COMBINING EXPEDITED CLEANUP WITH INNOVATIVE TECHNOLOGY DEMONSTRATIONS

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ABSTRACT

A Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) expedited response action (ERA) has been initiated at the Hanford Site, Washington, for the removal of carbon tetrachloride from contaminated soils to mitigate further contamination of the ground water. Soil vapor extraction with aboveground collection and treatment was chosen as the preferred remedial technology for the first phase of the ERA. At the same time, innovative technology demonstrations are being conducted in coordination with the ERA to determine the viability of emerging technologies that can be used to characterize, remediate, and monitor carbon tetrachloride and co-contaminants. The overall goal is to improve the performance and decrease the costs of carbon tetrachloride remediation while maintaining a safe working environment.

INTRODUCTION

Radioactively contaminated acidic aqueous wastes and organic liquids were discharged to the soil column at three disposal sites within the 200 West Area of the Hanford Site, Washington (Fig. 1). As a result, a portion of the underlying ground water is contaminated with carbon tetrachloride, a suspected carcinogen, several orders of magnitude above the maximum contaminant level accepted for a drinking water supply. An expedited response action (ERA) has been initiated to remove the contamination in the unsaturated soils using existing technologies to minimize further contamination of the ground water. To improve the rates and cost savings associated with the removal of carbon tetrachloride from the soils, innovative characterization, monitoring, and remediation technologies are being demonstrated in coordination with the ERA. This paper discusses the present ERA approach and the nature and applicability of innovative technologies for: (1) ERA characterization; (2) well field development; and (3) contaminant treatment.

Background

At Hanford, carbon tetrachloride was used primarily in plutonium recovery processes. From 1955 to 1973, radioactively contaminated acidic aqueous wastes and organic liquids from these processes were discharged to the soil column at three adjacent disposal sites (216-Z-1A Tile Field, the 216-Z-18 Crib, and the 216-Z-9 Trench) in the 200 West Area (Fig. 2). Between 363,000 and 580,000 L of carbon tetrachloride were discharged to these disposal sites along with 190 kg of plutonium and americium. It is thought that a substantial amount of carbon tetrachloride remains in the unsaturated soils beneath these disposal sites and continues to contribute to the long-term contamination of the ground water.

Preliminary site characterization and an engineering evaluation and cost analysis were conducted to evaluate the nature and extent of the contamination and remedial alternatives. The process included a soil vapor extraction pilot test because preliminary screening of alternatives in the early phase of the project indicated that soil vapor extraction of the carbon tetrachloride in the unsaturated zone, with some form of aboveground treatment of the soil vapor, would likely be the preferred remedial technology. Vapor extraction technology uses a vacuum to induce air flow through the soil, volatilizing carbon tetrachloride from the soil into the air stream. The relatively high volatility of carbon tetrachloride, in conjunction with the relatively ideal site characteristics (i.e., high permeability, low moisture content), suggested this

