HANFORD STAKEHOLDER PARTICIPATION IN EVALUATING INNOVATIVE TECHNOLOGIES:

VOC PRODUCT LINE,

PASSIVE SOIL VAPOR EXTRACTION USING BOREHOLE FLUX TUNABLE HYBRID PLASMA

Prepared by:

Todd Peterson
Gretchen McCabe

Battelle Seattle Research Center

and

Kathleen Niesen
Patricia Serie

EnviroIssues

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EXECUTIVE SUMMARY

INTRODUCTION AND BACKGROUND

Developing and deploying innovative environmental cleanup technologies is an important goal for the U.S. Department of Energy (DOE), which faces challenging remediation problems at contaminated sites throughout the United States. Achieving meaningful, constructive stakeholder involvement in cleanup programs, with the aim of ultimate acceptance of remediation decisions, is critical to meeting those challenges. DOE's Office of Technology Development sponsors research and demonstration of new technologies, including, in the past, the Volatile Organic Compounds Arid Site Integrated Demonstration (VOC-Arid ID)[1], hosted at the Hanford Site in Washington State. The purpose of the VOC-Arid ID has been to develop and demonstrate new technologies for remediating carbon tetrachloride and other VOC contamination in soils and ground water. In October 1994 the VOC-Arid ID became a part of the Contaminant Plume Containment and Remediation Focus Area (Plume Focus Area). The VOC Arid ID's purpose of involving stakeholders in evaluating innovative technologies will now be carried on in the Plume Focus Area in cooperation with Site Technology Coordination Groups and Site Specific Advisory Boards. DOE's goal is to demonstrate promising technologies once and deploy those that are successful across the DOE complex. Achieving that goal requires that the technologies be acceptable to the groups and individuals with a stake in DOE facility cleanup.

Such stakeholders include groups and individuals with an interest in cleanup, including regulatory agencies, Native American tribes, environmental and civic interest groups, public officials, environmental technology users, and private citizens. This report documents the results of the stakeholder involvement program, which is an integral part of the VOC-Arid ID. It reflects a regional approach, undertaken to add the perspectives of stakeholders from other sites to those of the Hanford Site community. It provides evidence for the conclusion that involving stakeholders on a regional basis adds significant value to a stakeholder involvement program, for two principal reasons:

- First, regional stakeholder involvement has validated the technology evaluation criteria developed by Hanford stakeholders. The ID now has a shared set of criteria, expressing broadly-held stakeholder priorities for technologies' technical effectiveness and practicality. This validation was augmented by site-specific interpretations of the criteria, which are critical to designing technology development and demonstration to achieve broad acceptance.

- Second, regional stakeholders validated Hanford stakeholders' application of the criteria to six innovative technologies. Regional stakeholders shared many of the concerns articulated by Hanford stakeholders. In addition, however, and most important, the regional effort defined local concerns that could determine the

[1]The technology development activities of the VOC-Arid ID will now be addressed through the Plume Focus Area, part of DOE's new approach to development and deployment of innovative environmental management technologies.

deployability of the technologies at DOE's other arid sites. These site-specific issues, while not as numerous as the commonly-held perspectives, could prove to be fatal impediments to technology deployment unless they are successfully addressed in development and demonstration of the technologies. Much of the information gathered, in fact, will be applicable to any new technologies slated for deployment across the DOE complex.

This report provides perspectives on technology acceptability that can be used for several purposes:

- To give technology developers, demonstrators, and deployers an understanding of the issues and information that are important to the broad range of stakeholders in evaluating the acceptability of innovative technologies, and to allow developers to organize issues and information within the framework of the technology evaluation criteria developed by stakeholders.

- To identify the site- and region-specific factors and influences that affect the acceptability of new technologies, and that may determine acceptance in a particular location or locations; in this way developers may be able to refine their demonstration plans to address the local concerns, or may be forewarned about problems at a particular site that may be crucial to technology acceptance there.

- To determine whether there is likely to be sufficient variability among stakeholder perspectives in different parts of the country to warrant site-specific stakeholder consultation in technology development, aiding in designing future stakeholder involvement.

METHODOLOGY FOR STAKEHOLDER INVOLVEMENT

The ID team sought out and recorded stakeholder values and information needs in the early stages of technology demonstration so that those values and needs could be incorporated into demonstration planning. A full compilation of stakeholder comments, issues, and concerns was provided to the technology developers for review and use in developing plans and conducting demonstrations. Demonstration results will later be provided to stakeholders to allow them to assess the acceptability of the technologies for deployment. The resulting stakeholder assessment information will help DOE and industry decision makers select remediation methods that will be acceptable to a broad range of stakeholders, thereby expediting cleanup.

Stakeholder involvement in the VOC-Arid ID began with the participation of Hanford stakeholders, who joined in defining criteria for evaluating innovative technologies and then applied those criteria to six ground-water and soil remediation technologies that are part of the VOC-Arid ID. The criteria developed reflected stakeholder concerns and values. Stakeholder input fell into these four categories of criteria:

- Effectiveness of the technology -- performance, cost, and time

- Environmental safety and health -- worker and public health and safety, and environmental impacts
- Socio-political interests -- public perception, tribal rights and future land uses, and socio-economic interests
- Regulatory objectives -- compatibility with cleanup milestones, regulatory infrastructure and track record, and regulatory compliance.

Criteria development activities and subsequent Hanford stakeholder input on the technologies are documented in earlier reports. This report documents expanded consultation with stakeholders at other DOE arid sites to confirm and apply the criteria, incorporating the perspectives and information needs of those sites' stakeholders in the demonstrations. In this way, a technology, which may be ultimately considered for deployment at many sites, can be demonstrated so as to reflect a broader and more complete understanding of regional stakeholder values. By conducting the stakeholder participation process first at Hanford, then expanding it to the other sites, it is possible to evaluate similarities and differences among stakeholders' perspectives in various regions. The four sites that participated, in addition to Hanford, were Sandia National Laboratories and Los Alamos National Laboratory in New Mexico, the Idaho National Engineering Laboratory, and the Rocky Flats Site in Colorado.

The ID team employed a multi-step process to involve stakeholders in evaluating six innovative technologies. The steps included:

- Developing information about the technologies for stakeholders (technology profiles, fact sheets, and evaluation criteria summaries).
- Contacting personnel at each site to learn about stakeholder involvement at those sites, and meeting with site representatives to develop site-specific strategies for involving local stakeholders in the ID.
- Identifying a cross section of stakeholders, and contacting them to assess their willingness to participate and to schedule interviews.
- Distributing the technology information for review, prior to the interviews, to the stakeholders who agreed to be interviewed.
- Conducting interviews in which the ID team explained its objectives, answered stakeholder questions about the technologies, and asked the people interviewed about their views on the technologies.

The interviews focused on learning what is important to the stakeholders in choosing an environmental restoration technology, and what additional information they would need about the technology in order to evaluate it for deployment. Stakeholders were asked about issues and concerns raised by the technologies, and were asked about their views on the advantages and disadvantages of the technologies compared with current baseline technologies.

The results of the interviews have been analyzed and summarized in this report, using earlier published input from Hanford stakeholders to illuminate common themes among the sites as well as to highlight site- or region-specific issues and perspectives.

DESCRIPTION OF THE DEMONSTRATION TECHNOLOGIES

Stakeholders evaluated six innovative remediation technologies that are being demonstrated within the VOC-Arid ID. They represented different types of technologies (e.g., subsurface access, contaminant extraction, and contaminant treatment). For ease of discussion, they were grouped into two systems, though each is a technology that could be used alone or in combination with other technologies. The six technologies are:

Ground-Water Technologies:

- **Sonic Drilling** is a subsurface access technology, which uses resonant vibration to cut a boring. No drilling fluids are needed, and there is minimal secondary waste (e.g., drill cuttings) produced.

- **In-Well Vapor Stripping** is a contaminant extraction technology which removes VOCs from ground water as vapor. Only the vapor then requires handling, and it is treated at the surface. In-well vapor stripping operates somewhat like a fish tank filter system, passing VOC-laden ground water repeatedly through the in-well system.

- **Membrane Separation** is an above-ground treatment system that condenses and captures contaminants emerging from underground in vapor form. The technology uses thin-film membranes to concentrate the gases.

- **In-Situ Bioremediation** uses naturally occurring microorganisms in ground water, stimulated by the addition of nutrients, to degrade VOCs in place. There is no need to pump the ground water to the surface for treatment.

Soil Technologies:

- **Passive Soil Vapor Extraction** takes advantage of natural atmospheric pressure changes to bring contaminant vapor to the surface through wells or boreholes. Potential enhancements include turbines or windmills at the surface, injection of hot air or steam, and one-way flow valves.

- **Tunable Hybrid Plasma** is an above-ground technology that can treat vapor extracted from either soil or ground water. It uses an electron beam to destroy VOC molecules, producing other molecules that can be scrubbed and reduced to salt.

COMMON DEMONSTRATION ISSUES

A number of themes emerged from the interviews held with stakeholders at Hanford, as documented in earlier reports. They include the following major objectives for the technology development and demonstration process, regardless of the type of technology:

- Define remediation objectives clearly, ensuring that the technology truly contributes to these objectives.

- Compare new technologies with existing technologies in an integrated, "total treatment train" manner.

- Design demonstrations to provide credible data on performance, cost, and time in order to reduce uncertainty and define technology trade-offs.

- Demonstrate the technology in consideration of differing site conditions to measure its versatility.

- Evaluate process waste and the environmental consequences of use of the technology from start to finish.

- Address effects of multiple contaminants, especially radioactive contaminants, in the demonstrations.

- Assess operational readiness of the technology.

- Plan for unintended consequences and test all potential failure control mechanisms.

- Demonstrate that future cleanup will not be foreclosed by using the technology.

- Involve credible third-party evaluators in assessing demonstration results.

Stakeholders at the other arid sites confirmed and supported these general objectives, adding points that supplemented those noted above. These points describe the kind of technologies or technology attributes that stakeholders indicated they will find appropriate for deployment. Taken together with Hanford's stakeholder objectives, these points create the framework within which stakeholders will decide the acceptability of remedial technologies. Although these views have been generalized from a number of individual interviews and may not represent all stakeholders' views, remedial project managers and others responsible for technology deployment will want to take these perspectives into account in selecting technologies:

- Stakeholders prefer that technologies destroy contamination on site as opposed to concentrating contaminants for off-site transport and destruction.

- Stakeholders oppose using technology merely to transfer contamination from one environmental medium to another. For example, stakeholders are consistently concerned about moving contaminants from earth or water into air.

- Stakeholders recommend that technologies work with as few steps as possible.

- Stakeholders prefer technologies that can be operated and maintained by existing staff. Stakeholders wish to avoid the need to call in distant experts for operation or to repair equipment.

- Stakeholders want technologies to be economical, simple, understandable, and robust.

- Technologies must be able to deal with co-contaminants. In order to be accepted for deployment, a technology must be effective with more than just one target pollutant. Acceptable technologies at DOE facilities must have the ability to deal with radioactive co-contaminants. Some stakeholders see the inability to do so as a "showstopper."

- A technology's entire treatment system matters to stakeholders. They evaluate the entire system, not just the most visible, active, or highly technical component. The entire system must be maintainable and economical. Secondary waste from each component of the technology's system must be safely manageable.

SITE-SPECIFIC DEMONSTRATION ISSUES

Certain site-specific concerns will also determine the deployability of technologies. Although the specific details of these concerns vary from site to site, the themes and requirements apply broadly.

- Technologies will be evaluated within the regulatory framework prevailing at a particular site. To enhance a technology's acceptability, the technology and its demonstration must be presented in terms of that site's specific regulatory framework. Applicable regulations vary among states and tribal nations. For example, in New Mexico, some tribal governments have more stringent cleanup standards than state government. Also in New Mexico, RCRA regulations are seen to govern technology demonstration and deployment at DOE sites.

- Where a natural resource is considered special, impacts on that resource may serve as an overriding factor in determining a technology's evaluation and acceptance. For example, water is extremely important to stakeholders in the arid west. Some communities in the Southwest are discovering that the quantity of available ground water is significantly less than previously estimated. Therefore technologies that do not involve removal and reinjection of ground water are regarded favorably. In another example, the Snake River Plain Aquifer in southern Idaho is of such economic, cultural, and political importance that any proposed technology's impacts on it will take precedence in the evaluation of that technology. Similarly Southwestern stakeholders prize the clarity of their air, and therefore will carefully scrutinize any proposed technology's possible air emissions.

- Remote sites place special requirements on technologies. These include the ability to withstand vandalism, and to operate reliably and automatically for long periods. Remoteness raises the question of power supply, an issue involving concerns about the negative impacts of needed power lines or the air emissions from generators.

- The ability to operate in locally prevailing weather will determine the acceptability of technologies. Extremes of temperature and humidity, high winds, and deep snow are among the conditions that must be taken into account.

