**Stakeholder Acceptance Analysis:
Tunable Hybrid Plasma**

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T.S. Peterson

December 1995

**Prepared for the U.S. Department of Energy's
Office of Technology Development
under Contract DE-AC06-76RLO 1830**

**Pacific Northwest Laboratory
Operated for the U.S. Department of Energy
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STAKEHOLDER ACCEPTANCE ANALYSIS

TUNABLE HYBRID PLASMA

Prepared by

**Todd Peterson
Battelle Seattle Research Center**

**for
U.S. Department of Energy
Office of Technology Development**

December 1995

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INTRODUCTION

This report presents evaluations, recommendations, and requirements concerning Tunable Hybrid Plasma (THP) derived from a three-year program of stakeholder involvement. THP destroys volatile organic compounds by directing a moderate energy (100-300 keV) electron beam into a flow of air containing organic contaminants. This report is for technology developers and for those responsible for making decisions about the use of technology to remediate contamination by volatile organic compounds. Stakeholders' perspectives help those responsible for technology deployment make good decisions concerning the acceptability and applicability of THP to the remediation problems they face.

The report provides:

- Stakeholders' final evaluation of the acceptability of THP in light of the technology's field test.
- Stakeholders' principal comments concerning THP.
- Requirements that stakeholders have of any remediation technology. Technology decision makers should take these conclusions into account in evaluating the effectiveness and acceptability of any remedial method proposed for their site.

In addition, this report presents data requirements for the technology's field demonstration defined by stakeholders associated with the Hanford site in Washington State, as well as detailed comments on THP from stakeholders from four other sites throughout the western United States.

STAKEHOLDER INVOLVEMENT PROCESS

The Volatile Organic Compounds in Arid Soils Integrated Demonstration (VOC-Arid ID) extensively involved stakeholders in the evaluation of innovative technologies to remediate contamination by VOCs. The stakeholder involvement program identified data requirements and issues at five arid sites. Data requirements are needs for specific information about a technology and its performance. They derive from questions about a technology's demonstration and operation. Issues and concerns are requirements and conditions for the acceptability of a technology; an example is "Technologies should be versatile in application and not transfer contaminants from one environmental medium to another."

A goal of the VOC-Arid ID was to test a technology once and then be able to deploy it broadly by ensuring that test plans for technologies to be demonstrated at one site included the issues, concerns, and data requirements of stakeholders from other sites where the technology was likely to be used. Ultimately, the process was designed to expedite deployment of effective and acceptable remedial technologies by determining what stakeholders required of these technologies.

Stakeholder involvement proceeded in three phases. Throughout, innovative technologies were evaluated in comparison to technologies in current use ("baseline" technologies.) In the first phase, through individual interviews, Hanford site stakeholders

contributed to the development of criteria by which technologies would be evaluated. In focus groups, these stakeholders defined data requirements and posed questions to be addressed in technology demonstrations. An integrated workshop was then held to augment the demonstration plans for six technologies. The workshop included all of the Hanford stakeholders and the scientists and engineers developing and testing the technologies. The six technologies were:

- Passive Soil Vapor Extraction Using Borehole Flux
- Tunable Hybrid Plasma
- ResonantSonic Drilling
- In-Situ Bioremediation
- In-well Vapor Stripping
- Membrane Separation

In the second phase of the technology evaluation program, 75 stakeholders from four other DOE arid sites accomplished two goals through individual interviews. First, they validated and further refined the data requirements, issues, and concerns identified by Hanford stakeholders. Second, they defined requirements specific to their site and region.

Demonstrations were subsequently completed for Passive Soil Vapor Extraction Using Borehole Flux, ResonantSonic Drilling, and Tunable Hybrid Plasma.

In the third phase of the technology evaluation program, principal investigators were interviewed to obtain answers to stakeholders' data requirements and questions in light of completion of technology demonstrations. These answers were recorded in the fourth column of a four column matrix (please see Appendix A). Demonstration results were provided to Hanford stakeholders, who used them to make final evaluations.

This report presents Hanford stakeholders' final evaluation of Tunable Hybrid Plasma.

TUNABLE HYBRID PLASMA TECHNOLOGY DESCRIPTION

A soil gas extraction system withdraws contaminants from the subsurface and makes them available to the THP technology in a stream of contaminated air. The technology is also compatible with air stripping from contaminated water.

The electrons in THP's electron beam lose their energy largely by colliding with electrons bound to atoms in the contaminated air stream. In the process, a very large number of previously bound electrons are freed, thus creating a room-temperature plasma. These plasma electrons cool by contacting air molecules and attaching to carbon tetrachloride molecules or other organic contaminants such as TCE. As a result of this attachment, the carbon tetrachloride molecules break apart into smaller, and in some cases, less toxic compounds: chlorine, carbon dioxide, and carbon monoxide. If water vapor is present in the contaminated air stream, hydrochloric acid can also be produced. Reducing water vapor in the contaminated air stream reduces both the energy required to remove carbon tetrachloride and the likelihood that hydrochloric acid will be produced;

therefore a molecular sieve dryer is used in front of the plasma reaction chamber. Compounds resulting from the plasma reaction can then be further broken down into harmless constituents by introducing them into a base, "scrubber" solution. The technology's end products are carbon dioxide and sodium chloride (salt).

STAKEHOLDER EVALUATION OF TUNABLE HYBRID PLASMA

This section contains four parts:

1. A summary of stakeholder evaluation of THP,
2. An overall evaluation of THP by Hanford stakeholders,
3. Interview comments that form the basis for Hanford stakeholders' final evaluation, and
4. A narrative of stakeholders' principal comments about THP.

Summary of Stakeholder Evaluation of THP

With some significant stipulations, stakeholders generally find Tunable Hybrid Plasma (THP) to be an acceptable technology. They view favorably:

- THP's ability to destroy contaminants on site;
- its tunability to react to varying levels of contaminants;
- the non-toxic nature of its final by-products;
- its apparently high destruction removal efficiency;
- the fact that THP appears not to promote the creation of dioxins;
- its capability to treat granular activated carbon (GAC);
- its mobility;
- the fact that its components are known commodities that are available "off the shelf;"
- its apparent safety; and
- its ease of application.

Stakeholders remain concerned about THP's cost of operation in comparison to GAC. Some point to what they see as the need for THP to earn a performance record—to go through the "commercialization loop" before it will be seriously considered by operable unit managers and other technology deployment decision makers. Stakeholders caution that the possible generation of dioxins, furans, and hydrochloric acid must be explicitly addressed. They strongly recommend the field testing of THP with contaminant mixtures. Even though THP can be remotely controlled, stakeholders require regular, frequent, direct monitoring. One said, "THP is acceptable with the condition that you monitor continually for phosgene and stay below 20% of the lower explosive level for explosive/flammable compounds such as normal hexane."

Overall Evaluation of THP

Considering stakeholders by category, most of the regulators participating in the final evaluation found Tunable Hybrid Plasma generally acceptable, but not all agreed that the

technology was applicable at Hanford. Several concluded that the technology needs further development and a commercial track record. All the public interest group representatives found THP acceptable with the conditions noted in this report, as did the technologists and tribal representatives. The following table lists overall evaluations.

Comment	Stakeholder Categories
OVERALL EVALUATIONS	
<ul style="list-style-type: none"> Results are such that one can go ahead. THP is very practical at a reasonable cost. 	<ul style="list-style-type: none"> Regulator
<ul style="list-style-type: none"> This is an acceptable technology. It is largely self-operating and automatic. All components are known. Finding the contaminants is a major first step that has not been sufficiently addressed. Also ease of access to plume will affect ultimate use. 	<ul style="list-style-type: none"> Regulator
<ul style="list-style-type: none"> More development work is necessary. THP may be more applicable in non-DOE areas with single contaminants. 	<ul style="list-style-type: none"> Regulator
<ul style="list-style-type: none"> Fine for secondary cleanup, but Hanford has bigger plumes to deal with. THP's best application is not at Hanford, where constructing a large number of wells is problematical. Possible better locations for use are sites like ASARCO in western Washington, where there's a threat of plume migration. More applicable at Western Washington sites to protect water quality. <p>Have not seen anything yet that makes it better than current alternatives. Do not believe that THP is the best way to get carbon tetrachloride into salt form.</p>	<ul style="list-style-type: none"> Regulator
<ul style="list-style-type: none"> Too new. Not convinced that it's cheaper. Active extraction coupled with GAC is doing OK. Technology deployment decision makers won't change from a known commodity to a technology without a track record. Hanford is looking for proven technologies. Technology has to be cheap. 	<ul style="list-style-type: none"> Regulator
<ul style="list-style-type: none"> THP is acceptable with the proviso that you monitor continually for phosgene and stay below 20% of the lower explosive level for explosive/flammable compounds such as normal hexane. 	<ul style="list-style-type: none"> Regulator
OVERALL EVALUATIONS (Continued)	
<ul style="list-style-type: none"> Technology is affordable and acceptable. Especially appealing because removal is a high priority. The technology seems useful with either active or passive extraction. 	<ul style="list-style-type: none"> Public Interest Group Rep

