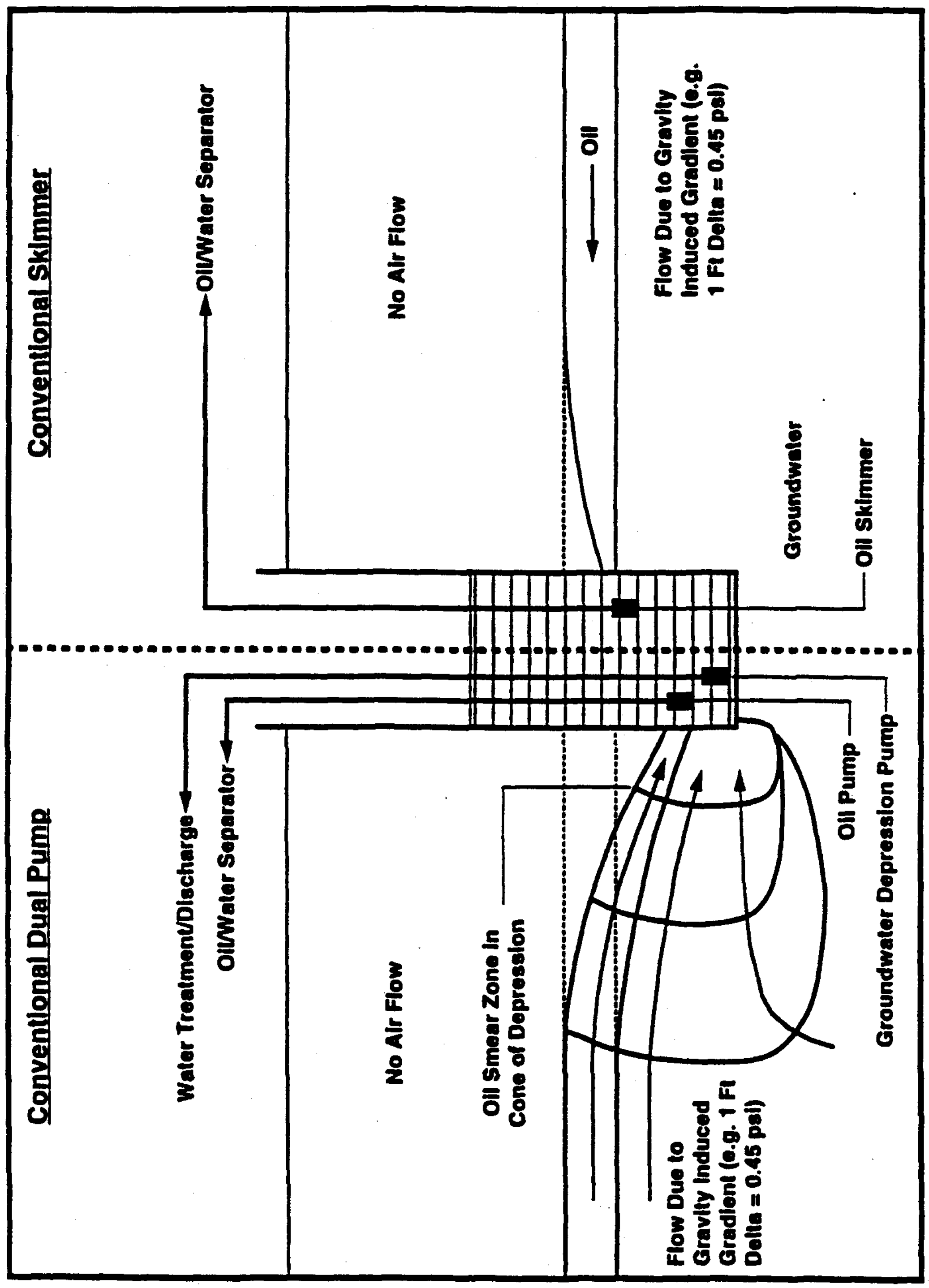

Figure 1. Comparison of Skimming and Pumping Methods for LNAPL Recovery

well. Except in instances when the LNAPL mass is very large and very mobile, and the subsurface permeability is high, skimmer systems tend to have very low LNAPL recovery rates.

2.2.2 Pump Drawdown Technologies

Pump drawdown LNAPL recovery systems are designed to pump LNAPL and groundwater from a LNAPL recovery well or trench (left side of Figure 1). Groundwater is extracted to lower the water table around the LNAPL collection system (cone of depression), inducing a gravity gradient for LNAPL to flow into the collection system. Each foot of groundwater-level depression provides a driving pressure of about 0.45 psi. In most instances, the cone of depression will increase LNAPL recovery rates.

The two types of drawdown recovery systems are single-pump, total-fluids recovery systems and dual-pump recovery systems. Both systems work under the same principle, i.e., the fluid flow gradient into the recovery system is increased by lowering the liquid level in the recovery well to induce gravity flow of LNAPL to the extraction pump. These systems work well when aquifer hydraulic conductivities and saturated thicknesses; are large. High aquifer conductivity reduces the resistance to LNAPL flow to the extraction point. A large saturated thickness allows recovery of a higher ratio of LNAPL to water and/or less complex pumping controls.

There are several drawbacks to drawdown LNAPL recovery systems. Large volumes of groundwater may need to be extracted to maintain the cone of depression, greatly increasing treatment and disposal costs for extracted groundwater. The cone of depression creates a contamination smear zone below the original water table level, which will be difficult to remediate. Permeability usually is higher in the horizontal direction, parallel to geologic stratification, which can inhibit flow down along the cone of groundwater depression. Complex water/LNAPL level detection and pump control systems may be needed to maintain desired fluid levels and/or improve LNAPL recovery. Pumps must be in the well or trench, requiring placement of complex equipment in a remote location and possibly corrosive environment. For pumping systems in wells, the diameter of the well must be large enough to accommodate the pumping equipment. Typical monitoring wells, therefore, cannot be used.

The bioslurper technology has advantages that overcome many of the drawbacks of skimmer system and drawdown pump systems. The following sections describe bioslurping technology in detail.

2.3 Bioslurper Technology Description

Bioslurping is the adaptation and application of vacuum-enhanced dewatering technology to the remediation of petroleum-contaminated sites. Bioslurping combines the two remedial approaches of bioventing and vacuum-enhanced free-product recovery. Bioventing stimulates the bioremediation of petroleum-contaminated soils in situ; and vacuum-enhanced free-product recovery extracts light, nonaqueous-phase liquids (LNAPLs) from the capillary fringe and the water table. An understanding of both technologies is necessary to understand the bioslurping technology.

2.3.1 Bioventing

Bioventing is the process of aerating subsurface soils to stimulate in situ bioremediation. Application of bioventing has been tested in the AFCEE Bioventing Initiative. The bioslurping protocol was developed based on the bioventing test protocol (Hinchee et al., 1992). Bioslurping is related to soil venting (aka soil vacuum extraction, soil gas extraction, or in situ soil stripping). The significant differences that soil venting is designed and operated to maximize volatilization of low-molecular-weight compounds. Some biodegradation occurs in most soil venting remediations. In contrast, bioventing is designed to maximize biodegradation of any aerobically biodegradable compound, regardless of molecular weight. The significant difference in the technologies is that the objective of soil venting is volatilization and the objective of bioventing is biodegradation. Although both technologies involve venting of air through the subsurface, the differences in objectives result in significantly different designs and operations of the remedial systems.

Petroleum distillate fuel hydrocarbons such as JP-4 fuel are generally biodegradable if naturally occurring microorganisms are provided an adequate supply of oxygen and basic nutrients (Atlas, 1986). Natural biodegradation does occur at many sites and eventually may mineralize most fuel contamination. However, the process is dependent upon natural oxygen diffusion rates (Ostendorf and Kambell, 1989) and as a result frequently is too slow to prevent the spread of containination. Such sites may require remediation of the contaminant source to protect sensitive aquifers. At these sites, acceleration or enhancement of the natural biodegradation process via bioventing may prove to be the most effective remediation.

An understanding of the distribution of contaminants is important in any in situ remediation. Much of the residue of hydrocarbons at a fuel-contaminated site is found in the unsaturated zone soils, in the capillary fringe, and immediately below the water table. Typically, seasonal water table fluctuations spread residues in the area immediately above and below the water table. To be successful, bioremediation efforts must treat these areas. Bioventing can provide oxygen to vadose zone soils.

A system engineered to increase the microbial biodegradation of fuel hydrocarbons in the vadose zone using forced air as the oxygen source is a cost-effective alternative to conventional systems. This process stimulates soil-indigenous microorganisms to aerobically metabolize fuel hydrocarbons in unsaturated soils.

By using air as an oxygen source, the minimum air mass to hydrocarbon mass ratio (based on stoichiometry) is approximately 13 to 1. This ratio compares with more than 10,000 to 1 water to hydrocarbon for a conventional waterborne-enhanced bioreclamation process. At least 1,200 gallons of water would be required to carry enough oxygen to degrade 1 pound of hydrocarbon contamination. The challenge of delivering oxygen dissolved in water increases when the soil has low permeability.

The significant features of bioventing technology include the following:

- Optimizing air flow to minimize volatilization while maintaining aerobic conditions for biodegradation

- Monitoring local soil gas conditions to ensure that aerobic conditions exist (not just monitoring vent gas composition)

- Conducting in situ respiration tests that provide for the effective measurement of continued contaminant biodegradation

- Manipulating the water table as required for air/contaminant contact.

2.3.2 Vacuum-Enhanced Pumping LNAPL Recovery

Vacuum-enhanced recovery is a common Pumping technique used in construction dewatering projects (Powers, 1981). Vacuum-enhanced pumping involves the application of a negative pressure to a well, point system to increase the rate of flow of groundwater and soil gas into the wells. In recent years vacuum-enhanced pumping has been applied to groundwater remediation pump-and-treat system and to LNAPL recovery system. Blake and Gates (1986) report increased groundwater extraction rates and increased residual hydrocarbon (LNAPL) recovery through the use of vacuum-enhanced pumping. Blake et al. (1990) report applying vacuum-enhanced pumping techniques to hydrocarbon-contaminated sites to facilitate:

1. increased liquid recovery and gradient control,
2. vapor and residual hydrocarbon recovery, and
3. combined vapor recovery and gradient control.

Reisinger et al. (1993) report enhancing groundwater extraction by a factor of 47 % as a result of vacuum extraction.

Two important factors that influence the movement of fluids into a recovery well are hydraulic gradient, or head difference into the well, and aquifer transmissivity, i.e., the rate at which groundwater moves through a unit thickness of the aquifer. Vacuum-enhanced recovery improves recovery rates by increasing the hydraulic gradient and increasing the aquifer transmissivity. Conventional dual-pump free-product recovery (FPR) systems increase hydraulic gradient into a well by setting a pump below the water table to establish a cone of depression around the well. Free-product then flows down the gradient (diagonally downward) into the well to be recovered by a second extraction pump. Vacuum-enhanced pumping systems use the same concept, except that the cone of depression actually is a cone of reduced pressure around the well. Fluids then flow horizontally across the pressure-induced gradient, from higher pressure outside the well to lower pressure inside the well. The transmissivity of the saturated zone is an intrinsic characteristic of an aquifer and is a function of the hydraulic conductivity and the aquifer saturated thickness.

Vacuum-enhanced pumping increases transmissivity by promoting flow along more-permeable horizontal flow lines and by decreasing the local pressure above the aquifer to, in effect, increase the saturated thickness of the aquifer. The sum effect of the increase in hydraulic gradient and aquifer transmisssivity is an enhanced liquid recovery rate.

Suction lift might appear to be a limitation to the application of vacuum-enhanced dewatering. In theory, the maximum suction lift attainable with an extremely efficient vacuum pump is approximately 25 ft, depending on elevation (Powers, 1981). In practice, however, greater suction lifts are attainable. Lifts greater than the theoretical maximum can be attained when the extracted fluid is not only water, but a mixture of soil gas bubbles and groundwater (Powers, 1981). A mixture of soil gas and water would have a specific gravity less than 1.0 and therefore can be lifted higher than a standard water column. Extractions that also include LNAPL (liquid with a specific gravity < 1.0) would add to this effect. Another phenomenon that can *help* in achieving greater than the theoretical suction lift is liquid entrainment or entrapment. Liquid entrainment occurs when the primary extraction fluid is soil gas, rather than a liquid. At high velocities, extracted soil gas can entrap water droplets and slugs and carry them to the surface at relatively high total liquid extraction rates.

2.3.3 Bioslurping

"Bioslurping" is a new dynamic technology application that teams vacuum-assisted free-product recovery with bioventing to simultaneously recover free product and remediate the vadose zone. Bioslurping is a vacuum-enhanced free-phase petroleum recovery technology. Unlike other LNAPL recovery technologies, bioslurping systems treat two separate geologic media simultaneously. Bioslurping pumps are designed to extract free-phase fuel from the water table and to aerate vadose zone soils through soil gas vapor extraction. The systems also can be designed to achieve hydraulic control as is done with conventional pump-and-treat technology. The bioslurper system withdraws groundwater, free product, and soil gas in the same process stream using a single pump. Groundwater is separated from the free product and is treated (when required) and discharged. Free product is recovered and can be recycled. Soil gas vapor is treated (when required) and discharged.

The bioslurper technology is unique because it utilizes elements of two separate remedial technologies, bioventing and free-product recovery, to address two separate contaminant media.

1. **Bioventing** is the process of enhancing natural in situ bioremediation of petroleum contamination in the vadose zone through forced aeration. Bioventing is accomplished through either air injection or soil gas extraction.

2. **LNAPL free-product recovery** is the process of removing free-phase petroleum from the capillary fringe in liquid form.

Bioslurping may improve free-product recovery efficiency without requiring the extraction of large quantities of groundwater. The bioslurper system pulls a vacuum of up to 20 inches of mercury on the recovery well to create a pressure gradient to force movement of fuel into the well. The system is operated to cause very little drawdown in the aquifer, thus reducing the problem of free-product entrapment.

Bioventing of the vadose zone soils is achieved by withdrawing soil gas from the recovery well. The slurping action of the bioslurper system cycles between recovering liquid (free product and/ or groundwater) and soil gas.

The rate of soil gas extraction is dependent on the recovery rate of liquid into the well. When free-product removal activities are complete, the bioslurper system is easily converted to a conventional bioventing system to complete remediation of the vadose zone soils.

Bioslurper systems are designed to minimize environmental discharges of groundwater and soil gas. As done in bioventing, bioslurper systems extract soil gas at a low rate to reduce volatilization of contaminants. In some instances volatile discharges can be kept below treatment action levels. The slurping action of a bioslurping system greatly reduces the volume of groundwater that must be extracted compared to conventional LNAPL recovery systems, thus greatly reducing groundwater treatment costs. Figure 2 illustrates the differences between conventional dual-pump LNAPL recovery and bioslurping.

Nonaqueous-phase liquids that are less dense than water move downward through the vadose zone and accumulate at and above the zone of saturation. The vertical interval containing the accumulated LNAPL also generally contains water and air. Near the top of the LNAPL zone, both water and LNAPL contents are low and most of the pore space is occupied by air. LNAPL contents usually are greatest toward the center of the LNAPL zone and decline to zero at the bottom where the pore space is fully occupied by water.

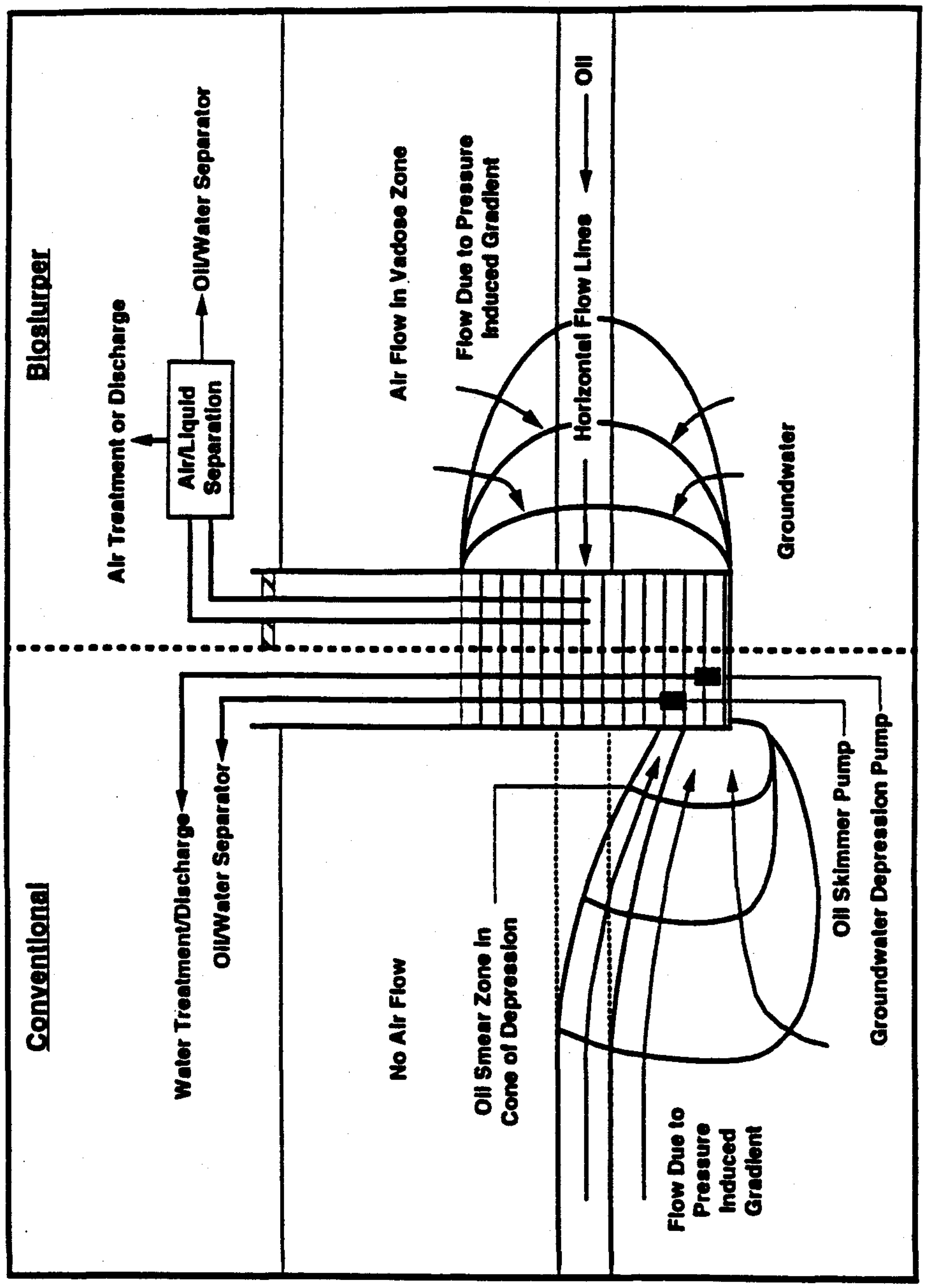

Figure 2. Comparison of Conventional LNAPL Recovery and Bioslurping

A significant feature of the slurping process is the induced air flow, which in turn induces LNAPL flow toward the well. The pressure gradient created in the air phase results in a driving force on the LNAPL that is significantly greater than that which can be induced by pumping the LNAPL with no air flow. Also of importance is the fact that the air flow created by the vacuum actually enhances the LNAPL content around the well. That is, the LNAPL tends to accumulate or pile up around the well. The accumulation around the well ensures that the permeability controlling the conductivity to LNAPL is maximum. For these reasons, slurping has the potential for removing more LNAPL and at greater rates than do other pumping mechanisms.

The flow of LNAPL to a well under a given driving force is dictated largely by the LNAPL conductivity. The single most important influence on the conductivity is the relative permeability of the soil to LNAPL. Relative permeability, in turn, depends strongly on the amount of LNAPL present. Because the LNAPL contents are low at both the top and bottom of the LNAPL zone, the relative permeability to LNAPL also is low at the top and bottom of the LNAPL zone. For this reason, LNAPL removal from these two portions of the LNAPL zone will be minimal, regardless of the quantity of LNAPL that has accumulated.

The quantity of LNAPL is greatest where the permeability is highest. The LNAPL quantity that may exist in this most conductive zone depends on the ratio of thickness of the LNAPL zone to a characteristic capillary pressure head. The feasibility of significant LNAPL recovery is small when this ratio is small. Unfavorable values of this ratio may occur, even when the LNAPL zone thickness is large. Such a circumstance occurs when the characteristic capillary pressure head is large due to very small pore openings, as in low-permeability soils.

In summary, the slurping process favorably influences both the driving force on the LNAPL and the relative permeability to LNAPL flow. These two features are responsible for the relative success of the slurping process. However, tight soils present a compounding unfavorable circumstance for LNAPL removal. First, tight soils have a low capacity to transmit fluid due to their low permeability. This feature is compounded by the fact that LNAPL quantities and relative permeabilities are lower in tight soils, other factors being equal. Thus, the slurping process cannot be expected to be successful in all circumstances, even when the LNAPL zone is thick.

3.0 BIOSLURPER PILOT TEST PREPARATION

The overall objective of this bioslurper protocol is to develop a short-term field pilot test method to determine the feasibility of NAPL recovery and the efficacy of bioslurping for LNAPL recovery and enhanced bioreclamation of contaminated soils (bioventing) at petroleum-contaminated sites. The short-term pilot study will focus primarily on bioslurping as a free-product recovery technology. Data will be collected to demonstrate that bioslurper systems enhance natural biodegradation through bioventing, but bioventing testing will be secondary to LNAPL recovery testing and data collection, especially since detailed bioventing testing has already been conducted at numerous sites within this initiative.

