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**ADDENDUM ONE TO TEST PLAN AND  
TECHNICAL PROTOCOL FOR A FIELD  
TREATABILITY TEST FOR BIOVENTING-**

**USING SOIL GAS SURVEYS TO  
DETERMINE BIOVENTING FEASIBILITY  
AND NATURAL ATTENUATION POTENTIAL**

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**ENVIRONMENTAL SERVICES OFFICE  
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by

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## 1.0 BACKGROUND

### 1.1 Overview

The objective of this addendum is to provide the reader with a working knowledge of how soil gas can be used as an indicator of subsurface hydrocarbon contamination and how bioventing feasibility can be determined using soil gas monitoring techniques. This addendum expands on soil gas discussions in the *Test Plan and Technical Protocol for a Field Treatability Test for Bioventing* (Hinchee *et al.*, 1992), or "Bioventing Protocol", and is intended to supplement that primary document. This addendum has been organized into five sections including this background section. Section 2.0 describes the mechanical aspects of soil gas monitoring, the use of soil gas probes, and construction of more permanent monitoring points. Section 3.0 explains how soil gas data are interpreted to indicate bioventing feasibility, and Section 4.0 describes how soil gas data can be used to design pilot- or full-scale bioventing systems. Section 5.0 lists the references cited in this addendum.

### 1.2 Soil Gas Chemistry

The chemical composition of soil gas can vary considerably from atmospheric composition as a result of biological and mineral reactions in the soil. Although numerous compounds and elements may be present in soil gas as a result of specific soil and bedrock geochemistry, three indicators are of particular interest in the bioventing context: oxygen, carbon dioxide, and hydrocarbon vapors. The soil gas concentrations of these indicators in relation to atmospheric air and uncontaminated background soils can provide valuable information on the ongoing natural biodegradation of hydrocarbon contaminants and the potential for bioventing to enhance the rate of natural biodegradation.

As described in the Bioventing Protocol, oxygen serves as a primary electron acceptor for soil microorganisms employed in the degradation of both refined and natural hydrocarbons. Following a hydrocarbon spill, soil microorganisms begin to use available soil gas oxygen. As the population of fuel-degrading microorganisms increases, the supply of soil gas oxygen is often depleted, creating an anaerobic volume of contaminated soil. Under anaerobic conditions, fuel biodegradation generally proceeds at significantly slower rates. In some cases, aerobic biodegradation will continue because the diffusion or advection of oxygen into soils from the atmosphere exceeds biological oxygen utilization rates. Under these circumstances the site is naturally aerated, and the hydrocarbons will be naturally attenuated over time.

Carbon dioxide is produced as a by-product of the complete biodegradation of natural or refined hydrocarbons, and can also be produced or buffered by the soil carbonate cycle (Ong *et al.*, 1991). Carbon dioxide levels in soil gas are generally elevated in fuel-contaminated soils when compared to levels in clean background soils. However, due to the buffering capacity of alkaline soils, the relationship between contaminant biodegradation and carbon dioxide production is not always a reliable indicator. In acidic soils, such as exist at Tyndall Air Force Base (AFB), Florida, carbon dioxide production was directly proportional to oxygen utilization (Miller and Hinchee, 1990).

Volatile hydrocarbons found in soil gas can also provide valuable information on the extent and magnitude of subsurface contamination. Fuels such as gasoline, which contain a significant fraction of C<sub>6</sub> and lighter compounds, are easily detected using soil gas monitoring techniques. Heavier fuels, such as diesel, contain fewer volatiles and are more difficult to locate based on volatile hydrocarbon monitoring. Methane is frequently produced as a by-product of anaerobic biodegradation and, like oxygen depletion, can also be used to locate the most contaminated soils at a site. Extensive literature is available on soil gas survey techniques for using volatile hydrocarbons as indicators of contamination (Rivett and Cherry, 1991). Section 3.0 explains how soil gas hydrocarbons can be used to better delineate potential bioventing sites.

### 1.3 Advantages and Limitations

The use of soil gas to determine bioventing feasibility and bioventing progress has several economic and technical advantages over more traditional drilling and soil sampling techniques. In shallow (<20 feet), predominantly sand soils, the labor and equipment cost for a two-person soil gas survey team is approximately one-third the cost of a three-person conventional drilling and sampling team. Many new hydraulically driven, multi-purpose probes can be used for soil gas sampling, as well as for collecting soil and groundwater samples at depth. These probes can be advanced as quickly as conventional augers and do not produce drill cuttings which require expensive analysis and disposal.

An additional advantage of soil gas sampling is that a properly collected gas sample can represent the average chemistry of several cubic feet of soil as compared to a discrete soil sample, which can only describe a few cubic inches of the subsurface. This advantage is of particular importance in risk-based remediation projects where the degree of benzene removal can most accurately be determined by using multiple soil gas sampling locations.

Soil gas techniques have several limitations which must be acknowledged if this approach is to be properly applied. Soil gas monitoring is often impossible in very moist soils and particularly in fined-grained units. Attempts to gather soil gas samples from low-permeability soils often result in the leakage of atmospheric air into the sampling system and inaccurate sampling results.

Although hydraulically driven probes such as cone penetrometers are extending the depth of application, deep contamination and contamination in tight or cobble soils can best be assessed by using standard drilling techniques to install permanent soil gas monitoring points.

Once installed, the spatial orientation of soil gas points in relation to actual fuel-contaminated soil can provide false-positive or false-negative readings, particularly when volatile hydrocarbons are the only analyte. Soil heterogeneities such as clay layers can prevent migration of volatiles from deeper contaminated intervals to shallow soil gas points. Conversely, volatile hydrocarbons can diffuse great distances through very permeable soils, creating volatile soil contamination far from the source area. Because degradation of volatile hydrocarbons exerts a significant oxygen demand in subsurface soils, bioventing wells may be mistakenly sited in soils which actually contain very little adsorbed or free-phase hydrocarbons.

## 2.0 SOIL GAS INVESTIGATION METHODS

### 2.1 Introduction

This section describes the test equipment and methods that are required to conduct field soil gas surveys, to monitor soil gas for bioventing systems, and to install temporary and permanent soil gas monitoring points. The procedures and equipment described in this section are intended as guidelines. Because of widely varying site conditions, site-specific applications will be required. In some states, soil gas surveys and permanent monitoring points must comply with well installation regulations.

### 2.2 Soil Gas Surveys

Whenever possible, soil gas surveys should be conducted at potential bioventing sites prior to locating the pilot test vent well(s) and monitoring points. The objective of the soil gas survey is to determine the areal extent and, in the case of shallow contamination, the vertical extent of soil contamination. These data are used to locate the vent well and soil gas monitoring points (MPs), and to determine the optimum depths of screened intervals. Additionally, the survey is used to determine if bioventing is required based on whether or not anaerobic soil gas conditions exist. If sufficient oxygen ( $O_2$ ) is naturally available and distributed throughout the subsurface, bioventing may not be required to enhance fuel biodegradation rates.