- Tradeoffs among criteria will vary from site to site. Local conditions will determine how stakeholders weigh the benefits and drawbacks of a technology's characteristics in relation to its capabilities.

- Versatility applies to all criteria, not just to performance. To be acceptable, a technology must be versatile and adaptable in terms of all the criteria used to evaluate it. For example, regulatory compliance acceptability can mean different things in different states.

ACTUAL STATE-SPECIFIC ISSUES IDENTIFIED DURING STAKEHOLDER INTERVIEWS

In addition to the common themes and supporting examples summarized above, stakeholders at the other arid sites provided site-specific inputs that illustrate the importance of defining technology acceptability objectives for deployment in those locations. Comments tended to fall into categories that the ID team has called natural factors, regulatory and policy factors, and contaminant factors. Table 1 below summarizes site-specific issues identified during the interviews.

STATE-SPECIFIC ISSUES IDENTIFIED
DURING STAKEHOLDER INTERVIEWS

STATE	NATURAL FACTORS	REGULATORY AND POLICY FACTORS	CONTAMINANT FACTORS
Colorado	1. Rocky, heterogeneous soils must be taken into account in technologies' demonstrations in order to have sufficient information to evaluate acceptability in Colorado. 2. The relatively shallow ground water at the Rocky Flats site reduces some of the advantages associated with in-situ technologies. 3. High winds and severe winter conditions must be accounted for in technologies' demonstrations in order to provide information sufficient to evaluate acceptability in Colorado.	1. Both RCRA and CERCLA apply to remediation at the Rocky Flats Site and elsewhere in Colorado. Both programs must be accounted for, and issues that address regulatory needs of both laws should be incorporated into test plans. 2. Limited hazardous and mixed waste storage space and time constraints are significant factors at Rocky Flats. Consequently, technologies that produce little or no process waste requiring storage are greatly preferred. 3. Stakeholder values are extremely diverse in Colorado, creating a difficult environment for predicting acceptance of new technologies. 4. Programmatic requirements to accelerate Rocky Flats cleanup to meet specific target dates have constrained the timeframe in which decisions on remediation technologies must be made. Consequently, technologies which have been fully demonstrated within the next 12 to 18 months may be the only ones that will be candidates for selection at Rocky Flats.	1. Plutonium co-contamination in soil is of particular concern to many stakeholders at the Rocky Flats Site. Materials-handling technologies which may create airborne plutonium contamination are regarded with disfavor. 2. Some stakeholders see a pressing need for technologies that deal with particulates (especially airborne radioactive particulates). 3. Variable but relatively low concentrations of VOCs (low ppms to ppb range) in ground water and the vadose zone are the prevailing conditions at Rocky Flats, and technologies that function under these conditions (as well as low flow rates) are most desirable.

STATE-SPECIFIC ISSUES IDENTIFIED
DURING STAKEHOLDER INTERVIEWS

STATE	NATURAL FACTORS	REGULATORY AND POLICY FACTORS	CONTAMINANT FACTORS
Idaho	1. The Snake River Plain Aquifer is considered the single most important natural resource in southern Idaho; consequently, treatment technologies that have minimal negative impact and withdraw as little water as possible from it are more positively regarded. 2. Severe cold temperatures and snow are important factors for demonstrating technologies for use in Idaho.	1. CERCLA is the principal regulatory program at INEL; however other applicable, relevant and appropriate requirements (ARARs) and certain captive operations bring RCRA regulations to bear. In order to achieve expeditious clean up, technologies that trigger more prescriptive RCRA regulations are not preferred. 2. Transportation of hazardous materials over tribal lands is regulated by tribal law, which is enforced by tribal police. Minimization of this type of transportation is regarded as positive and technologies that do not require the transportation of hazardous material have an advantage. 3. Tribal perspectives on cultural and archaeological resources differ from European-derived perspectives. Tribal stakeholders prefer technologies that disrupt cultural resources as little as possible.	1. Radioactive co-contaminants are "show stoppers" for any new technology at INEL. The inability to address the radioactive component of mixed waste will cause a technology (or technology system) to be deemed unacceptable.

STATE-SPECIFIC ISSUES IDENTIFIED DURING STAKEHOLDER INTERVIEWS

STATE	NATURAL FACTORS	REGULATORY AND POLICY FACTORS	CONTAMINANT FACTORS
New Mexico	1. Deep ground water (800' to 1000' below the surface) and lack of substantial contamination at that depth at the two New Mexico DOE sites result in little interest in ground-water treatment technologies at those sites. However, there is other ground-water contamination in New Mexico, specifically from nitrates, and stakeholders have concerns with respect to technology use in these other cases. 2. New Mexico residents have recognized that ground water is limited and that many areas are contaminated with domestic and agricultural waste. This has caused great concern about cleaning this resource (ground water) in place and wasting none. 3. The special value placed on air quality and expansive scenic vistas in New Mexico raised extensive concerns with respect to air emissions and any additional power lines or other view-obscuring elements. 4. The remote nature of many contaminated sites raised concerns about vandalism and the ability of technologies to be resistant to tampering and operable without constant attention.	1. RCRA (regulations and program culture) is the exclusive regulatory influence over the two New Mexico sites. All technologies must be demonstrated in light of RCRA TSDF permitting requirements. RCRA requirements can be extremely specific and are not always risk-based. 2. Certain tribal nations have imposed even more strict environmental regulations than the federal government, the state, or localities (e.g., wastewater discharge requirements). Demonstration and deployment in tribally controlled locations must take these requirements into account. 3. The ability of existing public works and maintenance staff to operate and maintain new technology was regarded as desirable. (Implies that simple, robust technologies are preferred.) 4. The ability to recoup the cost of remediation by property liens and/or taxing was regarded as desirable. (Implies that lower total technology cost is desirable.)	1. Nitrate contamination of ground water in many locations raised questions and concerns about the applicability of treatment technologies to this contaminant. 2. Non-DOE Superfund and state cleanup sites with ground-water and vadose-zone contamination exist in New Mexico. Chlorinated solvents and petroleum hydrocarbon contaminants were most frequently mentioned by stakeholders as requiring new and better treatment technologies.

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STATE-SPECIFIC ISSUES IDENTIFIED
DURING STAKEHOLDER INTERVIEWS

STATE	NATURAL FACTORS	REGULATORY AND POLICY FACTORS	CONTAMINANT FACTORS
Washington	1. The proximity to contaminated areas of the Columbia River and its associated resources creates special and potentially unique stakeholder concerns. 2. Hanford's glacial and outwash soils and relatively deep ground water are rare, and test plans should account for varying soil and ground-water conditions at other sites. 3. Large-scale problems (in terms of amount of contamination and areal distribution) are common at Hanford. Technologies that have potential for large- volume and large-area cleanup are most favored. 4. Natural habitat may restrict technology applications at certain locations at Hanford.	1. The Tri-Party Agreement (DOE/EPA/Washington State) with its incorporation of CERCLA, RCRA, and state regulations and associated site-specific time requirements, creates a regulatory framework that is unique. Technology demonstrations should be aware of and incorporate sufficient information to satisfy all regulations. 2. Time requirements (milestones) at Hanford may not be applicable to or appropriate at other facilities. 3. Tribal treaty rights and cultural resources may impose special requirements on demonstrations at certain locations on the Hanford Site.	1. Extensive ground-water contamination with few or no co-contaminants, specifically radioactive constituents, are found at Hanford's 200 West Area. This represents a relatively rare case at large contaminated federal facilities. Demonstrations should account for other situations as well. 2. Carbon tetrachloride is a relatively rare contaminant and, therefore, technologies should also be demonstrated with other VOCs and VOC mixtures in mind. 3. High-visibility, high-hazard radioactive contamination sites such as the Single Shell Waste Tanks at Hanford can cause stakeholder concern to be less focused on other contamination problems and can influence stakeholder priorities. 4. There is serious stakeholder distrust of failure control mechanisms and accident response for new technologies.

1.0 INTRODUCTION

1.1 PURPOSE AND OBJECTIVES OF HANFORD STAKEHOLDER PARTICIPATION IN EVALUATING SOIL REMEDIATION TECHNOLOGY

A three-phased stakeholder participation program was conducted to support the Volatile Organic Compounds Arid Site Integrated Demonstration (VOC-Arid ID). The U.S. DOE's Office of Technology Development (OTD) sponsored and directed the VOC-Arid ID. Its purpose was to develop and demonstrate new technologies for remediating VOC contamination in soil and ground water. The integrated demonstration, hosted by the Hanford site in Washington State, is being transitioned into the Department of Energy's (DOE) Plume Focus Area. The Plume Focus Area has the same basic objectives as the ID, but is broader in scope and is a team effort with technology developers and technology users. The objective is to demonstrate a promising technology once, and if results warrant deploy it broadly across the DOE complex and in private sector applications.

By involving stakeholders in the early stages of technology evaluation, the team has committed to incorporating stakeholder values and information needs into the demonstrations. When demonstrations are complete and performance data are available, stakeholders will receive those results. With this information, stakeholders can assess the technologies' acceptability for broad deployment. Stakeholders include: regulators, agency personnel, Native American tribes and nations, environmental and civic interest groups, elected officials, environmental industry users of technology, and private citizens.

The team has sought Hanford stakeholder involvement, obtained their input, and created mechanisms to incorporate stakeholder issues and concerns into the demonstration process. Hanford stakeholders reviewed two sets of remediation technologies. A ground water system that includes four technologies: sonic drilling, membrane separation treatment, in-well vapor stripping, and in-situ bioremediation. A soil remediation set of two technologies: passive soil vapor extraction using borehole flux, and a treatment technology named tunable hybrid plasma.

Phase II Stakeholder Participation in Evaluating Innovative Technologies: VOC-Arid Integrated Demonstration, Ground water Remediation System (TTP Number RL 311101) documents the process and results of involving Hanford stakeholders in reviewing the ground water system. Those activities included stakeholders reviewing technical information about the four technologies, conducting focus groups to understand stakeholder perspectives and information needs, preparing focus group reports, and conducting an all-participants workshop to integrate recommendations concerning the technologies' test plans.

Hanford stakeholders have reviewed the two soil remediation technologies. Their input on those technologies is the subject of this report.

1.2 REPORT ORGANIZATION

This report documents the participatory activities conducted concerning soil remediation technology, and complements similar information gathered on the ground water system. Section 2.0 describes the methodology to engage stakeholders in assessing the two technologies, and describes how stakeholder input will be integrated into the demonstrations.

Section 3.0 provides the results of stakeholder participation. Individual stakeholders were interviewed to obtain these results. A workshop conducted in October 1994 integrated these results into demonstration-specific input.

Appendix A contains fact sheets and profiles on the two soil remediation technologies.

2.0 STAKEHOLDER PARTICIPATION METHODOLOGY

2.1 APPROACH TO STAKEHOLDER PARTICIPATION

Stakeholders have been encouraged to participate in the evaluation of innovative technologies through the VOC-Arid ID in order to improve decisions made by DOE and its contractors about technology development, demonstration, and deployment. The approach is to identify people and organizations with a stake in the remediation process, and hence in the demonstration of innovative technologies. These people are invited to participate in ways that they find convenient and meaningful, and they are presented with detailed technical information about the technologies. Their input in identifying issues and concerns, defining the information needed from the demonstrations, and assessing the acceptability of the technologies for deployment, will help ensure that only broadly promising technologies are carried forward. This approach is designed to increase the likelihood of successful deployment of the new technologies needed to accomplish environmental restoration throughout the DOE complex and at private facilities.

2.2 METHODOLOGY FOR EVALUATING SOIL REMEDIATION TECHNOLOGIES

As a first step in involving stakeholders in evaluating the two soil remediation technologies, the ID team prepared descriptive profiles for each technology. Because the profiles are lengthy, the team also prepared a brief fact sheet for each technology which describes the technology's purpose and function, objectives, advantages and disadvantages, and challenges. Appendix A of this report includes fact sheets and profiles for passive soil vapor extraction and tunable hybrid plasma.

Approximately 40 Hanford stakeholders have been involved in the VOC-Arid ID process since the first phase, in which criteria to evaluate technologies were developed in consultation with a cross section of stakeholders identified from earlier Hanford outreach efforts. Although there have been some changes in the list of individuals involved, there has been substantial consistency in the people who have volunteered their time to evaluate technologies and participate in VOC-Arid ID activities.

To begin this phase of public consultation, the ID team sent letters to the Hanford stakeholders previously involved, providing fact sheets on the two technologies, describing the objectives of this round of discussion, and requesting an interview. Members of the ID team then called these stakeholders and asked if they were willing to be interviewed. Twenty-eight interviews were scheduled. Once stakeholders had agreed to the interview, they received a confirming letter and the profiles for each technology for review before meeting with the ID team interviewers.

The VOC-Arid ID team conducted interviews during July and August 1994 (one telephone interview occurred in September). Interviewers explained this activity in the context of the VOC-Arid ID stakeholder involvement program. They answered stakeholders' questions about the technology profiles, then discussed the stakeholders' issues, concerns, questions about, and reactions to the technologies. Discussion focused on three questions:

- What do you consider important in choosing an environmental restoration technology? What additional information would you need to evaluate these candidate technologies with confidence?

