INTERSTATE TECHNOLOGY & REGULATORY COUNCIL

TECHNOLOGY OVERVIEW

INTERSTATE TECHNOLOGY AND REGULATORY COOPERATION WORK GROUP (ITRC)
IN SITU BIOREMEDIATION WORK TEAM, CLOSURE CRITERIA FOCUS GROUP

FY-97 REPORT

-FINAL-

March 3, 1998

Prepared by
Interstate Technology and Regulatory Cooperation Work Group
***In Situ* Bioremediation Work Team**
Closure Criteria Focus Group

ABOUT ITRC

Established in 1995, the Interstate Technology & Regulatory Council (ITRC) is a state-led, national coalition of personnel from the environmental regulatory agencies of some 40 states and the District of Columbia; three federal agencies; tribes; and public and industry stakeholders. The organization is devoted to reducing barriers to, and speeding interstate deployment of, better, more cost-effective, innovative environmental techniques. ITRC operates as a committee of the Environmental Research Institute of the States (ERIS), a Section 501(c)(3) public charity that supports the Environmental Council of the States (ECOS) through its educational and research activities aimed at improving the environment in the United States and providing a forum for state environmental policy makers. More information about ITRC and its available products and services can be found on the Internet at **www.itrcweb.org.**

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ACKNOWLEDGMENTS

The members of the Interstate Technology Cooperation Work Group (ITRC), *In Situ* Bioremediation (ISB) Technical Work Team, Closure Criteria Focus Group wish to acknowledge the individuals, organizations and agencies that contributed to this document.

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Recognition of their efforts and thanks go to those representatives from state and federal government entities, and members from industry, who formulated the core of this work group and contributed regulatory, technical and policy considerations during the construction of this document. They are: Paul Hadley (Team Leader), and Bal Lee California Environmental Protection Agency; Jeff Kelley (Focus Group Leader), Nebraska Department of Environmental Quality; and, Steve Hill, Coleman Energy and Environment.

The work team also wishes to recognize the efforts of individual state regulatory staff and other ITRC members who made the time in their already over-taxing schedules to provide technical, regulatory, and "reality check" review of the documents, and to respond to the work team survey.

EXECUTIVE SUMMARY

The Interstate Technology and Regulatory Cooperation Work Group (ITRC) was established in February, 1995 to encourage interaction among various regulatory and non-regulatory parties. This federal, state, industry, and stakeholder group aims to improve the deployment of innovative technologies or approaches for the environmental remediation of sites across the U.S. Participating state environmental agencies are using the network to verify the effectiveness of various technologies and methodologies in an attempt to reduce paperwork and expensive duplication of effort.

In FY-97, the ITRC established six technical task teams, including one charged with reviewing a number of technical and regulatory issues surrounding *In situ* Bioremediation technologies. The *In situ* Bioremediation Technical Task Group established smaller, more focused groups to study specific aspects of the field, including the Focus Group on Closure Criteria. This is the report of that Focus Group.

Three relatively common approaches to remediation of sites with volatile organic compounds (VOCs), soil vapor extraction, bioventing, and natural attenuation, were included in a survey to determine practices and trends in establishing closure criteria for such sites. Closure criteria essentially define the performance required for any remediation technology. Based on 24 responses to a survey (sent out in November 1996), these basic approaches were observed for establishing closure criteria: attaining soil cleanup criteria (either soil chemical analysis or soil gas), a technology limits, and risk assessment. In general, these three approaches are remarkably dissimilar in principle and practice, and only the risk assessment approach robustly addresses issues related to protection of public health and the environment. The soil cleanup criteria approach is typically conservative, even in meeting conservative remediation objectives (MCLs in ground water back calculated for soil cleanup values). The technology-based approach, often associated with soil vapor extraction (SVE) projects, does not quantify residual risk associated with a site. However, soil vapor extraction has been remarkably successful in removing tremendous amounts of VOCs from the subsurface and has been shown to meet extremely conservative cleanup requirements in many states.

The conclusions of the Focus Group may be summarized that:

- the wide range of contaminant specific closure criteria may be due to differences in current or future resource use, site specific considerations (soil type, lithology, etc.), or the method of calculating closure criteria or modeling contaminant fate and transport; and,
- a national consensus on the methodology used to establish closure criteria would bring some consistency to the field, which would prove particularly beneficial for SVE technologies.

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1.0 BACKGROUND

The Interstate Technology and Regulatory Cooperation (ITRC) Work Group, established in 1995, is a state-led partnership between state environmental regulatory agencies, federal agencies, tribal, public and industry stakeholders. The purpose of the ITRC is to improve environmental cleanup by encouraging the use of innovative environmental technologies, while reducing regulatory paperwork and overall costs. States are collaborating to develop and facilitate the use of standardized processes for the performance verification of new technologies. The In-situ Bioremediation Work Team (ISB) of the ITRC initiated a project to survey various states' experiences and perceptions of regulatory and policy issues regarding a number of in-situ bioremediation methods.

2.0 INTRODUCTION

In FY-96, the ISB produced evaluations of, and consensus statements for, protocols dealing with the applications of bioventing and natural attenuation for the remediation of petroleum hydrocarbons. Those reviews identified that the perceived absence, uncertainty, or variability of closure criteria frequently impeded the use of certain technologies, including those being reviewed (i.e., soil vapor extraction, bioventing and natural attenuation).

There has been discussion for several years regarding when a treatment technology or facility may discontinue operations for the remediation of volatile organic compounds (VOCs), including petroleum hydrocarbons. Various jurisdictions have identified criteria for the closure (or designation of "No Further Action) of sites using soil vapor extraction (SVE), bioventing, and natural attenuation. Many states are re-thinking their approaches to site cleanup, and to petroleum sites in particular. These issues presented the ISB technical task team an opportunity to follow-up on perceived barriers by providing member and non-member states an analysis of closure criteria used at active and closed sites around the nation. By investigating current practices and trends among states in establishing closure criteria for technologies being deployed at petroleum and solvent contaminated sites, the common and unique elements among these projects can be examined and discussed. Collectively, *in situ* projects with established closure criteria offer a data set to evaluate these approaches and trends.

2.1 Closure Criteria Focus Group Objective

The objective of the Closure Criteria Focus Group was to evaluate current and changing practices among states for establishing and achieving closure criteria for bioventing, soil vapor extraction and natural attenuation for petroleum hydrocarbons and chlorinated solvents. These, particularly *in situ* technologies, face common obstacles in remediating soils and ground water.

2.2 Technologies Selected

Three approaches used to remediate sites contaminated with volatile organic compounds (VOCs), which are included in this report, include soil vapor extraction, bioventing and natural attenuation. We have considered all three approaches as technologies, although each could also be described as a technique rather than a technology.

2.2.1 Soil Vapor Extraction (SVE)

Soil vapor extraction is an *in situ* technology for the removal of volatile organic compounds (VOCs) from the unsaturated zone through the use of vapor extraction wells installed in the contaminated zone. As air is removed from the soil, ambient air is injected or drawn into the subsurface at locations around the contaminated site. When ambient air passes through the soil, contaminants are volatilized and removed. Depending on contaminant concentrations and regulatory requirements, the recovered vapors may require treatment before release to the environment.

2.2.2 Bioventing

Bioventing is the use of induced low volume air movement through unsaturated soils, with or without nutrient addition, to reduce soil contamination through biodegradation. The progress of biodegradation is monitored using respiration tests that measure the consumption of oxygen attributable to biological activity that destroys organic compounds.

2.2.3 Natural Attenuation (NA)

The natural attenuation processes that are at work in such a remediation approach include a variety of physical, chemical, or biological processes that, under favorable conditions, 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 biochemical stabilization, transformation, or destruction of contaminants. (*USEPA OSWER Directive 9200.4-17*)

2.3 Importance of Closure Criteria Development

Closure criteria can be considered at various points in the site cleanup process. The rationale used for establishing various closure criteria, the ability of technologies to achieve those criteria, and methods used to develop closure criteria are obviously important to demonstrating necessity and adequacy of remediation and the importance to the achieveability of site remediation. Closure criteria define the performance requirements for technologies or technical approaches employed at a given site. The relationship between technology performance, benefits due to cleanup, and the cleanup time frame and cost of cleanup are all dependent on establishment of closure criteria. Closure criteria can be similar, or identical to those criteria that caused a site to be investigated e.g. MCLs. Closure criteria can also differ from these same criteria by applying institutional controls and other factors.

3.0 METHODOLOGY

A survey was conducted by distributing a questionnaire to state Points of Contact (POCs) of the ITRC work group; and EPA, DOD and industry representatives of the ITRC work group. State POCs were asked to disseminate the survey throughout their agencies to obtain a broad response. The questionnaire asked agencies and industry to identify sites where closure criteria had been established and/or achieved using SVE, bioventing or natural attenuation. The questionnaire also asked for the rational agencies used for development of site specific closure criteria. The surveys were distributed in November, 1996 and in May, 1997 twenty four responses had been received. A spreadsheet tabulating the responses to the questionnaire is included in Appendix C.

