An Introduction to In-Situ Treatment of Hazardous Soil

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CONTENTS

1. **BIOLOGICAL TREATMENT**
2. **CHEMICAL OXIDATION**
3. **PERMEABLE TREATMENT BEDS**
4. **SOIL FLUSHING**
5. **VAPOR EXTRACTION**

1. BIOLOGICAL TREATMENT.

1.1 PROCESS DESCRIPTION.

1.1.1 ORGANIC MATERIALS in contaminated soils may be amenable to biodegradation in place, or in situ. The process consists largely of producing conditions in the soil mass which promote the rate of natural degradation by endogenous organisms. Conditions favoring biodegradation include increased aeration and nutrient concentrations. In some cases, seed cultures may increase the active population and be beneficial.

1.1.2 THE BIODEGRADATION PROCESS is slow relative to other remedial action technologies. Complete degradation of the waste could take several years and may never be complete if refractory compounds such as polynuclear aromatics are present. This is a major disadvantage, since additional migration of contaminants can occur during the treatment and even afterwards.

1.1.3 THIS TECHNIQUE IS GENERALLY limited to those situations where the waste material or contaminated soil is naturally aerated or where artificial aeration is feasible. Procedures for the addition of nutrients such as nitrogen and phosphorus may be necessary if the waste material is deficient in these constituents. Lime may be required to maintain proper pH.

1.2 APPLICATIONS.

1.2.1 SITUATIONS WHERE in situ bioremediation could be applied are those where complete mixing and/or aeration can be achieved. A primary application is a chemical spill or land-spreading operation where the wastes have not migrated below tilling depth (about 305 to 610 mm (12 to 24 inches)), or a surface impoundment in which the waste is fluid enough to be mechanically aerated and pumped for mixing.

1.2.2 BIODEGRADATION HAS BEEN USED most widely for treatment of oily sludges and refinery waste. Chlorinated solvents such as TCE or PCE are not degraded effectively using current technology; however, work is continuing on these materials. Naturally occurring bacteria and special cultures have been developed which are capable of degrading benzene, phenol, cresol, naphthalene, gasoline, kerosene, and cyanide, and many of their derivatives.

1.3 ADVANTAGES/DISADVANTAGES. In land treatment, if soils are not well aerated, waste degradation will occur only slowly, if at all. Because metals are not degraded, careful attention should be given to the toxic metal load at the site. Since the process can be very slow, additional migration of contaminants may take place during and after treatment. Also, the possibility of forming a toxic byproduct as a result of biodegradation should be considered.

1.4 DATA REQUIREMENTS.

1.4.1 THE TYPE, QUANTITY, AND DISTRIBUTION of the waste constituents will have to be determined to select a nutrient, and air requirements.

1.4.2 TESTS MUST BE MADE to determine if microorganisms are naturally occurring which will breakdown the target chemicals. If none are present, enriching or seed cultures may be required.

1.4.3 THE SITE TOPOGRAPHY, HYDROGEOLOGY, and soil physical, chemical, and biological properties are also necessary to determine the injection and withdrawal system requirements and design.

1.5 DESIGN CRITERIA. The key factors for biodegradation include:

- Nutrient balance.
- pH maintenance.
- Soil aeration and/or oxygen availability.
- Degradation rate of waste constituents.
- Waste constituents and location.

2. CHEMICAL OXIDATION.

2.1 PROCESS DESCRIPTION. In-situ leachate treatment introduces a reactant into the contaminated region to interact with the leachate plume. Chemical injection entails injecting chemicals into the ground beneath the waste (see Figure 1) to neutralize, precipitate, or destroy the leachate constituents of concern.

