SANDIA NATIONAL LABORATORIES CHEMICAL WASTE LANDFILL: INNOVATIVE STRATEGIES TOWARDS CHARACTERIZATION AND REMEDIATION*

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ABSTRACT

The Chemical Waste Landfill (CWL) was used by Sandia National Laboratories (SNL), Albuquerque for disposal of hazardous chemicals from the years 1962 to 1985. During routine sampling in the spring of 1990, low levels of trichloroethylene (TCE) were detected in groundwater samples from a water table aquifer approximately 146 meters below ground surface. Therefore, a RCRA Site Investigation (RSI) has been initiated and remediation of organic contaminants will be performed at the CWL prior to closure of this landfill. The RSI is focused on optimal characterization of the volatile organic contamination (VOC) and dense non-aqueous phase liquid (DNAPL) contamination at this site. This will be possible through application of innovative strategies for characterization and promising new technologies which are discussed in this paper.

The first part of this paper provides a discussion of conceptual models of VOC and DNAPL transport at the CWL and an overview of our investigative strategy. Each stage of the RSI has been developed to gather information which will reduce the uncertainty in the design of each subsequent phase of the investigation. Three stages are described; a source characterization stage, unsaturated zone characterization stage, and a saturated zone characterization stage. An important focus of the unsaturated zone characterization phase is to provide all data necessary to make decisions concerning the necessity of additional saturated zone characterization.

The second part of this paper presents a brief discussion of some innovative approaches to characterization and remediation that are being applied at the CWL. Through the SNL Environmental Restoration Program's desire to find new and improved methods for site characterization and remediation, several innovative technologies have been identified. These technologies include: the surface towed arrays developed by the Naval Research Laboratory for use in locating buried ordinance, core drilling using sonic energy, and soil gas measured from monitor wells to aid in characterization of the soil gas plume. Additionally, as the CWL is part of Department of Energy's (DOE) Integrated Demonstration Program, an on-site demonstration of the thermal-enhanced vapor extraction system (TEVES) will be completed and a discussion of this demonstration at the CWL is provided.

INTRODUCTION

Sandia National Laboratories, Albuquerque, New Mexico (SNL) under contract to the Department of Energy (DOE), utilized the Chemical Waste Landfill (CWL) for disposal of hazardous waste from the years 1962 to 1985 (see Fig. 1). A Closure Plan designed to meet RCRA Closure and Post-Closure Requirements (40 CFR 265) is currently under review by the New Mexico Environment Department's Radioactive and Hazardous Materials Bureau. Because low levels of trichloroethylene (TCE), a dense non-aqueous phase liquid (DNAPL), have been detected in groundwater samples from a water table aquifer approximately 146 meters below ground surface, the closure process at this landfill will include a RCRA Site Investigation (RSI) phase (which is focused on characterization of the organic contamination), a Corrective Measures Study (CMS) phase and a Corrective Measures Implementation (CMI) phase prior to final capping and post-closure monitoring of the site.

As the RSI is just beginning at the CWL, this paper provides an overview of our investigative strategy with highlights of some of the innovative technologies currently being employed at this site. Initially, we will present a discussion of the possible conceptual models of volatile organic contaminant (VOC) and DNAPL contaminant transport at the CWL. This will be followed by a discussion of the RSI Strategy which

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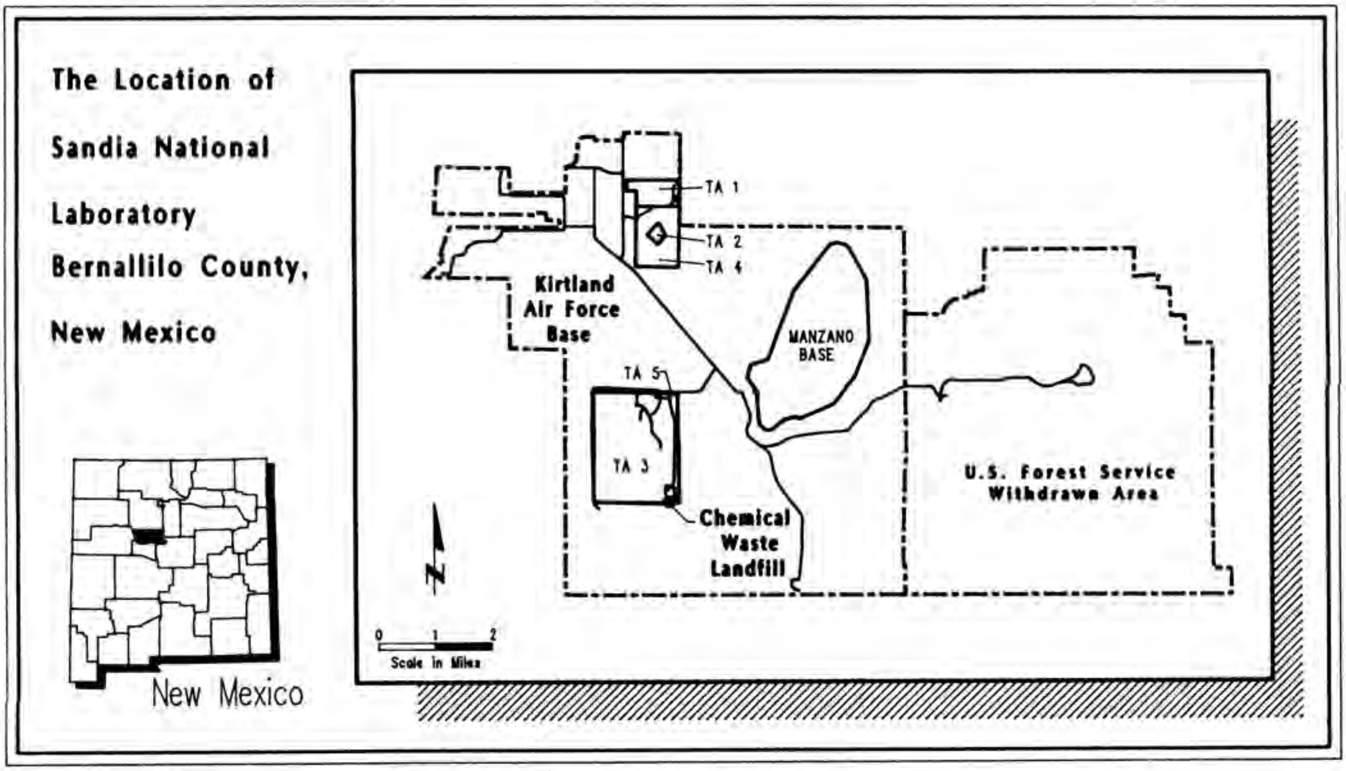