3.1 Closure Criteria Methodologies

According to the 24 responses received through the survey, closure criteria are based on various factors including contaminant concentrations in soils, ground water and soil gas; risk; system performance limitations or recovery rate asymptote; site use (existing or projected); threat to ground water; cost and time. Six parameters are reportedly used to establish closure criteria: soil gas concentration, soil contaminant concentration, defined asymptote or technology limits, time, risk reduction, and mass removal rate/cost basis. Each are discussed below:

1a. Soil gas based (mg/kg) without attenuation: Calculate vapor concentration in soil with contaminated ground water at MCL concentrations in equilibrium with the vadose zone:

Concentration (vapor) = [Concentration (water)] [*Henry's Law Constant* (dimensionless H-contaminant specific)]
(Bentley, H. W. and Walter, G. R., 1997, See Appendix D for this report)

1b. Soil gas based <u>plus</u> attenuation:

Soil gas concentration calculated from 1a above, plus incorporation of an attenuation factor based on modeling or other method.

2a. Soil based concentration (mg/kg) without attenuation: (*EPA Guidance 9355.4-23 and 9355.4-17A*)

Calculate soil concentration in equilibrium with ground water, at MCL concentrations using:
C (soil) = [C (water)] [Kd] = [MCL, ug/l] [Kd]
where Kd = (K_{oc}) (foc)
Kd: soil-water partition coefficient (L/kg)
foc: fraction organic carbon in soil (g/g)
K_{oc}: soil organic carbon/water partition coefficient (L/kg)

2b. Soil based concentration <u>plus</u> attenuation: Soil concentration calculated from 2a above, plus incorporation of an attenuation factor based on modeling or other method.

3. Defined Asymptote: (SVE technology/site condition limits) Conditions reach a line considered a limit to a curve in the sense that the perpendicular distance from a moving point on the curve to the line approaches zero (or other values) as the point moves an infinite distance from the origin, however the point never quite reaches zero (or the designated value). Figure 3.1 shows a typical asymptotic curve. SVE systems typically demonstrate a sharp decrease in initial concentration values. As time progresses mass removal rates and extracted vapor decrease approaching the asymptotic conditions.

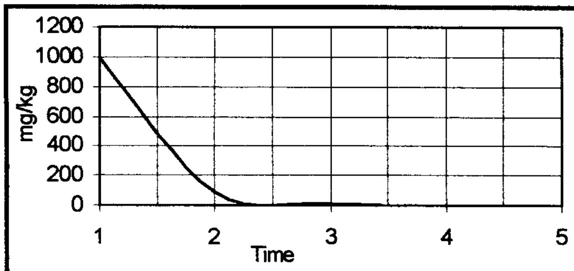

Figure 3.1 Example of an Asymptotic Curve

This is an alternative closure criteria for the case where the cleanup level based on MCLs, either soil based or soil gas based, cannot be attained, (i.e., the cleanup standard falls below the concentration asymptote). In the past, states have required multiple (2 - 3 or more) restarts after initial stabilization to an asymptotic concentration to assure contaminant levels do not rebound to unacceptable levels. A US EPA guidance document, "*How to Evaluate Alternative Cleanup Technologies for Underground Storage Tank Sites, a Guide for Corrective Action Plan Reviewers* (USEPA 510-B-95-007, page II-29)," recommends maintaining the pulsed-mode operation for six months after the concentration asymptote has been initially reached.

As an example, within the sites surveyed, site #8 (see Appendix C) contains silty sand in the vadose zone. The calculated cleanup level of PCE based on MCLs ranged from 5 to 52 ppb in soil depending on the depth of the vadose zone soil. Some of these closure criteria are beyond the performance limit of SVE technology under these conditions. To accommodate these limits, alternative closure criteria being proposed at the site are:

- as the initial concentration asymptote is reached, pulsed-mode (on/off type) operation will commence and continue for at least one year, and/or,
- confirmation sampling at the termination of SVE operation; and/or
- assess the risk based on residual PCE concentrations in the vadose zone.

The California Department of Toxics Substance Control has established draft guidelines for use when establishing and measuring alternative closure criteria (see Appendix D, *Alternative Closure Criteria Based on SVE Technology Limits)*.

4. Time basis: This is typically used as a precautionary measure to insure that rebound does not return to an unacceptable value (after remediation initially reaches an acceptable value) due to continued volatilization of contaminant from the unsaturated zone or shallow

unconfined aquifers. This includes continuous operation or pulsed operation as in the example above and in sites 9, 15, 16, 17, and 19 (Appendix C).

5. Risk Reduction Based Closure Criteria: Closure criteria are based on risk calculations (including risk to ground water), existing statutes, regulations and state guidance documents. Specific risk based closure criteria are typically based on risk assessment on a real or hypothetical (projected land use) receptor. Site # 6 used a local risk evaluation to establish soil gas concentration values for 2-butanone, ethylbenzene, xylene and PCE. Site # 8 established a soil gas risk based level for PCE as the target, with the stipulation that if this could not be achieved, due to variable lithology with depth, the performance limits of the SVE are to be applied at the site (and when asymptotic conditions are achieved [see # 3 above]) as the closure criteria. Site # 23 included a 10 -6 risk level for naphthalene plus 4.5 years of quarterly monitoring and 1.5 years of semi-annual confirmation monitoring to close the site.

6. Mass removal rate/cost basis: Three sites in Appendix C (Site # 1, 3, 12) used mass removal as a technology performance target. Each, however, included soil or soil gas concentrations as the cleanup criteria.

   Site # 1 used mass removal and cost as a basis for choosing SVE over pump and treat, however the ground water still required pump and treat after the vadose zone was satisfactorily treated with SVE.

   Site # 3 included a minimum removal rate to be the technology performance criteria. The minimum removal rate was established as 10% of the initial removal rate (lbs./day) and the closure criteria was established as maximum soil concentrations calculated from ground water MCLs.

   At site # 12, SVE was used only until its economic benefit approached zero (i.e. cost could not justify amount of product being removed). Natural attenuation will be proposed to complete remediation to the state's ground water standards for each contaminant. The rationale for the use of natural attenuation requires the demonstrated absence of any imminent impact to receptors.

3.2 Technology-Specific Implications of Survey Responses

3.2.1 Soil Vapor Extraction

SVE technology performance limitations do not appear to be a restriction to its use, however consideration of site-specific system design and site conditions (such as low permeability soils) is critical to the optimal performance of the system. Of the Sites using only SVE as a remediation technology, 6 of the 7 have been closed (see Figure 3.2). Those using SVE with sparging and bioventing have closed 3 of 4 and 1 of 3 respectively. In the initial stages of SVE operation, soil gas concentrations reduce rapidly and rate of contaminant recovery decreases with time. When the system is shut down, concentrations may rebound as contaminants in the soil matrix or pore water and underlying ground water volatilize into the soil/sediment pore space.

Most sites in this survey, where rebound was tested, indicated that it was not observed to any measurable extent. Most SVE sites attained closure goals within six to eighteen months. The exceptions are sites with significant interbedded clay lenses (i.e. Sites # 8 and #18). To accommodate site specific conditions, the systems are generally pulsed over a period of weeks or months to detect contaminant concentration rebound. Based on responses to the survey, costs for SVE averaged $500,000 for a 1000 SCFM system. Characterization and pilot studies, prior to the operation of a full scale SVE system, commonly took about five times the period necessary for the installed system to reach closure goals.

3.2.2 SVE / Bioventing

SVE and bioventing actions are typically installed to prevent or reduce migration of contaminants into the aquifer. MCLs for groundwater, or calculated soil or soil gas requirements, are typically used as the cleanup standards in ground water and vadose zone. In the survey, bioventing is restricted to BTEX contaminated areas and SVE for solvent and BTEX contaminants (see Sites #4, #13 and #18). Of the three sites using SVE and bioventing, site # 4 has been closed successfully over a two year operational period (Figure 3.2 & Appendix C). Site 13 closure is based on an asymptotic recovery rate followed by confirmation sampling for contaminant specific closure criteria and Site # 18 requires cleanup to soil gas concentrations calculated using Henry's Constant from MCLs (See Appendix D).

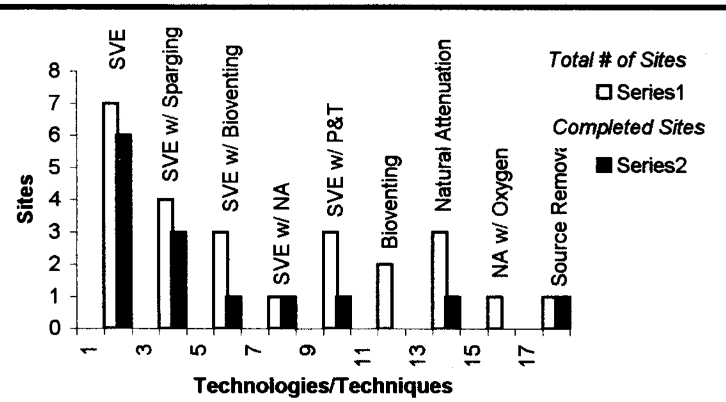

Figure 3. 2 Total # of Sites/Technology Reviewed and Completed Sites

3.2.3 Bioventing

Three sites use bioventing for remediation of TPH (Sites #s 18, 19, and 20) Sites 19 and 20 contain only BTEX contaminants and use either oxygen utilization rates or contaminant reduction as the performance measures. Bioventing for Site # 18 is only applied to a diesel contaminated area and defines the closure criteria in the vadose zone using equilibrium between the soil gas and ground water using Henry's Constant (see # 1a above). Site # 19 has defined closure criteria as, a measurable decrease in the oxygen utilization rate plus one year of continuous operation. Site # 20 is still in the pilot phase, therefore closure criteria have not been established, however, During the 200 day pilot test BTEX was reduced by 90%. As can be seen in Figure3.2 the two operational bioventing sites have not been closed. Site # 19 has operated since 1993 and is expected to operate through 1997 and submit a closure plan to the state. Site 18 began operation in 1996 and predicts 5 - 10 years of operation.