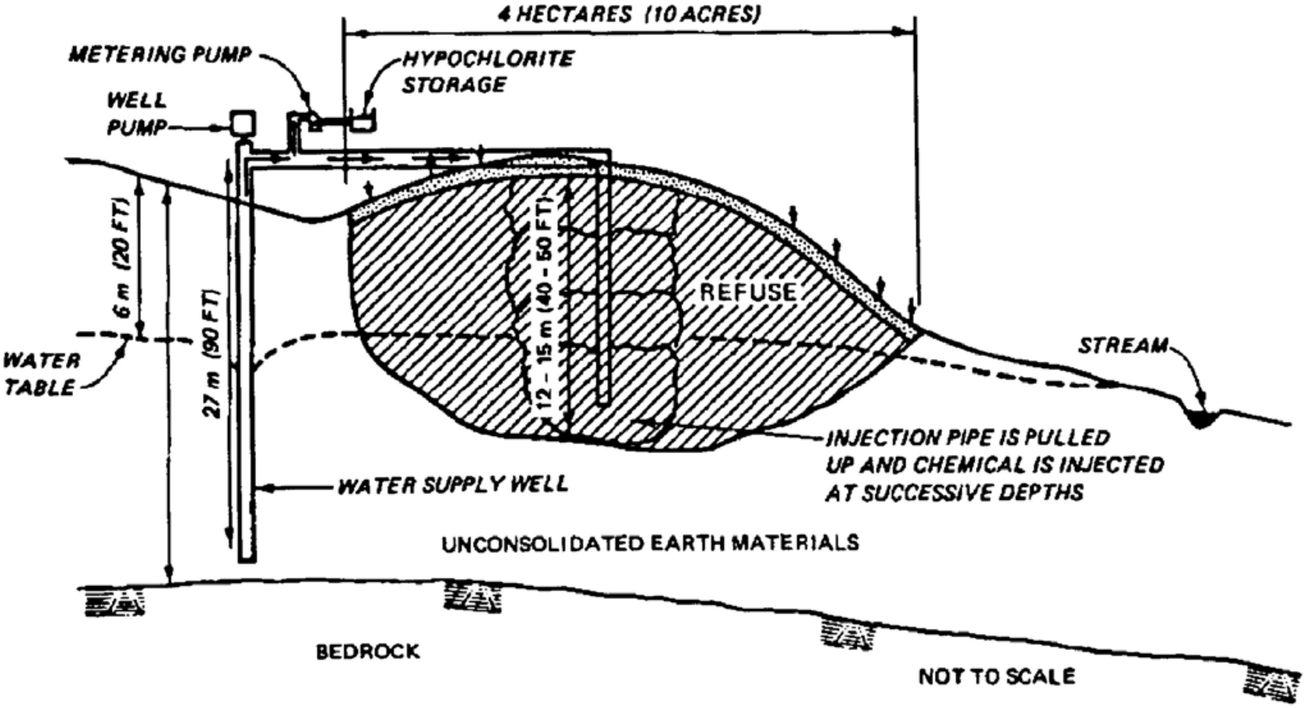

Figure 1

Cross section of landfill treated by chemical injection

2.2 APPLICATIONS. Sodium hypochlorite has been used to treat leachate containing cyanide. Very little field data are available. The areal spread and depth of the leachate plume must be well characterized so that injection wells can be placed properly to intercept all of the contaminated ground water.

2.3 ADVANTAGES/DISADVANTAGES.

2.3.1 POLLUTANTS may be displaced to adjacent areas when chemical solution is added.

2.3.2 HAZARDOUS COMPOUNDS may be produced by reaction of injected chemical solution with waste constituents other than the treatment target.

2.4 DATA REQUIREMENTS. The principal data requirements include the contamination plume characteristics: depth to bedrock, plume cross section, leachate or ground-water velocity, and hydraulic gradient. Also the soil permeability, leachate composition, and reaction rates will have to be determined.

2.5 DESIGN CRITERIA. Chemical injection systems are in the conceptual stage of development. The permeability of the soil beneath the waste must be known to determine the ground-water flow through the injected waste and the reaction time between the contaminated ground-water and chemicals.

3. PERMEABLE TREATMENT BEDS.

3.1 PROCESS DESCRIPTION. Permeable treatment beds use trenches filled with a reactive permeable medium to act as an underground reactor (see Figure 2). Contaminated ground water or leachate entering the bed reacts to produce a nonhazardous soluble product or a solid precipitate.