- Are there aspects of these technologies that concern you?

- What features of the technologies do you see as advantages compared to cleanup technologies now available?

The ID interview team recorded stakeholder comments and asked clarifying questions where needed to obtain complete and accurate documentation. Interviewers explained to participants that their input would be summarized in a draft report. The draft report was the basis for a workshop in October 1994. Comments derived from the interviews and the workshop are the basis of the data requirements presented in Section 3.0 for both passive soil vapor extraction and tunable hybrid plasma.

3.0 SUMMARY OF RESULTS

3.1 DESCRIPTION OF TECHNOLOGIES

The two soil remediation technologies stakeholders reviewed are both methods of cleaning up VOC contamination. Passive soil vapor extraction using wells and boreholes enhances a natural phenomenon to release and capture VOCs from the soil, while tunable hybrid plasma uses an electron beam process to destroy vapor-phase VOCs in air streams once they have been extracted from the earth. Both technologies are described briefly below, with more information provided in Appendix A.

3.1.1 Passive Soil Vapor Extraction

This method of remediation takes advantage of the natural phenomenon of atmospheric pressure change. Fluctuations in atmospheric pressure occur due to weather, seasonal, and diurnal changes, creating differential pressure between the atmosphere and air contained in vadose zone soils. When the subsurface is connected directly by a well or borehole to the surface, contaminants are carried by air flow to the surface as atmospheric pressure changes from high to low. This phenomenon occurs even at depth. Flux has been observed to the depth of the water table at Hanford.

With an understanding of the pressure relationship between the surface and subsurface at a given site under various atmospheric conditions, pathways (e.g., boreholes or wells) can be installed and managed to enhance contaminant removal. Enhancements to the natural phenomenon may include amplification devices at the surface such as turbines or windmills, use of a one-way flow valve to control air flow direction through the borehole, injection of hot air or steam, and well networks. VOCs may be captured at the surface by granular activated carbon units (GAC) or treated by various processes.

3.1.2 Tunable Hybrid Plasma

This technology operates above ground. A moderate-energy electron beam is directed into a flow of air containing organic contaminants. The electron beam is produced by applying electricity to a linear filament electron source in a vacuum chamber. The primary electrons that are generated pass through a titanium foil window. These primary electrons create several thousand secondary electrons, with lower energy levels than the primary electrons. The secondary electrons rapidly cool to room temperature and attach to halogenated hydrocarbon (VOC) molecules in the flow of contaminated air. This causes the VOC molecules to dissociate into simpler molecules, destroying the VOCs. Carbon tetrachloride and TCE are preferentially destroyed by this process because of the way their molecules are arranged. The products of the process are carbon dioxide, chlorine gas, water, oxygen, nitrogen, and hydrochloric acid. Further treatment in a conventional liquid/air scrubber reduces the secondary wastes to salt.

3.2 DATA REQUIREMENTS FOR TECHNOLOGY DEMONSTRATIONS

Individuals interviewed provided a range of perspectives on the two soil remediation technologies, including general concerns as well as detailed technical questions. This section lists the issues that stakeholders would like to see principal investigations address in demonstrating the technologies.

3.2.1 Data Requirements for Passive Soil Vapor Extraction

Stakeholders provided general insights into the demonstration and potential deployment of passive soil vapor extraction. The table below summarizes these comments.

GENERAL COMMENTS ON PASSIVE SOIL VAPOR EXTRACTION	
1.	A low-cost, slow technology such as this may be appropriate as long as there is no additional exposure in the interim (e.g., contaminants moving into ground water from the vadose zone, which would warrant using active soil vapor extraction or other techniques that work more quickly). In some cases, it is reasonable to trade time for money, but only when health or the environment are not put at risk. A specific argument for using a faster, more active method is the need to capture VOCs in the vadose zone, so that they do not reach ground water and become Dense Non-Aqueous Phase Liquids (DNAPLs) in the aquifer, a difficult problem to remediate.
2.	The release of contaminants to the air from passive soil vapor extraction is a significant issue, potentially requiring a specific regulatory framework. Some stakeholders perceive a higher risk from contaminants in the air than from those in the ground. For many people, uncontrolled release is not acceptable; they believe that off-gas must be captured and managed.
3.	There are disadvantages to drilling new wells, including potentially creating subsurface conduits for contamination, high costs, and the problems of abandoned wells. The drilling of new wells should be minimized. The oil and gas industry should be consulted for information on well networks and interconnection effects.
4.	The technology is attractive, as it speeds up a natural process, has a low cost, and is simple and logical to operate. However, the questions related to off-gas releases are critical. It is not clear whether this remediation method, relying as it does on variable rates of soil vapor flux, will be able to meet regulatory requirements and cleanup milestones.
5.	This VOC extraction method needs to be predictable in its results in order to be selected by remedial project managers.
6.	"Better, faster, cheaper" is a motto for new technology evaluation at Hanford. This method is not faster.

Stakeholders also provided specific input that can be translated into data requirements for the demonstration test plans. That input is summarized below. Workshop comments also include responses and perspectives by principal investigators.

SPECIFIC DATA REQUIREMENTS FOR PASSIVE SOIL VAPOR EXTRACTION	
INTERVIEW COMMENTS	**WORKSHOP COMMENTS**
Effectiveness	
1. Determine if passive soil vapor extraction (PSVE) may be used best as a long-term maintenance technology; for example, to provide containment at the edge of contaminant plumes, or as a secondary approach to be used in conjunction with other technologies, such as active soil vapor extraction.	1. Finalize demonstration results to determine PSVE's effectiveness on containing contaminant plumes or as a secondary remediation method.
2. Define the varying depths of the vadose zone at which this technology will work (e.g., will it operate at 200-250' depths in the Hanford formations).	2. No further comment.
3. Analyze the flow characteristics of air under different conditions. Determine the flow rate of contaminated air from PSVE wells, and factors affecting intake of clean air into the earth. Define what pressure changes are needed for the technology to succeed.	3. Develop efficiencies and predictions of performance of wells bored in certain soil classes. The demonstration will provide information about the flow characteristics of air form the surface and in the subsurface. Efficiencies can be predicted in air-flow terms and the VOC concentrations can be calculated based on the concentration present in the soil.
4. Define the subsurface radius of influence of PSVE wells, in terms of different soil types, moisture content, and contaminant concentrations. Define any local conditions that may affect the effectiveness of the technology (e.g., major subsurface fractures, nearby active soil vapor extraction, etc.).	4. Assess the effect on the method's radius of influence of placing plastic sheeting on the surface.

SPECIFIC DATA REQUIREMENTS FOR PASSIVE SOIL VAPOR EXTRACTION	
INTERVIEW COMMENTS	**WORKSHOP COMMENTS**
5. Determine the effect of surface temperature on the remediation method. Measure temperatures at the subsurface depths being assessed.	5. No further comment.
6. Define active soil vapor extraction's point of diminishing returns in site conditions similar to those where PSVE would be used.	6. Formulate the demonstration test plan so as to provide this information.
7. Define the applicability of the technology to a full range of VOCs (especially those that are heavier than air).	7. Formulate the test plan and carry out the demonstration to determine the behavior of VOCs that are heavier than air.
8. Assess the effects of radioactivity or other VOCs as co-contaminants.	8. PSVE encounters the same co-contaminants at Hanford as active systems. HEPA filters are an option in the PSVE system conceptual design. HEPA filters are used to capture radioactive particulates. Monitor PSVE emissions to determine if and when HEPA filters are necessary.
9. Develop information on diffusion rate limitations of sorbed carbon tetrachloride and TCE in various soils, including information on soil chemistry and partitioning coefficients. Determine the relationship of mass removal to desorbtion kinetics.	9. Characterize the exchange between the aquifer and the vadose zone in terms of VOC contamination and diffusion in and out of ground water. Site by site assessment is necessary to determine if PSVE works rapidly enough to prevent VOCs from migrating into ground water, and becoming dense non-aqueous phase liquids (DNAPLs) in ground water, which are difficult to remediate. Some data on these issues developed through work with active soil vapor extraction (ASVE) are being used to plan and verify the PSVE demonstration. PSVE is effective in the same conditions and geologic formations as ASVE.
10. Assess whether there are sites that will "clean themselves up" without enhancing the natural phenomenon.	10. No further comment.

SPECIFIC DATA REQUIREMENTS FOR PASSIVE SOIL VAPOR EXTRACTION	
INTERVIEW COMMENTS	**WORKSHOP COMMENTS**
Effectiveness - Practicality	
11. Define pre-characterization activities needed to construct networks of passive soil vapor extraction wells.	11. The demonstration report will evaluate needed pre-characterization.
Effectiveness - Cost	
12. Assess cost of operation and maintenance over the long periods potentially necessary to use this technology. Include drilling costs.	12. Define the breakpoint, in terms of cost, between ASVE and PSVE. Define the long-term costs of PSVE alone and in combination with ASVE. Early evaluations indicate that at less than 1000 ppm of VOC extracted, the economic advantage may turn from ASVE to PSVE.
13. Define monitoring needs and costs of the remediation method, including fencing, signs, and ecological monitoring.	13. No further comment.
14. Determine the costs of off-gas treatment. Compare GAC treatment cost with the cost of direct release, including the cost for obtaining air permits.	14. Determine the cost of PSVE's operation with and without off-gas treatment. The demonstration will compare the cost of treatment with the cost of direct release, including permitting costs.
15. Define the costs of enhancements. Define cost/benefit ratios in terms of incremental benefit for added costs (capital, operation, and management).	15. The demonstration will provide this information.
Effectiveness - Time	
16. Define the flux with varying atmospheric pressures, soil types, soil moisture, and depths. Define how this remediation method's performance will be measured. Monitor so that the effect of active soil vapor extraction will not be attributed to the passive approach.	16. Demonstration results will present and analyze this data.

SPECIFIC DATA REQUIREMENTS FOR PASSIVE SOIL VAPOR EXTRACTION	
INTERVIEW COMMENTS	**WORKSHOP COMMENTS**
Effectiveness - Process Waste	
17. Assess whether captured contaminants are classified as mixed waste if radionuclides are present.	17. No further comment.
Environmental Safety and Health — Worker Safety/Public Health and Safety	
18. The release of contaminants to the air from passive soil vapor extraction is a significant issue, potentially requiring regulatory attention. For many stakeholders, uncontrolled release is not acceptable; they believe that off-gas must be captured and managed.	18. The demonstration will provide data on off-gas quantities and concentrations of contaminants in relation to regulatory limits and risk levels. Hanford concentrations of VOCs have been measured between the 100s and 10,000s of parts per million (ppm). Off-gas capture and treatment associated with PSVE must be designed to accommodate low pressure differentials.
19. Assess potential health and safety concerns related to venting contaminants, including VOCs, radon, tritium, and carbon-14 at the surface, addressing long-term fate and transport as well as atmospheric breakdown of these contaminants.	19. Radon is sorbed on GAC. Correlate radon extracted with carbon tetrachloride extracted.
20. Assess the need for personnel protective equipment to guard against contact with carbon tetrachloride and other contaminants during well maintenance and monitoring.	20. The demonstration will examine and report on contaminant flux and exposure.
Environmental Safety and Health — Environmental Impacts	
21. There are disadvantages to drilling new wells, including potentially creating subsurface conduits for contamination, high costs, and future problems with abandoned wells. The number of new wells drilled should be minimized.	21. The demonstration will provide data on the number of wells needed for various applications and how both existing and new well networks can be used.

SPECIFIC DATA REQUIREMENTS FOR PASSIVE SOIL VAPOR EXTRACTION	
INTERVIEW COMMENTS	**WORKSHOP COMMENTS**
22. Determine the need to grout wells after use of the technology. (Some stakeholders see grout as permanently damaging.) Assess the possibility of complete well removal or other well-closure methods.	22. Wells must be closed in accordance with the Washington Administrative Code (WAC) regulations. Closing usually entails grouting and sealing. There is a concern that even closed wells may cause environmental damage. Formulate the test plan so as to determine the effect of closed wells.
23. Assess this technology's potential impacts to future land use.	23. Assess the impacts of the technology on future land use given that permanent covers are not planned, but temporary covers may be used.
24. Define any effects on climate resulting from use of the technology.	24. Determine, if off-gas is treated, the technology's effect on climate. Examine the possible effects of soil surface flux.
Regulatory Objectives	
25. Determine whether this remediation method, relying as it does on variable rates of soil vapor flux, will be able to meet regulatory requirements and cleanup milestones.	25. Determine how this approach to remediation fits in with deadlines establish
26. Define the types of well construction appropriate to support PSVE (i.e., what is the ideal well construction; is it consistent with existing well regulations). Assess the availability of wells that fit those criteria, since drilling new wells is expensive.	26. PSVE does not have unique well-installation requirements. Determine if existing small wells can be used for PSVE. (Determine how small).