Fig. 1. Map location of Sandia National Laboratories.

has been designed to reduce the uncertainty associated with the current conceptual model.

Secondly, and in keeping with the spirit of technology exchange for which the Waste Management '92 conference is a forum, we will highlight some of the innovative technologies which have been or will be employed at the CWL to enhance the effectiveness of the investigation. Additionally, the CWL has been selected by DOE to be a technology demonstration site in the DOE's Integrated Demonstration Program, a program initiated by DOE to demonstrate on-site innovative technologies. An on-site demonstration of the thermal-enhanced vapor extraction system (TEVES) will be implemented in parallel with the RSI program at the CWL. A brief introduction as to the nature of this demonstration is also presented.

Site Background

The CWL is approximately 1.9 acres in areal extent (see Fig. 2). Separate disposal pits are known to have been used for the disposal of acids, oxidizers, reducers, organics, reactives, bulky materials, metal, neutral compounds, and salts. Written records of disposal practices were not kept between 1962 and 1975, resulting in a fair degree of uncertainty concerning the actual locations of waste pits at the site and the actual volumes of different types of wastes disposed. It has been inferred from preliminary reconnaissance studies of the CWL (1,2) that the waste pits were rather uniformly distributed around the full extent of the CWL. Based on known disposal rates and volumes, a conservative estimate of the amount of waste disposed at the landfill is 600 m^3 of chemical waste during the period 1962-1985 (3). Liquid organics in the form of solvents and waste oils were the largest percentage of waste disposed at the CWL.

The sediments beneath the CWL are very heterogeneous, with discontinuous sedimentary layers of alluvial, and possibly fluvial origin, composed of varying percentages of sand, silt, and clay. Groundwater is at a depth of approximately 146 meters below ground surface, with a local apparent groundwater flow direction trending northwest. Ten monitor wells have been installed at the site, five of which are utilized for assessment monitoring (see Fig. 2). Based on the current understanding of site conditions, the contaminants of concern at the CWL with respect to impacts on groundwater resources are DNAPLs disposed of in the form of solvents which were sometimes mixed with oils.

TECHNICAL APPROACH TO SITE CHARACTERIZATION

Dense non-aqueous phase liquids (DNAPLS) are of primary concern for the CWL RSI as the physical nature of these contaminants provides for transport over a thick (146 meters) unsaturated zone. To date, only minor impacts to groundwater quality (i.e., concentrations near the EPA's drinking water standard of 5 ppb) have been identified, however the potential for further groundwater impacts must be assessed through site characterization of the unsaturated zone. Through the investigation, the contaminant transport mechanism through the vadose zone will be understood, and a conceptual model will be validated. Following is a brief discussion of possible conceptual models of DNAPL transport at this site, including the currently-accepted conceptual model.