3.2.4 Natural Attenuation

Four aquifer remediation sites using natural attenuation are include in the survey (Sites 21 And 22 contain solvents; Sites 23 and 24 contain BTEX. Site # 23 has been closed using 10-6 risk factor and deed restrictions as the closure criteria. Site # 24 established MCLs for BTEX components and naphthalene as the closure criteria. Both include dense monitoring configurations and post closure monitoring. The solvent sites (#21 and #22) established MCLs as the closure criteria, however extensive modeling and dense operational and post closure monitoring are required.

3.3 Closure Criteria Development Considerations

Cleanup goals, monitoring parameters and confirmation sampling requirements are finalized through negotiation with state (primarily) and federal agencies. Some states have established soil or soil gas closure criteria or provide the regulatory methodology or guidance to arrive at closure criteria. Closure criteria can be designed to accommodate multiple functions of the remediation project. For instance Site # 8 recognizes the asymptote, based on the limitation of the technology (SVE) at that particular site. However because the subsurface lithology is quite variable and controls the contaminant concentration, SVE can be terminated at the asymptote followed by one additional year of pulsed-mode operation, or when confirmation soil/sediment sampling results are below established PCE soil gas risk-based concentration levels.

Using soil gas concentrations, as closure criteria, provides a challenge to obtain representative samples and contaminant concentrations in gas. Contaminant concentration in gas is a function of the subsurface and can deceptively indicate that closure criteria have been met quickly only to find that continued contaminant volatilization from the pore fluid and matrix particle rebound gas concentrations in extraction wells. Restarts (pulsing) for weeks and months are required to document the absence of rebounding contaminant concentrations. Most sites surveyed indicated that rebounding soil gas concentrations were not a significant problem, however, the subsurface lithology (clay content) dictates the extent of diffusion/volatilization of the gas.

Closure confirmation, at the sites included in this survey, is typically based on MCLs or the soil or soil gas equivalent calculated in equilibrium with the ground water contaminant concentration (See 1a & b and 2a & b in the Survey Results section of this report). Typically if soil gas or soil contaminant concentrations are used as the closure criteria for SVE or bioventing, air sparging, pump & treat or natural attenuation are used to treat the remaining ground water contamination. Combinations of SVE and bioventing (if petroleum contamination) in the unsaturated zone; and natural attenuation, air sparging and pump & treat in the saturated zone can effectively address the contaminated system.

Verification that soil based closure criteria has been achieved is a difficult task. It is difficult to obtain reliable recoveries of VOCs from soil samples. Significant soil gas concentrations in the pore spaces of soils may be lost during sample collection, preparation and analysis. These analyses may yield lower apparent levels of VOCs as a result.

Regardless of the method used to establish closure criteria, it is critical to the success of the remediation project to define closure criteria early in the process and optimally before technology selection. This allows the owner/consultant the opportunity to model the effects of the various treatment techniques/technologies according to closure criteria, time and cost.

3.3.1 Technology Treatment Trains With *In situ* Bioremediation Technology

Technology combinations were more the norm than the exception in the sites surveyed. SVE and/or bioventing were typically used in combination with pump & treat, air sparging and natural attenuation. At one site, however, (site # 9) the owner persistently pulsed a SVE system, to clean a shallow aquifer, even though the closure criteria is based on soil contaminant concentrations. The closure criteria at this site were effectively achieved in two years of operation (1992 - 1994). Soil contaminant concentrations were reduced from an initial value of 26,000 mg/kg PCE to less than 0.5 mg/kg.

Treatment systems have been designed to operate sequentially or concurrently. For instance at Site #s 1 and 2 SVE was used to treat solvents in the unsaturated zone followed by pump & treat in the saturated zone. At Site # 15 a SVE system and air sparging system have been installed and run concurrently. Closure criteria on both are based on ground water MCLs and were achieved in two years.

3.3.2 Additional Considerations

At a uniform concentration of 1.0 mg/kg (1.0 ppm) of trichloroethylene (TCE), a site with one acre in surface area and a thickness of 10 feet would hold about 4.3 gallons of TCE. At a concentration of 1.0 ug/kg (1.0 ppb) this same volume of soil would contain about 0.5 fluid ounces of TCE. In light of the heterogeneous nature of soil contamination, it is entirely probable that post-closure sampling of a site will produce measurements of TCE in soil above closure criteria and will be reported in data sets otherwise containing nondetects. Since closure criteria are most often based on the highest reported concentration, the lower the closure criteria the less likely that there is no place on a site that does not exceed the criterion. At the same time, exceedences of the closure criteria in individual samples, or few samples, does not by itself indicate a significant mass of contamination and therefore a significant problem remaining at the site.

Clearly at the 1.0 ppb range, and even at the 1.0 ppm range, it is likely that the mass remaining at the closure criteria (0.5 fluid ounces and 4.3 gallons) is not distributed uniformly throughout the entire volume of the example site (435,600 cubic feet of material). To show comparatively that no sample at this site exceeds such low closure criteria would require an extraordinary number of soil samples and analyses; so many that the cost would be prohibitive.

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The closure criteria reported in the study gave no specific consideration to the mass of the residual contamination at a site. Since residual human or environmental risks are proportional to residual mass, this consideration might merit further development in future work.

4.0 CONCLUSIONS/FINDINGS

4.1 Soil Vapor Extraction

Contaminant recoveries from SVE generally far exceed pre-system start estimates of contaminants in place in the unsaturated soils.

a. SVE attainment of closure criteria is successful in the majority of survey responses.

b. Asymptotic conditions are not a concern for technology limits for most sites that reported reaching closure criteria. However, sites with very stringent closure criteria i.e. California (see figure 4.1) may find asymptotic concentrations higher than the closure criteria. In this case, alternative closure criteria based on SVE's technology limit could be considered (See Appendix E).

4.2 Bioventing

Bioventing sites included in the survey, and those achieving closure to date, are few. It should be noted that many pilot bioventing sites reported being started with no established closure criteria prior to system startup. This increases the uncertainty that the chosen technology is capable of achieving an acceptable endpoint. This results in projects continuing until budgeted funds are exhausted or a "cease operations" is issued by regulators.

4.3 Natural Attenuation:

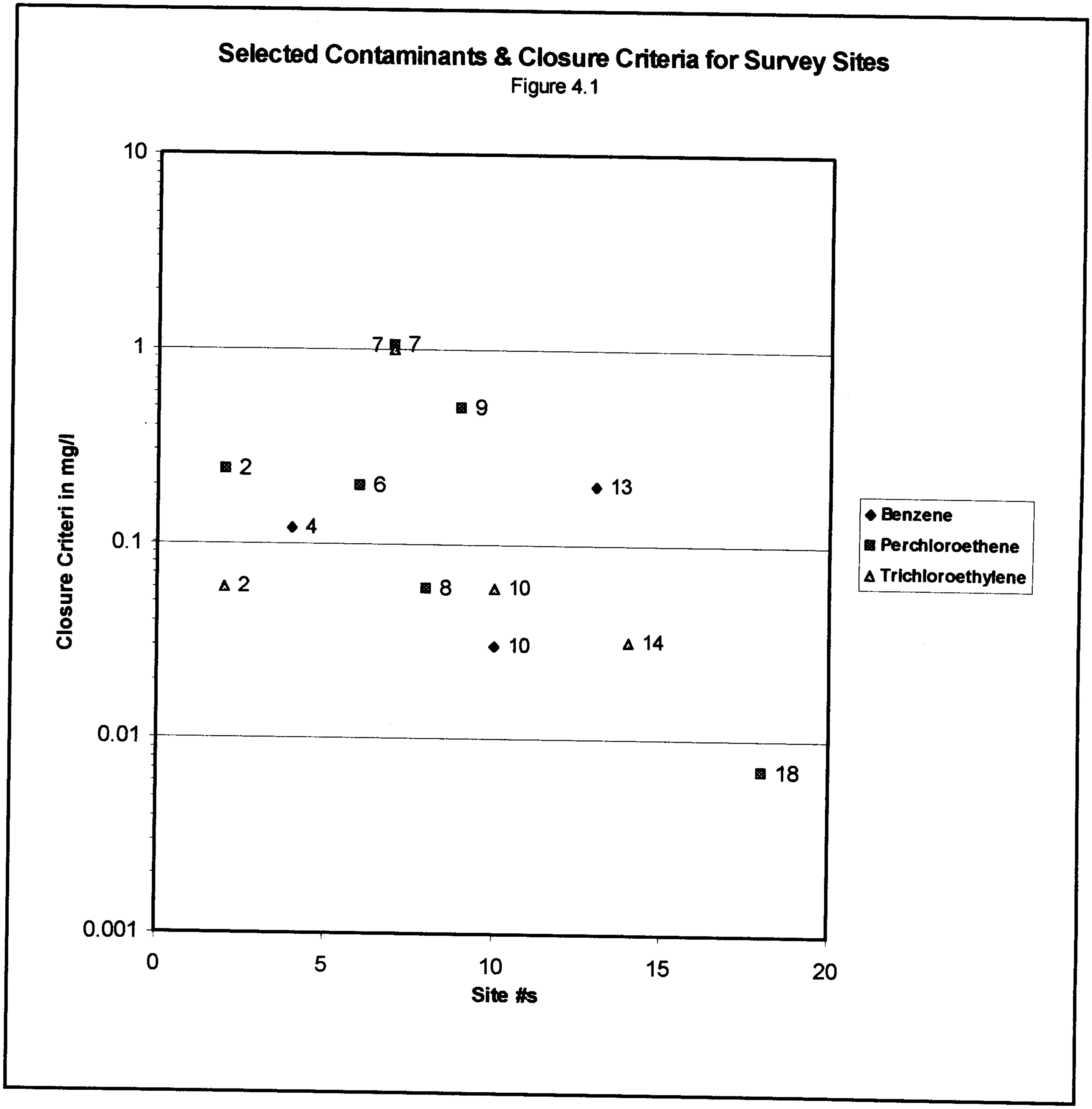
Natural attenuation sites are in the early stages of achieving compliance with existing MCLs as the closure criteria. One site is closed, however deed restrictions were imposed as a precautionary measure to final release. Sites in the survey typically continue to require significant operational and post closure monitoring data to validate fate and transport modeling of contaminant movement.