Comment	Stakeholder Categories
<ul style="list-style-type: none"> • Try it. In order to know whether it is deserving of continued financial support, need to have better understanding of problem and knowledge of competing technologies. 	<ul style="list-style-type: none"> • Public Interest Group Rep
<ul style="list-style-type: none"> • THP is generally acceptable; no red flags. Would like to see continued financial support. 	<ul style="list-style-type: none"> • Public Interest Group Rep
<ul style="list-style-type: none"> • There's a good fit between carbon tetrachloride and THP as a remediation method. 	<ul style="list-style-type: none"> • Public Interest Group Rep
<ul style="list-style-type: none"> • Gut feeling is try it. The technology should be developed to full scale. The scientists working on the technology are well qualified. 	<ul style="list-style-type: none"> • Technologist
<ul style="list-style-type: none"> • Did everything in test that stakeholders asked for. Very comprehensive results. No barriers to deploying THP at Hanford. 	<ul style="list-style-type: none"> • Technologist

Final Evaluation Interview Comments

In focus groups during the initial phase of the stakeholder involvement program, Hanford stakeholders identified data requirements and questions to be addressed in technology field demonstrations. The demonstrations provided answers to these data requirements and questions, with results recorded in a four-column matrix (please see Appendix A). The results were subsequently provided to Hanford stakeholders, who used them to develop final evaluations of the technology. The following table records their final interview comments.

Comment	Stakeholder Categories
BENEFITS AND DRAWBACKS <ul style="list-style-type: none"> The technology's high Destruction Removal Efficiency (DRE) rate and non-toxic waste make high up-front cost acceptable. The technology's speed and ability to extrapolate a date for cleanup (12 years) are benefits. On-site destruction is a distinct advantage. THP is one of the few remedial technologies that can really break down contaminants into something else. THP's ability to provide predictable results will facilitate DOE's financial commitment to the technology. 	<ul style="list-style-type: none"> Regulator
<ul style="list-style-type: none"> Benefits: high DRE, system compatible with other technologies, the by-product is "harmless" and has potential marketability, lots of familiarity with pieces of technology, off the shelf parts make replacement easy, low technical training, efficient at low concentration of contaminants. It is largely self-operating and automatic. No drawbacks identified assuming cost is spread out over number of years. 	<ul style="list-style-type: none"> Regulator
<ul style="list-style-type: none"> Benefit is by-product with potential market. Drawbacks are cost -- figures in four-column matrix may not be accurate -- and that THP is too new, doesn't have enough of a track record. Active extraction coupled with GAC is operating adequately. 	<ul style="list-style-type: none"> Regulator
<ul style="list-style-type: none"> THP's advantage is that it limits the secondary waste stream. Cost-effectiveness is a benefit if cost superiority over GAC plays out in the real world. 	<ul style="list-style-type: none"> Regulator
<ul style="list-style-type: none"> Advantage includes remote operation. THP avoids a lot of the public perception problems that thermal technologies have. Drawbacks include that THP requires skilled capabilities for maintenance and repairs. (The more advanced and complex a technology, the more challenging its maintenance.) THP may be more applicable in other areas with single contaminants. THP has a real opportunity in non-DOE markets. 	<ul style="list-style-type: none"> Regulator

Comment	Stakeholder Categories
BENEFITS AND DRAWBACKS (Continued)	
<ul style="list-style-type: none"> • THP is effective, but does it compare to GAC in terms of full-cycle cost? With THP the critical factor is cost. 	<ul style="list-style-type: none"> • Regulator
<ul style="list-style-type: none"> • Since incineration is so much cheaper, THP has to have other benefits. 	<ul style="list-style-type: none"> • Regulator
<ul style="list-style-type: none"> • Benefits are its portability, effectiveness, ability to be used with either active or passive extraction. The technology is affordable. 	<ul style="list-style-type: none"> • Public Interest Group Rep
<ul style="list-style-type: none"> • Benefits are high DRE, can destroy low concentrations of contaminants, waste products are innocuous, mobility and reasonable cost, multiple sites could be remediated with single machine, no high heat, can treat GAC, and leaves no permanent structure. The remediation equipment does not need to be decontaminated. Drawback is that it is only proven effective with single contaminant plume, is not field tested with mixtures of contaminants. 	<ul style="list-style-type: none"> • Public Interest Group Rep
<ul style="list-style-type: none"> • Advantage is that the plasma is low temperature. There is no additional risk to people, environment from deploying THP. Confidence in the scientists developing THP. 	<ul style="list-style-type: none"> • Technologist
<ul style="list-style-type: none"> • Key benefits are that it's efficient, versatile, and flexible. Primary clean-up goal is to get biggest bang for the buck, and the four-column matrix implies that THP is economical. Mobility is an advantage and the fact that THP is above ground so it can be seen, heard, and monitored. Drawback is lack of experience. Apparently it can meet set schedule given reliability and dependability. THP's advantages include that it is efficient, relatively economical, versatile and mobile. 	<ul style="list-style-type: none"> • Public Interest Group Rep
<ul style="list-style-type: none"> • The technology's advantages are that it's "off the shelf," it's tunable and it seems to work in efficiently destroying contaminants. It's not incineration. Drawback is that it relies on active vapor extraction that hasn't always been reliable at Hanford. 	<ul style="list-style-type: none"> • Public Interest Group Rep
<ul style="list-style-type: none"> • Advantages: THP doesn't promote creation of dioxins, it is tunable, it destroys contaminants on-site; no residual as with GAC. 	<ul style="list-style-type: none"> • Public Interest Group Rep
<ul style="list-style-type: none"> • Benefit is small amount of easily disposable secondary waste. Drawback is securing the funding for equipment purchase. 	<ul style="list-style-type: none"> • Technologist
<ul style="list-style-type: none"> • Benefit is on-site destruction, and using only as much energy as necessary. On-site destruction of VOCs is important. It's written into some Records of Decision, and is a commonly held goal. Thermal oxidation and catalytic oxidation take too much energy. THP seems to run reliably at low concentrations over a long period of time. THP's ability to regenerate GAC is an advantage. The drawback of creating x-rays is minimal. 	<ul style="list-style-type: none"> • Technologist

Comment	Stakeholder Categories
BENEFITS AND DRAWBACKS (Continued)	
<ul style="list-style-type: none"> Benefits are primarily ease of use, safety potential, and modest labor needs. Very good Destruction Removal Efficiency (DRE). Disadvantage: largely remote controlled so operator not always with the technology and thus a potential for an undetected malfunction. 	<ul style="list-style-type: none"> Technologist
<ul style="list-style-type: none"> THP's advantage is that it generates no chlorinated hydrocarbons, and that its by-products are non-hazardous. 	<ul style="list-style-type: none"> Tribal Rep
<ul style="list-style-type: none"> The technology's components are known commodities; they've been used for 20-25 years. THP provides very efficient removal. 	<ul style="list-style-type: none"> Tribal Rep
PERFORMANCE	
<ul style="list-style-type: none"> Too new. Active extraction coupled with GAC is operating adequately. 	<ul style="list-style-type: none"> Regulator
<ul style="list-style-type: none"> Big question is finding a plume and having ready access to it. Questions remain on the limits on water vapor concentration for effectiveness, evaluation of co-contaminants, market for salt by-product. Does the system assume a constant flow in estimates for carbon tetrachloride destruction, because Hanford plumes have unpredictable spikes. Is THP applicable in high humidity? Are air permits necessary? Selling secondary waste brings down the cost of the technology. Investigate selling THP's by-product (salt). 	<ul style="list-style-type: none"> Regulator
<ul style="list-style-type: none"> Any technology that uses energy must be viewed through an incineration lens. Have not disproved risk of re-combination of contaminants. Test results did not include detection limits. Concerned that that was sleight of hand. 	<ul style="list-style-type: none"> Regulator
<ul style="list-style-type: none"> More development work is necessary. The big issue is how THP will deal with co-contaminants - other organics, rads, heavy metals. How will the technology deal with complex waste streams? How will you use THP, as a primary or as a polishing method? Use THP in a treatment train of technologies. THP requires skilled capabilities for maintenance and repair. Best use is at the end of the treatment train. It will be important to determine how reliable and cost-effective THP is over time. Provide more information on maintenance as the technology develops a track record. Additionally, will need a lot of up-front time explaining to stakeholders how the technology works to de-mystify it. 	<ul style="list-style-type: none"> Regulator