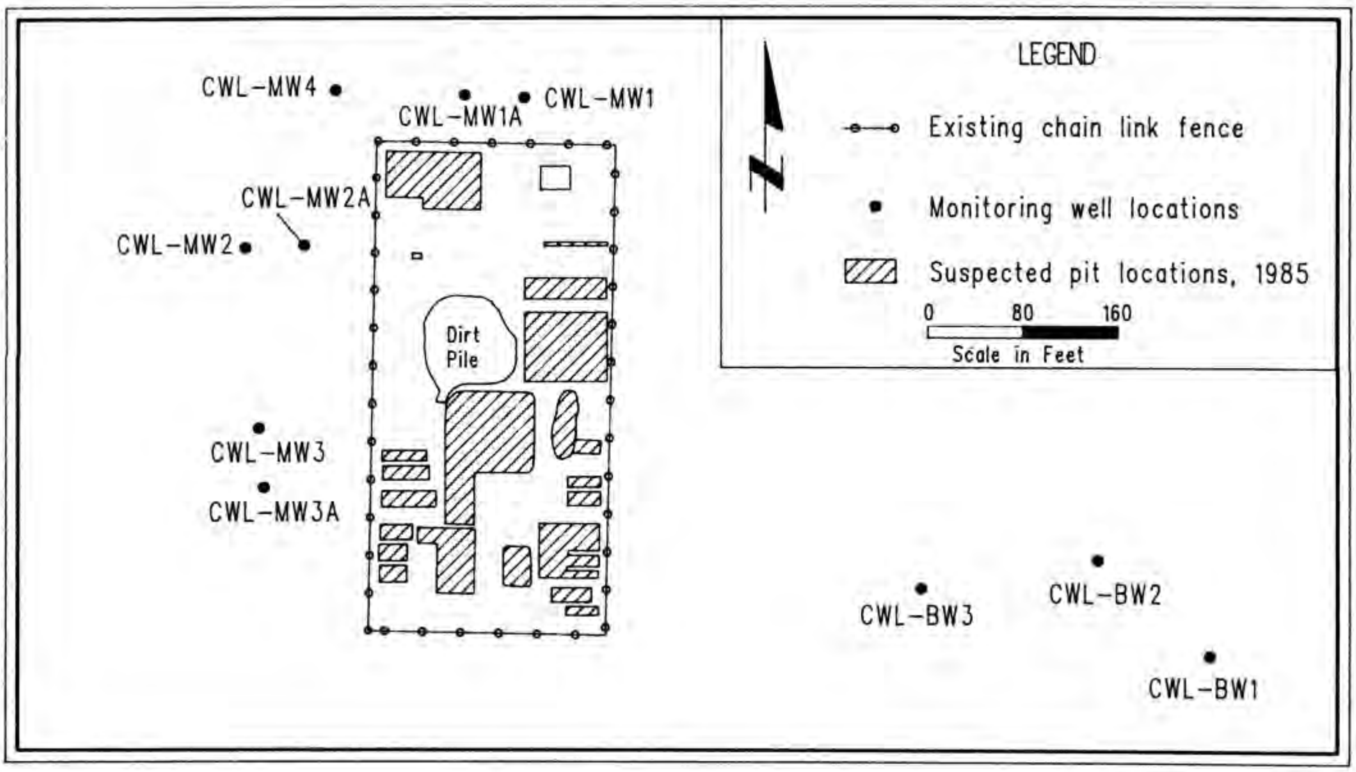

Fig. 2. The chemical waste landfill

Conceptual Models of VOC and DNAPL Contaminant Transport

There are three possible pathways for DNAPL contaminants to travel through the unsaturated zone and reach the water table. For a volatile organic contaminant such as TCE, these pathways correspond to the three fluid phases present in the unsaturated zone beneath the CWL: the aqueous phase (i.e., dissolved in soil water), a separate organic liquid phase (i.e., DNAPLs), and the vapor phase (i.e., soil gas or VOCs).

If contaminants were carried in the water as a dissolved phase (or aqueous phase), transport would be accomplished by the dissolution of a contaminant into precipitation that filters through the CWL and subsequently percolates down to the water table. Figure 3 depicts contaminant movement by aqueous-phase transport. Because of New Mexico's arid environment, only a very small flux of rainwater will infiltrate the CWL. The estimated seepage velocity for this area is on the order of $1x10^{-6}$ m/day. Therefore, for the unsaturated zone, aqueous-phase transport of contaminants is the least likely of the three migration pathways through this zone.

Transport of organic liquids as a separate dense, nonaqueous phase liquid (DNAPL) is the second possible migration pathway through the unsaturated zone. Figure 4 illustrates movement of a dense nonaqueous phase liquid from the CWL. For a separate organic-liquid phase to move, disposal of large volumes of organic solvents and oils is necessary. Once the organic-liquid phase reaches the water table, it dissolves into the groundwater. Preliminary calculations based on estimates of organic liquid volumes disposed of in the CWL demonstrate it is unlikely that organic liquid phases could have migrated as far as the water table.