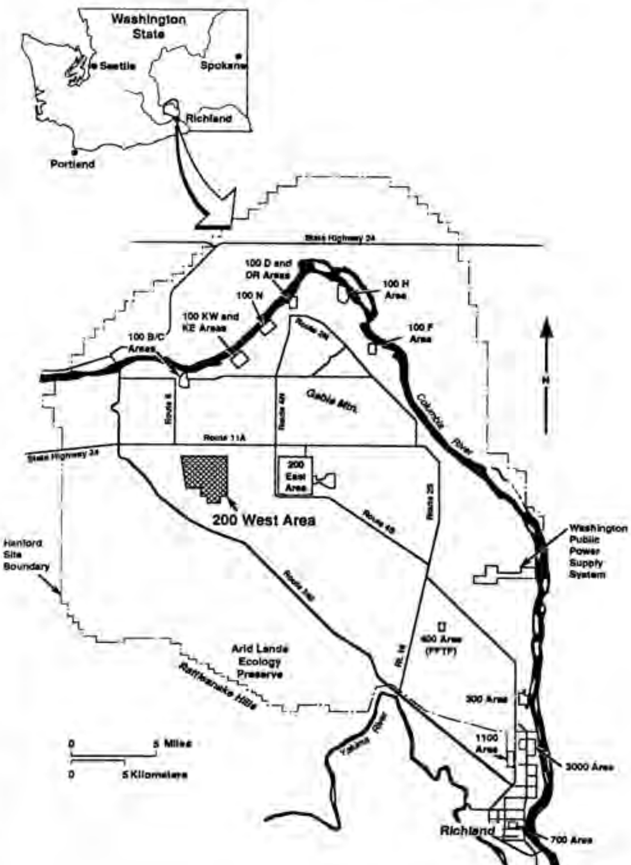

Fig. 1. Hanford site map and location of the 200 West Area.

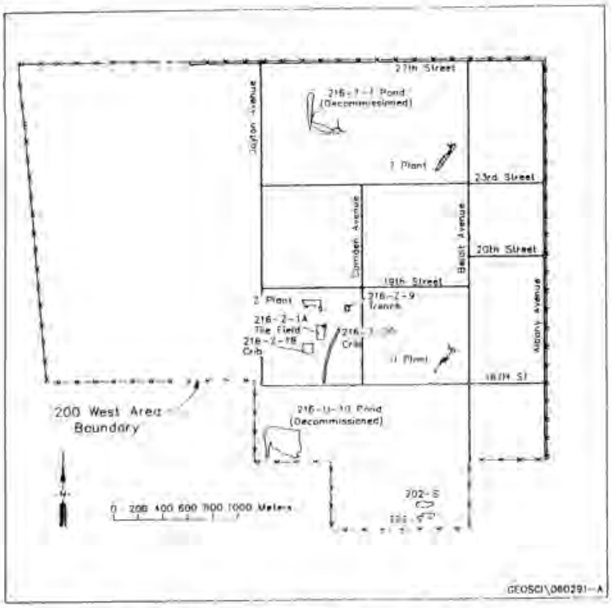

Fig. 2. Site map of the 200 West Area.

technology would be successful in the vicinity of the disposal sites (1,2,3). In addition, the technology is superior in that the carbon tetrachloride is readily separated from the plutonium in the soils due to the volatility of carbon tetrachloride.

In January 1992, the U.S. Environmental Protection Agency (EPA) and the Washington Department of Ecology (Ecology) authorized the U.S. Department of Energy (DOE) to proceed with the cleanup of the carbon tetrachloride in the unsaturated soils through an ERA. An ERA is a provision included in the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) that allows for accelerated cleanup activities. The goal of this ERA is to mitigate the spread of the carbon tetrachloride from the disposal sites to the ground water beneath Hanford's 200 West Area by removing carbon tetrachloride from the unsaturated soils.

Several innovative technology demonstrations are being conducted in coordination with the ERA and may eventually be integrated with the ERA effort to increase the efficiency of site remediation. The demonstration of innovative technologies is being conducted as part of the DOE's Volatile Organic Compounds - Arid Integrated Demonstration (VOC-Arid ID). The VOC-Arid ID was initiated in 1991 by DOE's Office of Technology Development to develop, demonstrate, and transfer for deployment the suite of technologies to characterize, remediate, and/or monitor arid or semiarid sites containing VOC (e.g., carbon tetrachloride) with or without associated metal and radionuclide contamination. The program is jointly managed by the Pacific Northwest Laboratory and Westinghouse Hanford Company. The initial focus of the integrated demonstration is the Hanford Site's 200 West Area carbon tetrachloride contaminated area. In the early phases of the VOC-Arid ID, activities are primarily focused on those technologies, characterization and monitoring, drilling, and gas-phase treatment, that may immediately improve the performance, or support the operation of the ERA.