The approach of the test initiative is to work at multiple sites to identify variables that are important in determining free-product recovery potential. The structure of this bioslurper protocol is based on the Air Force *Test Plan and Technical Protocol for a Field Treatability Test for Bioventing* (Hinchee at al., 1992). Many of the procedures outlined in the Bioventing Protocol will be used for the bioslurper initiative. Procedures from the Bioventing Protocol relevant to the bioslurper initiative are outlined in the bioslurper test plan in Sections 4 through 8, and will be provided in the test plans for individual sites. For detailed bioventing technology descriptions and procedures, the reader should refer to the Bioventing Protocol (Hinchee et al., 1992).

3.1 Site Selection

Sites to be included in the bioslurper initiative were selected by the Air Force based on the presence of free product in site monitoring wells and the geographical location. Sites were selected to represent varied geologic and climatic characteristics. In addition, priority was given to sites where other LNAPL recovery technologies have been used to allow for comparison to bioslurping, and the selected sites were to represent each U.S. EPA region and a variety of states to include a range of different geologic settings. The primary bioslurper initiative test sites are presented in Table 1. Figure 3 shows the geographic distribution of bioslurper test sites. Other sites may be included or substituted at the discretion of the Air Force.

Table 1. Bioslurper Study: Primary Sites

Region	Base	Site Sample Designations[a]			
		Monitoring Point Locations[b]	Soil Samples[c]	Aqueous Samples from Oil/Water Separator[c]	Organic Samples (LNAPL)[c]
Region A	Dover AFB, DE	DR-MP(A,B,orC)-(d)	DR-S-(#)	DR-OWS-(#)	DR-F-(#)
	Griffiss AFB, NY	GS-MP(A,B,orC)-(d)	GS-S-(#)	GS-OWS-(#)	GS-F-(#)
	McGuire AFB, NJ	MG-MP(A,B,orC)-(d)	MG-S-(#)	MG-OWS-(#)	MG-F-(#)
	Plattsburgh AFB, NY	PH-MP(A,B,orC)-(d)	PH-S-(#)	PH-OWS-(#)	PH-F-(#)
Region B	Andrews AFB, DC	AS-MP(A,B,orC)-(d)	AS-S-(#)	AS-OWS-(#)	AS-F-(#)
	Bolling AFB, DC (Site 1)	BG1-MP(A,B,orC)-(d)	BG1-S-(#)	BG1-OWS-(#)	BG1-F-(#)
	Bolling AFB, DC (Site 2)	BG2-MP(A, B, or C)-(d)	BG2-S-(#)	BG2-OWS-(#)	BG2-F-(#)
	Columbus AFB, MS	CS-MP(A, B, or C)-(d)	CS-S-(#)	CS-OWS-(#)	CS-F-(#)
	Eglin AFB, FL	EN-MP(A, B, or C)-(d)	EN-S-(#)	EN-OWS-(#)	EN-F-(#)
	Grissom AFB, IN	GM-MP(A, B, or C)-(d)	GM-S-(#)	GM-OWS-(#)	GM-F-(#)
	Keesler AFB, MS	KR-MP(A, B, or C)-(d)	KR-S-(#)	KR-OWS-(#)	KR-F-(#)
	Langley AFB, VA	LY-MP(A, B, or C)-(d)	LY-S-(#)	LY-OWS-(#)	LY-F-(#)
	Pope AFB, NC	PE-MP(A, B, or C)-(d)	PE-S-(#)	PE-OWS-(#)	PE-F-(#)
	Robins AFB, GA	RS-MP(A, B, or C)-(d)	RS-S-(#)	RS-OWS-(#)	RS-F-(#)
	Scott AFB, IL	ST-MP(A, B, or C)-(d)	ST-S-(#)	ST-OWS-(#)	ST-F-(#)
	Seymour Johnson AFB, NC	SJ-MP(A, B, or C)-(d)	SJ-S-(#)	SJ-OWS-(#)	SJ-F-(#)
	Shaw AFB, NC	SW-MP(A, B, or C)-(d)	SW-S-(#)	SW-OWS-(#)	SW-F-(#)
	Tyndall AFB, FL	TL-MP(A, B, or C)-(d)	TL-S-(#)	TL-OWS-(#)	TL-F-(#)
	Wright Patterson AFB, OH	WP-MP(A, B, or C)-(d)	WP-S-(#)	WP-OWS-(#)	WP-F-(#)
	Wurtsmith AFB, MI	WH-MP(A, B, or C)-(d)	WH-S-(#)	WH-OWS-(#)	WH-F-(#)

Table 1. Bioslurper Study: Primary Sites (continued)

Region	Base	Site Sample Designations[a]			
		Monitoring Point Locations[b]	Soil Samples[c]	Aqueous Samples from Oil/Water Separator[c]	Organic Samples (LNAPL)[c]
Region C	Eaker AFB, AR	ER-MP(A, B, or C)-(d)	ER-S-(#)	ER-OWS-(#)	ER-F-(#)
	Grand Forks AFB, ND	GF-MP(A, B, or C)-(d)	GF-S-(#)	GF-OWS-(#)	GR-F-(#)
	Havre AFS/Malstrom AFB, MT	HV-MP(A, B, or C)-(d)	HV-S-(#)	HV-OWS-(#)	HV-F-(#)
	Hill AFB, UT	HL-MP(A, B, or C)-(d)	HL-S-(#)	HL-OWS-(#)	HL-F-(#)
	Holloman AFB, NM	HO-MP(A, B, or C)-(d)	HO-S-(#)	HO-OWS-(#)	HO-F-(#)
	Kelly AFB, TX	KY-MP(A, B, or C)-(d)	KY-S-(#)	KY-OWS-(#)	KY-F-(#)
	Tinker AFB, OK	TK-MP(A, B, or C)-(d)	TK-S-(#)	TK-OWS-(#)	TK-F-(#)
Region D	Edwards AFB, CA	ES-MP(A, B, or C)-(d)	ES-S-(#)	ES-OWS-(#)	ES-F-(#)
	March AFB, CA	MH-MP(A, B, or C)-(d)	MH-S-(#)	MH-OWS-(#)	MH-F-(#)
	Nellis AFB, NV (Site 1)	NS1-MP(A, B, or C)-(d)	NS1-S-(#)	NS1-OWS-(#)	NS1-F-(#)
	Nellis AFB, NV (Site 2)	NS2-MP(A, B, or C)-(d)	NS2-S-(#)	NS2-OWS-(#)	NS2-F-(#)
	Travis AFB, CA	TR-MP(A, B, or C)-(d)	TR-S-(#)	TR-OWS-(#)	TR-F-(#)
Region F	Hickam AFB, HI	HM-MP(A, B, or C)-(d)	HM-S-(#)	HM-OWS-(#)	HM-F-(#)
	Johnston Atoll	JA-MP(A, B, or C)-(d)	JA-S-(#)	JA-OWS-(#)	JA-F-(#)
	Kaneohe MCBH, HI	KE-MP(A, B, or C)-(d)	KE-S-(#)	KE-OWS-(#)	KE-F-(#)

(a) Site codes have been established for sample and monitoring point labeling at each site.
(b) Location of three monitoring points indicated by code A, B, or C and the depth of the point "d".
(c) Sample-specific designation indicated by "#".

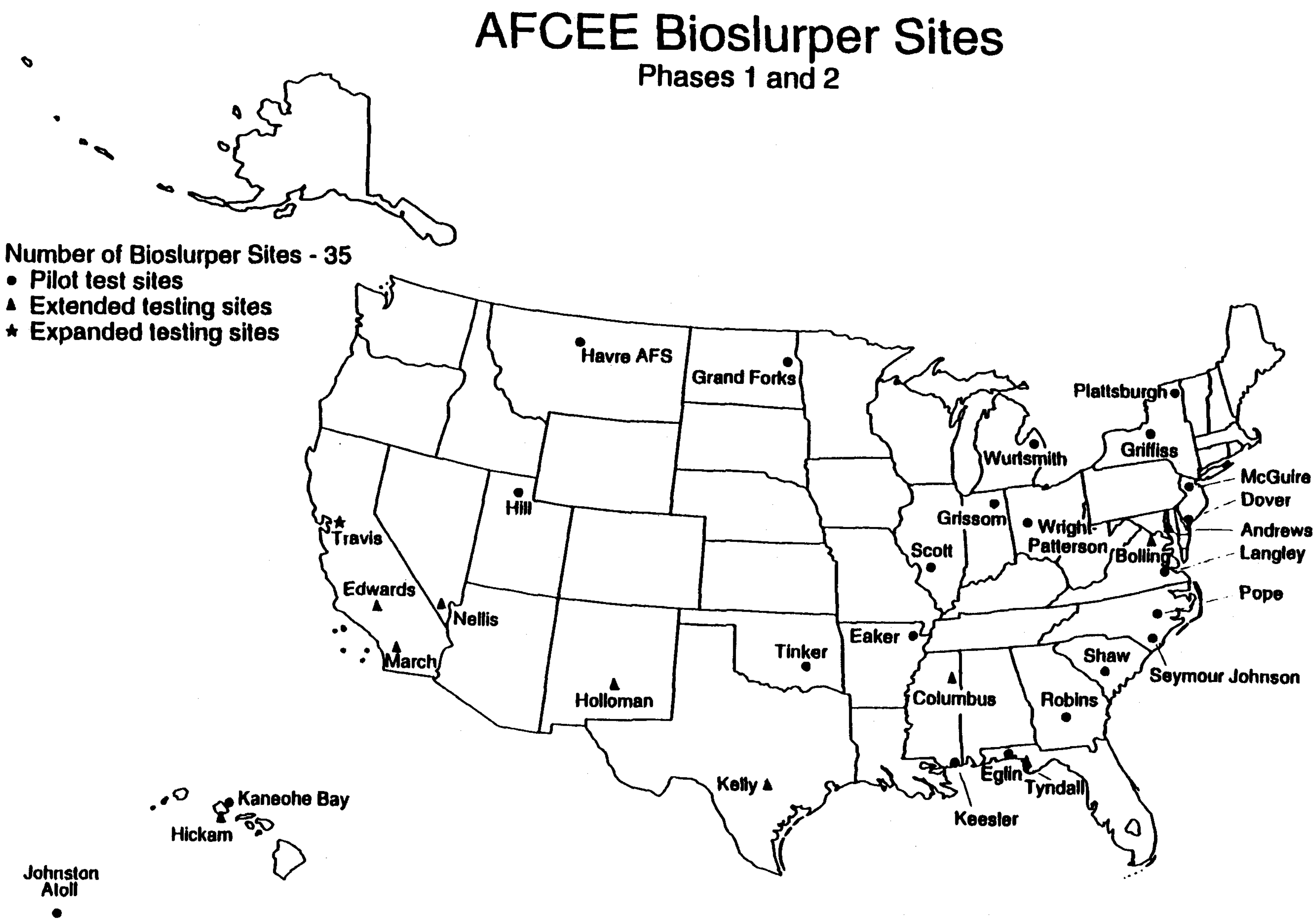

Figure 3. AFCEE Bioslurper Sites

3.2 Health and Safety Plan

All fieldwork conducted at bioslurper initiative sites will follow the General Health and Safety Plan (HASP) for Bioslurping Field Studies. A copy of the HASP is located in the Appendix. Site specific health and safety information will be included in the bioslurper site-specific test plans.

3.3 Site Characterization Review

To initiate site characterization, the project officer (i.e., AFCEE) will inform the contractor of the Air Force facilities and specific sites where these tests will be conducted. The project officer will provide a contact person at each Air Force facility (hereafter called Base point-of-contact [POC]. The project officer and/or the Base POC will supply any relevant documents (site characterization reports, remedial investigation/feasibility studies. etc.) pertaining to the contaminated area.

A tentative test site will be selected after reviewing all preliminary documents and consulting with the project officer and the Base POC. Final approval of the test area will be obtained from the project officer.

3.4 Development of Site-Specific Test Plan

All involved parties for a given site will be provided with a site-specific test plan. The site-specific test plan will consist of this generic test plan with a site-specific cover letter. This is done to maintain a consistent data collection approach and to streamline the site-specific documentation process. The following information typically will be provided in the cover letter:

- A map showing the chosen test location, and if possible, tentative bioslurper well and monitoring point locations
- A summary of relevant site data
- Construction details for tentative bioslurper well and monitoring points
- Details of any required permits and actions taken to obtain the permits

- Detailed descriptions of vapor and wastewater treatment requirements
- Estimated field start date
- Any anticipated deviations from the generic test plan
- Discussion of bioslurper pump size requirements
- Site-specific support required from the Base
- Site-specific health and safety requirements, if required.

The site-specific test plan will be submitted to the project officer, Base point of contact (POC), and any necessary regulatory agencies for approval. The test plan normally will be submitted to outside regulatory agencies by either the project officer or the Base POC. Unless specifically directed otherwise by the project officer, the contractor will not directly contact regulatory agencies or submit plans to them. No site work will be initiated without the necessary approval.

3.5 Application for Required Permits

As soon as a candidate site is identified by the Air Force project officer, applications must be submitted for any permits that may be required. Obtaining permits frequently is the greatest holdup in accomplishing this type of field work. It is likely that no state or local permits will be required, but this determination must be made early. Types of permits that may be required include:

- Drilling and/or well installation permits for the bioslurper well and/or monitoring points
- An air emissions permit for the bioslurper well vapor discharge
- A wastewater discharge permit for the bioslurper aqueous discharge

- A site investigation permit or approval. In some California jurisdictions (and likely elsewhere), regulatory agencies require that all investigations at contaminated sites receive prior approval. This test should not normally be considered a Comprehensive Response, Compensation, and Liability Act (CERCLA) treatability test.

Reasonable estimates of air and water discharges are best obtained through short-term pilot testing. The approach described in this protocol is to base waiver application, registration, or permit ting for the short-term pilot test on estimated release concentrations and quantities. Site-specific estimates will be provided as part of each site-specific test plan. Data collected during the short-term pilot test will be used to develop plans and permitting requests.

No direct contact will be made by the contractor with regulatory agencies without project officer and Base POC approval. In many cases the project officer or Base POC will handle regulatory contacts, if they are necessary.

3.6 Base Support Requirements

The bioslurper field initiative is designed to minimize Base support requirements for conduct of the short-term pilot testing. If onsite power is unavailable, electrical power required for conducting the pilot testing will be generated with portable generators. All site labor will be supplied by the contractor.

The contractor will coordinate with the Base POC to obtain access and necessary clearance to conduct the tests at the candidate test area. The contractor will coordinate with the Base POC to obtain any necessary security clearances or badges. As early as possible, the contractor will supply the Base POC with a list of all bioslurper-related personnel who will work on Base, including name, social security number, place and date of birth, and expected arrival date. The work crew size will be kept as small as possible, with particular attention to limiting travel to Johnston Atoll. The contractor also will request that the Base POC initiate the process of obtaining a digging permit.

The free product recovered from the site will remain the property of the Air Force, and Base support will be required to recycle/dispose of free-phase hydrocarbons. The bioslurper system will generate an aqueous wastestream; the contractor will coordinate with the Base POC to use onsite treatment systems whenever possible (e.g., a sanitary sewer). Contaminated soil cuttings generated at sites where drilling is required will be turned over to the Base for treatment/disposal. A general site health and safety plan has been developed. However, the Base is requested to provide site emergency contact and phone numbers. Also, Bases should submit any appropriate health and safety plans for incorporation.

4.0 TEST WELLS AND EQUIPMENT

This section describes the test wells and equipment that are required to conduct the field treatability tests. It must be recognized that site-specific flexibility will be required and, thus, details will vary. Local and/or state regulatory agencies and at times individual Air Force Bases may have specific requirements that differ from specifications in this Test Plan. All testing must comply with regulations, and must be acceptable to the host Base.

Field notes will be maintained describing all bioslurper well and monitoring point construction. Deviations from standard design will be noted in the final report.

4.1 Bioslurper Wells

A bioslurper well will be established to allow for extraction of groundwater, free product, and soil gas through the subsurface, creating a pressure-vacuum gradient for enhanced fluid recovery and air permeability testing, and increasing the subsurface oxygen levels for in situ respiration testing. In most instances, existing monitoring wells with a history of free-product contamination will be used for the pilot test bioslurper well. When no suitable monitoring well is present, a bioslurper well will be installed. Installed bioslurper wells (typically 2-in. or 4-in.) will be placed with the screened section in contaminated soil and groundwater and will be located near the center of the fuel spill. Siting and construction of the bioslurper well will follow these general specifications:

1. The bioslurper well will be sited as near to the center of the spill area as possible. This location will ensure that data gathered from the test will be as representative as possible of contaminated soil and groundwater conditions.

2. The diameter of the bioslurper well will be either 2 or 4 in. and will depend on the ease of drilling and the area and depth of the contaminated volume. At most sites a 2-in.-diametcr bioslurper well will provide adequate airflow for air permeability/radius of influence testing. For sites with contamination extending below 30 ft, a 4-in. bioslurper well is recommended. The cost of a larger

well is a minor component of the total drilling cost because a drill rig will be required to drill to this depth, regardless of well diameter.

3. The bioslurper well normally will be constructed of schedule 40 polyvinyl chloride (PVC), and will be screened with a slot size that allows free soil gas flow into the well while minimizing transport of fines into the well. The screened interval will start above the water table in contaminated soil and extend 10 or more ft into the water table, depending on the thickness of the saturated zone and the seasonal fluctuations of depth to groundwater.

4. Hollow-stem augering is the recommended drilling method. Whenever possible, the diameter of the annular space will be at least two times greater than the vent well outside diameter. The annular space corresponding to the screened interval will be filled with silica sand or equivalent. The annular space above the screened interva1 will be sealed with wet bentonite and grout to prevent short-circuiting of air to or from the surface. Figure 4 shows a typical bioslurper well.

4.2 Soil Gas Monitoring Points

Soil gas monitoring points will be used for pressure and soil gas measurements and will be installed at a minimum of three locations, and at each location to at least three depths. The total number will vary, with up to four monitoring point locations, and six or more depths, depending on site conditions. To the extent possible, the monitoring points will be located in contaminated soils with > 1,000 mg/kg of total petroleum hydrocarbons. These soils will have a strong odor and will feel oily to the touch.

It may not be possible to locate all monitoring points in contaminated soil, especially the points furthest from the bioslurper well. In this case, it is important to ensure that the point closest to the vent well is located in contaminated soil, and if possible, that the intermediate point is placed in contaminated soil. If no monitoring points are located in contaminated soil, no meaningful in situ respiration test results can be derived. The monitoring point for in situ respiration testing should be selected to have significant soil gas hydrocarbon concentrations (ideally < 10,000 ppmv) and low oxygen concentrations (ideally 5% O_2 or less).

Higher oxygen concentrations would indicate that the microbial activity is not oxygen-limited or that there is sufficient exchange of air with the atmosphere to keep the soil gas well-aerated. In either case, bioventing will not increase biodegradation rates. At some sites, where less-contaminated soils and low oxygen concentrations are encountered, bioventing still may be feasible. If these conditions are found, care must be taken to place the monitoring points in the most contaminated soil possible.

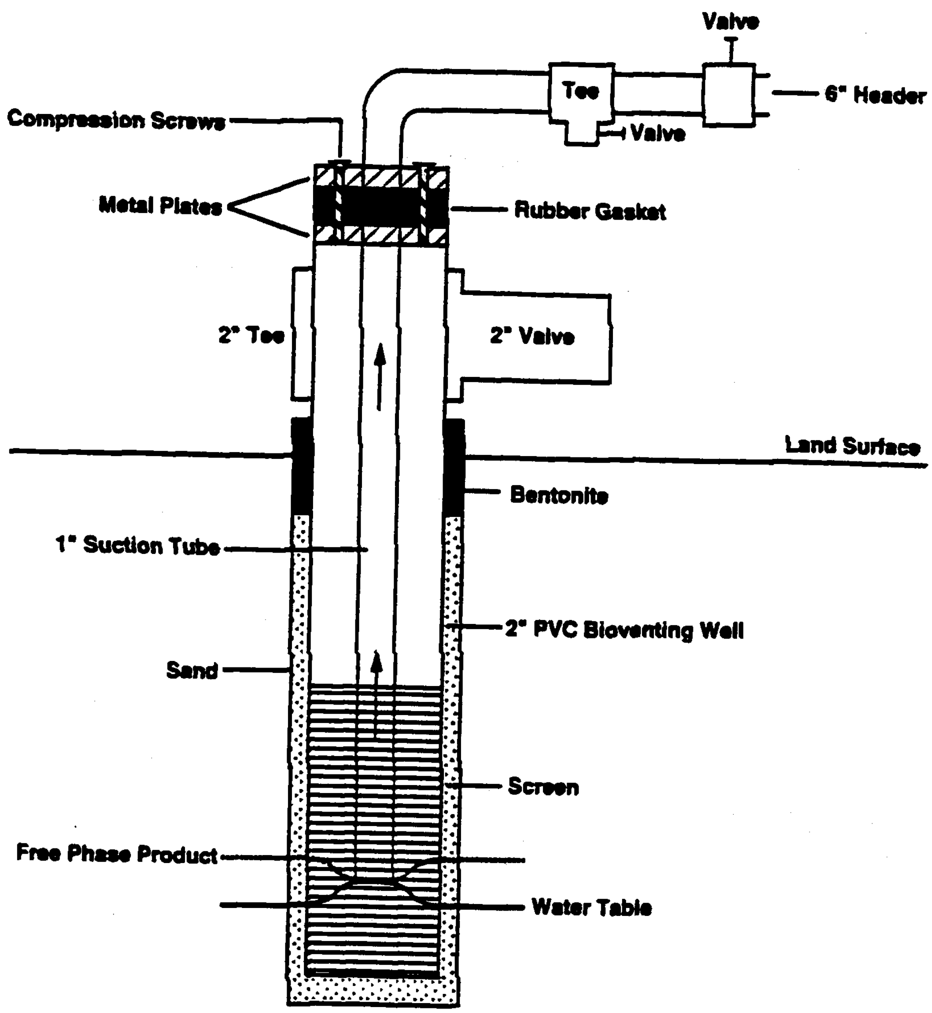

Figure 4. Diagram of a Typical Bioslurper Well

4.2.1 Locations of Monitoring Points

A minimum of three monitoring points is recommended. Monitoring points should be located in a generally straight line radially out from the bioslurping well at the intervals recommended in Table 2. In an unobstructed heterogeneous site, three monitoring points at these spacings would be appropriate. Additional monitoring point locations may be necessary for a variety of site-specific reasons including, but not limited to, spatial heterogeneities, obstructions, or the desire to monitor a specific location.

