5.0 CORRECTIVE ACTION REQUIREMENTS

The purpose of this section is to provide a summary of department accepted practices for cleaning up contamination at petroleum release sites. Based on the Administrative Rules of South Dakota (ARSD) Chapter 74:56:05, "Remediation Criteria For Petroleum-Contaminated Soils", the responsible person must implement corrective action to reduce the risks associated with petroleum-contaminated soils. Also, the soil remediation rules require corrective action if data indicate petroleum vapors have adversely affected structures or utilities, or in the opinion of the department, have the potential to do so in the future. The above referenced soil remediation standards must be sufficient to protect the ground water whether it is being used now or has the potential for use in the future. In accordance with ARSD Chapter 74:54:01, "Groundwater Quality Standards", the ground water must meet the standards as discussed in that chapter.

Therefore, this section will discuss cleanup methods to reduce contaminant concentrations in the soil, ground water and air, and the use of engineering controls to reduce the risk of impacts from petroleum contaminated soils left in place. Please contact the Ground Water Quality Program at 605-773-3296 for technical assistance. Contact the Petroleum Release Compensation Fund (PRCF) at 605-773-3769 for reimbursement eligibility requirements.

5.1 Source Removal

The "source" of the release should be determined immediately after discovering the release of a regulated substance. This “source” is defined as discharging tanks, lines, dispensing islands and associated product saturated soil, contaminated backfill, free phase product, etc. Upon discovery of the source, discharges must be stopped and any further release must be contained using appropriate release containment measures as discussed in Section 3.0.

5.1.1 Free product removal

If assessment data indicates the presence of free phase product, the responsible person must immediately remove as much free phase product, as practicable, per ARSD 74:56:05:16, Remediation Criteria For Petroleum-Contaminated Soils, ARSD 74:56:01:47, Underground Storage Tanks and ARSD 74:56:03:24, Above Ground Storage Tanks.

5.1.1.1 Initial Response

The initial response upon identification of free product must follow the required emergency response measures discussed in Section 3.0.

5.1.1.2 Free Product Removal Requirements

At sites where investigations indicate the presence of free product, the responsible person shall immediately remove free-floating product to the maximum extent practicable. At the same time, the responsible person must continue all other appropriate assessment and cleanup actions described in this handbook. In meeting the requirements of the free product removal regulations, the responsible person shall:

- Conduct free product recovery in such a manner that the actions do not spread contamination into previously uncontaminated areas through untreated discharge or improper disposal techniques;

- Handle any flammable products in a manner to prevent fires or explosions; and
- Unless directed to do otherwise by the department, prepare and submit within 30 days a free product removal plan to the department that provides at least the following information:
  a. The name of the person or persons responsible for implementing the plan;
  b. The estimated quantity and type of product on-site and the product thickness in wells, boreholes, and excavations;
  c. Details of the product recovery system;
  d. Whether any discharge will take place on- or off-site during the recovery operation;
  e. The type of treatment and expected effluent quality from any discharge; and
  f. The disposition of the recovered product.

5.1.1.3 Additional Assessment

Upon discovery of free product, additional assessment may be required to determine the full extent of the free product plume. The additional assessment results must be sufficient for determining the appropriate response action, including all appropriate recovery system design parameters. During assessment, pay particular attention to possible conduits for product migration, such as buried utilities and basements.

5.1.1.4 Recovery System

Recovery of free product may be passive or active. Passive recovery methods include hand bailing, inserting absorbent materials in the recovery well, or the use of a passive skimming system. The number of passive recovery wells needed to effectively recover the free product is dependent on site conditions and hydrogeologic characteristics.

Active recovery methods include pump and treat, recovery trenches, vacuum enhanced free product recovery, or other department approved methods. Minimum design criteria should follow the ground water pump and treat section discussed below. Vapor extraction or vacuum enhancement techniques may be used to vaporize volatile products. Minimum design criteria should follow the soil vapor extraction section discussed below. Product recovery systems should be designed to avoid excessive drawdown of the water table, limiting the possibility of leaving product isolated in the dewatered soil. Contact the department's project manager with questions about selecting an appropriate free product recovery strategy. The department will use EPA 510-R-96-001, "How to Effectively Recover Free Product at Leaking Underground Storage Tank Sites, A Guide for State Regulators", September 1996, as a general guide to determine if the proposed free product recovery system meets minimum design criteria.

A free product recovery plan must be submitted and approved by the department prior to implementing a recovery system (See Section 8.2, Corrective Action Plans and Corrective Action Reports), except in response to an immediate response action. A free product recovery plan and free product recovery report can be submitted as part of another report (such as an assessment report or monitoring report) or they can be submitted separately.

The recovery system may be required to demonstrate hydraulic control over the contaminated aquifer. A pump test or slug test may be performed, as necessary, to assist in the design of a recovery system (See SOP 14). Any well constructed for the recovery of free product must meet

South Dakota well construction standards and receive a water permit through application to the Department's Water Rights Program. Contact the Water Rights Program at 605-773-3352 for additional information. All electrical equipment and storage containers used during the investigation and the recovery of free product must conform to all federal, state and local fire codes. Recovered free-product and contaminated water must be disposed of properly. Check with the Department's Waste Management Program at 605-773-3153 concerning disposal.

Monitoring the effectiveness of the free product recovery system is required. After implementing a recovery system, the responsible person must submit to the department records of the quantity of product recovered and quantity of ground water pumped. Also, report static water level and product thickness information monthly or as approved by the department. For each set of measurements, submit ground water elevation contour maps and appropriate isopleth maps showing the free product plume. Use Table 5.1 to correct the ground water elevations for the thickness of free product measured.

TABLE 5.1 EXAMPLE FOR CORRECTION OF GROUND WATER ELEVATIONS FOR FREE-PRODUCT (GASOLINE)

Depth to Free Product (ft.)	Depth to Groundwater (ft.)	Thickness of Product (ft.)	Specific gravity of gasoline	Correction Factor	Corrected Depth to Groundwater (ft.)
10.45	10.75	0.3	0.729	0.3 X 0.729 = 0.219	10.53
10.3	11.25	0.95	0.729	0.95 X 0.729 = 0.693	10.56

Table 5.2 Specific Gravity of Selected Fuels

Automotive Gasoline	0.729
Automotive Diesel Fuel	0.827
Kerosene	0.839
No. 5 Jet Fuel	0.844
No. 2 Fuel Oil	0.866
No. 4 Fuel Oil	0.904
No. 5 Fuel Oil	0.923
No. 6 Fuel Oil or Bunker C	0.974

5.1.2 Tank system removal

Generally, if a release is suspected or known to have occurred from a tank system, the site should be assessed according to ARSD 74:56:05 "Remediation Criteria for Petroleum-Contaminated Soils" before the tank system is removed. Please refer to Section 4.1, "Tier 1 Assessment", for information regarding sampling locations. The site assessment will provide information as to the extent of soil contamination in and around the tank basin, distribution lines and dispensing island.

If the system is being upgraded or the tanks removed as part of a change in site activity, and no release is suspected, the tank system may be removed or abandoned without prior assessment only in cases where one of the external monitoring release detection methods allowed under 74:56:01:24 are in use at the time of closure and shows there is no release.

Information regarding the tank system and the site should be collected prior to abandonment or during the site assessment. Information such as number of tanks, age, size (diameter, length and capacity), construction material, substances stored, leak detection monitoring information, tank anchors and the orientation of the tank such as the location of the fill holes, suction or submersible holes and distribution lines is needed. Also, site information such as a site plan, blueprints and/or a contact person with knowledge of the tank installation and location, depth of installation, depth of water table, proximity to street, buildings and basements, storm drains, utilities, drinking water supply watersheds, recharge areas, wellfields, wellhead protection areas, and public or private wells should be submitted, if applicable.

Information concerning health and safety risks and proper precautions with respect to particular materials stored in the tanks should be obtained from the tank owner, supplier of the material and/or material safety data sheet. Consultants, contractors, subcontractors and their employees responsible for tank abandonment or removal should be familiar and in compliance with: a) all applicable safety rules and regulations; b) the use of equipment and procedures for testing and vapor-freeing the tanks; and c) the handling and disposal of the types of wastes likely to be encountered.

If contaminated soil is identified in the tank backfill during a routine tank removal, excavation and removal of the visibly stained backfill material must be performed. In some cases, over-excavation may be required. The excavation may proceed downward until either the visible soil contamination has stopped or until ground water is observed. A corrective action plan, with lateral excavation limits defined, must be reviewed and approved by the department and the PRCF prior to beginning the work.

5.2 Active Remediation: Ex-situ Methods

If corrective action is required at a petroleum release site, several options are available to remediate soil and ground water. Regardless of the type of remedial activity proposed, the responsible person must submit and the department must approve a Corrective Action Plan prior to implementation. A corrective action plan can be submitted as part of another report (such as an assessment report or monitoring report) or they can be submitted separately.

The department will use EPA 510-B-95-007, "How to Evaluate Alternative Cleanup Technologies for Underground Storage Tank Sites, A Guide for Corrective Action Plan Reviewers", May 1995, as a general guide to determine if the proposed ex-situ remedial action meets minimum design criteria. Based on the nature of the proposed corrective action, additional reference materials may be used by the department to evaluate corrective action design criteria.

5.2.1 Excavation of contaminated soil

Excavation may be a feasible remedial alternative if:

- The contaminated soil is accessible;
- The contaminated soil is acting as a secondary source and is contributing to ground water contamination; or
- The contaminated soil is impacting utilities or structures, and the soil type would not be amenable to other forms of remediation.