Comment	Stakeholder Categories
PERFORMANCE (Continued)	
<ul style="list-style-type: none"> If moisture level of influent varies, it's important to monitor what happens to the off gas. Be aware that halogens are going to attack the titanium foil window. Scale up to a full-scale system may change the dynamics of the plasma reaction and the contaminated air stream. It is unrealistic to state that THP could destroy all carbon tetrachloride contamination at the Hanford site in 12 years. As concentrations decline, removal rates will also decline until a point of diminishing returns is reached. 	<ul style="list-style-type: none"> Regulator
<ul style="list-style-type: none"> Concern that THP is not field tested with mixtures of contaminants. What is the predicted useful life of a full scale unit. If the vacuum chamber breaches will contaminants be released? Will contaminants continuing coming up from the subsurface? How much contamination could escape? Provide the chemical sequence for the possible production and break down of phosgene. More information on this is better even if the likelihood of production is remote. Provide information about where on a site the technology would be best applied: directly above plumes; at the edges of plumes? Is there a market for the salt by-product? 	<ul style="list-style-type: none"> Public Interest Group Rep
<ul style="list-style-type: none"> Provide information about how THP handles spikes of high concentrations of contaminants in the contaminated air stream. Would the technology tune automatically or be human-controlled? How will THP work with mixed contaminants? Operator training detail insufficient. Will extreme seasonal variations in temperature affect THP's use? 	<ul style="list-style-type: none"> Public Interest Group Rep
<ul style="list-style-type: none"> The water analytical report for THP shows non-detects for all the compounds listed. Does this mean nothing was present or nothing above reporting limits? Concerned about the cumulative effect of contaminants under the legal limit. 	<ul style="list-style-type: none"> Public Interest Group Rep
<ul style="list-style-type: none"> How will radionuclides and heavy metals be handled in scrubber solution? Continue to test THP's ability to handle contaminant mixtures -- need field test. Need data on processing rate. 	<ul style="list-style-type: none"> Technologist
<ul style="list-style-type: none"> THP units could be put in series to handle highly contaminated air streams; no upper limit to effectiveness. Provide information about how much contamination is captured in the molecular sieve as well as how much is in the water coming out of the air stream dryer. There is a challenge to have instrumentation able to monitor variations in contaminants in the air stream. Continuous monitor of VOC flow remains a technical challenge and is a make/break issue. Uncomfortable with molecular sieve and carbon tetrachloride -- how much carbon tetrachloride is taken off in sieve? 	<ul style="list-style-type: none"> Technologist

Comment	Stakeholder Categories
PERFORMANCE (Continued) <ul style="list-style-type: none"> Unclear what the temperature is for the plasma reaction. Provide a complete analysis of stack gas. Highlight the low temperature of the plasma reaction. What is the temperature of dissociation? Analyze for dibenzofurans and dioxins. Even though temperature of plasma reaction is low, reactants could have high kinetic energy. 	<ul style="list-style-type: none"> Tribal Rep
<ul style="list-style-type: none"> THP needs to be tested in the field with other VOCs and mixtures. Concerned about effect rads might have on the technology. Concerned about the possibility of condensation, about what happens when relatively warm subsurface air comes into the technology on a cold winter day. 	<ul style="list-style-type: none"> Tribal Rep
SAFETY <ul style="list-style-type: none"> Confident with results that addressed safety issues such as the failure control test. 	<ul style="list-style-type: none"> Regulator
<ul style="list-style-type: none"> Concerned about attempt not to be identified with incineration, although rules for incineration are cumbersome. 	<ul style="list-style-type: none"> Regulator
<ul style="list-style-type: none"> In terms of safety and health, THP looks good. 	<ul style="list-style-type: none"> Regulator
<ul style="list-style-type: none"> Although the redundancy automatic monitoring system is good and failure control was addressed, other questions remain. What is the worst case scenario? Do contaminants continue to be extracted if the filament burns? If the vacuum chamber breaches, will contaminants be released? How much contamination could escape? What is the chemical sequence for the production of phosgene gas? More information on this needed, even if the likelihood of production is remote. The questions relating to safety need to be re-written to be clearer. 	<ul style="list-style-type: none"> Public Interest Group Rep
<ul style="list-style-type: none"> Need to meet OSHA standards, not just lab standards. Monitor air quality in the THP trailer. Clarify question of shut down due to excess radiation - coming from x-rays? 	<ul style="list-style-type: none"> Public Interest Group Rep
<ul style="list-style-type: none"> Has faith that technology is safe. Not looking for zero risk, rather reasonable attention. It is necessary to assure adequate training of operators. 	<ul style="list-style-type: none"> Public Interest Group Rep
<ul style="list-style-type: none"> Found safety results quite acceptable 	<ul style="list-style-type: none"> Technologist
<ul style="list-style-type: none"> The issue of the possible generation of dioxins and furans must be explicitly addressed. 	<ul style="list-style-type: none"> Technologist

Comment	Stakeholder Categories
<p>COST</p> <ul style="list-style-type: none"> Not convinced that it's cheaper. Still has a long way to go to be considered commercialized. Need to get track record; start with PCE plumes, and be proven in the private sector before attempting to enter the DOE world. DOE is great for testing, not selling. Best market is new remediation site where they haven't yet made the investment in capital and don't have the momentum. THP should build a track record, attract capital investment and then come back through the commercialization loop. 	<ul style="list-style-type: none"> Regulator
<ul style="list-style-type: none"> Provide clear-cut cost comparison with GAC. Because of budget constraints, the Hanford cleanup is now focusing on areas of high concentration. THP is not applicable until high concentrations are cleaned up. Approximately 60% of the contamination -- that approaching 8,000 ppb - is in 8% of the area. Because of budget reductions, this has to be the target. Hanford only working on areas with greater than 1000 ppm. 	<ul style="list-style-type: none"> Regulator
<ul style="list-style-type: none"> Is THP cost-effective to use with passive extraction? 	<ul style="list-style-type: none"> Regulator
<ul style="list-style-type: none"> Include extra monitors to assure public confidence in cost estimates. Since energy needs are high, the cost of the technology will be significantly higher in areas in the country with higher priced electricity. 	<ul style="list-style-type: none"> Regulator
<ul style="list-style-type: none"> THP is effective, but how does it compare to GAC in terms of full-cycle cost. With THP the critical factor is cost. 	<ul style="list-style-type: none"> Regulator
<ul style="list-style-type: none"> Do apple-to-apple comparisons with GAC in terms of cost and efficiency. Do real world comparisons for energy consumption. Provide a chart comparing efficiency, cost, and energy demand. What is the useful life of a full-scale unit? The estimated cost is \$1 million. How much time does this investment buy? The length of the technology's useful life will help determine its acceptability. 	<ul style="list-style-type: none"> Public Interest Group Rep
<ul style="list-style-type: none"> Cost is high on importance scale. Provide better comparisons. 	<ul style="list-style-type: none"> Public Interest Group Rep
<ul style="list-style-type: none"> Provide itemized cost comparison to other systems. When doing comparison to other systems, the marketability of the by-product should be included. Factor in the environmental benefit of not having to regenerate GAC canisters and dispose of VOC. Compare cost of THP with cost of GAC. 	<ul style="list-style-type: none"> Public Interest Group Rep
<ul style="list-style-type: none"> Energy consumption should have no adverse effect on cost. 	<ul style="list-style-type: none"> Technologist

Comment	Stakeholder Categories
COST (Continued) <ul style="list-style-type: none"> Strongly disagree with cost figures provided in four-column matrix. THP is not cost effective in relation to GAC. GAC works and has low operating costs. Efficiency is less of an issue than economics. The cost of THP is two or three times the cost of GAC. Provide every detail on costs and be serious about solving problem, not just demonstrating the technology. 	<ul style="list-style-type: none"> Technologist
<ul style="list-style-type: none"> Cost words sound good, but need better comparison with GAC costs. 	<ul style="list-style-type: none"> Technologist
NAME <ul style="list-style-type: none"> Drop "plasma." 	<ul style="list-style-type: none"> Regulator
<ul style="list-style-type: none"> No opinion; plasma also has positive connotation of being life force in blood. Field personnel will be familiar with the complex nature of the technology. 	<ul style="list-style-type: none"> Regulator Technologist
<ul style="list-style-type: none"> Change the name. 	<ul style="list-style-type: none"> Regulator Tribal Rep
<ul style="list-style-type: none"> Tunable waste gas processor, waste gas processor, or versatile waste gas processor are better names. 	<ul style="list-style-type: none"> Public Interest Group Rep Tribal Rep
<ul style="list-style-type: none"> Avoid the word "plasma," since it connotes incineration. 	<ul style="list-style-type: none"> Public Interest Group Rep
OTHER ISSUES AND COMMENTS	
<ul style="list-style-type: none"> Time is of the essence. The faster the contaminant is removed, the less it will spread and the more cost-effective the cleanup is. 	<ul style="list-style-type: none"> Technologist
<ul style="list-style-type: none"> Technology developers need to do the up-front work to explain that this is not high temperature incineration. Go in early. Get the concerns of stakeholders as with the VOC-Arid ID program. Will have to do this every time. But the technology is explainable, and the people concerned about technology will understand it. Extra monitoring may be required to address concerns. 	<ul style="list-style-type: none"> Regulator
<ul style="list-style-type: none"> Need to be extremely responsive to sites/clients. 	<ul style="list-style-type: none"> Technologist
<ul style="list-style-type: none"> Clarify writing of lab analytical results. Are analytical results in Appendix 5 accurately portrayed? 	<ul style="list-style-type: none"> Tribal Rep
<ul style="list-style-type: none"> The THP principal investigators are a high quality team concerned about details. 	<ul style="list-style-type: none"> Technologist