#### 2.2.1 Location of Soil Gas Points

The soil gas survey points should be arranged in a grid pattern centered on the known or suspected contaminated area. The soil gas probes are positioned at each grid intersection, and the survey begins near the center of the grid and progress outward to the limits of significant detectable soil contamination. In many cases, soil gas measurements should be taken at a number of depths at each location to determine the vertical distribution of contamination and oxygen supply. At shallow sites, a soil gas sampling grid should be completed with samples collected from multiple depths if the contaminated interval exceeds 3 feet or if contamination is suspected in different soil types.

#### 2.2.2 Soil Gas Probes and Installation Techniques

Soil gas sampling is conducted using small-diameter [approximately 5/8- to 1-inch outside-diameter (OD)] steel probes. The typical probe consists of a drive point with a retractable, perforated tip that is threaded onto a series of drive rod extensions (Figure 2.1).

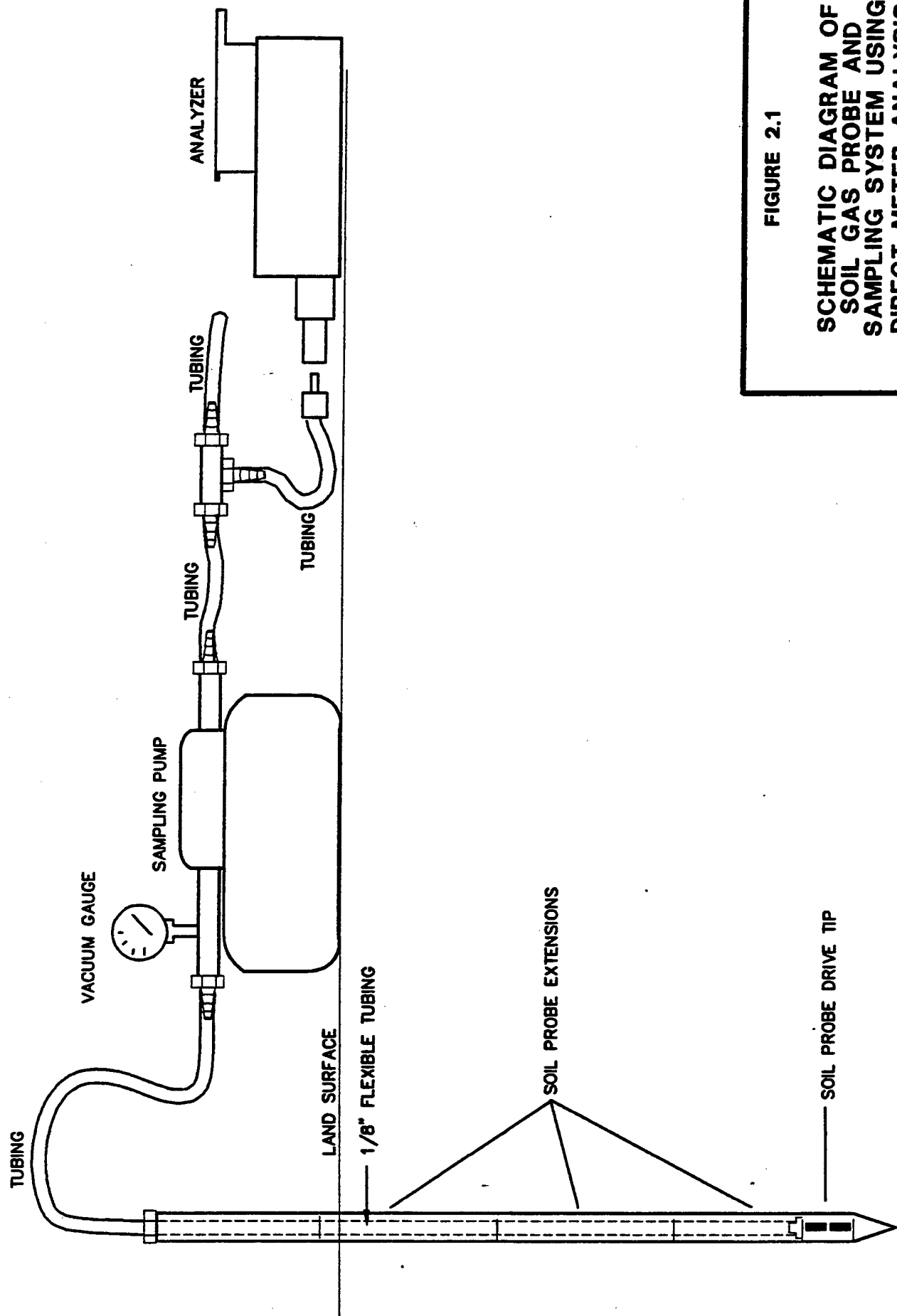


FIGURE 2.1

SCHEMATIC DIAGRAM OF  
SOIL GAS PROBE AND  
SAMPLING SYSTEM USING  
DIRECT METER ANALYSIS

The soil probe is fitted with a replaceable stainless steel screen to prevent fine-grained soils from clogging the perforations. Before use, 1/8-inch-diameter flexible tubing is connected to the soil probe and passed through the center of the drive rods. The 1/8-inch tubing, which is used to collect soil gas samples, extends from the soil probe to the purge pump or sampling device at the surface. This probe design greatly reduces the chance of vacuum leaks and is a standard feature on AMS® or equivalent soil gas sampling systems.

The method of probe installation will be dictated by soil conditions and depth of contamination. A digging permit from the host Air Force base and utility clearances from the local utility companies should be obtained prior to probe installation. Temporary probes are installed using either a hand-driven electric hammer or a hydraulic ram. The maximum depth for hammer-driven probes is typically 10 to 15 feet, depending on soil texture. Hydraulic rams are capable of driving the probes over 30 feet in a variety of soil conditions.

At sites with deeper contamination, where soil texture precludes the use of a hammer or hydraulic ram or where a permanent monitoring system is required, permanent soil gas MPs may be installed using either a portable or truck-mounted drill rig. Permanent MPs are discussed in the following section.

## **2.3 Permanent Monitoring Points**

Permanent, multi-depth soil gas MPs are typically used for monitoring pressure and soil gas near the vent well in pilot or full-scale bioventing systems. MPs are generally installed at a minimum of three locations near the vent well. The total number of monitoring locations and depth intervals will vary depending on site conditions. The location and installation of MPs are briefly described in this section. Additional discussion related to these topics is included in Section 4.0 of the Bioventing Protocol.

### **2.3.1 Location of Monitoring Points**

To the extent possible, the MPs should be located in heavily contaminated soil. The MPs are generally installed in a straight line, with the radial distances from the vent well determined based on soil type and depth of contamination. Typical MP spacings for different site conditions are listed in Table 4.1 of the Bioventing Protocol.