Excavated contaminated soil must be properly disposed or treated. Contaminated soils excavated at a site are removed and hauled to a permitted municipal solid waste landfill, landfarm, or restricted use site. These facilities are regulated under a solid waste permit or a general landfarm permit issued through the department's Waste Management Program. Persons responsible for proper soil disposal should contact the department’s Waste Management Program at 605-773-3153 for additional information prior to disposal. See Chapter 9.0 for information on disposal of construction derived waste or investigation derived waste.

Permitted municipal solid waste landfills, landfarms, and restricted use sites require testing of contaminated soils for total petroleum hydrocarbons by an approved lab before treatment. They may also require tests for ignitability, lead or other constituents. Clean soils should be segregated from contaminated soils wherever possible. If waste oil tanks are involved, check in advance with the local permitted municipal solid waste landfill and the department’s Waste Management Program for permission to dispose of waste oil contaminated soil. Permitted landfarms cannot accept waste oil contaminated soils. Depending on the landfill requirements, waste oil contaminated soils need to be tested for both metals (total or Toxicity Characteristic Leaching Procedure metals) and solvents. If the lab tests indicate the contaminated soil is non-hazardous, the soils may be accepted by permitted municipal solid waste landfills. It is advisable to keep contaminated soils associated with waste oil tanks segregated from other petroleum contaminated soils.

For a remedial excavation, a sufficient number of samples must be collected to characterize the levels of chemicals of concern left in place at the site. Typically the department will require a minimum of two samples from the bottom of the excavation and one from each wall of the excavation in the worst apparent locations. However, fewer samples may be needed if previous assessment has already delineated contamination outside of the planned excavation area. These samples must be analyzed as described in Appendix B, Recommended Analytical Methods For Petroleum Products. If the excavation is large or other special conditions exist, the department may require additional sampling.

5.2.2 Aboveground treatment of excavated soil

Excavated soils may also be treated on-site in aboveground piles. These piles are known as biopiles, biocells, bioheaps, biomounds or compost piles. This aboveground treatment reduces concentrations of petroleum constituents in excavated soils by extracting soil vapor or by stimulating aerobic microbial activity within the soils through the addition of air, minerals, nutrients and moisture. The most common method is to aerate the biopiles through slotted or perforated pipes placed throughout the pile. The suitability of a site for on-site treatment must be reviewed with the department's Groundwater Quality Program and Waste Management Program. Regardless of the type of remedial activity proposed, the department must give approval prior to installation.

The system design must address air emissions. Air emissions must not cause a risk to human health in excess of 1 in 100,000 excess cancer incidence or exceed a hazard quotient of one. Also, the system must be designed to prevent the aesthetic quality of the surrounding area from being degraded.

Soil piles must be placed on an impermeable barrier and covered to prevent runoff as per ARSD 74:56:05:21, "On-Site Storage of Contaminated Soil".

5.2.2.1 Soil Vapor Extraction

Soil vapor extraction is most effective when working with permeable soils and volatile contaminants. If the soils are not sufficiently permeable, bulking agents (such as sand) may be added to improve the permeability. The number of lifts of soil, thickness of lifts, size of pipes, blower size, pipe spacing and other design features must be submitted to the department for review prior to installation.

Soil vapors must be sampled to monitor contaminant degradation. Minimum monitoring requirements include screening samples for percent oxygen, carbon dioxide, organic vapors and percent of the lower explosive limit. Also, periodic collection of air samples for laboratory analysis of total petroleum hydrocarbons may be required to support the screening data.

5.2.2.2 Bioremediation

If the contaminant is less volatile and is not amenable to soil vapor extraction, the use of biopiles can enhance biodegradation. The department requires that all active bioremediation systems be designed to promote the activity of aerobic bacteria. The supply of oxygen is vital to the success of a bioremediation system. Therefore, the department will require that some method of supplying oxygen to the contaminated material be employed (such as injection or extraction of air with enough inlets to allow air to be drawn into the pile). Before approving a bioremediation system, the department requires information regarding:

- Soil characteristics: including "total bacterial count" and "total contaminant utilizing bacteria", soil pH, moisture content, soil temperature, nutrient concentrations and soil texture;

- Contaminant characteristics: including volatility, chemical structure, concentration and toxicity; and

- Climatic conditions: including ambient temperature, rainfall and wind.

Although the number of samples required is dependent upon site conditions, a minimum of four samples for each bacterial count test is required (a total of eight samples per site). Contaminant-utilizing bacteria are present at most locations. If necessary, bacteria cultures may be added to the soil and physically mixed to ensure even distribution throughout the soil. The addition of nutrients to obtain optimum bacterial activity may be necessary. The type and amount of nutrients must be experimentally derived by laboratory methods.

Periodic monitoring of the air within the biopile or biopile exhaust system must be conducted. Minimum air monitoring requirements include screening samples for percent oxygen, carbon dioxide, organic vapors and percent of the lower explosive limit. Also, periodic collection of air samples for laboratory analysis of total petroleum hydrocarbons is required to support the screening data.

5.2.2.3 Confirmation Samples

When an asymptotic level or 95% reduction of initial effluent contaminant concentration is reached, soil samples may be collected for laboratory analysis. The contaminated soil must be remediated to levels specified in ARSD 74:56:05, "Remediation Criteria for Petroleum-Contaminated Soils". Soil samples must be collected as specified in Table 5.3 below, and tested according to ARSD 74:56:05. Upon completion of the treatment and removal of the pile, soil samples must also be collected in accordance with ARSD 74:56:05:21, "On-Site Storage of Contaminated Soils".

TABLE 5.3 Soil Sampling Requirements for Aboveground Treatment Systems

Volume of Soil (cubic yards)	Number of Samples
<50	1
50-500	2
500-1,000	3
1,000-2,000	4
2,000-4,000	5
Each additional 2,000	One additional sample

5.2.3 Ground water pump and treat

If a release has impacted drinking water wells, water supply lines or surface water, refer to Section 3, "Steps Taken After A Petroleum Release Is Reported", for appropriate response actions. At a minimum, the design of a ground water recovery system must ensure the capture of the most contaminated portion of the dissolved phase plume. The calculations used to determine the capture zone must be submitted to the department. The treatment system must be designed for year-round operation. Any well constructed for the recovery of ground water must meet South Dakota well construction standards and receive a water permit through application to the department's Water Rights Program (605-773-3352).

An aquifer pump test may be completed to determine the suitability of the aquifer for recovery. Depending on the geologic material encountered, the pump test should be run for 24 to 72 hours. If free phase petroleum product is present or suspected at the site, the treatment system must be designed to allow for separation and collection of the free product. All electrical equipment and storage containers used during the investigation and the recovery of contaminated groundwater or free product must conform with all federal, state and local fire codes. Regardless of the type of remedial activity proposed, the department must give approval prior to installation. A permit to appropriate water is needed for ground water treatment systems and for pump tests. A temporary water permit is typically issued for pump tests. Call the Water Rights Program at 605-773-3352 for information about water appropriation permits.

Water and any free product collected from the pump test must be disposed of properly. Contact the Waste Management Program at 605-773-3153 with disposal questions. Properly treated wastewater from the treatment systems may be discharged into the sanitary sewer system with permission from the local wastewater treatment facility. Discharges into surface waters are regulated under a Surface Water Discharge permit. Contact the department's Surface Water Program at 605-773-3351 for additional information.

With prior approval, treated ground water can be re-injected into the contamination plume as long as the treated water is of better quality than the water into which it is being injected. Re-injection must not result in expansion of the plume, and monitoring is required for verification. If injection of water is proposed for areas outside of an existing ground water plume, an Underground Injection Control (UIC) Permit may be required by EPA. Contact the Ground Water Quality Program at 605-773-3296 with questions about the UIC program and for approval to inject any fluid into the subsurface.

Monitoring is required to determine the contaminant concentrations in the ground water being pumped into the treatment system and the contaminant concentrations remaining in the treated discharge water. Other monitoring may be required in conjunction with the discharge of the treated water as specified in any permits or other local, state or federal regulations.

5.2.4 Other technologies

Other ex-situ technologies that may be applied to soil or groundwater include, but are not limited to, vacuum enhanced groundwater recovery and low-temperature thermal desorption. All plans must be submitted to the department for review and approval prior to installation.

5.3 Active Remediation: In-situ Methods

If corrective action is required at a petroleum release site, several options are available to remediate soil and ground water in place (in-situ). Regardless of the type of remedial activity proposed, the responsible person must submit and the department must approve a Corrective Action Plan prior to implementation. A corrective action plan can be submitted as part of another report (such as an assessment report or monitoring report) or separately.

The department will use EPA 510-B-95-007, "How to Evaluate Alternative Cleanup Technologies for Underground Storage Tank Sites, A Guide for Corrective Action Plan Reviewers", May 1995, as a general guide to determine if the proposed in-situ remedial action meets minimum design criteria. Based on the nature of the proposed corrective action, additional reference materials may be used by the department to evaluate corrective action design criteria.

The information below describes department requirements for in-situ treatment systems. Due to the possible complex nature and variable characteristics of sites amenable to various treatment systems, information presented should not be viewed as a design manual or issuance of formal policy, but merely as a general reference guide for all parties involved. However, the report requirements and operation and monitoring recommendations are generally considered to be the minimum content required by the department to evaluate the feasibility of the technology at a particular site.

Disposal or treatment of contaminated soils generated by construction, installation or modification of treatment systems must meet department requirements. For more information, see Section 9.3, Disposal of Contaminated Soil, or contact the Waste Management Program at 605-773-3153.

