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Port Hueneme, California 93043-4301

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BIOPILE OPERATIONS AND MAINTENANCE MANUAL

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ABSTRACT

This Biopile Operations and Maintenance (O&M) Manual was created to support biopile work conducted at U.S. Navy and Marine Corps facilities and is a companion document to the site-specific biopile design and construction report that usually will be prepared upon completion of biopile construction at each site. The generic *Biopile Design and Construction Manual* (TM-2189-ENV), used as a basis for the site-specific design and construction report, provides detailed design guidance for selecting, planning, and building a biopile. The *Biopile Design and Construction Manual* covers both temporary and permanent biopile systems. Because operations and maintenance are similar for both types of units, the information in this O&M Manual is applicable to both temporary and permanent systems. This document details the O&M requirements for full-scale implementation of biopile treatment of petroleum-contaminated soils. The manual provides a general overview of biopile technology and describes biopile system management approaches, sampling and analysis methods, regulatory interactions, and health and safety requirements. The manual serves as a basis to operate, maintain, and close out a biopile treatment system effectively and efficiently.

The scope of this document is to present the operations (e.g., sampling) and maintenance procedures for a biopile. The companion *Biopile Design and Construction Manual* provides detailed procedures for biopile system design and construction.

Section 1.0: INTRODUCTION

1.1 Background and Objectives. A large number of U.S. Department of Defense (DoD) sites reportedly have petroleum- and fuel-contaminated soils and groundwater as a result of leaking underground storage tanks (USTs) and pipelines or other accidental releases. With so many sites requiring remediation at relatively high costs, the Naval Facilities Engineering Service Center (NFESC) has been developing and/or demonstrating more effective and less costly remedial alternatives (e.g., bioventing, bioslurping, biopiles) as compared to the conventional remedial alternatives for sites with such contamination. Following successful demonstration of the applicability of biopiles to reduce the concentration of petroleum constituents in excavated soils through the use of aerobic biodegradation, the NFESC decided to develop a biopile design and construction manual, and an operations and maintenance manual as part of its mission in technology transfer.

The purpose of this manual is to document operations and maintenance (O&M) practices for biopile treatment. The O&M practices described in this manual are based on the full-scale design presented in the *Biopile Design and Construction Manual* (NFESC, 1996, TM-2189-ENV).

1.2 Overview. Biopile treatment involves forming petroleum-contaminated soils into piles or cells above ground and stimulating aerobic microbial activity within the soils by aerating the soils with forced or natural air flow. Microbial activity also can be enhanced by adding moisture and nutrients such as nitrogen or phosphorus. The aerobic microbial activity degrades the petroleum-based constituents adsorbed to soil particles, thus reducing the concentrations of these contaminants. Most biopile systems include the following:

- an impermeable base to reduce the potential migration of leachate from the pile
- perforated drainage pipe installed above the base and connected to a blower to induce air flow through a soil pile constructed over the piping
- a cover or shelter to prevent uncontrolled water addition to the pile by precipitation and wind erosion from the pile
- an off-gas treatment system (optional)
- in-pile monitoring equipment
- a moisture and nutrient addition system (optional)
- a separate leachate collection sump and pump (optional).

Well-organized and scheduled inspection, adjustment, and maintenance of these features must be performed to ensure safe, reliable, efficient, and cost-effective operation of the biopile treatment system. The design features and equipment selection for biopile treatment help to minimize the O&M requirements. Because biopile systems operate at steady state for months, complex control equipment and remotely actuated valves are not required. Use of high-wear items such as electrical contacts and rotating or sliding seals is minimized, and where they are used, cycling occurs infrequently. Also, the types of equipment used have been through several generations of refinement in industrial service and have reached an advanced state of development and reliability. Nevertheless, a well-planned O&M routine is essential to ensure continued reliable operations.

1.3 Scope. This manual is intended to provide technical guidance on the operations and maintenance of biopiles used to remediate soils contaminated with petroleum-based organic contaminants. At the completion of design and construction of a specific biopile, a site-specific design and construction report should be generated. The information in this O&M Manual refers to the site-specific design and construction report, which is expected to contain the type of biopile (temporary vs. permanent), contaminant levels, soil volume, treatability test results (designed moisture and nutrient levels), and equipment and instrumentation used at the specific site. For example, some designs may not include a separate leachate collection system or off-gas treatment system.

This O&M Manual is a companion document to the general *Biopile Design and Construction Manual* (NFESC, 1996), but the two documents are designed as self-contained units for independent use. For presentation clarity and because operations and maintenance are similar for both temporary and permanent biopiles, this manual focuses primarily on the temporary biopile and refers to the permanent biopile where applicable.

The description of biopile operations and maintenance is grouped into six sections as follows:

- An introduction describing the purpose and scope of the manual (Section 1.0)
- A technical description of biopile treatment providing an overview of the basic scientific and engineering principles and practices in biopile treatment (Section 2.0)
- A discussion of the O&M activities involved in biopile system management (Section 3.0)
- A discussion of the sampling and analysis methods used in biopile management (Section 4.0)
- A review of regulatory interactions involved in biopile O&M (Section 5.0)
- An assessment of the sources of hazards and hazard mitigation methods for biopile O&M (Section 6.0).

Activities for O&M of a biopile are concisely described in the text to allow the user quick access to information. Bibliographic information for references cited in text is given in Section 7.0. The text is supplemented by appendices containing backup information, checklists, and blank data sheets. The biopile operator should use these planning and recordkeeping tools to aid in running and maintaining the system.

Example vendors or equipment items are mentioned in some sections of this O&M Manual. The examples are intended to help clarify principles and practices of biopile operation and maintenance by indicating some specific implementations, but many approaches are possible. **Mention of a vendor or product does not constitute a recommendation or endorsement by Battelle or the NFESC.**

Section 2.0: TECHNOLOGY OVERVIEW

This Biopile O&M Manual focuses on a 500-yd^3 (382-m^3) modular biopile system that can be replicated to increase capacity. Site-specific designs may be based on larger capacities; however, the basic design and construction features of a 500-yd^3 design would still apply to much larger systems. This section summarizes the biopile technology and the main features of the design presented in each site-specific design and construction report. The information herein is for a baseline design of 500 yd^3 (382 m^2).

The biopile design presented herein has been sized to accommodate 500 yd^3 (382 m^3) of contaminated soil. This size is sufficient to handle contaminated soil generated from most underground storage tank (UST) excavations. A larger biopile or additional biopile pads can be constructed to handle larger volumes. Although multiple cells can require somewhat more space than a single, larger cell, this modular approach has several advantages. Compared to designing larger systems, this modular approach enables better soil management with respect to receipt, storage, handling, and amendment of soils; prevents costly overdesign while allowing for expansion; and maintains a manageable and securable cover size. Having more than one biopile pad enables the site manager to process soils in smaller, discrete batches. Furthermore, if one shipment of soil is exceptionally difficult to treat, due to the level of contamination or other reason, it would be isolated from the rest of the soils being processed.

The 500-yd^3 (382-m^3) size is large enough to process a significant volume of soil, yet small enough to allow two workers to apply and remove the biopile cover. The 500-yd^3 design discussed can accommodate soil volumes up to 750 yd^3 per treatment cycle by varying the height of the piles to a maximum of 8 ft. With larger piles, the plastic cover becomes difficult to install and remove when conducting either moisture addition or soil sampling. Another advantage of a biopile limited to approximately 500 yd^3 (382 m^3) is that a smaller pile is easier to aerate evenly than a larger pile.

Biopile treatment is an ex situ, controlled, biological process where biodegradable organic contaminants are converted primarily to end-products such as water and carbon dioxide under aerobic conditions. The scope of the biopile operations described in this document is limited to soils with petroleum- and fuel-based hydrocarbon contamination.

To construct a biopile, excavated soil is prepared, formed into a pile, covered, and aerated to promote biodegradation. The soil is prepared by adding nutrients and water to bring the soil properties to the desired design condition. In most cases, the biodegradation is achieved by indigenous microorganisms. Figure 1 shows the general design schematic for a temporary biopile system, which is expected to be more commonly used at the Navy sites. A permanent system would have similar features and can be more elaborate at times (e.g., separate leachate collection and moisture delivery systems).

Maximum degradation efficiency is achieved by maintaining the moisture content, pH, aeration, temperature, and carbon-to-nitrogen ratio (DOD, 1994) at an optimum range. Unless otherwise established by treatability test studies, the soil should have the following characteristics to optimize the biopile process:

- total petroleum hydrocarbon (TPH) concentration $\leq$50,000 mg/kg
- moisture content at 70 to 95% of field capacity

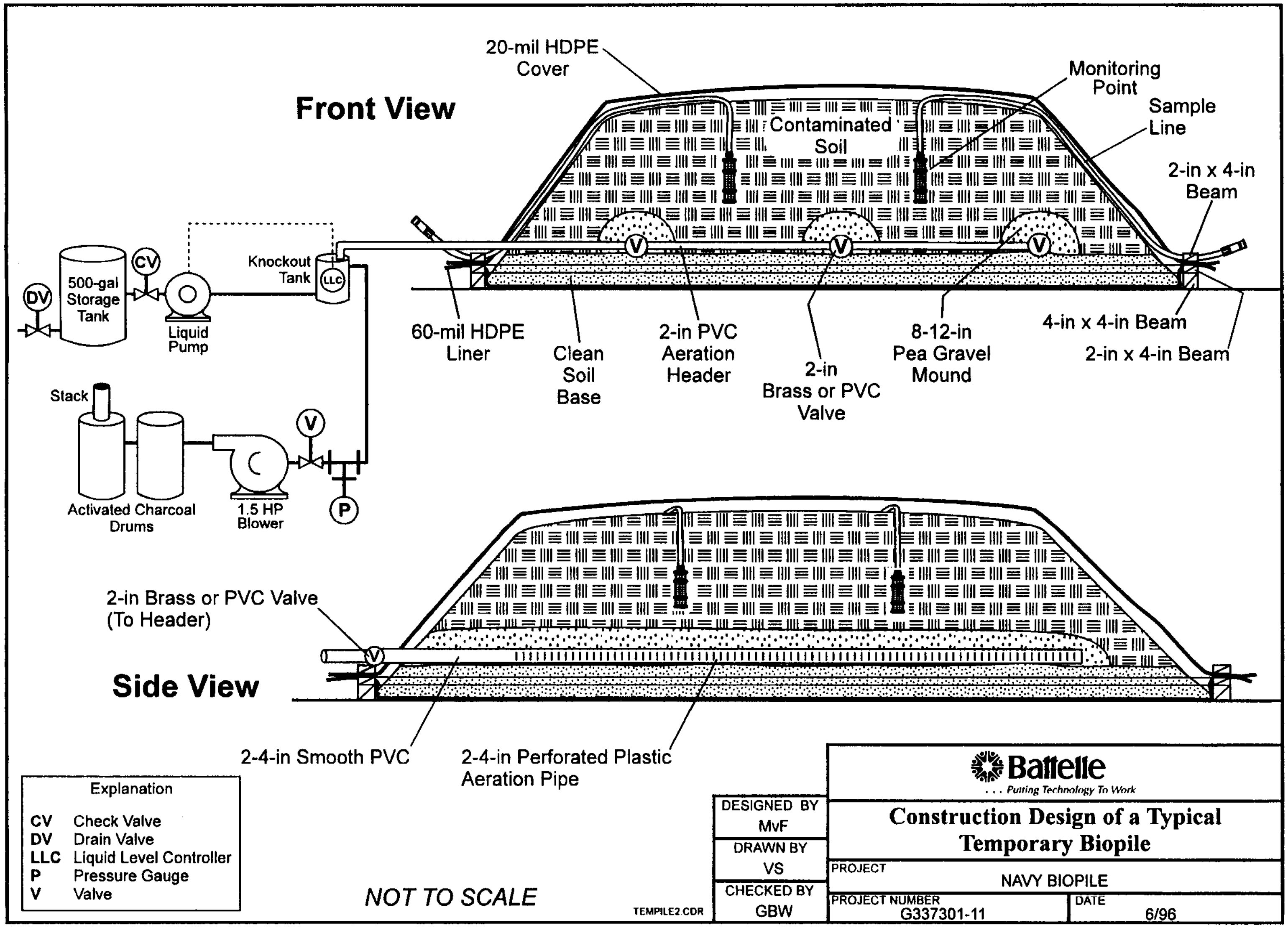

Figure 1. Biopile System Schematic.

- carbon to nitrogen to phosphorous to potassium ratio (C:N:P:K) = 100:15:1:0.5
- $6 \leq pH \leq 9$
- low clay or silt content (soil void volume >25%)
- toxic metals content <2,500 mg/kg.

For cases where the soil porosity is limiting, as in high-clay soil, soil to be treated may first pass through a soil treatment process consisting of bulk separation, shredding, and mixing steps. During the mixing step, moisture, a bulking agent (such as rice hulls or wood chips), and nutrients can be added. The pH, nutrient, and moisture additions are based on soil characterization data and, where performed, treatability study results. From the mixing unit, the soil is piled on the biopile pad and covered with a waterproof 12- to 20-mil high-density polyethylene (HDPE) liner.

Generally, any gases or liquids leaving the biopile must be controlled to minimize TPH emissions to the environment. Therefore, the biopile is formed on an impermeable liner and is surrounded by a berm to contain the soil and any leachate. When exhaust gas treatment is required, the biopile is aerated by pulling air through it, which allows for the off-gas to pass through a granular activated carbon (GAC) treatment unit only if it is expected to contain VOCs or particulates at levels of potential concern.

Once the biopile has been formed, the aeration blower is turned on to begin system operations. The typical operating period for a biopile ranges from 3 to 6 months per soil batch processed. The length of the operating period is a function of the contaminant type, proper soil preparation, and effective biopile operation. A given site may process several batches per biopile cell. The Biopile Design and Construction Manual (NFESC, 1996) describes how to reload the next batch of soil.

This O&M Manual focuses on effective biopile operation, which consists of maintaining the following system operating conditions:

- oxygen (O_2) concentration in the soil matrix > 15%

- soil water content above 40% of field capacity (minimum), with 70 to 95% being the initial target value (for high-clay soils, maintain water content < 70%)

- C:N:P:K = 100:15:1:0.5.

Target moisture percentage and nutrient concentrations are specified in the design report or treatability study and will be summarized on Master Data Sheet DS-1 (Appendix D). To ensure the biopile remains operating within these process ranges, the project officer should inspect the system to verify that the equipment is functioning properly, and should perform maintenance as necessary. Additionally, the biopile should be sampled periodically to track the TPH biodegradation progress. Chapter 3 describes the O&M components and associated tasks. Operators should refer to the site-specific design and construction report.

2.1 Biopile Pad. For a temporary biopile system designed to be in use for up to 5 years, the base consists of a soil or clay foundation, impermeable liner, leachate containment berm, and clean soil base. The optimal thickness of the soil or clay foundation ranges from 6 to 10 inches (15.2 to

25.4 cm) of loose soil that should be compacted to between 80 and 85%. The graded foundations for the storage area and the biopile will have been smoothed out with approximately a 1- to 2-degree slope toward the leachate collection drain line on the aeration lines or a sump located at one corner of the biopile. The foundation typically extends approximately 3 ft (0.9 m) beyond the biopile base to allow for the emplacement of the aeration manifold header, any irrigation lines, and the biopile berm.

An impermeable liner has been placed and secured over the base. A leachate containment berm framing the biopile liner has been constructed. A permanent biopile system, with an expected service life of more than 5 years, would have a concrete pad and berm rather than a soil/clay base with a wooden berm. The permanent pile design is covered in the *Biopile Design and Construction Manual* (NFESC, 1996). The operation of a permanent system closely follows the operations of a temporary system.

2.2 Aeration System. Air can be pushed or pulled through the biopile with a blower. Injecting (pushing) air is preferred, because the blower does not need to be preceded by a water knockout system that removes exhaust gas condensate and possible biopile leachate. However, in cases where exhaust gas treatment or a leachate collection system is required, the aeration system will need to operate in the extraction mode.

The basic aeration system components are an aeration pump, an air manifold with a header pipe connected to the pump, and valves at the manifold branch points. When operating in the extraction mode, a water knockout tank, cyclone separator (optional), knockout water collection tank, and exhaust gas treatment unit (optional) are added to the aeration system.