ERA Approach

The Environmental Division of the Westinghouse Hanford Company, a contractor to the DOE, initiated the ERA using a phased approach to characterize and remediate the residual carbon tetrachloride contamination remaining in the unsaturated soils. Characterization and remediation is phased; optimizes the use of field screening level data and existing wells, and minimizes the generation of radioactive and hazardous wastes (3,4,5). This is done to meet the accelerated ERA time schedule, constrain costs, and meet the safety requirements for working in a radiologically contaminated area.

Soil vapor extraction from existing wells in the 216-Z-1A Tile Field is used in the initial remediation phase of the ERA (Fig. 3). Treatment of the extracted vapor will consist of using granular-activated carbon (GAC) canisters for adsorption of the VOC. The GAC will initially be sent offsite to a permitted facility for regeneration and the destruction of carbon tetrachloride. Additional vapor extraction units are presently being procured and will begin extraction at the other two disposal sites by fall of 1992.

Concurrent with the initial remediation phase, a detailed search for, and evaluation of, extraction and onsite treatment technologies will be conducted. This will be followed by field testing of one or more selected technologies in conjunction with the DOE's VOC-Arid ID. The goal of the treatment assessment will be to find onsite treatment technologies (above-ground and in situ) which meet applicable or relevant and appropriate requirements (ARAR), protection of the environment, and other selection criteria.

To enhance the rate and removal efficiency of carbon tetrachloride from the soils, further study of the wellfield design will be conducted. This will include modeling and investigations of wellfield enhancement and monitoring technologies. This activity will also be integrated with the VOC-Arid ID.

Further phases of site characterization will be conducted concurrently with remediation and is designed to further refine the conceptual model of the nature and distribution of carbon tetrachloride and co-contaminants; and determine other soil physical properties to support remediation design modifications.

SITE CHARACTERIZATION TECHNOLOGY NEEDS AND DEMONSTRATIONS

Standard site characterization tasks conducted as part of the ERA include drilling and sampling, soil gas sampling, ground water sampling, and pipeline integrity testing. Sample analysis is generally conducted with a combination of field screening and laboratory techniques. Due to the high costs associated with drilling, sampling and analysis, safety concerns (especially related to radiologically contaminated soils), and the lengthy drilling process, the scope of ERA site characterization activities has been reduced. As a result, data necessary to refine the conceptual model to support more efficient remediation is lacking. Several technologies are being investigated to decrease characterization time and costs, including sonic drilling, cone penetrometer testing, Science and Engineering Associates Membrane Instrumentation and Sampling Technique (SEAMIST), and certain analytical technologies.

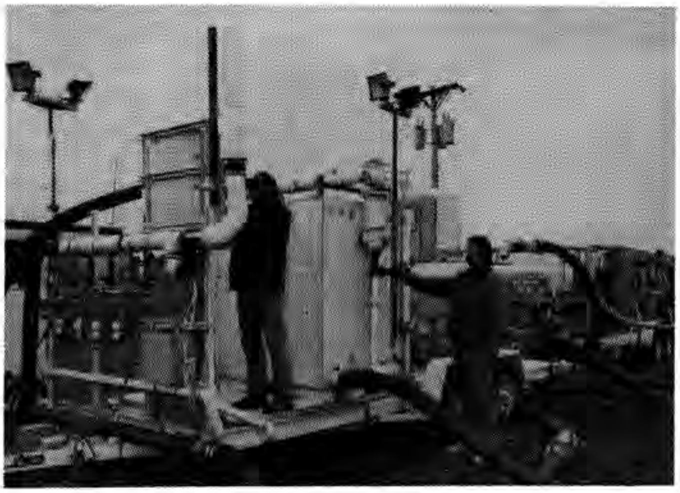

Fig. 3. Vapor Extraction System at the 216-Z-1A Tile Field.