If subsurface injection of water generated during the construction, installation, modification or operation of a treatment system is planned, a separate EPA Underground Injection Control (UIC) Permit may be required. For more information, contact the Ground Water Quality Program at 605-773-3296.

If a discharge to surface water is proposed, the applicant may be required to obtain a Surface Water Discharge Permit or a construction de-watering permit. Contact the Surface Water Quality Program at 605-773-3351 for more information. If groundwater extraction is proposed, contact the Water Rights Program at 605-773-3352 for information about a water permit.

5.3.1 Soil vapor extraction

Soil vapor extraction (SVE), also known as soil venting or vacuum extraction, is an in-situ remedial technology that targets the adsorbed, vapor and free (NAPL) phases of the volatile contaminant present in the unsaturated (vadose) portion of the subsurface. In this technology, a vacuum is applied to the soil matrix to create a negative pressure gradient that causes movement of vapors toward extraction wells. Volatile constituents are physically removed from the subsurface through the extraction wells. The extracted vapors are then treated, if necessary, and discharged to the atmosphere.

SVE is generally more successful when applied to the lighter, more volatile, petroleum products such as gasoline and less successful when applied to the heavier, less volatile, petroleum products such as diesel fuel, heating oils, and kerosene. However, the heavier, less volatile, petroleum products may be suitable for removal by bioventing (see Chapter 5.3.2, Bioventing). Regardless of the type of remedial activity proposed, the department must give approval prior to installation.

5.3.1.1 Initial evaluation of SVE feasibility

The key parameters that should be used to decide whether SVE is a feasible remedy for a particular site are permeability of the petroleum contaminated soils and volatility of the petroleum constituents. Permeability of the soil determines the rate at which soil vapors can be extracted. Volatility determines the rate (and degree) at which petroleum constituents will vaporize from the soil-absorbed state to the soil vapor state.

Below are several factors related to soil permeability and constituent volatility that must be considered before determining if SVE is a feasible at a particular site.

Factors That Contribute To Permeability of Soil

- *Intrinsic Permeability*: Intrinsic permeability (air permeability) is a measure of the ability of soils to transmit fluids and is the single most important factor in determining the effectiveness of SVE. Intrinsic permeability can be determined in the field by conducting an air permeability test (SVE pilot study).

- *Soil Structure and Stratification*: Preferential flow behavior from structural characteristics such as microfracturing can lead to ineffective or significantly extended remedial times. Stratification of soils with different permeabilities can increase the lateral flow of soil vapors in the more permeable stratum while dramatically reducing the soil vapor flow through the less permeable stratum. Adequate site characterization in the area of contamination is essential.

- *Depth to Ground Water*: Fluctuations in the ground water table may, at times, submerge some of the contaminated soil or a portion of the extraction well screen, making it unavailable for air flow. Special considerations must be taken for sites with a ground water table located less than 10 feet from the land surface because ground water upwelling can occur within SVE wells under vacuum pressures. In some cases it may be necessary to lower the ground water table to enlarge the unsaturated zone. The extracted ground water may require treatment before disposal.

- *Moisture Content*: High moisture content in soils can reduce soil permeability and the effectiveness of SVE by restricting the flow of air through soil pores.

Factors That Contribute To Constituent Volatility

- *Vapor Pressure*: Vapor pressure is the most important constituent characteristic in evaluating the applicability and potential effectiveness of an SVE system. The vapor pressure of a constituent is a measure of its tendency to evaporate. Constituents with vapor pressures higher than 0.5 mm Hg, such as MTBE, BTEX and ethylene dibromide, are generally considered amenable for extraction by SVE. The vapor pressure of naphthalene is 0.5 mm Hg.

- *Product Composition and Boiling Point*: In general, constituents in petroleum products with boiling points less than 250° to 300°C are sufficiently volatile to be amenable to removal by SVE. Therefore, SVE can remove nearly all gasoline constituents, a portion of kerosene and diesel fuel constituents, and a lesser portion of heating oil constituents. SVE cannot remove lubricating oils.

- *Henry's Law Constant*: Henry's law constant measures the degree to which constituents that are dissolved in soil moisture (or ground water) will volatilize for removal by the SVE system. Constituents with Henry's law constants greater than 100 atmospheres, such as BTEX and tetraethyl lead, are generally considered amenable to removal by SVE. Henry's law constant for naphthalene is 72 mm Hg.

Required Information

- Soil lithology and stratigraphy
- Contaminant
- Concentration in most contaminated area
- Vapor pressure
- Composition and boiling point
- Henry's Law constant

- Water table depth
- Soil moisture
- Pilot study if all above indicates SVE is feasible

The department may require additional information, such as laboratory soil permeability tests or slug tests, to assist in determining whether soil vapor extraction will be a feasible cleanup alternative.

5.3.1.2 SVE pilot scale studies[1]

After it is determined that soil vapor extraction may be applicable to the specific site conditions, an SVE pilot scale study is required to confirm the feasibility of the technology and to prepare final system design. The air permeability or intrinsic permeability is one of the most critical data needs for designing an effective SVE system and must be determined through a pilot study. Air permeability tests directly measure many pertinent site characteristics and potential geologic heterogeneities as an inherent part of the test procedure and, therefore, are required for all proposed SVE sites. An air permeability test is generally conducted for no longer than one day, although for larger sites long-term testing may be recommended. The tests need to be conducted for a long enough period of time to reach equilibrium conditions. Tests should be conducted under conditions that are typical at the site.

A successful air permeability test should estimate full-scale system operating air flow rate and vacuum, estimate initial VOC removal rates, determine subsurface vacuum distribution to evaluate air flow patterns and zone of influence, and acquire data needed for computer modeling if computer modeling will be used.

A typical test will include a minimum of one extraction well, several observation wells and/or monitoring points and the hookup of the extraction well to the vacuum equipment. Upon startup of the vacuum pump, several field measurements are taken at the extraction well(s) and monitoring points. Guidelines regarding standard practices for the design and implementation of air permeability tests are presented in SOP 13.

The pilot study report must be submitted to the department for review and approval. The department will respond to the report prior to the initiation of remedial design and installation work for the full-scale project.

[1](**Note:** Under certain circumstances an SVE pilot study may not be required, such as when pilot study information is available from adjacent site(s), soil conditions of the site are well documented, etc. However, the department must be contacted prior to designing an SVE system without a pilot study.)

5.3.1.3 Full-scale SVE system design

If the pilot study indicates favorable conditions, a full-scale soil vapor extraction system design report must be prepared and submitted to the department for approval prior to system construction. The design report should include discussion of the rationale for the design and, at a minimum, the conceptual engineering design.

The field data obtained from the air permeability test must be evaluated to determine or select the following:

- The air permeability of the site, including the relationship between horizontal and vertical permeability.
- The number and location of extraction points needed to achieve required air flow distribution in the contaminated subsurface areas.
- The appropriate type and size of extraction blower/vacuum pump.
- The appropriate air treatment technology, if required.

Full-scale SVE system design can be done with the aid of computer modeling for large or complicated projects, or done with an empirical analysis using pilot scale data without modeling for smaller or simpler projects. The use of air flow and multi-phase transport models allows for a more proficient choice of design parameters such as extraction well locations and air-flow velocities. All of the information presented previously and in SOP 13 regarding the implementation of an air permeability test is also relevant to full-scale systems. Below are the general requirements for the full-scale system design report.

Design Report- General Requirements

The design report must provide a discussion justifying the system design with a description of the systems' capabilities for remediating the soil at the site. Include engineering calculations (legible, hand written calculations are acceptable) for determining well spacing, including zone of influence measurements from the air permeability test. Clearly state all assumptions and include references for formulas used.

If any computer modeling is used, include model assumptions and results. Provide a brief description of off-gas treatment proposed (when treatment is required). Submit winterization provisions as continuous year-round operation is typically required. Include a process flow diagram indicating all components and direction of air/water flow through the system components. Include maps showing a profile view and a cross-sectional view of a typical monitoring well construction detail (one cross-section is sufficient for all wells constructed in the same manner).

Provide plan view site maps illustrating and identifying the contaminated area to be remediated, the potentiometric surface, the location of proposed and existing extraction wells and monitoring wells/points, zone of influence of each extraction well, and the location of manifold, blower and other equipment. Include residential underground utilities, areas and locations where basements may be present, paved or sealed surface areas and aboveground surface seals (if proposed).

Provide a representative cross-sectional view of the zone of highest contamination illustrating and identifying elevations of ground surface, boundaries between differing lithologies and/or permeabilities, water table, screened interval of extraction wells, and analytical soil sampling results at respective depths.

Include design specifications for the following equipment: size and type of blower/ vacuum pump including range of operating flow rates, manufacturers performance curves, and vacuum levels; piping specifications including sizing and compatibility of piping materials with contaminants; maximum flow ratings for activated carbon units, oil-water separators, or other treatment units proposed; and, specifications of measuring instruments including vacuum and flow gauges. Mitigation requirements may be necessary for air or noise public nuisance issues.

The full-scale system design report will be reviewed by the department and must be approved prior to implementation. It should be noted that department review of the remedial design is to ensure conceptual adequacy and does not include such items as quality of materials, structural soundness, and mechanical design features. Approval of the plans and specifications does not in any way release the responsible person from the responsibility that the project will be an operable system when construction is completed.

5.3.1.4 SVE system performance monitoring

A system performance monitoring plan must be developed by the responsible person and approved by the department prior to implementing a soil vapor extraction system. Monitoring plans for both the system start-up phase and the long-term operation phase must be included. System performance monitoring is necessary to ensure that system operation is optimized and contaminant mass removal is tracked.