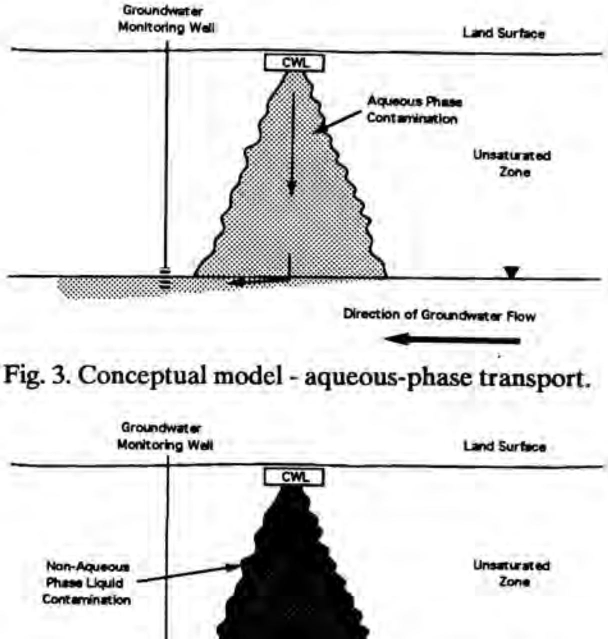

Fig. 3. Conceptual model - aqueous-phase transport.

Fig. 4. Conceptual model - dense nonaqueous phase liquid transport.

A "cloud" of organic vapors could migrate through the unsaturated zone and contaminate the groundwater through dissolution from the gas phase (see Fig. 5). For example, TCE volatilizes to form a mixture with soil gas that is about 1.35 times as dense as uncontaminated soil gas. Mendoza and Frind (4,5) have shown that under favorable conditions, it is *possible* to achieve density-driven transport of volatile organic contaminants. Although, sediments under the landfill are fairly coarse and dry, the highly layered soil structure makes density-driven transport more unlikely.

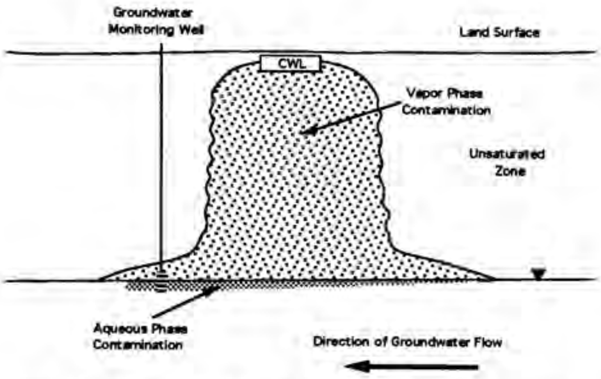

Fig. 5. Conceptual model - vapor phase transport.

It is possible that the TCE was transported to the water table in the vapor phase by gaseous diffusion. Calculations of the time required for vapor-phase TCE to reach the water table by diffusion processes alone have been completed. These calculations indicate that a travel time of 11 years is required for the contaminated vapors to reach groundwater (3). If density effects were to be included in these calculations, the travel time would be less.

Most likely, the actual contaminant pathway through the unsaturated zone is a combination of a dense, non-aqueous phase liquid (DNAPL) plume in the unsaturated zone with vapor-phase transport of contaminants from the DNAPL plume to the groundwater (Fig. 6). As the organic liquid phase moves through the unsaturated zone, a residual is left behind. Further migration of contaminants from the residual phase can only occur through volatilization of the contaminant from this phase and subsequent movement of the contaminant in the gas phase. Calculations utilizing the estimated amount of DNAPLs disposed of in the CWL suggest that some residual DNAPLs are to be expected under the CWL.

Because of the direct implications with regard to existing and potential impacts to groundwater quality, an important focus of the RSI is to determine the nature and extent of the VOC and the DNAPL plumes in the unsaturated zone. The *analysis* of the unsaturated zone investigation phase of the RSI will be used to determine the necessity of additional saturated zone characterization as is discussed in more detail below.

RCRA Site Investigation Strategy

Each stage of the RSI has been developed to gather information which will reduce the uncertainty in the design of each subsequent phase of the investigation. The DOE and some of its contractors have coined the phrase "the Observational Approach" to describe this process of performing an investigation. Figure 7 illustrates the strategy of the investigation, describes the dependencies of each stage *and the flow* of information through completion of the RSI and initiation of the CMS.

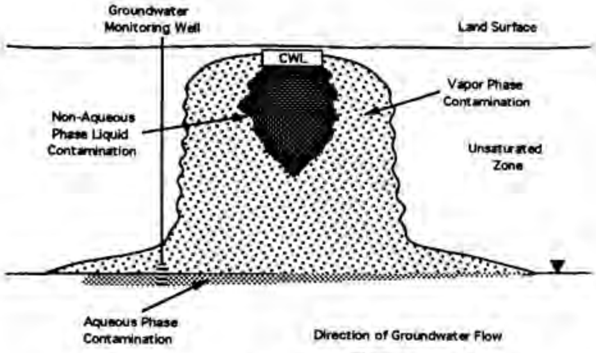

Fig. 6. Conceptual model - DNAPL and vapor phase transport

We are currently in Stage I of the CWL RSI, the source characterization phase. All historical information pertaining to waste characterization has been collected and is being quality-checked for reliability. Acceptable data will be input into SNL's geographic information system (GIS). Using the GIS will enable us to compile existing chemical and hydraulic data to assist in designing an optimal soil sampling strategy.