Stakeholder Principal Comments Concerning THP

Emissions. In the initial phase of the stakeholder involvement program, the major stakeholder issue concerning THP was whether any hazardous compounds are generated/recombined by the plasma reaction and emitted by the technology. Most stakeholders felt that the results of the demonstration as reported in the Field Test Milestone Report (March 2, 1995) showed that compounds of concern were not found in the scrubber solution and that the technology operated with a high destruction removal efficiency in relation to carbon tetrachloride. Two stakeholders, however, said that technology developers must explicitly present results of tests for the possible generation of dioxins and furans. Another, concerned about the cumulative effect of exposure to contaminants below regulatory limits, asked whether "Not Detected" meant that in fact no contaminants were present.

Relationship of THP to incineration. In early stages of evaluation, stakeholders raised concern about THP sharing characteristics with incineration. After reviewing demonstration results showing the scrubber solution in a field test unit achieving an equilibrium temperature of 32 degrees C – evidence of a low temperature plasma reaction – and no detection of a range of chlorinated hydrocarbons in the scrubber solution, stakeholders did not associate THP with incineration. They found its low temperature operation a distinct advantage. Generally they see THP avoiding many of the "public perception problems" associated with thermal technologies.

Scale up. Several stakeholders questioned THP's ability to scale up from a field test to a full scale unit, particularly in terms of the reliability and stability of the technology's instrumentation.

Cost. According to one stakeholder, "With THP the critical factor is cost." Stakeholders called for more information about the predicted useful life of a full scale unit in order to determine if the technology's cost is acceptable. One stakeholder said that THP is not cost effective in relation to GAC. This stakeholder said, "GAC works and has low operating costs. Efficiency is less of an issue than economics. The cost of THP is two or three times the cost of GAC." A number of stakeholders called for a direct comparison with GAC including efficiency, cost, and energy demand, taking into account that THP provides the environmental benefit of eliminating the need to transport and regenerate GAC canisters and dispose of VOCs. Others found THP's cost reasonable and acceptable. In order for THP to be accepted across the board, questions of cost need to be answered.

The name. A majority of stakeholders recommended that the name of the technology be changed to waste gas processor or tunable/versatile waste gas processor. Some recommended avoiding "plasma" with its multiple meanings. A minority found no name change necessary.

Contaminant Mixtures/Co-contaminants. Stakeholders require that THP be field tested with mixtures of contaminants. Stakeholders require more information about how THP will deal with organics other than carbon tetrachloride and TCE, and with radionuclides and heavy metals. The question remains: how will THP deal with complex waste streams?

Water vapor in the contaminated air stream/Generation of hydrochloric acid. Stakeholders require that the issue of water vapor in the contaminated air stream be

addressed, as air stream water vapor could possibly lead to the production of hydrochloric acid and unstable plasma reactions.

Energy use/tunability. Stakeholders found THP's tunability a distinct advantage, particularly in relation to energy use.

Best application. Several stakeholders pointed out that because of budget constraints, a principal focus of the Hanford cleanup is now areas with high concentrations of VOC contamination. They felt that THP is not applicable until high concentrations are cleaned up. One stakeholder concluded that THP may be best applied in areas with single contaminants. "THP has a real opportunity in non-Department of Energy markets," he said.

Track record. One stakeholder said that deployment decision makers won't change from a known technology such as active extraction coupled with GAC to a technology without a proven field performance record. THP, he said, should build a track record, attract capital investment, and then come back through the commercialization loop.

Comments Concerning THP from 75 Stakeholders at Four Arid Sites Other Than Hanford

These assessments were recorded before the technology's field test.

ISSUES BY CATEGORY	SITES WHERE ISSUES RAISED	STAKEHOLDER CATEGORIES
Remaining Contamination <ul style="list-style-type: none"> Assess the ability of the technology to handle a mixture of VOCs, heavy metals, and radionuclides. Evaluate the achievable level of destruction; it should attain a 99.9999% destruction removal efficiency (DRE). Evaluate the possibility of multiple passes through the technology to obtain higher DRE. 	<ul style="list-style-type: none"> INEL Sandia INEL Rocky Flats Sandia 	<ul style="list-style-type: none"> Technologist Public Interest Group Rep Technologist Technologist Regulator Public Interest Group Rep Technologist
Process Waste <ul style="list-style-type: none"> Assess the potential for producing ozone and secondary wastes and residues that will need disposal, and determine the quantity of these wastes. Define the nature of the resulting salt cake; its purity, the volume to be generated, and whether it contains any residual VOC contamination. Do by-products create a hazard in the brine? 	<ul style="list-style-type: none"> Los Alamos Rocky Flats Sandia INEL Rocky Flats Sandia 	<ul style="list-style-type: none"> Regulator Public Interest Group Rep Public Official Regulator Public Interest Group Rep Regulator Technologist Tribal Rep Regulator Public Interest Group Rep

ISSUES BY CATEGORY	SITES WHERE ISSUES RAISED	STAKEHOLDER CATEGORIES
Process Waste (Continued)		
<ul style="list-style-type: none"> Evaluate the potential market for recycling the salt and brine solutions. 	<ul style="list-style-type: none"> INEL Los Alamos Rocky Flats Sandia 	<ul style="list-style-type: none"> Public Interest Group Rep Regulator Tribal Rep Tribal Rep Public Interest Group Rep Regulator
<ul style="list-style-type: none"> Assess the ability to safely dispose of resulting salt. What will the salt do to the chemistry of a landfill? 	<ul style="list-style-type: none"> INEL Sandia 	<ul style="list-style-type: none"> Public Interest Group Rep Regulator Public Interest Group Rep
<ul style="list-style-type: none"> Assess whether elements may recombine in the technology's reaction chamber to form different residuals, and evaluate the formation of PICs (products of incomplete combustion). 	<ul style="list-style-type: none"> INEL Rocky Flats Sandia 	<ul style="list-style-type: none"> Technologist Public Interest Group Rep Technologist
<ul style="list-style-type: none"> Evaluate production of hazardous compounds that are not captured in a scrubber. 	<ul style="list-style-type: none"> Sandia 	<ul style="list-style-type: none"> Regulator Technologist
<ul style="list-style-type: none"> Avoid transportation of secondary waste through tribal land. 	<ul style="list-style-type: none"> INEL 	<ul style="list-style-type: none"> Tribal Rep
<ul style="list-style-type: none"> Define the efficiency of full-scale treatment. 	<ul style="list-style-type: none"> Rocky Flats 	<ul style="list-style-type: none"> Regulator
<ul style="list-style-type: none"> An advantage to this technology is that there are no by-products released and there is no problem in transporting the non-toxic solid wastes that are this technology's end product. 	<ul style="list-style-type: none"> INEL Sandia 	<ul style="list-style-type: none"> Public Interest Group Rep Regulator

ISSUES BY CATEGORY	SITES WHERE ISSUES RAISED	STAKEHOLDER CATEGORIES
Practicality <ul style="list-style-type: none"> Assess the compatibility of Tunable Hybrid Plasma with pumping technologies. Assess the reliability of the technology and its frequency of failure, including the mean time between failures. Evaluate the range of volumes, concentrations, materials/chemicals, and temperatures for which the technology is effective, and compare with the magnitude of the total problem. Consider the ability of the technology to handle mixed waste streams and pesticides. Define the maximum possible flow rate of the contaminated air stream to achieve speedy remediation. Assess the technology's removal efficiency in terms of mass and volume, and as affected by the moisture content of the input stream. Assess the effectiveness of the scrubbers and their need for maintenance. Evaluate maintenance needs and costs, such as for scrubber clogging, dryer fouling, and the production of acid gases in the chamber. 	<ul style="list-style-type: none"> INEL INEL Sandia INEL Rocky Flats Sandia Los Alamos Rocky Flats Sandia INEL Rocky Flats INEL Rocky Flats Los Alamos Sandia Rocky Flats 	<ul style="list-style-type: none"> Public Interest Group Rep Public Interest Group Rep Technologist Technologist Public Interest Group Rep Technologist Public Interest Group Rep Regulator Regulator Technologist Public Interest Group Rep Regulator Regulator Technologist Public Interest Group Rep Technologist Technologist Public Interest Group Rep Technologist Regulator Technologist