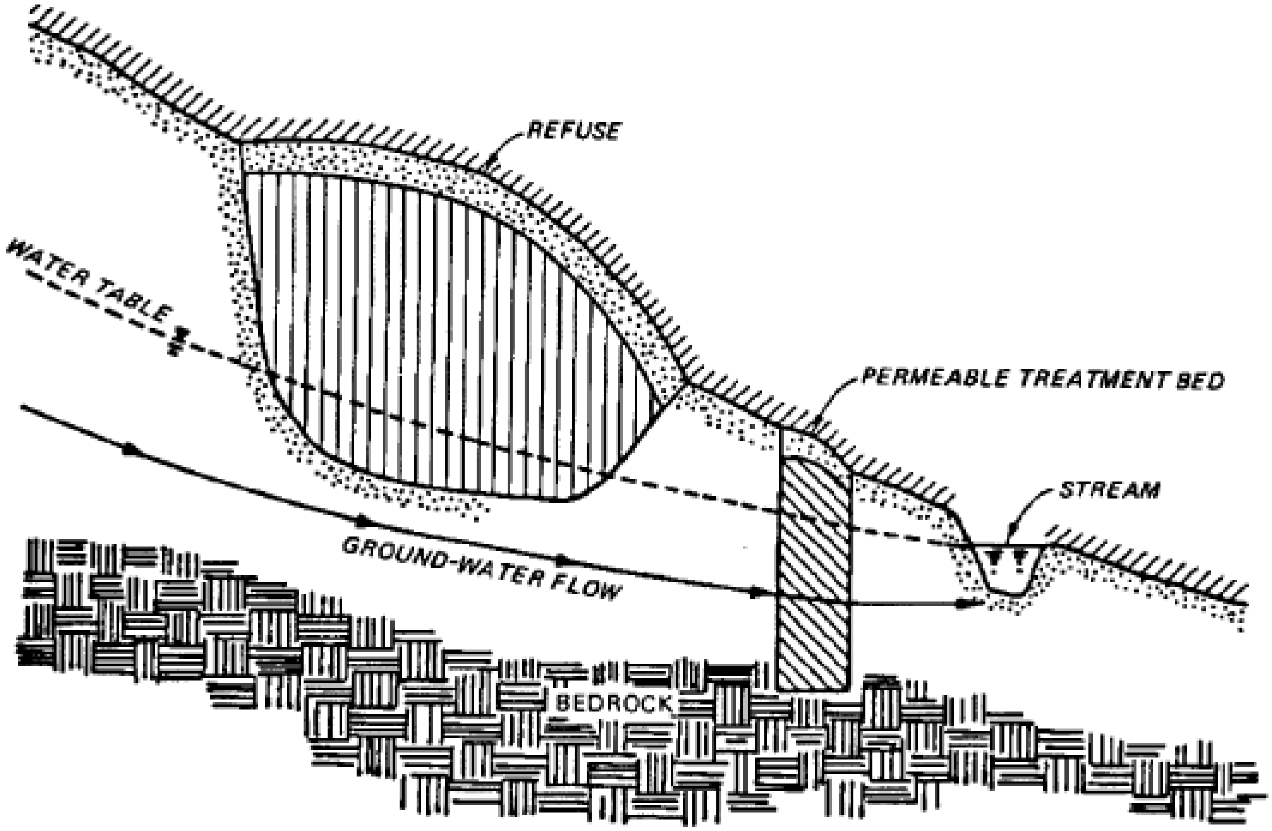

Figure 2

Installation of a permeable treatment bed

3.2 APPLICATIONS.

3.2.1 PERMEABLE TREATMENT BEDS are applicable in relatively shallow aquifers since a trench must be constructed down to the level of the bedrock or an impermeable clay. Permeable treatment beds often are effective only for a short time as they may lose reactive capacity or become plugged with solids. Overdesign of the system or replacement of the permeable medium can lengthen the time period over which permeable treatment is effective.