2.2.1 Aeration Manifold. The aeration pipes are placed on the clean soil base and lead back to the manifold header. Each aeration leg is joined to the manifold header via a gate valve. The valve is used to adjust the air flow through each leg. Although a relative humidity (rH) of up to 90% will not be detrimental (75% of max. rH is ideal), free water droplets can cause the activated carbon to lose effectiveness as it becomes saturated with water.

Each 4-inch (10.2-cm)-diameter aeration leg should be constructed from one 10-ft (3-m)-long section of blank polyvinyl chloride (PVC) pipe and one 30-ft (9-m)-long section of slotted, corrugated, and flexible drainage pipe. Some temporary and permanent biopiles may contain slotted, PVC pipes. The drainage pipe is capped at the end. A rubber union can join the flexible pipe to the PVC pipe. The PVC pipe is connected to the 4-inch (10.2-cm) valve that leads to the 2-inch (5.1-cm) manifold header pipe. The distance between aeration pipes should be 8 to 10 ft (2.4 to 3.0 m).

To prevent short-circuiting of the air flow through the pile, the slotted portions of the aeration legs should be placed toward the center of the pile. That is, the connection between the blank and the slotted pipe should be approximately 10 ft (3 m) from the biopile berm. Figure 2 shows a schematic of the aeration system.

2.2.2 Water Knockout Tank. A water knockout tank is required when the aeration system is operating in the extraction mode (see Section 2.2). The header pipe leads to a water knockout tank that separates the bulk of the water carried through the header from the biopile. Water from the knockout tank can be pumped to a 500-gal (1,895-L) water collection tank, which can be the same as the leachate collection tank, if one is used. Following the water knockout tank, a cyclone separator or a demister can be installed, if deemed necessary, to remove remaining moisture droplets still

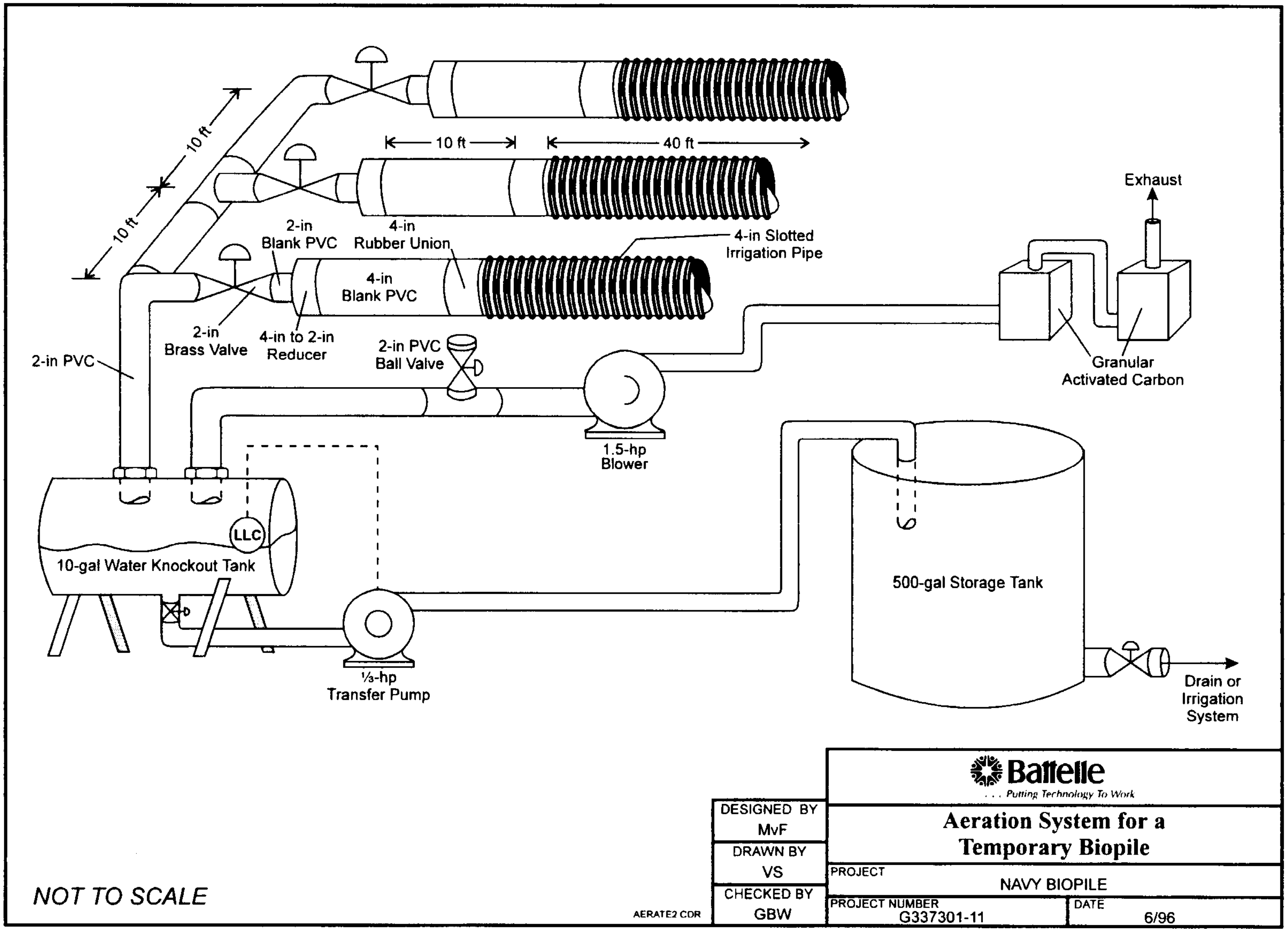

Figure 2. Biopile Aeration System for Operation in the Extraction Mode.

entrained in the biopile exhaust. Removing the remaining water droplets from the exhaust gas is important when a carbon adsorption unit is used to treat volatile organic compound (VOC) emissions.

The water in the knockout tank is controlled with a liquid level controller (LLC) that operates via float switches and an electrical contactor connected to a pump. As the water level in the tank rises, the float switch closes a circuit to power a pump that moves the water in the knockout tank to the 500-gal (1,895-L) leachate collection tank. As a safety measure, the float switch should cut power to the blower when the water level is high enough to pump from the knockout tank. Otherwise, should the pump fail, the water would be pulled through the blower and to the GAC treatment unit.

2.2.3 Regenerative Centrifugal Blower. The vacuum source that pulls air through the pile should be a 1½-hp regenerative centrifugal (preferred) or rotary positive-displacement blower capable of drawing approximately 120 scfm (3,400 sLm). The maximum flowrate may be dictated by the flowthrough capacity of the off-gas treatment unit. For example, refer to the GAC canister flowrate specification in the manufacturer's instructions that should be included in each site-specific design and construction report. The blower should be placed on an improved, level surface, preferably a concrete pad. Power requirements for the blower, generally single-phase 110/220-V, will be specified by the vendor and in the blower installation manual. A tee fitting with a ball valve attached to the unconnected end should be installed just prior to the blower inlet. The valve can be used to regulate air flow through the pile. Housing the pump in a shed will protect it from the weather. The same shed can house other equipment and the off-gas treatment unit, and can serve as a storage area for materials.

The blower can be set to a given flowrate to run continuously or can be set to cycle on and off, based on initial soil respiration test data. Alternatively, a variable-speed blower can be used. The blower speed is controlled by a process controller that measures the oxygen content in the soil gas and adjusts the blower speed to keep the O_2 level between 15 and 20% in the biopile. As a result, the biopile is not overaerated, and less water is evaporated from the pile and through the aeration system.

2.3 Off-Gas Treatment Unit. If exhaust gas treatment is deemed necessary, two activated carbon canisters can be installed in series to remove VOCs. Duplicate carbon canisters are installed to ensure continued off-gas treatment should the first canister reach the contaminant breakthrough stage. To monitor the continued efficacy of the off-gas treatment unit, a sampling port can be installed between the two canisters for periodic off-gas monitoring.

The carbon canisters should be sized to handle the air flowrate. A typical size would be a 225-lb (102-kg) GAC bed in a 55-gal (208-L) drum. The GAC can operate effectively in an exhaust stream having up to 90% relative humidity. Saturated vapor exhaust streams will tend to reduce the carbon life. Free water entering the carbon canisters can cause the carbon to fuse, leading to a blockage in the exhaust stream. To prevent a reduced useful life or blockage of the exhaust stream, a demister can be placed between the blower and the GAC treatment unit. The demister traps and removes entrained water drops from the exhaust stream. Another measure that effectively reduces water buildup in the GAC canisters is the use of a variable-speed blower or one that cycles on and off.

2.4 Leachate Collection System. The biopile configuration featured in this document is designed to minimize the formation of leachate. Therefore, unless mandated by special circumstances, the construction of a leachate collection system should not be necessary, because the bermed liner is designed to contain any water or leachate that migrates to the bottom of the pile. However, if a leachate collection system is installed (e.g., in some permanent systems), it should be constructed by sloping the biopile base toward one corner of the pile to channel any leachate to a leachate collection pipe or, preferably, by incorporating the leachate collection with the aeration system. When a leachate collection system and a biopile irrigation system are both installed, the leachate can be recycled back to the pile through the irrigation lines.

If a separate collection pipe is used, it should be a 2-inch (5.1-cm)-diameter slotted PVC pipe connected to a blank 2-inch (5.1-cm)-diameter PVC pipe that leads to a leachate collection sump. The sump must be located below the grade of the biopile foundation and must have an impermeable surface (e.g., a plastic tank or concrete sump).

A pump would be required to transfer the leachate from the sump to an aboveground storage tank. A liquid level controller (LLC), such as a float switch, may be useful to turn the pump on and off as leachate collects and is removed from the leachate collection sump. Typically, the capacity of aboveground leachate collection tanks ranges from 500 to 1,500 gal (1,895 to 5,685 L). This tank should be located within a secondary containment area, such as a lined berm and foundation that are large enough to contain the volume of the tank.

2.5 Moisture Addition System. Unless the feed air is dry and hot, the aeration rate is excessive, or the soil organic content is low, an initial adjustment of moisture content usually is sufficient to eliminate the need for water addition during operation. In some cases, however, an irrigation system is warranted. The irrigation system will pull water from a source, such as a tank or a hydrant, and distribute it across the top of the biopile via a dripline. The irrigation system is a closed loop, with the return header flowing back to the source. The irrigation system can be turned on and off manually or by a timer connected to a regulator valve. Figure 3 depicts a schematic of a typical irrigation system.

2.6 Soil Storage Area. The soil storage area generally will be a pad of similar design to the biopile pad, consisting of a compacted soil or clay base or an existing improved surface, such as asphalt or concrete. An impermeable liner and containment berm will be required to contain the soil and any leachate. The contaminated soil should be covered with a plastic cover, primarily to prevent rainfall infiltration and subsequent leachate formations. Additionally, the cover serves to prevent wind from blowing the soil. In some cases, the soil storage area may be in a building, in which case it would not need to be covered.

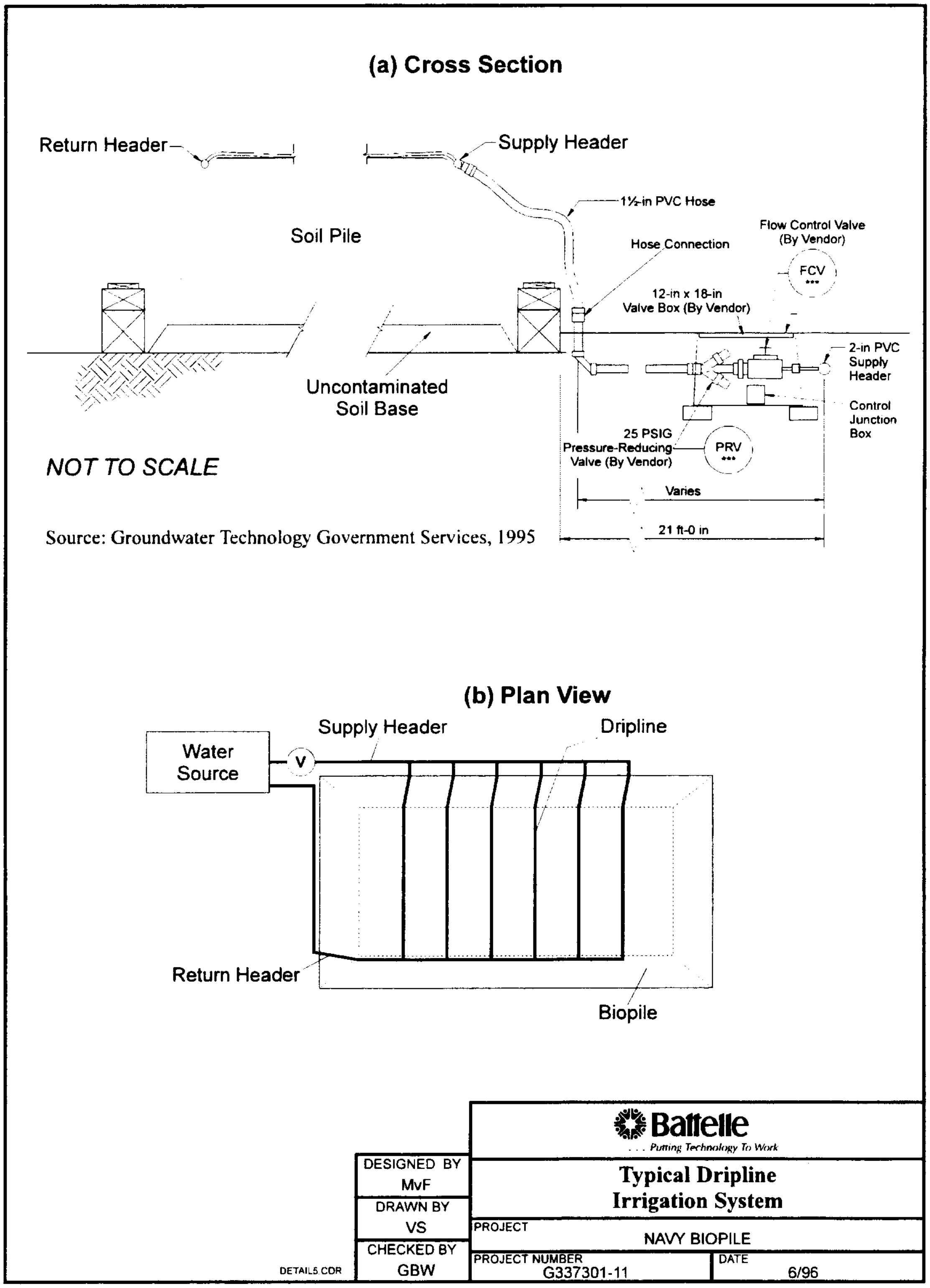

Figure 3. Schematic of a Biopile Irrigation System.

Section 3.0: BIOPILE SYSTEM MANAGEMENT

Biopile treatment requires a period of operations and maintenance before cleanup goals can be reached. Typically, a biopile treatment cell is operated for 3 to 6 months, at which time the treated soil should meet the remedial objectives. Well thought-out plans for operations, maintenance, and closeout are required to ensure high-quality, safe, and cost-effective operation.

3.1 Operating Requirements. This section describes methods for operating a full-scale biopile system.

3.1.1 Crew Training and Experience Requirements. The workers at the biopile site should be familiar with the chemical and physical hazards involved in biopile O&M and methods to mitigate the hazards. Typical sources of hazards include organic contaminants on the soil, chemical fertilizers, heavy equipment movement, and rotating equipment. More information about the health and safety aspects of biopile operation and maintenance is provided in Section 6.0.

3.1.2 Operational Management. The site manager and operators must not accept any soil without proper base authorization and documentation certifying the amount of soil, the contamination type and concentration, the originator, and the place of origin. Furthermore, soils must be rejected if the site is not licensed to accept the contaminants they contain. Examples of contaminants normally prohibited include but are not limited to:

- chlorinated organics
- toxic metals
- explosives contaminants
- pesticides
- polychlorinated biphenyls (PCBs)
- some polycyclic aromatic hydrocarbons (PAHs)
- dioxins/furans
- solid wastes not categorized as soil.