Sonic Drilling

The primary methods for accessing subsurface soils for characterization is through vertical drilling. At Hanford, cable-tool drilling techniques have been used because of (1) sample quality while drilling through unconsolidated sands, gravels, and cobbles; (2) containment of drill cuttings in radiological or chemical contamination; and (3) minimal secondary wastes from drilling fluids. However, cable-tool techniques are generally slower than other well drilling techniques.

Sonic drilling (Fig. 4) is being evaluated as an alternative to the cable-tool technique, while still providing the advantages of reliability, containment, and waste minimization. The sonic drilling method's primary component is the sonic drill head. Sonic frequencies range up to 150 Hz with a peak force of 21,800 kg. The hole is advanced through shearing or cutting the formation. Drill cuttings are captured in a core tube and brought to the surface via a wireline winch retrieval system.

The effectiveness of sonic drilling was recently demonstrated at Hanford at depths to 30 m with an 7.6-cm-diameter well completion. Additional testing around the carbon tetrachloride disposal sites is under way and will focus on developing, testing, and evaluating the technology for deeper depths and larger diameter well completions and the impact on samples collected during drilling.

Cone Penetrometer Testing

Another technology that could augment and, in some cases, replace standard drilling at Hanford is cone penetrometer testing (CPT). CPT has not been used successfully at the Hanford Site in the past due to concerns that the cone penetrometer would be unable to penetrate coarse-grained Hanford soils. The cone penetrometer is an instrumented rod that is hydraulically inserted into the soil. CPT has been used extensively for soil studies and more recently in environmental investigations. In the right soil conditions, the cone penetrometer can penetrate up to approximately a meter per minute, a rate significantly greater than standard drilling methods, with little waste generation (no drill cuttings and no drilling fluids) and to depths approaching 60 m. Several soil parameters can be measured in situ with various probe instrumentation. Samples of soil gases and ground water can also be extracted for analysis. Another recent innovative CPT feature is its grouting capabilities, which allows grouting as the probe is withdrawn from the soils.

Fig. 4. Sonic drilling rig near the 216-Z-18 Crib.

In September 1991, Applied Research Associates conducted tests in the 200 West Area to evaluate the feasibility of using existing CPT technology in Hanford soils, which include coarse-grained sands and granule to boulder gravels. A total of 13 penetration tests were conducted at eight locations within a 20-km^2 area. The cone penetrometer achieved depths >3 m in six of the tests, each at a different location. The maximum depth reached was 20 m. CPT was used to install a permanent soil-gas monitoring probe at 20-m depth near one of the disposal sites. In addition, soil-gas sampling using the cone penetrometer was successfully conducted during selected tests.

Successful application of the CPT technology will require the development of an improved ability to penetrate the coarse gravel units common to 200 West Area soils. The U.S. Army Corps of Engineers is developing a CPT system for use in DOE's radiological environments, and efforts will be made to include improved penetration capability for future testing at Hanford.

SEAMIST

Determining the identity and distribution of VOC in the subsurface is critical to the design and operation of the vapor extraction system (VES). Currently, there is no technology at Hanford for routinely collecting in situ soil-gas samples during borehole drilling. Instead, soil samples that are brought to the surface may be screened at the drill site with a photoionization device or transferred to containers for subsequent analysis. However, VOC may be easily lost from the sample by disturbance during drilling, sample retrieval, and/or sample handling.

The SEAMIST system is designed to collect in situ depth-discrete soil samples and air permeability data during drilling. The system consists of an impermeable membrane, which is deployed down a borehole. As the membrane is lowered into the borehole and presses against the borehole wall, it has the effect of a continuous packer. A small sample line allows extraction of vapor for analysis at the surface. As the gas is pulled to the surface, the flow rate, the pressure at the flowmeter outlet, and the withdrawal zone pressure are measured. These data can be used to calculate air permeability.