3.2.2 Data Requirements for Tunable Hybrid Plasma

Stakeholders made a number of general comments in relation to tunable hybrid plasma, including the following:

GENERAL COMMENTS ON TUNABLE HYBRID PLASMA
1. The major issue with tunable hybrid plasma (THP) is emissions. Some stakeholders equate the emissions from this technology with those from incineration, and want complete information on what is released to the environment. Tunable hybrid plasma will need to meet or do better than any standards for incinerator operation.

2.	Comparisons have been made between this technology and incineration. Principal investigators may benefit from understanding resistance to thermal technologies in general.
3.	The mobile nature of the technology is appealing, enhancing its possible application at other sites.
4.	This technology may be useful for eliminating the hazardous component of mixed waste, facilitating the subsequent management of the waste as solely radioactive waste.
5.	This technology offers the advantage of destroying contaminants on site, eliminating the necessity for further treatment or transportation of secondary wastes.
6.	High potential costs are a concern. Costs for tunable hybrid plasma should be compared with costs of other technologies performing similar functions.
7.	Examine conditions outside the test site to determine whether the technology can be applied to industrial sites.

Tunable hybrid plasma is a complex technology, and raised a number of questions with interviewees and workshop participants. They were able to identify a number of questions that translate to demonstration data requirements, which are summarized in the table below.

SPECIFIC DATA REQUIREMENTS FOR TUNABLE HYBRID PLASMA	
INTERVIEW COMMENTS	**WORKSHOP COMMENTS**
Effectiveness	
1. Define how much VOC-contaminated soil there is at Hanford and what percentage this technology can clean up.	1. 1,000,000 pounds of CCl_4 are known to have been dumped at Hanford. About 80,000 pounds have been extracted now (third quarter 1994). The demonstration report will evaluate THP's degree of effectiveness with Hanford's conditions of contamination.
2. Determine if this technology could be used as a secondary treatment for the vapor that is stripped from GAC during regeneration, or to treat incineration off-gas. Define any potential conflicts with other technologies that can be used to perform these treatments.	2. Determine THP's applicability to GAC regeneration and to VOC off-gas stripped from contaminated water.

SPECIFIC DATA REQUIREMENTS FOR TUNABLE HYBRID PLASMA	
INTERVIEW COMMENTS	**WORKSHOP COMMENTS**
3. The demonstration team should consider how the demonstration of Tunable Hybrid Plasma may impede the ongoing effectiveness of the Expedited Response Action (ERA) at the Hanford 200 West operable unit.	3. ERA continues to function while evaluating new technologies. Experiments occur on a split air stream with some minor shutdown time for equipment hookup. Evaluate the effects of the THP demonstration on the ERA.
4. Define the versatility of the technology. Can it be used with passive as well as active extraction? What are the pressure and concentration ranges of operation? Examine conditions outside the test site to determine whether the technology can be applied to industrial sites.	4.. Also examine application at DoD sites. During the demonstration, spike the contaminated air stream with co-contaminants and mixtures because most sites have VOC mixtures. During the demonstration, vary the flow rate and concentration of the contaminated air stream. Also determine what are the requirements if GAC is used as a polishing step? There is a need to know physical/chemical operating parameters.
5. Define the limits for air stream drying in advance of the electron beam application. How dry or wet can the air be? Is any carbon tetrachloride pulled out in the dryer? Define corrosion or fouling issues for the dryer. Determine the energy requirements for the electron beam based on the range of moisture in the air.	5. Also determine where the water removed from the contaminated air stream will go. Air from VVE has 75 - 80% humidity at 55 degrees at Hanford, so there may be quite a bit of water.
6. Define technology shutdown and decommissioning requirements.	6. Include in the demonstration report details on the operation of detector devices for the shutdown interlocks.
7. Define the limits of the unit's mobility, and the costs for startup, shutdown, and movement to another location.	7. No further comment.
Effectiveness – Performance	
8. Determine the effects of particulates in the air stream. Will the system foul if particulates are present at any stage?	8. Will particulates "poison" the plasma reaction process? Will they (at what level) mask off the beam? Determine the effects of particulates on other components of the technology.

SPECIFIC DATA REQUIREMENTS FOR TUNABLE HYBRID PLASMA	
INTERVIEW COMMENTS	**WORKSHOP COMMENTS**
9. Define the temperature limitations of the system (ambient, and input vapor stream.)	9. Also define the temperature of the gas that enters the scrubber. Perform a mass and temperature balance and noise analysis.
Effectiveness – Process Waste	
10. Define the design and operating details of the processes for managing the secondary waste resulting from the plasma reaction.	10. Determine the cost of managing all secondary waste and byproducts including salt.
11. Define the impacts of co-contaminants possibly being incorporated in the resulting salt.	11. Determine the cost of managing all secondary waste and byproducts including salt.
Effectiveness – Maintainability	
12. Define the requirements for maintenance, including the scrubber (staffing, equipment, power source, etc.).	12. Address this and check operating and maintenance needs. Do not ignore any system components.
Effectiveness – Time	
13. Define the length of time the technology takes to remove given levels of contaminants (e.g., pounds per day at various concentrations and flow rates).	13. Determine mass loading and flow rate limitations in the drier, plasma unit, and scrubber. Determine the technology's processing rate. What are the limiting factors?
Effectiveness – Environmental Impacts	
14. Address the purity of the required power supply.	14. Define overall energy consumption, including operation of all three units that make up the treatment system, as a basis for comparison with competing remediation methods.

SPECIFIC DATA REQUIREMENTS FOR TUNABLE HYBRID PLASMA	
INTERVIEW COMMENTS	**WORKSHOP COMMENTS**
Cost	
15. The niche for this technology should be defined in comparison with other technologies. What competes and why? Define potential conflicts with other technologies. How do costs compare? The high potential cost of this technology is a concern. Provide detail bases for all cost estimates.	15. THP is predicted to work best with concentrations from 1 to 10,000 ppm, and to have a cost advantage starting at the 100s ppm range for CCL_4. The cost advantage for TCE starts at the 1000s ppm range. GAC competes at higher concentrations. Break out capital vs. electricity cost based on concentration of CCl_4. Also distinguish capital vs. operating and maintenance costs. Define if this is a primary treatment technology or a secondary treatment technology.
Time -- Cost	
16. What time is required for the technology's testing and scale-up?	16. Define the scale up factors for the technology and the ultimate maximum processing rate. Provide operating ranges for the full-scale unit. Include the cost of scaling up and time to do this.
Public Perception	
17. There was concern about the complexity of the technology, the challenge of clearly explaining it, and the system's name, which has associations unrelated to this technology.	17. Clearly describe the technology and its performance in the report of the demonstration's results.
Worker Safety	
18. Demonstrate where the heat of the reaction goes, and whether there is a chance of explosion.	18. The air temperature goes up from 10° C to 100° C during reaction. Coolers can be added to the unit if they are necessary. If GAC is used, air may need to be cooled. Determine cooling requirements.
19. Assess worker safety issues related to the operation of the technology, including OSHA exposure levels, risks of changing out scrubber liquid and components, and exposure to electromagnetic releases.	19. Also address these requirements during failure scenarios.

SPECIFIC DATA REQUIREMENTS FOR TUNABLE HYBRID PLASMA	
INTERVIEW COMMENTS	**WORKSHOP COMMENTS**
Worker Safety – Public Health and Safety	
20. Failure control is an issue of concern. Test for catastrophic failure and define response. Include the scrubber operation. Examine the impact if the x-ray shielding fails. Provide and test examples of mechanisms to control failure.	20. Include failure mode testing in the test plan. Address these questions: What happens if the safeguards fail? Does anything "poison" the destruction process? What happens then?
21. Define the testing, monitoring, and oversight that will be used to control the demonstration.	21. In addition, test with VOC mixtures and check for energy use.
22. Define how heavy metals, radionuclides, or petroleum products in the waste stream will affect the technology's operation. Address the potential for explosion especially if other VOCs such as gasoline are present.	22. Also determine the effects of co-contaminants and daughter products (intermediates) on the system's efficiency. Determine if the technology's performance drops when multiple contaminants are present. What happens if the technology encounters an unanticipated contaminant spike?

SPECIFIC DATA REQUIREMENTS FOR TUNABLE HYBRID PLASMA	
INTERVIEW COMMENTS	**WORKSHOP COMMENTS**
Public Health and Safety – Regulatory Compliance – Environmental Impacts	
23. A major issue with tunable hybrid plasma is the question of air emissions. Some stakeholders equate the emission aspects of the technology with those of incineration, and want complete information on what is released to the environment. Some stakeholders believe tunable hybrid plasma will need to meet or do better than standards set for incinerator stack emissions and operations.	23. In the technology's demonstration evaluate tunable hybrid plasma in comparison to incineration. Specifically, determine if THP falls under the regulatory requirements for incineration. (Interim actions may face lower regulatory requirements than final action.) Determine tunable hybrid plasma's performance in comparison to GAC. Determine if the plasma reaction is breaking down co-contaminants and if so what they are breaking down into and at what temperatures. Define the technical requirements for and results of continuous monitoring of off gas. Fully characterize all off gas and byproducts from the system to the highest level of detection, including concentration and mass, before and after scrubber operation. Address other organic compounds that are of concern with incineration such as dioxins and dibenzofurans, and the full range of RCRA Appendix 9 constituents. Define the cost for and limits of this monitoring program.
Environmental Impacts	
24. Define the technology's overall energy consumption including operation of all three units that make up the treatment system, as a basis for comparison with competing remediation methods.	24. No further comment.
Environmental Impacts – Process Waste	
25. Determine alternatives to landfilling the resulting salt or brine solution. Reuse would be best.	25. Determine the amount of salt expected. Discuss transportation requirements for the disposal or reuse of salt. Determine if there is a market for the salt.

4.0 CONCLUSIONS

Stakeholder participation in evaluating two VOC-Arid ID soil remediation technologies has provided detailed data requirements for test plans and identified other issues and concerns. These requirements and issues can now be addressed in the technologies' demonstrations and in subsequent analyses. Discussions between the principal investigators and stakeholders improved technical understanding and clarified data requirements.

Stakeholders have committed to evaluating the technologies further once completion of the demonstrations makes data on their performance available. Stakeholders' evaluations will be included in technology acceptance reports, which DOE and private sector managers can use in making decisions about technology deployment.

APPENDIX A

FACT SHEETS AND
TECHNOLOGY INFORMATION PROFILES

- Passive soil vapor extraction
- Tunable hybrid plasma

FACT SHEET:
PASSIVE SOIL VAPOR EXTRACTION USING BOREHOLE FLUX

NEED:

Soil at many U.S. Department of Energy (DOE) and other sites throughout the country is contaminated with volatile organic compounds (VOCs). These contaminants include carbon tetrachloride, trichloroethylene (TCE), and gasoline. Exposure to these compounds above certain concentrations and over certain periods of time is hazardous to human health and the environment. Economical and efficient technologies are needed to clean up these contaminants.

DESCRIPTION:

Passive soil vapor extraction using borehole flux is an approach to remediation that takes advantage of changes in atmospheric pressure and wind to expedite the release of VOCs from subsurface soil. Low atmospheric pressure, which occurs in daily and seasonal patterns as well as with less predictable changes in weather such as the movement of fronts, allows the release of VOCs from contaminated soil. Technological enhancements of wells and boreholes as well as modifications to the soil surface can control, channel and direct the flow or "flux" of VOCs out of the soil. The passive soil vapor extraction method of remediation may have particular application to the edges of subsurface contamination or in situations where active extraction technologies have reached the point of diminishing returns in removing VOCs economically.

ADVANTAGES:

Passive soil vapor extraction using borehole flux offers the following advantages:

Its motive force is a naturally occurring phenomenon and as a result this approach to remediation requires relatively minimal energy and equipment to operate.

This approach is considerably less expensive than other cleanup technologies.