### **2.3.2 Monitoring Point Construction**

A typical multi-depth soil gas MP is shown in Figure 2.2. Soil gas should be monitored at discrete depths determined based on the soil stratigraphy and the contamination profile at each site. At deeper sites, permanent MPs should be completed at 10-foot intervals

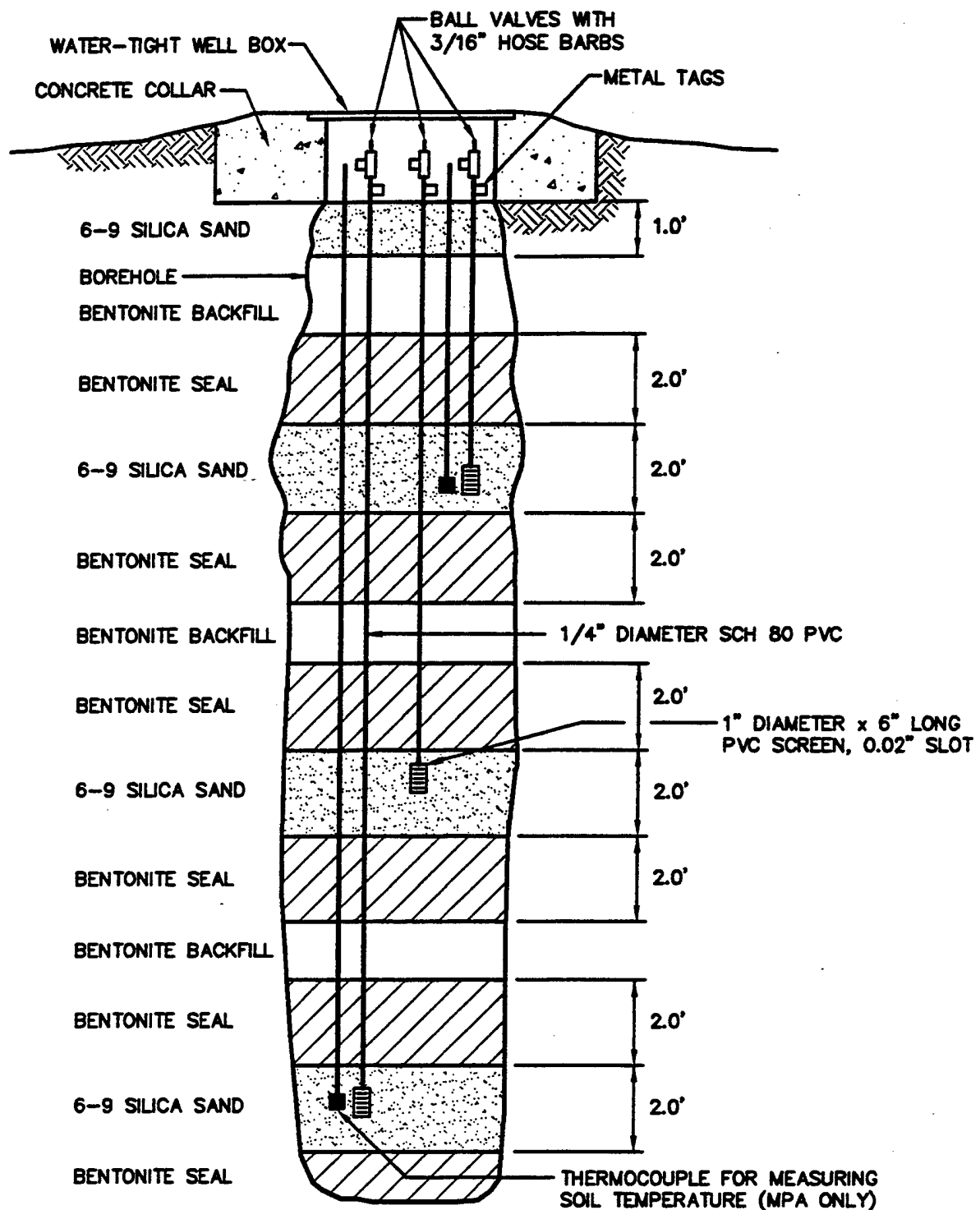


FIGURE 2.2

TYPICAL MONITORING POINT  
CONSTRUCTION DETAIL

or in the middle of strata where oxygen transfer will be most limited by lower soil gas permeability. Soil temperature can be monitored using either J- or K-type thermocouples installed at the same depths as the deepest and shallowest vapor probes. Depending on soil conditions, MPs should be constructed either through hollow-stem augers or, in cohesive soils, in the open borehole.

Each MP can be constructed with multiple vapor probes placed within sand intervals and separated by bentonite seals. Vapor probes, constructed of 6-inch-long sections of 1-inch-diameter polyvinyl chloride (PVC) well screen, are placed within a 2-foot-thick layer of coarse-grained silica sand. One-quarter-inch-diameter PVC risers extend from each vapor probe to the surface. The annular spaces between the MP sand intervals are sealed with bentonite to isolate the monitoring intervals. The top of each riser is fitted with a ball valve and hose barb, and labeled to indicate the MP location and vapor probe depth. Additional details on MP construction is presented in Section 4.0 of the Bioventing Protocol.

## 2.4 Field Instrumentation and Measurements

Sections 2.4.1 through 2.4.4 discuss the equipment used for soil gas measurements. Additional discussion of this topic is included in Section 4.5 of the Bioventing Protocol.

### 2.4.1 Oxygen and Carbon Dioxide

Gaseous concentrations of carbon dioxide ( $\text{CO}_2$ ) and  $\text{O}_2$  can be analyzed using an  $\text{O}_2/\text{CO}_2$  analyzer. The analyzer will generally have an internal battery-powered sampling pump and range settings of 0 to 25 percent for both  $\text{O}_2$  and  $\text{CO}_2$ . Prior to taking measurements, the analyzer should be checked for battery charge level and should be calibrated daily using atmospheric concentrations of  $\text{O}_2$  and  $\text{CO}_2$  (20.9 and 0.05 percent, respectively) and a gas standard containing 0.0 percent  $\text{O}_2$  and 5.0 percent  $\text{CO}_2$ .

### 2.4.2 Volatile Hydrocarbon Concentration

Total volatile hydrocarbon (TVH) concentrations can be analyzed using a variety of hydrocarbon analyzers. The analyzer must be capable of measuring hydrocarbon concentrations in the range of 1 to 10,000 parts per million, volume per volume (ppmv) and be capable of distinguishing between methane and non-methane hydrocarbons. Although flame ionization detectors are the most accurate instruments for fuel hydrocarbons, platinum catalyst detectors are also acceptable and are easier to use in the field. Photoionization detectors are not recommended for the high levels of volatile hydrocarbons found at many sites. Prior to

taking measurements, the battery charge level should be checked and the analyzer should be calibrated against a hexane calibration gas to ensure proper operation.

The analyzer should also have a selector switch to change the response to eliminate the contribution of methane gas to the TVH readings. Methane gas is a common constituent of anaerobic soil gas and is generated by degrading manmade or natural hydrocarbons. Methane is commonly produced in swampy areas or in fill areas containing organic material. If the methane is not excluded from the TVH measurement, TVH results may indicate erroneously high levels of petroleum hydrocarbon contamination in the soil. The methane content can also be estimated by placing a large carbon trap in front of the hydrocarbon analyzer. Heavier hydrocarbons will be retained by the carbon while methane passes through to the detector.