4.4 Closure Criteria:

There is a wide range of contaminant specific closure criteria among the survey responses (orders of magnitude). This may be due to differences in current or future resource use, site specific considerations (soil type, lithology, etc.), or the method of calculating closure criteria or modeling contaminant fate and transport (Figure 3).

5.0 RECOMMENDATIONS:

There is a tremendous need for a detailed evaluation of the various methods used to establish closure criteria. Such an analyses would benefit all *in situ* technologies, especially soil vapor extraction, which is commonly deployed in many states. It is our recommendation that such an analysis expands on this current work and could identify an approach, which promotes broad consensus in a consistent methodology to establish closure criteria at contaminated sites.


Selected Contaminants & Closure Criteria for Survey Sites
Figure 4.1
Closure Criteri in mg/l
10
1
0.1
0.01
0.001
0
5
10
15
20
Site #s
7
7
9
2
6
13
4
2
8
10
10
14
18
Benzene
Perchloroethene
Trichloroethylene

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USEPA 510-B-95-007, 1995, "*How to Evaluate Alternative Cleanup Technologies for Underground Storage Tanks: A Guide for Corrective Action Plan Reviewers*"

APPENDIX A

Acronyms

ACRONYMS

AFCEE:	Air Force Center for Environmental Excellence
ARARs:	Applicable Relevant and Appropriate Requirements
Cal-EPA:	California Environmental Protection Agency
DTSC:	Cal-EPA, Department of Toxic Substances Control
EPA:	United States Environmental Protection Agency
FID:	Flourescent Ion Detector
ISB:	*In situ* Bioremediation Technical Task Group of the ITRC
ITRC:	Interstate Technology and Regulatory Cooperation Work Group
NA:	Natural Attenuation:
MCL:	Maximum Concentration Limits
PCE:	Perchloroethylene
SCFM:	Standard Cubic Feet per Minute
SVE:	Soil Vapor Extraction
VOCs:	Volatile Organic Compounds

APPENDIX B

ITRC Work Team Contacts
ITRC Fact Sheet
Product Information
User Survey

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INTERSTATE TECHNOLOGY and REGULATORY COOPERATION WORK GROUP

FACT SHEET

WHAT IS THE ITRC?

The Interstate Technology and Regulatory Cooperation Work Group (ITRC) is a state-led, national coalition with the mission of focusing on creating tools and strategies to reduce interstate barriers to the deployment of innovative hazardous waste management and remediation technologies. Originating in 1995 from a previous initiative by the Western Governors Association, the ITRC has expanded to include the environmental agencies of more than 25 states, three federal partners, public and industry stakeholders, and two state associations -- the Western Governors Association and the Southern States Energy Board.

WHAT PROBLEM IS THE ITRC TRYING TO ADDRESS?

As environmental regulations have increased over the past two decades, they have created a maze of federal, state and local requirements which often vary from state to state and region to region. Correspondingly, many regulators are unable to accept performance data collected in another state, because the data do not address the needs of their state. This lack of consistency from state to state is further amplified because often neither the technology developer nor the state regulator consider other sites in designing the test plan(s) for the collection of performance data.

WHAT SOLUTION IS PROPOSED BY THE ITRC?

One solution proposed by the ITRC is that state environmental regulatory agencies should accept performance data gathered under another state's oversight as if the testing had been done in their own state. To accomplish this, the ITRC develops consensus among state regulators, with input from industry and public stakeholders, on the type of technical regulatory information that should be addressed when using a specified technology. This information is captured in guidance documents which are intended to help regulatory staff in an expeditious review of the use of a specified technology. Thus, these guidance documents foster greater consistency in technical requirements among states and result in reduced fragmentation of markets.

Additionally, these guidance documents help technology developers and vendors collect performance data that can be used to support regulatory approval at other sites. By looking ahead to the typical technical requirements that will be imposed by a regulatory agency, they can collect and evaluate information that will facilitate and smooth the regulatory approval process for multi-state deployment.

WHAT HAS BEEN DONE TO DATE?

To date, the ITRC has developed (either final or near final) 24 guidance documents intended to help regulatory staff and technology vendors in the deployment of innovative technologies In general, ITRC guidance documents are defined as providing a regulatory perspective on the informational needs (background and/or regulatory requirements) of state environmental agencies to approve the use of a specified technology.

More specifically, these guidance documents are categorized into three areas:

1. *Technical/ Regulatory Guidelines*: Previously called "protocols", these guidance documents reflect a consensus of state technical/regulatory concerns that should he considered when approving the use of a specified technology or in demonstrating a technology. Documents of this nature are formally circulated to the state environmental program managers to seek their concurrence to use the proposed guidance.

2. *Technology Overviews*: These documents may come in the form of status reports on emerging technologies or state input into guidance documents and deployment activities being developed by other organizations.

3. *Case Studies*: Reports include benchmarking of state practices in areas relating to the verification, testing and/or approval of emerging technologies, as well as, documenting state approaches to implementation of various programs and policies.

Within these categories, thirteen technical/regulatory guidelines documents, seven technology overview documents and four case studies have been completed. (A complete list of these products is available.)

HOW CAN YOU BENEFIT FROM USING THE ITRC GUIDANCE DOCUMENTS?

The use of these tools offers a consistent approach to the review and approval of specified technologies to clean up a specific site. This saves the state time in reviewing applications, training costs, and helps lessen the uncertainty associated with innovative technologies. Likewise, these tools offer industry a consistent and predictable process for the regulatory review and approval of these technologies. Similarly, technology developers also have a guide to the collection of performance data that will likely be requested by regulators when their technology is commercialized. Finally, as more states incorporate guidance from ITRC documents into their formal guidance to site managers, technologies which are successfully used by these states can gain even more expeditious review and approval for multi-site deployment across the nation.

WHERE CAN I GET MORE INFORMATION?

From the Internet: http://www.westgov.org/itrc

INTERSTATE TECHNOLOGY and REGULATORY COOPERATION WORK GROUP

PRODUCT ORDER FORM

Please fax your order form to: **Chris McKinnon, Western Governors Association fax: (303) 534-7309**

Please send the indicated documents to the mailing address shown below.

Name: ______________________________

Mailing Address: ______________________________

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City, State, ZIP ______________________________

Phone Number: ______________________________

More information on the ITRC can be found on the WGA web site at: http//www.westgov.org/itrc. Documents and associated concurrence information will soon be available at this site. All documents have been peer reviewed by members of individual ITRC Work Teams. Those designated as Technical /Regulatory Guidelines also have undergone/will undergo full ITRC multi-state review through the ITRC concurrence process.

Doc. #	Product Category	TITLE	PRODUCT DESCRIPTION	# Ordered
Accelerated Site Characterization				
ASC-1	Technology Overview	ITRC/ASTM Partnership for Accelerated Site Characterization	**FINAL** Information Document. ITRC review and input on ASTM *Guide for Expedited Site Characterization of Hazardous Waste* and report on the options for the future collaboration between the ITRC and ASTM	
ASC-2	Technology Overview	ITRC/EPA Consortium for Site Characterization Technologies Partnership - Technology Review	**FINAL** Information Document. ITRC participation with the EPA Consortium for Site Characterization Technologies verification program evaluating PCB field analytical, VOC well-head monitoring and soil/soil-gas sampling technologies.	
ASC-3	Technical/ Regulatory Guidelines	Multi-State Evaluation of Expedited Site Characterization Technology, Site Characterization and Analysis Penetrometer System Laser-Induced Fluorescence (SCAPS - LIF) - May 1996.	**FINAL** Concurrence document released in 1996. California Certification, EPA verification and Multi-state acceptance of the SCAPS sensor for in-situ subsurface field screening method for Polynuclear Aromatic Hydrocarbons (PACS).	
ASC-4	Technical/ Regulatory Guidelines	Multi-State Evaluation of the Site Characterization and Analysis Penetrometer System - Volatile Organic Compounds (SCAPS-VOC) Sensing Technologies	**FINAL** scheduled to be sent out for Concurrence /available Feb. 1998. Evaluation and approval of SCAPS deployed hydrosparge VOC sensor for real-time, in-situ detection of VOCs *below* the water table.	
ASC-5	Technical/ Regulatory Guidelines	Technology Review of SCAPS Thermal Desorption VOC Sampler	**FINAL** scheduled to be sent out for Concurrence /available June 1998. Evaluation and approval of SCAPS deployed thermal desorption VOC sampler for real-time, in-situ detection of VOCs *above* the water table.	