4.2.2 Depth of Monitoring Points

In general, each monitoring point will be screened to at least three depths (see Figure 5). The deepest screen will be placed approximately 1 ft above the water table. Consideration will be given to potential seasonal water table fluctuations and soil type in determining the depth. In more permeable soil, the monitoring point can be screened closer to the water table. In less-permeable soil it must be screened further above the water table. The shallowest screen normally will be 3 to 5 ft below land surface. The intermediate screen will be placed at a reasonable interval at a depth corresponding to the center to upper 1/4 of the depth of the bioslurper well screen.

As an example, in a sandy soil with groundwater at 30 ft and a bioslurper well screened from 25.0 to 40.0 ft below land surface, reasonable screened depths for the monitoring points would be 28 ft, 22.5 ft, and 3 ft. For sites with vadose zone deeper than 30 ft, more depths will be screened; for example, if the vadose zone extends to 100 ft, typical monitoring point screened depths will be 3, 20, 30, 40, 50, 60, 70, 80, 90, and l00 ft.

It will be necessary in some cases to add additional screened depths to ensure a well-oiled soil is encountered, to monitor differing stratigraphic intervals, or to adequately monitor deeper sites with broadly screened bioslurper wells. Consideration will be given to placing monitoring points in distinct lithologic units.

Table 2. Recommended Spacing for Monitoring Points

Soil Type	Depth to Top of Bioslurping Well Screen[(a)] (ft)	Lateral Spacing from Bioslurping Well[(a)] (ft)
Coarse Sand	5	5-10-20
	10	10-20-40
	> 15	20-30-60
Medium Sand	5	10-20-30
	10	15-25-40
	> 15	20-40-60
Fine Sand	5	10-20-40
	10	15-30-60
	> 15	20-40-80
Silts	5	10-20-40
	10	15-30-60
	> 15	20-40-80
Clays	5	10-20-30
	10	10-20-40
	> 15	15-30-60

(a) Assuming 10 ft of well screen. If more screen is used, the > 15-ft spacing will be used.

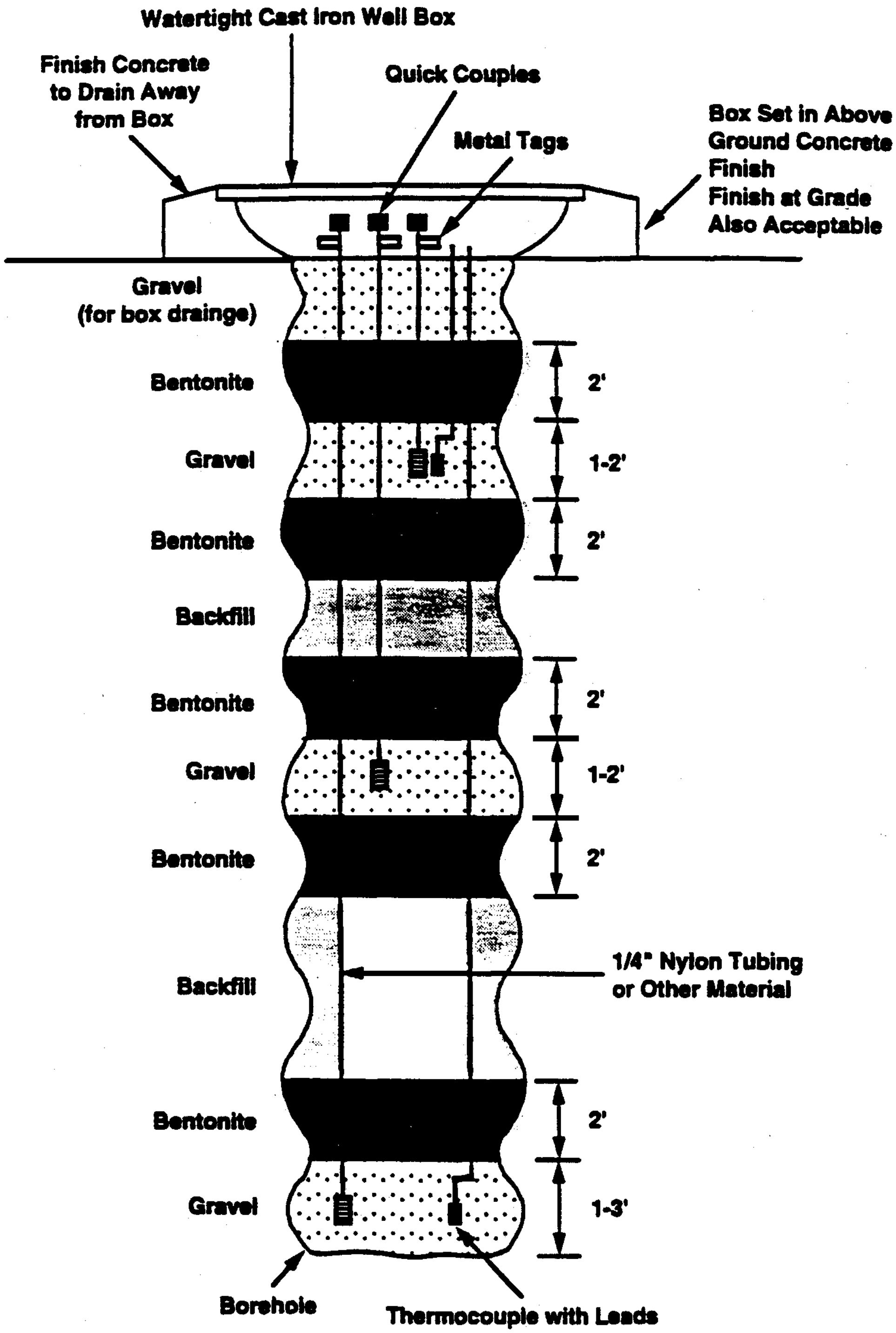

Figure 5. Diagram of a Typical Soil Gas Monitoring Point

4.2.3 Construction of Monitoring Points

Most state and local regulatory agencies do not regulate unsaturated zone soil gas monitoring point construction. Nevertheless, prior to construction it is necessary to check with regulators to ensure compliance with any regulations that may exist.

4.2.3.1 Monitoring Point Construction. Monitoring point construction will vary depending on the depth of drilling and the drilling technique. The monitoring points will consist of a small diameter 1/4-in. tube to the specified depth with a screen of approximately 6 in. in length and 1/2 to 1 in. in diameter. In shallow hand-augered installations, rigid tubing (i.e., schedule 80 ¼” PVC) terminating in the center of a gravel or sand packed may be adequate. The gravel or sand pack normally will extend for an interval of 1 to 2 ft with the screen centered. In low-permeability soils, a larger gravel pack may be desirable. In wet soils, a longer gravel pack with the screen near the top may be desirable. A bentonite seal at least 2 ft thick normally is required above and below the gravel pack. Figure 5 shows a typical installation.

Tubes will be used to collect soil gas for carbon dioxide and oxygen analysis in the 0 to 25 % range, and for JP-4 hydrocarbons in the 100 ppmv range or higher. The tubing material must have sufficient strength and be nonreactive. Sorption and gas interaction with the tubing materials have not been significant problems for this application. If a monitoring point will be used to monitor specific organics in the low ppm or ppb range, Teflon™ or stainless steel may be necessary. However, this normally will not be the case.

All tubing from each monitoring point will be finished with quick-connect couplings and will be labeled twice. Each screened depth will be labeled with a name as follows:

[Code for Site]—[Code for Monitoring Point]—[Depth to Center of Screened Interval].

The tubing will be labeled with a metal tag firmly attached or directly by engraving or in waterproof ink. Or instead of the metal tag, a metal plate will be placed at the bottom of the monitoring point compartment with holes drilled for each tube. The metal plate will be engraved to identify each tube where it passes through the plate. If this method is used, the tube itself must still be labeled with ink or by engraving. The label will be placed close to the ground so that if the tube is damaged, the label will likely survive.

The top of each monitoring point will be labeled to be visible from above. This will be done either by writing in the concrete or with spray paint.

The monitoring points will be finished by placement in a watertight cast aluminum well box. The well box will be placed either aboveground in a concrete pad or at grade, also in concrete. The box will be drained to prevent water accumulation.

4.2.3.2 Subsurface Oxygen Sensors. Recent developments in soil gas monitoring include the commercial availability of a subsurface in situ oxygen sensor. The Subsurface Oxygen Monitoring System (Datawrite Research Company, Visalia, California) includes a subsurface oxygen sensor (model #XT-252) with a cable lead to the surface. At the surface, the cable is connected to a miniature data logger (Micrologger Analog Data Records) that allows for continuous logging of subsurface oxygen concentrations.

At selected sites, the subsurface oxygen monitoring system will be installed to collect soil gas oxygen concentration data. The sensors will be installed in the same boring as the conventional soil gas monitoring points. One sensor will be installed in each monitoring point location, at the depth interval corresponding to the visibly most contaminated soil. The monitoring system will be turned on to continuously monitor oxygen concentrations throughout the bioslurper pilot test and in situ respiration test. Standard soil gas monitoring procedures will be employed using the GasTech monitoring instrumentation turning the pilot testing. When testing is complete, the Subsurface Oxygen Monitoring System data will be compared to the standard GasTech-collected data for consistency.

Detailed procedures for the calibration and use of the Subsurface Oxygen Monitoring System currently are unavailable. The sensors tested in this study will be field-calibrated to atmospheric oxygen concentrations prior to installation. Operation of the monitoring system is performed using menu-driven software supplied by the vendor. The intent of testing the subsurface oxygen sensor is to determine ease of use, quality and consistency of data, and cost effectiveness. Detailed procedures for the calibration and use of the monitoring system will be developed based on field experience.

Application and evaluation of the performance of the Subsurface Oxygen Monitoring System is a value-added procedure to increase the efficiency of the Bioslurper Field Initiative Testing Program. Standard field data will continue to be collected until it is determined that the Subsurface Oxygen Monitoring System performance is suffient to replace standard soil gas oxygen monitoring procedures. If it is determined that the Subsurface Oxygen Monitoring System data are comparable to data acquired through stardard monitoring techniques, the standard in situ respiration test will be replaced with the exclusive use of the subsurface sensors.

4.2.4 Thermocouples

Two thermocouples will be installed at each site. These will be installed at the monitoring point closest to the vent well and, as shown in Figure 3, at a depth of the shallowest and deepest screen. Thermocouples used are the K type, either nickel-cadmium or nickel-aluminum. The thermocouple wires will be labeled using the same system as for the tubing, except that a two-letter abbreviation for the thermocouple, TC, is added to the idenification label.

Each thermocouple will be calibrated against ice water and boiling water by the contractor before field installation. The thermocouple reading will be checked immediately after installation. If an open circuit indication is shown, the thermocouple will be assumed to have been damaged during installation. The damaged thermocouple will be removed and a new thermocouple will be installed. Operation of the reader will be checked prior ro each series by connection to a thermocouple in air and comparison to the reading of a thermometer.

4.2.5 Background Monitoring Point

A background soil gas monitoring point will be established to sample background soil gas concentrations. This monitoring point may be an existing monitoring point or monitoring well in an uncontaminated location, or it may be a temorpary driven soil gas monitoring point.

4.3 Field Instrumentation and Measurements

Sections 4.3.1 through 4.3.6 discuss the equipment used for measurements. Figures supplement the text.

4.3.1 Oxygen and Carbon Dioxide

Gaseous concentrations of carbon dioxide and oxygen will be analyzed using a GasTech model 32520X CO_2/O^2 analyzer or equivalent. Two analyzers will be used. Both meters read percent oxygen from O to 25 %. One meter has a carbon dioxide range of 0 to 5 %, and the other has a range of 0 to 25% carbon dioxide.

The battery charge level will be checked to ensure proper operation. The air filters will be checked and, if necessary, will be cleaned or replaced before the experiment is started. The instrument will be turned on and equilibrated for at least 30 minutes before conducting calibration or obtaining measurements. The sampling pump of the instrument will be checked to ensure that it is functioning. Low flow of the sampling pump can indicate that the battery level is low or that some fines are trapped in the pump or tubing.

Meters will be calibrated each day prior to use against purchased carbon dioxide and oxygen calibration standards. These standards will be selected to be in the concentration range of the soil gas to be sampled. The carbon dioxide calibration will be performed against atmospheric carbon dioxide (0.05%) and a 5% standard. The oxygen will be calibrated using atmospheric oxygen (20.9%) and against a 5% and 0% standard. Standard gases will be purchased from a specialty gas supplier. To calibrate the instrument with standard gases, a Tedlar™ bag (capacity -1 L) is filled with the standard gas, and the valve on the bag is closed. The inlet nozzle of the instrument is connected to the Tedlar™ bag, and the valve on the bag is opened (see Figure 6). The instrument is then calibrated against the standard gas according to the manufacturer's instructions. Next, the inlet nozzle of the instrument is disconnected from the Tedlar™ bag and the valve on the bag is shut off. The instrument will be rechecked against atmospheric concentration. If recalibration is required, the above steps will be repeated.

4.3.2 Hydrocarbon Concentraion

Petroleum hydrocarbon concentrations will be analyzed using a GasTech TraceTector™ hydrocarbon analyzer (or equivalent) with range settings of 100 ppmv, 1,000 ppmv, and 10,000 ppmv. The analyzer will be calibrated against two hexane calibration gases (500 ppmv and 4,400 ppmv).

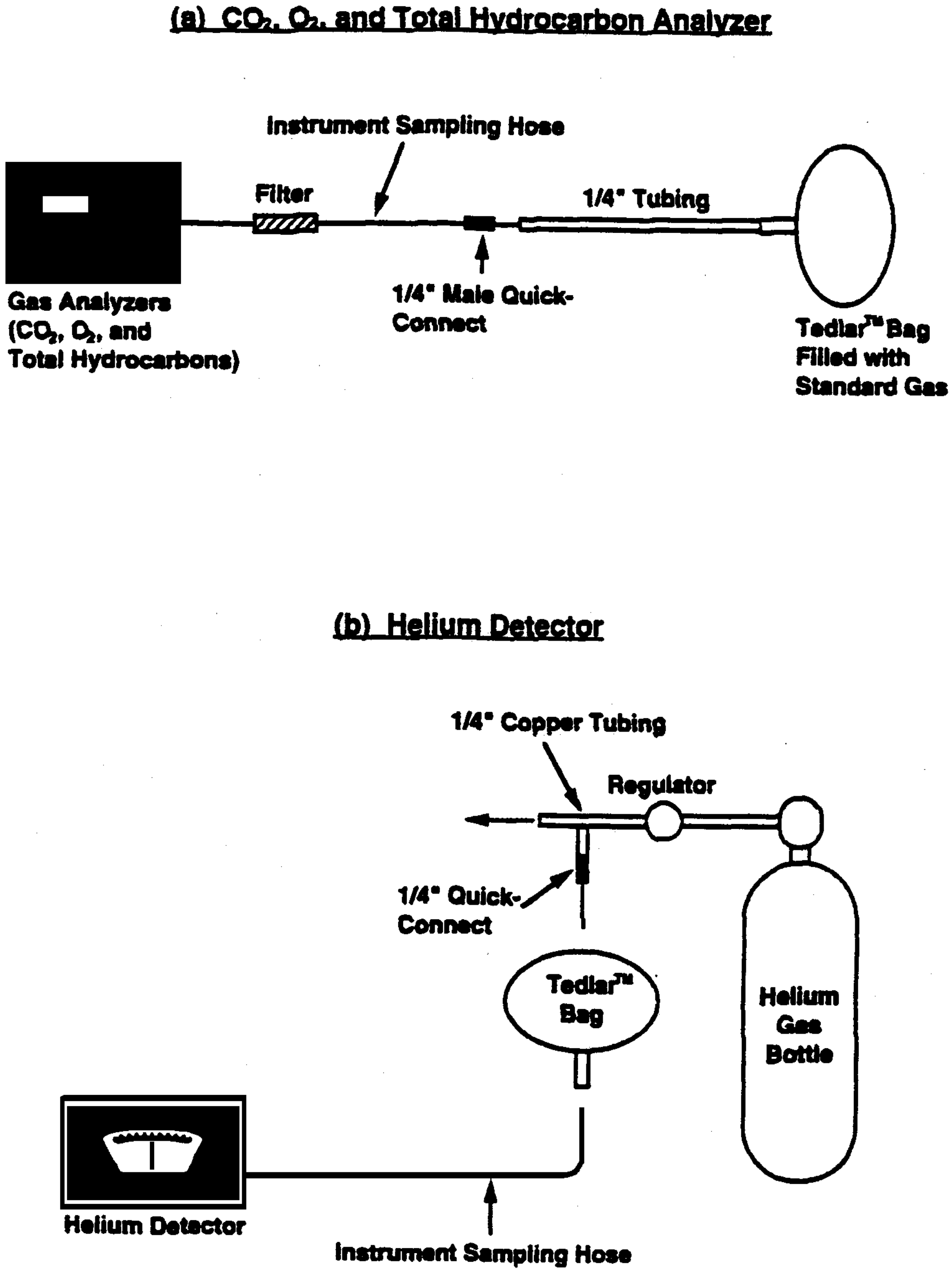

Figure 6. Typical Setup for Calibration of Field Instruments

The TraceTector™ has a dilution fitting that can be used to calibrate the instrument in the low concentration range.

Calibration of the GasTech TraceTector™ is similar to that of the GasTech Model 32402X, except that a Mylar™ bag is used instead of a Tedlar™ bag. The oxygen concentration must be above 10% for the TraceTector™ analyzer to be accurate. When the oxygen drops below 10%, a dilution fitting must be added to provide adequate oxygen for analysis.

Hydrocarbon concentrations also can be determined with a flame ionization detector (FID), which can detect low (< 100 ppmv) concentrations. A photoionization detector (PII)) is *not* acceptable.

4.3.3 Helium Monitoring

Helium in the soil gas will be measured with a Marks Helium Detector Model 9821 or equivalent with a minimum sensitivity of 100 ppmv (0.01%). Calibration of the helium detector follows the same basic procedure described for oxygen calibration, except that the setup for calibration is different (see Figure 6[b]). Helium standards used are 100 ppmv (0.01%), 5,000 ppmv (0.5%), and 10,000 ppmv (1%).

4.3.4 LNAPL Thickness and Groundwater Level Measurements

The depth to groundwater and apparent thickness of LNAPL in site wells will be measured with an oil/water interface probe (ORS Model #1068013 or equivalent). The interface probe distinguishes between polar and nonpolar fluids in the well. The probe gives a solid tone when it encounters a nonpolar liquid (LNAPL) and a constant beep when it encounters a polar liquid (water). The probe lead is a 50- to 200-ft measuring tape with 0.01-ft increments.

During the bioslurper testing, the depth to groundwater and product thickness will be monitored in wells adjacent to the bioslurper well, if an existing well is close by. Product thickness and depth to groundwater at in situ subsurface soil pressures should be monitored during the pilot test. When a well is open to the atmosphere, the pressure inside the well equilibrates to atmospheric pressure, which affects the static depth to liquid in the well. Under ambient conditions, the subsurface soil vapor pressure often varies from atmospheric pressure. When the bioslurper system is operating, the subsurface soil gas pressure always is under vacuum with respect to the atmosphere, making air-flow short-circuiting a problem. Therefore, it is important to monitor the depth to groundwater and LNAPL thickness in the well at in situ soil gas pressures. A system has been devised to install an oil/water interface probe in a site monitoring well with a vacuum-tight well seal.

Figure 7 illustrates the in situ interface probe construction. The oil/water interface probe is threaded through a section of clear 1-inch PVC, which is fitted to a specialized well seal. The probe is placed in the well at the top of the liquid layer (LNAPL or groundwater), sealed tightly at the wellhead. The sanitary well seal has a Teflon™ gasket that seals the PVC to the well seal. Teflon™ is self-lubricating, so the PVC tubing can be moved up and down in the well without short-circuiting to the atmosphere.

4.3.5 Temperature Monitoring

In situ soil temperature will be monitored using Omega type J or K thermocouples (or equivalent). The thermocouples will be connected to an Omega OM 400 thermocouple thermometer (or equivalent).