Minimum performance monitoring data should include the proposed monitoring frequency for air flow rates, vacuum and VOC concentrations, descriptions of analytical methods and sampling procedures, and the proposed frequency of reporting.

Below are recommendations and general guidelines for system monitoring. The department, depending on site-specific conditions, may approve significant variation. Winter conditions may require more frequent site visits.

Vacuum Monitoring Recommendations

- Monitor operating vacuum at the blower inlet at startup and at least weekly for the first month after startup. After the first month, monitor system operating vacuum at least quarterly for the duration of system operation.
- Measure vacuums at individual extraction wells at startup. If the system operating vacuum or the vacuums in surrounding monitoring wells changes significantly, the individual extraction well vacuums need to be rechecked.
- Record vacuums of surrounding monitoring wells with the same frequency as the air permeability test during the initial startup of the full-scale system (typically at 15 minute intervals for 1-2 hours, and weekly for first month) to verify the zone of influence estimates. After the first month, measure vacuums at least quarterly to verify that the zone of influence has not changed and that short circuiting or mechanical failures have not occurred.

Air Flow Monitoring Recommendations

- Monitor total system airflow rate at startup and at least weekly for the first month after startup. After the first month, measure system airflow at least quarterly for the duration of system operation.
- Monitor airflow rates at individual extraction wells at start-up. If system air flow rate significantly changes during subsequent operations, the airflow rate needs to be measured again at each well.
- Measure airflow rates directly with a dedicated device (do not estimate from blower performance curves).
- Balance flow rate of individual wells in SVE system to obtain a nearly equivalent airflow rate and to maximize the contaminant mass removal, not to achieve equivalent vacuums.

Effluent Concentration Monitoring Recommendations

- Monitor VOC concentrations in system effluent using a portable meter at startup and at least weekly for the first month after startup. After the first month, VOC field screening of the system effluent should be performed at least quarterly for the duration of system operation, concurrently with airflow.
- Sample off-gas BTEX and TPH composition by an analytical laboratory at start-up and at least weekly for the first month after startup (See SOP 11). After the first month, perform laboratory sampling at least quarterly for the duration of system operation.
- Perform VOC field screening quarterly at individual wellheads following start-up.
- Measure air temperature concurrently with VOC monitoring to enable the accurate calculation of the mass removal rates. Also monitor for percent oxygen, carbon dioxide and lower explosive limit.
- Optimize the flow rate of individual wells to maximize the contaminant mass removal rate.

Remedial Progress Monitoring

Monitoring the effectiveness of the SVE system in reducing contaminant concentrations in soils is necessary to determine if remedial progress is proceeding at a reasonable rate.

The mass removed during long-term monitoring intervals can be calculated using vapor concentration and flow rate measurements taken at the manifold. The instantaneous and cumulative mass removal must be plotted versus time. The contaminant mass removed during an operating period can be calculated using the equation provided below. This relationship can be used for each extraction well (and then totaled) or for the system as a whole, depending on the monitoring data that is available.

$$M = C \bullet Q \bullet t$$

Where: M = cumulative mass removal (kg)
C = vapor concentration (kg/m^3) [from laboratory analysis]
Q = extraction flow rate (m^3/hr)
t = operational period (hr)

$$\text{Mass removed (kg)} = \text{kg/m}^3 \bullet \text{m}^3\text{/hr} \bullet \text{hr}$$

Note: Specify whether the total mass removed is calculated as wet or dry.

Remedial progress of SVE systems typically exhibits asymptotic behavior with respect to both vapor concentration reduction and cumulative mass removal. When asymptotic levels begins to occur, the operator should closely evaluate alternatives that increase mass removal rate concentrations, such as terminating vapor extraction from extraction wells with low vapor concentrations or pulsing. Pulsing involves the periodic shutdown and startup operation of extraction wells to allow the subsurface environment to come to equilibrium (shutdown) and then begin extracting vapors again (startup). Other more aggressive steps to increase removal rates can include installation of additional injection wells or extraction wells.

If asymptotic levels persist longer than six months and the concentration rebound is sufficiently small following periods of temporary system shutdown, termination of operation may be appropriate. If not, operation of the system as a bioventing system with reduced vacuum and airflow may be an effective remedial alternative.

5.3.2 Bioventing

Bioventing is an in-situ remediation technology that uses indigenous (naturally occurring) microorganisms to biodegrade organic constituents adsorbed to soils in the unsaturated or vadose zone. As with SVE systems, bioventing involves inducing airflow in the subsurface. However, while SVE removes contaminants primarily through volatilization, bioventing promotes biodegradation and minimizes volatilization. This is accomplished by stimulating indigenous bacteria with additional oxygen delivered by the induced subsurface air flow, which is generally supplied at a lower rate than with SVE systems. In practice, some degree of volatilization and biodegradation occurs when either SVE or bioventing is used.

Bioventing can be accomplished using extraction wells, injection wells, or a combination of both. Since bioventing can potentially transform contaminants into less hazardous substances (i.e., CO_2), off-gas treatment may not be required (especially true of air injection systems). As with SVE systems, the water table may be lowered during bioventing in order to enlarge the vadose zone to be treated and the extracted groundwater may require treatment prior to disposal.

Bioventing is potentially applicable to any contaminant that is more readily degradable aerobically than anaerobically. In particular, bioventing has proven to be effective for petroleum hydrocarbon releases including gasoline, diesel, jet fuel, kerosene, motor oil, heavy fuels oils, lubricating oils and crude oils. The key to successful bioventing is biodegradability versus volatility. If the rate of volatilization significantly exceeds the rate of biodegradation, removal essentially is through volatilization and SVE should be optimized as such. With this in mind, systems can be designed to be operated as SVE until the volatile fraction of the contaminant is removed, at which point the system would be operated as a bioventing system in order to remove the remaining biodegradable contaminants.

5.3.2.1 Initial evaluation of bioventing feasibility

The key parameters that should be used to decide whether bioventing is a feasible remedy for a particular site are permeability of the petroleum-contaminated soils and biodegradability of the petroleum constituents. Permeability of the soil determines the rate at which oxygen can be supplied to the hydrocarbon-degrading microorganisms found in the subsurface. Coarse-grained soils (sands and gravels) have higher permeability than fine-grained soils (clays and silts). Biodegradability determines both the rates at which and the degree to which the petroleum constituents will be metabolized by microorganisms.

Below is a summary of several site and constituent characteristics that must be considered before determining if bioventing is feasible at a particular site.

Site Characteristics

- *Intrinsic Permeability*: Intrinsic permeability (air permeability) is a measure of the ability of soils to transmit air and is the single most important factor in determining the effectiveness of bioventing because it determines how much oxygen can be delivered to the subsurface bacteria. Intrinsic permeability can be determined in the field by conducting an air permeability test (See SVE pilot study).

- *Soil Structure and Stratification*: Soil structure and stratification are important to bioventing because they affect how and where soil vapors will flow within the soil matrix when extracted or injected. Adequate site characterization in the area of contamination is essential.

- *Microbial Presence*: Evaluate the presence of naturally occurring bacteria that contribute to degradation of petroleum constituents. Although heterotrophic bacteria are normally present in all soil environments, the presence of toxic constituents or concentrations of inorganic or organic compounds or the depletion of oxygen or other essential nutrients may limit or eliminate the bacteria. In this case, further site evaluation may be necessary to determine if changes to the soil environment may be needed.

- *Soil pH:* The optimum pH for bacterial growth is approximately 7 with the acceptable range for bioventing between 6 and 8. If the soil pH is less than 6 or greater than 8, pH adjustments must be included in the design and operational plans.

- *Moisture Content*: Generally, soils saturated with water prohibit air flow and oxygen delivery to bacteria, while dry soils lack the moisture necessary for bacterial growth. The ideal range for soil moisture is between 40 and 85 percent of the water-holding capacity of the soil.

- *Nutrient Concentrations:* Bacteria require inorganic nutrients such as ammonium and phosphate to support cell growth and sustain biodegradation processes. Chemical analysis of soil samples from the site should be completed to determine the concentrations of nitrogen (expressed as ammonia) and phosphate that occur naturally in the soil. The carbon:nitrogen:phosphorus ratio necessary to enhance biodegradation is about 100:10:1.

Constituent Characteristics

- *Chemical Structure:* Although nearly all constituents in petroleum products typically found at petroleum release sites are biodegradable, the more complex the molecular structure of the constituent, the more difficult and less rapid is biological treatment. Evaluate the chemical structure of the constituents proposed for reduction by bioventing to determine the most difficult to degrade. Use the most difficult to degrade constituents as a basis for determining remedial time estimates, biotreatability studies, field-pilot studies, and operation and monitoring plans.

- *Concentration and Toxicity:* The presence of very high concentrations of petroleum organics or heavy metals in site soils can be toxic or inhibit the growth and reproduction of bacteria responsible for biodegradation. Very low concentrations of organic material will also result in diminished levels of bacterial activity. In general, concentrations of petroleum hydrocarbons in excess of 25,000 ppm in soils are considered inhibitory and /or toxic to aerobic bacteria and should be removed, if practicable.

- *Vapor Pressure*: Vapor pressure is important in evaluating the extent to which constituents will be volatilized rather than biodegraded. The vapor pressure of a constituent is a measure of its tendency to evaporate. Constituents with vapor pressures higher than 0.5 mm Hg, such as MTBE, BTEX and ethylene dibromide, are generally volatilized rather than biodegraded. The vapor pressure of naphthalene is 0.5 mm Hg.