To the extent possible, the biopile system should be operated on "just-in-time" inventory principles. Plans for receiving new soil for treatment and purchasing fertilizer chemicals should be designed to minimize the time materials are stored on site. Ideally, the new batch of contaminated soil would be placed directly on the biopile just after the treated batch has been removed. If the contaminated soil can be directly placed on the biopad rather than stored on the storage pad, the material would be handled only one time. However, scheduling must be flexible to account for the uncertainties inherent in environmental projects. Factors such as unexpected variations in the biodegradation rate, long-term deviations from normal climatic conditions, delays in receiving analysis results for soils, or results indicating that required contaminant concentrations were not achieved may occur. These factors increase the uncertainty in planning for new waste shipments.

The biopile site manager should coordinate transport schedules with officials desiring to deliver additional soil and with the authority receiving treated soil for final disposition. Proper scheduling will optimize biopile throughput, labor, and equipment resources.

3.1.3 System Startup and Shakedown. The first step in biopile operation is to perform and document the initial system startup and shakedown test as part of construction of each biopile treatment cell. Checklists CL-2a and CL-2b in Appendix C can guide the operator through the system startup. An initial inspection and startup test should be conducted to ensure all biopile system components are installed and operating properly, and to ensure balanced air flow. A visual inspection of the biopile cover, berm, blower suction piping, water knockout tank, blower, the blower discharge piping and instrumentation, and off-gas treatment system should be performed. It is particularly important to ensure that the inlet and discharge lines of the blower are not obstructed. Operation of the blower with low air flow due to starved suction or obstructed discharge will result in overheating and eventual damage to the blower. Field instrumentation should be visually examined, zero-point checked and adjusted, and field-calibrated. The ambient air temperature, relative humidity, and barometric pressure should be recorded.

The flow initially should be adjusted prior to placing soil on the aeration legs using the following method.

Step 1. Fully open the flow-control valve at each air extraction leg.

Step 2. Switch on the blower and slowly adjust the valve at each extraction leg to a partially closed position to provide approximately equal flow to each extraction leg.

Step 3. Use an in-line air flowmeter, such as a hot-wire anemometer, to measure flowrates. The design flow for each leg should be known and will be the target for adjustment. The total flow from all legs combined should be maintained at a rate within the design flow for the system. When the flowmeter reading in each leg is equalized, the aeration system is balanced.

The flowmeter typically gives a higher total flow reading when measuring air flow in the main header than the sum of the three readings taken in the aeration legs. This apparent discrepancy is caused by the slightest pressure drop across the flowmeter. Once balanced flow is achieved, the air flowrate or pressure in each leg and in the blower outlet should be recorded on Checklist CL-2a (Appendix C). The blower is then stopped and the soil pile is formed over the aeration legs.

Once soil is placed over the extraction legs and the blower is restarted, the oxygen (O_2) concentration in each monitoring point should be measured. The soil gas O_2 concentration in the monitoring points is the most important control feature. Soil gas composition monitoring should be performed every several hours until the O_2 concentration in each monitoring point is stable. After constant O_2 concentrations are reached in the monitoring points, the total air flow and position of the valves controlling the flow to each air extraction leg should be adjusted to give a minimum 15% O_2 in soil gas sampled from each monitoring point. Often, no air flow adjustment will be required, provided the aeration legs initially were balanced properly and the soil in the site is relatively homogeneous. Air flowrates should not be readjusted until the soil gas O_2 concentration stabilizes so that the biopile equilibrates before the next adjustment.

Soil samples should be collected and analyzed after the biopile cell is filled. The plan for collecting soil samples should be designed on a sound statistical basis as described in ASTM D 4687, "Standard Guide for General Planning of Waste Sampling." Sample locations for the biopile normally will be selected by arranging a square grid array over the pile and randomly selecting grid squares for sampling. The soil type, soil moisture content, soil nutrient content, contaminant type, and contaminant concentration should be measured and recorded. The initial pressures; temperatures; and soil gas concentrations of O_2, carbon dioxide (CO_2), and TPH vapors should be measured at each monitoring point. Checklist CL-2a for the initial inspection and shakedown of the biopile system is provided in Appendix C.

3.1.4 Routine Operations. Once installed, the biopile should be operated in a flexible manner to optimize biological destruction of contaminants while limiting the quantity of contaminants removed by vapor transport. Periodic monitoring is required to measure system performance, and system adjustments may be needed to adapt to declining contaminant concentrations or other changing conditions in or around the biopile.

Once the preliminary air flow balancing is completed, a routine schedule of operating checks should be established and documented. A walkby check to confirm normal operation of the system should be performed weekly. The walkby should include visual inspection of the pile cover, berm, blower, and piping. The operator should also be alert for unusual sounds or odors. A loud rattling noise from the blower may indicate bearing failure, water in the blower casing, or other undesirable conditions. Odors may indicate that the pile is not adequately aerated or that the off-gas system is not operating effectively. A weekly check of the off-gas treatment system and water knockout tank and leachate handling system may be adequate, but more frequent inspections may be required for regulatory compliance. The weekly check should be supplemented monthly by a more complete set of checks and measurements. Monthly checks and measurements include:

- Record date and time of measurements and log name of sample collector.
- Record ambient air temperature on Data Sheet DS-2 in Appendix D.
- Document a visual inspection of the components as described in the shakedown test.
- Measure soil gas concentrations of O_2, CO_2, and TPH and temperatures in each monitoring point. Record data on Data Sheet DS-2 in Appendix D.
- Measure air flowrate at the blower inlet. Record data on Checklist CL-3 in Appendix C.
- Measure air flowrate or pressure in each aeration leg. Record data on Checklist CL-3 in Appendix C.
- Measure the TPH vapor concentration at the inlet, between canisters, and at the outlet to the off-gas treatment system. Record data on Checklist CL-3 in Appendix C.
- Perform a shutdown respiration test.

If the monthly measurements indicate that the O_2 concentration in soil gas near an aeration leg is below 5% to 8%, the air flow to the extraction leg should be increased. Similarly, if the O_2 concentration in soil gas near an aeration leg approaches 20%, the air flow to the leg should be decreased. The target O_2 concentration in the soil gas during biopile operation is 15 to 20%. A checklist (CL-3) for the periodic inspection of the biopile system is provided in Appendix C.

3.1.5 Off-Gas Treatment System Operation. The operating requirements for the off-gas treatment system are specific to the type of system selected. Requirements should be set consistent with the manufacturer's direction and regulatory requirements. This information is expected to be in each site-specific design and construction report.

3.1.6 Spill Prevention and Contingency. Biopile operation may generate small quantities of aqueous solutions such as nutrient addition solutions or leachate from the biopile. Piles or containers of contaminated soil and agricultural chemicals will be present in the operating area. Spill prevention and control methods should be instituted to minimize the possibility of releases and allow rapid response should an accidental release occur. Checklist CL-4 is provided in Appendix C for the monthly spill control and housekeeping tasks.

3.2 Maintenance Requirements. Biopile systems are simple and reliable but are not immune to wear and breakage. This section describes routine maintenance that is needed to ensure continued operation of the biopile.

3.2.1 Aeration Manifold. Preferential flow paths may develop at the edges of the biopile. This "short-circuiting" condition can cause inadequate aeration of the center of the pile and should be corrected when detected. Short-circuiting is indicated by any of the following conditions:

- The pressure in monitoring points near the edge of the biopile is lower than points at the same depth near the top of the pile.
- The oxygen content in soil gas from monitoring points near the edge of the biopile is higher than points at the same depth near the middle of the pile.
- The monitoring points near the edge of the biopile show rapid helium loss during an initial respiration test (Section 4.5.2).

To correct short-circuiting, reduce the air flow from the short-circuited extraction leg by adding a layer of clean soil to the surface of the biopile around the edge, by gently compacting the soil around the edge, or by adjusting the appropriate aeration leg valve to reduce air flow through the portion of the pile that is short-circuiting.

3.2.2 Biopile Cover Repair. Openings in the biopile cover may allow excessive moisture input from rain or soil dispersion by wind erosion. A damaged cover should be repaired or replaced immediately if visual inspection detects more than a few small slits in the cover. Slits or tears at depressed areas in the cover will result in larger leaks after a rainfall. If the cover is sloped 1 to 2% and depressed areas are avoided, small slits will have little impact. Ideally, an HDPE cover should be welded to repair tears. Adhesive or heat bonding will be ineffective. Small tears in polyethylene liners can be repaired with a patch kit such as FABTAPE™, available from Reef Industries, or a similar product. Areas of the cover having small tears or holes should be elevated where possible by forming a dirt mound under the affected area. If a repair is completed with a patch kit, ensure that the surfaces to which the patch is applied have been cleaned to remove dirt and moisture. If a patch kit repair is not feasible and the cover damage is significant, replace the cover.

3.2.3 Biopile Piping Repair. Inspections may identify damaged valves or piping in the biopile treatment system. Small holes in plastic piping may be repaired using plastic sheeting and cement. However, it may be easier to insert a replacement piece. More extensively damaged plastic piping, damaged metal piping, or damaged valves should be replaced. In desert climates, use of ultraviolet-protected plastic piping will reduce degradation of exposed pipes.

3.2.4 Blower Maintenance. A flow obstruction in the blower piping must be diagnosed and repaired immediately. Operating the blower with plugged piping results in frequent shutdowns due to thermal overload and eventual blower damage. Indications of plugged piping include:

- visual observation of an obstruction or unusual sounds from the blower
- decrease in vacuum pressure gauge reading
- decreased air flow
- decreased blower outlet pressure (indicates plugging of the blower suction piping)
- increased blower outlet pressure (indicates plugging of the blower outlet piping or the off-gas treatment system).

The blower should be lubricated and maintained in accordance with the manufacturer's directions. The requirements will vary depending on the type of blower used. Centrifugal regenerative blowers typically are supplied with long-running, self-lubricating seals and require little or no routine maintenance. Rotary-lobe blowers may require periodic lubrication. Specific diagrams should be supplied by the vendor as part of the blower manual.

3.2.5 Off-Gas Treatment System Maintenance. The maintenance requirements are specific to the type of system selected. Requirements should be set consistent with the manufacturer's direction and regulatory requirements. In most cases, off-gas treatment will be provided by replaceable canisters of granular activated carbon (GAC). During site walkthrough inspections, check the GAC canisters for rust and leaks. Routine maintenance involves monitoring the organic vapor content in the air exiting the downstream canister and the pressure drop across the canisters. Measure the exhaust gas between the GAC canisters weekly or as dictated in the site workplan. Once the upstream canister shows breakthrough of TPH vapors, replace it with the downstream canister and install a new GAC canister in the downstream position.

To protect the GAC canisters from water fouling, ensure that the water knockout system is functioning correctly. Identify and significant amounts of water collecting in or leaking from the inlet to the first GAC canister. Excessive backpressure on the blower can be an indicator of GAC fouling by water. Replace fouled or blocked GAC canisters. Inspect the water knockout system and repair as necessary.

3.3 Project Closeout Requirements. Completing treatment of a batch of soil in the biopile requires establishing and documenting statistical evidence that the cleanup goals have been reached.

3.3.1 Soil Gas Sampling. Respiration testing serves as the primary indicator for monitoring pile performance and provides a cost-effective method for estimating effectiveness prior to soil sampling. The number of samples required to demonstrate a statistically valid conclusion renders the cost of soil analysis prohibitive until contamination levels approach 90 to 99% of the cleanup goal. The cost of soil sampling and analysis is a significant portion of the overall cost of a biopile project. Minimizing soil sampling will make the remediation effort more cost effective.

The respiration rate in the biopile measured by a shutdown test (Section 4.2.2) can indicate when the soil is clean and therefore when to collect final soil samples. As remediation of the soil in the biopile cell progresses and contaminants are degraded, the measured respiration rates will decline. The respiration rate in the contaminated area approaching zero is a good indication that the soil in the biopile cell has been remediated, provided that the moisture content is not limiting, and final soil sampling can be conducted.

Factors other than reduced contaminant concentration can decrease the respiration rate measured by a shutdown. The factors that contribute to a lower respiration rate are low moisture content, short-circuiting of the airflow, insufficient nutrients, and low temperature. The respiration rate will decrease with time as the contaminant concentration declines toward the target cleanup levels (usually around 500 to 1,000 mg/kg). If the shutdown respiration rate has approached zero but subsequent soil sampling shows concentrations exceeding the cleanup level, biopile conditions should be analyzed to determine if adjustment and continued treatment are warranted. The most likely cause of low biodegradation rates is low moisture content. If soil moisture is low, dripline or spray nozzle water addition should be used to increase soil moisture, and the biodegradation rate should be remeasured. Similarly if nutrients are out of balance or if the pile temperature is low, adjustments and continued treatment may succeed in further reducing the petroleum hydrocarbon concentration. Lower shutdown respiration rate estimates also can result from short-circuiting of ambient air to the biopile. If soil sampling indicates high organic contaminants but the respiration studies show a lower respiration rate, an initial respiration test using helium tracers should be performed to determine whether ambient air migrates in significant quantities during passive conditions (Section 4.2.1).

3.3.2 Soil Analysis. For nearly all contaminated soils, cleanup goals are stated in terms of contaminant concentrations in soil. A variety of approaches are conceptually possible for defining the required cleanup goals for a biopile soil, but in practice soil sampling is the most common method used to demonstrate compliance. However, due to the high cost, soil sampling should not be used for routine process monitoring (see Section 3.3.1).

The number of final soil samples collected usually is driven by a regulatory requirement to demonstrate a high confidence that the required cleanup goals have been achieved. To allow direct comparison with the initial conditions, the confirmation samples should be collected from the same locations as the initial biopile characterization samples (see Section 3.1.3).

Different cleanup goals will be specified if different contaminants are present. Petroleum hydrocarbons are the most common contaminants treated in biopiles, so the most common cleanup goal specification is based on TPH. Benzene, toluene, ethylbenzene, and xylenes (BTEX) are components of petroleum hydrocarbon materials that frequently are targeted by regulators in specifying cleanup goals. The BTEX compounds are more mobile and more of a potential concern than the remaining TPH compounds. When BTEX compounds are present, the cleanup goals required for these compounds will be more stringent than for TPH. In some instances, cleanup goals also will address PAHs that may be present as soil contaminants. Methods for collecting samples and performing analyses are described in Section 4.0.

The measured concentration of hydrocarbons in soils typically shows wide variability due to the heterogeneous distribution of contaminants in the soil. Statistical analysis is needed to allow a meaningful comparison of the results with the action limit. Typically, the upper confidence limit (UCL) of the mean of the distribution of contaminant concentrations is compared to the action limit. The UCL must be determined by applying the statistical analysis for the appropriate distribution type. The analytical results should be checked to determine how they are distributed (Gilbert, 1987). The population may be distributed in one of the following ways:

- normally
- log-normally
- nonparametrically.

Although many populations of environmental contaminant concentrations are log-normally distributed, a log-normal distribution should not be assumed without justification (U.S. EPA, 1989, EPA/530-SW-89-026).

A UCL of 90% should be acceptable to establish that the remedial objectives have been met. If the calculated UCL is below the cleanup goal, the soil cleanup is complete. If the UCL is slightly above the cleanup goal, additional sampling may result in lowering the UCL, particularly when the standard deviation of the distribution is large. The decision between taking additional samples or continuing the remediation includes consideration of:

- the cost of sampling versus the cost of continued remediation
- the current shutdown respiration rate
- the current status of moisture and nutrient content in the pile
- regulatory acceptance of additional sampling to lower the calculated UCL.

3.3.3 **Documentation.** Attainment of cleanup goals for the soil should be documented in a soil treatment report. Before preparing the report, the biopile operator should determine the format and content required by the lead regulatory agency. A typical report will cover the following topics areas:

- contaminant types
- initial contaminant concentrations
- cleanup goal(s)
- biopile design and operating features
- the results of sampling and analysis to ensure attainment of cleanup goals
- final soil disposition.

To assist with the data collection and documentation, data sheets have been compiled in Appendix D.