4.3.6 Pressure/Vacuum Monitoring

Changes in soil gas pressure during the air permeability test will be measured at monitoring points using Magnehelic™ or equivalent gauges. Tygon™ or equivalent tubing will be used to connect the pressure/vacuum gauge to the quick-disconnect fitting on the top of each monitoring point. Similar gauges will be positioned before and after the blower unit to measure pressure/vacuum across the blower and at the head of the bioslurper well. Pressure/vacuum gauges are available in a variety of pressure/vacuum ranges, and the same gauge can be used to measure either vacuum or pressure simply by switching inlet ports. Gauges are sealed and calibrated at the factory and will be rezeroed before each test. The following pressure ranges (in inches H_2O) typically will be available for this field test:

0-1”, 0-5”, 0-10”, 0-20”, 0-50”, 0-100”, and 0-200”

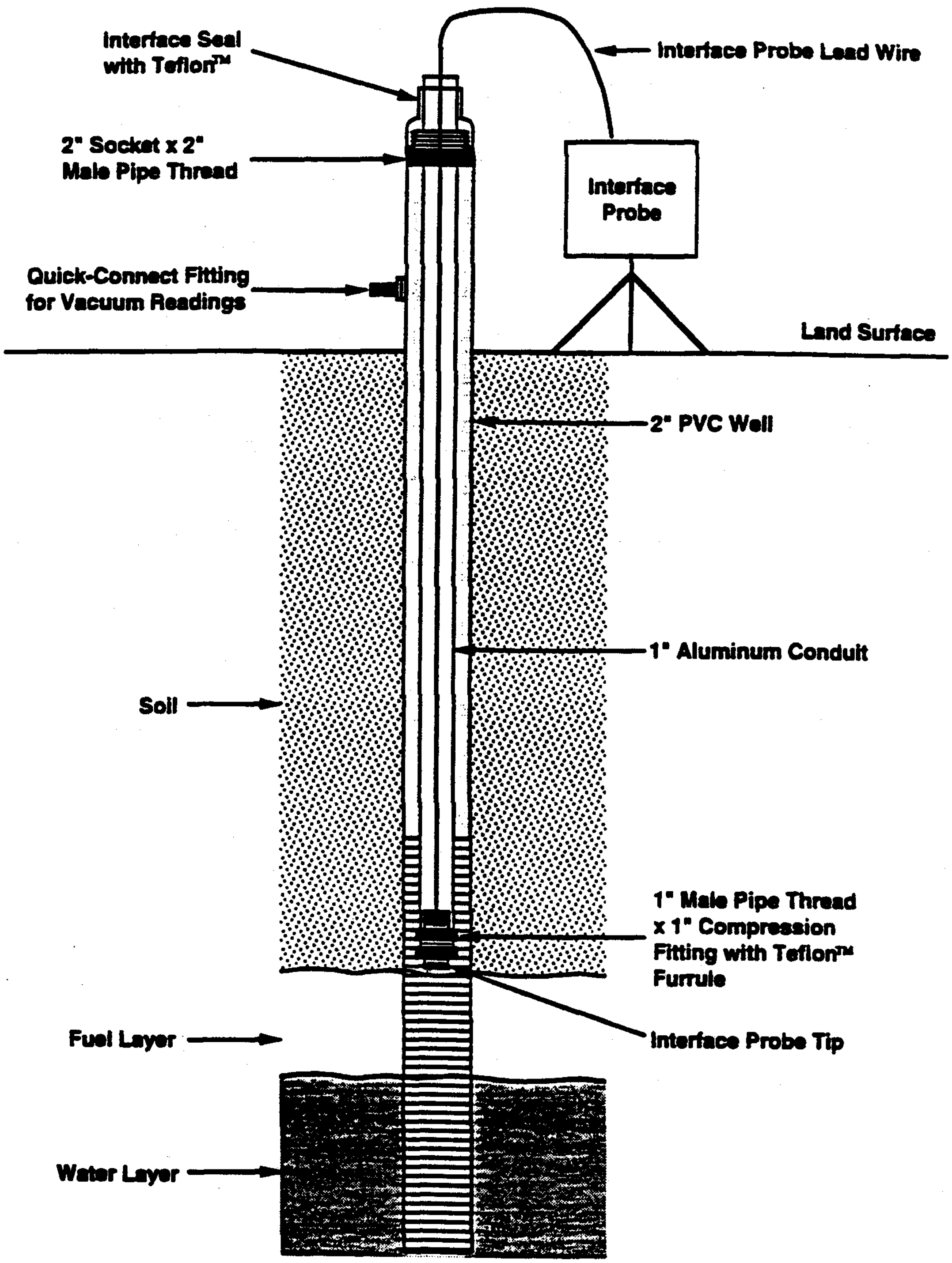

Figure 7. Diagram of the In Situ Interface Probe Setup

4.3.7 Airflow

Pitot tubes or orifice plates combined with an inclined manometer or differential pressure gauge are acceptable for measuring flow velocities of 1,000 ft/min or greater (- 20 scfm in a 2-in. pipe). For lower flowrates, a large rotometer will provide a more accurate measurement. If an inclined manometer is used, the manometer must be rezeroed before and after the test to account for thermal expansion/contraction of the water. Devices to measure static and dynamic pressure must be installed in straight pipe sections according to manufacturers' specifications. All flowrates will be corrected to standard temperature and ambient pressure (altitude) conditions.

5.0 TEST PROCEDURES

The initial phase of onsite work will be the site investigation phase of the bioslurper pilot study. Investigations will be conducted to evaluate the geology, hydrogeology, bioactivity, and freeproduct availability at each site.

5.1 Data Review

For all sites it will be important to evaluate existing data for the presence of LNAPL in site monitoring wells. Historical data on the presence, persistence, and thickness of LNAPL in site wells will assist in selection of the site bioslurper extraction well. These data will be included in the site specific test plan and will be used to supplement field activities directed at selecting the optimum extraction well or wells.

5.2 Soil Gas Survey

At sites where a suitable existing well cannot be used, a soil gas survey will be conducted to locate an optimum site for installation of the bioslurper well and the soil gas monitoring points. Ideally, the bioslurper well and soil gas monitoring points will be located in soils containing measurable hydrocarbon contamination where the oxygen is depleted and the carbon dioxide levels are elevated. If at least three monitoring point screens are not located in the most contaminated soils, the in situ respiration test may not provide adequate information on the biodegradation rates for the site.

A soil gas survey will be conducted prior to locating the bioslurper well and monitoring points at sites with relatively shallow groundwater where soils are penetrable to a depth of within 5 ft of the water table using hand-driven gas probes. The survey will not be a complete site soil gas survey of the type that would fully delineate the extent of contamination.

Accessibility to the site will be determined in the soil gas survey, along with possible restrictions that could hamper the tests. Existing groundwater and soil gas monitoring wells near the test area will be identified. Groundwater will be checked for free-floating product, and soil gas from any existing monitoring points or wells will be analyzed for oxygen, carbon dioxide, and total hydro carbons before proceeding with the soil gas survey. To assist in the soil gas survey, a sampling grid will be established using existing monitoring wells or prominent landmarks for identification.

Soil gas sampling will be conducted using small-diameter (1/4 inch OD) stainless steel probes (KVA Associates or equivalent) with a slotted well point assembly. The maximum depth for hand-driven probes typically will be 10 to 15 ft, depending on soil texture. In some dense silts or clays, penetration of the soil gas probe will be less, whereas, in some unconsolidated sands, deeper penetration may be possible. At a given location on the grid, a probe will be driven (manually or with a power hammer) to a depth determined by preliminary review of the site contamination documents. Soil gas at this depth will be analyzed for oxygen, carbon dioxide, and total hydrocarbons. The probe then will be driven deeper, and the soil gas will be measured. For a typical site with a depth to groundwater of 9 ft, soil gas will be measured at depths of 2.5 ft, 5 ft, and 7.5 ft.

The main criterion for selecting a suitable test site is the existence of oxygen-limited microbial activity. Under such conditions, the oxygen level will be low (usually 0 to 2%), carbon dioxide will be high (typically 5 to 20%, depending on soil type), and the hydrocarbon vapor content in the soil gas will be high (> 10,000 ppmv).

An uncontaminated site also will be located to be used as an experimental control to monitor background respiration of natural organic matter and inorganic sources of carbon dioxide. Typical oxygen and carbon dioxide levels at an uncontaminated site are 15 to 20% and 1 to 5%, respectively. The hydrocarbon vapor content in the soil gas of an uncontaminated site generally is below 100 ppmv.

Prior to sampling, soil gas probes will be purged with a sample pump. To determine adequate purging time, soil gas concentrations will be monitored until the concentrations stabilize. This will not always be possible, particularly when shallow soil gas samples are being collected, as atmospheric air may be drawn into the probe and produce false readings. When shallow soil gas samples are collected, air withdrawal will be kept to a minimum. Figure 8 shows a typical setup for monitoring soil gas.

5.3 Selection and Installation of the Bioslurper Well

For most of the short-term tests, an existing well will be selected for installation of the bioslurper. Based on a review of available site characterization data, a preliminary location will be pro-

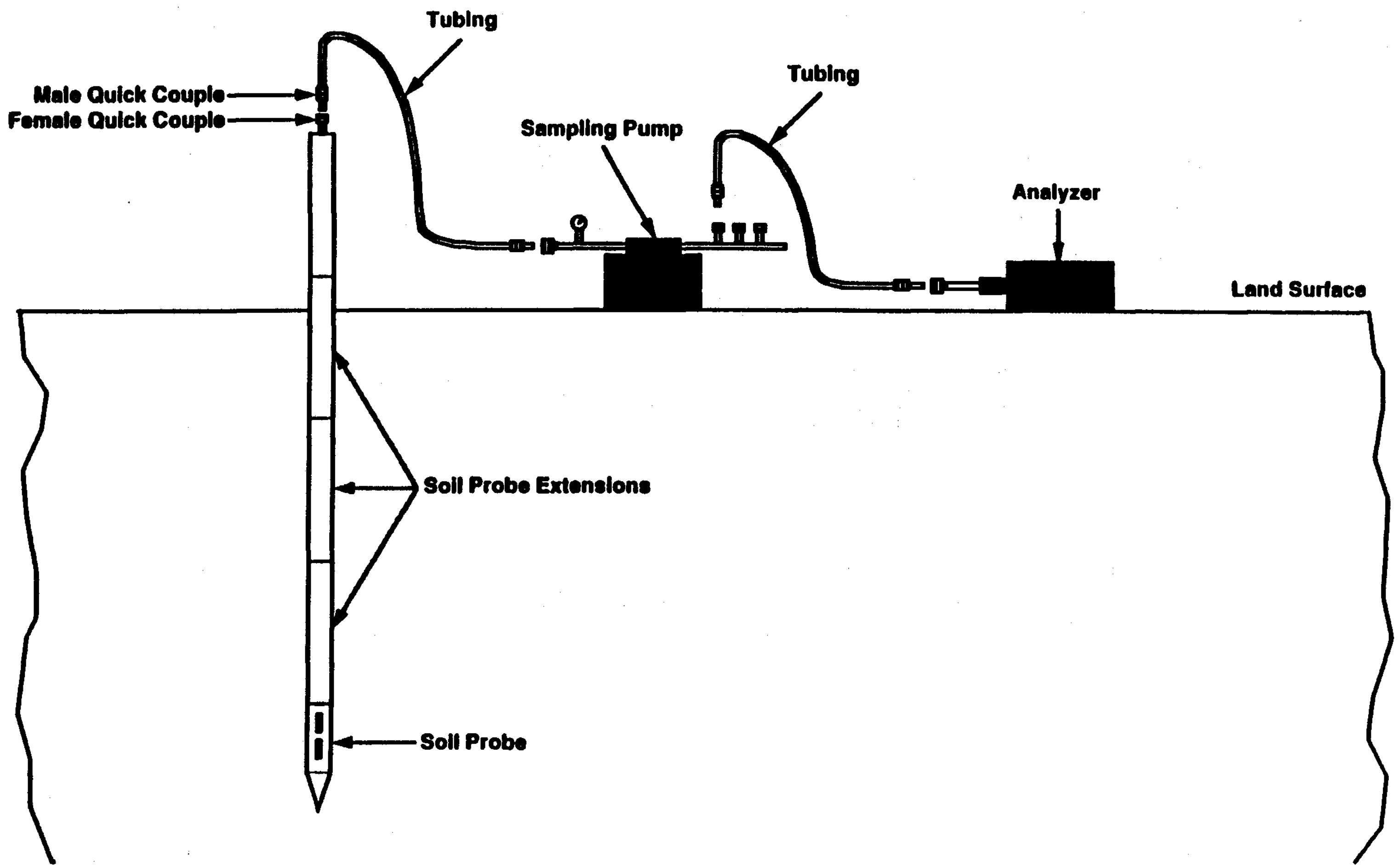

Figure 8. Typical Setup for Monitoring Soil Gas

posed for the bioslurper well. Following the soil gas survey and/or exploratory boring, a bioslurper well will be selected. If no suitable existing well is identified, a new well will be drilled to accept the bioslurping suction tube. Siting and construction of the bioslurper wells will follow the specifications listed in Section 4.1. Soil samples will be collected through the capillary fringe while the bioslurper well is being drilled. Soil sampling will follow the procedures outlined in Section 5.5.

5.4 Drilling and Installation of Monitoring Points

Based on the location of the bioslurper well and available site characterization data, locations for installation of three monitoring points will be selected. The monitoring points are placed to provide sufficient data to allow determination of the soil permeability to gas flow (see Section 5.7). The monitoring points are also used for in situ respiration testing (see Section 5.8). Table 2 gives general criteria for placement of monitoring points in relation to the location of the bioslurper well. The monitoring points generally will be located in a contaminated area.

When possible, the monitoring points will be placed in hand-augered borings or in borings augered with a small portable drill. At deeper sites, it will be necessary to hire a driller for both the monitoring points and the bioslurper well. When a drill rig is used, a hollow-stem auger will most likely be used.

5.5 Sampling and Analysis of Soil, Groundwater, and LNAPL

During installation and operation of the Bioslurper Remediation Technology, samples will be collected to characterize the level of contamination at the site and to determine physical soil characteristics across the capillary fringe.

Soil samples will be analyzed for the presence of organics and for physical characteristics. The soil organic analyses will indicate the contaminant constituents present in the subsurface. Physical properties of the soil will assist in formulating the design of the demonstration system by identifying how well air would be expected to move through the soil profile.

Groundwater and soil gas will be screened for organics with qualitative/quantitative analyses of benzene, toluene, ethylbenzene, and xylenes (BTEX). Additionally, the TPH concentration will be reported. These concentrations will be tracked during the demonstration to show the extent of remediation.

The light, nonequeous-phase liquid (LNAPL) also will be sampled and analyzed for BTEX concentrations. To further characterize the nature of LNAPL free product, a boiling point distribution of the hydrocarbons present in these samples will be determined from the EPA SW-846 Method 8020 results. The distribution will be based on molecular weight ranges and will be identified as such (i.e., C_4 to C_6, C_6 to C_8, etc.). This analytical effort, performed at the start of the demonstration, will make it possible to determine any weathering affects that may have occurred on the original organic contamination.

5.5.1 Soil Sampling and Analysis

Soil samples will be taken during drilling of holes for placement of monitoring points and wells. The samples will be withdrawn from the center of the hollow stem auger being used to bore the holes.

Soil samples will be collected with a 2-inch-inside-diameter (ID) X 6-inch split-spoon sampler containing brass sampling sleeves. Two soil samples will be taken from a single borehole across the capillary fringe to evaluate chemical/physical properties at the test site. Following collection of the soil samples, the sleeves will be sealed with inert caps, labeled, sealed in plastic bags, and placed in insulated boxes. The coolers will also contain dry ice or precooled Blue Ice™ to maintain low temperature for sample preservation. The samples will be analyzed for particle size distribution, bulk density, porosity, moisture content, BTEX, and TPH. Chain-of-custody documentation will accompany the samples, which will be shipped in chilled, insulated boxes via an overnight courier to the appropriate laboratories for the respective analyses. The analytical methods and relevant sampling information are summarized in Table 3.

5.5.2 Aqueous Effluent Sampling and Analysis

Aqueous effluent samples are to be collected from the bioslurper oil/water separator discharge. The samples will be held in 40-mL borosilicate glass volatile organic analysis (VOA) vials.

The pH of the aqueous effluent samples will be adjusted to a value of < 2 with hydrochloric acid to stabilize the organic species. The vials will be labeled, stored at 4°C, and shipped with the proper chain-of-custody forms via an overnight courier to the appropriate laboratory for analyses. Analytical methods and relevant sampling information are presented in Table 3.

5.5.3 LNAPL Effluent Sampling and Analysis

LNAPL samples are to be collected from the bioslurper well immediately following the baildown test (see Section 5.6). A Teflon™ bailer will be used to collect a sample from the organic layer that recharges into the well during the baildown test. The organic samples are to be transferred to glass vials (5 mL to 10 mL) that are fitted with Teflon™ lined caps. No preservation is necessary for these samples. The vials will be labeled and shipped inside an outer shell to protect them from breakage or spillage. A sorbent material will be used to package the vials inside the shell. These samples will be shipped either separately or in tightly sealed containers so that they do not compromise the nature of the soil, groundwater, and soil gas samples. Shipment will be via the most rapid method to the appropriate laboratory for analysis. Chain of-custody and any additional documentation for samples of this nature will accompany the shipment. The analytical method and relevant sampling information are presented in Table 3.

5.5.4 Vapor Discharge Sampling and Analysis

Vapor discharge samples are to be collected by connecting an evacuated 1-L, Summa polished air-sampling canister to the bioslurper vapor discharge stack. Prior to connecting the canister to the sampling line, a vacuum pump will be used to pull vapor from the bioslurper stack to ensure that the sample line is flushed with a representative vapor sample. Following this flushing process, the evacuated canister is connected to the sampling line, the valve is opened, and a vapor sample is pulled from the bioslurper discharge stack. The vacuum is displaced with the vapor sample until atmospheric pressure is reached. The vacuum/pressure on each canister will be confirmed for each sampling event to ensure that the canister was received in an evacuated state and was completely filled during sampling. The canisters are then tagged with the appropriate sample identification and shipped via

Table 3. Sampling and Analytical Methods

Analysis	Method	MDL[a]	Container	Sample Size	Preservation	Holding Time
Soil Samples						
Particle Size Distribution[b]	ASTM D422	NA	Brass sleeve, polyethylene or glass container	200 g	Cool, @ 4°C	180 days
Bulk Density[b]	ASTM D4531	NA	Brass sleeve, polyethylene or glass container	200 g	Cool, @ 4°C	28 days
Porosity[b]	ASTM D2434	NA	Brass sleeve, polyethylene or glass container	200 g	Cool, @ 4°C	28 days
Moisture Content[b]	ASTM D2216	NA	Brass sleeve, polyethylene or glass container	50-300 g	Cool, @ 4°C	28 days
BTEX	EPA 8020/624/8240	10 μg/kg	Brass sleeve	100 g	Cool, @ 4°C	14 days
TPH (as JP-4)	EPA Mod. 8015/5030	10 mg/kg	Brass sleeve	100 g	Cool, @ 4°C	14 days
Soil Gas						
BTEX	EPA TO-14 (Modified)	0.1 ppmv	Summa Canister	Both analyses from a common 1-L canister	NA	30 days
TPH	EPA TO-14 (Modified)	0.1 ppmv	Summa Canister		NA	30 days
Groundwater Samples						
BTEX	EPA 602	1 μg/L	Borosilicate glass, VOA vials	Both analyses from a set of 3 × 40 mL vials	HCl to pH <2, @ 4°C	14 days
TPH	EPA Mod. 8015/5030	0.5 mg/L	Borosilicate glass, VOA vials		HCl to pH <2, @ 4°C	14 days
Light, Nonaqueous-Phase Liquid						
BTEX	EPA Mod. 8020	100 mg/L	Glass vial with Teflon™ septum or lined cap	5-10 mL	Cool, @ 4°C	14 days

(a) MDL = method detection limit.
(b) Particle size distribution, bulk density, porosity, and moisture content can be derived from the same oven-dried soil sample.
NA = not applicable.
ppmv = parts per million by volume.
VOA = volatile organic analysis.

overnight courier to the appropriate laboratory for analysis of the BTEX and TPH levels. Chain-of-custody forms will accompany the samples. The analytical method and relevant sampling information are presented in Table 3.

5.6 Baildown Tests

After the depth to groundwater and the initial LNAPL thickness have been determined, the rate of LNAPL recovery will be determined via baildown testing. Simple baildown tests will be conducted on all site wells that have LNAPL present at the time of pilot test initiation. A clean Teflon™ bailer (bottom filling) will be lowered into each well to collect any floating LNAPL. The LNAPL will be removed from the well and poured into a graduated cylinder to determine its volume. Efforts will be made to minimize the volume of water removed from the well, and bailing will cease when the measurable thickness in the well cannot be further significantly reduced (confirmed with the oil/water interface probe).

Baildown test wells will be monitored periodically using the oil/water interface probe to determine the rate of LNAPL recovery. Measurements will be taken every hour for 2 hours, then every 2 to 4 hours for a maximum of 24 hours. The time between measurements can be more frequent if LNAPL recovery is rapid or less frequent if recovery is very slow. Data will be recorded on a baildown test record sheet as shown in Figure 9.

5.7 Soil Gas Permeability Test

5.7.1 Test Implementation

The soil gas permeability test will be conducted concurrently with the startup of the bioslurper (vacuum-assisted) LNAPL recovery test. After the skimmer recovery test is complete, the bioslurper system will be configured for the vacuum-assisted pump test. A short system test will be conducted to ensure that the bioslurper is operating properly and to confirm that the pressure monitoring boards are set up for vacuum monitoring. When the system shakedown test is complete, and when all monitoring point pressures have returned to zero, the soil gas permeability/radius of influence test will begin. Two people will be required during the initial hour of this test. One person will be responsible for reading the Magnehelic™ gauges, and the other person will be responsible for recording pressure (P') vs. time on the example data sheet shown in the Bioventing Protocol (Hinchee et al., 1992). Having two people will improve the consistency in reading the gauges and will reduce confusion.

Baildown Test Record Sheet

Site: ______________________

Well Identification: ____________________

Well Diameter (OD/ID): ______________________

Date at Start of Test: ___________ Sampler's Initials: ____

Time at Start of Test: ___________

Initial Readings

Depth to Groundwater (ft)	Depth to LNAPL (ft)	LNAPL Thickness (ft)	Total Volume Bailed (L)

Test Data

Sample Collection Time	Depth to Groundwater (ft)	Depth to LNAPL (ft)	LNAPL Thickness (ft)

Figure 9. Typical Baildown Test Record Sheet

Typically, the test sequence will follow these steps:

1. Connect the Magnehelic™ gauges to the top of each monitoring point with the stopcock opened. Return the gauges to zero.