Required Information

- Soil lithology and stratigraphy
- Contaminant
- Concentration in most contaminated area
- Chemical structure
- Vapor pressure
- Water table depth
- Soil pH, nitrogen (expressed as ammonia) and phosphate
- Soil moisture
- Pilot scale study if all above indicates bioventing feasibility

The department may require additional information, such as laboratory soil permeability tests or slug tests, to assist in determining whether bioventing will be a feasible cleanup alternative.

5.3.2.2 Bioventing pilot scale studies

After it is determined that bioventing may be applicable to the specific site conditions, additional field pilot studies may be required to confirm the feasibility of the technology and to prepare final system design. A short-term air permeability test is generally required to determine the spacing, number, and type of wells needed for the full-scale bioventing system (see the discussion in Chapter 5.3.1.2, SVE Pilot Scale Studies, and SOP 13). However, it may not be cost effective to perform this test for sites with areas smaller than 5,000 cubic yards of in-situ contaminated soil.

An in-situ respiration test may also be required for bioventing systems to determine the oxygen transport capacity of the site soils and estimate biodegradation rates under field conditions. The test involves short-term injection of air or an air/inert gas mixture into a well that is screened in the contaminated soil. Carbon dioxide, oxygen, and inert tracer gas (typically helium) concentrations are measured in the injection well periodically for one to five days. The measurements are then compared to baseline concentrations of the gases prior to injection. Baseline measurements are taken at the injection point and at a well located in uncontaminated soils. Increases in carbon dioxide and/or decreases in oxygen concentrations are indications of microbial activity in soils surrounding the injection point. Although the use of an inert tracer gas is not required, it is highly recommended since it provides baseline information on air diffusion rates and confirms that no system leaks are present.

Respiration studies are usually only needed for sites with large areas of contamination (perhaps greater than 100,000 cubic yards of in-situ soils requiring remediation), at sites with relatively low soil permeability (silt, loess, glacial till, clay), or when reductions of more than 80 percent of the constituents that have vapor pressures less than 0.5 mm Hg are required.

Standard pilot testing procedures and reporting requirements for air permeability and in-situ respiration testing are presented in SOP 13 and SOP 14, respectively.

Pilot study data must be submitted to the department for review and approval. The department will respond to the report prior to the initiation of remedial design and installation work for the full-scale project.

5.3.2.3 Full-scale bioventing system design

If a detailed evaluation indicates favorable conditions, a full-scale bioventing system design report must be prepared and submitted to the department for approval prior to system installation. The design report should include discussion of the rationale for the design and, at a minimum, the conceptual engineering design. The data obtained from both the air permeability test and the in-situ respiration test, if required, must be used to design the bioventing system.

The most important design parameter is maintaining an adequate oxygen supply in the contaminated soils in order to sustain aerobic biodegradation. Bioventing air flow rates are typically an order of magnitude lower than SVE systems in order to accomplish maximum oxygen usage by the vadose zone microbial populations.

Design Report- General Requirements

The design report must provide a discussion justifying the system design with a description of the systems' capabilities for remediating the soil at the site. The general reporting requirements outlined in Chapter 5.3.1.3, full-scale SVE System Design, also apply to design of a full-scale bioventing system.

The full-scale system design report must be submitted for review by the department and must be approved prior to system implementation. It should be noted that department review of the remedial design is to ensure conceptual adequacy and does not include such items as quality of materials, structural soundness, and mechanical design features. Approval of the plans and specifications does not in any way release the responsible person from the responsibility that the project will be an operable system when construction is completed.

5.3.2.4 Bioventing system performance monitoring

A system performance monitoring plan must be developed by the responsible person and approved by the department prior to implementing a bioventing system. Monitoring plans for both the system start-up phase and for long-term operation phase must be included. System performance monitoring is necessary to ensure that system operation is optimized and contaminant mass extraction and degradation are tracked.

Monitoring of remedial progress for bioventing systems is more difficult than for SVE systems in that mass removal rates cannot be directly measured in extracted vapors. VOC concentrations (extracted mass), O_2 and CO_2 (a product of microbial respiration) concentrations should be monitored. Systems employing only injection wells have limited capability for performance monitoring because of the impossibility of collecting off-gas. The monitoring plan may need to include subsurface soil sampling to track constituent reduction and biodegradation conditions. Final clean-up approval will require soil sampling to verify effectiveness of bioventing.

Minimum performance monitoring data should include the proposed monitoring frequency for vacuum, air flow rates, VOC concentrations, O_2 and CO_2. A description of the analytical methods and sampling procedures, and the proposed frequency of reporting, must also be included in the performance monitoring plan.

Below are recommendations and general guidelines for system monitoring. Significant variation may be warranted depending on site-specific characteristics. Winter conditions may require more frequent site visits.

Vacuum Monitoring Recommendations

- Monitor operating vacuum at the blower inlet at startup and at least weekly for the first month after startup. After the first month, monitor system operating vacuum at least quarterly for the duration of system operation.
- Measure vacuums at individual extraction wells at startup. If the system operating vacuum or the vacuums in surrounding monitoring wells changes significantly, the individual extraction well vacuums need to be rechecked.

Air Flow Monitoring Recommendations

- Monitor total system air flow rate at startup and at least weekly for the first month after startup. After the first month, measure system air flows at least quarterly for the duration of system operation.
- Monitor air flow rates at individual extraction wells at start-up. If system air flow rate significantly changes during subsequent operations, the air flow rate needs to be measured again at each well.
- Adjust air flow to balance flow, optimizing the carbon dioxide production and the oxygen uptake rate while, to the extent possible, minimizing volatilization by concentrating pressure (or vacuum) on the wells that are in areas of higher contaminant concentrations.
- Measure air flow rates directly with a dedicated device (do not estimate from blower performance curves).

Effluent Concentration Monitoring Recommendations

- Monitor VOC, O_2 and CO_2 concentrations in the system effluent at startup and at least weekly for the first month. After the first month, monitor the system effluent for VOC, O_2 and CO_2 at least quarterly for the duration of system operation, concurrently with air flow monitoring.
- Sample off-gas BTEX and TPH composition by an analytical laboratory at start-up and at an acceptable frequency following start-up.
- Field screen for VOC, O_2 and CO_2 monthly at individual wellheads following start-up.
- Measure air temperature concurrently with VOC monitoring to enable the accurate calculation of the mass removal rates (water vapors should be subtracted from the total mass removed).

Remedial Progress Monitoring

Monitoring the effectiveness of the bioventing system in reducing contaminant concentrations in soils is necessary to determine if remedial progress is proceeding at a reasonable rate. A variety of methods can be used.

Since concentrations of petroleum constituents may be reduced due to both volatilization and biodegradation, both processes must be monitored in order to track the cumulative effect. The constituent mass extraction component can be tracked and calculated using the VOC concentrations measured in the extraction manifold multiplied by the extraction flow rate. The constituent mass that is degraded is more difficult to quantify, but can be monitored qualitatively by observing trends in carbon dioxide and oxygen concentrations in the extracted soil vapors.

After a certain period of operation, bioventing systems typically exhibit asymptotic behavior with respect to VOC, oxygen, and carbon dioxide concentrations in extracted vapors. When asymptotic behavior begins to occur, alternatives that may increase bioventing effectiveness (e.g., increasing extraction flow rate or nutrient addition) should be closely evaluated. Other, more aggressive steps to control asymptotic behavior can include adding injection wells or additional extraction wells.
If asymptotic behavior is persistent for periods longer than 6 months, modification of the system design and operations (e.g., pulsing of injection or extraction air flow) may be appropriate. If asymptotic behavior continues, the department may approve the termination of system operation.

5.3.3 Air sparging

Air sparging (AS) is an innovative technology developed to address contamination present below the water table. Air sparging is the process of injecting air into the subsurface saturated zone, enabling a phase transfer of hydrocarbons from a dissolved state to a vapor phase. Contaminants are removed both by venting air through the unsaturated zone and through aerobic biodegradation. Typically, AS is used in conjunction with SVE, allowing for treatment of vadose zone soils, saturated zone soils and groundwater in the saturated zone. Implementing an AS system without SVE can potentially create a net positive pressure in the subsurface, inducing contaminant migration into previously uncontaminated areas.

Air sparging is generally more applicable to the lighter gasoline constituents (BTEX) because they readily transfer from the dissolved to the gaseous phase. Air sparging is less applicable to diesel fuel, kerosene and heating fuel. Appropriate use of air sparging may require that it be combined with other remedial methods such as SVE or pump-and-treat.

Biosparging is a similar process to air sparging. However, while air sparging removes constituents primarily through volatilization, biosparging promotes biodegradation rather than volatilization, generally by using lower flow rates than air sparging.

5.3.3.1 Initial evaluation of air sparging feasibility

If the following conditions are detected during the site investigation phase, in-situ air sparging will not be approved as a remedial technology:

- Free product. If a measurable quantity of free product is present (i.e. greater than a floating sheen or film), an AS system cannot be implemented without first recovering the free product. Air sparging can create groundwater mounding which could potentially cause free product to migrate.

- Confined spaces. If nearby basements, sewers, or other subsurface confined spaces are present at the site, potentially dangerous constituent concentrations could accumulate in basements unless a vapor extraction system is used to control vapor migration.

- Confined aquifer. AS cannot be used to treat groundwater in a confined aquifer because the injected air would be trapped by the confining layer and could not escape to the unsaturated zone. The trapped air could cause an increase in the downgradient movement of dissolved phase contamination.

The effectiveness of air sparging depends primarily on two factors, vapor/dissolved phase partitioning and soil permeability. In general, air sparging is more effective for constituents with greater volatility and higher solubility and for soils with higher permeability. Below is a summary of several factors related to constituent characteristics and soil permeability that must be considered before determining if air sparging is feasible at a particular site.