Section 4.0: SAMPLING AND ANALYSIS PROCEDURES

This section outlines the reasons and methods of sampling and analysis for the biopile installation and routine monitoring. Procedures for sampling soil, soil gas, off-gas, and leachate are described. Information is provided for the test parameters and the analytical methods required. In addition, a sampling schedule is provided in Table 1. All site activities should be recorded on the checklists, on the data sheets, or in the site record book. Individual checklists and data sheets should be placed in a binder in chronological order and by category. The checklists and data sheets referred to in this section are provided in Appendices C and D, respectively.

Table 1. Sampling Schedule

Sampling Event	Sample Interval
Soil sampling	Upon pile construction and then as dictated by respiration test and soil-gas sampling
Soil gas sampling	At startup, 1 week after startup, and then monthly
Respiration testing (in situ and shutdown respiration tests)	24 to 48 hours after turning on the blower, 1 week after the initial test, and then monthly
Blower exhaust-gas sampling	Weekly or as dictated by the site permit
Exhaust gas sample collection for laboratory analysis	Monthly

4.1 Soil Sampling Procedures. Soil samples are collected to track the extent of contaminant degradation in the pile with time to estimate the minimum required treatment period to verify analytically whether or not cleanup levels have been or can be reached. Soil samples also can be used to verify proper biopile operation. The Design and Construction Manual (NFESC, 1996) and each site-specific design and construction report present the analytical methods and sample parameters to be used in sampling soils.

A wide variety of methods can be used to collect soil samples from the biopile and soil collection pile. Typically, soil samples are collected using a hand-auger and a hand-driven sampler. Using the combination of auguring and driving a sampler to collect a soil sample preserves the integrity of the sample by minimizing both the volatilization of VOCs and disturbance to the soil. If volatilization of contaminants is not a concern, the sample can be collected directly from the auger bucket by scraping the soil into a collection jar. For quality assurance/quality control (QA/QC) purposes, a duplicate sample should be collected every fifth sample. To collect a soil sample from the biopile using a hand-auger/hand-sampler method, proceed as follows:

Step 1. Determine the sampling grid and identify the sampling locations. Set up the grid so that samples are collected at a minimum of 1 sample per 100 yd^3 (76.5 m^3).

Step 2. Obtain and assemble a tee handle, extension bar, and bucket auger.

Step 3. Using the auger, bore the sampling hole to approximately 6 inches (15.2 cm) above the desired sample depth (normally 2 to 3 ft [61 to 99.4 cm] below the surface).

Step 4. Remove the bucket auger and the tee handle and install the sampling attachment, which has a brass sleeve at one end of the extension bar and the slide-hammer on the other end.

Step 5. Place the sampling tool down the borehole and drive the tool with the slide-hammer to fill the sampler.

Step 6. Remove the brass sleeve from the sampling tool; cap both ends of the sleeve with inert caps; and label the sample sleeve with indelible ink, ensuring that the label cross-references with the grid location documented on Soil Sample Data Sheet DS-3 in Appendix D.

Step 7. Fill out the chain-of-custody form, place the sample on blue ice or equivalent (avoid wet ice), and ship the soil to the analytical laboratory for analysis.

NOTE: When collecting soil samples after the biopile has been placed in operation, remove the cover prior to collecting samples. *Do not* cut through the cover, because rainwater could then easily saturate the biopile.

4.2 Soil Gas Sampling and Soil Temperature Data Collection

4.2.1 Initial Respiration Test. The initial respiration test is conducted using the screened intervals of the soil gas monitoring points in the biopile. Results from this test will be used to determine the rate of microbial activity and will indicate if the biopile is oxygen-limited.

Generally, six to eight monitoring points per 500 yd^3 of soil should be sufficient. Monitoring points should be installed to measure soil gas from different geometrical areas of the pile. For example, placing monitoring points in two diagonally opposed corners, one in the center, one over an aeration line, one between the aeration lines, and one or two close to the pile edge should provide good sampling coverage of the biopile airflow.

Air containing 1 to 2% helium (He) is injected into the biopile by reversing the blower configuration. The air/He mixture is fed at a rate of approximately 120 cfm (3,400 sLm) for 1 to 6 hours to fully aerate the soil. A manifold generally is used to dilute the He concentration while maintaining a relatively high air-injection rate (Figure 4). After injection of air and He has been completed, the soil gas will be measured for O_2, CO_2, He, and TPH. To measure these parameters, soil gas will be extracted from the contaminated area using the soil sampling method described in Section 4.2.4.

The He injection test procedure is recommended, provided the operators have access to a He detector and He gas, and if the blower can be operated in both the injection and extraction modes. However, if these resources are not readily available, the shutdown respiration test (Section 4.2.2) will be a satisfactory procedure.

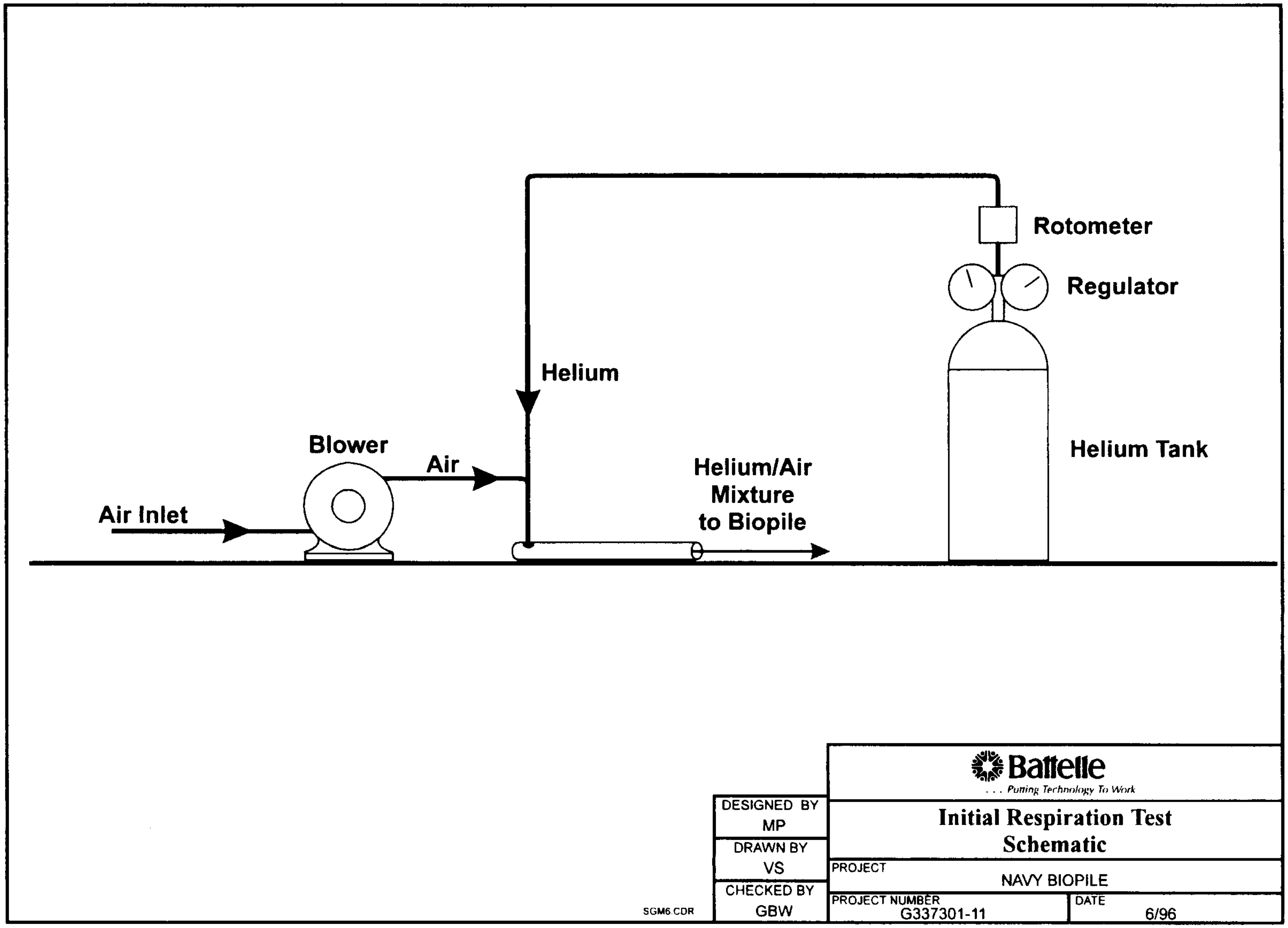

Figure 4. Initial Respiration Test Apparatus.

Typically, soil gas samples are collected at 2, 4, 6, and 8 hours and then every 4 to 12 hours, depending on the rate at which O_2 is being utilized. If O_2 uptake is rapid (>3%/hour), more frequent monitoring will be required. If it is slower (<0.5%/hour), less frequent readings will be acceptable. Standard initial respiration testing samples will be collected for 2 days; however, low O_2-use rates will require longer test periods. If the O_2 concentrations have not decreased below 10% after 5 days, the test will be terminated. Record data using Data Sheet DS-2 in Appendix D.

Because of the shallow depths of the monitoring points in the biopile, there is a risk of pulling in atmospheric air in the process of purging and sampling. Therefore, excessive purging and sampling may result in erroneous readings. There is no benefit in oversampling, and care should be taken to minimize the volume of air extracted from a soil gas monitoring point. Table 2 provides a summary of the various parameters that will be measured. All of the parameters in Table 2 should be measured for the initial respiration test.

The biodegradation rate can be calculated from the rate of oxygen utilization. The method for calculating the oxygen utilization and biodegradation rates is presented in Appendix G. The He is used to monitor if ambient air is infiltrating the pile significantly. If the He concentrations

Table 2. Parameters to be Measured for the Initial and Shutdown Respiration Tests

Parameter/ Media	Suggested Instruments	Suggested Frequencies	Instrument Sensitivity (Accuracy)
CO_2/soil gas	Infrared adsorption method, GasTech Model 32520X (0 to 25% CO_2), Riken Model RI-411, Landtec Models GA-90 and GEM-500	Initial soil gas sample before air/He injection and immediately after injection shutoff, every 2 hours for the first 8 hours, and then every 8 to 10 hours for the next 2 to 5 days	±0.2%
O_2/soil gas	Electrochemical cell method, GasTech Model 32520X, Bacharach Model 302, MSA Microguard (0 to 25% oxygen)	Same as above	±0.5%
Total hydrocarbons/ soil gas	GasTech hydrocarbon detector, Bacharach TLV meter	Same as above	±1 ppm
He/soil gas	Marks helium detector Model 9821	Same as above	±0.01%
Flowrate/air-He mix	Mass flowmeter, rotameter	Reading during air injection	±0.5 scfm (14 sLpm)
Pressure	Pressure gauge (0 to 30 psia)	Reading during air injection	±0.5 psia (34.5 mBar)

decrease with time, then ambient air is entering the pile that will reduce the O_2 reduction rate (see Section 4.5.2).

4.2.2 Shutdown Respiration Testing. The shutdown respiration test is generally easier to perform than the initial respiration test, because the blower is operated in the usual air extraction configuration, and He gas is not used or measured. Ideally, a respiration test should be conducted approximately once per month to track biodegradation rates.

The initial respiration test will have been conducted 24 to 48 hours after turning on the blower. A second respiration test should be performed 1 week after the initial test, because the highest microbial activity rates will occur at the beginning of the treatment. Subsequent respiration tests should be conducted monthly. For the shutdown respiration tests, only CO_2, O_2, and total hydrocarbons in soil gas should be measured (Table 2).

Shutdown respiration testing is similar to initial respiration testing with regard to sample collection and results. After the oxygen concentrations in the biopile have stabilized and have been measured and recorded on Data Sheet DS-2 (Appendix D), the blower is turned off to start the shutdown respiration test. As shown in Table 1, the same sampling schedule is used during the shutdown respiration test as is used for the initial respiration test (Section 4.2.1). The oxygen utilization rate is then used to calculate the biodegradation rate, as described in Appendix G.

4.2.3 Tedlar™ Sampling Bag Method. A Tedlar™ gas sampling bag is used to collect soil gas samples for field measurements. Soil gas sampling can be conducted monthly, at the start of the respiration tests. Additionally, soil gas may be sampled during periods between respiration tests to spot check biopile performance. The soil gas samples are obtained from the soil gas monitoring points by pumping soil gas into the sampling bag using a vacuum pump (Figure 5) or by pulling the sample directly into the bag contained in a portable vacuum chamber (the vacuum dessicator, Figure 6). The soil gas samples can be analyzed using hand-held analytical meters for O_2, CO_2, and TPH. The O_2 data are critical for ensuring and tracking proper biopile performance. Sample collection using the Tedlar™ sampling bag is relatively simple, but care must be taken not to cross-contaminate samples through improper cleaning of the bags between samples. Before the Tedlar™ bag is reused, it should be flushed twice with ambient air and flushed twice again with the soil gas before collecting the sample. Sample the soil gas in the biopile according to the following procedure:

Step 1. Connect the vacuum pump to the quick-connect coupling at the monitoring probe. A liquid trap may be placed between the pump and the monitoring probe to collect any water that might be pulled from the monitoring probe (Figure 5).

Step 2. Connect the pump outflow to a 1-L Tedlar™ bag.

Step 3. Turn on the pump and fill the Tedlar™ bag with soil gas, making sure the valve on the bag is in the open position.

Step 4. Flush the bag with soil gas twice repeating Steps 1 through 3 and collect the final soil gas sample.

Step 5. Disconnect the bag from the pump and close the valve on the bag.

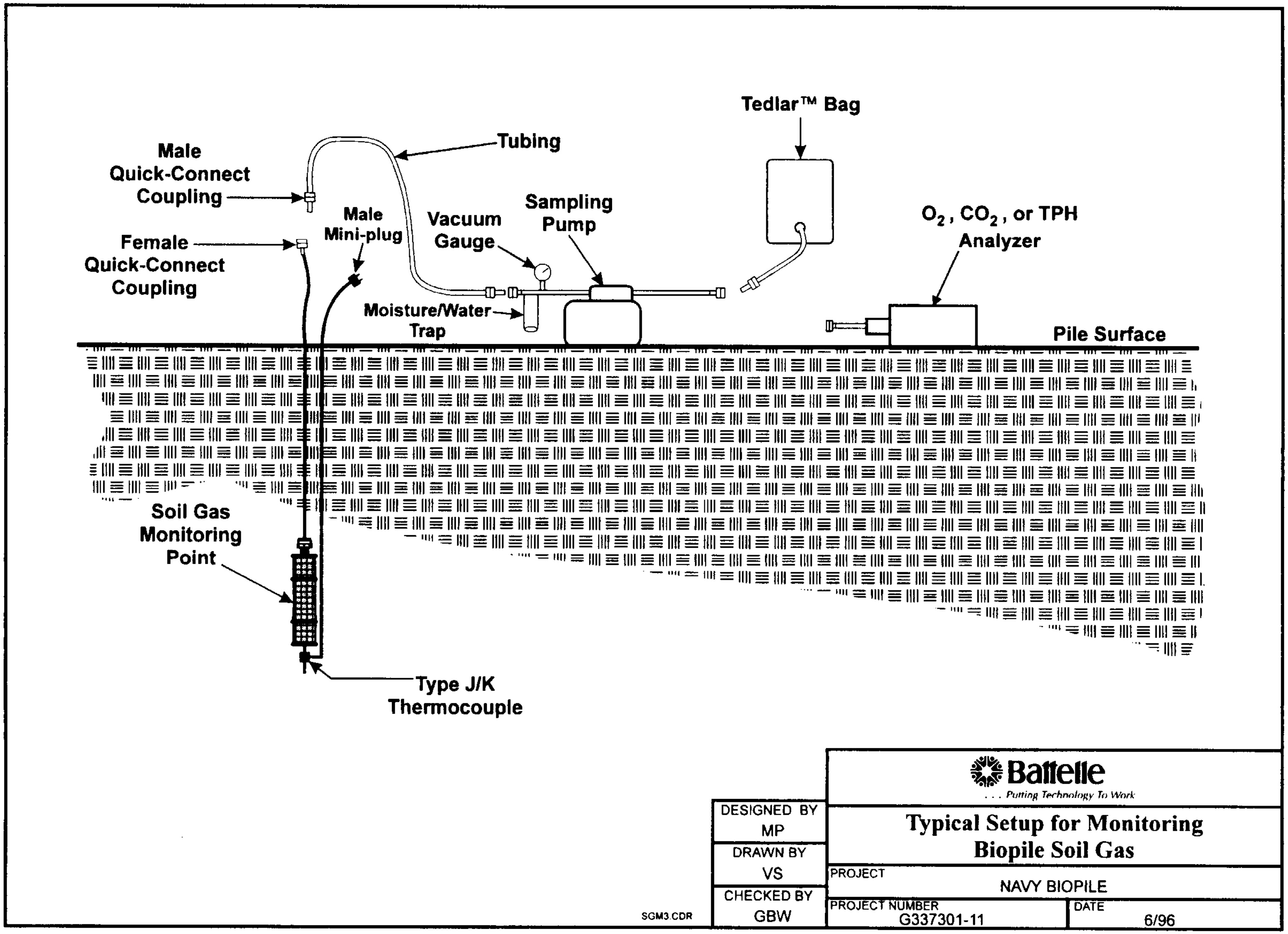

Figure 5. Typical Setup for Monitoring Biopile Soil Gas.