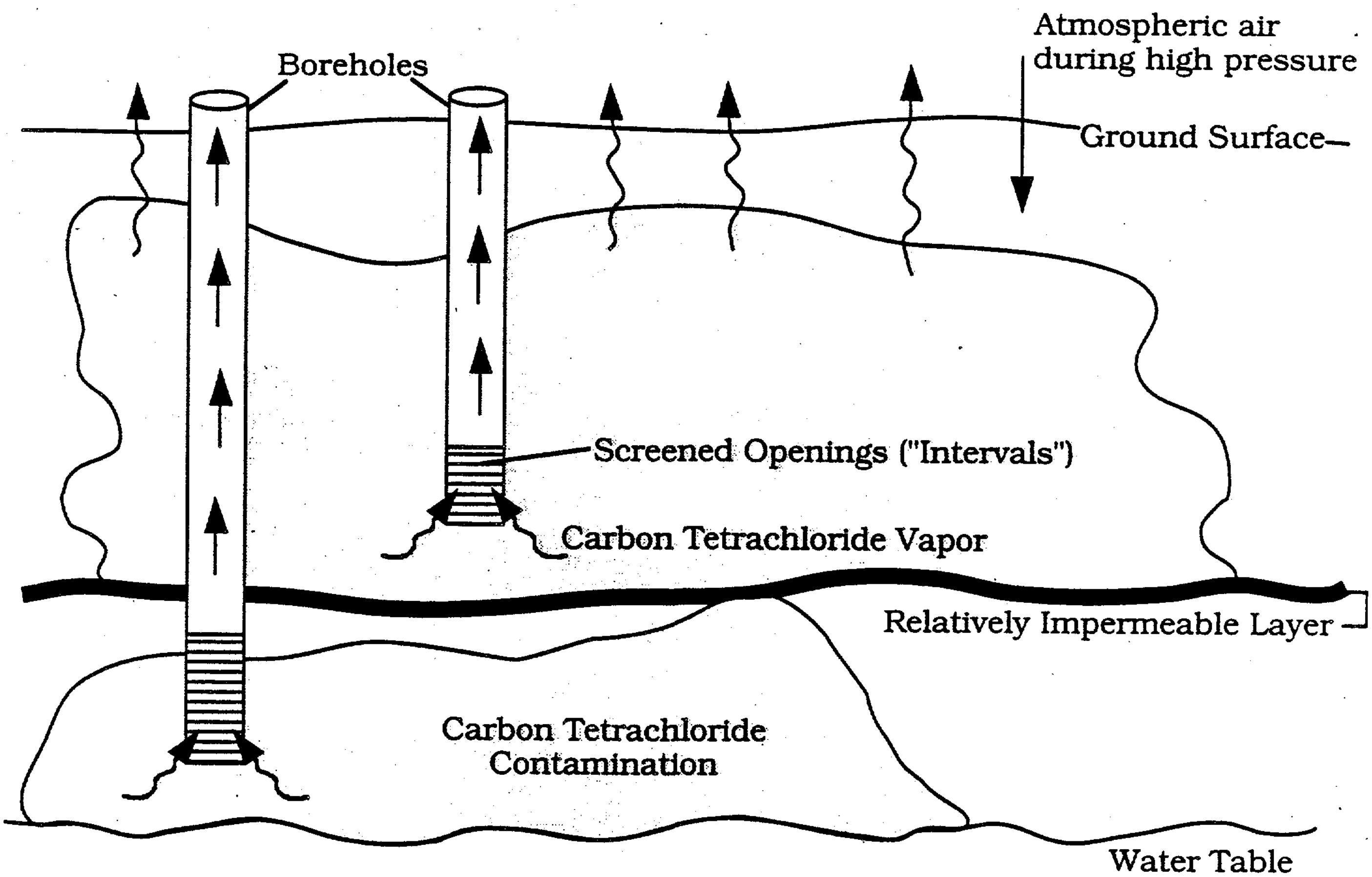
This method of remediation is well suited to addressing particular conditions of contamination such as those found at the edges of subsurface pollution or the contamination remaining after more active, energy and equipment-intensive technologies have been used.

Passive soil vapor extraction is easy to explain and understand, which may contribute to its acceptance and deployment.

CHALLENGES:

The principal initial objective for passive soil vapor extraction is to understand precisely the dynamics of the atmospherically driven VOC removal process, and where best to use it.

Passive Soil Vapor Extraction Using Borehole Flux



Technology Information Profile: Passive Soil Vapor Extraction

Full Name of Technology: Passive Soil Vapor Extraction (PSVE) Using Wells and Boreholes

Common Names of Technology: Barometric Pumping, Borehole Flux, PSVE

Principal Investigators:
Virginia J. Rohay, Westinghouse Hanford Company, 509-376-5507 (Technology coordinator)
Wayne Downs, Idaho National Engineering Laboratory, 208-526-0754
Joe Rossabi, Westinghouse Savannah River Company, 803-725-5220

Technology Category: Retrieval (removal from soil matrix)

Developed by: This technology is based on a natural phenomenon acting on subsurface soils. Subsurface soils are accessed through wells and boreholes, and the phenomenon is thereby enhanced. This remediation approach therefore, has not been invented. The natural phenomenon of air flow from the subsurface to the surface (and the reverse) due to atmospheric pressure change is being channeled and controlled during this demonstration. Some of the equipment used to enhance the natural air flow has been developed or improved by Principal Investigators.

1. **What is the need for the technology? (If this technology is part of a system of technologies, what is its role in the system and what is the need for the system?)**

This technology can be complementary to active soil vapor extraction. (Active soil vapor extraction uses non-renewable power to create a vacuum. That vacuum is applied to a subsurface soil area through a well or wells.) When the point of diminishing returns in removing a volatile contaminant is reached with active soil vapor extraction (because of mass transfer and energy cost limitations), there may still be significant contamination left in the ground. To remove the residual contamination efficiently, the removal process must be tailored to the physical and chemical limitations of the situation. Passive soil vapor extraction offers a lower cost method to remove the residual contamination.

2. What are the technology's objectives? (How does it satisfy the needs identified above?)

a. What are the objectives of this technology (for example, will this technology destroy VOCs in groundwater)?

The objective of the technology is to use fluctuations in natural atmospheric pressure and the gradients they produce between air at the surface and air in the subsurface to create a flow of contaminant-laden air from the subsurface to the surface.

b. What is the technology that is currently used for this application (baseline technology)?

The current baseline technology is active vapor extraction (commonly called Soil Vapor Extraction, or SVE). Active SVE uses vacuum systems which require power to operate. Twenty years or longer is often necessary to remediate a site to acceptable contaminant levels. The removal rate achieved by active SVE is initially high, followed by a rapid rate decline to a steady-state removal rate. This rate is determined by distribution of the contaminant in the substrate, and does not increase substantially with increased vacuum. When this condition is reached, the economic efficiency is low, due to power costs. The high cost of contaminant removal during this low removal rate time is difficult to justify, because there is only a marginal reduction of risk.

3. Process Description (Please describe the technology in terms that can be easily understood by interested members of the public. Include information on where the technology is applied -- in place or above ground -- what media the technology is used in -- soil, groundwater, air -- and what contaminants the technology targets.)

Fluctuations in atmospheric pressure occur due to weather and seasonal changes. These fluctuations create differential pressure between the atmosphere and air entrained in unsaturated subsurface soils. This approach to remediation uses these differences in air pressure. If the two zones are connected (by a well or borehole), air flow results. If the subsurface contains a volatile contaminant, this contaminant will be carried with the air flow to the surface. Since the driving force (atmospheric pressure fluctuations) of this removal process occurs naturally, this remediation method is inherently inexpensive. The key to its effective use is an understanding of the pressure relationship between the surface and subsurface at a given site under various atmospheric conditions. This knowledge can be used to accurately install pathways (e.g., vadose zone boreholes and wells) to effect contaminant removal. The flow through these pathways can then be controlled or enhanced to facilitate contaminant removal. The following table presents potential enhancements that will be part of the demonstration, and describes their expected effects.

PSVE Potential Enhancements

Enhancement	Projected Effect/Benefit
Wind-driven turbines on the off-gas stack	Amplify volume of air extracted by passively increasing the pressure differential in the well.
Venturi on off-gas stack	Amplify volume of air extracted by passively increasing the pressure differential in the well.
Windmill on the off-gas stack	Amplify volume of air extracted by passively increasing the pressure differential in the well.
One-way flow valve	Control air flow direction through borehole which will lead to contaminant plume migration control and increased extraction efficiency.
Hot air, stream, or nutrient injection	Contaminant plume migration control, increased extraction efficiency, or degradation of contaminants in place.
Off-gas treatment: Collection on GAC or other absorbent	Reduced VOC in off gas.
Off-gas treatment: Destruction by photocatalytic or energy process	Reduced VOC in off gas.
Interconnected or systemically controlled well networks	Control of contaminant plume migration rate and direction.

4. What is the status of the technology's development?

This remediation method is operational, and is being tested in basic configurations. In some cases, demonstration wells are open to the atmosphere; in other cases off-gas capture devices are being employed. In some cases, operational demonstration wells were existing and have been retrofitted for the demonstration; in other cases, new wells or borings have been installed. The dynamics of the process are being studied to understand and optimize removal, to minimize plume spread, and to effectively use the specific circumstances of given situations.

5. **Summary of Technology Advantages (compared with the baseline technology: Is it faster, better, cheaper, safer?)**

This remediation method is significantly less expensive than the baseline of active soil vapor extraction (ASVE). Once a low removal rate is reached with the baseline technology, then the passive removal technology is more cost effective. The demonstration will attempt to quantify advantages and limitations.

6. **Summary of Technology Limitations (compared with the baseline technology)**

The rate of VOC removal is slower than the baseline technology. The demonstration will quantify rates and costs.

7. **Major Technical Challenges for the Technology**

Understanding the dynamics of the atmospherically driven removal process requires measurement over a period of time sufficient to characterize the broad range of atmospheric changes and conditions that can occur. These measurements must then be understood and compared with contaminant removal rates. After gathering and understanding these measurements, the process must be designed, and the parameters of operation must be set and controlled, both in general and at a specific particular site.

8. **Technical Effectiveness: Performance Criteria**

a. **What contamination will remain after the technology is applied? (Will the mobility of the contamination be reduced? Will the volume be reduced? Will the contaminant be less toxic? This criterion applies primarily to retrieval treatment technologies.)**

PSVE is a removal method. When operated for a sufficient period of time and under the proper conditions, residual VOC contamination in the vadose zone will be appreciably reduced. The mobility of VOC contamination within the soil will be steadily reduced over the course of operating the technology, because removal reduces concentration and volume of VOCs present in the subsurface environment. Concentrations of VOCs in the groundwater beneath the area treated by PSVE will also be reduced, since contamination in the vadose zone contributes to groundwater contamination.

b. **What process waste (secondary waste) does the technology produce? (Is the secondary waste mobile? What is its volume? What hazards are associated with the secondary waste? Can it be recycled?)**

Contaminant-laden air is removed from the subsurface and brought to the surface. If this air is contained (for example on GAC) or treated, then secondary waste is created. Details of off-gas treatment and management options for any secondary wastes will be included in the demonstration and in subsequent analysis of results.

If the off gas is not contained or treated, it constitutes the secondary waste from PSVE. The concentration and total amount of VOC in this waste stream will be measured as part of the demonstration. Potential hazards will be evaluated.

c. Describe the treatment or storage needed for the secondary waste and its availability.

The contaminant is removed from the subsurface and introduced to the air at the surface, where it can be treated by active treatment methods (e.g. thermal, free-radical, photolytic, high energy, carbon adsorption), or allowed to disperse and react in natural atmospheric processes. Dispersion and solar and atmospheric processes can break down the contaminants. The off-gas management method selected depends on the amount of contaminant removed, the rate of removal, applicable regulations, and the particular contaminant.

d. Describe the requirements for decontamination or decommissioning of equipment.

The wells used for PSVE can be left in place and filled with grout. Decontamination and decommissioning of wells and boreholes is achievable.

e. How must the secondary waste be disposed? Is disposal available?

The disposal of process off gas, if it is not captured, depends on regulatory limits regarding the release of volatile contaminants to the atmosphere. Treatment methods for off-gas may produce secondary waste. Disposal and treatment methods for spent GAC and other off-gas treatment residuals are generally available.

f. What future cleanup options are precluded by this technology? (Applies primarily to treatment technologies)

No future cleanups are precluded by this technology.

g. How reliable is the technology? (Please address potential breakdowns, effectiveness, and sensitivity to operating conditions).

This technology is very reliable. Because the motive force to extract contaminants is naturally occurring, the only moving parts are those associated with control valves, recording equipment (if used), and off-gas treatment . Low-power solid state electronics may be used to control and operate valves and recording equipment. This technology is expected to operate effectively for years with no intervention.

h. If the technology fails, how are the effects of the failure controlled?

Electronic and mechanical control systems are being used in the demonstration. One system has a "watchdog" timer that can reset control in the event of electric disturbances. One-way valves can be set to close in the event of power or other system failures. Because the flow of contaminant-laden air is relatively slow, no safety hazards are anticipated in the event of a failure.

i. How easy is the technology to use? (Please describe the level of skills and training required to use the technology.)

Operational control of the system is automated and the motive force is naturally occurring. Therefore, the system is very easy to operate.

j. What infrastructure (buildings, power sources, personnel) is needed to support the technology?

Because of the passive nature of the process limited infrastructure is required. Examples include: a rechargeable battery or a solar panel to power the control and valve system and an enclosure for recording devices. Staff is required to change out the off-gas control system components, and to retrieve collected data.

k. How versatile is the technology? (That is, can it be applied to other types of contamination, in other media, or at other locations?)

The technology can be applied at a variety of sites that have volatile contaminants in the unsaturated zone. The system can also be used to enhance removal or biodegradation by supplying the subsurface with air, heat, or nutrients. In this mode, the technology can be applied to any contaminant that is volatile or biodegradable.

l. Describe the technology's compatibility with other elements of the system. (Please include a general description of the system.)