Doc. #	Product Category	TITLE	PRODUCT DESCRIPTION	# Ordered
In-Situ Bioremediation				
ISB-1	Case Studies	Case Studies of Regulatory Acceptance of ISB Technologies (1996)	**FINAL** Information Document. Case studies on the regulatory barriers and implementation of In-Situ Bio in six states.	
ISB-2	Technical/ Regulatory Guidelines	ISB Protocol Binder and Resource Document for Hydrocarbons (1996).	**FINAL** scheduled to be sent out for Concurrence /available Feb. 1998. General protocol and outline for ISB and literature review for natural attenuation and bioventing of petroleum hydrocarbons. Includes by reference EPA/AFCEE Guidances on Bioventing and Natural Attenuation .	
ISB-3	Technical/ Regulatory Guidelines	Natural Attenuation of Chlorinated Solvents in Groundwater - Principles and Practices	**FINAL** scheduled to be sent out for Concurrence /available July 1998. Description of practices to be used to recognize and evaluate the presence of naturel attenuation of chlorinated solvent contamination.	
ISB-4	Technical/ Regulatory Guidelines	Closure Criteria Focus Group Report	**FINAL** scheduled to be sent out for Concurrence /available July 1998. Evaluation of state practices for establishing and implementing closure criteria for bioventing, vapor extraction and natural attention of petroleum hydrocarbons and chlorinated solvents.	
ISB-5	Technical/ Regulatory Guidelines	Cost & Performance reporting for In-Situ Bioremediation Technologies	**FINAL** scheduled to be sent out for Concurrence /available Feb. 1998. Template for obtaining and reporting cost and performance information about the use of an in-situ bioremediation technology.	
Metals in Soils				
MIS-1	Technical/ Regulatory Guidelines	Technical and Regulatory Guidelines for Soil Washing	**FINAL** scheduled to be sent out for Concurrence / available Feb. 1998. Technical and regulatory guidelines for using soil washing technologies.	
MIS-2	Case Studies	Fixed Facilities for Soil Washing: A Regulatory Analysis	**FINAL** Information Document. A case study of fixed facilities for soil washing in the US and other countries, identifying successful models of deployment.	
MIS-3	Technology Overview	Emerging Technologies for the Remediation of Metals in Soils - Electrokinetic Remediation	**FINAL** Information Document. Status report on the technology and potential regulatory issues for its use in remediation of metals in soils.	
MIS-4	Technology Overview	Emerging Technologies for the Remediation of Metals in Soils - Phytoremediation	**FINAL** Information Document. Status report on the technology and potential regulatory issues for its use in remediation of metals in soils.	
MIS-5	Technology Overview	Emerging Technologies for the Remediation of Metals in Soils - Insitu Stabilization/In place Inactivation	**FINAL** Information Document. Status report on the technology and potential regulatory issues for its use in remediation of metals in soils.	

Doc. #	Product Category	TITLE	PRODUCT DESCRIPTION	# Ordered
Permeable Barrier Walls				
PBW-1	Technical/ Regulatory Guidelines	Regulatory Guidance for Permeable Barriers Designed to Remediate Chlorinated Solvents	**FINAL** scheduled to be sent out for Concurrence /available Feb 1998. Review of regulatory guidelines for using Permeable Barrier Walls (PBW).	
PBW-2	Technical/ Regulatory Guidelines	Design Guidance for Application of Permeable Barriers to Remediate Dissolved Chlorinated Solvents	**FINAL** scheduled to be sent out for Concurrence / available Feb 1998. US Air Force document, revised with state input to provide technical guidelines for PBW design.	
Policy				
Pol-1	Case Studies	An Analysis of Performance Based Systems for Encouraging Innovative Environmental Technologies	**FINAL** Information Document. Case studies of performance-based environmental, regulatory and contracting practices and an analysis of activities which could encourage development and deployment of innovative technologies	
Pol-2	Case Studies	Case Studies of Selected States Voluntary Clean-Up/Brownfields Programs	**FINAL** Information Document. In-depth case studies of selected states' voluntary clean-up/brownfields programs and recommendations for possible enhancements.	
Plasma Technologies				
PT-1	Technology Overview	Regulatory Overview of Plasma Technologies	**FINAL** Information Document scheduled for May 1998. Status report on emerging plasma technologies and report on regulatory issues, barriers, and recommendations, including survey and case study.	
Thermal Desorption				
TD-1	Technical/ Regulatory Guidelines	Technical Requirements for On-Site Low Temperature Thermal Treatment of Non-Hazardous Soils Contaminated with Petroleum/Coal Tar/Gas Plant Wastes (1996)	**FINAL** Concurrence Document released 1996. Minimum technical requirements for use of thermal desorption on non-hazardous soils.	
TD-2	Technical/ Regulatory Guidelines	Technical Requirements for On-Site Thermal Desorption of Solid Media Contaminated with Hazardous Chlorinated Organics	**FINAL** scheduled to be sent out for Concurrence /available Feb 1998. Minimum technical requirements for use of thermal desorption on solid media contaminated with hazardous chlorinated organics.	
TD-3	Technical/ Regulatory Guidelines	Technical Requirements for On-Site Thermal Desorption of Solid Media and Low Level Mixed Waste Contaminated with Mercury and/or Hazardous Chlorinated Organics	**FINAL** scheduled to be sent out for Concurrence /planned for late 1998. Minimum technical requirements for use of thermal desorption for special categories of mixed waste.	

APPENDIX C

Spreadsheet Summary of Survey Responses

In Situ Bioremediation
Closure Criteria Focus Group
Survey Results Summary

SITE NAME, LOCATION	TECHNOLOGY, CONTAMINANTS	STATUS	CLEANUP LEVEL	RATIONALE	NOTES, COMMENTS
1. Well M-3 Site Hastings, Nebraska	SVE, solvents	Complete	Reach extraction rate of 0.001 lbs/hr	Represents cost per pound equivelant of SVE operation versus pump and treat costs to recover the same amount of contaminant	Cleanup criteria reached in 9 months, followed by a 2 month shutdown period (no rebound). Site now in pump and treat phase with ground water contaminant levels near MCL. Initial CCl_4 concentration was 1,234 ppmv. At end of action CCl_4 was 0.33 ug/l at GAC inlet. Total costs: $448,000.
2. Colorado Avenue Site Hastings, Nebraska	SVE, solvents	Operational	Two tiers: both must be reached: Soil Based: TCE 0.06 mg/kg PCE 0.23 1,1 DCE 0.08 1,2 DCA 0.02 TCA 2.0 Soil Gas: TCE 0.25 ppm PCE 0.30 1,1 DCE 1.5 1,2 DCA 0.10 TCA 15.0	Soil: Organic Leachate Model (Fed. Reg. 7/29/86) Soil Gas: concentration of VOCs in air in equilibrium with ground water at MCLs using Henry's Law ($C_v = [C_w][H']$)	System startup in July 1996, includes horizontal SVE pilot, will be followed by pump and treat of 10E-4 plume "hot spots" with air sparging pilot. Initial TCE concentrations were 6,000 mg/m3; PCE was 225 mg/m3.
3. Fairchild Site, San	SVE, solvents	Closed, attained closure criteria	Operate until total removal rate less than 10 lbs/day and removal rate from individual wells to 10% of initial rate or removal rate declines to less than 1% for 10 consecutive days	Removal rate decline and asymptote defined	Achieved cleanup goal of 10 lbs per day in 8 months. After 16 months of operation, the removal rate declined to less than 4 lbs/day. Total recovered: 16,000 pounds. Rebound was tested at 2, 4 and 8 week intervals (no rebound observed). The original ROD specified a cleanup goal of 1 mg/kg for each contaminant, but an amendment was issued. Soil sampling after 7 months of operation showed only 3 samples that had reached the original 1 mg/kg goal. Initial TCA 3,530 mg/kg, xylene 141 mg/kg.

In Situ Bioremediation
Closure Criteria Focus Group
Survey Results Summary

SITE NAME LOCATION	TECHNOLOGY, CONTAMINANTS	STATUS	CLEANUP LEVEL	RATIONALE	NOTES, COMMENTS
4. Hill AFB Site 914, Ogden UT	SVE then Biovent, TPH	Closed, attained closure criteria	Soil TPH maximum 65 mg/kg with: Benzene <0.2 Toluene < 100 Xylenes <1000 Ethylbenzene <70	Utah Dept. of Health "Guidelines for Estimating Numeric Cleanup Levels for Petroleum-Contaminated Soil at Underground Storage Tank Release Sites".	Over two year operational period reduced TPH concentrations in soil to an average of 6 mg/kg. Recovered 211,000 pounds of contaminants at a removal rate of 20 to 400 lbs/day. Total Costs costs were $599,000. TPH max. 10,200 mg/kg.
5. Luke AFB North Fire Training Area, Arizona	SVE, TPH/BTEX	Completed, attained closure criteria	TPH 100 mg/kg Benzene 0.13 Ethylbenzene 68 Toluene 200 Xylenes 44 Total BTEX 412	Arizona Action Levels	Achieved cleanup goals in 30 weeks of operation. Removed 12,000 pounds of contaminants with a removal rate of 40 lbs/day at completion. 96% reduction of benzene. Total costs were $507,000. Initial TPH max. 1,380 mg/kg; Benzene 16; Toluene 183; Ethylbenzene 84; and xylenes 336 mg/kg.
6. Sacremento Army Depot Tank 2 OU, Sacremento	SVE, Chlorinated and Non-Chlorinated Aliphatics	Completed, attained closure criteria	ROD: 2-Butanone 1.2 ppm Ethylbenzene 6 Xylenes 23 PCE 0.2 ppm	Risk calculations based on a public health evaluation corresponding to risk reductions of 92-99% depending on the contaminant	Achieved cleanup goals in six months of operation (contaminants actually reduced to non-detect at 0.01 mg/kg). Site soils were low permeability. System recovered 2300 pounds of contaminants. Total costs were $556,000. Initial max. contaminants: 2-Butanone 150 mg/kg; Ethylbenzene 2,100; PCE 390; and xylenes 11,000 mg/kg.