ISSUES BY CATEGORY	SITES WHERE ISSUES RAISED	STAKEHOLDER CATEGORIES
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<p>Practicality (Continued)</p> <ul style="list-style-type: none"> • Evaluate power needs and the purity required of the power source, recognizing the difficulty of providing power to remote locations. • Evaluate the ability to re-circulate the air stream to control efficiency. • Define potential malfunctions and failures (leaks, formation of harmful compounds, combustion, explosion), including those caused by co-contaminants. • Assess the durability of the unit and the trailer in high wind and severe weather. • Define the skills and training needed for workers. There is concern about the highly technical skills needed to operate the technology. • Define the schedule and requirements for adjusting the electron beam. • Assess the potential for titanium foil to become coated and block the pass- through of electrons. • Assess the portability of the full-scale technology. • Evaluate alternative sources for the technology; there appear to be multiple vendors. 	<ul style="list-style-type: none"> • Los Alamos • Los Alamos • Sandia • Sandia • Sandia • Rocky Flats • Rocky Flats • Sandia • Sandia 	<ul style="list-style-type: none"> • Regulator Technologist • Technologist • Public Interest Group Rep Technologist • Public Interest Group Rep • Public Official • Regulator • Regulator • Technologist • Public Interest Group Rep • Technologist
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ISSUES BY CATEGORY	SITES WHERE ISSUES RAISED	STAKEHOLDER CATEGORIES
Practicality (Continued) <ul style="list-style-type: none"> Evaluate security requirements to prevent vandalism. Evaluate the trailer size needed to support the technology; a 40-ft trailer is too big. Compare THP with the catalytic oxidation (cat-ox) unit used at INEL in terms of cost, time, efficiency, power needs, maintenance, and down time. 	<ul style="list-style-type: none"> Sandia Sandia INEL 	<ul style="list-style-type: none"> Technologist Technologist Regulator
Works as Intended <ul style="list-style-type: none"> Define the technology's efficiencies and assess whether efficiency changes with different input parameters and when the technology is tuned. Express the destruction efficiency in terms of mass removal, and define the range of concentrations at which the technology is effective. Evaluate the effectiveness of the scrubber. Compare the effectiveness of the technology directly with competing technologies. Document the ability of the technology to destroy trichloroethane (TCE) and the costs to do so. Evaluate the effects of metals and radionuclides on the unit, and assess the need for handling if they pass through untreated. A significant benefit is that the technology destroys contamination on-site, and does not transfer it to another environmental medium. 	<ul style="list-style-type: none"> Rocky Flats Sandia Sandia Sandia Rocky Flats Sandia Rocky Flats 	<ul style="list-style-type: none"> Public Interest Group Rep Regulator Public Interest Group Rep Technologist Public Interest Group Rep Technologist Public Interest Group Rep Technologist Regulator

ISSUES BY CATEGORY	SITES WHERE ISSUES RAISED	STAKEHOLDER CATEGORIES
<p>Works as Intended (Continued)</p> <ul style="list-style-type: none"> • Evaluate the ability to capture some heat from the process and use it for another purpose. Assess where heat is exhausted. • Evaluate the entire treatment train, including costs, risks, and worker safety. • Determine whether lines from extraction wells can be run to the technology or if more than one unit is needed. • This technology would be of interest to environmental restoration staff at Rocky Flats because of the difficulty of treating carbon tetrachloride at the site. 	<ul style="list-style-type: none"> • Sandia • Sandia • INEL • Rocky Flats 	<ul style="list-style-type: none"> • Technologist • Technologist • Technologist • Regulator
<p>Cost</p> <ul style="list-style-type: none"> • Define capital costs with certainty; \$1 million appears low. It may be necessary to use more than one unit. • The public will probably see the capital costs of this technology as too high. • Evaluate the total cost, including the cost of extraction, labor, requisite off-gas treatment, and maintenance. Maintenance costs and cost per unit treated appear high, and the technology appears to require a heavy capital investment. • Define total system costs, including acid gas scrubbing, which seem expensive. Competing thermal technology produces salable metal products as by-products. Consider recycling the carbon tetrachloride. • Evaluate operating costs, considering poor maintenance, vandalism, transportation damage, lost-time shutdowns, etc., as inputs. 	<ul style="list-style-type: none"> • INEL • INEL • INEL • Los Alamos • Sandia • INEL • Los Alamos • Rocky Flats • Sandia • Sandia 	<ul style="list-style-type: none"> • Technologist • Technologist • Regulator • Technologist • Regulator • Technologist • Public Interest Group Rep • Technologist • Technologist • Technologist

ISSUES BY CATEGORY	SITES WHERE ISSUES RAISED	STAKEHOLDER CATEGORIES
<p>Cost (Continued)</p> <ul style="list-style-type: none"> • Evaluate cost effectiveness on a per-well basis, and costs per unit removed, expressed as a range. Power costs may significantly affect costs per unit of contaminant removed. • Evaluate power usage and relate to understandable comparative units, such as home usage or cost. • Define total life-cycle costs compared with existing technologies. There are few drawbacks if this is more economical than other technologies. • The technology appears to have a high cost and provides few jobs. Jobs are preferable to expensive technologies. 	<ul style="list-style-type: none"> • Los Alamos • Rocky Flats • Sandia • INEL • Sandia • Sandia 	<ul style="list-style-type: none"> • Technologist • Technologist • Public Interest Group Rep Technologist • Public Interest Group Rep • Regulator • Public Interest Group Rep
<p>Time</p> <ul style="list-style-type: none"> • Evaluate the technology's rate of performance. Relate the rate of the process to understandable comparative units. 	<ul style="list-style-type: none"> • INEL 	<ul style="list-style-type: none"> • Public Interest Group Rep
<p>Worker Safety</p> <ul style="list-style-type: none"> • Confirm that the technology meets OSHA requirements. • Evaluate risks to operators, including radioactive emissions from the electron beam. • Realistically define the number of people needed to operate the technology safely. There is an advantage that few workers are required. • Define and evaluate scenarios for worker accidents, especially in cases where workers make mistakes in adjusting the technology. Define protective activities for both the workers and equipment. 	<ul style="list-style-type: none"> • INEL • INEL • Los Alamos • Sandia • INEL • Sandia • Rocky Flats • Sandia 	<ul style="list-style-type: none"> • Public Interest Group Rep • Public Interest Group Rep • Regulator • Public Interest Group Rep Regulator • Public Interest Group Rep • Public Interest Group Rep • Public Interest Group Rep • Public Interest Group Rep

ISSUES BY CATEGORY	SITES WHERE ISSUES RAISED	STAKEHOLDER CATEGORIES
Worker Safety (Continued) <ul style="list-style-type: none"> Evaluate the skill and training needed by the maintenance and startup labor force. 	<ul style="list-style-type: none"> Sandia 	<ul style="list-style-type: none"> Technologist
Public Health and Safety <ul style="list-style-type: none"> It is important to evaluate air emissions, including the characterization, capture, and treatment of stack gas. Evaluate the technology's ability to meet state air standards. Stack gas control is a major issue. Define the possibility of dioxins or furans being formed and released. This technology has been used in other applications. If the usual safeguards are in place, there is no problem with its use. Evaluate the formation of products of incomplete combustion (PICs), especially with fuels as co-contaminants. 	<ul style="list-style-type: none"> INEL Los Alamos Sandia Los Alamos Rocky Flats Rocky Flats Sandia 	<ul style="list-style-type: none"> Public Interest Group Rep Tribal Rep Technologist Public Interest Group Rep Technologist Public Interest Group Rep Regulator Technologist
Environmental Impacts <ul style="list-style-type: none"> Define power needs and cost, and the needs for input resources. Will the technology have an inordinately high energy demand or affect neighboring power flows? Evaluate the aesthetic effect of the technology, including power lines (or find an alternative, low-energy power source). Evaluate noise and the exhaust emissions from the on-site generator used for power. 	<ul style="list-style-type: none"> INEL Los Alamos Rocky Flats Sandia Los Alamos Sandia Sandia 	<ul style="list-style-type: none"> Public Interest Group Rep Technologist Public Official Technologist Public Interest Group Rep Technologist Public Official Public Interest Group Rep Technologist