#### 2.4.3 Sampling Pumps

Electric sampling pumps are used both to purge and collect samples from MPs and soil gas probes. The pumps should be either oilless rotary-vane or diaphragm pumps capable of delivering approximately 1 cubic foot per minute (cfm) of air at a maximum vacuum of 270 inches of water. The pumps have oilless filters to eliminate particulates from the air stream.

#### 2.4.4 Differential Vacuum Gauges

Differential vacuum gauges are used to monitor the vacuum in the sampling point during purging and to estimate the permeability of soil to air flow. Typical vacuum ranges of the gauges are 0 to 50 and 0 to 250 inches of water for sites with sandy and clayey soils, respectively.

### 2.5 Soil Gas Sampling Procedures

The following soil gas sampling methods are recommended for extracting and analyzing soil gas samples from either temporary soil gas probes or permanent MPs. Proper sampling procedures will ensure that representative soil gas samples are collected from the subsurface.

#### 2.5.1 Purging

Purging the soil gas probe or MP is a prerequisite for obtaining representative soil gas samples. A typical purging system (Figure 2.1) will consist of a 1-cfm sampling pump, a vacuum gauge, and an O<sub>2</sub>/CO<sub>2</sub> meter. The vacuum side of the pump is connected to

the soil gas probe or MP. A vacuum gauge is attached to a tee in the vacuum side of the system to monitor the vacuum produced during purging, and the O<sub>2</sub>/CO<sub>2</sub> analyzer is connected to a tee in the outlet tubing to monitor O<sub>2</sub>/CO<sub>2</sub> concentrations in the extracted soil gas. The magnitude of vacuum measured during purging is inversely proportional to soil permeability and will determine the method of sample collection.

After the purging system is attached to the soil gas probe or MP, the valve or hose clamp is opened and the pump is turned on. Purging is continued until O<sub>2</sub> and CO<sub>2</sub> concentrations stabilize, indicating that purging is complete. Before turning off the pump, the hose clamp or MP valve is closed to prevent fresh air from being drawn into the soil gas probe or MP.

#### 2.5.2 Soil Gas Sampling - High-Permeability Soils

Sampling methods for high-permeability soils (sand and silt) should be followed if the vacuum measured during purging is less than 10 inches of water. Soil gas sampling and analysis is performed using the same equipment used for purging, minus the vacuum gauge. After opening the sampling point valve or hose clamp, the sampling pump is turned on, and the extracted soil gas is analyzed for stable O<sub>2</sub>/CO<sub>2</sub> and TVH concentrations.

#### 2.5.3 Soil Gas Sampling - Low-Permeability Soils

A different sampling procedure should be followed to collect soil gas samples from low-permeability soils. The higher vacuums required for sampling increase the risk of vacuum leaks introducing fresh air and diluting the soil gas sample.

After purging the sampling point, a soil gas sample is collected in a Tedlar® bag prior to analysis. The evacuated Tedlar® bag should be placed inside a desiccator modified for soil gas sample collection. The desiccator is then connected to the sampling point via a hose barb that passes through the desiccator wall. The desiccator is then closed, sealed, and connected to the pump inlet with flexible tubing. The sampling system is shown in Figure 2.3. To collect the sample, the MP valve is opened, the pump is turned on, and the pressure relief port on the desiccator is sealed using either a valve or the sampler's finger. The partial vacuum within the desiccator created by the pump will draw soil gas into the Tedlar® bag. When the Tedlar® bag is nearly filled, the sampling point valve or hose clamp is closed, and the pump is turned off. The desiccator is then opened, the Tedlar® bag valve is closed, and the bag is removed from the desiccator. The soil gas sample is then analyzed by attaching the O<sub>2</sub>/CO<sub>2</sub> and TVH analyzers directly to the Tedlar® bag.