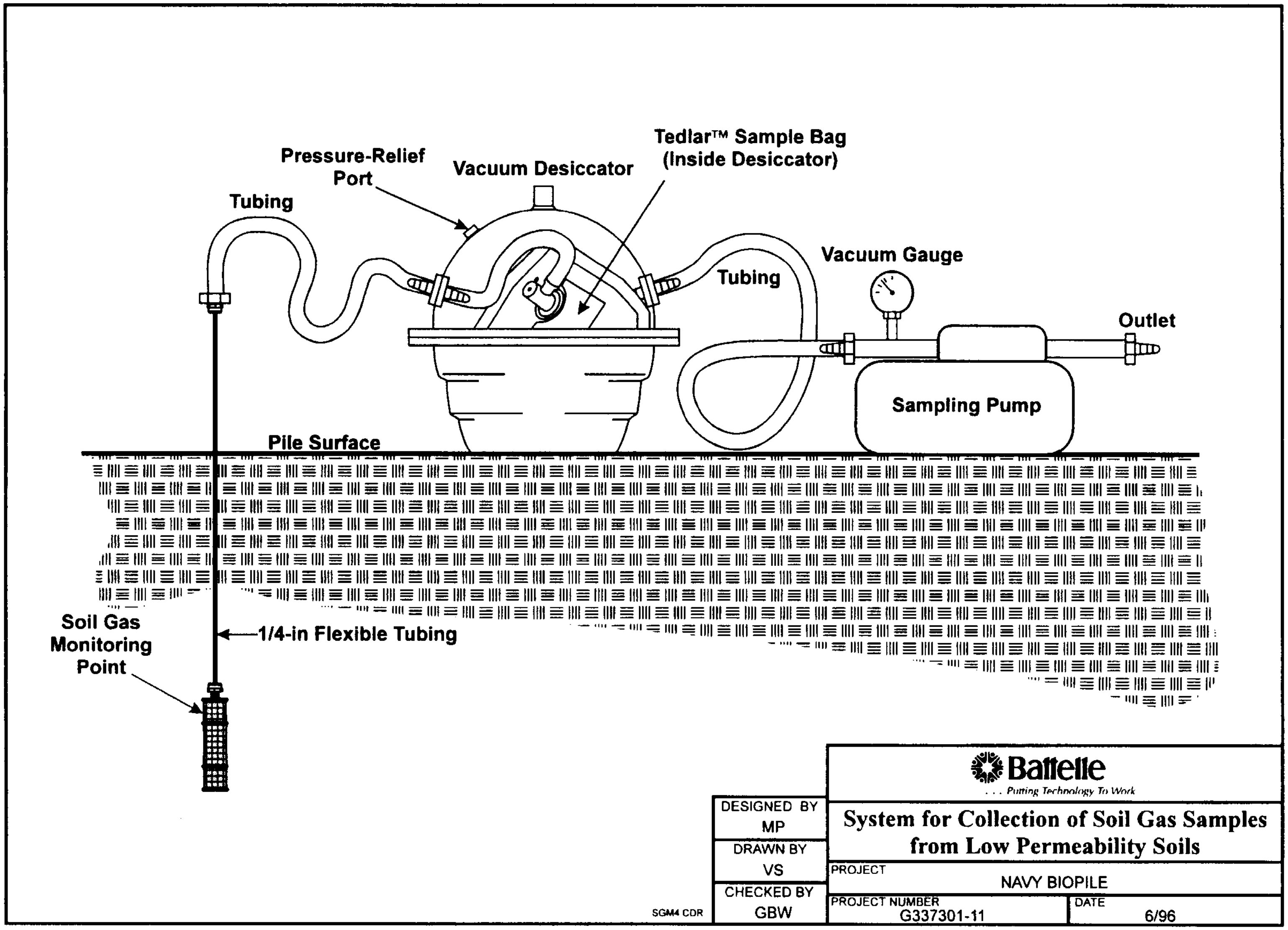

Figure 6. System for Collection of Soil Gas Samples from Low-Permeability Soils.

Step 6. Analyze the soil gas in the bag for O_2, CO_2, and TPH using portable gas analyzers. Record the readings on Data Sheet DS-2 (Appendix D). If the oxygen concentrations are below 10%, a 1:1 diluter must be used when the TPH concentrations are being analyzed.

4.2.4 Direct Soil Gas Sampling Method. A convenient alternative to the Tedlar™ bag sampling method is to directly attach the gas detector to the monitoring point lines via the quick-connect couplings and proceed as described in steps 1 through 4:

Step 1. Calibrate the O_2/CO_2 detector and the TPH detector using the appropriate span gases.

Step 2. Attach the O_2/CO_2 detector to the monitoring point and draw soil gas through the detector until the reading stabilizes. Do not record the initial reading, because enough soil gas must clear through the detector to equal the amount originally in the monitoring point sampling line.

Step 3. Record the O_2 and CO_2 readings on Data Sheet DS-2 (Appendix D).

Step 4. Repeat steps 1 through 3 using the TPH meter.

For TPH readings, this direct soil gas sampling method can be used only when the soil gas oxygen concentrations are $>10\%$. If the O_2 levels drop below 10%, the 1:1 diluter must be used to collect accurate TPH concentrations. Directly collecting soil gas samples with the 1:1 diluter attached to the TPH meter will improperly dilute the sample and generate incorrect data.

4.2.5 Soil Temperature Measurement. Soil temperature data are collected by means of soil temperature thermocouples or thermistors placed in predetermined locations and depths during the biopile construction. The data are collected through the thermocouple lead located in the monitoring point box. Temperature readouts are obtained by connecting a Fluke 52 or equivalent digital readout instrument to the thermocouple lead and recording the data. Temperature data are recorded along with soil gas data on Data Sheet DS-2 (Appendix D). To establish the net temperature increase in the biopile, changes in the ambient temperature also should be recorded on Data Sheet DS-2.

4.3 Leachate Sampling Method. Leachate samples should be collected by a grab sampling method. Grab samples of surface water are collected manually in a clean glass vessel and transferred immediately to a volatile organic analysis (VOA) vial. A Teflon™-lined cap is installed and the vial is inverted to ensure that there is zero headspace. Multiple vials may be filled from the single grab sample so that enough water is available for the analyses. After the sample is contained and properly labeled, place the sample on ice and ship it to a laboratory for the appropriate analyses.

4.4 Off-Gas Monitoring and Sampling. If off-gas monitoring is a regulatory requirement, the monitoring and sampling schedule will be site specific. A typical schedule for off-gas field measurements will include weekly monitoring with the results verified by monthly off-gas sampling and laboratory analysis (Checklist CL-3, Appendix C).

Generally, hand-held meters are used to monitor O_2, CO_2, and TPH concentrations in the vapor stream. TPH meters are available from several manufacturers and distributors. The operator should read the operating instruction manual and have continued access to it during instrument calibration and sampling. The off-gas stack emissions are monitored according to the following method:

Step 1. Install a female quick-connect fitting into the vapor discharge stack. Install a male quick-connect fitting onto a Tedlar™ bag.

Step 2. Calibrate the hand-held meters according to the operator's manual provided with each meter.

Step 3. Connect the Tedlar™ bag to the vapor discharge stack to collect an off-gas sample. Generally the pressure in the stack is great enough to inflate the Tedlar™ bag. However, a small diaphragm pump may be required to fill the sample bag.

Step 4. Analyze the off-gas sample for O_2, CO_2, and TPH using the hand-held meters.

An evacuated Summa canister often is required to collect and sample off-gas. A vapor sample is collected with a Summa canister according to the following method:

Step 1. Install a female quick-connect fitting into the vapor discharge stack. Install a male quick-connect fitting on the Summa canister.

Step 2. Check the vacuum on the Summa canister using a 0- to 10-inch (0- to 30.5-cm) mercury (Hg) vacuum gauge. Typically, the vacuum prior to sampling is ~30 inches (91.5 cm) Hg gauge pressure.

Step 3. Connect the Summa canister to the vapor discharge stack via the quick-connect fittings and open the valve on the Summa canister to collect the sample.

Step 4. Close the valve on the Summa canister and disconnect the canister from the stack. Recheck the vacuum in the Summa canister. It should now be at 0 inch (0 cm) Hg gauge pressure.

Step 5. Fill out the chain-of-custody form, package the form and the sample canister, and ship to the laboratory via air express for analysis.

4.5 Short-Circuiting of Air from the Edge of the Pile. One problem that may arise with a biopile is the air short-circuiting from the edge of the pile instead of being pulled evenly through the pile. This problem was alluded to in Section 3.2.1. Short-circuiting may be detected when monitoring soil gas pressures or during initial respiration testing. Each case is described further in the following sections.

4.5.1 Short-Circuiting and Soil Gas Pressures. When the blower is operating and pulling air through the pile, a vacuum is created in the pore spaces of the pile. This small vacuum ($\sim$2 inches [5.1 cm] H_2O) can be detected by attaching a vacuum gauge to the soil gas monitoring points. Generally, soil gas monitoring points that are not sealed from the atmosphere will have a smaller vacuum.

Use of vacuum gauges on the soil gas monitoring points is a field-expedient method for indicating if short-circuiting may be occurring. Difficulties with this method result from the fact that differences in soil gas pressure may not be the result of short-circuiting alone; some differences may result from heterogeneities in the soil.

4.5.2 Detection of Short-Circuiting During the Initial Respiration Test. Helium is mixed with the air as it is injected during the initial respiration test to determine if oxygen is being used in a reaction or if it is merely diffusing from the soil. He loss over time is attributable to either diffusion through the soil or leakage. A gradual loss of He along with a first-order curve generally indicates diffusion. A rapid drop in He concentration indicates leakage.

As a rough estimate, the diffusion of gas molecules is inversely proportional to the square root of the molecular weight of the gas. Based on molecular weights of 4 for He and 32 for O_2, He diffuses approximately 2.8 times faster than O_2. As a general rule, if He concentrations at test completion are at least 50% to 60% of the initial levels, the pile construction is satisfactory. Greater He loss indicates short-circuiting.

4.6 Correcting a Short Circuit. A short circuit can be corrected relatively easily by lowering the air flow through the leg closest to the area in which the short circuit was detected. A short circuit also may be remedied by adding more soil to the offending edge or portion of the edge of the biopile.

Section 5.0: REGULATORY REQUIREMENTS

Environmental regulations are categorized as chemical-specific, location-specific, and action-specific regulations. Each type may be issued at the federal, state, or local level. Examples of chemical-specific regulations include the federal Clean Air Act and Clean Water Act, which set numerical limits on the emissions and discharges of specific substances. Some chemical-specific regulations also specify target cleanup limits. Location-specific regulations include laws protecting site-specific resources such as endangered wildlife, wetlands, and wilderness areas. Action-specific regulations apply to specific activities or technologies and include monitoring requirements, effluent and leachate discharge limits from specific processes, and worker health and safety requirements.

Regulatory requirements for biopile operation can be divided into four groups: operational requirements, closeout requirements, disposal requirements, and Occupational Safety and Health Administration (OSHA) requirements. Operational, closeout, and disposal requirements are site specific based on federal, state, and local regulations. OSHA regulations, covering the health and safety of workers during remedial operations, are federal and state regulations that have been standardized for the remediation industry.

5.1 Operational Requirements. The primary operational regulatory requirements are chemical-specific regulations. The requirements focus on the discharge water and off-gas streams produced during biopile operation. The water discharge stream will be regulated by the Clean Water Act (CWA), and the off-gas stream will be regulated by the Clean Air Act (CAA).

The CWA sets standards and requirements for pollutant discharge to surface waters. The National Pollutant Discharge Elimination System (NPDES) (40 CFR Parts 122 and 125) requires permits for the discharge of pollutants from any point source into the waters of the United States. General pretreatment regulations for publicly owned treatment works (POTW) are enforceable standards if remediation results in discharge to a POTW.

If the process water is discharged to a body of water, the U.S. Water Quality Criteria apply (U.S. EPA, 1986). The water quality criteria are recommended ceiling concentrations of pollutants that were calculated to protect human health and aquatic life for ambient surface water quality. Criteria are set for both acute and chronic effects. Although these usually are nonenforceable concentrations, they may have been adopted by the state as part of that state's water quality standards.

The CAA, established in 1990, set standards for vapor and particulate air emissions. In addition to these federal standards, local authorities usually have air release permitting requirements. These release standards vary widely and may range from little or no formal regulation to contaminant-specific mass discharge rates. Some authorities base their standards on the concentration at the nearest receptor, but others consider each site on a case-by-case basis.

In addition to chemical-specific regulations, location-specific regulations may apply if the site is located in a unique area. The regulations vary widely by location. Potential location-specific areas include floodplains, wetlands, endangered species habitats, and archaeologically or historically significant sites.

5.2 Closeout Requirements. Prior to biopile construction, target cleanup levels should be negotiated with the lead agency based on the type of contaminant, extent of contamination, and limits of the technology. Target cleanup levels should be listed in the biopile design report and on the site Master Data Sheet (DS-1 in Appendix D). Sometimes the chosen cleanup levels are set based on public drinking water standards or Resource Conservation and Recovery Act (RCRA) Land Disposal Restriction (LDR) requirements. However, higher concentrations may be acceptable if risk-based analysis shows that the concentration is protective of human health and the environment.

Remediation of the biopile must be able to reach the required cleanup limits to be acceptable. For a biopile, the target cleanup level for TPH contamination generally ranges from 100 to 1,000 ppm. Some states may specify target cleanup levels for BTEX and PAH compounds. The actual target cleanup level is dependent on the initial TPH contamination level, the soil type, the desired final soil disposition, and the applicable regulatory agency's specifications.

5.3 Disposal Requirements. After closure requirements have been met, the remediated soil must be disposed of. With the exception of soils containing wastes regulated by the Toxic Substances Control Act (TSCA) or RCRA, there are no universal regulations governing soil disposal. Therefore, the method of disposal of the remediated soil must be negotiated with the lead regulatory agency point of contact. Often, the remediated soil is used as daily landfill cover or as agricultural backfill.

5.4 OSHA Requirements. All field and laboratory procedures must comply with OSHA regulations. All biopile field activities are regulated by the standards defined in OSHA's "Hazardous Waste Operations and Emergency Response" (29 CFR 1910.120). This standard requires a health and safety program to be in place prior to initiating field activities. The requirements for the health and safety program are discussed in Section 6.

Laboratory support activities are regulated by the OSHA chemical hygiene standards as defined in 29 CFR 1910.1450. This standard requires that the supporting laboratories have a Health and Safety Plan (HASP) for laboratory operations. Appendix H contains a general HASP outline the site manager can use to prepare a biopile operations HASP.

Section 6.0: HEALTH AND SAFETY REQUIREMENTS

The biopile must be designed and implemented in a manner that maximizes protection of health and safety for workers and the public. The biopile design must incorporate features to avoid unsafe conditions and activities. The health and safety program must comply with OSHA's provisions in 29 CFR 1910.120 and other OSHA requirements. All laboratory activities must comply with the OSHA chemical hygiene standards defined in 29 CFR 1910.1450. Additional health and safety standards generally applicable to protection of workers at biopile sites are summarized in Table 3.