Factors That Contribute To Constituent Vapor/Dissolved Phase Partitioning

- *Henry's Law Constant*: The most important characteristic to evaluate vapor/dissolved phase partitioning is the Henry's law constant, which quantifies the relative tendency of a dissolved constituent to transfer to a vapor phase. As with SVE, constituents with Henry's law constants greater than 100 atmospheres, such as BTEX and tetraethyl lead, are generally considered amenable to removal by air sparging. The Henry's law constant for naphthalene is 72 mm Hg.

- *Product Composition and Boiling Point*: In general, constituents in petroleum products with boiling points less than 250° to 300°C are sufficiently volatile for removal from the saturated zone by air sparging. Therefore, air sparging can remove nearly all gasoline constituents and a portion of kerosene and diesel fuel constituents. Although heating and lubricating oils cannot be removed by air sparging, air sparging can promote biodegradation of semi-volatile and nonvolatile constituents.

- *Vapor Pressure*: The vapor pressure of a constituent is a measure of its tendency to evaporate. Constituents with vapor pressures higher than 0.5 mm Hg, such as MTBE, BTEX and ethylene dibromide, are generally considered amenable to air sparging.

Factors That Contribute To Permeability of Soil

- *Intrinsic Permeability*: Intrinsic permeability (air permeability) is a measure of the ability of soils to transmit fluids and is the single most important factor in determining the effectiveness of air sparging. Intrinsic permeability of saturated-zone soils is usually determined in the field by aquifer pump tests that measure hydraulic conductivity. Intrinsic permeability of the unsaturated zone (when SVE is used) must be determined in the field by conducting an air permeability test (SVE pilot study).

- *Soil Structure and Stratification*: The presence of fine grained materials or other geologic heterogeneities which may limit the migration of air to the water table surface, will adversely effect the efficiency of an air sparging system and may even promote dissolved and vapor phase contaminant migration. Semi-confined aquifer conditions or overlying low permeability zones will require the need for an adequate number of soil vapor extraction wells to relieve the positive pressures caused by the AS system. If heterogeneous conditions prevail, significant data must be collected during the site investigation phase in order to substantiate the appropriateness of air sparging as the remedial alternative and to have an effective remedial design.

- *Dissolved Iron Concentrations:* Dissolved iron concentrations must be measured when determining groundwater characteristics during the site investigation. Injected air can precipitate dissolved iron during the sparging operation, reducing the porosity and permeability of the saturated zone soils and clogging air sparging wells. Dissolved iron is a concern for air sparging effectiveness when dissolved iron concentrations are greater than 10 ppm (wells may need periodic replacement). If dissolved iron concentrations are greater than 20 ppm, air sparging is not recommended.

Required Information

- Soil lithology and stratigraphy
- Contaminant
- Concentration in most contaminated area
- Composition and boiling point
- Vapor pressure
- Henry Law constant
- Water table depth
- Dissolved iron concentration
- Pilot scale studies if all above indicates air sparging feasibility

The department may require additional information, such as laboratory soil permeability tests or slug tests, to assist in determining whether air sparging will be a feasible cleanup alternative.

5.3.3.2 Air sparging pilot scale studies

In order to implement an efficient AS system, it is necessary to understand the pattern of air flow that will occur in the subsurface. This is generally accomplished by conducting short-term pilot studies, consisting of three sequential tests over a period of at least 24 hours or until stabilized readings or measurements of required parameters are achieved. For sites with significant subsurface heterogeneities, prolonged testing may be warranted. Typically, SVE systems must be installed in conjunction with air sparging systems to enhance VOC removal, treat unsaturated zone soils, and/or prevent off-site migration. These tests are required of all proposed soil vapor extraction/air sparging systems and should be executed in the following order:

- Air permeability test for SVE portion of system (if SVE is to be included in the design). See Chapter 5.3.1.2, SVE Pilot Scale Studies, and SOP 12, for test recommendations and requirements.

- Air sparging test with SVE turned off. This portion should be conducted for a period of at least 4 hours or until stabilized readings or measurements of required parameters are achieved.

- Combined sparge/vent test with SVE and AS operating concurrently. Final portion with both SVE and AS activated for no less than 12 hours or until stabilized readings or measurements of required parameters are achieved.

Effective implementation of these tests should determine the SVE zone of influence, estimate the areal influence of the air sparging system to determine number and placement of sparging wells, define the vacuum and pressure requirements for effective treatment and capture of volatilized contamination, and determine if hydraulic controls will be necessary to contain possible plume migration.

The air sparge well used for pilot testing is generally located in an area of moderate constituent concentrations. Testing the system in areas of extremely low constituent concentrations may not provide sufficient data, while testing in areas of extremely high contamination can induce migration of constituents. Department guidelines regarding standard practices for the design and implementation of AS pilot testing and combined AS/SVE testing are presented in SOP 12. Deviations may be necessary due to varying site conditions.

5.3.3.3 Full-scale air sparging system design

If the pilot study indicates favorable conditions, a full-scale system design report must be prepared and submitted to the department for approval prior to system installation. The design report should include discussion of the rationale for the design and, at a minimum, the conceptual engineering design. The data obtained from pilot tests must be used to design the air sparging system.

The field data obtained from the pilot scale tests should be carefully evaluated to determine the intrinsic permeability of the site (both air and hydraulic permeability), including the relationship between horizontal and vertical permeability in the vadose and saturated zone. The pilot test field data must also be used to determine the number and location of extraction (vent) wells and injection points needed to achieve the required air flow distribution in the subsurface, ensuring that vapors in the vadose zone are captured by the SVE system. All of the information presented previously and in SOP 13 regarding the implementation of pilot tests is also relevant to the full-scale system.

Design Report – General Requirements

The design report must provide a discussion justifying the system design with a description of the systems' capabilities for remediating the soil and ground water at the site. If any stratification is present at the site, the discussion must address how heterogeneities affect subsurface air flow patterns. The general reporting requirements outlined in Chapter 5.3.1.3, Full-Scale SVE System Design, also apply to design of a full-scale air sparging system.

The full-scale system design report must be submitted for review by the department and must be approved prior to system implementation. It should be noted that department review of the remedial design is to ensure conceptual adequacy and does not include such items as quality of materials, structural soundness, and mechanical design features. Approval of the plans and specifications does not in any way release the responsible person from the responsibility that the project will be an operable system when construction is completed.

5.3.3.4 Air sparging system performance monitoring

A system performance monitoring plan must be developed by the responsible person and approved by the department prior to implementing an air sparging system. Monitoring plans for both the system start-up phase and for long-term operation phase must be included. System performance monitoring is necessary to ensure that system operation is optimized and contaminant mass removal is tracked.

Minimum performance monitoring data should include the proposed monitoring frequency for air flow rates, vacuum and VOC concentrations for the SVE (if installed) portion of the system. For the AS portion, include the proposed monitoring frequency for air flow rates, pressure, VOC concentrations, O_2 and CO_2. Include a description of analytical methods and sampling procedures, and the proposed frequency of reporting.

Below are recommendations and general guidelines for system monitoring. Variation may be warranted depending on site-specific characteristics. Winter conditions may require more frequent site visits.

Vacuum, Pressure and Air Flow Monitoring Recommendations

- Monitor vacuum, pressure and air flow at startup, at least weekly for the first month after startup, and at least quarterly thereafter for the duration of system operation. Measurements should be taken at each injection wellhead, extraction wellhead, manifold branch and after the blower.
- Measurements should be taken at surrounding monitoring wells with the same frequency as the pilot test during initial startup to verify zone of influence estimates. Groundwater levels should be measured daily at startup and as needed thereafter to monitor for groundwater mounding.
- Air flow rates need to be measured directly with a dedicated device, not estimated from blower performance curves.

Effluent Concentration Monitoring Recommendations

- Monitor VOC concentrations in system effluent using a portable meter at startup and at least weekly for the first month after startup. After the first month, VOC field screening of the system effluent should be performed at least quarterly for the duration of system operation, concurrently with air flow.
- Sample off-gas BTEX and TPH composition by an analytical laboratory at start-up and at least weekly for the first month after startup (See SOP 11). After the first month, perform laboratory sampling at least quarterly for the duration of system operation.
- Perform VOC field screening quarterly at individual wellheads following start-up.
- Optimize the flow rate of individual wells to maximize the contaminant mass removal rate.
- When monitoring the biodegradation performance (biosparging), monitor for CO_2 and O_2 in the vadose zone and below the water table at startup and at least quarterly for the duration of system operation.

Remedial Progress Monitoring

Monitoring the effectiveness of the air sparging system in reducing contaminant concentrations in the saturated zone is necessary to determine if remedial progress is proceeding at a reasonable rate. The rate of remedial progress can be measured by monitoring contaminant levels in the ground water and vapors in the monitoring wells and blower exhaust.

Asymptotic behavior can be measured by plotting both the VOC concentrations in extracted soil vapor (ppm) and the cumulative VOC mass removed (lbs) against time. Systems that use SVE can monitor progress through mass removal calculations (see Chapter 5.3.1.4, SVE System Performance Monitoring). Once asymptotic behavior persists for longer than six months, and concentration rebound is sufficiently small following periods of temporary system shutdown, termination of the system operation may be appropriate.

5.3.4 Air Quality Permits

In certain cases, an in-situ treatment system may be required to obtain a Part 70 air quality operating permit before construction or operation of the in-situ treatment system begins. To determine if the in-situ treatment system requires a Part 70 air quality operating permit, the responsible person must first determine the potential amount of volatile organic compounds and hazardous air pollutants that will be emitted to the ambient air.