In Situ Bioremediation
Closure Criteria Focus Group
Survey Results Summary

SITE NAME LOCATION	TECHNOLOGY CONTAMINANTS	STATUS	CLEANUP LEVEL	RATIONALE	NOTES, COMMENTS
7. SMS Instruments, Deer Park, NY	SVE, Chlorinated and Non-Chlorinated Aliphatics and Semi-volatile compounds	Completed, attained closure criteria	T-1,2 DCE 0.5 mg/kg 2-Butanone 0.5 2-Hexanone 0.7 PCE 1.5 Toluene 1.5 TCE 1.0 Xylenes 1.2 Ethylbenzene 5.5 Chlorobenzene 1.0 1,4-DCB 1.0 1,3-DCB 1.5 1,2-DCB 1.0 Naphthalene 1.0 1,2,4-TCB 2.3 2-Methylnaphthalene 2.0 mg/kg Phenol 0.33 2-Methylphenol 2.6 Bis(2-ethylhexyl)-phthalate 4.5	Developed by the New York State Dept. of Environmental Conservation. No more than 20% of soil samples at closure could exceed individual contaminant cleanup levels, and for individual samples contaminant levels could not exceed twice the soils cleanup levels.	Cleanup achieved in 400 days at a cost of $450,000. Initial max. concentrations: volatiles 1,200 mg/kg; semi-volatiles 1,800 mg/kg.
8. California Central Valley	SVE, PCE	Closure critera developed	Assymptote defined as mass removal and VOC concentration rates do not vary by more than 2% over four consecutive weekly monitoring events. Cycling is required, with a minimum of one year operation required. PCE soil gas risk-based level 0.4 to 3.9 ppmv depending on lithology and depths. PCE soil levels are 5 to 50 ppb depending on lithology and depths. If risk-based level is not achievable the performance limit of the SVE unit will be used.	California Regional Water Quality Control Board (LA Region) "Interim Guidance for Remediation of VOC Impacted Sites".	Pilot tests conducted, in design stage. Initial PCE level in soil gas was 1,000 ppmv.

In Situ Bioremediation
Closure Criteria Focus Group
Survey Results Summary

SITE NAME LOCATION	TECHNOLOGY CONTAMINANTS	STATUS	CLEANUP LEVEL	RATIONALE	NOTES, COMMENTS
9. West Boise PCE Contamination Site, Idaho	SVE, PCE	Complete, attained closure criteria	PCE 0.5 mg/kg	Based on the elimination of leachable material to ground water. System removed essentially all vadose zone contamination so cleanup levels in soil did not become an issue.	System reached cleanup goals in two years (1992-1994). System is now pulsed to aid in removal of VOCs from shallow water table. Closure requirements called for 10 soil borings to be analyzed. Initial PCE levels were 26,000 mg/kg.
10. Verona Well Field, Battle Creek, MI	SVE, Chlorinated and Non-Chlorinated Aliphatics	Complete, attained closure criteria	Benzene 0.02 mg/kg Carbon tetrachloride 0.01 1,1-DCA 0.02 1,1-DCE 0.01 cis-1,2-DCE 0.02 trans-1,2-DCE 2.0 Ethylbenzene 1.4 Methylene chloride 0.1 TCE 0.014 Toluene 16 1,1,1-TCA 4 TCE 0.06 Xylenes 6 mg/kg	1991 ROD levels established to coincide with cleanup levels for two nearby OUs. State of Michigan law (Act 307) also established cleanup goals that correspond to 10E-6 risk.	Operational four years. A total of 45,000 lbs of VOCs were removed. EPA's first application of SVE at a Superfund site cost was $1,645,000.
11. ACME Printing, Kansas City, Kansas	SVE, hydrocarbons and solvents	Closure criteria developed, remedial action started.	System is interim SVE is temporarily shut down having reached asymptotic levels. Awaiting installation of air sparging system to treat the ground water.	Planned for reaching technology limit (asymptote), then staged to air sparge.	System startup in 1991. Long term monitoring will be required after system shut down. Alternate cleanup levels have been established to delineate area of active air sparging. Institutional controls will be part of the final remedy. Quarterly monitoring is required. Initial and current levels: Initial (mg/m3): Benzene 53.65 Toluene 274.96 Ethylbenzene 5.14 Xylene 51.38 n-Hexane 72.97 n-Heptane 80.83 n-Octane 32.71 iso-Octane 17.51 Acetone

In Situ Bioremediation
Closure Criteria Focus Group
Survey Results Summary

SITE NAME LOCATION	TECHNOLOGY, CONTAMINANTS	STATUS	CLEANUP LEVEL	RATIONALE	NOTES, COMMENTS
12. State of New Jersey	SVE, Natural Attenuation, BTEX	Closure Criteria SOP	Economic limit for SVE, then ground water standards for NA	Responsible party determines that the cost of operation does not justify the amount of product removed. Submits proposal to NJ DEP for natural attenuation to reach ground water goals if there is no imminent receptor impact.	Draft rules to be adopted 1/97: Natural attenuation requirements include: characterize site to show evidence of NA; a minimum of 12 quarters of monitoring data; four monitoring wells; and use of the Mann-Whitney U-Test to show NA occurring. 25 year planning horizon.
13. State of South Dakota	SVE, Bioventing BTEX compounds	Closure Criteria SOP	Soils: Benzene 0.2 ppm; Toluene 15.0 ppm; Ethylbenzene 10.0 ppm; Xylene 300.0 ppm; Napthalene 25 ppm	RBCA-generated from Groundwater Services software: "Tier 1/Tier 2 RBCA Spreadsheet System and ASTM.	When an asymptotic level or 95% reduction of initial effluent concentration is reached, soil samples may be collected and analyzed and compared to the closure criteria to consider the site for closure by SDDENR.
14. Cascade Corp, Trontdale Oregon	SVE, Solvents with sparging	Closure Criteria developed, remedial action ongoing	TCE soil gas 5 ppm, ground water TCE MCL of 5 ppb.	Restrore vadose zone so no longer a source for contamina-ing ground water. 5 ppm in soil gas represents equilibrium concentrations between soil and ground water.	29 monitoring wells, ground water at 10 feet. Offsite migra-tion threatening municipal and private wells. ROD 12/96. Start summer 1997. Estimate 7 years to completion for operation. Must maintain 5 ppm during one year monitoring after shutdown. Costs: $800,000 capital and $3.1 million O&M.

In Situ Bioremediation
Closure Criteria Focus Group
Survey Results Summary

SITE NAME LOCATION	TECHNOLOGY CONTAMINANTS	STATUS	CLEANUP LEVEL	RATIONALE	NOTES, COMMENTS
15. Varner's Oil, Maize Kansas	SVE with air sparging, petroleum hydrocarbons	Closure Criteria developed, remedial action ongoing	Ground water: Benzene: 5 ppb Toluene: 1000 ppb Ethylbenzene: 680 Total Xylenes: 440 Naphthalene: 143	MCL's based on Kansas Action Levels.	Contaminated soil excavated. SVE/AS system installed 6/96 Concentrations: Initial (10/94) Current (12/96) BTEX: 638 ppb ND (DL 0.2) MTBE: 15 ND Five air sparging vertical wells total 70 cfm. 10 monitoring wells. Plume 270 ft. long, 210 ft. wide and 25 ft. deep. Reach ND 3.5 months after start. Confirmation samples will be required for closure. System will be run for one more quarter. Quarterly sampling required. Costs: Investigation and design $35K; Installation and startup $150K; monthly operation, maintenance and monitoring costs $30K.
16. Petro & Pantry Grantville, Kansas	SVE with air sparging Petroleum hydrocarbons	Closure Criteria developed, remedial action ongoing	Ground Water: Benzene: 5 ppb Toluene: 1000 Ethylbenzene: 680 Total Xylenes: 440 Naphthalene: 143	MCL's based on Kansas Action Levels Reached cleanup levels in six months. Original plume 350 feet in diameter.	System operational since 4/96. Ground water has been non-detect for one quarter but the SVE system concentrations are still at 100 ppm. Will run for one quarter, shut down for a quarter, then restart. Will require more sampling before closure. Current quarterly monitoring. Costs including two years of O&M are estimated to be approx. $240,000. Levels: Initial Current (12/96) Benzene 6000 ppb ND MTBE 337 Naphthalne 655 ND 12 SVE wells, 4 air sparging wells and 12 monitoring wells.