Field activities are controlled by a site Health and Safety Plan (HASP), per 29 CFR 1910.120. The HASP must assign roles and responsibilities, establish standard operating procedures, and provide for safety contingencies. A typical HASP consists of a facility description; project and technology descriptions; key personnel and training requirements; hazardous and toxic materials identification; hazard evaluation; site control procedures; monitoring procedures; protective, monitoring, and emergency equipment; decontamination and disposal procedures; and emergency procedures.

Table 3. Applicable Health and Safety Regulations

Topic	Reference
General industry standards — 29 CFR Part 1910	
Walking and working surfaces	Subpart D 1910.21-.32
Occupational noise exposure	Subpart G 1910.95
Hazardous Waste Operations and Emergency Response	Subpart H 1910.120
Personal protective equipment	Subpart I 1910.132-.140
Sanitation	Subpart J 1910.141
Medical and first aid	Subpart K 1910.151-.153
Toxic and hazardous substances	Subpart Z 1910.1000-.1500
Construction industry standards — 29 CFR Part 1926	
Occupational health and environmental controls	Subpart D 1926.50-.57
Personal protective and life-saving equipment	Subpart E 1926.100-.107
Fire protection	Subpart F 1926.150-.155
Signs and signals	Subpart G 1926.200-.203
Motor vehicles and mechanical equipment	Subpart O 1926.600-.604
Excavations, trenching, and shoring	Subpart P 1926.650-.652
Power transmission and distribution	Subpart V 1926.950-.957

An annotated outline of a general HASP is found in Appendix H. The HASP must be developed individually for each site, because health and safety risks are highly site-specific, depending on the contaminants present and the nature of the demonstration activities that will be conducted. Table 4 lists the threshold limit values (TLVs) expressed as time-weighted averages (TWAs) for the primary contaminants that would be encountered at a site where a biopile is used to remediate petroleum hydrocarbon contamination.

Table 4. Threshold Limit Values for Contaminants Found in Petroleum-Contaminated Biopile Sites

Chemical	TWA (ppm)[a]
Benzene	10
Ethylbenzene	100
Toluene	50[b]
Xylenes	100
Gasoline	300
V.M. & P. naphtha[c]	300

(a) American Conference of Governmental Industrial Hygienists, 1995.
(b) Skin contact.
(c) Varnish Makers and Painters naphtha, a petroleum distillate.

Some of the hazards specific to biopile system installation and operation are summarized in Appendix B. Typical hazards, their sources, and some possible mitigation methods are presented in the appendix.

Training must be performed on a regular basis as part of the health and safety program. Personnel working at field operations must recognize and understand the potential health and safety risks associated with work at the site. All site personnel must be trained in accordance with the OSHA 29 CFR 1910.120 regulations covering hazardous waste operations and emergency response (HAZWOPER). Consistent with these regulations, each site team member must provide a document certifying the dates of his or her 40-hour HAZWOPER training (and the 8-hour annual refresher training, if applicable). Individuals designated as site supervisors must receive an additional 8 hours of supervisory training consistent with OSHA 29 CFR 1910.120.

All team members must have a minimum of 3 days of actual field experience under the direction of a skilled supervisor. Also, one team member trained and certified in first aid and cardiopulmonary respiration (CPR) should be present on the site during field activities.

The health and safety program also must include a medical surveillance program that complies with the regulations and guidelines set forth in OSHA 29 CFR 1910.120(f) and 29 CFR 1910.134. As a prerequisite to fieldwork, all workers must undergo a physical examination that includes a medical examination and documentation of work history with emphasis on symptoms related to the handling of hazardous substances, health hazards, and fitness for expected tasks, including the ability to wear any required personal protective equipment.

During employment, a physical examination must be performed at regular intervals as determined by the health and safety officer and the attending physician. In addition, upon termination of employment, another examination must be performed. Any worker who has received a potentially harmful level of exposure to a hazardous material must undergo a supplemental examination. Copies of medical documentation certifying that each worker is medically qualified to perform the tasks associated with biopile installation and implementation must be maintained on site at all times and include the date of the individual's last exam.

As part of the health and safety program, procedures must be implemented to maintain site-specific documentation. Documents required on site at all times include the HASP, material safety data sheets (MSDSs) for every chemical that is used and/or stored on site, medical records, health and training certification, and accident reports. These documents must be readily accessible by all field personnel.

Section 7.0: REFERENCES

American Conference of Governmental Industrial Hygienists (ACGIH). 1995. *1995-1996 Threshold Limit Values (TLVs™) for Chemical Substances and Physical Agents and Biological Exposure Indices (BEIs™)*.

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APPENDIX A

GLOSSARY OF TERMS USED TO DESCRIBE BIOPILE DESIGN AND IMPLEMENTATION

adsorption - the process by which molecules collect on and adhere to the surface of a solid due to chemical or physical forces

aeration - process of supplying or introducing air into a medium such as soil or water

aerobic biodegradation - biodegradation occurring in the presence of oxygen

aromatic hydrocarbon - a class of hydrocarbons consisting of cyclic conjugate carbon atoms, e.g. benzene

biodegradable - a material or compound that is able to be broken down by natural processes of living things such as metabolization by microorganisms

biodegrade - breaking down material (usually into more innocuous forms) by natural processes of living things such as metabolization by microorganisms

biodegradation rate - the mass of contaminant metabolized by microorganisms per unit time. In soil contamination this is normalized to the mass of soil and usually is expressed as mg contaminant degraded/kg soil-day (mg/kg-day).

biopile - soil pile constructed to allow aerobic bioremediation by aeration, possibly supplemented with water and nutrient additions

blower - a unit of rotating mechanical equipment used to increase the pressure in a gas stream and providing a total pressure rise of more than 4 inches of water and less than 14.7 psi

BTEX - benzene, toluene, ethylbenzene, and xylenes

bulking agent - biodegradable organic material, such as rice hulls or wood chips, added to improve the permeability, water-holding capacity, or other properties of soil to be treated in a biopile

CAA - Clean Air Act

CFR - Code of Federal Regulations

CL - checklist

clay - fine-grained soil that can exhibit putty-like properties within a range of water content and which shows considerable strength when air-dry

CO_2 - carbon dioxide

contaminant - something that makes material in contact with it impure, unfit, or unsafe; a pollutant

CPR - cardiopulmonary resuscitation

CRZ - contamination reduction zone

CWA - Clean Water Act

DoD - U.S. Department of Defense

DS - data sheet

ex situ - refers to a technology or process for which contaminated material must be removed from the site of contamination for treatment

extraction - aerating the biopile by removing air under vacuum to induce air flow

EZ - exclusion zone

FC - field capacity

field capacity - the amount of water held in soil after excess water has drained away and after the rate of downward drainage has become negligible

GAC - granular activated carbon

hand-auger drilling - hand-drilling by rotating a spiral channel supported on a shaft

HAZWOPER - hazardous waste operations and emergency response

HDPE - high-density polyethylene

He - helium

heterotrophic bacteria - bacteria that obtain energy and carbon from organic compounds

Hg - mercury

impermeable membrane - sheeting material designed to retain water

injection - aerating the biopile by forcing in air under vacuum to induce air flow

in situ remediation - a treatment process that can be carried out within the site of contamination without bulk excavation

K - elemental potassium

LDR - Land Disposal Restriction

leachate collection point - area to which biopile leachate drains and from which leachate is transferred to the collection tank via a leachate suction line

LLC - liquid level controller

monitoring point - soil gas sampling port consisting of a porous gas collection port connected to tubing that is placed in the biopile to allow withdrawal of a gas sample for analysis

N - elemental nitrogen

NFESC - Naval Facilities Engineering Service Center

NPDES - National Pollutant Discharge Elimination System

nutrient amendment - chemical or organic fertilizer, usually rich in nitrogen, phosphorus, or potassium, that is added to support the life and growth of microorganisms in the biopile

O_2 - molecular oxygen

off-gas - gaseous effluent, possibly containing contaminant vapors, that leaves a process, typically from a point source during process operations

O&M - operations and maintenance

OSHA - Occupational Safety and Health Administration; Occupational Safety and Health Act

oxygen use rate - rate of oxygen consumption due to biological and chemical action (used to determine respiration rate when the chemical oxygen demand is negligible)

P - elemental phosphorus

permeability - measure of the capacity of a rock, soil, or sediment to allow passage of liquid or gas through its pores without damage to the structure of the media

PAH - polycyclic aromatic hydrocarbon

PCB - polychlorinated biphenyl

pH - measure of the acidity or alkalinity of a solution; the negative log of the hydrogen ion activity

PID - photoionization detector

pore space - the void space and minute passages in a solid material

porosity - measure of the amount of available pore space in a material through which liquid and gas can move

POTW - publicly owned treatment works

PPE - personal protective equipment

ppmv - part(s) per million by volume (indicates vapor concentration)

PVC - polyvinyl chloride

QA/QC - quality assurance/quality control

RA - remedial action

RCRA - Resource Conservation and Recovery Act

remediation - activity involved with reducing the risk from a contaminated site

respiration - oxidation of compounds to provide energy for cells

respiration rate - rate of reduction of oxygen concentration due to biological action

respiration test - test used to provide rapid field measurement of biodegradation rates to determine the potential applicability of aerobic bioremediation at a contaminated site and to provide information for a full-scale treatment system design

rH - relative humidity

sand - unconsolidated rock and mineral particles with diameters ranging from 1/16 to 2 mm

scfm - standard cubic feet per minute

shredding - mixing and grinding soil to improve homogeneity and increase permeability

short-circuiting - undesirable condition in which air flows unevenly through the biopile due to the existence of low-resistance pathways

silt - unconsolidated rock and mineral particles with diameters ranging from 0.0002 to 0.05 mm

sLm - standard liter per minute

soil gas - mixture of air and vapors in soil porosity

soil gas permeability - a soil's capacity to allow gas flow. The soil gas permeability varies according to grain size, soil uniformity, porosity, and moisture content.

soil matrix - soil as the environmental media containing contaminants

soil type - system of classification of soils based on physical properties

soil vapor extraction - an in situ soil aeration process designed and operated to maximize the volatilization of low-molecular-weight compounds, with some biodegradation occurring sorption - general term for physical and chemical absorption and adsorption phenomena

TLV - threshold limit values

TPH - total petroleum hydrocarbons

treatability study - a planned group of measurements, bench-scale studies, or pilot-scale studies performed to measure the effectiveness of a process option for remediating a contaminated site or to collect design data for implementing a process option

TSCA - Toxic Substances Control Act

TWA - time-weighted average

UCL - upper confidence limit

U.S. DoD - United States Department of Defense

U.S. EPA - United States Environmental Protection Agency

UST - underground storage tank

vacuum pump - a unit of mechanical equipment used to increase the pressure in a gas stream and providing a nearly complete vacuum at the suction flange

vapor pressure - the pressure exerted by a single component phase at a given temperature

V. M. & P. - Varnish Makers and Painters

VOA - volatile organic analysis

VOC - volatile organic compound

volatile - easily vaporized at relatively low temperatures

APPENDIX B

HAZARD SOURCES AND MITIGATION METHODS IN BIOPILE IMPLEMENTATION

Hazard	Typical Hazard Sources	Possible Mitigation Methods
Flying particulates	Rotating equipment such as blowers, soil shredders, paddle mixers	• Safety glasses
Binding-in equipment	Rotating equipment such as blowers, soil shredders, paddle mixers	• Shields to prevent contact with rotating equipment
Objects striking head	Overhead operations such as front-end loaders	• Proper rigging practices • Hard hats
Objects striking foot	Equipment operations such as front-end loaders	• Proper rigging practices • Steel-toed shoes
Slips, trips, and falls	General site hazards	• Good housekeeping • Limit access to site with fencing
Exposure to organic contaminants in soil or organic liquids	Organic contaminants	• Monitoring • Good housekeeping • Gloves, coveralls, boot covers
Exposure to organic vapors	Organic contaminants	• Monitoring • Respirators
Exposure to dust	Dust created from moving, screening, shredding, and blending soils	• Monitoring • Face mask, respirators
Exposure to dust	Chemical dust created by adding nutrients to soil	• Monitoring • Proper nutrient addition • Face mask, respirator
Dermal exposure	Nutrient additives	• Use of proper procedures • Gloves, coveralls, boot covers
Electric shock	Power supply to mechanical equipment and instruments	• Follow local utility codes • Do not use temporary wiring • Disconnect, tag, and lock out power supply before doing maintenance (see OSHA 29 CFR 1910.147)
Fire and explosion	Organic vapors	• Use explosion-proof equipment • Monitor • Provide ventilation for enclosures (e.g. blower shelter)
Noise	Pumps, blowers, shredders, mixers Nearby aircraft or vehicles	• Monitor • Hearing protection equipment (see OSHA 29 CFR 1910.95)
Vehicle hazards	Site vehicle operations (e.g., front-end loader)	• Train and license personnel for operation of site equipment
Traffic	Vehicle operations near the site	• Install distinctive marking, lights, and barricades • Limit access to site with fencing

APPENDIX C

OPERATIONAL CHECKLISTS

General Biopile Worker Training Checklist (CL-1)

Treatment Cell: ________ Soil Batch: ________

Date: ________ Operator's Initials: _______

Safety and Security Feature Checked	Yes	No	Document Corrective Action Taken for any Features Checked "No"
Are employees trained in the use of required safety equipment such as respirator, protective clothing, eye protection, and hearing protection?			
Are frequent, regularly scheduled safety meetings and training sessions held and documented?			
Are employee training records up to date and available for inspection?			
Are employees who use soil moving and handling equipment trained/licensed in its use?			
Are employees who use soil shredding and similar equipment trained/licensed in its use?			
Are employees familiar with hazards due to petroleum hydrocarbons, fertilizer chemicals, and any other chemicals used in biopiles?			
Are all employees aware of the contents and location of Material Safety Data Sheets (MSDSs)?			
Do employees use appropriate protective gear and equipment when handling contaminated soil or chemicals?			
Is work area marked with fencing, caution tape, or other boundary marker?			
Are eye washes, safety showers, respirators (if required), and other personal protective equipment readily available and in good working order?			
Are employees instructed not to eat or smoke in the biopile area?			
Are warning signs regarding chemical and no smoking areas prominently displayed?			
Have employees read and signed off on HASP?			

Biopile System Startup Checklist (CL-2a)

Treatment Cell: ________ Soil Batch: ________

Date: ________ Operator's Initials: _______

Activity	Check When Done	Enter Data/Comments
Record initial characterization data for soil batch in cell		Attach Data Sheet DS-1
Inspect berm		
Inspect cover and tiedowns		
Ensure that the biopile aeration manifold is installed and intact		
Inspect blower		
Inspect water knockout tank		
Inspect blower piping		
Ensure grounding connections are properly installed and functional		
Inspect and manually cycle valves		
Inspect instrumentation		
Ensure all air flow balancing valves are open; if so, ensure they are returned to original position		
Start blower		
Adjust equal air flow to each extraction leg		
Measure air flow in each extraction leg		
Measure air flow, pressure, and temperature at outlet of blower		
Shut off blower		
Place soil into biopile treatment cell as described in Design and Construction Manual		
Collect initial soil samples		Attach Data Sheet DS-3
Inspect condition of monitoring points		
Ensure that off-gas treatment system is installed and operational		
Ensure that off-gas treatment system fuel supply (if required) is available		
Check and field-calibrate instruments GasTech™ O_2/CO_2 analyzer TraceTector™ hydrocarbon analyzer Fluke™ thermocouple reader		

Biopile System Startup Checklist (CL-2b)

Activity	Check When Done	Enter Data/Comments
Measure temperature and soil gas composition (O_2, CO_2, and TPH) in monitoring points		Attach Data Sheet DS-2
Restart blower[(a)]		
Repeat monitoring point measurements until oxygen concentrations stabilize		Attach Data Sheet DS-2
Stop blower and perform shutdown respiration test[(b)]		Use Data Sheet DS-2
Readjust air flow balance based on oxygen (and shutdown respiration[(b)]) measurements		
After O_2 concentrations stabilize, adjust air flow in each manifold leg to achieve 15 to 18% O_2 in each monitoring point		
Remeasure air flow, pressure, and temperature at inlet of blower		

(a) Optional startup testing activity.
(b) Perform 24 to 48 hours after initiating blower if not conducted as part of biopile construction.