The major source threshold for requiring a Part 70 air quality operating permit is listed below (see Administrative Rules of South Dakota 74:36:05:03):

- Potential volatile organic compound air emissions equal to or greater than 100 tons per year; or
- Potential hazardous air pollutants equal to or greater than 10 tons per year for a single hazardous air pollutant or 25 tons per year for two or more hazardous air pollutants (i.e., benzene, ethyl-benzene, toluene, and xylenes).

The major source threshold includes the air emissions from the in-situ treatment system and air emissions from other operations at the site; for example, air emissions from above ground petroleum storage tanks.

If the potential emissions from all operations equal or exceed the major source threshold, the responsible person must submit an application and receive a Part 70 air quality operating permit before construction or operation of the in-situ treatment system. If the in-situ treatment system is located at a facility that already has a Part 70 air quality operating permit, the responsible person must apply for a modification to the existing permit before construction or operation of the in-situ treatment system begins. A permit is not required if the potential emissions from all the operations are less than the major source threshold levels. In addition, according to CERCLA § 121(e), no federal, state, or local permit shall be required for the portion of any removal or remedial action conducted entirely onsite, where such remedial action is selected and carried out in compliance with CERCLA requirements.

For more information about a Part 70 air quality operating permit or to receive a list of all the hazardous air pollutants, please contact the Air Quality Program at 605-773-3151.

5.4 Monitored Natural Attenuation at Petroleum Release Sites

This section defines monitored natural attenuation (MNA), discusses natural attenuation mechanisms, and specifies initial screening criteria that will help determine when it may be appropriate to apply the technology. This section also defines the monitoring strategy the department requires. Typically three kinds of monitoring are required where natural attenuation is to be implemented as a remedial option. First, site characterization, second, validation monitoring and thirdly, long-term monitoring

This monitoring strategy is designed to ensure natural attenuation processes are taking place, to determine how long will it take for contaminant concentrations to attenuate to the established standards, and to predict how far the contaminants will migrate from the source (EPA/600/R-96/087 “Natural Attenuation Decision Support System” and also EPA’s directive number 9200.4-17p “Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites”, dated, April 21, 1999). This monitoring strategy will confirm whether petroleum constituents are being degraded or dissipated at acceptable rates and whether receptors are likely to be impacted. The department must approve ground water modeling methods used to predict the rate of contaminant migration and degradation.

The term “monitored natural attenuation” refers to the reliance on natural processes to achieve site-specific remedial objectives within a reasonable time frame compared to that offered by other more active methods. The “natural attenuation processes” that are at work in such a remediation approach include a variety of physical, chemical, or biological processes that act without human intervention to reduce the mass, toxicity, mobility, volume, or concentration of contaminants in soil or ground water. These in-situ processes include biodegradation, dispersion, dilution, sorption, volatilization, and chemical or biological stabilization, transformation, or destruction of contaminants.

5.4.1 Natural attenuation mechanism

In order to assess site conditions to determine whether natural attenuation is an acceptable alternative to active treatment, it is important to understand the mechanisms that degrade petroleum products in soil and ground water. Mechanisms may be classified as either destructive (i.e., result in a net decrease in contaminant mass) or non-destructive (i.e., result in decrease in equilibrium concentrations but no net decrease in mass).

The following destructive mechanisms are primarily *biological***:**

- *Aerobic* (requires oxygen): Microbes utilize oxygen as an electron acceptor to convert contaminant to carbon dioxide (CO_2), water, and biomass. This mechanism is most significant if sufficient oxygen is present (soil air oxygen (O_2) $\geq$ 2 percent and ground water dissolved oxygen (DO) $\geq$ 1 to 2 ppm); and,

- *Anaerobic* (must occur in the absence of oxygen): Microbes utilize alternative electron receptors. For example, NO_3^- , SO_4^{2-} , Fe^{3+}, and CH_4 are utilized by microbes to degrade contaminants.

The following non-destructive mechanisms are primarily *abiotic*, or physical phenomena:

- *Volatilization*: In this process contaminants are removed from ground water by volatilization to the vapor phase in the unsaturated zone. This mechanism is more significant in shallow or highly fluctuating water tables;

- *Dispersion*: Mechanical mixing and molecular diffusion processes reduce concentrations. This mechanism may decrease concentrations but does not result in a net loss of mass; and,

- *Sorption*: This mechanism is controlled by the organic carbon content of the soil, soil mineralogy and grain size. Sorption retards plume migration, but does not permanently remove BTEX from soil or ground water.

5.4.2 Initial screening

Natural attenuation processes are typically occurring at all sites, but to varying degrees of effectiveness depending on the types and concentrations of contaminants present and the physical, chemical, and biological characteristics of the soil and ground water. The department is confident that MNA may be, at some sites, a reasonable and protective component of a broader remediation strategy. Consider the following when conducting the initial screening to evaluate the potential effectiveness of MNA:

- MNA will not be considered a default or presumptive remedy at any contaminated site. MNA must only be selected when it is proven that the active remedial technology will not be operable. MNA may be an acceptable option for sites that have been subjected to active remediation and which now have substantially reduced concentrations of contaminants. In addition, MNA may be an acceptable option for sites that have undergone source removal or source control.

- Contaminant concentrations, presence of free phase product and nearby receptors must be considered when conducting the initial screening to evaluate the potential effectiveness of MNA. The department will not approve use of MNA at sites where free phase product or petroleum saturated soil is present. MNA should not be used where such an approach could result in significant migration or impacts to receptors and other environmental resources. These concerns should be addressed in the Tier 2 Assessment.

5.4.3 Site characterization

Once the department approves MNA as a remedial option for use at a site, the following indicators of natural attenuation must be collected to describe the disposition of contamination and to predict its future behavior. Fate and transport modeling may be used to predict future behavior of the contaminants. Some of the necessary site characterization data may be collected as part of a standard Tier 2 assessment, while other data will need to be collected specifically for the purpose of evaluating natural attenuation effectiveness.

Soil parameters

- *Soil texture*: Coarse-grained soils provide the greatest drainage and aeration, but may also promote contaminant migration;

- *Lithology*: Provide information to understand preferential migration pathways;

- *Soil structure*: Layered soils inhibit vertical migration and dispersion of constituents, but may promote lateral spreading;

- *Adsorption potential*: Higher organic carbon content and smaller grain size in soil results in greater adsorption of chemicals and retards migration;

- *Soil aeration*: Greatest when soil oxygen (O_2) ≥ 2% ;

- *Soil pH*: Microbial growth is optimized between soil pH values of 6 to 8;

- *Soil nutrient concentration*: Microbial growth is optimized when carbon: nitrogen: phosphorus (C:N:P) ratio is about 100:10:1; and,

- *Historical concentrations along the primary flow path from the source to the leading edge*: Evaluate status of the plume (i.e., steady state, decreasing, migrating).

Ground water parameters

- *Direction and gradient of ground water flow*: Estimate direction of plume migration;

- *Depth of ground water*: Estimate volatilization rate;

- *Historical concentrations along the primary flow path from the source to the leading edge*: Evaluate status of the plume (i.e., steady state, decreasing, migrating);

- *Range of water table fluctuations*: Evaluate potential source smearing, influence of fluctuations on ground water concentrations, and variation in flow direction;

- *Background DO levels upgradient of the source and plume*: Typical clean ground water levels are less than 4ppm;

- *DO levels inside the contaminant plume*: Determine if sufficient DO is present for aerobic biodegradation. Dissolved oxygen levels within the plume may reach levels less than 0.5 ppm;

- *Methane*: Background methane levels need to be established for comparison with methane levels in the contaminant plume;

- *Ground water temperature*: Ground water remains at a constant temperature of 11.7 ^{0}C (53^0 F) at four feet or more below grade, but ground water temperature may decrease during winter months at ground water levels less than 4 feet below grade. For every 10^{0}C reduction in ground water temperature, the metabolic rate of bacteria decreases by 50%;

- *Ground water pH*: The majority of microbial populations are most active at a neutral pH (between 6 and 8);

- *Soluble Fe inside and outside the contaminant plume*: As oxygen is depleted inside the plume of contamination, an anaerobic environment is created in which Fe^{3+} is changed to Fe^{2+}. Fe^{2+} is more soluble and should be detected downgradient of the plume;

- *Nitrate inside and outside the contaminant plume:* Nitrate concentration will decrease inside the plume suggesting biodegradation is occurring;

- *Sulfate inside and outside the contaminant plume:* Sulfate concentration will decrease inside the plume suggesting biodegradation is occurring;

- *Methane inside and outside the contaminant plume:* Methane concentration will increase inside the plume suggesting biodegradation is occurring; and,

- *Redox potential values inside and outside the contaminant plume:* Redox potential values will be lower inside the plume as compared to background redox values. The oxidation/reduction (redox) potential of ground water is a measure of electron activity and is an indicator of the relative tendency of a solution to accept or transfer electrons.

5.4.4 Validation monitoring

Monitoring the progress of natural attenuation is necessary to confirm whether petroleum constituents are being degraded or dissipated within a reasonable time frame as predicted by the modeling and to ensure receptors are not likely to be impacted. A sufficient number of appropriately located monitoring wells are necessary to demonstrate that natural attenuation is occurring in ground water. If natural attenuation is occurring, contaminant concentrations in these wells should decrease with distance from the source area.

The number of wells required to sufficiently monitor natural attenuation must be determined based on site-specific considerations and will require department approval. In situations where potential receptors (e.g., a drinking water supply well) are located downgradient, MNA should not be used as the only remedial action technique.