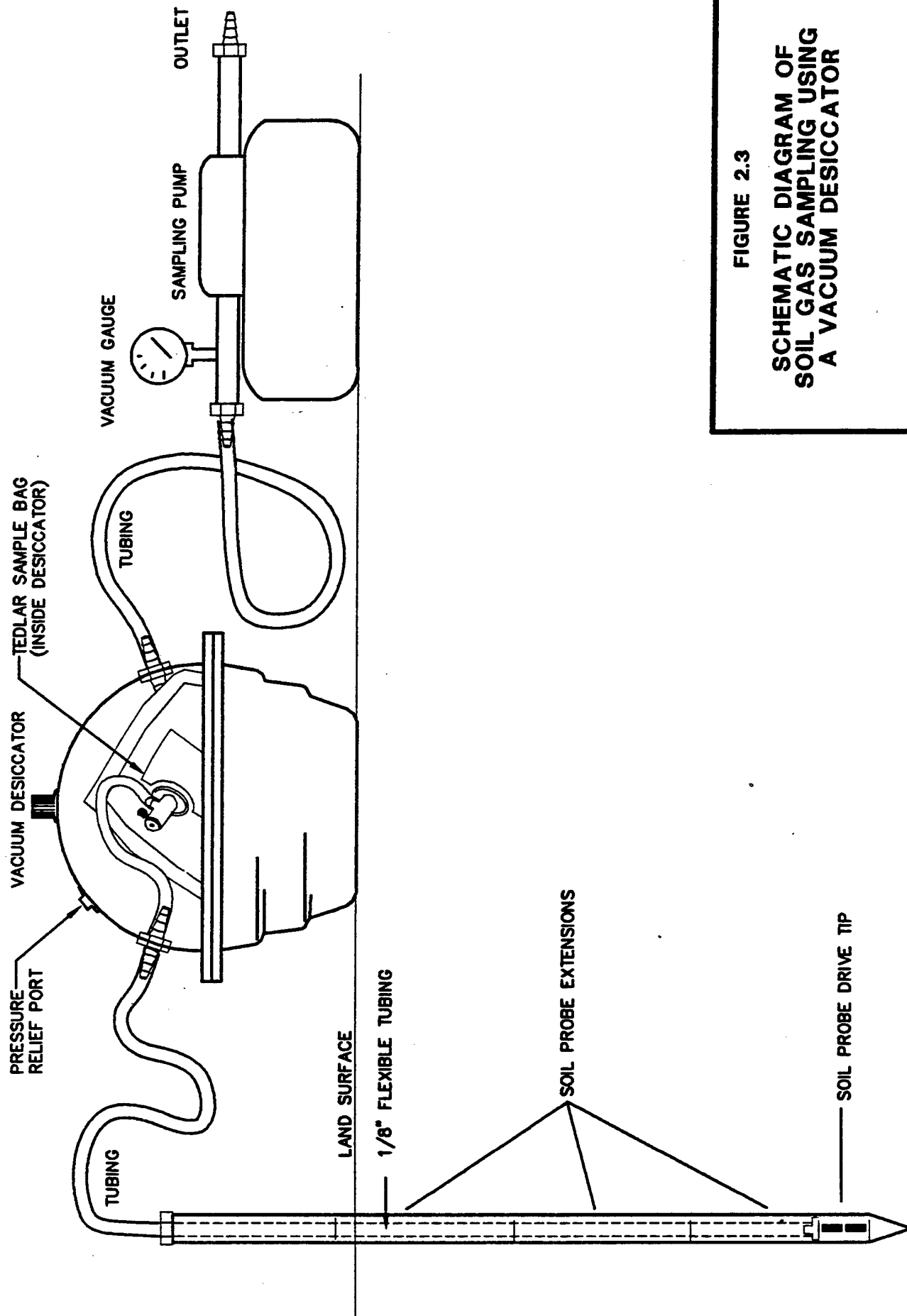


FIGURE 2.3  
SCHEMATIC DIAGRAM OF  
SOIL GAS SAMPLING USING  
A VACUUM DESICCATOR

#### 2.5.4 Troubleshooting Common Problems

Most problems encountered during soil gas sampling and purging can be divided into three categories: 1) difficulty extracting soil gas from the sampling point, 2) water being drawn from the sampling point, and 3) high oxygen readings in areas of known soil contamination. Some of the more common problems and solutions are discussed in this section.

Difficulty extracting soil gas from a sampling point is typically caused by low-permeability (clayey and/or nearly saturated) soils. Collecting soil gas samples from low-permeability soils is facilitated by allowing the vacuum in the sampling point to equilibrate after purging and allowing additional time for the Tedlar® bag to fill with soil gas during sampling. After purging, the valve or hose clamp at the sampling point is closed until the vacuum in the point, induced by purging, equilibrates with the atmospheric pressure. Sampling is then performed as described in Section 2.5.3, but the vacuum should be applied to the desiccator for an extended period of time to collect a sufficient volume of soil gas for analysis.

Difficulty extracting soil gas from a soil gas probe can also be caused by the screen being fouled by fine-grained soil or heavy petroleum residuals. The probe should be removed from the soil, and the screen should be either cleaned or replaced if visibly fouled.

Water being drawn from the sampling point by the purge pump may be the result either of the point being installed in the saturated zone or, in the case of permanent MPs, the filter pack being saturated with water during construction. In the former case, a temporary probe can be pulled up to a shallower depth above the saturated zone and resampled. With a permanent MP installed within the saturated zone, sampling must be delayed until either the water table drops because of seasonal variations or the water table is artificially depressed by a dewatering operation.

If the screened interval in a permanent MP is installed above the saturated zone but the filter pack was saturated with water during construction, sampling may still be possible if the water is pumped from the MP. This method will only work if the screened interval is at a depth of less than approximately 22 feet, which is the practical limit of suction lift.

High soil gas O<sub>2</sub> readings in areas of known soil contamination may indicate a leak in the sampling or purging system. The potential for leakage, and the resulting dilution of the sample with atmospheric air, is higher in low-permeability soils where higher vacuums are required for purging and sampling. If a leak is suspected, all connections in the sampling

system and the seal around the MP or soil gas probe should be inspected for leaks. Seals around a soil gas probe or MP can be checked for leaks by inspecting for air bubbles while injecting air with a sampling pump after adding water around the probe or MP. Any observed or suspected leaks should be corrected by tightening connections, repositioning the soil gas probe, or attempting to repair the MP seal.

The purpose of gathering soil gas data during bioventing investigations is to locate those areas which are most in need of additional  $O_2$  to enhance fuel biodegradation. If a pilot test is to be completed, the area of lowest  $O_2$  concentrations should first be determined. For full-scale applications, it is useful to determine the entire areal extent and depth of soils which exhibit an  $O_2$  deficit (for practical purposes less than 5 percent  $O_2$ ). Finally, soil gas data is useful for determining which sites are naturally aerated and therefore do not require mechanical bioventing systems. The following soil gas data sets were collected from six actual candidate sites. The first two sites are typical of anaerobic site conditions which definitely warrant the testing and design of mechanical bioventing systems. The next four sites show how soil gas surveys can be used to determine that remaining contaminants could naturally biodegrade without engineered bioventing enhancements.

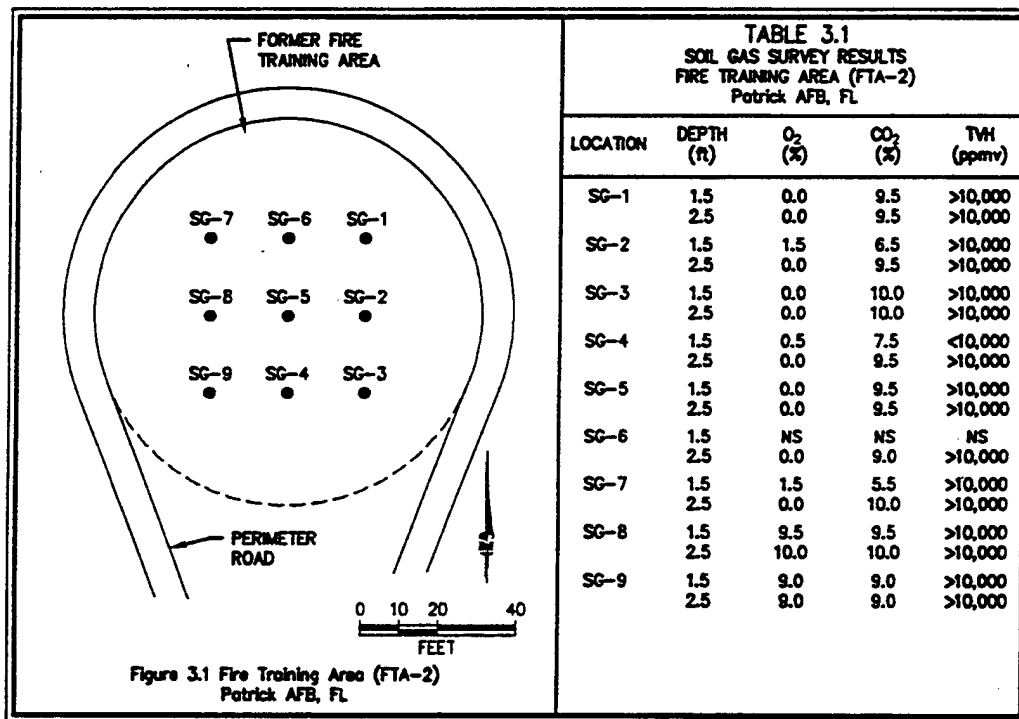
### 3.1

#### Candidate Site 1

**Site Location/History:** Fire Training Area (FTA-2) at Patrick AFB, FL. The site had been used as a fire training facility for 22 years, and soils are visibly contaminated with JP-4 jet fuel and waste oils.

**Soil Type(s):** Sandy soil with shell fragments. Groundwater is approximately 4 feet below the surface.

**Soil Gas Survey:** A soil gas survey was conducted at the nine locations shown in Figure 3.1. An attempt was made to sample soil gas at two depths. Soil gas results are presented in Table 3.1.