2. Turn the bioslurper unit on, and record the starting time to the nearest second.

3. At 1-minute intervals, record the pressure at each monitoring point beginning at t = 60s.

4. After 10 minutes, extend the interval to 2 minutes. Return to the bioslurper unit and record the vacuum reading at the wellhead, the temperature readings, and the flowrate from the vent well.

5. After 20 minutes, measure P' at each monitoring point in 3-minute intervals. Continue to record all blower data at 10-minute intervals during the first hour of the test.

6. Continue to record monitoring point pressure data at 3-minute intervals until the 3-minute change in P' is less than 0.1 in. of H_2O. At this time, a 5- to 20-minute interval can be used. Review data to ensure accurate data were collected during the first 20 minutes. If the quality of these data is in question, turn off the blower, allow all monitoring points to return to zero pressure, and restart the test.

7. Begin to measure pressure at any groundwater monitoring points that have been converted to monitoring points. Record all readings, including zero readings and the time of the measurement. Record dl blower data at 30-minute intervals.

8. Once the interval of pressure data collection has increased, collect soil gas samples from monitoring points and the bioslurper exhaust, and analyze for oxygen, carbon dioxide, and hydrocarbons. Continue to gather pressure data for 4 to 8 hours. The test typically will be continued until the outermost monitoring point with a pressure reading does not increase by more than 10% over a 1-hour interval.

9. Estimate the values of k (permeability) and R_1 (radius of influence) with the data from the completed test.

5.7.2 Data Interpretation

The technology of soil venting has not advanced far enough to provide firm quantitative criteria for determining the applicability of venting based solely on values of k or R. In general, k must be sufficiently high to allow movement of oxygen in a reasonable time frame (1 or 2 days) from either the vent well, in the case of injection, or the atmosphere or uncontaminated soils, in the case of extraction. If such a flowrate cannot be achieved, oxygen cannot be supplied at a rate to match its demand. The estimated R_1 actually is an estimate of the radius within which measurable soil gas pressures are affected and does not always equate to gas flow. In highly permeable gravel, for example, significant gas flow can occur well beyond the measurable radius of influence. On the other hand, in a low-permeability clay a small pressure gradient may not result in significant gas flow. In this study, the assumption will be made that the R_1 does equate to the area of significant gas flow; however, care must be taken in applying this assumption. During soil gas permeability testing, an increase in oxygen concentration within the monitoring points often is an additional indicator of R.

In general, if the R_1 is greater than the depth of the vent well, the site probably is suitable for bioventing. If the R_1 is less than the vent well depth, the question of practicality arises. To scale up a bioventing project at such a site may require more closely spaced vent wells than is either economically feasible or physically possible. The decision to proceed with bioventing will be site specific and somewhat subjective.

5.8 ln Situ Respiration Test

The in situ respiration test will be conducted using the screened intervals of the monitoring points on the bioslurper test site. In situ respiration testing will not be conducted at the background location. The results from this test will determine if in situ microbial activity is occurring and if it is oxygen-limited. Detailed procedures for performing the in situ respiration test are provided in Section 5.7 of Hinchee et al. (1992).

5.8.l Test Implementation

Air containing 1 to 2% helium is injected into the monitoring point for 24 hours to fully aerate the soil. After injection of air and helium has been completed, the soil gas will be measured for oxygen, carbon dioxide, helium, and total hydrocarbon. Soil gas will be extracted from the contaminated area with a soil gas sampling pump system similar to that shown in Figure 8. Typically, the soil gas will be measured at 2, 4, 6, and 8 hours and then every 4 to 12 hours, depending on the rate at which the oxygen is utilized. If oxygen uptake is rapid, more frequent monitoring will be required. If it is slower, less frequent readings will be acceptable. Standard in situ respiration testing sampling will be conducted for 2 days (during the 2-day pump drawdown testing). If soil gas oxygen concentrations have not decreased to below 5% after 2 days, the Datawrite data loggers (at selected sites) will be left in place for an additional 3 days. Battelle will demobilize from the site after 2 days of in situ respiration test monitoring (at the conclusion of the drawdown test), and instructions will be left for the Base POC to ship the data loggers back to Battelle (prepaid) for data analysis.

At shallow monitoring points, there is a risk of pulling in atmospheric air in the process of purging and sampling. Excessive purging and sampling may result in erroneous readings. There is no benefit in oversampling, and when sampling shallow points, care will be taken to minimize the volume of air extraction. In these cases, a low-flow extraction pump of about 2 to 4 cfh will be used. Field judgment will be required at each site in determining the sampling frequency. Table 4 provides a summary of the various parameters that will be measured.

The in situ respiration test will be terminated when the oxygen level is about 5 %, or after 2 days of sampling. The temperature of the soil before air injection and after the in situ respiration test will be recorded.

5.8.2 Data Interpretation

Oxygen utilization rates will be determined from the data obtained during the bioventing tests. The rates will be calculated as the percent change in oxygen over time. The oxygen utilization rate is determined as the slope of the oxygen percent versus time line. A zero-order respiration rate is

Table 4. Parameters to be Measured for the In Situ Respiration Tests

Parameter/Media	Suggested Method	Suggested Frequency	Instrument Sensitivity (Accuracy)
Carbon dioxide/soil gas	Infrared adsorption method, GasTech Model 32520X (0 to 5% and 0 to 25% carbon dioxide)	Initial soil gas sample before pumping air, immediately after pump shutoff, every 2 hours for the first 8 hours, and then every 8 to 10 hours	±0.2%
Oxygen/soil gas	Electrochemical cell method, GasTech Model 32520X (0 to 21% oxygen)	Same as above	±0.5%
Total hydrocarbons (THC)/soil gas	GasTech hydrocarbon detector or similar field instrumentation	Initial soil gas sample before pumping air, then same as above if practical	±1 ppm
Helium	Marks Helium Detector Model 9821 or equivalent	Same as for carbon dioxide	±0.01%
Pressure	Pressure gauge (0 to 30 psia)	Reading taken during air injection	0.5 psia
Flowrate/air	Flowmeter	Reading taken during air injection	± cfh

typical of most sites; however, a fairly rapid change in oxygen levels also may be seen. In the latter, the oxygen utilization rate is obtained from the initial linear portion of the respiration curve.

To estimate biodegradation rates of hydrocarbon from the oxygen utilization rates, a stoichiometric relationship for the oxidation of the hydrocarbon will be used. Hexane will be used as the representative hydrocarbon, and the stoichiometric relationship used to determine the degradation rates will be:

$$C_6H_{14} + 9.5O_2 \longrightarrow 6CO_2 + 7H_2O \qquad (1)$$

Based on the utilization rates (change of oxygen [%] per day), the biodegradation rate in terms of milligram(s) of hexane-equivalent per kilogram(s) of soil per day will be estimated using the following equation.

$$K_B = \frac{-K_o A D_o C}{100} \qquad (2)$$

where:
- K_B = biodegradation rate (mg/kg·day)
- K_o = oxygen utilization rate (percent per day)
- A = volume of air/kg of soil (L/kg)
- D_o = density of oxygen gas (mg/L)
- C = mass ratio of hydrocarbon to oxygen required for mineralization

Using several assumptions, values for A, D_o, and C can be calculated and substituted into equation 1. Assumptions used for these calculations are:

- Porosity of 0.3 (the air-filled porosity; varies with moisture content in any given soil)
- Soil bulk density of 1,440 kg/m^3
- D_o oxygen density of 1,330 mg/L (varies with temperature, altitude, and atmospheric pressure)
- C, hydrocarbon-to-oxygen mass ratio of 1/3 from equation (1) for oxidation of hexane

Based on the above assumed porosity and bulk density, the term A (volume of air/mg of soil) becomes 300/1,440 = 0.21. The resulting equation is:

$$K_\beta = \frac{-K_o(0.21)(1{,}330)\left[\frac{1}{3.5}\right]}{100} \qquad (3)$$

This conversion factor, 0.8, was used by Hinchee et al. (1991) in their calculations of biodegradation rates of hydrocarbons. Another way to estimate biodegradation rates is based on carbon dioxide generation rates, but this is less reliable than using oxygen utilization rates.

6.0 BIOSLURPER SYSTEM CONSTRUCTION

At most sites a trailer-mounted bioslurper system will be used to conduct all pilot testing. The units will be constructed off site and will be mobilized to each site as needed. At sites in the contiguous 48 states the trailer-mounted system will pulled using a pickup truck or van. Air Force bases will be scheduled to allow efficient travel from site to site, generally requiring only l to 2 days driving between each base. For sites outside the contiguous 48 states (i.e., Hawaii, Alaska, and Europe), system components will be shipped via air freight.

6.1 Bioslurper Extraction Well Selection

One bioslurper extraction well will be selected at each site, based on the data collected during the site characterization phase of the bioslurper initiative. The following factors will be evaluated:

1. Historical data on the persistence and recoverability of LNAPL from each well. Preference will be given to wells that have a history of sustained LNAPL recovery using conventional recovery techniques.

2. Results of the LNAPL baildown tests. The well exhibiting the highest rate of LNAPL recovery during the 24 hour baildown test will be selected.

3. Well construction. Wells with a proper surface seal and optimum screened interval in the vadose zone will be selected. In general, a bentonite grout seal of a minimum of 3 ft from the ground surface, and a screen length of a maximum of 3 ft in the vadose zone, are desirable.

6.2 System Components

In general, bioslurper short-term pilot testing will be conducted in a 2-week span at each site. It is important, therefore, that the bioslurper pilot systems be designed to operate with minimal site support requirement. Each trailer-mounted unit will include a bioslurper liquid ring pump, a gasoline- or diesel-powered electrical generator capable of supplying all power requirements for the pilot testing, an oil/water separator with l0-gpm flow capacity, a transfer tank and pump for directing extracted groundwater to the base-supplied effluent disposition system, and vapor treatment equipment (as specified in site-specific test plans). In addition, all monitoring and sampling equipment will be transported on the pilot system trailer. Figure 10 shows a mobile bioslurper pilot test system.

6.2.1 Liquid Ring Pump

Liquid ring pumps will be used for all pilot testing. Liquid ring pumps are ideal bioslurper pumps because they have efficient pump curves (i.e., pump performance remains relatively uniform even at vacuums as high as 29 inches of mercury), and they are inherently explosion-proof total fluid pumps. Varying conditions will require the use of different pump sizes at some sites. The different liquid ring pump sizes available for this study are 3 horsepower (hp), 5 hp, 7.5 hp, and 10 hp (Atlantic Fluidics Models A20, A75, A100, and A130, respectively). Because only one well will be used for the pilot testing, the 3-hp pumps probably will be sufficient for most test sites. However, the larger pumps are more flexible for use at sites with deeper groundwater (greater than 25 ft) and for applications where more than one well will be utilized. The cost for the larger pumps is only marginally higher than the cost of the 3-hp systems. Pump selection will be site specific and will be addressed in the site-specific test plans.

6.2.2 Oil/Water Separator (OWS)

Operation of the bioslurper system will result in a liquid discharge of a LNAPL/groundwater mixture. The LNAPL will be separated from the aqueous phase by passing the liquid discharge stream through a gravity oil/water separator (OWS) (Megator Corp. Model #S-1-A-1.5, or equivalent). Recovered LNAPL will gravity-drain into a small holding tank on the pilot system trailer. Extracted groundwater will gravity-drain into an effluent transfer tank located on the pilot test trailer or on the ground adjacent to the trailer.

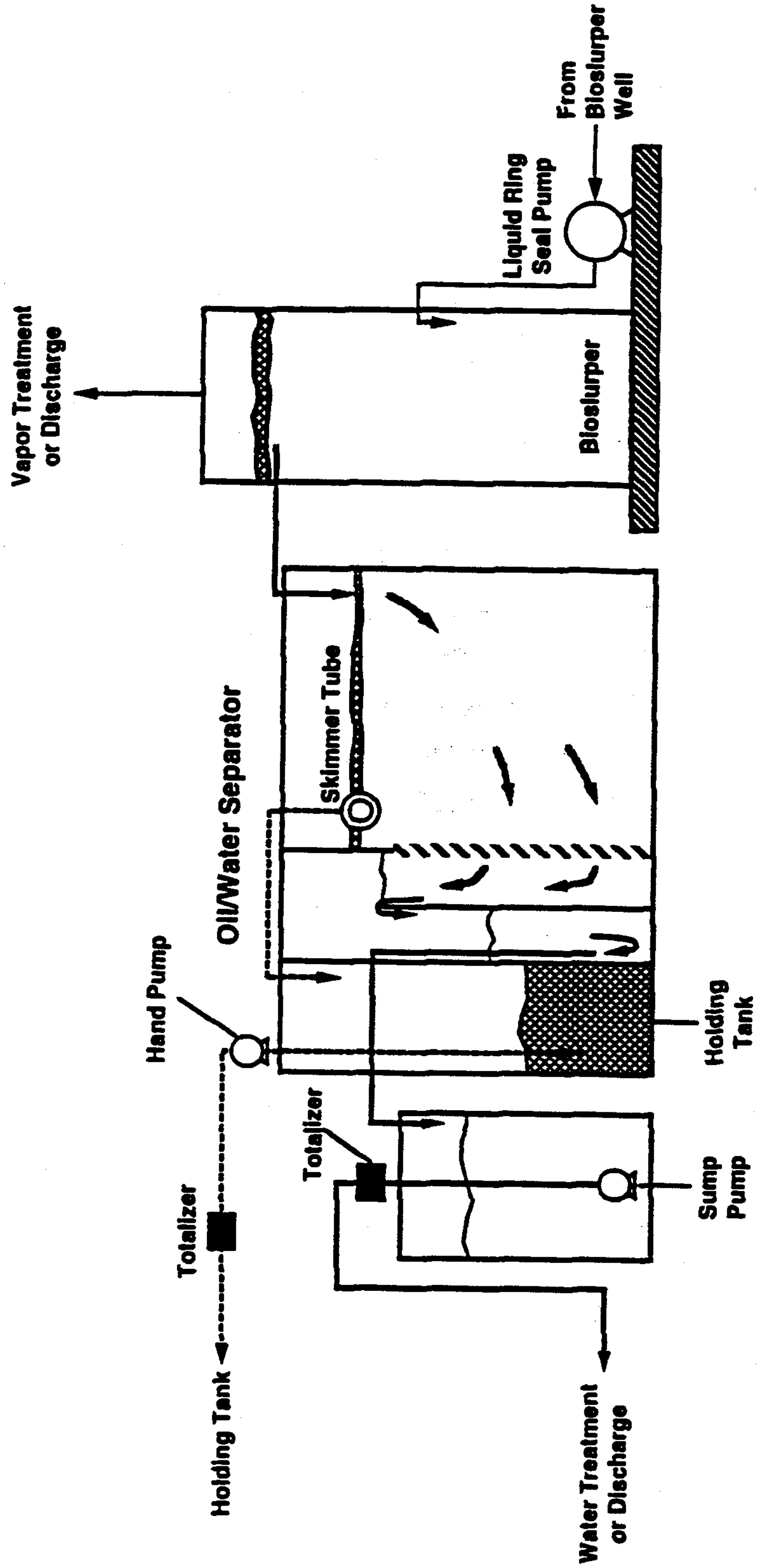

Figure 10. Diagram of Mobile Bioslurper Pilot Test System

6.2.3 Effluent Transfer Pump

The aqueous effluent from the OWS will gravity-drain into an effluent transfer tank. A float-switch-activated transfer pump will be placed in the tank. The pump will be plumbed to discharge effluent to the Base sanitary sewer in most instances. At some sites groundwater will be pumped through activated carbon canisters prior to discharge.

6.3 Aqueous/Vapor Discharge

The bioslurper system generates a point source vapor emission and has an aqueous discharge as well. Petroleum hydrocarbon constituents will be present in each discharge at a rate in pounds per day (lb/day) related to the fuel type and the extraction rate. In many cases the discharge rate of petroleum contaminants in the vapor stream will be below local regulatory treatment levels, and will be discharged directly to the atmosphere with regulatory approval. The mass of hydrocarbons dissolved in the aqueous phase will be much lower than the mass dissolved in the vapor discharge. In most cases, bioslurper aqueous effluent will be discharged to the Base sanitary sewer for treatment.

In some instances, the vapor and/or the aqueous effluent will require treatment before discharge. Generally, the contaminant of concern will be benzene, which is present in relatively high concentrations in JP-4 jet fuel and in gasoline. Local regulatory requirements vary, and at each site it will be necessary for the Air Force to determine discharge treatment requirements prior to mobilization to the field site. Sections 6.3.1 and 6.3.2 describe groundwater and vapor treatment options that are available for this study.

6.3.1 Groundwater Treatment

The preferable treatment option for the bioslurper system aqueous discharge will be a tie-in to the base sanitary sewer. The groundwater extraction rate is expected to be low at most sites (less than 5 gpm), and the concentration in the aqueous phase leaving the OWS generally will be less than 20 ppm total petroleum hydrocarbons (TPH). These two factors will result in low mass loading rates to the sanitary sewers, most of which typically have throughputs in the millions of gallons per day (mgd). In instances where discharge to the sanitary sewer is not feasible, or is not allowed, and treatment is required by local regulations, carbon filtration treatment systems will be used.

When required, activated carbon will be used to remove petroleum hydrocarbons from the OWS effluent prior to discharge. The discharge line from the effluent transfer pump (Section 6.2.3) will be plumbed to two canisters of activated carbon (Carbtrol Corp. Model L-1, or equivalent) connected in series. In most cases, the treated groundwater will be discharged to a nearby storm sewer or directly to the ground. Construction, operation, and sampling of the groundwater carbon treatment systems will be site specific and will be described in detail in the site-specific test plans.

6.32 Vapor Treatment

The cost effectiveness of the bioslurper technology will be greatly affected by the treatment option selected for the system vapor discharge. The requirements for treatment will depend on local regulations, the composition and concentration of hydrocarbons in the extracted vapor, and the system vapor extraction rate. The vapor extraction rate will be dependent on site soil gas permeability and bioslurper pump size. The composition and concentration of petroleum hydrocarbons in the vapor discharge will be dependent on the fuel type present at the site and the age of the release (degree of weathering). As with the groundwater discharge, treatment requirements generally will be driven by the mass of benzene released in the vapor discharge. At sites contaminated with JP-5 or diesel fuel, benzene concentrations will be very low and should not require treatment. Sites contaminated with JP-4 or gasoline could have significant concentrations of benzene in the bioslurper vapor discharge, and treatment of vapors prior to discharge may be required.

If permits and vapor treatment are required, the cost of the bioslurper pilot test will increase, and project scheduling will be affected. Most states can waive permitting and vapor treatment requirements for short-term pilot tests. At sites where waivers cannot be obtained there are several vapor treatment options, as described in Sections 6.3.2.1 through 6.3.2.3. Vapor treatment will be addressed in detail in the site-specific test plans.

6.3.2.1 Reinjection/In Situ Biodegradation of Vapor Emissions. In situ bioremediation of the bioslurper vapor emissions may be the most cost-effective and environmentally sound treatment

option. This treatment technology consists of the reinjection of hydrocarbon vapors into the subsurface to be remediated in situ via aerobic biodegradation (bioventing). If vapor treatmemt is required, reinjection of vapors should be considered as one of the primary treatment options. Regulatory approval may be required for vapor reinjection.

Vapor reinjection will be accomplished as follows. Results of the soil gas survey must indicate that the site is oxygen-limited to ensure that the site is biologically active. An existing vent well or monitoring well will be identified as the vapor injection well. If no existing well is available, a vent well should be installed using hand-augering techniques. The vapor discharge stack will be plumbed to the injection well. A pressure gauge, a pilot tube flow indicator, and a vapor sampling port will be installed in line between the vapor stack and the injection well. After connection to the injection well is complete, a short-term air injection test should be conducted to ensure that proper flow can be maintained.

At sites with low-permeability soils, vapor reinjection may require the use of additional reinjection wells and/or a secondary blower to boost injection pressure. At sites with highly impermeable soils, vapor reinjection may not be feasible.

6.3.2.2 Carbon Treatment. Activated carbon vapor treatment systems are a proven technology for removing petroleum hydrocarbon constituents from a vapor stream. At sites where it is determined that reinjection of vapors is not feasible, activated carbon will be the vapor treatment most often used for short-term pilot testing.

When activated carbon is used for vapor treatment, two 200-pound carbon canisters (Carbtrol Model G-1, or equivalent) will be plumbed in series to the bioslurper vapor discharge stack. A pressure gauge and a vapor sampling port will be placed on the vapor discharge stack and between the two carbon canisters. The discharge line from the second canister will be fitted with a vapor sampling port and with a pitot tube flow indicator (see Figure 11).

After the bioslurper system has been started up, vapor concentrations will be monitored in the discharge piping ahead of the carbon canisters, between the carbon canisters, and at the discharge from the second carbon canister. Monitoring will be conducted using a field hydrocarbon detector (GasTech Model TraceTector™, or equivalent) calibrated versus a 50-ppm hexane standard. If hydrocarbons are detected in line between the two canisters, a third canister will be added to ensure that no breakthrough can occur. Laboratory samples will be collected from the discharge stack and from the discharge of the second carbon canister in Summa canisters as described in Section 5.5.4.