Table 5.4 below summarizes the department's minimum monitoring requirements for the purpose of evaluating ongoing natural attenuation.

Table 5.4 Validation Monitoring Requirements

Medium	Parameter	Frequency	What to Look For
Ground Water	BTEX and TPH	-Site Specific- (see Chapter 6)	A decrease may be indicative of bioremediation
	Dissolved Oxygen	Quarterly for one year	A decrease is indicative of bioremediation
	Soluble Iron	Quarterly for one year	An increase is indicative of biodegradation
	Sulfate	Quarterly for one year	A decrease is indicative of biodegradation
	Nitrate	Quarterly for one year	An increase downgradient of the source is indicative of biodegradation
	Methane	Quarterly for one year	An increase is indicative of bioremediation
	Temperature	Quarterly for one year	A decrease will indicate a reduction in bioremediation
	pH	Quarterly for one year	Remain between 6 and 8 in order to avoid a possible reduction in microbial growth

5.4.5 Long-term monitoring

Long-term monitoring is required to ensure that the behavior of the contaminant plume as predicted by the modeling does not change. It is also important in evaluating the remedial effectiveness and to ensure human health and environment is protected. See Table 5.5 for long-term monitoring requirements.

Table 5.5 Long-term Monitoring Requirements

Medium	Parameter	Frequency	What to Look For
Ground Water	BTEX and TPH	Site Specific	A decrease may be indicative of bioremediation
	Dissolved Oxygen	Site Specific	A decrease is indicative of bioremediation
	Soluble Iron	Site Specific	An increase is indicative of biodegradation
	Sulfate	Site Specific	A decrease is indicative of biodegradation

Table 5.5 Cont'd

	Nitrate	Site Specific	An increase downgradient of the source is indicative of biodegradation
	Methane	Site Specific	An increase is indicative of bioremediation
	Temperature	Site Specific	A decrease will indicate a reduction in bioremediation
	pH	Site Specific	Remain between 6 and 8 in order to avoid a possible reduction in microbial growth

If the monitoring suggests that natural attenuation does not appear to be effective in remediating the contamination at the site within a reasonable time frame, then an alternative remedial option will be required.

5.4.6 MNA confirmation soil samples

Prior to recommending site closure, soil samples may be collected from the unsaturated zone in locations where soil contamination is known to be the greatest. Sample results should be compared to soil sample results collected during the initial site assessment to determine whether concentrations are being reduced. Soil samples should also be collected from the boundary of the contaminated soil area to evaluate whether the extent of contamination in the soils is increasing or decreasing.

5.5 Oxygen Release Compounds

Introducing oxygen into a petroleum contaminated environment is another form of remediation. The most common way of introducing oxygen is with the use of Oxygen Release Compound (ORC®).

ORC® may be an appropriate remediation technology when ground water has been impacted. ORC® is magnesium peroxide (MgO_2), which reacts with water to form oxygen and magnesium hydroxide [$Mg(OH)_2$]. After application, ORC® generally releases oxygen for about six months. ORC® is useful as a slow release source of oxygen in the remediation of any compound that is aerobically degradable.

The main assumption with the use of ORC® is that oxygen is the limiting factor in aerobic bioremediation. The microorganisms, nutrients, and moisture are typically present, but most sites are oxygen deficient. With the addition of oxygen, the bioremediation rate increases significantly.

5.5.1 Initial Site Screening

The department supports the use of ORC® as a 'polishing step' when ground water BTEX and TPH concentrations are relatively low. The department considers a 'polishing step' to be the point where contaminant concentrations have reached the asymptotic level as a result of the use of other remedial technologies. ORC® may be considered when dissolved phase BTEX and TPH concentrations are significantly above state ground water quality standards if other remedial technologies are not an option. ORC® may also be used to create an oxygen barrier between ground water contamination and a downgradient receptor.

ORC® must not be used in the following situations:

- when free phase product is present; and,
- when existing soil contamination is considered an ongoing source. If it can be demonstrated that contaminated soils can be eliminated as an ongoing source through an alternative remedial approach, simultaneous use of ORC® may be warranted.

5.5.2 Evaluation of Site Parameters

Although lack of oxygen is typically the limiting factor in the bioremediation of a site, some atypical environmental conditions may exist which preclude or deter bioremediation from occurring. Therefore, to determine whether or not ORC® should be used as a remedial action alternative, the following site parameters must be evaluated prior to application:

- *Contaminant Concentrations in the Soil and Ground Water*;

- *Plume Size*;

- *Soil Nutrients*: microbial growth is optimum when the carbon/nitrogen/phosphorous ratio (C:N:P) is about 100:10:1;

- *Dissolved Oxygen (DO) levels*: minimum acceptable oxygen concentration for natural microbial activity is 0.5 ppm (clean ground water is typically <4 ppm);

- *Dissolved Carbon Dioxide (CO_2) levels*: background dissolved CO_2 levels need to be established for comparison with CO_2 levels in the contaminant plume;

- *pH levels*: the majority of microbial populations are most active at a neutral pH (between 6 and 8). In addition, an acidic pH range can accelerate the release of oxygen from the ORC®, supersaturating the surrounding ground water for a brief period;

- *Ground Water Temperature*: Ground water remains at a constant temperature of 11.7 ^{0}C (53^0 F) at four feet or more below grade, but ground water temperature in South Dakota may decrease during winter months at ground water levels less than 4 feet below grade. For every 10^{0}C reduction in ground water temperature, the metabolic rate of bacteria decreases by 50%.

- *Background Chemical Oxygen Demand (COD)*, determination of background COD is useful in determining the total oxygen demand for the site. A conservative calculation provided by Regenesis converts COD to the *Additional Demand Factor (ADF*). This ADF is used in calculating the amount of ORC and the proper spacing of application points. Typical ADF values range from 8 to 10.

5.5.3 Application Methods and Monitoring Requirements

Application Methods

Since water is needed to hydrate magnesium peroxide (MgO_2), ORC® must not be applied above the capillary fringe. A monitoring well must not be used to monitor contaminant concentrations if it falls within an ORC® plume. If ORC® is injected too close to a monitoring well (or if a monitoring well is used to install ORC®), the contaminant concentrations measured in the monitoring well will not be indicative of actual site conditions.

ORC® may be applied with any of the following methods:

- placed in the bottom of an excavation if ground water had been encountered in the excavation; or,
- installed in the contaminated saturated zone using a hand auger, direct-push hydraulic punch equipment, or hollow-stem augers.

Monitoring Requirements

After the appropriate site information is collected to determine if ORC® is an appropriate remedial technology for the site, a Corrective Action Plan must be submitted for departmental review.

Prior to ORC® application, a minimum of three ground water monitoring wells are required to be monitored semi-annually. Two of these monitoring wells should be within the plume of contamination. One of these wells must be upgradient of the plume in order to establish background levels.

Periodic ground water monitoring is required to determine the effectiveness of ORC® treatment. See Table 5.6 below for monitoring requirements.

Table 5.6 ORC® Monitoring Requirements

Parameter	Frequency After Application	What to Look For
BTEX and TPH	3, 6, and 12 months	A decreasing trend may be indicative of bioremediation
DO	3, 6, and 12 months	A decrease is indicative of bioremediation
Dissolved CO_2	3, 6, and 12 months	An increase is indicative of bioremediation
Temperature	3, 6, and 12 months	A decrease in temperature is indicative of a reduction in bioremediation
Dissolved Iron	3, 6, and 12 months	An increase is indicative of bioremediation
Nitrogen	3, 6, and 12 months	A decrease is indicative of bioremediation
Phosphorous	3, 6, and 12 months	A decrease is indicative of bioremediation

5.6 Other Technologies

Other technologies for in-situ remediation may be approved by the department based on site specific conditions, the technical feasibility of remediation, and the nature of the chemical of concern.

5.7 Engineering Controls

The use of engineering controls may provide alternatives to remediation of contaminated soils as per ARSD 74:56:05 "Remediation Criteria for Petroleum-Contaminated Soils". These controls must be designed to reduce the risks involved with petroleum contaminated soils left in place. Regardless of the type of remedial activity proposed, the department must give approval prior to installation.

5.7.1 Engineering controls to eliminate exposure routes

Options to eliminate exposure routes include:

- Rerouting impacted or potentially impacted utilities around the contamination area;
- Apply positive pressure on potentially impacted structures to prevent vapors from entering the building;
- Placement of low permeability caps over the contamination area to prevent infiltration of surface water and contact with surficially contaminated soils;
- Placement of grout curtain walls or interceptor trenches upgradient of the contamination area to prevent migration of ground water through the contamination;
- Placement of barrier wells or interceptor trenches to prevent the contaminated water from moving off-site; and
- Other technologies as approved by the department.

5.7.2 Engineering controls for vapors

Options to control vapors include:

- Installation of vapor extraction system around a building foundation to prevent vapors from entering the structure or utilities;
- Apply positive pressure to the structure or utility to prevent vapors from entering;
- Install explosion-proof fans to remove the vapors from the structure or utility;
- Replacement of basement concrete walls;
- Flush the sewer lines with water;
- Replace or reroute the utility lines; and

- Other technologies as approved by the department.

5.7.3 Engineering controls to treat or protect drinking water supplies

Options to treat or protect drinking water include:

- Develop alternative source of drinking water either by drilling a deeper well into a different water bearing zone not hydraulically connected to the contaminated zone or extending a local public water supply line;
- Place carbon filter system on the water supply system;
- Reroute water supply line to eliminate exposure; and
- Other technologies as approved by the department.