**Interpretation:** High TVH levels remain in these soils, indicating that remaining fuels are not highly weathered and contamination is widespread within the bermed area. O<sub>2</sub> at both the 1.5-foot and 2.5-foot sampling depths was completely depleted, indicating that natural diffusion is not meeting the biological oxygen demand of fuel-degrading microorganisms. CO<sub>2</sub> concentrations are also elevated, indicating that this primary biodegradation by-product is also being produced. This is in sharp contrast to background soil gas concentrations in these soils which are at near-atmospheric levels. This site is an excellent candidate for engineered bioventing.

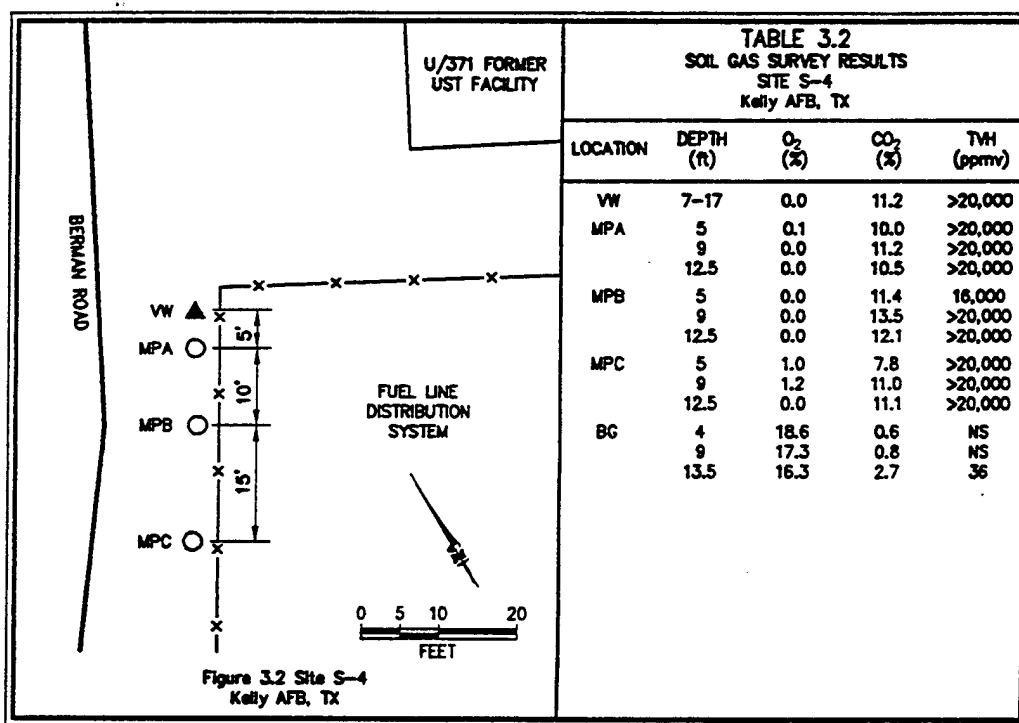
### 3.2

### Candidate Site 2

**Site Location/History:** JP-4 spill, Site Area S-4, Kelly AFB, TX. Free product has been recovered in this area, and a rising and falling water table has smeared contamination over a 6- to 8-foot interval.

**Soil Type(s):** Predominantly gravelly clay, with groundwater at approximately 13 feet below the surface.

**Soil Gas Survey:** Soil sample samples were collected from multi-depth MPs and an air-injection vent well, as shown in Figure 3.2. Soil gas was sampled from three depths at each MP. Soil gas results are presented in Table 3.2.



**Interpretation:** High TVH levels remain in these soils, indicating that remaining fuels are not highly weathered and contamination is widespread within the test area. O<sub>2</sub> levels at most sampling locations and depths were completely depleted, indicating that natural diffusion is not meeting the biological O<sub>2</sub> demand of fuel degrading microorganisms. CO<sub>2</sub> concentrations are also elevated, indicating that this primary biodegradation by-product is also being produced. This is in sharp contrast to background soil gas concentrations in these soils, which are at near-atmospheric levels. This site is an excellent candidate for engineered bioventing.

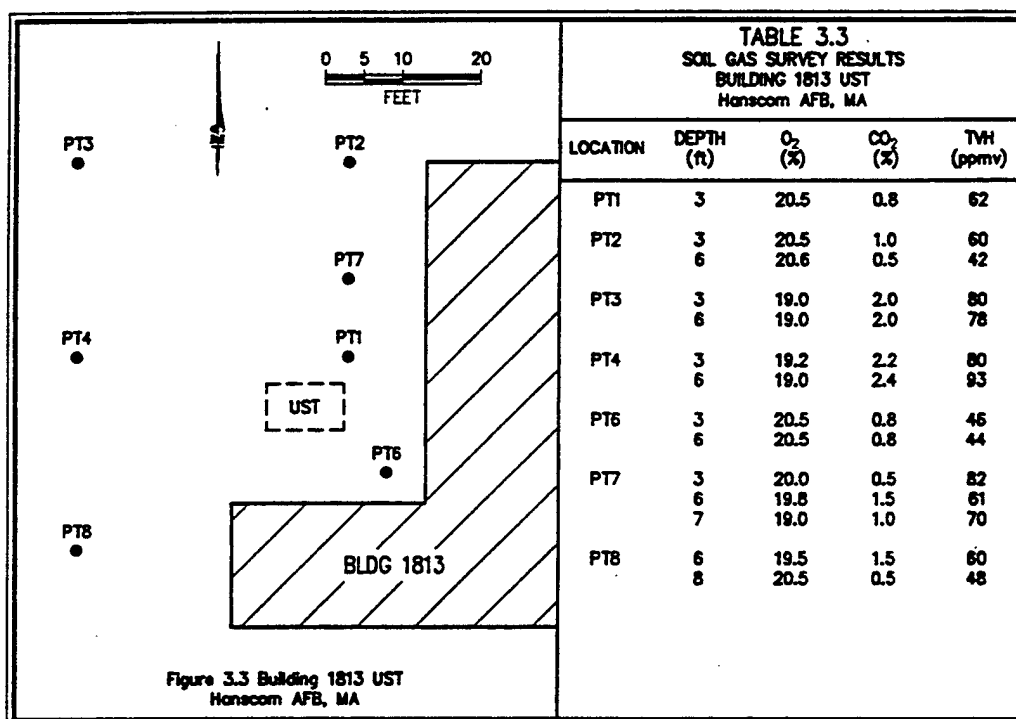
### 3.3

### Candidate Site 3

**Site Location/History:** Building 1813 Underground Storage Tank Leak, Hanscom AFB, MA. Tank containing diesel fuel had leaked. Tank was removed, but an unknown quantity of fuel-contaminated soil remains at the site.

**Soil Type(s):** Sandy soil to groundwater, which occurs at 8 to 9 feet.

**Soil Gas Survey:** A soil gas survey was conducted at the seven locations shown in Figure 3.3 and at multiple depths. Soil gas results are presented in Table 3.3.