ISSUES BY CATEGORY	SITES WHERE ISSUES RAISED	STAKEHOLDER CATEGORIES
Public Perception <ul style="list-style-type: none"> • This technology is preferred because it destroys toxic compounds. • The technology's name does not illustrate its function. The name has connotations unrelated to the technology. • The public will be concerned about the possibility of radioactive emissions from the electron beam. The technology should be deployed away from populations. • Similarities to incineration, with off-gas emissions, may make the technology unacceptable. Evaluate the ability to fully control the process. • Demonstrate how the "tunability" of the technology works. Provide a cut-away model of the technology. • This is a difficult technology to understand. • The technology's small size is an advantage. • Not much support exists for high-tech, high-cost, high-energy technologies. 	<ul style="list-style-type: none"> • INEL • INEL • Sandia • Los Alamos • Sandia • INEL • Los Alamos • Rocky Flats • Sandia • Sandia • Sandia 	<ul style="list-style-type: none"> • Public Interest Group Rep • Public Interest Group Rep • Public Interest Group Rep • Regulator • Regulator • Technologist • Regulator • Technologist • Public Interest Group Rep • Public Interest Group Rep • Regulator • Technologist
Socio-Economic Interests <ul style="list-style-type: none"> • Technologies are preferred that do not require a large labor force. 	<ul style="list-style-type: none"> • INEL 	<ul style="list-style-type: none"> • Public Interest Group Rep

ISSUES BY CATEGORY	SITES WHERE ISSUES RAISED	STAKEHOLDER CATEGORIES
Regulatory Compliance <ul style="list-style-type: none"> • Will regulations allow the technology's use? Will the Tunable Hybrid Plasma unit itself have to be permitted? • Consider the synergistic effects of combined contaminants: don't just meet regulatory requirements for single contaminants considered in isolation. • Determine if the technology's end product, the salt brine/cake, will be regulated as a hazardous waste because it may be considered to be derived from a hazardous waste. Can it be disposed of in solid waste landfills? • Assess air permitting requirements. Failure of automated monitors may cause off-gas releases. • Evaluate regulatory requirements for the power source for the technology; an air permit may be needed. 	<ul style="list-style-type: none"> • Los Alamos • Rocky Flats • Rocky Flats • Rocky Flats • Sandia • Sandia 	<ul style="list-style-type: none"> • Regulator • Regulator • Public Interest Group Rep • Regulator Public Official • Public Interest Group Rep Technologist • Technologist

Appendix A presents the four-column matrix developed by Hanford stakeholders and THP's developers. Appendix B presents the general comments of Hanford stakeholders concerning THP, recorded before the technology's field demonstration. Appendix C presents comments applicable to the development of any innovative technology. Appendix D offers a fact sheet describing the operation of THP.

APPENDIX A

FOUR-COLUMN MATRIX

TUNABLE HYBRID PLASMA			
FOCUS GROUP DATA REQUIREMENTS	WORKSHOP COMMENTS	TEST PLAN ELEMENTS TO ADDRESS DATA REQUIREMENTS	DEMONSTRATION RESULTS
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 had been extracted by the third quarter of 1994. The demonstration report will evaluate THP's degree of effectiveness with Hanford's conditions of contamination.	1. The demonstration is scheduled to run for approximately 300 hours on an actual VOC contaminated air stream from the ERA wells at the 200 West Area. Results of lab studies will be used to calculate how much contamination this technology could treat.	1. Input VOC concentrations to the tunable hybrid plasma (THP) field test unit were 150 - 300 ppm. Output concentrations were less than 1 ppb. Flow rates ranged from 0.5 cfm to 3 cfm. Based on lab results, a full scale unit of 175 kW could treat 76,173 pounds of VOC per year, therefore over 12 years 1 THP system could destroy all known CCl ₄ at Hanford.
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.	2. Destruction efficiencies and rates will be measured. Effectiveness for other applications with contaminated air can be extrapolated.	2. Vapor from GAC regeneration and VOC water stripping could be treated with THP if moisture and contaminant concentrations are within system limits. The technology also treats TCE. Economic consideration make THP more effective than GAC or incineration at CCl ₄ concentrations less than 100 ppm and TCE concentrations less than 4000 ppm.
3. The principal investigators 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. The ERA continues while new technologies are evaluated. 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.	3. The demonstration is scheduled to work with the on-going ERA.	3. During the field test ERA systems and the THP unit operated without any interference.
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.	4. A blower is part of the THP demonstration unit, thus even in low flow conditions an air stream can be drawn through the unit.	4. The Hanford test did not contain mixtures, but mixtures have been studied in the lab. These mixtures are: TCE and CCl ₄ , TCE and TCA and CCl ₄ , TCA and PCE and CCl ₄ . A VOC mixture tested in the laboratory did not have a negative effect on the THP destruction reaction.

TUNABLE HYBRID PLASMA			
FOCUS GROUP DATA REQUIREMENTS	WORKSHOP COMMENTS	TEST PLAN ELEMENTS TO ADDRESS DATA REQUIREMENTS	DEMONSTRATION RESULTS
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.	5. The test plan will incorporate these requirements.	5. The Hanford 200 West ERA equipment includes a vapor knock out unit so in the field test some water was withdrawn in advance of the THP dryer. In 300 hours running time the THP dryer yielded 1/2 gallon of water. 6.2 $\mu\text{g/l}$ of CCl_4 was measured in the water coming out of the dryer. Sometimes the THP unit ran at 1000 ppm water content and still achieved 1 ppb CCl_4 destruction efficiency. The operating limit seems to be 0.1% relative humidity for CCl_4 . The quantity of energy needed to destroy CCl_4 at a given relative humidity depends on the final concentration required.
6. Define technology shutdown and decommissioning requirements.	6. In the demonstration report, provide details on the operation of detector devices for the shutdown interlocks.	6. Two simulated emergency shut downs are part of the demonstration plan.	6. All safety functions worked successfully in the presence of Bruce Tuttle, Hanford Site Safety Officer and Tom Spicer, Hanford Site Field Superintendent. Kathy Dunks was the Hanford Site Test Engineer supervising the field test. Decommissioning of the demonstration unit is very limited because of its small size.
7. Define the limits of the unit's mobility, and the costs for startup, shutdown, and movement to another location.	7. No further comment.	7. The field test unit is transportable on a standard-length tractor trailer truck. Packing, driving, and unpacking the unit are the only transportation costs.	7. Two person weeks were required both to pack and to unpack the demonstration unit.
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.	8. The field test will address possible effect of particulates on the THP reaction.	8. There is a particle filter ahead of the THP dryer - it was cleaned after the field test and showed very few particulates. There was a HEPA filtration unit in the soil vapor extraction system. There was no observed effect of particulates on the THP test.
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.	9. Test did not include VOC gas temperature records.	9. The trailer is heated and air conditioned to account for ambient conditions. The system as a whole, including the electronic components, work between 5°C and 40°C.

TUNABLE HYBRID PLASMA			
FOCUS GROUP DATA REQUIREMENTS	WORKSHOP COMMENTS	TEST PLAN ELEMENTS TO ADDRESS DATA REQUIREMENTS	DEMONSTRATION RESULTS
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.	10. The test plan includes provisions for managing secondary waste.	10. The used scrubber solution was pumped out, analyzed, and disposed by the Hanford Waste Management group. The scrubber solution has to be changed when the NaCl concentration reaches 18 g/l. Results of detailed analysis of the scrubber solution are attached as Appendix A.
11. Define the impacts of co-contaminants possibly being incorporated in the resulting salt.	11. No further comment.	11. The test plan includes this data requirement.	11. The used scrubber solution was pumped out, analyzed, and disposed by the Hanford Waste Management group. No co-contaminants or CCl_4 were detected in the salt resulting from the test units operation. Detailed analysis results are attached as Appendix A.
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.	12. Maintenance needs will be recorded.	12. General maintenance during the demonstration included: changing the scrubber solution monthly, and draining the air compressor once every two weeks. The antifreeze in the chiller is checked at the start of operation. During the demonstration one of the o-rings which holds the titanium foil in place needed to be replaced to maintain vacuum in the reaction chamber.

TUNABLE HYBRID PLASMA			
FOCUS GROUP DATA REQUIREMENTS	WORKSHOP COMMENTS	TEST PLAN ELEMENTS TO ADDRESS DATA REQUIREMENTS	DEMONSTRATION RESULTS
13. Define the 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 dryer, plasma unit, and scrubber. Determine the technology's processing rate. What are the limiting factors?	13. This will be measured.	<p>13. The e-beam size is the limiting factor for destruction. Variable concentrations can be accommodated by adjusting the flow rate to keep the VOC mass loading at the level the e-beam can destroy.</p> <p>The total quantity of CCl_4 destroyed per day will depend, in part, on what final concentration is required. For example, if the final concentration of CCl_4 is 1 ppm, a 175 Kw e-beam system is calculated to be able to destroy 233 pounds of CCl_4 per day (the Hanford field test unit was a 1.75 Kw e-beam system). If a final concentration of 10 ppm is required, a 175 Kw system is calculated to be able to destroy 387 pounds of CCl_4 per day. In general, the higher the destruction removal efficiency (DRE) required the more energy is needed and the less CCl_4 can be processed daily.</p>
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.	14. Power supply issues will be addressed in the field test.	14. Regular power from the Hanford supply grid was used during the demonstration. There were no power supply problems during the demonstration. The most electrically sensitive component of system is the computer controller. Standard circuit breakers and surge protectors were used in the demonstration.