As part of this stage of the RSI, a surface geophysical survey was performed and the data is currently being evaluated by the Naval Research Laboratory (NRL). The NRL utilized the surface towed array locator systems (STOLS) and a surface towed ground penetration radar system (RADAR) (discussed further below) to locate all buried metallic waste, and to further define pit boundaries. These data will be input to the GIS, and will be compared with earlier geophysical survey data as well as other historical data to produce a final target map which will define pit locations and buried metallic waste. The target map will be used for design of a soil gas survey grid that will provide for effective characterization of the volatile organic contaminants in all pit locations at the CWL.

A mobile lab with a portable gas chromatograph/mass spectrometer (GC/MS) will permit on-site interactive analysis of all VOCs the vicinity of the CWL during the soil gas phase of Stage I. There is uncertainty with respect to migration pathways through the heterogeneous sediments at the CWL. A soil gas survey provides an excellent way to collect numerous data points thereby reducing uncertainty in the locations for optimal soil sampling sites to completely characterize the unsaturated zone contamination. Areas with high levels of VOCs, or "hot spots," as well as the lateral extent of the gas plume in the source area, will be determined through the soil gas survey. These data will be evaluated and input to the GIS to develop of the soil sampling plan.

During the Unsaturated Zone Characterization phase (Stage II), soil samples will be collected in "hot spot" areas to define the extent and transport mechanism of contamination in the unsaturated zone. Samples will be collected for chemical analysis and characterization purposes. The mobile GC/MS will enable us to collect real-time data of VOC contaminant levels, and, through an interactive process of utilizing the field data, unsaturated zone modeling and decision theory (6), the plumes in the unsaturated zone will be optimally characterized. Monitor-well gas sampling (discussed further below) and in situ air permeability testing will be performed during Stage II to provide data for unsaturated zone modeling and remedial-action design. Data collected during Stage II of the RSI will help to reduce the uncertainty about the location of the plumes and will put constraints on travel times through the unsaturated zone. The dimensionality of the plumes and the mass available for transport will also be determined. At the conclusion of Stage II, the conceptual model will be updated if necessary.

The conceptual model formulated in Stage II will be used as a basis to design the investigative strategy for the Saturated Zone Characterization (Stage III). If data support the conceptual model discussed above (i.e., diffusion-only gas-phase transport), and, as based on an understanding of the dimensionality and total mass of the plumes, unsaturated zone modeling does not predict that additional groundwater impacts will occur, then we will consider the existing monitor well network (see Fig. 2) adequate to determine the maximum extent of the saturated zone plume. If the conceptual model is not supported through the site characterization and additional impacts on groundwater are found to be likely, then a saturated zone investigation will be completed prior to the CMS. Through evaluation of the unsaturated zone and existing saturated zone characterization data, optimal well locations will be evaluated.

INNOVATIVE TECHNOLOGIES

Through SNL Environmental Restoration Program's desire to find new and improved methods for site characterization and remediation, the following innovative technologies have been identified and have been or will be applied during the CWL RSI.

Naval Research Laboratory's Towed Arrays

Standard methods for surface geophysical surveys often produce data of marginal quality as the surveys are grid-based, and often the grids are too coarse to allow for accuracy in determining the location of buried drums and or disposal pit boundaries. It is important to have accurate data on locations of buried waste for health and safety reasons during intrusive investigations, and for economic reasons if waste extraction is a necessary component of a corrective action process.

For these reasons, in June of 1991, SNL contracted with the Naval Research Laboratory (NRL) to employ a relatively new application of existing surface geophysical methodologies developed by the Naval Explosive Ordnance Disposal Technology Center and the NRL through a contract with Geo-Centers, Inc. The need for a high level of accuracy to locate buried ordnance and the need to cover large tracts of land rapidly were the driving forces in development of the surface towed ordnance locator system (STOLS) and a towed ground penetrating radar system (RADAR). One of the main advantages of these systems is that continuous data and complete coverage of a site are accomplished as the STOL's magnetometer and the RADAR's GPR antennae arrays are towed across the site. This greatly enhances the accuracy of predicting locations of buried objects and soil disturbances.

The STOLS is a low-magnetic, self-signature, six-wheel all-terrain vehicle (ATV) that carries a computerized data