Biopile System Periodic Inspection Checklist (CL-3)

Treatment Cell: ________ Soil Batch: ________

Date: ________ Operator's Initials: _______

Activity	Check When Done	Data/Comments
Inspect berm (weekly)		
Inspect cover and tiedowns (weekly)		
Inspect water knockout tank and transfer pump (weekly)		
Measure organic vapor concentration at inlet, between canisters, and at the outlet of off-gas treatment system. (Frequency as required for regulatory compliance, or weekly.)		
Collect off-gas samples in Summa cans or Tedlar™ bags from inlet of GAC unit, between GAC canisters, and from outlet (monthly)		
Inspect the condition of the off-gas treatment system (weekly)		
Inspect blower (weekly)		
Inspect blower piping (weekly)		
Inspect instrumentation (weekly)		
Inspect condition of monitoring points (monthly)		
Check and field-calibrate instruments (monthly) GasTech™ O_2/CO_2 analyzer TraceTector™ hydrocarbon analyzer Fluke™ thermocouple reader		
Measure temperature and soil gas composition (O_2, CO_2, TPH) in monitoring points (monthly)		Attach Data Sheet DS-2
Measure air flow in each extraction leg (monthly)		
Measure air flow pressure at blower outlet and vacuum at inlet of blower (monthly)		
Perform shutdown respiration test (monthly)		Attach Data Sheet DS-2
Perform housekeeping inspection (monthly)		Attach Checklist CL-4

If problems are detected, refer to Maintenance Log (Data Sheet DS-4) and Troubleshooting Guidelines (Appendix E).

Monthly Biopile Spill Control and Housekeeping Checklist (CL-4)

Treatment Cell: ________ Soil Batch: ________

Date: ________ Operator's Initials: ______

Spill Control/Housekeeping Feature Checked	Yes	No	Document Corrective Action Taken for any Features Checked "No"
Are containers accurately labeled?			
Are MSDSs available?			
Are incompatible chemical types stored in separate area?			
Are flammable and combustible materials segregated from ignition sources?			
Is fire-fighting equipment available and operational?			
Are bulk chemicals stored under a roof or other cover?			
Is fugitive dust from dry fertilizer, soil, or other solids contained and controlled?			
Are bulk chemical storage areas contained by a berm?			
Is the berm of the contained area capable of holding 110% of the largest single liquid container volume?			
Are containers adequate? (Identify and repair or contain any damaged or deteriorating containers.)			
Is general area clean and free of debris? (Identify and clean up spills and repair leaks.)			
Is spill control kit available? (e.g., plugs; absorbent pads, booms, and particulate; brooms, mops, and scoops; pails; and overpacks)			

APPENDIX D

DATA SHEETS

Biopile Master Data Sheet (DS-1)

Site Location ______________________ Site Operator ______________________

______________________ ______________________

Treatment Cell ID ______________ Date Constructed ______________________

Soil Volume in Biopile (yd^3 or m^3) ______________

Contamination Type (1)______________ Initial Concentration (mg/kg) (1)__________

(2)______________ (2)__________

(3)______________ (3)__________

(4)______________ (4)__________

(5)______________ (5)__________

(6)______________ (6)__________

Soil moisture content as received: (wt%) ________ (% field capacity[a])________

Soil nutrient content as received:

nitrogen (N) (mg/kg)________

phosphorus (P) (mg/kg)________

potassium (K) (mg/kg)________

Soil nutrient content as adjusted:

N (mg/kg)__________

P (mg/kg)__________

K (mg/kg)__________

Soil moisture content as adjusted: (wt%)________ (% field capacity)________

Acceptable moisture range to reach
a 70 to 95% field capacity: (wt%)________

Initial total organic carbon in soil: (mg/kg)________

Initial heterotrophic bacteria in soil (cfu/g dry soil): ______________

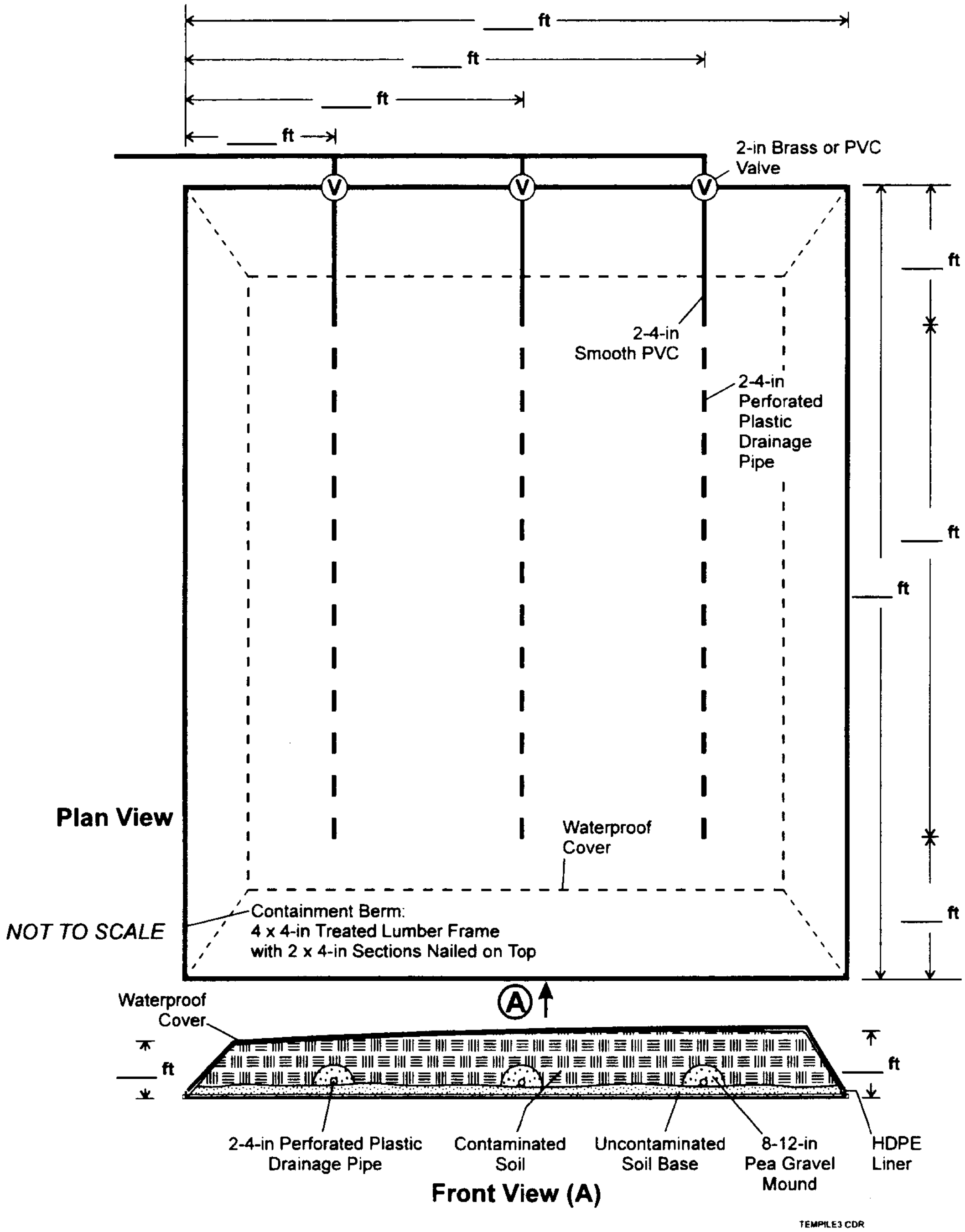
Date of Initial Soil Samples[b] (N/A if not taken) ______________

Date of Initial Respiration Test (N/A if not performed) ______________

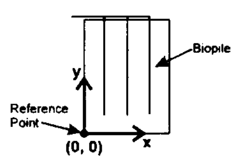
(a) Acceptable field capacity range is 70 to 95% of field capacity. See Appendix G of the Biopile Design and Construction Manual (NFESC, 1996) for methods of determining field capacity. Appendix F of this O&M Manual has a table of estimated field capacities related to moisture content for various soil types.

(b) Soil sample locations are shown on the attached plan view of a biopile cell. The plan view of a biopile cell should illustrate pile dimensions, aeration manifold location, soil monitoring point locations, and locations of initial soil samples. Indicate locations of monitoring points with an "X" and label each. Indicate locations of initial soil samples with a circle and label each. These labels should cross-reference to the initial soil gas and soil data sheets (DS-2 and DS-3) that should be attached to complete this Master Data Sheet.

Biopile Master Data Sheet (continued)



	Sample Labels	Grid Coordinates
Monitoring Point Location =	MP1 ×	(x_1, y_1)
Soil Sample Location =	S1 ●	(x_2, y_2)



Monitoring Point Data Sheet (DS-2)

Date: ______________ Time: _______ Ambient Temperature: ________

Monitoring Point	Depth (ft bgs)[a]	O_2 (%)	CO_2 (%)	TPH (ppmv)	Temperature (°C)	Moisture (%)	He[b] (ppmv)

(a) bgs = below ground surface.
(b) Use this column when performing an initial respiration test.

Soil Sample Data Sheet (DS-3)

Person collecting sample: ______________________________ Reference Point (0,0) ________

Sample Identification	Date	Time	Sample Depth	Location (X,Y)

Maintenance Log (DS-4)

Date/Time	Nature of Problem	Corrective Action

Chain-of-Custody Record (DS-5)

Proj. No.	Project Title
SAMPLERS: (Signature)	

DATE	TIME	SAMPLE I.D.	SAMPLE TYPE (√)														Container No.	Number of Containers	Remarks

Relinquished by: (Signature)	Date/Time	Received by: (Signature)	Relinquished by: (Signature)	Date/Time	Received by: (Signature)
Relinquished by: (Signature)	Date/Time	Received by: (Signature)	Relinquished by: (Signature)	Date/Time	Received by: (Signature)
Relinquished by: (Signature)	Date/Time	Received for Laboratory by: (Signature)	Date/Time	Remarks	

Page ______ of ______

Treatment Report Data Sheet (DS-6)

Site Location ______________________________ Site Operator ______________________________

______________________________ ______________________________

Treatment Cell ID ______________________ Date Constructed ________________

Date Completed ________________

Soil Volume Treated (yd^3 or m^3) __________

Final Disposition ______________________ Final Destination ______________________________

Date Transported ______________________ ______________________________

Releasing Official ______________________ Transporting Company ______________________

______________________________ ______________________________

Receiving Official and Station ____________

____

Contaminant	Initial Concentration (mg/kg)	Final Concentration (mg/kg)	Cleanup Target[a] (mg/kg)

(a) Attach supporting analytical laboratory results.

APPENDIX E

TROUBLESHOOTING GUIDE

Problems that may occur while operating the biopile remediation system are described in the following table. The table lists the problem, the most likely causes for each problem, and the corrective action that should be taken to correct the problem. In the case of electrical problems, a certified electrician should be called to diagnose the problem and perform the repairs. In general, pumps and blowers should not be disassembled in the field as this may void the manufacturer's warranty and compromise the explosion-proof rating of the unit. Repair of these units should be performed by the manufacturer or a licensed repair shop.

Table E-1. Troubleshooting Guidelines for Operating a Biopile Treatment System

Problem	Probable Cause	Corrective Action
Blower will not start	Power is off	Turn on power
	Motor and fan seized up	Remove from housing clean fan and shaft, manually rotate to free-up shaft and fan. If rotor turns but makes a rattling noise bearings may be bad. Have bearing replaced. Refer to manufacturer's literature before servicing the blower. Opening an explosion-proof blower may void the warranty and may compromise the integrity of the explosion-proof seal. If necessary, ship blower to manufacturer for repair.
	Motor overload element burned out	Check continuity on each of the elements. The elements are located on the motor starter inside the motor starter box. Turn the power off to the blower, open the motor starter box, unscrew the elements and replace the burned-out elements with identical parts.
	Coil burnout in motor starter	Turn off power to the blower. Open the motor starter box and replace the motor starter. Consult a qualified electrician.
Blower trips on motor current	Low line voltage	Check line voltage. Low voltage may be the result of a voltage drop resulting from other equipment operating on the same circuit. Consider a step-up transformer. Consult a qualified electrician.
	Short in motor	Measure motor resistance and replace, if defective. Defective windings can be replaced at motor refurbishing shops.
	Excessive load	Check inlet plumbing for water, remove water if present. Examine knockout tank and float switch to determine if they are operating properly. Turn blower on; measure current.
		Rotate rotor by hand. If rotor turns but makes a rattling noise, the bearings may be bad. Have bearings replaced. If motor will not turn, there may be an internal obstruction. Refer to manufacturer's literature before servicing the blower. Opening an explosion-proof blower may void the warranty and may compromise the integrity of the explosion-proof seal. If necessary, ship the blower to the manufacturer for repair.

Table E-1. Troubleshooting Guidelines for Operating a Biopile Treatment System (Continued)

Problem	Probable Cause	Corrective Action
Blower trips on high motor temperature	Low flowrate through blower or high load on motor	Turn off blower, check suction and discharge piping, and clear obstruction. Check for excessive moisture content. Check cover condition, moisture addition system (if any), and other sources of excessive water addition. Check operation of water knockout tank.
		Check pressure drop across carbon drums. Significant backpressure will prevent air from flowing through the blower causing the blower to overheat. Backpressure may be created in the drums if the drums fill with water or particulate. Measure the exhaust gas flowrate with the carbon drums in place. Remove the drums and remeasure the flowrate. Replace the drums if the drums are preventing the blower from operating properly. Check the drums for water. If significant water is present, examine the knockout system.
	Defective thermostat	Replace thermostat. Refer to the manufacturer's literature for thermostat specifications. Consult a qualified electrician.
Knockout tank will not drain	Discharge valve is closed	Open valve.
	Transfer pump is not operating	Check transfer pump, make necessary repairs (refer to problems associated with the transfer pump). Follow manufacturer's literature.
	Float switch is bad	Check continuity of float switch. Replace bad switch.
Excessive water collection rate in water knockout tank	High water content in biopile	Check soil moisture and if $>95\%$ of field capacity, check cover condition, moisture addition system (if any), and other sources of excessive water addition.
Transfer pump inoperative	No power	Check power supply. Ensure all breakers are on.
	Bad fuse or motor overcurrent element	A variety of types of small pumps may be used. Follow manufacturer's literature for replacing fuses or similar devices.
High organic vapor content in off-gas	Activated carbon capacity exhausted	Replace carbon canister.
	Activated carbon damaged by water intrusion or condensation	Replace carbon canister.
High pressure drop in off-gas treatment system	Activated carbon plugged with particulate	Replace carbon canister.
	Activated carbon damaged by water intrusion or condensation	Replace carbon canister.
Small rip in the biopile plastic cover	Penetrated by rocks or metal. Cover becomes worn out over time	Wipe down the ripped area. Ensure surfaces to be joined by tape are clean. Repair with duct tape.
Large rip in the biopile plastic cover	Torn by rocks or metal. Cover becomes worn out over time	Wipe down the ripped area. Try to patch the area with a scrap piece of plastic and duct tape. If patching does not work, replace the cover.

Table E-1. Troubleshooting Guidelines for Operating a Biopile Treatment System (Continued)

Problem	Probable Cause	Corrective Action
Oxygen concentration in monitoring point drops below 10%	Air flow has short-circuited	Compact dirt around the area that is short-circuiting.
		Add dirt to the area that is short-circuiting.
		Increase air flowrate to the area by adjusting valves.
	Monitoring point is located in soil with low porosity	Continue sampling and note the low reading.
Oxygen concentrations decrease below 10% in multiple monitoring points	Air flow has short-circuited through the sides of the pile	Repack the sides of the pile.
		Add dirt to sides of pile.
	High microbial activity consumes oxygen rapidly	Increase air flowrate to reach oxygen concentrations of 15 to 18%.
Biopile dries up	High aeration flowrate	Decrease aeration flowrate or cycle flowrate on/off.
	Insufficient moisture addition	Add water to 70 to 95% of field capacity.
Parts of the biopile dry up	Inconsistent moisture addition across pile	Reconfigure moisture-addition system.
Biodegradation not occurring	Biopile is dry	See above.
	Moisture content too high	Check for leaks in pile cover and repair and replace cover.
		Decrease moisture addition rate.
		Increase air flowrate.
	Insufficient nutrients	Add nutrients at concentrations specified in design manual.
	Insufficient air flow	See above.
	Insufficient microbes	Check fuel-degrading microbe population density.
Pile temperature exceeds a 45°C average	High microbial activity	Increase air flowrate to reduce temperature to below 45°C.