This technology can be used in conjunction with any other treatment or removal strategy. The volatilization of VOCs from the soil, either through soil pore spaces or other avenues (wells or boreholes), occurs naturally under common atmospheric conditions. Pressure gradients causing contaminant-laden air to flow out of wells have even been observed during active vapor extraction.

m. Can the technology be procured "off the shelf"? (Is it an innovative use of an existing technology?) Which components are available and which must be developed?

The basic technology components are available off the shelf. The process can be used in its most basic mode without valves or off-gas treatment (open venting). In both the enhanced and un-enhanced mode, installation and completion components are readily available.

n. How difficult is the technology equipment to maintain? (Please include information on frequency as well as ease of maintenance. Also describe the level of skill or training required to maintain the technology.)

The technology should require no maintenance besides periodic inspections of any control and recording equipment (monthly initially, then yearly). This maintenance will not be necessary if the most basic form of the remediation method is used with no control or recording equipment or off-gas capture systems.

o. What equipment safety measures (such as automatic shutdown devices) are needed and in place to protect workers and the public?

In the valved system, the controller hardware and software can be programmed to close the valves on the wells, should that be necessary. For non-valved wells, no special safety measures are planned.

p. Describe the technology's ability to function as intended. (Does the technology work as intended? If not, describe functional problems.)

The process has been demonstrated in several basic configurations and functions as intended. The enhancements to the process, such as valving and well network controls, are being demonstrated to determine their effectiveness.

q. What are the scale-up issues and how are they being addressed?

Scale-up issues include determining the mass of VOCs removed by, and the zone of influence of, individual wells. This is dependent on site features. Tests are being conducted to understand and define these issues and determine how to appropriately scale up use of PSVE.

9. Cost (Please include assumptions on which you base your estimates.)

a. What is the start-up cost of the technology (including development costs, procurement and construction, permitting, and other costs necessary to begin operation)?

Installation and completion for a 100' deep well can cost between $500 and $2,000, depending on site conditions and the drilling equipment used.

Control equipment is generally inexpensive and is expected to be less than $100 per well (or borehole). The cost of off-gas treatment equipment varies.

b. What are the operations and maintenance costs of the technology?

Excluding off-gas treatment systems, it is anticipated that the operations and maintenance cost will be extremely low. The demonstration will quantify these costs.

c. What are the life cycle costs of the technology (including facility capital cost; startup, operation, and maintenance; decommissioning, regulatory, or institutional oversight; and future liability)?

With an expected life of at least 30 years, the life cycle cost per well is anticipated to be very low. The demonstration will collect cost data to support determination of life cycle costs.

10. Time

a. When will the technology be available for commercial use or use at other sites?

The technology is expected to be available for commercial use by late 1995.

b. What is the speed or rate of the technology? (Please use metrics)

The rate of the technology is dependent on the particular site but has been measured to date ranging from 0.1 to 2 kilograms of VOC removed per day per borehole.

c. At the speed or rate identified in 10(b), what is the total time required for the technology to achieve its objectives?

The time required to achieve acceptable conditions is dependent on the number of wells employed, the nature and concentration of contaminants, and the site. The demonstration will attempt to quantify the time required for satisfactory completion of remedial action over a range of conditions.

11. Environmental Safety and Health: Worker Safety

a. What potential is there for workers to be exposed to hazardous materials and/or other hazards? Describe those materials and hazards.

Worker exposure risks are expected to be minimal because the well control systems (if used) are automated, and power sources are renewable. Well air flow is low, installation exposures are well understood, and releases from the well heads are being monitored during the demonstration.

b. What are the physical requirements for workers?

There are no special physical requirements for workers.

c. How many people are required to operate the technology?

None for routine operation, because it is either a natural or an automated system and once it is installed it works by itself. Workers are required to change out off-gas control devices (if used) and to retrieve data.

12. Environmental Safety and Health: Public Health and Safety

a. What is the technology's history of accidents? (Has there been a history of accidents and, if so, what was the nature of the accidents.)

No accidents have been experienced or are anticipated due to the passive nature of the extraction and the low flux rate of contaminated air out of the wells.

b. Does this technology produce routine releases of contaminants?

Yes, the technology produces routine releases of contaminants at low flow rates. These releases can be captured and treated.

c. Are there potential impacts from transportation of equipment, samples, waste, or other materials associated with the technology?

There are no transportation issues in most cases. The only exception is transportation off-site of spent off-gas treatment materials.

13. Environmental Impacts

a. What impact will this technology have on the ecology of the area (for example, wildlife, vegetation, air, water, soil, or people)?

Unknown at this time. The demonstration will monitor for potential effects.

b. What aesthetic impacts does the technology have (for example, visual impacts, noise)?

This technology has a very low profile. The technology can be designed so that minimal adverse aesthetic impacts are produced and so that the equipment at each well head is small and quiet.

c. What natural resources are used in the technology's development, manufacture, or operation? (Address energy resources in 13[d].)

The technology is driven by natural atmospheric pressure fluctuations and the control and measurement equipment (if used) can be driven by solar power, wind, or battery.

d. What are the technology's energy requirements? (Use metrics)

The basic technology, without control systems or off-gas treatment, uses natural atmospheric pressure as its only energy.

14. Socio-Political Interests: Public Perception

a. What is the reputation of the technology's developer and/or user? (Principal investigators: this is a point of discussion for stakeholders; do not answer.)

b. How familiar is the technology to the public?

The public is believed to be generally unfamiliar with this technology.

c. How easy is the technology to explain to the public?

This process and the natural phenomenon driving it are very easy to explain and understand.

15. Socio-Political Interests: Tribal Rights/Future Land Use

a. How will the technology affect future unrestricted use of land and water?

No negative effects are expected. Return of subsurface soils to pristine conditions would allow unrestricted future land use. Removal or abandonment of wells and boreholes may be required.

16. Socio-Economic Interests

a. What are the potential economic impacts of this technology? (For example, what are the effects on the economic base of the community? Are there infrastructure requirements?)

Cleanup can be achieved at a much lower cost with this technology than is presently achievable.

b. How will the technology affect labor force demands?

Little labor is required for this technology.

17. Regulatory Objectives

a. Describe the technology's compatibility with cleanup milestones.

This technology can achieve similar cleanup residual levels to the baseline technology (ASVE) at a much lower cost. The demonstration will attempt to determine the time required for this technology to achieve acceptable results.

b. How familiar are regulators with this or a similar technology?

Most regulators are unfamiliar with the technology, but it is easy to explain.

c. What is the technology's regulatory track record?

Regulators have been favorable to this technology on a demonstration basis at the Hanford Site, Idaho National Engineering Laboratory, and the Savannah River Site. However, the regulatory infrastructure and method of dealing with this technology on a fully deployed basis is currently unknown.

d. How does the technology comply with applicable regulations?

This technology reduces the subsurface concentration and mass of VOC contaminants. Air quality regulations and this technology's ability to comply with those will be analyzed during and after the demonstration.

18. Industrial Partnerships

a. What is the name of the industrial partner?

No individual partner is identified at this time.

b. What is the rationale for this partnership?

NA

c. What is the contract mechanism?

NA

d. Are there other potential partners?

There are believed to be potential partners because this is a low cost technology that is accessible to small and large businesses.

e. Are there potential international partners?

There are believed to be potential international partners because this is a low cost technology that is applicable to volatile contamination found worldwide.

19. Intellectual Property

a. Who owns the patent for this technology?

Patents are pending for various enhancements. The PSVE process is natural and cannot be patented.

b. Are there other patent owners?

No other patent owners are known.

c. Is there a patent number for this technology?

Patent Number SRS-93-217 (This patent number is for a specific enhancement used at the Savannah River demonstration site)

20. Cost Sharing

a. What is the background of this technology? (Where did the idea come from? Who else is doing similar work? What have the results been to date? What is the most significant competitor to this technology?)

The subsurface to surface flow of air induced by atmospheric pressure changes has been observed for a long time. The first reference found in the literature was 1906 but it is doubtful that this is the first observation. A PSVE team has been formed as a result of the interest by the Arid Sites Integrated Demonstration Program consisting of researchers from Westinghouse Hanford Company (WHC), Pacific Northwest Laboratory (PNL), Lawrence Livermore National Laboratory (LLNL), Los Alamos National Laboratory (LANL), Idaho National Environmental Laboratory (INEL), U.S. Environmental Protection Agency (EPA), Westinghouse Savannah River Company (WSRC), and industry partners. WHC and INEL have incorporated the technology into their environmental restoration activities (EM-40) and WSRC is also planning to implement it in their EM-40 activities.

21. References

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FACT SHEET: TUNABLE HYBRID PLASMA

NEED:

The soil at a number of U.S. Department of Energy (DOE) sites is contaminated with volatile organic compounds (VOCs). These compounds include carbon tetrachloride, trichloroethylene (TCE) and gasoline. Exposure to these compounds above certain concentrations and over certain periods of time is hazardous to human health and the environment. Economical and efficient technologies are needed to clean up these contaminants.

DESCRIPTION:

Tunable hybrid plasma is an innovative use of existing technology to treat VOCs specifically carbon tetrachloride and TCE. Operating above ground, the technology uses a moderate energy electron beam to create energy conditions within a flow of contaminated air that lead to the breaking down of carbon tetrachloride and TCE molecules. The byproducts of the interaction of electrons associated with the electron beam and carbon tetrachloride are hydrochloric acid, chlorine gas, and carbon dioxide. The carbon dioxide can be released into the atmosphere and the other byproducts are further broken down in a wet scrubber containing a caustic such as lye (sodium hydroxide) to produce carbon dioxide and non-toxic, chlorine-based salt. The salt can be disposed of in a solid waste landfill.

ADVANTAGES:

Tunable hybrid plasma offers the following advantages:

The technology provides on-site treatment of toxic substances in gas streams. It achieves high destruction and removal efficiency. In laboratory tests, the technology reduced carbon tetrachloride concentrations from 760 ppm to 0.6 ppm with a 99.97 % removal efficiency.

It eliminates contaminants from high-volume waste gas streams with end products of small volumes of non-toxic precipitates and gases.

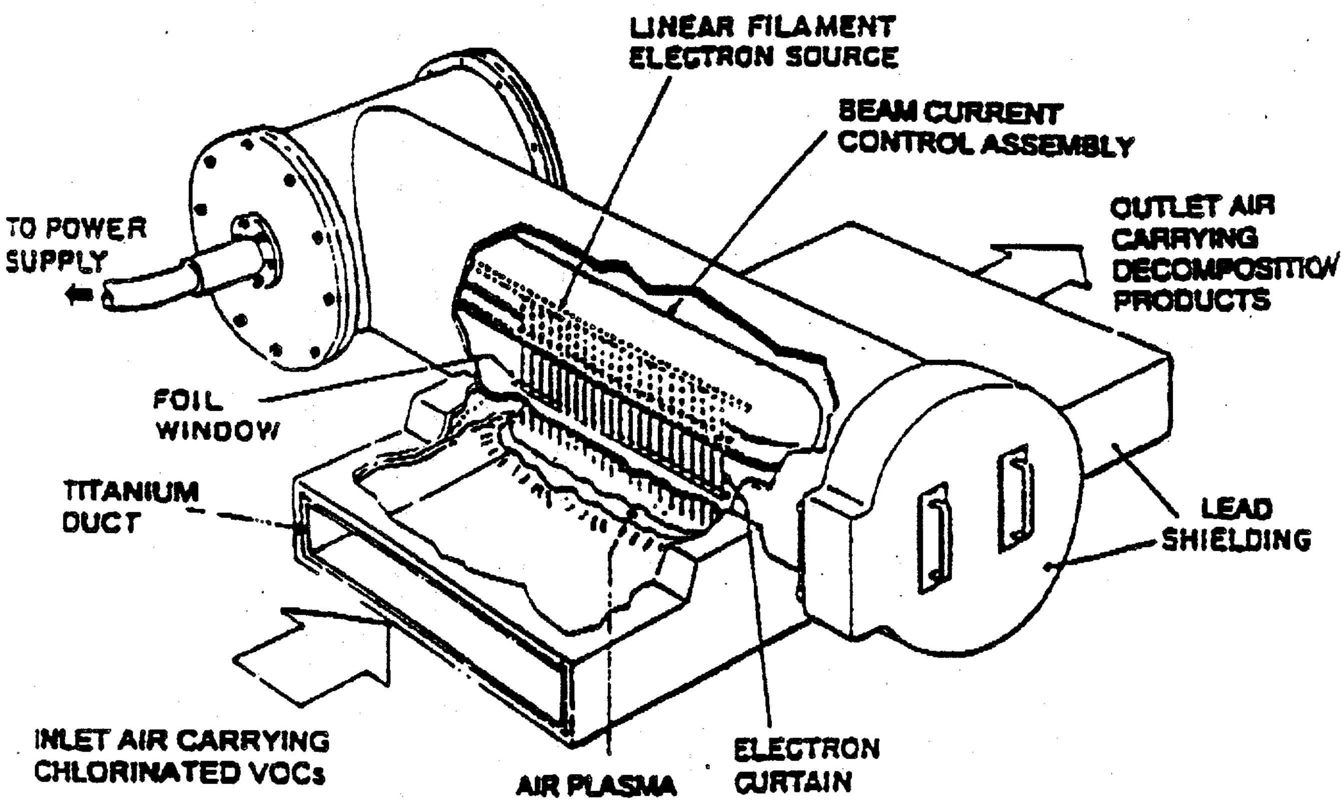
The technology promises to operate economically. The objective is to treat one pound of carbon tetrachloride for about $4. The costs for destroying TCE are lower, approximately 40 cents a pound.