3.2.2 THE MATERIALS USED for this form of treatment are:

3.2.2.1 LIMESTONE OR CRUSHED SHELL - Limestone neutralizes acidic ground water and may remove heavy metals such as Cd, Fe, and Cr. Dolomitic limestone ($MgCO_3$) is less effective at removing heavy metals than calcium carbonate limestone. The particle size of the limestone should match a mix of gravel size and sand size. The larger sizes minimize settling of the bed and channeling as the limestone dissolves. The small sizes maximize contact. Extrapolated bench-scale data indicate contact time needed to change 1 pH unit is 8 to 15 days.

3.2.2.2 ACTIVATED CARBON - Activated carbon removes nonpolar organic contaminants such as CCl_4, PCBs, and benzene by adsorption. Activated carbon must be wetted and sieved prior to installation to ensure effective surface solution contact.

3.2.2.3 GLAUCONITIC GREEN SAND - This sand, actually a clay, is found predominantly on the coastal plain of the Mid-Atlantic States and has a good capacity for adsorbing heavy metals. Bench-scale studies indicate removal efficiencies of greater than 90 percent for As, Cu, Hg, and Ni, and 60 to 89 percent for Al, Cd, Ca, Cr, Co, Fe, Mg, Mn, and Zn, for detention times on the order of several days.

3.2.2.4 ZEOLITES AND SYNTHETIC ION EXCHANGE RESINS - These materials are also effective in removing solubilized heavy metals. Disadvantages such as short lifetime, high costs, and regeneration difficulties make these materials economically unattractive for use in permeable treatment beds.

3.3 DISADVANTAGES.

3.3.1 PLUGGING OF THE BED may divert contaminated ground water and channeling through the bed may occur. Both problems permit passage of untreated wastes.

3.3.2 CHANGING HYDRAULIC LOADS and/or contaminant levels may render the detention inadequate to achieve the design removal level.

3.4 DATA REQUIREMENTS. The principal data requirements include the contamination plume characteristics: depth to bedrock, plume cross section, leachate or ground-water velocity, and hydraulic gradient. Also the soil permeability, leachate composition, and reaction rates will have to be determined.

3.5 DESIGN CRITERIA.

3.5.1 A PERMEABLE TREATMENT bed is constructed by digging a trench to an impermeable layer (bedrock or clay), filling the trench with the appropriate material, and capping to control infiltration. The width of the trench is determined by the permeability of the material used for treatment, the groundwater flow velocity, and the contact time required for treatment. These parameters are related as:

$$\mathrm{W_b} = (\mathrm{V_b})(\mathrm{t_c}) \tag{1}$$

where

W_b = barrier width, m

V_b = ground-water flow velocity in the barrier, m/sec

t_c = contact time to achieve the desired removal, sec

Ground-water velocity, v, in turn, is determined by Darcy's law:

$$\mathrm{v} = \mathrm{k}s \tag{2}$$

where

s = the gradient or loss of head per unit length in the direction of flow (unitless)

k = coefficient of permeability, a soil-specific value, m/sec

3.5.2 SINCE THE GROUND-WATER velocity through the permeable bed cannot be predetermined, the trench should be designed for the maximum ground-water velocity through the soil. If one assumes the hydraulic gradient is equal for the soil and the permeability bed, the permeability of the barrier must equal that of the soil.

4. SOIL FLUSHING.

4.1 PROCESS DESCRIPTION. Solution mining (extraction) is the application of a solvent to a waste solid or sludge, and collection of the elutriate at well points for the removal and/or treatment of hazardous waste constituents. Typically, solvents used are water, acids (sulfuric, hydrochloric, nitric, phosphoric and carbonic), ammonia, and/or chelating agents such as EDTA which solubilize heavy metals and other inorganic ions. As the solvent is collected, a fraction can be recycled through the landfill with a make-up solution. The remainder can be treated and disposed.

4.2 APPLICATIONS. Chemical extraction has been used by the chemical processing and mining industries for many years. The techniques are well understood, but experience with in-situ treatment of hazardous waste is lacking. Therefore, very little data are available on the application of this technology in a remedial action setting. Bench-scale laboratory studies of extraction of heavy metals from sludges and plans to conduct full-scale metal extraction from industrial wastes have been made.