The SEAMIST is being tested in a 200 West Area borehole principally to evaluate its ability to be deployed in wells/boreholes with varying configurations and soil types, extract depth-discrete soil samples, maintain sample representativeness, and measure air permeability during drilling. If successful, the SEAMIST will be investigated for use with other sensors.

Analytical Technologies

Analytical technologies to support characterization are being developed for use in 1993 and 1994. These include testing of supercritical fluid extraction (SFE) and analysis for non- and semivolatile organic co-contaminants, and development and testing of an unsaturated flow apparatus (UFA™) developed by Washington State University for the elucidation of transport parameters and other transport information.

Organic compounds such as tributyl phosphate, lard oil, and kerosene were disposed with carbon tetrachloride during Z Plant operations. The presence of these co-contaminants in subsurface soils may affect the effectiveness of monitoring and remediation strategies; therefore, methods are needed for detection of these materials in soil samples. Currently, analysis of these contaminants requires solvent extraction and liquid chromatography techniques. These methods generate secondary wastes and can be time consuming and costly. SFE is an available technology that may prove a rapid, low cost alternative method for characterization when integrated with appropriate detection systems. SFE and appropriate detection equipment are being evaluated for applicability to these organic co-contaminants and will be integrated into a field transportable system for rapid field analysis to aid in the site characterization efforts.

Transport properties of VOC and co-contaminants are necessary for defensible model predictions of the migration of VOC and water in the subsurface environment of arid sites (6). This type of information is site specific and traditionally requires long (>3 mo) of costly, and difficult experiments to obtain data under unsaturated moisture conditions. Application of UFA circumvents this problem by allowing rapid achievement of steady-state unsaturated flow conditions in soils/sediments through the use of centrifugal force and precision fluid flow. Acquisition of data requires hours to days rather than months to years.

WELLFIELD DEVELOPMENT TECHNOLOGY NEEDS AND DEMONSTRATIONS

The current wellfield design incorporates extraction wells for removing soil vapor from the subsurface and monitoring wells to provide indication of the radial influence of the extraction wells. The extraction and monitoring wells are selected from existing steel-cased vertical wells and perforated at intervals, which are based on an assessment of the geology, distribution of radioactive contaminants in the soil, well accessibility, and well construction. Presently, it is preferable to use the existing wells due to the costs, duration, and safety issues related to drilling through radiologically contaminated soils.

Several innovative technologies are being investigated in coordination with the ERA to enhance the removal of the carbon tetrachloride in the well-field. These technologies include the use of directional drilling for potential use in injection/extraction, in situ heating, and wellfield monitoring devices.

In Situ Heating

In conjunction with the VOC-Nonarid ID, a six-phase soil heating technology (Fig. 5) is being developed to increase subsurface soil temperatures and subsequently increase volatilization and removal of VOC from less permeable soils. In 1991, a 30-kW test facility capable of operating voltages up to 30 kV line-to-line was developed to investigate soil venting along with soil heating. Using this test system, data were obtained on the scale-up characteristics of six-phase electrical fields and the ability of these fields to heat and dry sandy soil at various initial moisture concentrations, simulating different locations within the vadose zone. It was found that extremely uniform heating could be achieved by the six-phase method.

Soil heating tests will be conducted this spring at an uncontaminated outdoor site and data from a bench-scale laboratory test will help determine the ability to remove trichloroethylene (TCE) and perchloroethylene (PCE) from clays by combined soil heating and soil venting. These activities will culminate in detailed specifications for a full-scale power system for testing at the VOC-Nonarid ID site, which may have applicability to removal of carbon tetrachloride.