In Situ Bioremediation
Closure Criteria Focus Group
Survey Results Summary

SITE NAME / LOCATION	TECHNOLOGY / CONTAMINANTS	STATUS	CLEANUP LEVEL	RATIONALE	NOTES, COMMENTS
17. Kansas Soldier's Home Fort Dodge, Kansas	SVE, BTEX with P&T system	Closure Criteria developed, site to be closed after confirmation sampling	Ground water: Benzene: 5 ppb Toluene: 1000 Ethylbenzene: 680 Total Xylenes: 440 Naphthalene: 143	MCL's based on Kansas Action Levels. Original plume 500 ft. in diameter.	System consists of 22 monitoring wells, 5 SVE wells, and 5 ground water extraction wells. Operated from 10/93 to 11/95 then shut in with non detect in vadose and saturated zones. Date: BTEX ppb 10/93 38590 4/95 5.95 7/95 8.15 10/95 ND Monthly monitoring required during operation. Recently restarted SVE with 10 ppmv then ND after 1.5 hours. Will take confirmation boring samples to officially close. Costs: $200,000
18. Davis Transmitter Davis, California	SVE, Biovent Diesel, solvents	Closure Criteria developed, action started.	Interim ROD 2/95: PCE 500 ppbv; other VOCs reduced to level where no longer acting as a continuing source to groundwater.	Equilibrium established between groundwater at MCL for PCE (5 ppb). Cleanup goal is MCL times Henry's Constant	SVE system for chlorinated area; biovent for diesel area; groundwater pump and treat Chemical Initial Current Groundwater: PCE 2000 ppb 200 ppb TCE 2000 ppb DCE 200 ppb 120 ppb Soil gas: PCE 45,000 ppbv 100 TCE 2,400 100 DCE 1,000 25 System start in June 1996, estimate 5-10 year duration.

In Situ Bioremediation
Closure Criteria Focus Group
Survey Results Summary

SITE NAME / LOCATION	TECHNOLOGY / CONTAMINANTS	STATUS	CLEANUP LEVEL	RATIONALE	NOTES, COMMENTS
19. Building 406, Offutt AFB, Omaha, NE	Biovent, BTEX	Action started, closure criteria developed.	By respiration tests: want to see oxygen utilization rates decrease. By soil gas: BTEX nondetect. Closure plan to be submitted to NDEQ.	Decrease in oxygen utilization rates will indicate cleanup is complete. Will confirm with soil gas and respiration tests.	System start October 1993. Respiration tests and soil gas conducted annually. Will run system for one more year and submit closure plan to NDEQ. One blower: current 18 CFM Four vent wells, 3 vapor monitoring wells. Soil gas: Chemical 10/93 11/96 TVH 26,000 ppmv 860 Benzene 370 0.004 Degradation Rate: Start: 1,000-23,000 mg/kg/yr 11/96: 99-3,100 mg/kg/yr Oxygen utilization rate: Start: 0.4-10.2 %O2/hour 11/96: 0.04-1.4 %O2/hour Oxygen (percent): Start: 0-20 11/96: 0-16.2
20. Tyndall AFB, Florida	Bioventing, petroleum hydrocarbons	Pilot study			200 day pilot study: initial TRPH max. in two test plots was 5,100 and 7,700 mg/kg. Average reduction was 2,900 mg/kg TRPH (40%) with BTEX reduced by 90%
21. Confidential Mississippi	Natural Attenuation, Solvents	Operational	Vinyl Chloride 2 ug/l (MCL)	Maximum contaminant level for vinyl chloride	11 monitoring wells. Cleanup standard will be reached by 2004 based on computer simulation (MOD FLOW MT3D)

In Situ Bioremediation
Closure Criteria Focus Group
Survey Results Summary

SITE NAME LOCATION	TECHNOLOGY, CONTAMINANTS	STATUS	CLEANUP LEVEL	RATIONALE	NOTES, COMMENTS
22. Koch Industires, Wichita Kansas	Natural attenuation, solvents	Closure criteria developed, remedial action started	Established 1/30/96 Plume will be allowed to naturally attenuate within site boundary. MCLs are preserved as final closure goals. Compliance wells (29) downgradient to be monitored quarterly. If detects >MCL = re-evaluate. If >4X MCL, contingency actions to contain and reduce contamination will be implemented. TCE MCL 5 ppb 1,1,1-TCA 200 ppb Benzene 5 ppb	Maximum initial levels include acetone 170 ppm TCE and degradation products 31 ppm, 1,1,1-TCA and degradation products 34 ppm and benzene 4 ppm. The closure critera rationale is based on the site investigation, risk evaluation, ground water flow and modeling which suggests that, with the carbon sources available, the migration of contaminants had reached or was nearing equilibrium. There are no direct or immediate health threats.	14 compliance wells installed in April 1996, and will be sampled quarterly indefinitely. Seven additional wells in the plume will be monitored semi-annually to document changes in contaminant location and concentration. For closure, sampling must document that no contamination is detected at or above the MCL in four consecutive, equally spaced sampling episodes over a period no less than two years.
23. ODT Maintenance Detroit, Oregon	BTEX, Natural Attenuation	Closure Criteria reached, site closed	Initial: Benzene 5 ppb Napthlalene 28 ppb Final: Benzene 3.9 ppb Napthlalene 150 ppb Vapor phase Benzene 23 ppb Outside air Benzene 12,000 ppb	Initial: MCL's for ground water Final: 10-6 risk plus institutional controls and deed restrictions (site specific with no ground water targets	Eleven monitoring wells. Initial benzene 3,000 ppb and napthalene 1,000 ppb in ground water. Current levels 250 ppb and 20 ppb respectively. Monitoring demonstrated plume reduction, and Oregon DEQ reduced closure criteria to the outside air standard of 12,000 ppb. Napthalene closure level of 150 ppb represents 10-6 risk level. Required quarterly sampling for 4.5 years, then semi-annual for last 1.5 years.

In Situ Bioremediation
Closure Criteria Focus Group
Survey Results Summary

SITE NAME LOCATION	TECHNOLOGY CONTAMINANTS	STATUS	CLEANUP LEVEL	RATIONALE	NOTES, COMMENTS
24. Steve's Standard Great Bend, Kanas	Natural Attenuation (enhanced), BTEX	Closure criteria developed, action started	Ground Water: Benzene: 5 ppb Toluene: 1000 Ethylbenzene: 680 Total Xylenes: 440 Naphthalene: 143	MCL's based on Kansas Action Levels. Original plume 375 by 500 ft.	Injected oxygen releasing compound (ORC- 2325 lbs) in 118 Geoprobe borings in July and August 1996. 20 piezometers were also installed. Total BTEX in most contaminated monitoring well measured 13,230 ppb at start. During first quarterly sampling in 11/96 BTEX had decreased to 1,684 ppb. It is estimated that it will take three to four years to closure. Ground water must be below MCL's for at least four quarters. Total costs are estimated to be $95,000.

APPENDIX D

Soil Gas Data to Define the Presence of NAPL

The Use of Soil Gas Data to Obtain Soil VOC Concentrations

and

To Identify the Presence of NAPL

by

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The Use of Soil Gas Data to Obtain Soil VOC Concentrations

and

To Identify the Presence of NAPL

1. Conversion of Soil Gas Concentrations to Soil Concentrations

The concentration of a VOC in soil gas can be converted to its total concentration in the soil by considering the equilibrium laws governing the partitioning of the VOC between the gas, liquid, and solid phases. The reasoning and methodology are as follows:

Unless a separate liquid phase of VOC, i.e. a NAPL, is present, the soil gas concentration is controlled by the distribution of the VOC between the soil, water and the soil organic matter. If the moisture content in the soil is greater than 5%, normally the case, the vapor phase contaminant concentration will be controlled by its gas water distribution coefficient, the Henry's Law coefficient (H). The Henry's Law coefficient can be written in its dimensionless form, H_D. The dimensionless Henry's Law coefficient relates the concentration of a compound in the vapor phase to its concentration in the aqueous phase.

$$H_D = C_g/C_w = H/RT - P_s/S \qquad (1)$$

Where: H is the Henry's Law Coefficient

R is the ideal gas constant

T is degrees Kelvin

P_s is the VOC's vapor density (the vapor pressure of the pure liquid expressed as mass/unit volume)

and S is the water solubility

The aqueous-phase concentration will in turn be controlled by the distribution of contaminants between water and the solid soil matrix. This distribution is governed by K_D, the water-solid distribution coefficient. Rarely is the direct distribution of contaminants between the gas and solids important.

If the water-solid distribution is controlled by adsorption onto organic carbon, which occurs above organic carbon concentrations of approximately 0.001 (fraction), (Chiou and Shoup, 1985) the water-solid distribution coefficient is:

$$K_D = C_S/C_W \ - ((K_{OC})(\%OC))/100 \qquad (2)$$

Where C_S is the concentration in the solid (mass VOC/mass solids)

C_W is the concentration in the water (mass VOC/volume water)

K_{OC} is the water-organic carbon distribution coefficient

F_{OC} is the fraction, by weight, of organic carbon in the soil

The total soil VOC concentration (M/L^3) is the sum of the mass/unit volume in each of the three phases.

$$C_t = C_s P_b + C_W \theta_W + C_g(\theta_T - \theta_W) \quad (3)$$

Where C_g is the concentration in the gas (M/V air)
C_t is the total concentration in the soil (M/V (bulk volume soil))
P_b is the bulk dry soil density (M/V solid)
θ_T is the total porosity
and θ_w is the water filled porosity

The ratio of a VOC's total concentration in the soil gas to its concentration in the soil is given by substituting (1) and (2) and (3) and dividing the bulk density (p_b) to convert soil concentration units from mass/volume to mass/mass:

$$C_T/C_g = (K_D/H_D)\ (\theta_T/H_D P_b)\ (\theta_T - \theta_W)/P_b \quad (4)$$

Where C_T is the total concentration in the soil (M/V)

Table 1 represents an example of the results of using (4) to relate soil gas and soil concentrations. For each of the compounds listed, a soil gas concentration of 100ug/L was converted to the equivalent soil VOC concentration in ug/kg. The soil parameters utilized in the calculation were f_{oc} (fraction) = 0.005: total porosity (fraction) = 0.40; volumetric moisture content (fraction) = 0.2; and dry soil bulk density (gm/cm ^{3}) = 2.00.