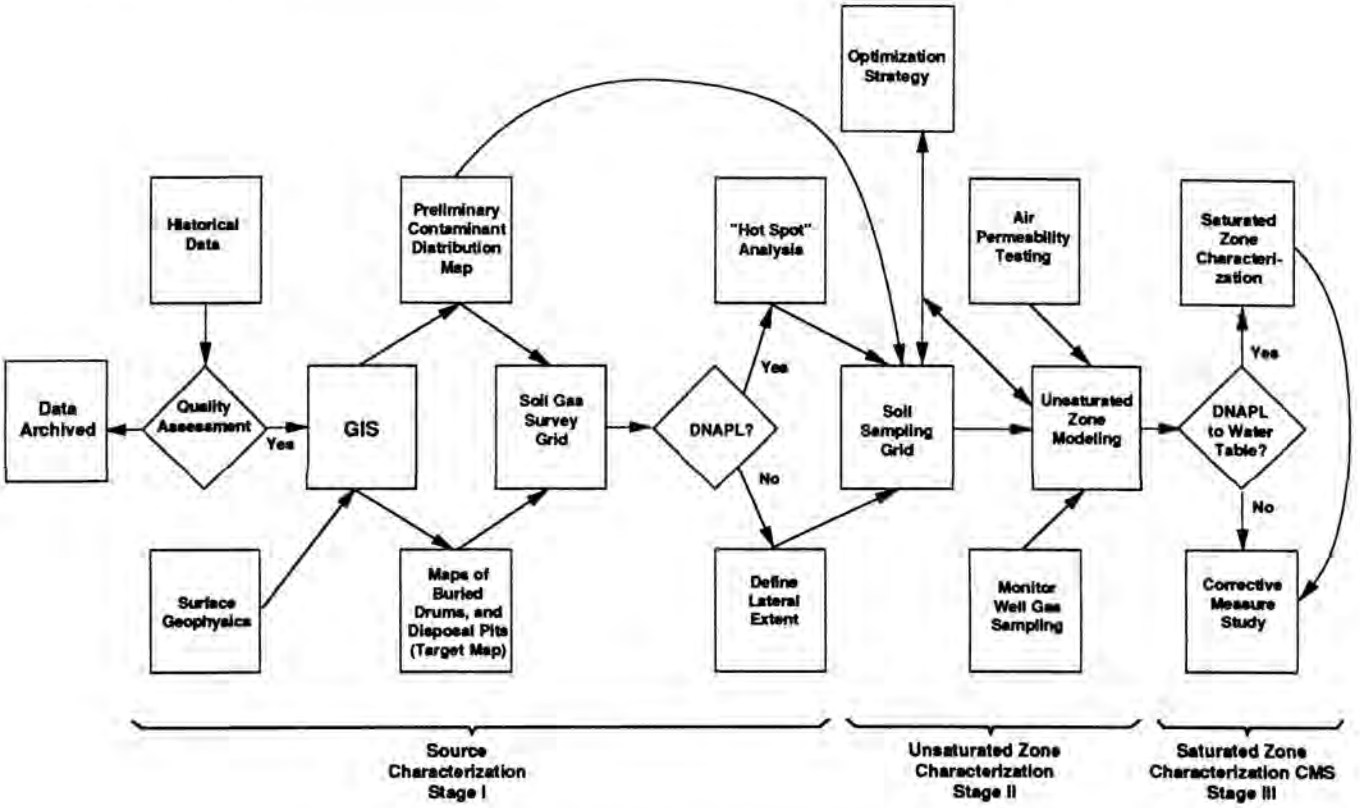

Fig. 7. General investigative approach for the CWL RSI.

acquisition system, an operator control panel, a track finder, and a microwave positioning system; it has an array of seven sensitive magnetometers in ruggedized tubes and a digital electronic compass for positioning. The STOLS can locate and estimate depths to buried metallic objects to ±1 m within 5 m of the land surface and categorize targets as small, medium, or large. It operates at temperatures between 2 and 43°C under conditions of from 0% to 99% humidity. The STOLS consists of a tow vehicle (STV), a tow platform (STP), a remote navigation station (RNS), a reference sensor (SRS), a command center (SCC), and system support.

The RADAR is an automated, multisensor array of four GPR antennas (functioning at 300 MHz) that is towed by an all-terrain vehicle for use on- and off-road. The RADAR can detect metallic objects and areas of disturbed soil or sediment, such as trenches or pits, within 5 m of the surface. The RADAR system consists of five major components: the RADAR tow vehicle (RTV), the tow platform (RTP), remote navigation stations (RNS), a command center (RCC), and system support. The total system enables the user to evaluate large amounts of data on-site.

Some disadvantages of this equipment include the following: (1) the RADAR and the STOLS are prototypes, and the reliability under adverse field conditions is currently being tested; (2) the locator systems can be "confused" due to interference from nearby buildings, fence posts, etc.; and (3) the magnitude of the signal can affect the resolution of final target maps (e.g., metal objects buried close to the soil surface can appear larger than they are).

For STOLS data, target-location and target-size analysis is performed via application of a target analysis algorithm. The initial estimate gained from collection of the field data is used as a seed for an iterative model-matching algorithm that performs a least-square fit of the data to a dipole model of the field survey data. The derived dipole coordinates are reported as target location and depth; the dipole strength is used to classify the target as small, medium, or large.

The STOLS has had a high success rate in locating both buried ordnance and 209-L drums in a variety of geologic environments. At a site in Maryland, the STOLS successfully located a 209-L drum buried 1.8 m under the surface. At sites in California, Maryland, and Massachusetts, the RADAR system had a 97% success rate in locating buried targets to within ±1 m. The RADAR was sensitive enough to locate a 0.16-m target buried 1.5 m under the surface.