APPENDIX F

FIELD CAPACITY AND BULK DENSITY APPROXIMATION FOR VARIOUS SOIL TYPES
(Adapted from: Lyle, 1987)

Soil Texture[1]	Field Capacity (kg H_2O/kg dry soil)	Bulk Density (kg/m^3)
Silt loam and clay loam	26.0	1,300
Loam	25.0	1,390
Very fine sandy loam	22.0	1,350
Fine sandy loam	20.0	1,350
Sandy loam	16.0	1,400
Loamy fine sand	13.5	1,400
Loamy sand	11.0	1,450
Fine sand	9.0	1,450
Sand	9.0	1,500
Coarse sand	6.0	1,600

(1) These values should be used as estimates only. Actual values for any specific soil could vary significantly.

Appendix F Reference

Lyle, Jr., E.S. 1987. *Surface Mine Reclamation Manual*. Elsevier, New York.

APPENDIX G

RESPIRATION TEST DATA CALCULATION AND WORKSHEET

The respiration test is performed to obtain data for calculating the TPH degradation rates in the biopile soil. In the respiration test, O_2 levels are measured in soil gas sampled from the monitoring points installed in various locations of the biopile. Readings generally are taken until oxygen concentrations drop below 7% or until the O_2 concentration no longer decreases. If O_2 decreases rapidly, more frequent readings will be necessary than if O_2 decreases slowly. To determine the oxygen utilization rate, oxygen percent is plotted against time. The slope of this line is referred to as the oxygen utilization rate and is reported as change of oxygen percent per day.

If low oxygen levels become a limiting factor for biodegradation, the slope of the line will level off and no longer be indicative of oxygen consumption relative to TPH degradation. In this case, only the linear portion of the curve, generally limited to data points at or above 12% O_2, will be used to calculate biodegradation rates.

The stoichiometric relationship between oxygen consumption and TPH degradation using hexane as a representative compound is shown in Equation 1:

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

Using this equation, the biodegradation rate in terms of milligrams of hexane-equivalent per kilogram of soil per day can be estimated.

The first step in this calculation (Equation 2) is to convert the percentage of O_2 in soil gas to the actual amount in the form of mg O_2/kg of soil. Properties of both oxygen and the soil consistency in the biopile are used to calculate this value. One mole of air at a temperature of 300 K would occupy a volume of 24.6 L. Assuming a soil-gas oxygen concentration such as that of ambient air (20.9%), only 5.14 L of the 24.6 L/mole soil gas would be occupied by O_2.

$$24.6 \text{ L/mole of soil gas} \times 20.9\% \ O_2 = 5.14 \text{ L of } O_2\text{/mole of soil gas} \qquad (2)$$

This value would vary according to the reported oxygen concentration. As shown in Equation 3, for example, an oxygen concentration of 15% would result in 3.69 L O_2/mole of air instead of 5.14 L O_2/mole of soil gas.

$$24.6 \text{ L/mole of soil gas} \times 15\% \ O_2 = 3.69 \text{ L of } O_2\text{/mole of soil gas} \qquad (3)$$

To determine the mass of the 5.14 L O_2/mole of soil gas, the density of O_2 must be used. Because 1 mole of O_2 would have a mass of 32 g and occupy a volume of 24.6 L, the density of O_2 would be 1,300 mg/L (Equations 4 and 5).

$$32 \text{ g} \div 24.6 \text{ L of } O_2 = 1.300 \text{ g/L of } O_2 \qquad (4)$$

$$1.300 \text{ g/L of } O_2 \times 1000 \text{ mg/g} = 1{,}300 \text{ mg/L of } O_2 \qquad (5)$$

This value multiplied by 5.14 L/mole soil gas would yield 6,682 mg O_2/mole soil gas (Equation 6) or 271.6 mg O_2/L soil gas (Equation 7).

$$1{,}300 \text{ mg/L of } O_2 \times 5.14 \text{ L of } O_2\text{/mole of soil gas} = 6{,}682 \text{ mg } O_2\text{/mole of soil gas} \quad (6)$$

$$6{,}682 \text{ mg } O_2\text{/mole of soil gas} \div 24.6 \text{ L/mole of soil gas} = 271.6 \text{ mg } O_2\text{/L soil gas} \quad (7)$$

Once this relationship has been established, it must be determined what quantity of oxygen would exist in the void volume of 1 kg of soil. Assuming a soil density of 2,400 lb/yd^3 (1,424 kg/m^3), Equation 8 shows that 1 kg of soil would occupy a volume of 0.702 L.

$$(1{,}424 \text{ m}^3\text{/kg}) \times 1{,}000 \text{ L/m}^3 = 0.702 \text{ L/kg} \quad (8)$$

Assuming a void volume of 30% in the soil, the volume of 1 kg of soil that would be occupied by soil gas is 0.21 L (Equation 9).

$$0.702 \text{ L/kg} \times 30\% \text{ void volume} = 0.21 \text{ L soil gas/kg soil} \quad (9)$$

Using the conversion factor from Equation 7 of 271.6 mg O_2/L air, it can be calculated in Equation 10 that 57.04 mg of O_2 would be present in 1 kg of soil at an O_2 concentration of 20.9%.

$$0.21 \text{ L soil gas/kg soil} \times 271.6 \text{ mg } O_2\text{/L soil gas} = 57.04 \text{ mg } O_2\text{/kg soil} \quad (10)$$

Once the change in mass of O_2 has been calculated, Equation 1 can be used to determine the mass of hydrocarbons that theoretically would be degraded. The equation yields a hydrocarbon-to-oxygen mass ratio of 1:3.5 to oxidize hexane. Therefore, if a decrease of 50 mg O_2/kg soil were seen, then it could be assumed that 14.3 mg TPH/kg of soil had been degraded. As shown in Equation 11, the TPH degradation rate can be calculated from the O_2 degradation rate (mg O_2/kg·h) divided by 3.5, which is the O_2-to-hydrocarbon mass ratio described above.

$$50 \text{ mg } O_2\text{/kg} \div 3.5 \text{ mg } O_2\text{/mg TPH} = 14.3 \text{ mg TPH/kg of soil} \quad (11)$$

Figure G-1 is a completed example of a worksheet to convert respiration sampling data (%O_2 decrease with time) to the TPH degradation rate. Figure G-2 is a blank TPH degradation worksheet that can be copied and used on site.

TPH DEGRADATION RATE WORKSHEET

1. a) O_2 concentration reading at time of blower shutdown	20	%
b) O_2 concentration reading nearest to and greater than 12%	15	%
c) Change in O_2 concentration (Line 1a − Line 1b)	5	%
2. a) Elapsed time from shutdown to final O_2 reading	1	hr
3. Oxygen Utilization Rate		
a) Change in O_2 concentration/elapsed time (Line 1c/Line 2a)	5	%/hr
b) Line 3a × 24	120	%/day

Based on the oxygen utilization rate, use the following equation to calculate degradation rate:

$$K_B = \frac{-K_O A D_O C}{100}$$

where:

K_B = degradation rate (mg/kg-day)		
K_O = oxygen utilization rate (%/day)		
From Line 3b	120	%/day
4. A = volume of air/kg soil (L/kg)		
a) Density of soil (if unknown assume a bulk density of 2,400 lb/yd^3)	2,400	lb/yd^3
b) Vol soil/kg soil: (764.6 L/yd^3 × 2.205 lb/kg) ÷ Line 4a =	0.702	L/kg
c) Vol air/kg soil: Line 4b × 0.30* = * (assuming 30% soil porosity)	0.21	L/kg
5. D_O = density of oxygen gas (mg/L)		
a) Size temperature: °C** + 273 = ** (assume 27°C if unknown)	300	K
b) Volume per mole: 0.08205 × Line 5a =	24.6	L/mole
c) Mass O_2 per liter: 32,000 mg/mole ÷ Line 5b	1,300	mg/L
6. C = mass ratio of hydrocarbon to oxygen required for mineralization (1/3.5)	0.2857	
TPH Degradation Rate = (Line 3b × Line 4c × Line 5c × Line 6) ÷ 100	93.9	mg/kg-day

Figure G-1. Example of a Completed TPH Degradation Rate Worksheet.

TPH DEGRADATION RATE WORKSHEET

1.	a)	O_2 concentration reading at time of blower shutdown	______ %
	b)	O_2 concentration reading nearest to and greater than 12%	______ %
	c)	Change in O_2 concentration (Line 1a − Line 1b)	______ %
2.	a)	Elapsed time from shutdown to final O_2 reading	______ hr
3.		Oxygen Utilization Rate	
	a)	Change in O_2 concentration/elapsed time (Line 1c/Line 2a)	______ %/hr
	b)	Line 3a × 24	______ %/day

Based on the oxygen utilization rate, use the following equation to calculate degradation rate:

$$K_B = \frac{-K_O A D_O C}{100}$$

where:

K_B = degradation rate (mg/kg-day)

K_O = oxygen utilization rate (%/day)

From Line 3b ______ %/day

4.	A	= volume of air/kg soil (L/kg)	
	a)	Density of soil (if unknown assume a bulk density of 2,400 lb/yd³)	______ lb/yd³
	b)	Vol soil/kg soil: (764.6 L/yd³ × 2.205 lb/kg) ÷ Line 4a =	______ L/kg
	c)	Vol air/kg soil: Line 4b × 0.30* = * (assuming 30% soil porosity)	______ L/kg
5.	D_O	= density of oxygen gas (mg/L)	
	a)	Size temperature: °C** + 273 = ** (assume 27°C if unknown)	______ K
	b)	Volume per mole: 0.08205 × Line 5a =	______ L/mole
	c)	Mass O_2 per liter: 32,000 mg/mole ÷ Line 5b	______ mg/L
6.	C	= mass ratio of hydrocarbon to oxygen required for mineralization (1/3.5)	0.2857

TPH Degradation Rate = (Line 3b × Line 4c × Line 5c × Line 6) ÷ 100 ______ mg/kg-day

Figure G-2. TPH Degradation Rate Worksheet

APPENDIX H

GENERAL SITE HEALTH AND SAFETY PLAN

The purpose of this general health and safety plan (HASP) is to define the basic contents that must be included in the site-specific HASP written by qualified health and safety personnel. The site-specific health and safety plan must identify procedures to be followed to protect the health and safety of field personnel during construction and operation of a biopile remediation site. The subjects that must be addressed in the HASP are as follows:

1. PROJECT DESCRIPTION

This section should contain a facility description, including the history of operations, current operating/closure status, and a description of the process or operation that generated the soil. The type of potential human and ecological receptors surrounding the site should be identified.

2. TECHNOLOGY DESCRIPTION

This section should include a brief description of the biopile technology, including process equipment and materials involved, and any associated hazards.

3. KEY PERSONNEL

Key project personnel and their responsibilities must be identified.

4. HEALTH AND SAFETY TRAINING

The training requirements for the field personnel must be specified in this section. Training must be performed in accordance with Occupational Safety and Health Administration (OSHA) 29 CFR 1910.120 regulations covering hazardous waste operations and emergency response (HAZWOPER).

This section should also include requirements for site-specific health and safety training. The site specific health and safety training should involve a comprehensive review of the health and safety procedures and equipment required for daily activities at the site. A daily health and safety meeting with field personnel should be held to discuss hazardous substances, conditions, and areas known to exist at the site.

5. MEDICAL PROGRAM

All personnel shall be included on a hazardous waste workers' medical surveillance program consistent with the regulations and guidelines set forth in 29 CFR 1910.120(f) and 29 CFR 1910.134.

6. COMMUNICATION PROCEDURES

Protocol for onsite as well as external communication must be established. Means of communication will be site specific but generally will include the use of visual signals and telephones. The locations of telephones and telephone numbers should be provided to personnel prior to initiating fieldwork. Communication procedures should be reviewed during the daily health and safety meetings.

7. SITE HAZARDS ANALYSIS AND CONTROL

General hazards and task-specific activities that may expose personnel to potential hazards should be discussed in this section. Both chemical and physical hazards must be discussed.

8. SITE CONTROL

Rules and procedures for the proper conduct of site personnel must be outlined in this section to minimize the possibility of worker exposure to toxic materials or hazardous situations. A clean/support zone, a contamination reduction zone (CRZ), and a exclusion zone (EZ) must be established. The clean/support zone is the area in which workers can enter and leave a working area, where contaminated personnel or objects are prohibited to minimize risk of exposure from toxic and hazardous substances. The EZ is an area with a possible or known risk of exposure to toxic or hazardous materials. The CRZ is defined as the corridor between the clean area and the EZ area. Decontamination of personnel occurs in the CRZ. The decontamination procedures should be discussed in this section.

9. PERSONAL PROTECTIVE EQUIPMENT

This section must specify the levels of personal protective equipment (PPE) required during field operations. The equipment used to protect the body against contact with known or expected chemical hazards has been divided into four levels according to the degree of protection afforded:

Level A: Must be worn when the highest level of respiratory, dermal, and eye protection is needed.

Level B: Must be worn when the highest level of respiratory protection is needed, with a lesser level of dermal protection.

Level C: Will be worn during all activities with potential for exposure to soil or water containing inhalable toxic or hazardous substances.

Level D: Will be the minimum level of protection on site to be worn in areas where no airborne threat to personnel is measurable to monitoring instruments.

PPE must be worn by all field personnel working within the EZ and the CRZ. The level of PPE required should be based on prior sampling results that indicate conditions likely to be encountered.

10. EXPOSURE MONITORING PLAN AND EQUIPMENT

This section should include the protocol and instrumentation for monitoring contaminant levels at the site during field operations.

11. GENERAL SAFETY

The following information should be included in this section:

- fire prevention and protection
- procedures for reducing the likelihood of heat-related illnesses
- procedures for cold weather operations.

12. WASTE DISPOSAL

Include the proper procedures for disposing of liquid and solid waste that may be generated as a result of field activities.

13. EMERGENCY PROCEDURES

Protocol for responding to emergencies should be included in this section. A list of emergency telephone numbers and a map showing the location of the nearest hospital should be attached.

APPENDIX I

POINTS OF CONTACT

Fill in relevant lines as information is received.

Function	Name	Telephone	Address
Project Manager			
Site Safety Officer			
Base Environ-mental Officer			
Security Police			
Fire Department			
Facilities Support			
Groundskeeping			
Heavy Equipment Operator			
Electrician			
Nutrient Supplier			
Soil Transporter			
GAC Supplier			
Blower Supplier			
Soil-Gas Instru-ment Vendor(s)			
Soil Sampling Laboratory			

APPENDIX J

CONVERSION TABLE[a]

Unit	Equivalent Values
Mass	2,000 lb = 1 ton = 0.907 metric ton = 907.19 kg 1 kg = 1,000 g = 2.2046 lb
Length	1 ft = 0.3048 m = 12 in. = 30.48 cm 1 yd = 0.9144 m = 3 ft = 914.4 cm
Area	1 ft^2 = 0.1111 yd^2 = 0.0929 m^2
Volume	1 ft^3 = 7.48 gal = 0.037 yd^3 = 28.317 L 1 m^3 = 1,000 L = 35.315 ft^3 = 1.308 yd^3
Temperature	°C = (°F − 32)/1.8 °F = 1.8 × (°C) + 32
Pressure	1 atm = 14.7 psi = 29.921 in. Hg @ 0°C = 33.9 ft H_2O @ 4°C 14.7 psi = 1.01325 × 10^5 N/m^2 = 101.325 × kPa = 1.01325 bar
Power	1 hp = 745.71 W = 745.71 J/s = 550.04 ft-lb_f/s = 0.7074 Btu/s

(a) Adapted from Felder, R. M., and R. W. Rousseau. 1978. *Elementary Principles of Chemical Processes*. John Wiley & Sons, New York, NY.