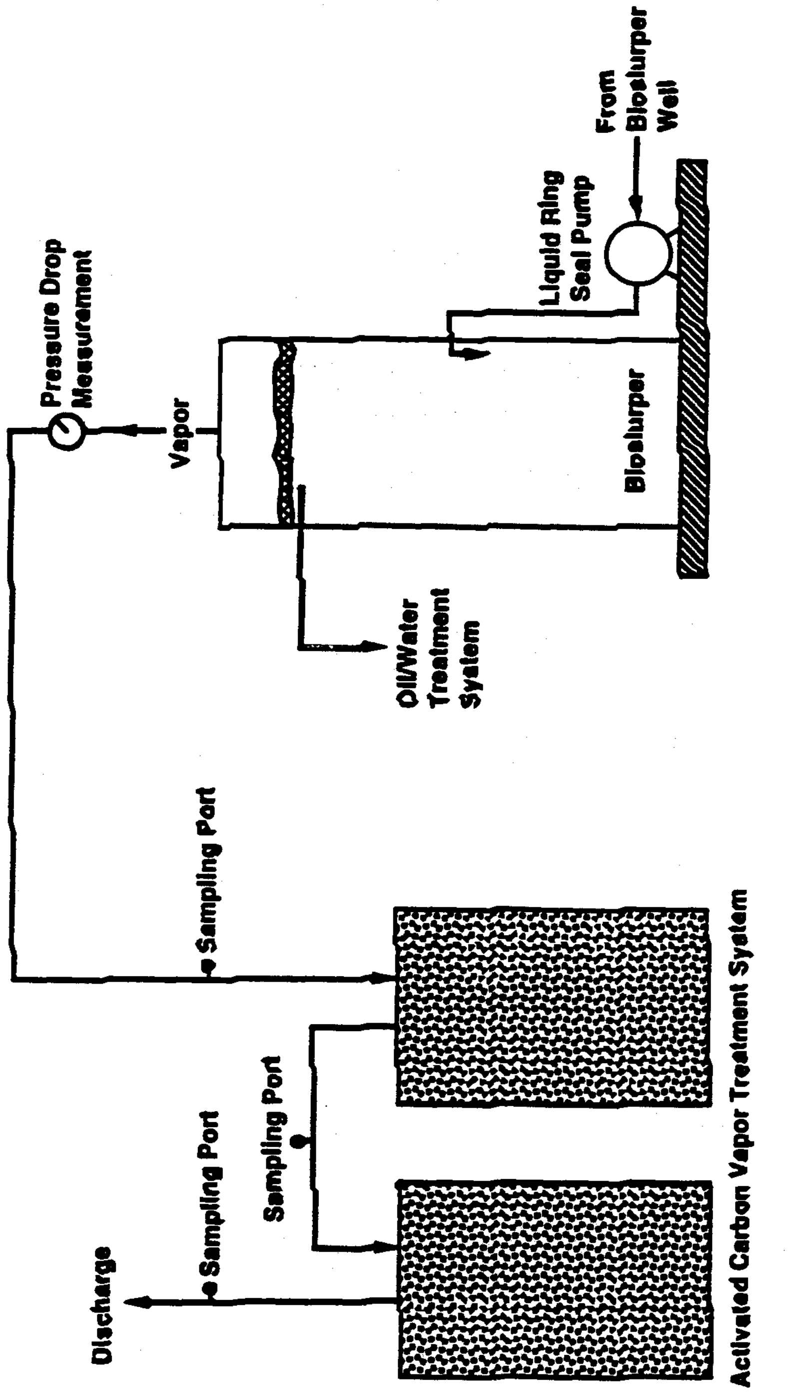

Figure 11. Setup of Activated Carbon Vapor Treatment System

6.3.2.3 Destruction in an Internal Combustion Engine. A third vapor treatment alternative to be evaluated on the bioslurper initiative will be use of a internal combustion engine (ICE) for destruction of VOCs. The ICE is a modified automobile engine with a special carburetor that allows it to operate using the petroleum hydrocarbons in the extracted soil gas as the fuel source. ICE technology has been permitted for hydrocarbon vapor treatment in several states, including California. ICE systems are capable of running solely on hydrocarbon vapors if VOC concentrations are high enough. If vapor concentrations are not sufficient to fuel the ICE, then a makeup fuel, such as natural gas or propane, will be required to ensure complete combustion of contaminants. Because of the cost of using makeup fuels, only sites with gasoline or JP-4 contamination (i.e., high-volatility fuels) will be cost effective for use of the ICE unit.

When the ICE unit is selected for use in vapor treatment at a site, the air intake of the trailer-mounted ICE unit (RSI, Inc. Model S.A.V.E., or equivalent) will be plumbed directly to the bioslurper system vapor discharge stack. The ICE system will be operated according to the RSI S.A.V.E. system manual, which will be attached to relevant site-specific test plans. ICE vapor discharge concentrations will be monitored using a Horiba engine analyzer, Model MEXA-53AGE, or equivalent.

7.0 PILOT TEST INITIATION

Initiation of the bioslurper field pilot test will begin after completion of the site characterization and system installation phases. This section describes the short-term pilot test. Extended testing and expanded-scale testing are discussed in Sections 9 and 10. The pilot test will evaluate LNAPL recovery efficiencies under the following system configurations: (1) skimming fuel from the well with no vacuum enhancement; (2) bioslurping from the well with vacuum enhancement; and (3) extracting fuel from the well with a cone of depression. Table 5 presents a generic schedule for bioslurper pilot test activities.

7.1 Baseline Measurements

Prior to initiating the LNAPL recovery tests, baseline field data must be collected and recorded. Baseline data to be collected will include soil gas concentrations, initial soil gas pressures, depth to groundwater, and LNAPL thickness. Additionally, ambient soil and atmospheric temperatures, and weather conditions will be recorded.

7.1.1 Soil Gas Survey (Limited)

A small-scale soil gas survey will be conducted to identify the best location for installation of the bioslurping system. The soil gas survey will be conducted adjacent to site monitoring wells where historical site data indicate the highest contamination levels. The area around these wells will be surveyed to select the locations for installation of soil gas monitoring points.

7.12 Baildown Tests

Baildown tests will be performed at wells that contain measurable light, nonaqueous-phase liquid (LNAPL) thicknesses to estimate the LNAPL recovery potential at those particular wells.

Table 5. Schedule of Activities for Bioslurper Initiative

Pilot Test Activity	Schedule
Site-Specific Test Plan Completed	14 days prior to approval
Test Plan Approval (only when specifically required)	day (to be determined)
Mobilization	day 1-2
Site Characterization	day 2-3
Product/Groundwater Interface Monitoring	
Baildown Tests	
Soil Gas Survey (limited)	
Monitoring Point Installation (3 monitoring points)	
Soil Sampling (TPH, BTEX, and physical characteristics)	
System Installation	day 2-3
Test Startup and Operation	day 3
Skimmer Test (2 days)	day 3-4
Bioslurper Vacuum Extraction (4 days)	day 6-9
Soil Gas Permeability Testing	day 6
Skimmer Test (repetition) (1 day)	day 10
In Situ Respiration Test (air/helium injection)	day 10
In Situ Respiration Test (including Datawrite oxygen monitoring)	day 11-16
Drawdown Pump Test (2 days)	day 11-12
Demobilization/Mobilization	day 13-14

7.1.3 Monitoring Point Installations

Upon conclusion of the initial soil gas survey, baildown tests, and slug tests, at least three soil gas monitoring points will be installed. These monitoring points should be within the free-phase plume and should be positioned to allow detailed monitoring of the in situ changes in soil gas composition caused by the bioslurper system. At selected sites, each monitoring point will have one Datawrite oxygen sensor installed in the borehole at the depth with the highest visible NAPL contamination concentration.

7.1.4 Soil Sampling

Soil samples from the chosen site will be collected from boreholes advanced for monitoring point installation. Two soil samples will be collected from a single borehole to characterize soils across the capillary fringe.

Soil samples will be analyzed for particle size distribution, bulk density, porosity, moisture content, BTEX, and TPH.

7.1.5 Product/Groundwater Interface Monitoring

Each site well, including the bioslurper extraction well, will be surveyed for depth to groundwater and LNAPL thickness using an oil/water interface probe (ORS Model #1068013 or equivalent).

7.2 System Shakedown

A brief startup test will be conducted to ensure that all system components are operating properly. Components to be checked include the liquid ring pump; aqueous effluent transfer pump; vapor, fuel, and water flow meters; oil/water interface probes; soil gas analysis instrumentation; emergency shutoff float switches in the OWS and the effluent transfer tank; and any vapor/effluent treatment system components. A checklist will be provided to document the system shakedown (see Figure 12).

Checklist for System Shakedown

Site: ____________

Date: ____________ **Operator's Initials:** ______

Equipment	Check If Okay	Comments
Liquid Ring Pump		
Aqueous Effluent Transfer Pump		
Oil/Water Separator		
Vapor Flowmeter		
Fuel Flowmeter		
Water Flowmeter		
Emergency Shut off Float Switch Effluent Transfer Tank		
Analytical Field Instrumentation GasTector™ O_2/CO_2 Analyzer TraceTector™ Hydrocarbon Analyzer Oil/Water Interface Probe Magnehelic Boards Thermocouple Thermometer		

Figure 12. Bioslurper Pilot Test Shakedown Checklist

7.3 Bioslurper System Startup

7.3.1 Initial Skimmer Simulation Test

Three LNAPL recovery tests will be performed during the bioslurper pilot test. The first pump test will be a 48-hour skimmer test. In this test the sluper tube will set at the LNAPL/groundwater interface with the wellhead ball valve open to the atmosphere (see Figure 13). Prior to starting the pump test, the bioslurper pump and the OWS will be primed with diesel fuel to ensure that any product that enters the system can be quantified. The flow totalizers for the LNAPL and the aqueous effluent will be zeroed and the liquid ring pump will be started. The skimmer test will be operated continuously for 48 hours, with free product and groundwater extraction rates being monitored on an as-needed basis throughout the test. LNAPL/groundwater levels will be monitored periodically in the site monitoring wells (every 0.5 hour for 2 hours, then as needed thereafter). All data will be entered on the site bioslurper pilot test data sheets shown in Figure 14. After 48 hours have elapsed, final readings will be taken for LNAPL and groundwater extraction rates. Final LNAPL and groundwater levels in the site monitoring wells also will be recorded.

7.3.2 Bioslurper Vacuum-Enhanced Extraction Test

When the skimmer test is complete, the ball valve at the extraction wellhead will be closed to begin bioslurping (see Figure 15). The bioslurper test will begin immediately after the skimmer test is completed and will continue for 96 hours. Before closing the extraction wellhead ball valve, initial soil gas pressures will be taken at all soil gas monitoring points and from any site monitoring wells fitted with the vacuum-tight oil/water interface probe. The bioslurper test will continue for 96 hours. Process monitoring will be conducted throughout the test as outlined in Section 8.0.

7.3.3 Soil Gas Permeability Testing

The soil gas permeability test data will be collected beginning immediately after the wellhead ball valve is closed (see Section 5.7). Data will be collected frequently the first 20 minutes of the

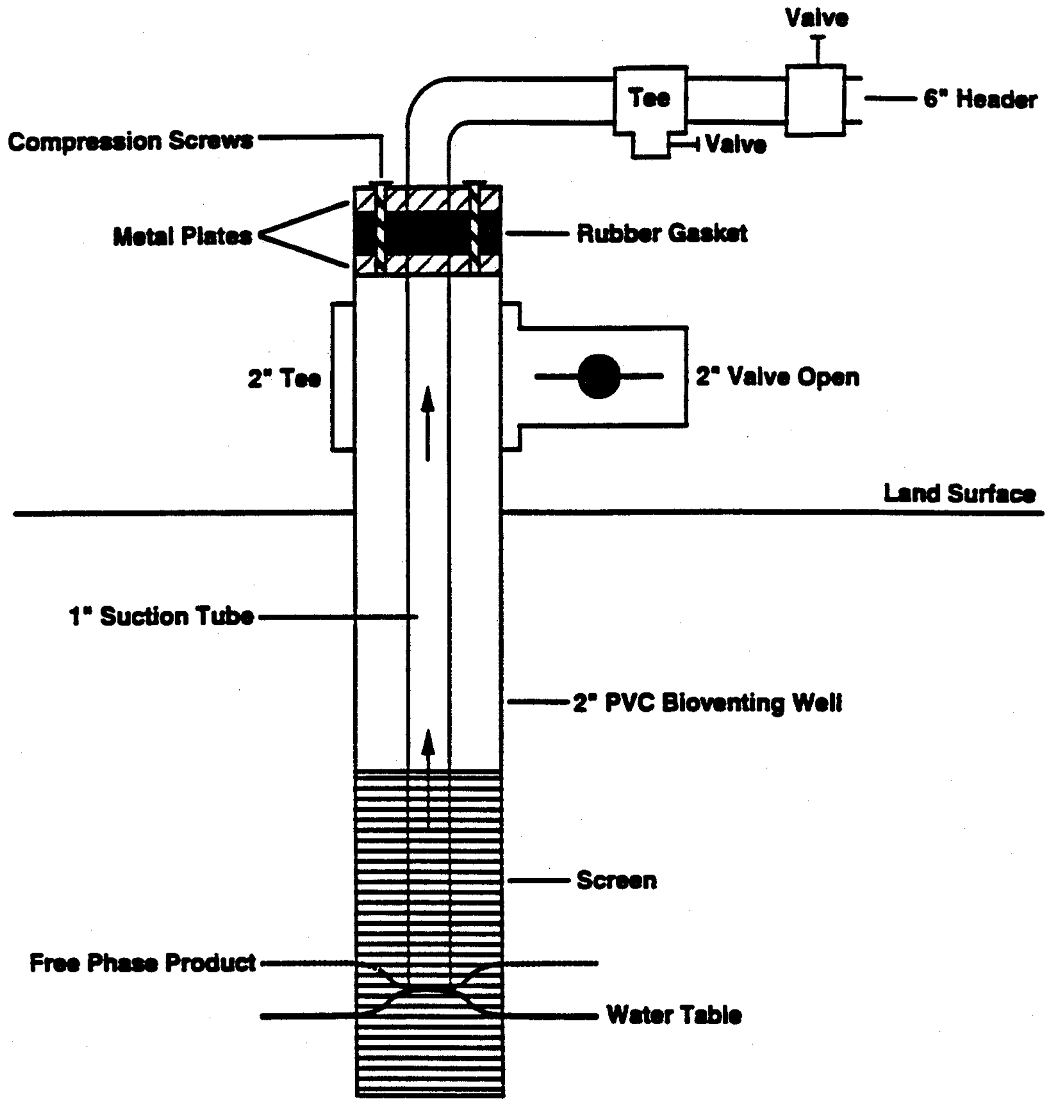

Figure 13. Slurper Tube Placement for the Skimmer Simulation Recovery Test

Bioslurping Pilot Test
(Data Sheet 1)
Well Characteristics

Page ____ of ____

Site: ____________________

Test Type (skimmer, bioslurper vacuum extraction, drawdown): ____________________

Depth to Groundwater: __________ **Depth to Fuel:** __________ **Depth of Slurper Tube:** __________

Date at Start of Test: __________

Time at Start of Test: __________ **Operator's Initials:** __________

Date/Time	Well ID:			Well ID:			Well ID:		
	LNAPL Level	Water Level	Pressure (in H_2O)	LNAPL Level	Water Level	Pressure (in H_2O)	LNAPL Level	Water Level	Pressure (in H_2O)

Figure 14. Typical Record Sheets for Bioslurper Pilot Testing

Bioslurping Pilot Test
(Data Sheet 2)
Pilot Test Pumping Data

Page ___ of ___

Site: ____________________ Start Date: __________

Operators: ________________ Start Time: __________

Test Type: ________________ Well ID: ____________

Depth to Groundwater: ________ Depth to Fuel: ________ Depth of Tube: ________

Date/Time	Run Time	Vapor Extraction Stack Pressure (in. H_2O)	Vapor Extraction Carbon Drums (in. H_2O)	Vapor Extraction Flowrate (scfm)	Pump Stack Temp (°C)	Pump Head Vacuum (in. Hg)	Extraction Well Vacuum (in. H_2O)

Figure 14. Typical Record Sheets for Bioslurper Pilot Testing (continued)

Bioslurping Pilot Test
(Data Sheet 3)
Fuel and Water Recovery Data

Page ____ of ____

Site: ______________________ **Start Date:** __________

Test Type: __________________ **Operators:** ____________________

Date/Time	Run Time	LNAPL Recovery (volume collected in time period)	Groundwater Recovery (volume collected in time period)

Figure 14. Typical Record Sheets for Bioslurper Pilot Testing (continued)

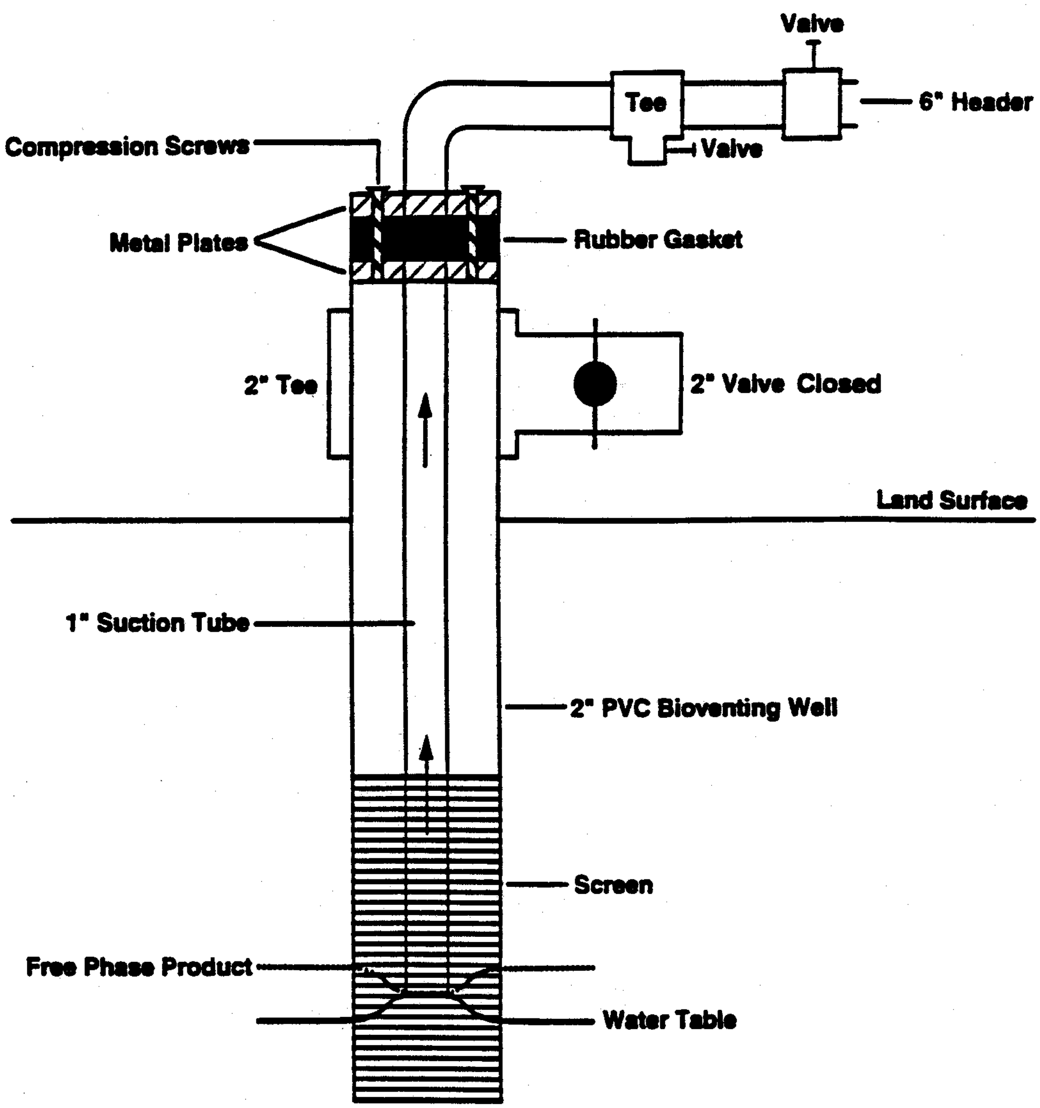

Figure 15. Slurper Tube Placement for the Bioslurper (Vacuum-Enhanced) LNAPL Recovery Test

bioslurper test. After the first 20 minutes, data can be collected less frequently, depending on the rate of pressure change. Soil gas pressures will continue to be monitored throughout the bioslurper test. Soil gas samples will be collected and analyzed for oxygen, carbon dioxide, and hydrocarbon concentrations, beginning 1 hour after the air permeability test is started, and soil gas will be monitored throughout the bioslurper test to determine the bioventing radius of influence. Oxygen concentrations observed using standard field measurement techniques (GasTech instrumentation) will be compared to results observed with the Datawrite oxygen monitoring systems installed in the monitoring points.

7.3.4 Skimmer Simulation Test Repetition

Following the 96-hour bioslurper test, the skimmer simulation test will be repeated. The wellhead valve will be reopened to simulate skimmer operation. Flow totalizers for the LNAPL and the aqueous effluent will be zeroed and the liquid-ring vacuum pump will be started. The postslurping skimmer simulation test will be run for 24 hours. The flow and water level data collection described in Section 7.3.1 will be repeated. Repeating the skimmer simulation test will provide a more accurate basis for comparing sustainable LNAPL recovery rates with conventional technology and bioslurping.

7.3.5 Dual-Pump/Drawdown Simulation Test

A drawdown simulation test will be conducted for 48 hours after completion of the 96-hour bioslurper vacuum enhanced LNAPL recovery test and the second skimmer simulation test. The extraction wellhead ball valve will be opened to the atmosphere and the slurper tube will be lowered further into the well, to a level below the static groundwater level measured during baseline measurements (see Figure 16).

To allow a direct comparison between the bioslurper test and the drawdown simulation test, the drop tube will be placed at a depth equal to the wellhead vacuum observed during the bioslurper test. For example, if the wellhead vacuum during bioslurping is approximately 18 in. (H_2O), the drop tube would be placed 18 in. below the original elevation of the water table. In cases of extremely high vacuum or very low vacuum, default values of 3 ft (maximum) and 1 ft (minimum) will be used. Some sites will have extremely permeable aquifers, for which drawdown tests are not feasible.