Monitor Well Gas Sampling

The sampling and analysis of VOC gas in the vicinity of the water table provides for additional data which can be fitted to an unsaturated zone model of contaminant transport at the CWL. Even though depth to water is over 146 meters below ground surface, sampling of soil gas in this area is possible through use of existing monitor wells. Six monitor wells at the CWL have screened intervals which span the air/water interface. Through a system of packers and the use of the on-site mobile GC/MS, VOC concentrations of the gas plume in contact with groundwater can be periodically evaluated.

A major objective for this monitoring is to evaluate the vapor concentrations over time. For diffusional transport of vapors, the change of concentration with time will depend on a number of factors including distance from the source, and the time since source emplacement. Monitoring the change in vapor concentration over a time can provide information on the mechanism of aquifer contamination. If free organic liquid is located near the water table the rise in vapor concentration would be more rapid than if free organic liquid is restricted to the immediate vicinity of the CWL. Furthermore, tracking the changes in vapor concentrations in contact with the water table will act as an early warning system of changes in the contamination concentrations in vicinity of the groundwater.

In December, 1990, monitor well gas was first sampled at the CWL, however these samples were sent to a laboratory for analysis. Figure 8 illustrates the concentration of the major contaminants found to present in the soil vapor in contact with groundwater at the CWL. The major contaminants detected at the time of this sampling were Freon 113 (1,1,2-trichloro-1,2,2-trifluoroethane), trichloroethylene and trichlorofluoromethane. Toluene was also detected but its source was determined to be from packer contamination. (Note that the concentration of the other contaminants remained constant with purge volume while the concentration of toluene did not.)

Figure 9 illustrates the monitor well gas sampling equipment that will be used for all future monitor well gas evaluations. A packer is placed just above the screened interval and inflated to ensure that only vapors from the vicinity of the air/water interface are collected for analysis with the GC/MS.

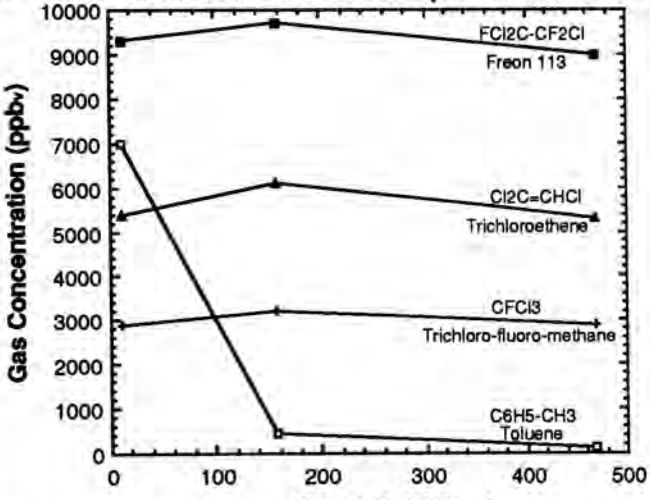

Fig. 8. Contaminant gas concentrations versus purge volumes.

The sample pump is used to extract gas from the bottom portion of the well casing. The rotameter is used to measure the flow rate of the sample gas for calculation of purge volumes and contaminant concentrations.

Sonic Well Drilling

The sonic (or rotasonic) drilling technique has been used for many years in the mining and construction industries but has had relatively little application in the environmental fields. Recently, several drilling companies have modified the sonic drilling system for use in site investigation work. Through a contract with Water Development Corporation, SNL will apply this technology to several sites currently undergoing RFI's. This method will be used during the CWL RSI to collect soil samples and perform soil gas profiling at borehole locations.

The sonic drilling technique involves use of a sonic drive composed of two opposing 6.8 kg counterweights mounted in

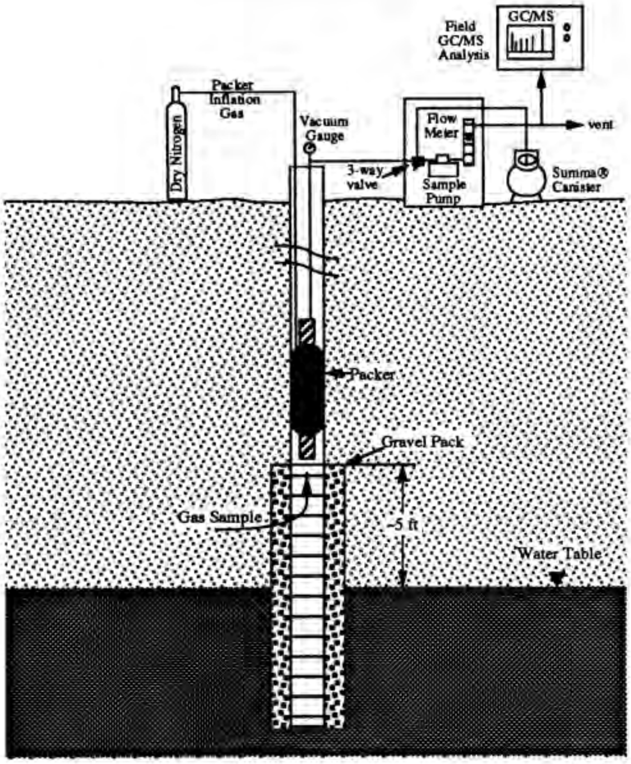

Fig. 9. Monitoring well gas sampling equipment schematic.

an internal casing in the drive unit. These weights are rotated at 9,000 revolutions per minute, causing the drill head to vibrate in a vertical direction of force. This vibrational energy is ultimately transferred to the soil/sediment at the bottom of the drill stem and causes the particles to behave more like a fluid during that instant of contact and allows the drill stem to advance. At optimum vibrational frequency, the sonic drive produces approximately 13,600 kg of downward or upward force.