It is capable of treating a range of contaminants with a wide range of concentrations.

The technology is portable and is compatible with a range of extraction methods.

CHALLENGES:

A major technical objective for this technology is to remove carbon tetrachloride and similar hazardous compounds from waste gas streams containing dilute concentrations of toxic gases. Another principal objective is to apply a full-scale system of the technology in the field, and precisely quantify the technology's capabilities. The technology's system must include the electron beam apparatus, scrubber, and a control system in order to be fully automated and to be cost competitive with other remediation methods that carry out the same function. A technical challenge facing the technology is to avoid producing toxic byproducts.



PLASMA REACTOR CUTAWAY DIAGRAM

Technology Information Profile
Tunable Hybrid Plasma

Full Name of the Technology: Tunable Hybrid Plasma

Principal Investigators: Richard M. Patrick, Massachusetts Institute of Technology
(617) 253-8790
Daniel R. Cohn, Massachusetts Institute of Technology
(617) 253-5524
Leslie Bromberg, Massachusetts Institute of Technology
(617) 253-6919

Technology Category: Treatment

Developed by: Massachusetts Institute of Technology (MIT)

1. What is the need for the technology? (If this technology is part of a system of technologies, what is its role in the system, and what is the need for the system?)

Most Department of Energy (DOE) sites are contaminated with volatile organic compounds (VOCs). Specifically, there are 220 sites in arid environments with VOC contamination. Efficient, economical technologies are needed to treat this contamination once it has been removed from the ground.

The Tunable Hybrid Plasma technology provides important improvements over current baseline technology in efficiency, cost, versatility, and availability of on-site treatment for remediating VOC contamination.

2. What are the technology's objectives? (How does it satisfy the needs identified above?)

a. What are the objectives of this technology? (for example, will this technology destroy VOCs in groundwater?)

The objective of this technology is to provide, through the use of an electron beam process, the versatile, on-site treatment of gaseous toxic and hazardous compounds, particularly carbon tetrachloride and trichloroethylene, with minimal creation of undesirable byproducts (secondary waste), and minimal need for additional treatment. Tunable Hybrid Plasma destroys vapor phase VOCs including those in air streams generated by stripping VOCs from groundwater.

b. What is the technology that is currently used for this application (baseline technology)?

Soil vapor extraction is the baseline technology for remediating contamination in vadose zone soils. The baseline treatment technology for extracted VOCs is adsorption onto granulated activated carbon (GAC) with off-site regeneration of GAC.

3. Process Description. (Please describe the technology in terms that can be easily understood by interested members of the public. Include information on where the technology is applied - in place or above ground - what media the technology is used in - soil, groundwater, air - and what contaminants the technology targets.)

The technology is applied above ground. A moderate-energy electron beam (100-300 keV) is directed into a flow of air containing organic contaminants. An electron beam consists of electrons moving at high speed initially through gas such as air. The electron beam is produced by applying electricity to a linear filament electron source in a vacuum chamber. Electrons thus generated pass through a titanium foil "window." The titanium foil allows the electrons but not the air to pass into the vacuum.

Electron beams are in widespread commercial use, particularly in the paper industry. Specifically, they are used in the lamination process that makes cereal boxes. The titanium duct that directs the flow of electrons, as well as the electron generating apparatus, are shielded with lead. The entire apparatus is contained in and transported on a tractor trailer.

The primary electrons that pass through the titanium foil, with energies approximately equal to 200,000 eV, create several thousand secondary electrons. These secondary electrons have lower energy levels than the primary electrons that come from the filament. The major reason for the energy transfer is the impact of the primary electrons on the orbiting electrons of the molecules in the carrier gas (air). Those "collisions" create electron/ion pairs (plasma).

The secondary electrons, which are much greater in number than the primary electrons, rapidly cool to room temperature due to collisions in the air. The secondary electrons attach to the halogenated hydrocarbon molecules in the waste gas stream causing the VOC molecules to dissociate. This occurs preferentially because of the way the molecules are arranged. Technically, the "attachment cross-sections" of molecules like carbon tetrachloride are extremely large, allowing for ready attachment of the secondary electrons. This accounts for the preferential destruction of carbon tetrachloride.

A soil vapor extraction system makes contaminants entrained in the air stream available for destruction by the electron beam. Tunable Hybrid Plasma is compatible with a number of soil gas retrieval technologies.

The end products of this process, due to dissociative attachment, are carbon dioxide, chlorine gas, water, oxygen, nitrogen, and hydrochloric acid. The products of the reaction of carbon tetrachloride destruction are passed through the liquid of a conventional wet scrubber, which removes soluble contaminants. Chlorine gas and hydrochloric acid dissolve in the aqueous solution. The scrubber's solution can contain a caustic such as sodium hydroxide (lye). The caustic solution is preferred because it produces salt (NaCl) after scrubbing out the chlorine, which can be easily disposed of. The gases that do not dissolve in the aqueous solution (carbon dioxide, oxygen and nitrogen) pass through and are released into the atmosphere.

4. What is the status of the technology's development?

Tunable Hybrid Plasma is a new use of existing technology. The technology has been demonstrated in the MIT laboratory. Carbon tetrachloride has been converted to chlorine gas and hydrochloric acid, which have been dissolved in an aqueous solution of sodium hydroxide and converted to salt.

The electron beam unit for the field demonstration at the Hanford Site in Washington state has been delivered to MIT. The field test system is fully operational and has been operated autonomously with a personal computer and modem.

5. Summarize the advantages of the technology (compared with the baseline technology - Is it faster, better, cheaper, safer?)

The advantages of this technology include:

- It provides on-site treatment of toxic substances in gas stream with high destruction and removal efficiency.
- It eliminates contaminants from high-volume waste gas streams with end products of small volumes of solid precipitates and non-toxic gases.
- It operates at a relatively low cost. The objective is to treat one pound of carbon tetrachloride for about $4. The costs for destroying trichloroethylene are lower, approximately 40 cents per pound.
- It entails minimum pre- and post-treatment requirements.
- It has the capability to treat gases from solid waste treatment systems, resulting in non-toxic emissions and small volumes of solid non-toxic residues.
- It offers versatile operation to process a wide range of contaminants and concentrations.

- It has the capability to operate without onsite personnel, requiring only periodic maintenance.

- It has the capability of destroying VOCs over a very wide range of initial concentrations, while maintainig high efficiency and low cost.

6. Summary of Technology Limitations (compared with the baseline technology)

The technology's effectiveness is limited at very high concentrations of contaminants where other processes become cost competitive.

7. Major Technical Challenges

The major technical challenge for this technology is to remove carbon tetrachloride and similar toxic compounds from waste gas streams containing dilute concentrations of toxic gases. The system must include the electron beam apparatus, scrubber, and a control system in order to be fully automated, and be cost competitive with other methods that carry out the same function.

8. Technical Effectiveness: Performance Criteria

a. What contamination will remain after the technology is applied? (Will the mobility of the contamination be reduced? Will the volume be reduced? Will the contaminant be less toxic? This criterion applies primarily to retrieval treatment technologies.)

A field test system has been assembled and tested at MIT. It has been used to demonstrate the reduction in carbon tetrachloride concentration from 760 ppm to 0.6 ppm with a 99.97% removal efficiency.

Trichloroethylene (TCE) has been tested with the Tunable Hybrid Plasma technology. The destruction of TCE requires less than 10% of the energy needed to destroy carbon tetrachloride. The byproducts of the decomposition of TCE can be dissolved in an aqueous solution containing sodium hydroxide. The end product is a non-toxic sodium salt. The air stream need not have a low vapor pressure of water, eliminating the necessity of the air stream dryer required for the destruction of carbon tetrachloride.

Laboratory tests indicate that the products of the electron beam dissociation of carbon tetrachloride can be dissolved in an aqueous solution. This solution preferably contains a base such as sodium hydroxide that combines with dissolved hydrochloric acid and chlorine to form sodium chloride (salt). The remaining byproduct, carbon dioxide, can be released to the atmosphere. The salt is a non-hazardous waste that can be disposed of in a landfill if reduced to a solid. Brine solutions may be amenable to reuse.

b. **What process waste (secondary waste) does the technology produce? (Is the secondary waste mobile? What is its volume? What hazards are associated with the secondary waste? Can it be recycled?)**

The initial action of the technology produces hydrochloric acid, chlorine gas, and carbon dioxide. Subsequent actions of the technology - scrubbing in a caustic aqueous solution - reduces the hydrochloric acid to sodium chloride (salt).

c. **Describe the treatment or storage needed for secondary waste and its availability.**

After treatment in the scrubber, limited further treatment of the secondary waste (salt cake or brine) is required. Management is commonly available.

d. **Describe the requirements for decontamination or decommissioning of equipment.**

The technology's equipment requires no decontamination and only standard decommissioning.

e. **How must secondary waste be disposed? Is disposal available?**

This technology decomposes carbon tetrachloride into non-toxic carbon dioxide and salt (such as NaCl). The salt may be disposed of as salt brine or evaporated and disposed as salt cake in a solid waste disposal facility. Disposal for these materials is available.

f. **What future cleanup options are precluded by this technology?**

The technology precludes no future cleanup options.

g. **How reliable is the technology? (Please address potential breakdowns, effectiveness, and sensitivity to operating conditions.)**

All of the principal components of the Tunable Hybrid Plasma system are standard items that have been manufactured for industrial use for several years. These include the major component, the electron beam, manufactured by Energy Systems, Inc. , Wilmington, Massachusetts. More than 100 nearly identical units have been built and sold over the last 20 years. The system's air dryer and scrubber are standard catalogue items that have been used in industry for many years.

Some of potential breakdowns are vacuum failure in the electron beam, clogging of the scrubber, failure of the computer control system, and failure of the sensors monitoring the system.

h. If the technology fails, how are the effects of the failure controlled?

All failures are controlled by turning off the electron beam, which is done electronically. A computer will monitor the technology's functions and will be used to restart the system or aid in diagnosing the failure. The following will be monitored:

- VOC levels in the extracted air stream
- The air stream coming out of the apparatus
- Levels of halogens (chlorine type elements) inside the trailer
- Levels of hydrochloric acid going into the scrubber
- Radiation levels outside the lead shielding of the linear filament electron source

"Interlocks," electronic controls connecting monitors and shutdown devices, will automatically stop the electron beam if monitors record levels above programmed limits.

i. How easy is the technology to use? (Please describe the level of skills and training required to use the technology.)

A skilled technician is required for startup procedures for operation of the technology. Knowledge of the technology's monitoring and safety systems are required. Normal operation is fully automatic. System setup and startup require knowledge of personal computer operation using Windows.

j. What infrastructure (buildings, power sources, personnel) is needed to support the technology?

Infrastructure requirements include electric power and make-up water for the scrubber. The unit will be contained in a 40-foot trailer; no other utilities will be necessary.

k. How versatile is the technology? (That is, can it be applied to other types of contamination, in other media, or at other locations?)

The technology can be applied to a wide variation of VOC concentrations - from 10 ppm to 2000 ppm. It has been demonstrated to destroy carbon tetrachloride, chloroform, and trichloroethylene. Laboratory tests are planned to determine how many other VOC contaminants the Tunable Hybrid Plasma technology can destroy.

l. Describe the technology's compatibility with other elements of the system. (Please include a general description of the system that the technology is part of.)

Tunable Hybrid Plasma is a treatment technology. It is compatible with all pumping systems and VOC air stripping technology that make contaminated air streams available for treatment.

m. Can the technology be procured "off-the-shelf?" (Is it an innovative use of an existing technology?) Which components are available and which must be developed?

All of the components are standard items manufactured in quantity. Tunable Hybrid Plasma is an innovative use of existing technology.

n. How difficult is the technology equipment to maintain? (Please include information on frequency as well as ease of maintenance. Also describe the level of skill or training required to maintain the technology.)

A skilled technician is required to perform such tasks as periodically maintaining the scrubber. All of the technology's components have been developed over a period of 20 years. Spare parts for all components will be available onsite, for example, a spare electron beam foil and foil holder.

o. What equipment safety measures (such as automatic shutdown devices) are needed and in place to protect workers and the public?