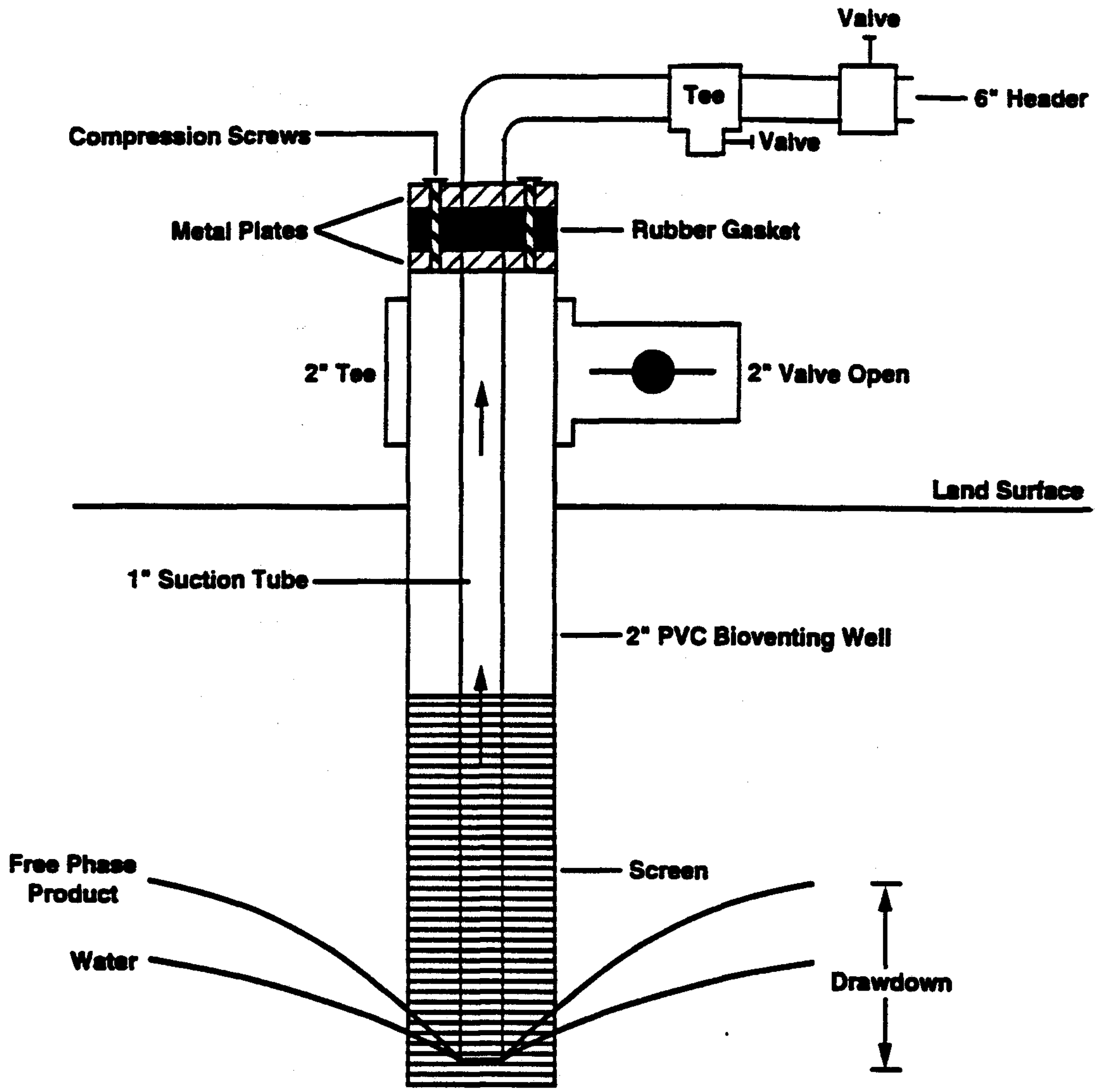

Figure 16. Slurper Tube Placement for the Drawdown Simulation Recovery Test

LNAPL and groundwater will be extracted for 24 hours in the dual-pump/drawdown simulation mode. Data collection and process monitoring will continue as with the skimmer and bioslurper recovery tests.

7.3.6 In Situ Respiration Testing

As described in Section 7.3.3, the oxygen concentrations observed using standard field techniques (GasTech instrumentation) will be compared to results observed with the Datawrite system during the 96 hour bioslurper test. After the bioslurper test is completed, and concurrent with the second skimmer simulation test, air/helium will be injected into the three monitoring points that contain the Datawrite Subsurface Oxygen Monitoring System™. Air with 1 to 2% helium will be injected for 20 to 24 hours during the drawdown extraction test. When air/helium injection has been completed, respiration test monitoring will begin. The respiration test procedure is outlined in Section 5.8.1. Standard in situ respiration testing sampling will be conducted for 2 days (during the 2-day pump drawdown testing). If soil gas oxygen concentrations have not decreased to below 5% after 2 days, the Datawrite data loggers will be left in place for an additional 3 days. Battelle will demobilize from the site after 2 days of in situ respiration test monitoring (at the conclusion of the drawdown test). Instructions will be left for the Base POC to ship the data loggers back to Battelle (prepaid) for data analysis.

The consistency and reliability of the Datawrite system will be compared to the consistency and reliability of the standard monitoring techniques now used. If the Datawrite system proves effective for in situ respiration test monitoring, the conventional monitoring techniques will be discontinued and the Datawrite system will be used exclusively.

8.0 PROCESS AND S1TE MONITORING

The three LNAPL recovery tests will be conducted as a single extraction test with the extraction well/slurper tube in three different configurations as outlined in Sections 7.1 through 7.3. Data collection for process monitoring will be conducted the same way during each configuration. All data will be recorded on the pilot test data record sheet (see Figure 12). The objective of process monitoring is to estimate the mass of hydrocarbons removed in the free phase (LNAPL), aqueous phase (dissolved in groundwater), and vapor phase (gaseous), and the mass of hydrocarbons mineralized (bioremediated).

8.1 Vapor Discharge Analysis

Due to the short duration of the bioslurper pilot test, it can assumed that the concentration of hydrocarbons in the vapor discharge will remain relatively constant throughout the pilot test. The assumption of constant off-gas composition is based on the gas/liquid equilibrium in the liquid ring vacuum pump. Two vapor samples for laboratory analysis will be taken for process monitoring purposes during the bioslurper vacuum-enhanced recovery test. The samples will be analyzed for BTEX and for TPH. One sample will be taken after startup and one sample will be taken just before changing the extraction configuration to the dual-pump/drawdown extraction test. No vapor samples will be taken during the skimmer test or the drawdown test for process monitoring. Field analyses using the field soil gas screening instruments will be conducted periodically during all three extraction configurations to monitor vapor discharge concentration variability. Additional laboratory analysis may be required for vapor-phase treatment monitoring. Table 3 describes the vapor sampling and analysis methods.

8.2 Aqueous and LNAPL Effluent Analysis

As with the vapor concentrations, it can be assumed that aqueous-phase petroleum hydrocarbon concentrations will remain relatively constant throughout the pilot test. Due to residence time in the pump and decanting tank, the aqueous-phase concentration should be near equilibrium with the nonaqueous-phase materials. Two aqueous effluent samples will be taken for process monitoring purposes. These samples will be analyzed for BTEX and TPH. The samples will be collected at the beginning and the end of the vacuum-enhance bioslurping test. Table 3 describes water sampling and analysis procedures.

8.3 LNAPL Recovery Volume

LNAPL will be transferred from the small holding tank on the pilot test trailer to a larger holding tank on the ground. LNAPL will be pumped with a hand operated drum pump, and the recovery volume will be quantified using an in-line flow-totalizer meter calibrated in gallons.

For all recovery tests, the following procedure will be used to monitor LNAPL recovery rates. LNAPL recovery volumes will be measured every 30 minutes for the first 2 hours of the test, every 2 hours for the next 10 hours, then every 12 hours until the test is complete. This procedure will make it easier to differentiate the initial slug of LNAPL recovered during the start of each test from sustainable LNAPL recovery.

8.4 Vapor Discharge Volume

The volume of vapor discharge will be quantified using a pilot tube (Annubar Flow Characteristics Model #HCR-15) flow indicator. The pilot tube is connected to a differential pressure gauge calibrated in inches of H2O. The flowrate in cubic feet per minute (cfm) is determined by referencing the differential pressure to a flow calibration curve as shown in Figure 17. The volume of vapor discharge will be calculated based on the average flowrate in cubic feet per minute (cfm) and the hours of operation. The mass of hydrocarbons extracted in the vapor phase will be based on the average concentration of the two vapor samples taken (see Section 8.1) and the volume of soil gas extracted.

8.5 Groundwater Discharge Volume

The groundwater extraction volume will be quantified using an in-line flow totalizer meter calibrated in gallons. The mass of petroleum hydrocarbons removed in the aqueous phase will be calculated based on the results of the effluent analysis (see Section 8.2) and the groundwater discharge volume.

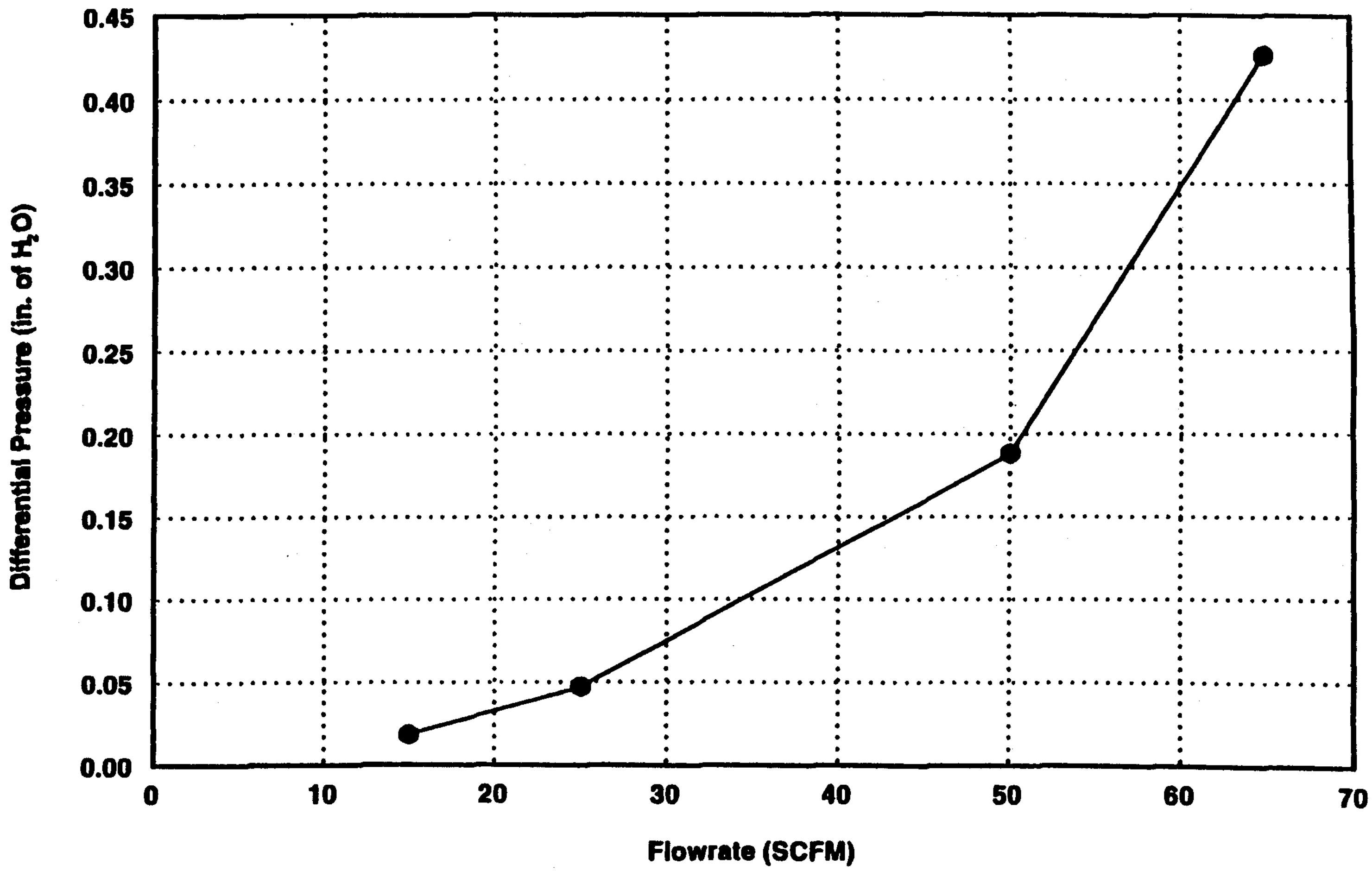

Figure 17. Typical Flow Calibration Curve for the Bioslurper Vapor Discharge Pitot Tube, 3-Inch, Schedule 80 PVC Stack

8.6 Biodegradation Monitoring

Results of the in situ respiration test performed during the bioslurping tests will be used to estimate the bioventing biodegradation rue (see Section 5.9.2). The results will be reported in mg/kg day biodegraded, and an estimate of the potential mass of petroleum hydrocarbons biodegraded in mg/kg year will be made based on the initial respiration rates.

9.0 EXTENDED BIOSLURPER TESTING

At sites where LNAPL recovery rates are high, and at the Air Force's discretion, extended bioslurping testing may be conducted for up to 6 months. The extended testing phase of the bioslurper initiative is considered an extension of the 4-day bioslurper pilot test. At these sites additional Base support from the Air Force will be required. The decision to implement extended testing must be made as soon as the 4-day bioslurper test is complete, before demobilization of the bioslurper system.
Slug tests will be performed early in the extended test program to determine the characteristics of the wells where the extended bioslurper test will be located. Slug tests will be performed using an in situ pressure transducer and data logger to track pressure (water level) changes and a know-volume polyvinyl chloride (PVC) capsule (slug) to introduce a rapid change in level.

At sites where extended testing is implemented, the bioslurper system will be connected to a permanet power source by the Air Force. Additional site wells will be incorporated into the recovery system by the contractor, if possible. The liquid ring pump and the oil/water separator used in the pilot test will be left on site. The Air Force will be responsible for vapor and extraction water effluents, and for removal and disposition of recovered LNAPL. A brief operations manual will be provided to the base for routine operations and m~ of the bioslurper system. The Air Force will be responsible for all routine operations and maintenance of the bioslurper system. The contractor will provide a point-of-contact to troubleshoot non-routine maintenance issues, and will have weekly communication with the Air Force Base POC to monitor the bioslurper system status.

Extended testing will end when LNAPL recovery ceases (or becomes impractical due to low recovery volumes), or at the end of 6 months, or at the discretion of the Air Force. If extended testing is completed at or before 6 months, Battelle will return to the site to remove the bioslurper system for mobilization to another site.

10.0 EXPANDED-SCALE BIOSLURPING TESTING

Expanded-scale testing may be conducted at sites where LNAPL recovery rates achieved during the short-term and extended test indicate that useful performance data can be collected. Expanded-scale testing will be performed at sites selected by, and at the discretion of, the Air Force. The scope of expanded-scale testing will be site specific and may include additional site characterization and well installation. A site-specific test plan will be developed for each expanded-scale bioslurping site. Expanded-scale testing will be conducted for up to 1 year.

11.0 REPORTING

The section describes the reports to be generated. For consistency, the following units will be used:

- English measurements for length, volume, flow, and mass, specifically:
  - feet and inches for length
  - gallons and ft^3 for volume
  - cfh and cfm for flow
  - lb for mass
- Metric units for concentration and rates, specifically:
  - mg/L for aqueous concentrations
  - mg/kg for soil concentrations
  - mg/(kg day) for hydrocarbon degradation
- Gaseous concentrations and oxygen utilization rates as follows:
  - ppm for hydrocarbons (parts per million, i.e., µL/L, by volume)
  - percent (%) for oxygen, carbon dioxide, and He (percent by volume, i.e., L x 100%/L)
  - % per hour for oxygen utilization.

To avoid confusion when discussing gases, the term percent (%) will refer only to concentration. Relative changes will be expressed as fractions. For example, if the oxygen concentration changes from 20% to 15%, the change will be referred to as a 5% reduction or a fractional reduction of 0.25, not a 25 % reduction.

11.1 Test Plan

A Test Plan for each site will be prepared and submitted to the project officer and the Base POC for approval. The Test Plan will consist of this generic Test Plan, which provides the scope and planned activities, and a cover letter describing site-specific applications. The Test Plan will be submitted to the project officer and Base POC as early as possible before the start of the onsite test.

11.2 Monthly Reports

The contractor will provide a written monthly progress report to the project officer outlining the work accomplished for the month, the problems encountered, approaches to overcome the problems, and expected progress for the following month. Included in this report will be the monthly expenditures and the accumulated expenditures to date.

11.3 Verbal Communication

The contractor will maintain communication with the project officer and the Base POC and will report on field activities and associated problems. Oral reports will be made either to the project officer or Base POC upon request, and at least weekly to the project officer.

11.4 Site Reports

The contractor will provide a letter report (normally less than 15 pages) for each site describing the results of the soil gas permeability and in situ respiration tests as well as a description of the bioventing test initiated. This report normally will be submitted to the project officer, Base POC, and others as directed by the project officer 60 days after completion of the treatability test.

12.0 RECORD OF DATA AND QUALITY ASSURANCE

A project record book will be maintained during the field tests to record events pertaining to site activities, including sampling, changes in process conditions (flow, temperature, and pressure), equipment failure, location of the test wells, calibration checks, and data for the respiration/air permeability tests and extended bioslurper tests. The record book will be reviewed by the contractor's project manager.

Quality assurance will be implemented throughout the project through quality planning, quality control, and quality assessment. The field analytical instruments will be calibrated prior to use each day with purchased calibration standards. Field blanks will consist of ambient air drawn through the entire sampling train setup in an uncontaminated area of the field site. Quality assurance activities include a review of all field activities and procedures by the project manager to ensure compliance with this protocol and with the quality guidelines. Monthly reports to the project officer will include any significant quality assurance problems and recommended solutions.

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APPENDIX

GENERAL SITE HEALTH AND SAFETY PLAN

for

BIOSLURPING FIELD STUDIES

GENERAL SITE HEALTH AND SAFETY PLAN

for

BIOSLURPING FIELD STUDIES

SEPTEMBER 9, 1994

Battelle
505 King Avenue
Columbus, Ohio 43201

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FIGURE

TABLE

GENERAL SITE HEALTH AND SAFETY PLAN

for

BIOSLURPING FIELD STUDIES

1.0 INTRODUCTION

This Health and Safety Plan (HASP) is designed to address potential health and safety risks associated with the bioslurping project field activities to be performed under the Bioslurping Field Initiative Program at approximately 35 Air Force petroleum contaminated sites. The safety and health of the field team will be ensured through an integrated program of training, standard operating procedures, and careful site planning and operations. Refer to the Site Specific and Generic Test Plan for a detailed description of planned project activities at each site.

This HASP will be posted in the site control center (office/laboratory). All site personnel and visitors will be required to read and understand the HASP before they are admitted to the project site. During all project activities, the site Health and Safety Officer or a designate will be responsible for implementation of the HASP.

2.0 PROJECT DESCRIPTION

2.1 Site Investigation

Site characterization activities will consist of collecting data on the geological, microbial, hydrological, and contaminant characteristics of each Air Force site. The site investigation is being conducted to collect additional data to define subsurface conditions at each site. The overall objective of the investigation is to collect sufficient site-specific data to determine the potential efficacy of bioslurping for remediating contaminated soils at each site.

The site investigation activities will consist of the following tasks:

(1) Advancement of soil borings. Soil samples for hydrocarbon analysis will be collected from the borings. In most cases the soil borings will be converted to vent wells or soil gas monitoring points. A maximum of 3 soil samples will be taken from each site.

(2) Collection of LNAPL samples. LNAPL free product will be collected and analyzed for BTEX concentrations. A boiling point distribution of the hydrocarbons present in these samples will be determined as well.

(3) Performance of soil gas surveys. Soil gas samples will be collected and field analyses will be conducted for total petroleum hydrocarbons, oxygen, and carbon dioxide.

(4) Performance of an air permeability test.

(5) Conduct in situ respiration tests. Soil gas samples will be collected, and field analysis will be conducted for total petroleum hydrocarbons, oxygen, carbon dioxide, and helium.

(6) Performance of bail tests. Baildown tests will be performed to determine the rate of LNAPL recovery.

(7) Performance of slug tests.

2.2 Key Personnel and Responsibilities

The Program Manager is responsible for appointing a site supervisor or Health and Safety Officer for field operations. The site supervisor or designated Health and Safety Officer will be responsible for ensuring that proper health and safety requirements are followed as specified in this HASP. The site supervisor or designated Health and Safety Officer will have the authority to modify the HASP on site if conditions require this response.

The personnel to be used at each site will vary. A list of personnel who will work at a particular site will be attached to this HASP before field operations begin at that site.

3.0 TRAINING REQUIREMENTS

Personnel working at field operations must recognize and understand the potential safety and health risks associated with the work at that site. Workers must be thoroughly familiar with procedures contained or referenced in this HASP and must be trained to work safely in controlled areas. All of Battelle's site employees will have received 40 hours of hazardous waste site training and applicable 8-hour annual updates. A field health and safety meeting will be held before field work begins to discuss the HASP.

All visitors to the site, even if escorted, must receive a briefing on safety if exposure to hazardous chemicals in amounts above recommended guidelines is possible. This HASP will be available on site. Visitors not complying with the above requirements will not be allowed to enter the restricted work areas but may observe site conditions from a safe distance.

4.0 ANTICIPATED WEATHER CONDITIONS

Performance of project activities will occur throughout the year in varying climatic regions. All personnel will be equipped with clothing/gear that is appropriate to the weather conditions. A heated control center will be accessible to all personnel.

5.0 JOB HAZARD ANALYSIS

Preparation of this HASP was based on the proposed scope of project activities at bioslurping field study sites and the available analytical data regarding the chemical contamination expected at the sites. The soils in the area of the proposed sites are known to be contaminated with JP 4 and JP-5 jet fuel, gasoline, or diesel fuel.