This drilling method has several advantages important to characterization at hazardous or mixed waste sites. The drilling process produces no cuttings and requires no drilling fluids which would have to be disposed of as hazardous waste at a very high cost. The rate of drilling is several times faster than other drilling methods (up to 60 meters a day). Additionally, the method produces continuous undisturbed core which allows complete description and screening of the soil/sediment column. A retractable plug at the base of the drill stem allows for soil gas profiling at depths of over 120 meters.

Thermal Enhanced Vapor Extraction System

All types of typical laboratory-generated organic wastes including: alcohols, aldehydes, amines, ketones, benzene and substituted benzenes, ethers, phenols, polymers, heterocyclic compounds were disposed of at the CWL. However, the largest volume of organic wastes were composed of VOCs, and various types of oils (hydraulic, transformer, heat transfer fluid and motor oils).

Remediation of VOCs in soils has been successful using vacuum venting technology (7). However, at the CWL, the mixing of VOCs and oils reduces the vapor pressure of the VOCs. This mixing may limit the effectiveness of typical vacuum venting remediation technologies. Volatilization of organic chemical mixtures is a function of the mole fraction of the constituent of interest and its solubility in the primary liquid phase. At some locations within the CWL, the primary liquid phase is probably oil rather than soil water. Volatile solvents dissolved in oil have been found to have lower evaporation rates compared to the pure solvent (8). A wide spectrum of organic solvents in oils will have lower volatilization rates compared to a single component in an aqueous phase. With these limiting factors, typical ambient temperature vacuum extraction may not be effective in remediating the contamination at the CWL. To overcome the volatilization limitations of the waste forms placed in the CWL, in-situ soil heating of the near surface will be combined with typical vacuum extraction technology.

The TEVES project is part of a DOE Office of Technology Development program to demonstrate remediation technologies that have the potential for near-term, high-return and cost-effective solutions to environmental restoration problems. The TEVES is planned as a three stage demonstration where subsurface temperature, pressure, air phase permeability, and extracted mass load data are collected during an ambient temperature phase, a 90°C electromagnetic heating phase and a 150°C radio frequency heating phase. Each of these three venting stages is discussed in more detail below.

Ambient Temperature Venting Operation - The system is anticipated to be operated for 60 to 90 days. Data will be collected from the subsurface monitoring system and pre/post off-gas treatment to estimate mass removal rates. Soil-gas samples from the subsurface monitoring system will be used to evaluate the effectiveness of this first vapor extraction operation.

In-Situ Electromagnetic Heating and Venting Operation - This phase will be the first step in thermal enhanced vapor extraction with the use of 60Hz electromagnetic heating. This utilizes the principle of ohmic heating of the soil pore fluid and is expected to heat the soil to a maximum of 100°C. The system is anticipated to be operated for 30 days.

In-Situ Radio-Frequency Heating and Venting Operation - This is the second step in the thermal enhanced vapor extraction and will use high-frequency radio frequency energy to dielectrically heat the soils. This energy can heat the soil higher than 100°C and has been used up to 160°C (9). The system is anticipated to be operated for 30 days.

Data will be collected to assess enhanced removal efficiency with increased temperature. After each venting operation, soil gas sampling will be performed to determine the mass of contamination removed and the remaining contamination types and concentrations. It is anticipated that a wider spectrum of higher boiling constituents will be removed as the temperature is increased and that mass removal rates will increase with temperature. Critical to the evaluation of this project is the cost savings of thermal enhanced vapor extraction over ambient temperature vacuum extraction. Key to cost savings is expected in the reduction in the time needed to reach soil cleanup criteria.

CONCLUSIONS

Through application of innovative strategies for performing the CWL RSI and utilization of promising new technologies, we will be able to effectively characterize the CWL and design a remediation system for the VOC and DNAPL contamination that has impacted groundwater in this area.

Through optimization of sampling strategies and field testing of vapor extraction technologies concurrently with the RSI, we will be able to save time and money during the course of site characterization and remediation of this site.

We will apply risk-based assessment methodologies which take into consideration contaminant transport phenomenon and provide defensible analysis of the ultimate fate of contaminants in the unsaturated zone at the CWL. With this knowledge base, closure decisions concerning the efficacy in constructing additional deep monitor wells, an expensive impermeable cap and/or completing 30 years of post-closure monitoring at the CWL can be made.

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