TUNABLE HYBRID PLASMA			
FOCUS GROUP DATA REQUIREMENTS	WORKSHOP COMMENTS	TEST PLAN ELEMENTS TO ADDRESS DATA REQUIREMENTS	DEMONSTRATION RESULTS
<p>15. The niche for this technology should be defined in comparison with other technologies. What competes and why? Define potential conflicts with other technologies.</p> <p>How do costs compare? The high potential cost of this technology is a concern. Provide detail bases for all cost estimates.</p>	<p>15. THP is predicted to work best with concentrations from 1 to 10,000 ppm, and to have a cost advantage at below 100 ppm for CCL₄ and below 1000 ppm for TCE. GAC competes at higher concentrations.</p> <p>Break out capital vs. electricity cost based on concentration of CCL₄. Also distinguish capital vs. operating and maintenance costs.</p> <p>Define if this is a primary treatment technology or a secondary treatment technology.</p>	<p>15. Demonstration results will be used to calculate this information.</p>	<p>15. GAC is the competing technology. The costs for a THP full scale (175 Kw) unit based on demonstration results have been calculated as follows:</p> <p><u>Capital cost</u>: \$2 to \$3/pound of CCL₄ destroyed <u>Electrical cost</u>: \$0.5 to \$1.5/pound of CCL₄ destroyed <u>Caustic cost</u>: 43¢/pound of CCL₄ destroyed <u>Maintenance cost</u>: 33¢/pound of CCL₄ destroyed</p> <p>The maintenance cost includes the operating cost because the system is automatic and has a feedback control loop.</p> <p>Detailed cost estimates are attached as Appendix B.</p>
<p>16. What time is required for the technology's testing and scale-up?</p>	<p>16. Define scale up factors for the technology and the ultimate maximum processing rate. Provide operating ranges for the full-scale unit. Include the cost and time required to scale up.</p>	<p>16. All components are available at full scale from standard suppliers. Consequently, investor confidence may be the limiting factor to full scale deployment.</p>	<p>16. One to two more field tests may be required to create investor confidence.</p> <p>If investors are willing, a full scale unit could be operational within 12 - 18 months of initial investment.</p>
<p>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.</p>	<p>17. Clearly describe the technology and its performance in the report of the demonstration's results.</p>	<p>17. Proponents are evaluating other names for the technology.</p>	<p>17. Tunable Electron Beam Waste Gas Processor has been suggested as a more descriptive name. A general brochure describing the technology is being prepared.</p>
<p>18. Demonstrate where the heat of the reaction goes, and whether there is a chance of explosion.</p>	<p>18. The air temperature goes up from 10° C to 100° C during reaction. Coolers can be added to the unit if necessary. If GAC is used, air may need to be cooled.</p> <p>Determine cooling requirements.</p>	<p>18. There is a chiller around the reaction chamber. This will be tested during the demonstration.</p>	<p>18. Scrubber solution also acted as a heat sink. An equilibrium temperature of 32° C was achieved in the scrubber water after approximately 8 hours of operation.</p>

TUNABLE HYBRID PLASMA			
FOCUS GROUP DATA REQUIREMENTS	WORKSHOP COMMENTS	TEST PLAN ELEMENTS TO ADDRESS DATA REQUIREMENTS	DEMONSTRATION RESULTS
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.	19. Worker safety issues including possible exposure to electromagnetic releases and scrubber liquid have been taken into account in designing the field test unit and planning the field test. The pH of sodium bicarbonate is less than 10 thus the personnel hazard from this unit's operation is low.	19. No radiation leaks were measured during the demonstration.
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?	20. Lead shielding is integral to the e-beam unit thus x-ray exposure is unlikely. There is also radiation monitoring in the trailer. Control mechanisms inter-tie to the monitors. If radiation is detected, power to the unit shuts off automatically.	20. There are temperature sensitive shut down interlocks on the e-beam. If they don't work the vacuum chamber would breach and the e-beam filament would burn in air thus shutting down the e-beam. Radiation was measured during the demonstration at less than 0.5 millirems/hr. Because destruction efficiency during the field test was so high no phosgene gas was generated.
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.	21. Automatic control of the system is planned for demonstration. This includes the following: <ul style="list-style-type: none"> ● electron-beam high voltage, ● electron-beam current, ● air flow rate, ● scrubber vacuum. 	21. In the demonstration, the PC and FTIR monitored: the e-beam high voltage and current; inlet and outlet concentrations of the compounds. This includes: CCl ₄ inlet concentrations before and after the dryer; water vapor after the dryer; CCl ₄ chloroform, and water outlet concentration after the scrubber; quantity of CCl ₄ that can be processed before the scrubber solution has to be changed; Recycle pump, scrubber blower, dryer blower, and dryer power status (On or Off); scrubber solution, water tank, sodium bicarbonate tank, and dryer tank level; flow rate and the pressure in the channel; high voltage power, filament power; pressure in the vacuum chamber as well as the mechanical pump and the diffusion pump status; inlet multiport valve position which can be open to the waste air stream or to ambient air or can be closed; and vapor extraction system status (On or Off).

TUNABLE HYBRID PLASMA			
FOCUS GROUP DATA REQUIREMENTS	WORKSHOP COMMENTS	TEST PLAN ELEMENTS TO ADDRESS DATA REQUIREMENTS	DEMONSTRATION RESULTS
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?	22. Evaluation of co-contaminants is not a part of the Hanford demonstration.	22. To use the THP unit with atmospheric air, all VOC concentrations must be below lower explosive limits (LEL). Explosive levels of compounds could be dealt with by a nitrogen carrier gas if necessary. Heavy metals and radioactive co-contaminants, if present, will end up in the scrubber solution.
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.	23. Detailed regulatory analysis is not currently part of the Hanford demonstration. However, stack gas monitoring is planned.	23. During the field test at Hanford stack gas was collected and analyzed. Analytical results are included as Appendix C.

TUNABLE HYBRID PLASMA			
FOCUS GROUP DATA REQUIREMENTS	WORKSHOP COMMENTS	TEST PLAN ELEMENTS TO ADDRESS DATA REQUIREMENTS	DEMONSTRATION RESULTS
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.	24. During the field test energy consumption will be measured.	<p>24. The field test THP units energy requirements were as follows: e-beam generator - 1.8 kW, dryer heater - 7.0 kW, dryer blower - 0.74 kW, scrubber pump - 1.00 kW, scrubber blower - 0.23 kW, vacuum pump - 1.00 kW, chiller - 4.16 kW, air compressor - 1.2 kW, and Three Variacs - 1.0 kW.</p> <p>The energy required to destroy CCl_4 depends on the final concentration of contaminant required.</p> <p>THP's energy consumption can be illustrated by comparison with everyday uses of electricity. Destroying a pound of CCl_4 to a final concentration of 1 ppm takes as much electricity as running a 100-watt light bulb for 90 hours or a laundry machine for 6 hours or a TV set for 18 hours. Destroying a pound of CCl_4 to a final concentration of 10 ppm requires as much electricity as running a 100-watt lightbulb for 54 hours or a laundry machine for 3.6 hours or a TV set for 11 hours. Destroying a pound of TCE to a final concentration of 1 ppm requires as much electricity as running a 100-watt lightbulb for 10 hours or a laundry machine for 40 minutes or a TV set for 2 hours.</p>
25. Determine alternatives to landfilling the resulting salt or brine solution. Reuse would be best.	<p>25. Determine the amount of salt expected.</p> <p>Discuss transportation requirements for the disposal or reuse of salt. Determine if there is a market for the salt.</p>	25. Determining possible markets for the salt is not part of the Hanford demonstration at this time.	25. 2,700 mg/l of salt were produced during the Hanford field test.

APPENDIX B

HANFORD STAKEHOLDERS' COMMENTS CONCERNING THP PRIOR TO THE TECHNOLOGY'S FIELD TEST

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.	Because 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 THP 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.

APPENDIX C

STAKEHOLDER COMMENTS APPLICABLE TO ANY INNOVATIVE ENVIRONMENTAL TECHNOLOGY

An analysis of stakeholders comments collected during focus group meetings and individual interviews revealed concerns and data requirements that apply to all of the technologies evaluated in the VOC-Arid ID. Those making decisions about the use of any environmental technology should take these perspectives into account. Comments are sorted into the following categories: performance, cost, environmental health and safety, regulatory issues, and socio-political issues.

PERFORMANCE

Potential to increase contaminant mobility. Stakeholders require that a technology not increase the mobility of contaminants it is designed to remediate.