The Tunable Hybrid Plasma system includes two separate and redundant gas monitoring systems to monitor inlet, outlet and ambient air. The electron beam is completely interlocked, with safety monitoring devices that will shut down the technology if they detect unacceptably high levels of chemical contamination or radiation. The electron generating filament creates small amounts of x-rays and are shielded with lead to block exposure of workers or the public. The technology meets all Occupational Safety and Health Administration (OSHA) standards.

p. Describe the technology's ability to function as intended. (Does the technology work as intended? If not, describe functional problems.)

The technology's function has been successfully demonstrated several times including full operation of the field test system.

q. What are the scale-up issues and how are they being addressed?

Cost analyses for field units are based on standard, large-scale, off-the-shelf components. This allows the prediction of performance and cost for units with 100 to 1, 000 times more capacity.

9. Cost (Please include assumptions on which you base your estimates.)

a. What is the start-up cost of the technology (including development costs, procurement and construction, permitting, and other costs necessary to begin operation)?

Only projected cost information is available at this time . Additional information concerning costs will be available in October 1995. A full-scale Tunable Hybrid Plasma system (175 kW electron beam that directs 100 kW into the contaminated gas stream) costs about $1 million. This cost includes the electron beam and support equipment. The system is projected to treat about ten pounds of carbon tetrachloride per hour and operate 90% of the time. Hence, the system should be able to treat about 78,000 pounds of carbon tetrachloride a year. For a field unit, the objective is to treat one pound of carbon tetrachloride for about $4. The cost of treating trichloroethylene is estimated to be less than 40 cents per pound.

b. What are the operations and maintenance cost of the technology?

Information about operation and maintenance costs will be available in October 1995.

c. What are the life cycle costs of the technology (including facility capital cost, startup, operation, and maintenance; decommissioning, regulatory, or institutional oversight; and future liability)?

These costs are not known at this time. Information will be available in October 1995.

10. Time

a. When will the technology be available for commercial use at other sites?

The goal is to have the technology available for commercial use by the fourth quarter of 1996.

b. What is the speed or rate of the technology?

The field unit to be used in the demonstration is capable of processing from one to 20 cubic feet per minute of contaminated air. Based on this rate, large scale units will be capable of processing 50 cubic meters per minute.

c. At the speed or rate identified in 10b, what is the total time required for the technology to achieve its objective?

The total time required for the technology to achieve its objective will depend on the extent and concentration of contamination at the site of the technology's use.

11. Environmental Safety and Health: Worker Safety

a. What potential is there for workers to be exposed to hazardous materials and/or other hazards? Describe those materials and hazards.

All hazards, including radiation and emissions, are continuously monitored. Monitors are connected to electronic interlocks and a computer, which will shut down the apparatus if contaminants or x-ray levels exceed programmed limits. The linear filament electron source and the beam current control assembly are shielded with lead. Standard precautions for handling corrosive solutions need to be followed in operating and maintaining the scrubber.

b. What are the physical requirements for workers?

There are no special physical requirements for workers.

c. How many people are required to operate the technology?

Once started, the technology's operation is fully automatic, by telephone connection. A trained technician will be required to maintain the scrubber and to periodically observe other components of the system.

d. Public Health and Safety

What is the technology's history of accidents? (Has there been a history of accidents, and if so, what was the nature of the accidents?)

The technology has no history of accidents.

e. Does this technology produce routine releases of contaminants?

If the scrubber is operating properly no contaminants are released.

f. Are there potential impacts from transportation of equipment, samples, waste, or other materials associated with the technology?

The technology's end-product - non-toxic, chlorine based salt brine or salt cake - will have to be transported for final disposal in a solid waste landfill.

13. Environmental Impacts

a. What impacts will this technology have on the ecology of the area (for example, wildlife, vegetation, air, water, soil or people)?

The use of this technology will have no impact on the ecology of the area where it is used, other than the transportation of its end product - salt brine or salt cake - to a permitted solid waste disposal facility.

b. What aesthetic impacts does this technology have (for example, visual impacts, noise)?

The technology will be transported in and operate from inside a 40-foot truck trailer which is moved after use of the technology.

c. What natural resources are used in the technology's development, manufacture or operation?

Metals, fossil fuels, and electricity are used in the technology's development and manufacture. Water and electric power are used in the technology's operation.

d. What are the technology's energy requirements?

A prototype unit of the technology uses 15 kVA. Large units use 200 kVA.

14. Socio-political Interests: Public Perception

a. What is the reputation of the technology's developer and user?

MIT and Metcalf & Eddy are renowned institutions in the area of process development and commercialization.

b. How familiar is the technology to the public?

The public is probably unfamiliar with this technology.

c. How easy is the technology to explain to the public?

Explaining the technology to the public requires the following:

- a clear description of the creation and operation of a moderate energy electron beam
- a clear description of the interaction of the electrons in the electron beam with the VOCs entrained in the contaminated air stream

- an explanation of the safety measures taken to shield the electron beam generating components of the technology and to prevent fugitive emissions of VOCs,
- an explanation of the measures taken to reduce secondary wastes to non-toxic end-products and to safely dispose of these end-products.

15. Socio-political Interests: Tribal Rights/ Future Land Use

a. How will the technology affect future unrestricted use of land and water.

The technology will promote the future unrestricted use of land and water by destroying VOCs in the soils of contaminated sites.

16. Socio-Economic Interests

a. What are the potential economic impacts of this technology? (For example, what are the effects on the economic base of the community? Are there infrastructure requirements?)

The technology will have minimal economic impact on the communities where it used because it has no special requirements for infrastructure, requires limited staff to operate, and is portable.

b. How will the technology affect labor force demands?

The technology will place very few demands on the labor force of the communities where it is used.

17. Regulatory Objectives

a. Describe the technology's compatibility with cleanup milestones.

The goal is to make the technology available in two years for multi-site use to promote the achievement of cleanup milestones.

b. How familiar are regulators with this or a similar technology?

Because Tunable Hybrid Plasma is a new use of technology, regulators are generally unfamiliar with it.

c. What is the technology's regulatory track record?

The technology has yet to develop a regulatory track record.

d. How does the technology comply with applicable regulations?

The technology meets all applicable regulations for air emissions, byproduct disposal and radiation levels.

18. Industrial Partnerships

a. What is the name of the industrial partner?

Negotiations to establish an industrial partner are under way at this time.

b. What is the rationale for this partnership?

The selection criterion for an industrial partner for this technology is a large company involved solely in environmental cleanup to license MIT patents in the area of plasma technology.

c. What is the contract mechanism?

The contract mechanism is patent licensing.

d. Are there other potential partners?

Yes, but none are being pursued at this time.

e. Are there potential international partners?

Yes, but no negotiations are under way at this time. International partners will be sought in partnership with the licensee.

19. Intellectual Property

a. Who owns the patent for this technology?

The patent is held by the Massachusetts Institute of Technology as a subcontractor to Battelle Pacific Northwest Laboratories, a contractor to the United States Department of Energy.

b. Are there other patent owners?

No.

c. **Is there a patent number for this technology?**

Yes. The patent number is U.S. 5, 256, 854 - Tunable Plasma Method and Apparatus Using Radio Frequency Heating and Electron Beam Irradiation. In addition, MIT has submitted one other patent application.

20. Cost Sharing

N/A

21. What is the background of this technology? (Where did the idea come from? Who else is doing similar work? What have the results been to date? What is the most significant competitor to this technology?)

In the late 1970s, electron beams were shown to be an effective treatment for sulfur dioxide and nitrous oxide. However, little research has been carried out to determine the effects of electron beams on organic (carbon based) materials. Some research has been conducted in Germany to remove toluene, and AVCO Research Laboratory (R. Slater and D. Douglas Hamilton) used electron beams to destroy vinyl chloride. A combination of electron beam ionization and direct current electric fields was used to create low temperature plasmas used in the construction of large, powerful carbon dioxide lasers. This method was developed by scientists at the AVCO Research Laboratory in Everrett, Massachusetts. The same technology was used to develop very large pulsed carbon dioxide lasers for experiments at the Los Alamos National Laboratory. Combined electron beam and direct current electric fields, microwaves have not yet been used for treatment of toxic materials. Zapit Technology has recently completed a licensing agreement with Lawrence Livermore National Laboratory (LLNL) for an approach that uses high voltage electron beam radiolytic destruction of organic compounds. The LLNL work involved destruction of trichloroethylene using pulsed electron beam technology developed for military uses. This high voltage electron beam approach requires heavy shielding for x-rays, and relatively large reaction chambers are needed to efficiently use the electron beam.

High energy electron beam processing of aqueous waste streams is presently being investigated by the University of Miami in conjunction with the Los Alamos National Laboratory. MIT uses electron beams with moderate voltages of up to 300 keV. This allows the construction of a system based on established electron beam technology which can be compact, portable, easily shielded and widely available .

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2 DOE/Office of Scientific and
Technical Information

Donna L. Powaukee
Nez Perce Tribe
Environmental Restoration Program
P.O. Box 365
Lapwai, ID 83540

Al Conklin
Air Emissions/Defense Waste
Washington Department of Health
P.O. Box 47820
Olympia, WA 98504-7820

Ralph Patt
Oregon Water Resources Dept.
3850 Portland Road NE
Salem, OR 97310

Doris Cellarius
Sierra Club
2439 Crestline Dr. NW
Olympia, WA 98502

Nancy Rust
Washington State Legislator
17544 Midvale Ave N #105
Seattle, WA 98133

Rick Cameron
Foster Wheeler
1201 Jadwin Ave, Suite 202
Richland, WA 99352

James Cochran
Dean, WSU Tri-Cities Campus
100 Sprout Road
Richland, WA 99352

Joe King
City Manager
P.O. Box 190
Richland, WA 99352

Dave Livesay
CH2M Hill
P.O. Box 428
Corvallis, OR 97339

Todd Martin
Hanford Education Action League
1720 North Ash
Spokane, WA 99205-4202

Bill Mitchell
Nuclear Safety Campaign
1914 North 34th Street #407
Seattle, WA 98103

Gordon Rogers
1108 Road 36
Pasco, WA 99301

Cynthia Sarthou
Heart of America Northwest
1305 - 4th Avenue, #208
Seattle, WA 98101

Karen Verrill
Washington League of Women Voters
7806 Manzanita Dr. NW
Olympia, WA 98502

W.A. Wallace
CH2M Hill
P.O. Box 91500
Bellevue, WA 98009-2050

Dib Goswami
Washington Department of Ecology
7601 West Clearwater Ave. Suite 102
Kennewick, WA 99336

Betty Tabbutt
Washington Environmental Council
1063 South Capitol Way, Room 212
Olympia, WA 98504

John J. Barich III
Environmental Protection Agency
1200 Sixth Avenue
Seattle, WA 98101

Lynn Coleman
Washington Department of Ecology
Toxics Cleanup Program
P.O. Box 47600
Olympia, WA 98504-7600

Dennis Faulk
U.S. Environmental Protection
Agency
712 Swift Blvd. Suite 5
Richland, WA 99352

Toby Michelena
Washington Department of Ecology
P.O. Box 47600
Olympia, WA 98504-7600

Nancy Uziemblo
Washington Department of Ecology
7601 West Clearwater Ave. Suite 102
Kennewick, WA 99336

Chuck Cline
Nuclear Mixed Waste Programs
Washington Department of Ecology
P.O. Box 7600
Olympia, WA 98504-7600

John Erickson
Washington Department of Health
Division of Radiation Protection
Airdustrial Building 5
P.O. Box 47827
Olympia, WA 98504-7827

Bob Cook
Yakama Indian Nation
1933 Jadwin Avenue, Suite 225
Richland, WA 99352

Tom Gilmore
Confederated Tribes of the
Umatilla Indians
P.O. Box 638
Pendleton, OR 97801

Dirk Dunning, P.E.
Oregon Department of Energy
625 Marion Street NE
Salem, OR 97310

Drew Thatcher
Washington Department of Health
Division of Radiation Protection
P.O. Box 47827
Olympia, WA 98504-7827

Dennis A. Peters
CH2M Hill
2300 NW Walnut Blvd.
Corvallis, OR 97339

David R. Lee
CH2M Hill
2300 NW Walnut Blvd.
Corvallis, OR 97339

Jerry Tracey, P.E.
CH2M Hill
2300 NW Walnut Blvd.
Corvallis, OR 97339

Allen Danielson
Washington Department of Health
Division of Radiation Protection
PO Box 47827
Olympia, WA 98504-7827

Dave Livesay
CH2M Hill
PO Box 42
Corvallis, OR 97339

Nancy Pearson
National Board Member
League of Women Voters
6708 Bridgeport Way W
TaWmoen Votersa coma, WA 98467

Maureen McCarthy
Leargue of Wmoen Voters
c/o Pacific Northwest Laboratory
PO Box 999, MSIN K1-90
Richland, WA 99352

J.R. Wilkinson
Confederated Tribes of the Umatilla
Indians
PO Box 638
Pendleton, OR 97801

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