Directional Drilling

In addition to vertical drilling, directional and horizontal drilling methods are being evaluated for VES remedial activities (and characterization and monitoring) at arid sites. Directional drilling techniques have been demonstrated at the DOE's Savannah River Site as a method for accessing contaminated zones at depths >30 m for characterization and more effective removal of VOC (7). Shallower applications of directional drilling have been frequently used for river-crossing cable installations and in other near-surface utility applications. In addition, the technology has recently been demonstrated at Sandia National Laboratory and at Tinker Air Force Base for shallow environmental applications. However, application of current technology to Hanford is not likely to be effective because of the geology of the site, need for containment and minimization of drilling fluids, and depths of 24 to 75 m required to address the primary contamination zones. Therefore, the VOC-Arid ID, in conjunction with the ERA, and other DOE integrated demonstrations, is conducting development and demonstration activities to test and evaluate directional drilling techniques for applications at Hanford and other arid sites.

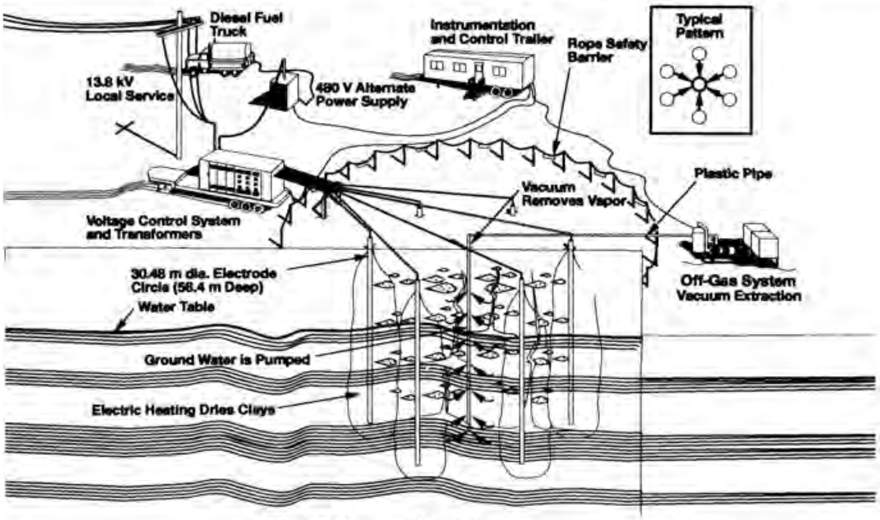

Fig. 5. In situ heating process.

Sensors

Monitoring in the wellfield provides operational information regarding flow rates and vacuum pressures. Additionally, sampling in the wellfield provides a measure of the remediation of the soils. Techniques for subsurface VOC monitoring are needed to support operations of the VES and improve the efficiency of the cleanup. Improved sensor systems for carbon tetrachloride and other VOC are being developed to meet these needs and also to support development and demonstration of enhanced remediation systems.

Sensors are under development for both offgas and borehole monitoring of VOC and include a solvatochromatic fiber-optic sensor from Lawrence Livermore National Laboratory (8), a portable acoustic-wave sensor (PAWS) from Sandia National Laboratory (9), and total organic chloride optical emissions sensor from Pacific Northwest Laboratory (10).

The PAWS and fiber-optic sensor will be integrated with borehole delivery systems for real-time monitoring of subsurface VOC concentrations at discrete depths. These sensors will be integrated with characterization technologies such as SEAMIST and CPT to provide enhanced subsurface characterization and monitoring capability.

TREATMENT TECHNOLOGY NEEDS AND DEMONSTRATIONS

The ERA VES processing system consists of two separate mobile units: a filtration unit and a blower unit. The general functions of these two units is to create the vacuum necessary to extract the soil vapor from the well-field and remove moisture and particulate from the soil gas, prior to sending the soil vapor through the treatment process. The treatment system removes the VOC from the extracted soil vapor. The present system uses GAC canisters in series. The activated carbon in the canisters adsorbs the contaminant vapor molecules. As it reaches its sorptive capacity, the GAC canisters are taken offline for the carbon to be regenerated and the VOC destroyed. The canisters are regenerated off the Hanford Site.