4.3 ADVANTAGES/DISADVANTAGES.

4.3.1 THE ADVANTAGES OF THE PROCESS are that, if the waste is amenable to this technique and distribution, collection, and treatment costs are relatively low, solution mining can present an economical alternative to the excavation and treatment of the wastes. It may be particularly applicable if there is a high safety and health hazard associated with excavation. Also, the effectiveness and completion of the treatment process can be measured via sampling prior to wastewater treatment.

4.3.2 DISADVANTAGES INCLUDE an uncertainty with respect to adequate contact with wastes; that is, because the wastes are buried, it is difficult to determine whether the solvent has contacted all the waste. Also, containerized waste cannot be treated effectively by this method. Another disadvantage is that the solution mining solvent or elutriate may become a pollutant itself if the system has been poorly designed.

4.4 DATA REQUIREMENTS. Principal data requirements would include laboratory testing to determine extraction efficiency of the solvents and waste analysis for presence of constituents not compatible with the solvent. Also, field testing and a geohydrologic site survey to establish potential for solvent migration into uncontaminated ground water and to establish well placement sites for collection of the elutriate are required.

4.5 DESIGN CRITERIA. The data requirements will determine the selection of an extraction solvent, the well placement for collection of the elutriate, and the injection well locations for the extracting solvent.

5. VAPOR EXTRACTION.

5.1 BACKGROUND. Soils may become contaminated in a number of ways with such volatile organic chemicals as industrial solvents and gasoline components. The sources of contamination at or near the earth*s surface include intentional disposal, leaking underground storage tanks, and accidental spills. Contamination of ground water from these sources can continue even after discharge has stopped because the unsaturated zone above a ground-water aquifer can retain a portion or all of the contaminant discharge. As rain infiltrates, chemicals elute from the contaminated soil and migrate toward ground water.

5.2 PROCESS DESCRIPTION.

5.2.1 A SOIL VAPOR EXTRACTION, a forced air venting, or an in situ air stripping system (Figure 3) revolves around the extraction of air containing volatile chemicals from unsaturated soil. Fresh air is injected or flows into the subsurface at locations around a spill site, and the vapor-laden air is withdrawn under vacuum from recovery or extraction wells.