5.1 Soil Borings

The site investigation will involve the use of a drilling rig to advance soil borings and install vent wells and monitoring points. Soil samples will be taken. Possible hazards include: objects striking head (overhead hazard posed by drilling rig), exposure to organic vapors or free-phase petroleum, objects striking feet, objects striking eyes, exposure *to* the elements, and possible fire/explosion.

5.2 Air Permeability and In Situ Respiration Testing

Activities conducted for the air permeability ant in situ respiration testing will include soil gas sampling and analysis and minor maintenance repairs. Possible hazards include: exposure to organic vapors, objects striking feet, objects striking eyes, electrical shock, exposure to the elements, and possible fire or explosion.

5.3 LNAPL Sample Collection

LNAPL free product will be collected for sample analysis and during baildown testing. Potential hazards include exposure to free-phase petroleum and organic vapors and possible fire.

5.4 Primary Health Hazards

The contaminated soil and groundwater in the area of the proposed sites contains a variety of organic compounds, including:

- Total Petroleum Hydrocarbons (TPH)
- Benzene
- Toluene
- Xylene
- JP-4 (jet fuel)
- JP-5 (jet fuel)

The two most significant of these compounds in terms of possible health effects are TPH and benzene. In addition, free-phase (liquid) JP 4 and JP-5 may contain higher concentrations of the above constituents and could present a fire hazard.

The primary potential health hazards associated with exposure to the chemical substances identified in detectable concentrations are summarized in Table 1. Applicable employee 8-hour permissible exposure limits (PELs) and threshold limit values (TLVs) also are indicated in Table 1. The PELs are defined by the United States Department of Labor, Occupational Safety and Health Administration (OSHA), in the Code of Federal Regulations (CFR), Title 29, Labor, Section 1910.10, or other appropriate sections.

The TLVs listed are recommended by the American Conference of Governmental Industrial Hygienists (ACGIH). TLVs refer to airborne concentrations of substances and represent conditions to which it is believed nearly all workers can be exposed repeatedly, 8 hours per day, day after day, for a 40 year working lifetime, without adverse effect. Because of wide variations in individual susceptibility, however, a small percentage of workers may experience discomfort from chemical substances at concentrations equal to or below TLV. A still smaller percentage of persons may be affected more seriously from exposures at or below TLV due to aggravation of a pre-existing condition or the development of an occupational illness. TLVs are based on the best available information from industrial

TABLE 1. PRIMARY HEALTH HAZARDS AND EXPOSURE LIMITS FOR CHEMICAL SUBSTANCES DETECTED ON SUBJECT SITE

Compound	Federal OSHA Exposure Limit (TLV-TWA) (ppm)	ACGIH TLV (ppm)	Primary Health Hazard
Total Petroleum Hydrocarbons	300[1]	300	Dizziness, drowsiness, irritated eyes
Benzene	1	10	Irritated eyes and nose, headache, nausea, fatigue, carcinogenic
Toluene	100[1]	100	Irritated eyes and nose, nausea, affects liver and central nervous system
Xylene	100[2]	100[2]	Irritated eyes and nose, nausea, affects liver and central nervous system
JP-4	—	200	Irritated eyes and nose, nausea, dizziness

[1] Limit based on gasoline.
[2] Short-term exposure limit (STEL) for these two compounds is 150 ppm.

experience, from human and animal studies, ant when possible from a combination of the three sources.

The time-weighted average TLV (TLV-TWA) represents a time-weighted average exposure for an 8-hour day, 40-hour workweek. The majority of TLVs are expressed as TLV-TWAs. The TLV for certain substances is followed by a skin notation which implies that the overall exposure to a substance is enhanced by skin, mucous membrane, ant/or eye exposure. Some substances have a ceiling value designated by the letter “C”. Ceiling values should not be exceeded at any time during the workday.

5.5 Potential Safety Hazards and Required Control Measures

In addition to the hazards associated with exposure to the organic contaminants present on site, there are general potential hazards associated with conducting site investigation activities and the installation and operation of the remediation system. The following potential hazards and required control measures have been identified for the proposed scope of environmental project activities to be conducted for the Bioslurping Initiative.

- Flying particulate: Safety glasses will be worn by all site personnel.

- Objects striking head: Hard hats will be worn in the vicinity of overhead hazards (e.g., in the drilling rig area).

- Objects striking foot: Steel-toed boots will be worn.

- Slips, trips. falls: Attempts will be made to minimize slips, trips, and falls by providing clear footing.

- Exposure to organic contaminants: Disposable gloves, coveralls, and boot covers will be worn when sampling contaminated soil and water.

- Exposure to free product: Safety goggles, disposable gloves, coveralls, and boot covers will be worn when sampling free product.

- Exposure to organic vapors: Negative pressure, National Institute for Occupational Safety and Health (NIOSH)-approved cartridge respirators will be available to site personnel should conditions warrant.

- Electrical shock: All major electrical work(e.g., wiring, control panel construction), will be subcontracted to a qualified electrical contractor. Care will be taken to de-energize and ground any electrical equipment before conducting repair work. Before any repair work is undertaken, the energy source will be either permanently disconnected or temporarily tagged and locked to prevent the equipment from energizing accidentally.

- Fire: Open-flame ignition sources (e.g., smoking materials) will be restricted from the work area. Any free-phase petroleum will be stored in appropriate containers. Signs indicating flammable liquids will be posted where appropriate. Appropriate fire extinguisher will be available to site personnel during drilling activities. A fire extinguisher will be located permanently in the site office/lab building.

- Noise: Ear plugs/ear muffs will be worn as warranted by site conditions.

6.0 RISK ASSESSMENT SUMMARY

The project activities will involve minimal disturbance of contaminated soils. No risk to the communities at or near the site or to the environment is anticipated as a result of project activities. Free-phase LNAPL collected during the duration of the pilot test will be stored in an aboveground storage tank. The source of worker exposure will be organic vapors released when drilling boreholes, installing monitoring wells, digging trenches, emptying sample devices, and collecting samples. There is also an exposure risk of splashing LNAPL during baildown tests and sample collection and transfer. The air permeability and in situ respiration testing systems are expected to vent minimal organic vapors and will be designed to discharge vapors away from the work area. The total organic vapor exposure as a result of project activities is not expected to approach the concentration limits of an 8-hour, time-weighted average as listed in Table 1.

7.0 MEDICAL PROGRAM

Given the risk assessment that exposure to organic vapors will be minimal, an aggressive medical surveillance program is not necessary. Should any site personnel exhibit symptoms of overexposure to organic vapors (e.g., diziness, nausea, irritated eyes and nose), they will be removed from the project site to fresh air. If the symptoms persist, the individual will be taken to the base clinic.

8.0 EXPOSURE MONITORING PLAN

Volatile organic hydrocarbon (VOC) emissions will be monitored in the breathing zone using a field calibrated organic vapor monitor (e.g., OVA, HNU). A total organic VOC emissions action level of 50 ppm will be set. If VOCs exceed 50 ppm above background for 5 minutes, work will be interrupted until the VOC level returns to near background concentrations.

9.0 PERSONNEL PROTECTIVE EQUIPMENT

Based on the risk assessment that exposure to vapor concentrations of hydrocarbons during project activities will be below applicable exposure threshold limit values, all persons entering the work site shall wear level D personnel protective equipment. Level D equipment includes the following:

- Coveralls
- Steel-toed boots
- Gloves
- Safety glasses or goggles

In addition, level C equipment shall be available in the event that upgrading of the protection level is required. This equipment will include level D equipment plus the following:

- Disposable outer coveralls
- Chemical-protective gloves and boots
- Negative-pressure, NIOSH-approved cartridge respirators

Level C personnel protective equipment will be donned if the site Health and Safety Officer or designate deems it necessary.

10.0 GENERAL SAFETY

10.1 Housekeeping

The housekeeping procedures described below relate to uncontaminated trash, debris, and rubbish. The following housekeeping rules will apply at the jobsite.

- Work areas must be kept clean and free from trash and debris. Trash containers must be located throughout the jobsite.
- Excess scrap material and rubbish must be removed from the work area.
- All surplus materials must be returned to a designated area of the site at the completion of a job.
- Tools and materials must be put in toolboxes or returned to the toolboxes after use to avoid creation of a hazard for others.
- Oily rags must be placed in approved noncombustible metal containers.
- Personnel Protective Equipment (PPE) will be returned to the designated area at the end of the work period and will be placed in designated receptacles.

10.2 Work Practices

The following work practices will be followed by all site workers or visitors.

- Whenever possible, workers will remain upwind of all activities that are expected to result in the potential release of airborne contaminants. These include soil boring and sampling activities.

- No eating, drinking, chewing of gum or tobacco, or smoking will be permitted in the work area. These activities will be confined to designated break areas.

- Any skin contact with contaminated or potentially contaminated surfaces, samples, or equipment shall be avoided.

- Removing materials from protective clothing or equipment by blowing, shaking, or any other means that could disperse contaminated materials is prohibited.

- The hands and face shall be thoroughly washed upon leaving the work area or engaging in any other activities.

- Whenever decontamination procedures for outer garments are in effect, the entire body should be thoroughly washed as soon as possible after the protective garment is removed.

- Because medicine can exaggerate the effects of exposure to toxic chemicals, prescribed drugs should be carefully administered.

- Personnel and equipment in the contaminated area should be limited to the numbers consistent with effective operations.

- Procedures for leaving a contaminated area must be explained before going to the site. Work areas and decontamination procedures must be observed on the basis of prevailing site conditions.

- In addition, all applicable AFB standard procedures will be followed.

10.3 Fire Prevention and Protection

10.3.1 Fire Protection

The following rules will be enforced to prevent fires:

- Smoking will be prohibited at, or in the vicinity of, operations that may present a fire hazard. “No Smoking Open Flame” markings will be conspicuously posted.

- Flammable and/or combustible liquids must be handled only in approved, properly labeled metal safety cans equipped with flash arresters and self-closing lids.

- Transfer of flammable liquids from one container to another will be done only when the containers are electrically interconnected (bonded).

- The motors of all equipment being fueled will be shut off during the fueling operations.

- Flammable/combustible liquids stored in metal drums will be equipped with self-closing safety faucets, vent bung fittings, and drip pans. Such containers will be stored outside buildings in an area approved by the site supervisor and the plant Fire Marshall whenever working within an operating facility. Such metal drums will be properly grounded.

10.3.2 Fire Protection

The following measures will be used to protect against fires:

- All construction equipment (cranes, bulldozers, drilling rigs, etc.) will be eqipped with a fire extinguisher of 10 ABC units or higher.

- All vehicles will be equipped with a fire extinguisher of 5 ABC units or higher.

- Temporary offices will be equipped with a fire extinguisher of 10 ABC units or higher.

- At least one portable fire extinguisher of 20 ABC units will be located not less than 25 ft or more than 75 ft from any flammable liquid storage area.

10.4 Heat Stress

One of the most common types of stress for field personnel is heat stress. Current thinking is that heat stress may be the most serious hazard to hazardous waste workers.

10.4.1 Causes and Preventive Measures

Heat stress usually results when protective clothing decreases natural ventilation and cooling of the body. However, it may occur whenever work is being performed at elevated temperatures.
If the body’s physiological processes fail to maintain a normal body temperature because of excessive heat, a number of physical reactions can occur ranging from mild (such as fatigue, irritability, anxiety, and decreased concentration, dexterity, or movement) to fatal. Because heat stress is one of the most common

and potentially serious illnesses that hazardous waste site workers encounter, regular monitoring and other preventive measures are vital. Site workers must learn to recognize and treat the various forms of heat stress.

At all sites, the following procedures shall be followed.

- Suggest workers drink 16 ounces of water before beginning work, such as in the morning or after lunch. Provide disposable 4-ounce cups and water. Urge workers to drink 1 to 2 gallons of water per day. Provide a cool, preferably air-conditioned area for rest breaks. Discourage the use of alcohol in nonworking hours and discourage the intake of coffee during working hours. Monitor for signs of heat stress. An individual who has high blood pressure must be monitored more often and take precautions such as drinking more water.

- Acclimate workers to site work conditions by increasing workloads slowly. That is, do not begin site work activities with extremely demanding activities.

- Provide cooling devices to aid natural body ventilation. However, these devices add weight, and their use should be balanced against worker efficiency. An example of a cooling aid is long cotton underwear which acts as a wick to help absorb moisture and protect the skin from direct contact with heat-absorbing protective clothing.

- Install showers and/or hose-down facilities to reduce body temperature and cool protective clothing.

- Ensure that adequate shelter is available to protect personnel against heat, as well as cold, rain, snow, etc., which can decrease physical efficiency and increase the probability of both heat and cold stress. If possible, set up the command post in the shade.

- Maintain good hygienic standards by frequently changing clothing and showering. Clothing should be permitted to dry during rest periods. Workers who notice skin problems should immediately consult the site supervisor.

10.4.2 Heatstroke

Heatstroke is an acute and dangerous reaction to heat stress caused by a failure of the heat-regulating mechanisms of the body. The individual's temperature control system that causes sweating stops working correctly. Body temperature rises so high that brain damage and death will result if the person is not cooled quickly.

- Symptoms: Red, hot, dry skin, although person may have been sweating earlier; nausea; dizziness; confusion; extremely high body temperature; rapid respiratory and pulse rate; unconsciousness or coma.

- Treatment: Remove the person to a cool, air-conditioned place, loosen clothing, place in a head-low position, and provide bed rest. Consult physician, especially in severe cases. Because the normal thirst mechanism is not sensitive enough to ensure body fluid replacement, have the patient drink 1 to 2 cups of water immediately and every 20 minutes thereafter until symptoms subside. Total water consumption should be about 1 to 2 gallons per day in high heat stress environments.

10.4.3 Heat Exhaustion

Heat exhaustion is characterized by fatigue, weakness, and collapse due to intake of water inadequate to compensate for loss of fluids through sweating. The symptoms of and treatment for heat exhaustion described in the following paragraphs.

- Symptoms: Approximately normal body temperature; pale and clammy skin; profuse perspiration; tiredness, weakness; headache, perhaps cramps; nausea, dizziness, possible vomiting; possible fainting, but the victim probably will regain consciousness as the head is lowered.

- Treatment: Give the victim sips of salt water (1 teaspoonful of salt per glass, half a glass every 15 minutes), over a period of about 1 hour; have the victim lie down and raise the feet 8 to 12 inches; loosen the victim's clothing; apply cool, wet cloths and fan the victim or remove to an air-conditioned room; if the victim vomits, do not give any more fluids. Take the victim as soon as possible to a hospital, where an intravenous salt solution can be given. After an attack of heat exhaustion, advise the victim not to return to work for several days and see that she/he is protected from exposure to abnormally warm temperatures.

10.4.4 Heat Cramps

Heat cramps are caused by perspiration that is not balanced by adequate fluid intake. Heat cramps are often the first sign of a condition that can lead to heatstroke.

- Symptoms: Acute painful spasms of voluntary muscles, e.g., abdomen and extremities.

- Treatment: Remove victim to a cool area and loosen clothing. Have patient drink 1 to 2 cups of water immediately, and every 20 minutes thereafter, until symptoms subside. Total water consumption should be 1 to 2 gallons per day. Consult with physician.

10.4.5 Heat Rash

Heat rash is caused by continuous exposure to heat and humid air and is aggravated by chafing clothes. The condition decreases the ability to tolerate heat.

- Symptoms: Mild red rash, especially in areas of the body in contact with protective gear.

- Treatment: Decrease amount of time in personnel protective equipment and provide powder to help absorb moisture and decrease chafing.

10.4.6 Heat Stress Monitoring and Work Cycle Management

For strenuous field activities that are part of ongoing work-site activities in hot weather, the following procedures may be used to monitor the body's physiological response to heat and to manage the work cycle. These procedures may be instituted when the temperature exceeds 70°F.

Heart rate (HR) should be measured by the radial pulse for 30 seconds as early as possible in the resting period. The HR at the beginning of the rest period should not exceed 110 beats/minute for most individuals. The maximum rate is based on an individual's base rate. Base rates vary across the population. If the HR is higher, the next work period should be shortened by 33 %, while the length of the rest period stays the same. If the pulse rate still exceeds 110 beats/minute at the beginning of the next rest period, the following work cycle should be further shortened by 33%. The procedure is continued until the rate is maintained below 110 beats/minute.

10.5 Cold Weather Operations

Cold weather conditions can severely affect operations. The program manager and site supervisor must plan work schedules and project tasks accordingly. Weather conditions and forecasts must be watched closely and on-site activities and procedures modified accordingly. On site personnel must be made aware of the hazards of cold weather and of the symptoms and treatment of cold weather injuries. A sufficient number of warm-up breaks must be provided to on-site personnel. Enclosed, heated decontamination facilities may be required. Additional time must be allotted in the morning to check out and warm up field equipment. Additional time must also be allotted at the end of the day to drain hoses and pumps, pack and secure equipment, and plan the next day's activities based on up-to-date weather forecasts.

10.5.1 Preliminary Assessment

If staff will be working outdoors in cold weather, assess the local weather conditions through the news media (radio, television, newspapers) in order to know the amount of preparation needed. Carefully consider such questions as:

- What are the typical wind and weather conditions for the period in which you will be sampling?
- Are the areas in which you will work sheltered or open to the wind?
- Is there a place nearby for periodic warming breaks? Can you obtain or heat warm food and beverages there? Is there a source of drinking water?
- Are there ways to minimize the length of time that crew members will have to work outdoors in the cold?
- If you use a vehicle for a warming area or will use a heater in a closed room, how can you ensure that there is adequate ventilation to prevent carbon monoxide poisoning?

10.5.2 Scheduling

Try to schedule work in the least severe weather. Plan to rotate crew members to keep exposures to cold short. Allow sufficient time for frequent warming breaks. Remember that workers in heavy clothing may need more time to complete tests and may become fatigued more easily. Be aware that you may have to discontinue operations if winds increase or the temperature drops. Remember that winter days are short. Scheduling should allow time for taking care of equipment and supplies before nightfall when it is more difficult to gauge terrain and when temperatures are likely to drop.

10.5.3 Site Access

Snow and ice could make travel on site access roads treacherous or impossible. Personnel should not be allowed to work on site if conditions would severely hamper the arrival or departure of emergency vehicles. An otherwise minor injury could result in a major medical emergency if the route to off-site medical facilities is blocked by snow or ice.

If conditions warrant, the following provisions should be made:

- Snow removal/plowing services for site access roads should be secured.
- A dependable four-wheel drive vehicle should be immediately available on site to transport injured personnel to off-site medical facilities.
- Sleeping bags, blankets, a food supply, and water should be kept on site in the event a sudden storm requires personnel to remain on site overnight.

The site supervisor must decide when weather conditions make site access unsafe and must stop work until conditions improve.

10.5.4 Equipment and Supplies

Obtain equipment and supplies that will help prevent cold stress and that will help in the treatment of cold stress disorders. Take a reliable ambient temperature thermometer, a wind gauge, and a wind-chill chart to the site. If the site is very windy, try to provide a way to shield workers from the wind. If you are working at a distance from stores, carry extra food and water because hunger and dehydration contribute to cold stress. Try to take a means of providing hot food and beverages if one is not available nearby. Provide emergency communication equipment for use between ground crews and those working in the cold, at heights, or in remote locations.

Very close attention must be paid to the effects of cold weather on field equipment. Many types of batteries can be severely affected by cold resulting in disabled radios, air-monitoring equipment, sampling pumps, and vehicles. A supply of fresh batteries, a sufficient number of charging units, and a set of automotive jumper cables should be maintained on site. The electronics in field instruments such as Lower Explosive Limit (LEL) meters or oxygen meters can be adversely affected by the cold. Consult manufacturers' literature for operating ranges.

11.0 SITE CONTROL

The proposed project sites are in active areas of each AFB. Base security personnel control access to the proposed sites, limiting access to the project facilities to persons cleared for access to the area. The control center will be used to house portable equipment and will be locked when authorized personnel are not on site.

An area will be designated for equipment and personnel decontamination. This area will be located between the project field and the control center to limit the spread of any contamination.

12.0 DECONTAMINATION PROCEDURES

All disposable materials (e.g., gloves, paper towels), will be placed in appropriately marked containers (e.g., plastic bags) and disposed of appropriately. Sampling equipment will be decontaminated with a laboratory-grade detergent solution followed by a distilled water rinse. Decontamination activities will be conducted in a designated area. Wastewater will be handled in accordance with Air Force procedures.

13.0 WASTE DISPOSAL

Liquid and solid wastes could be generated as a result of environmental project activities. It is anticipated that the only regulated substances encountered during project activities will be petroleum constituents of the contaminants at each site. All generated wastes will be disposed of in accordance with base policy.

14.0 EMERGENCY PROCEDURES

There are three primary scenarios for emergencies occurring during project activities:

- Personal injury requiring medical treatment
- An uncontrolled release of a dangerous substance (e.g., petroleum spill)
- A fire or explosion

In the event of any emergency, the base Environmental Director will be notified immediately. Emergency information (phone numbers, emergency care facility, etc.) will be filled in on the attached Emergency Information Form (Figure A-1).

EMERGENCY INFORMATION

The following emergency information will be obtained by the Site Health and Safety Officer prior to beginning operations:

Emergency Contacts

Hospital Emergency Room: ____________________ ____________________

Point of Contact: ____________________ ____________________

Fire Department: ____________________ ____________________

Emergency Unit (Ambulance): ____________________ ____________________

Security: ____________________ ____________________

Explosives Unit: ____________________ ____________________

Community Emergency Response Coordinator: ____________________ ____________________

Other: ____________________ ____________________

Program Contacts

Air Force: ____

Battelle: ____

Other: ____

Emergency Routes

Hospital (maps attached): ____

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Other: ____

Figure A-1. Emergency Information Form