Several innovative technologies are being investigated in coordination with the ERA to improve the treatment process of the carbon tetrachloride, either aboveground or in situ. As the existing treatment process is costly and requires the offsite regeneration of the GAC, it is the goal of the ERA to find a technology, or combination of technologies, to treat carbon tetrachloride at the site at less expense and still meet regulatory requirements.

Offgas Treatment

Offgas VOC treatment technologies being readied for demonstration include a steam reforming system (Synthetica Technologies, Inc.) for GAC regeneration and a membrane separation system (Membrane Technology & Research, Inc.) for concentrating VOC in a liquid form for subsequent recycling or treatment. Steam reforming (Fig. 6) is commonly employed as a catalytic process to make hydrogen gas from methane. Noncatalytic steam reforming has been studied extensively for use as a coal gasification process (11,12). The Synthetica detoxifier is a noncatalytic, resistively heated steam reforming process for destruction of toxic organic compounds (13). The steam reforming system will be demonstrated this spring using GAC canisters loaded with carbon tetrachloride and chloroform from the ERA's VES. Synthetica and Sandia National Laboratory will conduct the demonstration. If successful, the steam reforming system will be considered for longer-term testing and used to support the ERA.

A pilot-scale membrane separation system will be demonstrated this year to evaluate its effectiveness for reducing VOC loading of GAC canisters, thereby reducing the ultimate cost of GAC regeneration. Membrane Technology & Research, Inc. will be demonstrating the pilot-scale commercial system in collaboration with Westinghouse Hanford Company. Performance and cost analyses will be conducted as part of the demonstration to fully evaluate the benefits of the membrane separation process for enhancing the existing VES system.

These offgas treatment systems either regenerate GAC or remove the VOC from the offgas stream to minimize the loading of GAC canisters. Technologies are also being developed to destroy the VOC to minimize the need for GAC and eliminate the need for liquid-phase VOC treatment. These technologies include high-energy electrical discharge (corona) technology being developed at the Pacific Northwest Laboratory, and a tunable hybrid plasma (THP) system being developed at Massachusetts Institute of Technology. The corona technology is being tested with TCE at the bench scale for demonstration at the VOC-Nonarid ID, and will be tested and scaled up for demonstration with carbon tetrachloride at Hanford. The THP device combines RF heating and low temperature plasma in a tunable system that will automatically adjust to variations in the VOC offgas concentration. The THP will be tested at a bench scale this fiscal year. Both systems are scheduled for larger-scale demonstrations in 1993.

In Situ Contaminant Destruction

In addition to heating, research efforts are under way to evaluate the feasibility of producing a high energy corona in situ to destroy VOC in place. Development of the six-phase technology is an important preliminary step toward the development of the high energy corona technology for demonstration at Hanford. Laboratory tests will be accomplished this year to investigate the electrical characteristics of high energy corona in soils, and a bench-scale test will study the ability to remove carbon tetrachloride from a silty soil in support of the ERA and VOC-Arid ID.

Sensors

Several parameters are measured at selected locations on the existing VES processing equipment for operational, engineering, compliance, and safety purposes. Particulate radiation is measured by alarmed CAM between the high efficiency particulate air (HEPA) filter banks as a backup safety feature. Vapor carbon tetrachloride concentration measurements are made before, between, and after the GAC canisters for compliance monitoring and system trend analysis with in-line sensors. In-line ports to allow soil vapor samples to be drawn for field gas-chromatograph or laboratory analyses are also available. In addition, naturally occurring radon measurements are made before, between, and after the GAC canisters. Further development of these detectors may be required and will be utilizing VOC-Arid ID sensors. The initial focus of the sensor development efforts is to demonstrate real-time process monitoring for the VES offgas system to provide direct support to the ERA. These sensors are discussed in the wellfield development technology needs and demonstrations section.