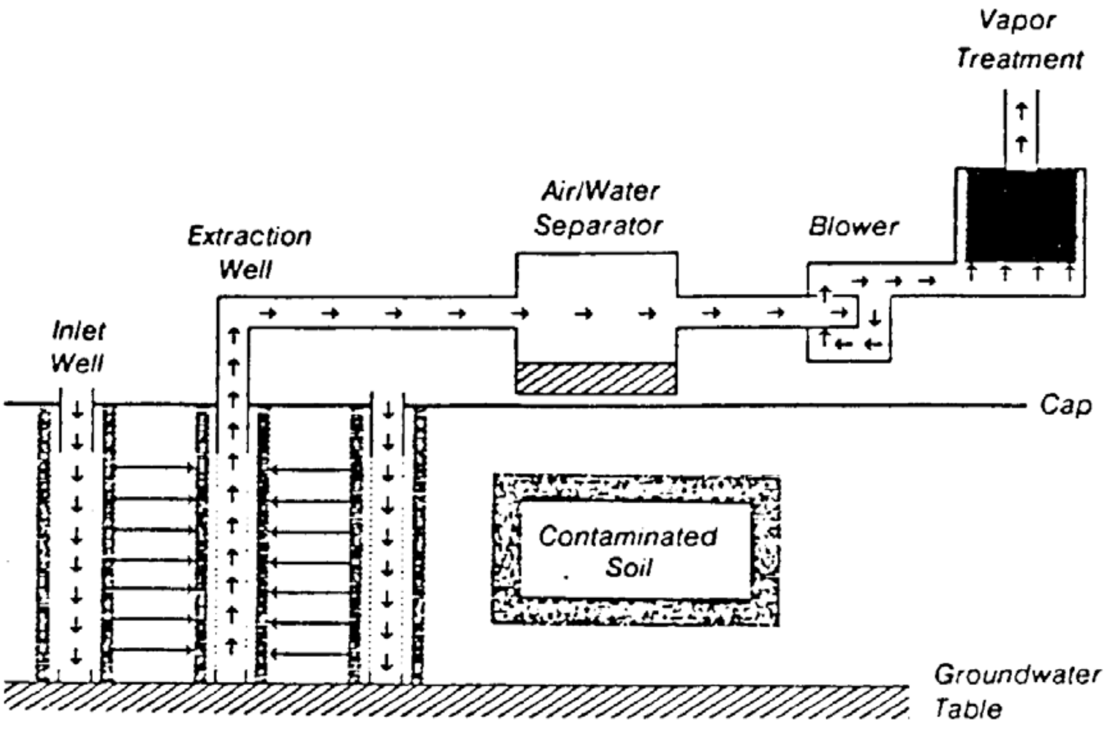

Figure 3

Soil vapor extraction system

5.2.2 IN THE SIMPLEST SOIL VAPOR EXTRACTION SYSTEMS, air flows to an extraction well from the ground surface. To enhance air flow through zones of maximum contamination, it may be desirable to include air inlet wells in the installation. These injection wells or air vents, whose function is to control the flow of air into a contaminated zone, may be located at numerous places around the site. Typically, injection wells and air vents are constructed similarly to extraction wells. In some installations, extraction wells have been designed so they can also be used as air inlets. Usually, only a fraction of extracted air comes from air inlets. This indicates that air drawn from the surface is the predominant source of clean air.

5.2.3 EXTRACTION WELLS ARE TYPICALLY DESIGNED to fully penetrate the unsaturated zone to the capillary fringe. Extraction wells usually consist of slotted plastic pipe placed in permeable packing and sealed near the surface to avoid "short-circuiting."

5.2.4 DURING REMEDIATION, the blower is turned on and the air flow through the soil comes to an equilibrium. The flows that are finally established are a function of the equipment, the flow control devices, the geometry of well layout, the site characteristics, and the air permeability of the soil. At the end of operation, the final distribution of VOCs in the soil can be measured to ensure decontamination of the site. Wells may be aligned vertically or horizontally. Vertical alignment is typical for deeper contamination zones and for residue in radial flow patterns. If the depth of the contaminated soil or the depth to the ground-water table is less than 10 to 15 feet, it may be more practical to dig a trench across the area of contamination and install horizontal perforated piping in the trench bottom rather than to install vertical extraction wells. Usually several wells are installed at a site.

5.2.5 THE MEANS TO VERIFY THE SUCCESS of cleanup is often problematic. Soil sampling is difficult to use because of the uncertainties in replicating the sampling results at a location. Measuring the soil gas concentrations are more repeatable but difficult to relate to regulatory standards, where they exist.

5.3 APPLICATIONS. Alternatives for decontaminating unsaturated soil include excavation with onsite or offsite treatment or disposal, biological degradation, and soil flushing. Soil vapor extraction is also an accepted, cost-effective technique to remove volatile organic chemicals from contaminated soils. Soil vapor extraction can be effectively used for removing a wide range of volatile chemicals in a wide range of conditions. The design and operation of these systems is flexible enough to allow for rapid changes in operation, thus, optimizing the removal of chemicals.

5.4 ADVANTAGES/DISADVANTAGES. Advantages and disadvantages of soil vapor extraction are summarized below:

Advantages	Disadvantages
Minimal disturbance of the contaminated soil	There are few guidelines for the optimal design, installation, and operation of soil vapor extraction
Systems can be constructed from standard equipment	Theoretically based design equations defining the limits of this technology are lacking and system designs are mostly empirical
Systems have been demonstrated at pilot- and field-scale	
Systems can be used to treat larger volumes of soil than are practical for excavation	Alternative designs can only be compared by the actual construction, operation, and monitoring of each design
Systems have the potential for product recovery system	
Spills can be cleaned up before the chemicals reach the ground water table	Vapors and condensed liquids collected from the wells may require treatment prior to discharge to the air
Systems can be integrated with other cleanup technologies to provide complete restoration of contaminated sites	Extraction of volatile chemicals from clays and silts may be difficult
Can treat soils at depths greater than in range of excavation	Determining when the site is sufficiently clean to cease operation

5.5 DATA REQUIREMENTS. A number of variables characterize the successful design and operation of a vapor extraction system:

5.5.1 SITE CONDITIONS: Distribution of VOCs, depth to ground water, infiltration rate, location of heterogeneities including paved or sealed areas, temperature and atmospheric pressure.