**Interpretation:** Low levels of TVH indicate that little diesel-contaminated soil remains at the site or that residual fuels are highly weathered. Near-atmospheric O<sub>2</sub> levels at all depths indicate that remaining hydrocarbons are being biodegraded with oxygen supplied by natural diffusion. CO<sub>2</sub> was found at levels above the atmospheric concentration of 0.03 percent, indicating some biological respiration was occurring. Higher CO<sub>2</sub> levels and slightly depressed O<sub>2</sub> levels at PT3 and PT4 indicate remaining fuel is probably located in this area of the site. Natural aeration appears to be providing sufficient O<sub>2</sub> for biodegradation of remaining fuel residuals.

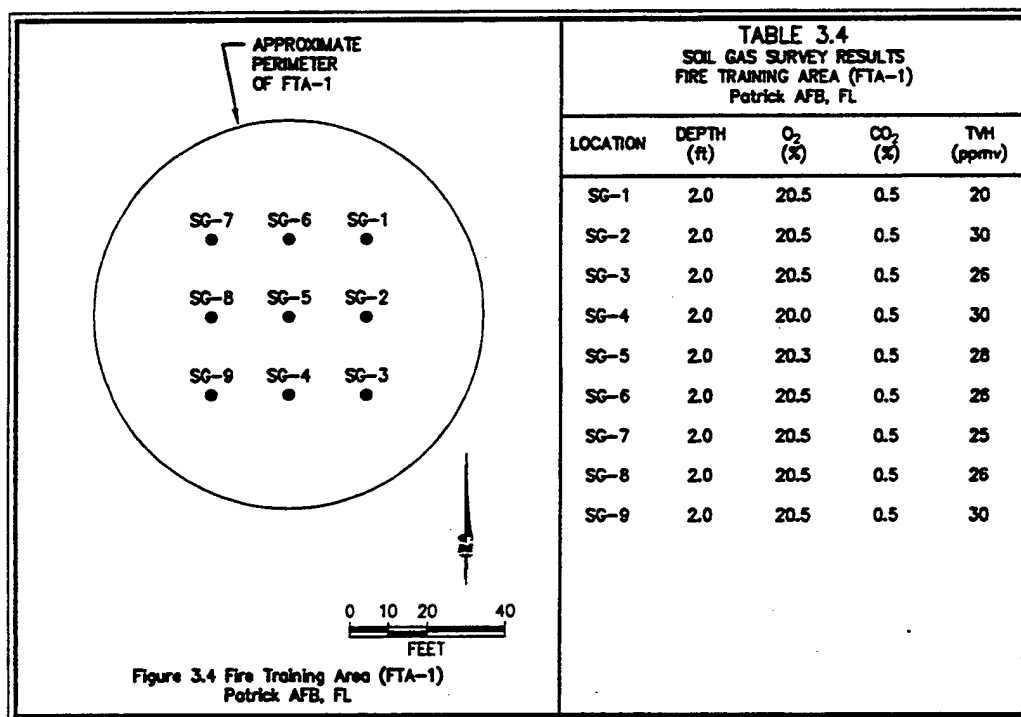
## 3.4

## Candidate Site 4

**Site Location/History:** Fire Training Area (FTA-1), Patrick AFB, FL. Site was thought to have been used as a fire training area. Suspected contaminants are JP-4 and waste oils. Some surface staining is evident.

**Soil Type:** Sand and shell fragments. Groundwater is located approximately 3 feet below the surface.

**Soil Gas Survey:** A soil gas survey consisting of a nine-point grid was completed within the berm, as shown in Figure 3.4. All points were sampled at a depth of 2 feet. Results of the survey are provided in Table 3.4



**Interpretation:** Very low concentrations TVH were detected in the soil gas at this site. Both O<sub>2</sub> and CO<sub>2</sub> were at near-atmospheric levels. This site contains only small quantities of surface contamination which are being biodegraded before they impact groundwater.

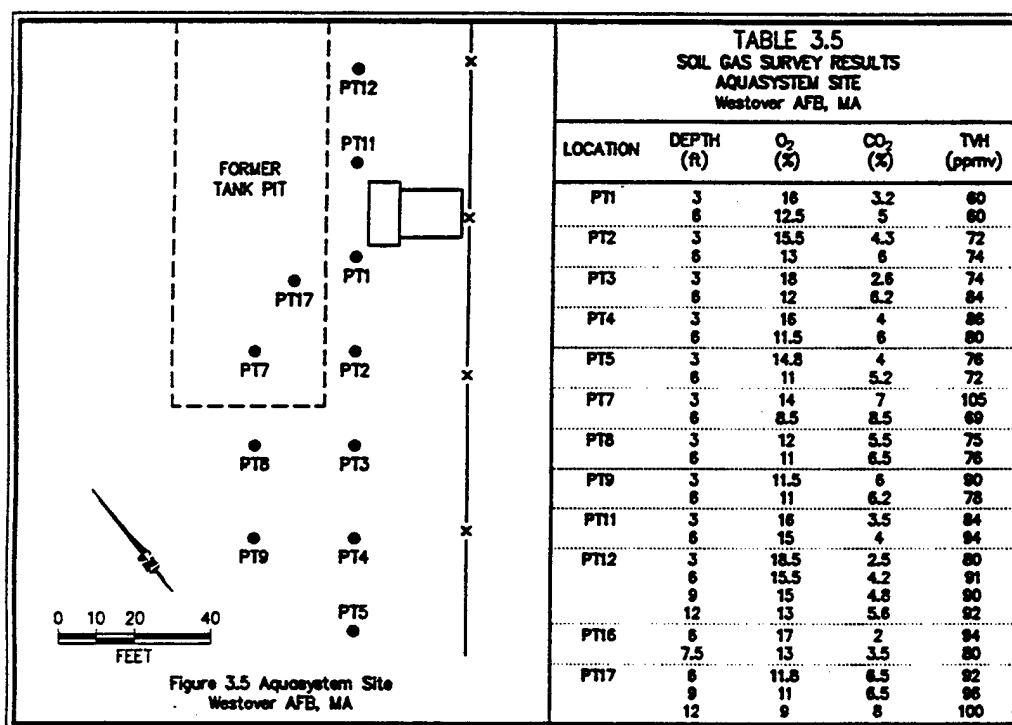
## 3.5

## Candidate Site 5

Site Location/History: Aquasystem Site, Westover AFB, MA. Removal of USTs at this site revealed soil contamination. An unknown quantity of mixed fuels contamination remains in the soil.

Soil Type: Predominantly sand, with groundwater at approximately 13 feet below the surface.