Groundwater Treatment

Although not part of the ERA, treatment of the 13-km^2 carbon tetrachloride plume underlying the disposal sites may need to be addressed in the future. Presently, the difficulty in remediating the ground water is related to (1) existing pump-and-treat technology being costly and creating a large volume of purge water, and (2) carbon tetrachloride in the ground water being mixed with other contaminants, including radiological contaminants.

An in situ bioremediation process is being developed that uses native microorganisms to anaerobically destroy carbon tetrachloride and nitrates in ground water. Evidence of carbon tetrachloride degradation by microorganisms native to the Hanford Site was first obtained with a denitrifying consortium from ground water samples (14). Additional studies conducted at laboratory, bench, and pilot scales confirmed that nitrate and carbon tetrachloride were degraded by these natural microorganisms (15,16).

A field test site is being developed in the 200 West Area north of the ERA site to demonstrate and evaluate the effectiveness of in situ bioremediation of carbon tetrachloride in ground water. The first test site borehole was drilled in 1991 to obtain aquifer samples for biological, chemical, and physical characterization. A second, adjacent borehole is being installed to obtain additional well-to-well field data on the geohydrology, geochemistry and microbiology of the test site. Laboratory- and bench-scale studies using sediment and core samples from the field site are being conducted to obtain kinetic information and design data for field testing. Field data, as well as laboratory- and bench-scale kinetic data are being incorporated into a three-dimensional transport and reaction model provided by Rice University under a collaborative agreement. Predictive simulations will be conducted to evaluate design options for the field test site and to aid in the evaluation of test data. Critical to the success of the technology, parallel research efforts are under way to assess the potential impacts that bioremediation may have on long-term radionuclide or heavy metal mobility and aquifer permeability, and to improve the understanding of the mechanisms of biodegradation of carbon tetrachloride and chloroform. Field test site development will continue through 1992 and 1993, with initial tests of microbial stimulation scheduled for 1994.

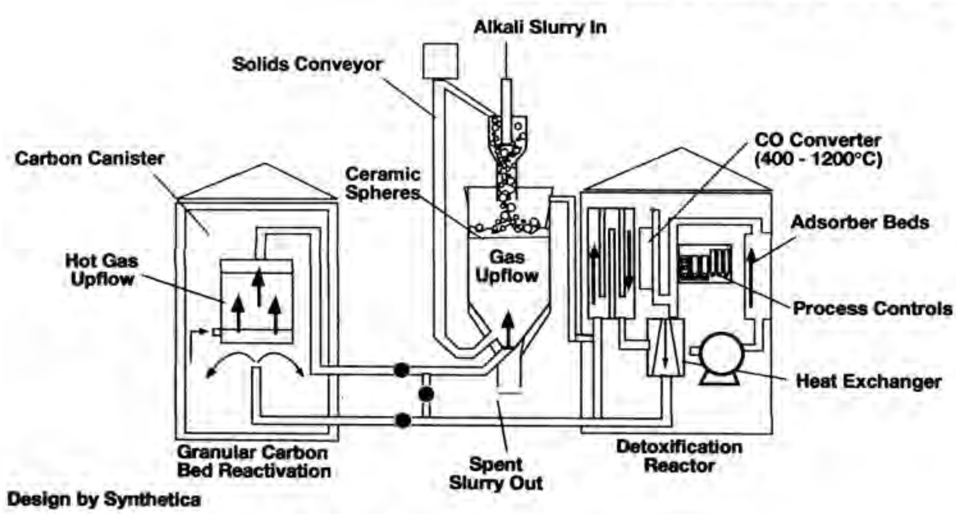

Fig. 6. Steam reformation process.

CONCLUSION

By combining ERA and ID activities, short- and long-term cost and time savings are expected. Cost savings have already been realized through the use of sonic drilling at the Hanford Site. Longer-term cost savings are expected, especially with the introduction of better characterization tools and treatment processes. In addition, the efficiency of carbon tetrachloride removal will be increased with the introduction of new characterization and wellfield development technologies.

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