5.5.2 SOIL PROPERTIES: Permeability, porosity, organic carbon content, soil structure, soil moisture characteristics, particle size distribution.

5.5.3 CONTROL VARIABLES: Air withdrawal rate, well configuration, extraction well spacing, vent well spacing, ground surface covering, inlet air VOC concentration and moisture content, pumping duration.

5.5.4 RESPONSE VARIABLES: Pressure gradients, final distribution of VOCs, final moisture content, extracted air concentration, extracted air temperature, extracted air moisture, power usage.

5.5.5 CHEMICAL PROPERTIES: Henry*s constant, solubility, adsorption equilibrium, diffusivity (air and water), density, viscosity.

5.6 DESIGN CRITERIA. The design and operation of soil vapor extraction systems can be quite flexible; changes can be made during the course of operation with regard to well placement, or blower size, or air flows from individual wells. If the system is not operating effectively, changes in the well placement or capping the surface may improve it. Based on the current state of the technology of soil vapor extraction systems, the following design criteria can be recommended.

5.6.1 INTERMITTENT BLOWER OPERATION is probably more efficient in terms of removing the most chemical with the least energy.

5.6.2 EXTRACTION WELLS ARE USUALLY screened from a depth of from 1.5 to 3 m (5 to 10 feet) below the surface to the ground-water table. For thick zones of unsaturated soil, maximum screen lengths of 6.1 to 9.1 m (20 to 30 feet) are specified.

5.6.3 AIR/WATER SEPARATORS are simple to construct and should probably be installed in every system.

5.6.4 INSTALLATION OF A CAP over the area to be vented reduces the chance of extracting water and extends the path that air follows from the ground surface, thereby increasing the volume of soil treated.

5.6.5 INCREMENTAL INSTALLATION of wells, although probably more expensive, allows for a greater degree of freedom in design. Modular construction where the most contaminated zones are vented first is preferable.

5.6.6 USE OF SOIL VAPOR PROBES in conjunction with soil borings to assess final cleanup is less expensive than use of soil borings alone. Usually a complete materials balance on a given site is impossible because most sites have an unknown amount of VOC in the soil and in the ground water.

5.6.7 SOIL VAPOR EXTRACTION SYSTEMS are usually only part of a site remediation system.

5.6.8 ALTHOUGH A NUMBER OF VARIABLES intuitively affect the rate of chemical extraction, no extensive study to correlate variables to extraction rates has been identified.

5.6.9 WELL SPACING IS USUALLY based on some estimate of the radius of influence of an individual extraction well. Well spacing has ranged from 15 to 100 feet. Well spacing should be decreased as soil bulk density increases or the porosity of the soil decreases. One of the major differences noted between systems was the soil boring diameter. Larger borings are preferred to minimize extracting liquid water from the soil.

5.6.10 WELLS SHOULD BE CONSTRUCTED with approximately 20 feet of blank casings between the top of the screen and the soil surface to prevent the short circuiting of air and to aid in the extraction of deep contamination.

5.6.11 INITIAL VOC RECOVERY rates are relatively high, then decrease asymptotically to zero with time. Several studies have indicated that intermittent venting from individual wells is probably more efficient in terms of mass of VOC extracted per unit of energy expended. This is especially true when extracting from soils where mass transfer is limited by diffusion out of immobile water.

5.6.12 OPTIMAL OPERATION OF A SOIL VAPOR extraction system may involve taking individual wells in and out of service to allow time for liquid diffusion and to change air flow patterns in the region being vented.

5.6.13 AIR INJECTION HAS THE advantage of controlling air movement, but injection systems need to be carefully designed.