Subsurface injection. Some technologies inject substances ranging from water to microorganisms into the subsurface. This injection raises stakeholders' concerns related to regulation (e.g. Washington State's non-degradation standard for groundwater), effects on groundwater levels, effects on indigenous microorganisms, or the ability to monitor and control the consequences of subsurface injection.

Transfer of contaminants from one environmental medium to another. Stakeholders oppose removing contamination from one area or environmental medium only to transfer it to another, for example from the subsurface to the atmosphere. Technologies that do not immobilize or destroy contaminants on site will raise these concerns.

Ability to deal with co-contaminants. Stakeholders clearly express concern about a technology's ability to remediate all the contaminants it is likely to encounter. They are concerned about technologies that do not take care of the entire problem, leaving or mobilizing other contaminants. This is a particular concern with mixed radioactive and hazardous contaminants and important for in-situ technologies facing the challenge of residual co-contaminants.

Versatility. In a related issue, stakeholders prefer technologies that deal with a range of contaminants and that are effective in varying conditions of soil, temperature, climate, and other site conditions. Stakeholders will challenge the wisdom of investing in a technology with narrow application.

Process/Secondary waste. Although almost all remediation methods produce some type and quantity of process waste, there is significant stakeholder concern about how that waste will be treated, stored, transported, disposed of, or otherwise managed. Therefore, stakeholders will likely be critical of any innovative technology that generates secondary waste that concentrates toxicity or is more difficult to dispose of or recycle than secondary waste generated by a baseline technology.

Complexity. A technology's complexity of design and operation raises questions for stakeholders. There is a common belief that the more complex a technology, the more expensive it is, the more likely it is to fail, and the more costly and difficult it is to repair.

Maintenance and operation. Technologies that local labor can operate and maintain are preferable to those that require complicated, expensive, off-site maintenance.

Auxiliary technologies. Stakeholders evaluate a technology within the context of the entire system within which it operates. In order to assess one component of the system, stakeholders point out that it is necessary to evaluate the benefits and drawbacks of the entire system. Technologies that require auxiliary components raise issues if the supporting technologies are not completely described, understood, or reliable.

Off-site treatment/transport. Off-site transport, treatment, or disposal of contaminants concern stakeholders. These considerations include the complexities of dealing with varying jurisdictional authorities, possible environmental and health exposure, and accidents, as well as the impact of treatment and disposal facilities.

Timeliness. A technology may have significant benefits in terms of effectiveness, cost or other attributes, but may operate more slowly than a baseline technology. In evaluating technologies, stakeholders take into account rate of performance and time required to complete the job. Many believe that time is of the essence in remediation, particularly in relation to blocking the migration of contaminated plumes.

COST

In evaluating technology, cost is important to stakeholders without taking precedence over certain other considerations, especially health and safety. Stakeholders are concerned about the following aspects of cost:

Cost greater than baseline. Stakeholders will be interested to know if the cost to develop, operate, or decommission a new technology is greater than that for the baseline technology. A particular point of concern to stakeholders is life-cycle cost, including startup, operations, maintenance, and decommissioning. Stakeholders will ask to see an estimate of complete life-cycle costs.

Reduced budgets. Stakeholders point out that many decisions about technology development and deployment now have to be made in light of reduced budgets.

ENVIRONMENTAL HEALTH AND SAFETY

Stakeholders are interested in the effect any new technology may have on the health and safety of workers and the public. Specifically they will be concerned about the following:

Failure, and emissions or releases. This is a critical issue with stakeholders. Effects on the environment, the public, or on workers from the failure of a technology - which may range from release of contaminants to mechanical failure and injury - must be carefully considered. Stakeholders require that the ability to control and mitigate failure be built into any technology.

They are very concerned about any uncontrolled emissions or releases of contaminants or other hazardous materials resulting from the installation, operation, or removal of a technology. Stakeholders require detailed information about the possible impact of releases on people, wildlife, vegetation, air, water, and soil.

Energy demand. The use of large amounts of energy, for example electric power, to construct, operate, remove, or decommission a technology will matter to stakeholders. A projected energy demand greater than the baseline technology's energy requirements will raise concern as will the possibility that using the technology and supplying it with energy will place an inordinate demand on or damage natural resources.

REGULATORY ISSUES

Track record. A technology with no history of approval within the federal, state, or local regulatory system will raise stakeholders' concerns. Regulatory track record refers to the regulations and regulatory guidance needed to evaluate a technology's compliance. Regulators' familiarity with a technology reduces regulatory uncertainty. Stakeholders will also have concerns about a technology that requires many complex regulatory approvals.

SOCIO-POLITICAL ISSUES

Future options. Stakeholders evaluate unfavorably technologies they see as foreclosing future options for remediation or land use. They will likely prefer methods that promote unrestricted future use of currently contaminated sites, including spiritual, traditional, and practical uses. Stakeholders are critical of technologies that change the physical nature of the land itself, or that preclude future waste processing or other remediation.

Potential to impact natural or cultural resources. Any potential impact from a technology on resources valued by a particular community or region will raise significant concern among stakeholders. These resources include clear air and scenic vistas, drinking water/groundwater supplies, important habitats, open space, and tribal resources and traditional land uses.

Hanford stakeholders identified the following data requirements as applicable to all technologies:

DATA REQUIREMENTS - ALL TECHNOLOGIES	
1.	Demonstrate the technology in differing geological conditions and with a broad range of contaminants and contaminant mixtures to measure its versatility.
2.	Define the demonstration's assumptions and expectations about the production, storage, treatment, and disposal of secondary waste from the technology.
3.	Define the specific elements of risk and the risk management strategy to be used in the demonstration and in subsequent deployment of the technology.
4.	Define the elements of and process for assessing operational readiness for the demonstration of the technology.
5.	Define the liability implications and insurance requirements for the deployment of the technology.
6.	Define the control mechanisms and methods of response to all potential technology failures.
7.	Define the methods and equipment necessary to monitor the effectiveness of the technology both as an operating unit and with respect to effects on the environment.
8.	Demonstrate that further cleanup action is not foreclosed by the technology's use.

APPENDIX D

FACT SHEET

Fact Sheet: Tunable Hybrid Plasma

Category: Treatment

NEED:

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

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

DESCRIPTION:

The technology is applied above ground. A moderate energy electron beam (100-300 keV) is directed into a flow of atmospheric air containing organic contaminants. The electron beam is created by accelerating electrons from a heated tungsten filament in a vacuum system toward a thin titanium window which forms the vacuum seal and allows the electrons to enter a flowing air stream. The energy required to generate the electron beam and destroy volatile organic compounds is many orders of magnitude less than the energy required to heat all of the waste gas stream to sufficient temperatures to destroy the compounds.

Electron beams are in widespread commercial use, in particular, to polymerize compounds to form bonding and to polymerize print on cereal boxes, milk cartons, etc. The waste gas stream is directed with a titanium duct past the electron beam window; this forms the reaction chamber. All of the duct work near the electron beam is shielded with lead; the apparatus meets OSHA standards for ionizing radiation emissions. The entire apparatus is contained

and transported as well as operated in a 45-foot trailer.

A soil gas extraction system extracts contaminants from the vadose zone and makes available a waste gas air stream for the THPR. The THPR is compatible with a number of extraction techniques such as air stripping from contaminated water.

The THPR destroys carbon tetrachloride vapors in the following way: The primary high energy electrons that pass through the titanium window lose their energy in the waste gas air stream in large part by creating secondary electrons which scatter many times off of the bound electrons tied to the atoms in the air stream. These bound electrons become free, and a room temperature plasma is created. These plasma electrons cool by contacting the air molecules and attach to the carbon tetrachloride molecules. As a result, the carbon tetrachloride molecules break apart into smaller and in some case less toxic compounds. This process is called "dissociative attachment." The products of dissociative attachment are chlorine, carbon dioxide, and carbon monoxide. These molecules can then be further broken down into harmless constituents by introducing them into an aqueous (water-based) caustic solution. The energy requirements for carbon tetrachloride removal are several times less than when water vapor is present; therefore a molecular sieve dryer is used upstream from the THPR to remove water vapor, and the reaction does not produce hydrochloric acid.

ADVANTAGES:

The advantages of this technology include:

- provides on-site treatment of toxic substances in gas stream with high destruction

and removal efficiency

- eliminates contaminants from high-volume waste gas streams with end-products of small volumes of brine solutions and toxic gases
- 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.
- entails minimum pre- and post-treatment requirements
- has the capability to treat gases from solid waste treatment systems resulting in non-toxic

emissions and small volumes of solid non-toxic residues, as well as destroying VOC's from contaminated water.

- offers versatile operation to process a wide range of contaminants and concentrations.

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 includes the electron beam apparatus, scrubber, a dryer, and a control system in order to be fully automated, and be cost competitive with other methods that carry out the same function.

Tunable Hybrid Plasma