Soil Gas Survey: A soil gas survey consisting of a 12-point grid was completed in and downgradient of the former tank pit, as shown in Figure 3.5. All points were sampled at multiple depths. Results of the survey are provided in Table 3.5



Interpretation: Low levels of TVH were detected in the soil gas at this site. O<sub>2</sub> levels were significantly depleted below atmospheric concentrations in soils near PT7 and PT17, and generally decreased with depth. However the 8 to 9 percent of O<sub>2</sub> available in this area is more than sufficient to sustain *in situ* biodegradation. CO<sub>2</sub> ranged from 2 to 8.5 percent and generally increased with depth. The available data suggest that significant natural biodegradation is occurring at the site. It is possible that more O<sub>2</sub>-depleted soil exists in the capillary fringe, and that engineered bioventing could accelerate biodegradation if this anaerobic zone exists. The decision to biovent this site should be based on other factors, such as the impact and potential risk that soil contamination poses to groundwater.

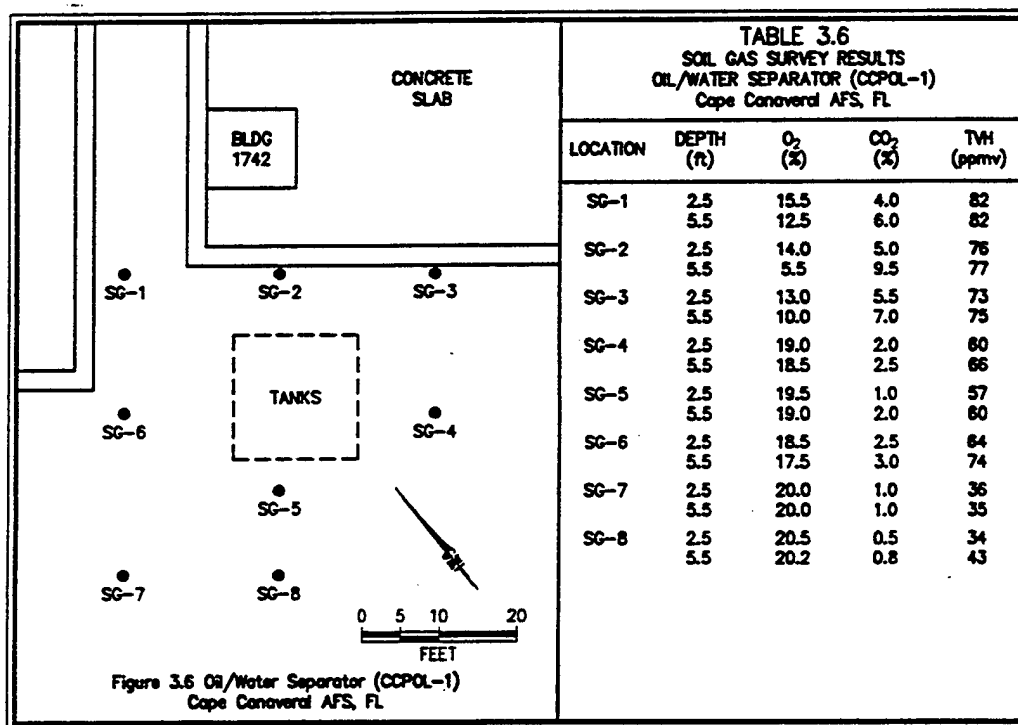
## 3.6

## Candidate Site 6

Site Location/History: Oil/water separator leak (CCPOL-1) located near a diesel transfer station at Cape Canaveral AFS, FL.

Soil Type(s): Sandy soil with shell fragments. Groundwater is approximately 6 feet below the surface.

Soil Gas Survey: A soil gas survey was conducted at the eight locations shown in Figure 3.6. An attempt was made to sample soil gas at two depths. Soil gas results are presented in Table 3.6.



Interpretation: Low levels of TVH indicate that little diesel-contaminated soil remains at the site or it is highly weathered. O<sub>2</sub> levels were significantly depleted near SG-2, and generally decreased with depth in points near the oil/water separator. CO<sub>2</sub> levels are elevated in areas with low O<sub>2</sub>, indicating that *in situ* biodegradation is proceeding in the vicinity of the oil/water separator. It is possible that more O<sub>2</sub>-depleted soil exists in the capillary fringe, and that engineered bioventing could accelerate biodegradation, if this anaerobic zone exists. The decision to biovent this site should be based on other factors, such as the impact and potential risk that soil contamination poses to groundwater. One additional note: it is possible that if the oil/water separator was connected to a sanitary line, the biological oxygen demand could be the result of leaking sewage. An analysis of soil gas for BTEX compounds could help to determine if the O<sub>2</sub> demand is fuel related.

## 4.0

## USING SOIL GAS DATA FOR BIOVENTING DESIGN

In the absence of very complete, multi-depth soil sampling data, a soil gas survey is essential for the efficient placement of air injection vent wells and permanent soil gas MPs. At sites with deep contamination, more expensive exploratory drilling is required to determine the center and areal extent of contamination.

### 4.1 Air Injection Well Design

In most cases, the optimum location for an air injection well is at the center of contaminant mass, with a screened interval extending over the depth interval of soil contamination. The center of contaminant mass can generally be located by completing a soil gas survey grid, as shown in Section 3.0, and locating the volume of soil with the lowest O<sub>2</sub> concentrations and highest levels of volatile hydrocarbons. At sites with shallow groundwater, this often corresponds with the capillary fringe where past or present free-phase product has accumulated. At deeper sites, the highest levels of contamination are often found on top of a low-permeability layer in the vicinity of the suspected spill source. The screened interval of the air injection well should be limited to a depth interval with O<sub>2</sub> levels of less than 5 percent. This will focus air flow through the soils with the greatest O<sub>2</sub> demand, and reduce the volume of air injection. One important exception to this design is when the center of contamination is beneath or adjacent a building or underground utility corridor. If high levels of TVH (> 1,000 ppmv) are found in soil gas, air injection can result in undesirable vapor migration into these structures. Under these circumstances, short-term soil vapor extraction may be required to reduce initial high volatile hydrocarbon concentrations.

### 4.2 Permanent Monitoring Point Design

Permanent soil gas MPs have two primary functions in bioventing applications: measuring the rate of O<sub>2</sub> utilization to determine approximate rates of biodegradation, and monitoring the pressure and movement of soil gases in the treatment area. Because the rate of O<sub>2</sub> utilization is most accurately measured in the most anaerobic soil volume, data from the soil gas survey can be used to place several soil gas points in the most O<sub>2</sub>-depleted soil volume.

For bioventing pilot tests it is also important to locate at least one multi-depth soil gas point at the outer limit of contamination or outer limit of expected O<sub>2</sub> influence from the single air injection well. In a properly completed soil gas grid, the outer limit of contamination can often be estimated both by a noticeable reduction in TVH concentrations

and an increase in O<sub>2</sub> levels. The depth interval of perimeter MPs should be the same as MPs located in contaminated soils to monitor oxygen influence at critical depths.

#### 4.3 Summary

Data on soil gas concentrations of O<sub>2</sub>, CO<sub>2</sub>, and TVH can provide valuable insight into the extent of subsurface contamination and the potential for *in situ* bioventing. The procedures outline in this addendum are intended to assist in the collection and interpretation of soil gas information, with the ultimate goal of promoting a more cost-effective approach to fuel-contaminated soil remediation.

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