Table 1. Conversion of Soil gas to Total Soil Concentration

Compound	K_{oc} (ml/g)	Henry's Coefficient (H)	H_D* (H/RT)	K_D (mg/L)	Sgas-Soil Conversion Factor	Soil Gas Conc. (ug/L)	Soil Conc. (ug/kg)
CCL_4	110	2.41E^{-2}	1.0	0.55	0.75	100	75
Chloroform	31	2.87E^{-2}	0/119	0.155	2.24	100	224
1,1 DCA	30	4.31E^{-3}	0.179	0.15	1.50	100	150
1,2 DCA	14	0.978E^{-3}	0.047	0.07	10.2	100	1020
1,1 DCE	65	3.40E^{-2}	1041	0.325	0.401	100	40.1
cis 1,2 DCE	49	7.58E^{-3}	0.315	0.245	1.2	100	120
Trans 1,2 DCE	59	6.56E^{-3}	0.273	0.295	1055	100	155
1,1,1 TCA	155	1.70E^{-2}	0.707	0.775	1.33	100	134
TCE	126	9.10E^{-3}	0.379	0.63	2.03	100	203
PCE	364	2.59E^{-2}	1.08	1.82	1.88	100	188

Vinyl Chloride	57	$8.19E^{-2}$	3.41	0.285	0.212	100	21.2
Benzene	83	$5.59E^{-3}$	0.233	0.415	2.31	100	232
Ethyl Benzene	1100	6.43^{-3}	0.267	5.5	19.4	100	1940
Toluene	300	$6.37E^{-3}$	0.265	1.5	5.86	100	586
Xylene	240	$7.04E^{-3}$	0.293	1.2	4.53	100	453

*Roy & Griffin, 1989 – 1,1,1 TCA - *Montgomery & Welkom, 1990 – all others

It can be shown by sensitivity analysis of (4) that for all but the most water-soluble compounds, the ratio of soil gas to total soil concentration is most sensitive to K_D, next to K_D, and that the other parameters have relatively little effect. Thus, for all but the most quantitative applications, the soil parameters important in calculating the conversion of soil gas concentration to total soil concentration is total organic carbon. Reasonable estimates of moisture content, porosity, and bulk density, the additional soil parameters, would be sufficient for most purposes.

2. Predicting the Presence of NAPL from Soil Gas Concentrations

Equation 4 is valid in most soil gas applications, but can under predict a total soil concentration in cases where a separate non-aqueous liquid phase is present. The total VOC concentration is then a function of the VOC concentration in the NAPL and the amount of NAPL in the soil. In such a case, although Equation 4 continues to account for the VOCs partitions into soil, water, and soil gas, it does not account for the VOCs dissolved in the NAPL. Where NAPL is present, the prediction of soil VOC soil concentrations from soil gas concentrations is not possible because vapor pressure of a VOC in the NAPL is a function of its concentration in the NAPL and the amount of NAPL is generally unknown.

When a VOC concentration in the NAPL is high, its distribution between the NAPL and the gas phase can be estimated by Rault's Law.

$$C_g(i) - (P_s)\,(X_i) \tag{5}$$

Where P_s is the vapor density (pure-compound vapor pressure0 of the VOC
and X_i is the mole fraction of the *i*th VOC

The sum of the mole fractions of compounds making up a NAPL (or any liquid0 is equal to 1.

$$\sum_{id}^{n} X_i = 1.0 \tag{6}$$

Where n is the number of compounds in the NAPL.

Assuming the NAPL is composed of VOCs, that is, each of the dissolved compounds has a reasonable vapor pressure, the substitution of (5) into (6) yields.

$$\sum_{i-1}^{N} \frac{(C_g)\,(i)}{(P_s)\,(i)} = 1 \qquad (7)$$

Thus, in a soil NAPL zone where NAPL is composed of VOCs, the sum of the quotients of soil gas concentrations divided by their respective pure-compound vapor pressure should approach 1. However, a lower than the theoretical value of 1.0 for the summation in (7) should be used to indicate the presence of a NAPL in unsaturated soils. In water saturated soils, because of attenuation by advective and diffusive processes, only 1% of the saturated solubility of a ground water contaminant is the criterion used to determine the presence of NAPL in ground water (Feenstra and others, 1991). Soil gas is less likely to be attenuated by advective processes, and the diffusive transport of a gas borne compound is much more effective than that of a compound dissolved in water, both processes leading to a larger zone of detection for soil gas sources. Thus a larger criterion than the 1% of the theoretical value is appropriate. We suggest, based on observations at a number of soil gas sites that 10% of the theoretical value be used to determine that a NAPL as present at a soil gas sampling location. The appropriate criterion, therefore, is:

$$\sum_{i-=1}^{n} \frac{Cg\ (i)}{p_s\ (i)} \geq 0.1 \qquad (8)$$

As an example of the use of this criterion, suppose that the soil gas data obtained at a point location are:

PCE	=	2,500 ug/l
TCE	=	4,200 ug/l
Cis 1,2-DCE	=	10,000ug/l

The calculations utilizing Equation 8 are summarized in Table 2.

Table 2. EXAMPLE OF USING SOIL GAS TO DETERMINE NAPL PRESENCE

Soil Gas Analyte	Vapor Pressure (mm @ 20°C)	Molecular Weight (g)	Conversion Factor [ug/(mm*1*g)]	Vapor Density p_s (ug/l)	Observed Concentration C_g (ug/l)	C_g/p_s
PCE	14	165.8	54.7	127,000	2,500	0.02
TCE	19	131.4	54.7	137,000	4,200	0.03
1,2 CIS DCE	180	97	54.7	955,000	10,000	0.01
					Sum of C_g/p_s	0.06

According to this calculation, the soil gas concentrations divided by their respective pure-solvent vapor pressure sum to less than 0.1. Thus the NAPL is not present where this soil gas probe was located, and the concentrations of PCE, TCE, and 1,2 cis-DCE at this location can be calculated by the methods summarized in Table 1.

References:

Chiou, C. T. and T. D. Shoup, Environ. Sci. Technol., 1985, 19, 1196.

Feenstra, S., D. M. McKay, and J. A. Cherry, 1991. A method for assessing residual NAPL based on organic concentrations in soil samples.

APPENDIX E

Alternative Closure Criteria
Based on Technology Limits

Alternative Closure Criteria Based on SVE Technology Limit

As an alternative closure criteria for a site, where closure criteria (typically MCL-based) cannot be achieved before reaching concentration asymptote, the following pulsed mode operation between 6 to 12 months has been implemented by California Department of Toxic Substance Control.

1. Define the Asymptote: The concentration of extracted VOC typically decreases rather quickly within several weeks (up to a few months) to a concentration asymptote. The asymptote should be defined where the VOC concentration, in combined extracted vapor, does not vary by more than 5 - 10% during four consecutive weekly monitoring events. Typically a FID is used for monitoring.

2. Optimize Recovery: When the VOC concentration (and mass removal rate) near the asymptote, SVE operation should be optimized by:
   1. Increasing the flow from the extraction wells, with the higher VOC concentrations, by shutting down the wells with low VOC concentrations, or
   2. Adjusting blower/total extraction rates to maximize the rate of contaminant removal.

   The optimization efforts should start from the beginning of full scale operation, however, it will become particularly important near the asymptote because the optimization will extend the time to reach the asymptote. This optimization effort should be documented in the closure/post closure report.

3. Pulse-Mode Operation: Pulsed mode operation should begin once the asymptote is reached (see A above). The process is described below:
   1. The SVE unit is temporarily shut down.
   2. The criterion for assessing rebound should be based on undisturbed soil gas (as opposed to diluted soil gas concentrations at the blower inlet) concentrations obtained from SVE extraction and monitoring well on a weekly basis. Undisturbed/undiluted soil gas samples will represent equilibrium condition and also will tell us how close we are to the closure criteria.
   3. Document VOC rebound as the mean value of the soil gas concentration from extraction and monitoring wells within the radius of influence.
   4. When VOC concentrations reach 200% of the stabilized asymptote the SVE unit should be restarted and extraction should continue until the extracted gas restabilizes at the initial asymptotic concentration. (e.g. if the initial asymptotic concentration was 20 ppmv, the SVE unit should be restarted when the mean of the undisturbed equilibrium soil gas concentration reaches 40 ppmv.) This will avoid unnecessary restarts.
   5. Continue this cycle for 6 - 12 months.

4. Confirmation Sampling: After a period of pulsed-mode operation, site closure should proceed as follows:
   1. Soil and gas confirmation sampling will be conducted at the end of the SVE operation to assess residual VOC concentrations. If closure criteria is based on soil VOC concentrations, soil gas screening data can be used to minimize the number of samples to be collected.
   2. The closure/post closure report should be prepared and include, at a minimum:
      - Documentation of the optimization efforts described above,
      - confirmation sampling results,
      - estimated total VOC mass in the vadose zone before SVE treatment compared to the total estimated mass of VOC removed during SVE operation, and
      - through the SVE operation (with the pulsed-mode) period the plots of:
        a. .... VOC concentration vs. Time, and
        b. .... Cumulative extracted VOC mass vs. Time
   3. Assess the residual contaminant impact to groundwater and;
      - Install post closure monitoring, or
      - estimate residual contaminant concentration risk, or
      - apply deed restrictions where appropriate.