Soil Desiccation Techniques: Strategies for Immobilization of Deep Vadose Contaminants at the Hanford Central Plateau - 12413

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ABSTRACT

Deep vadose zone contamination poses some of the most difficult remediation challenges for the protection of groundwater at the Hanford Site where processes and technologies are being developed and tested for use in the on-going effort to remediate mobile contamination in the deep vadose zone, the area deep beneath the surface. Historically, contaminants were discharged to the soil along with significant amounts of water, which continues to drive contaminants deeper in the vadose zone toward groundwater. Soil desiccation is a potential in situ remedial technology well suited for the arid conditions and the thick vadose zone at the Hanford Site. Desiccation techniques could reduce the advance of contaminants by removing the pore water to slow the rate of contaminants movement toward groundwater.

Desiccation technologies have the potential to halt or slow the advance of contaminants in unsaturated systems, as well as aid in reduction of contaminants from these same areas. Besides reducing the water flux, desiccation also establishes capillary breaks that would require extensive rewetting to resume pore water transport. More importantly, these techniques have widespread application, whether the need is to isolate radionuclides or address chemical contaminant issues. Three different desiccation techniques are currently being studied at Hanford.

Desiccation Pilot Test: Slowing the advance of Tc-99 utilizing desiccation is being evaluated In the 200 Areas of Hanford's Central Plateau. The BC Cribs and Trenches Waste Site is an area of considerable Tc-99 contamination in the deep vadose zone, with some plumes as deep as 67 m (229 ft) and groundwater is at 107 m (350 ft) below ground surface (bgs). Testing was initiated in November 2010 and continued through June 2011. The field test system consisted of a nitrogen gas injection well, a soil-gas extraction well, and 25 test zone monitoring locations with over 700 in situ monitoring instruments. The target zone was 9 to 15 meters bgs with a volume of ~300 m^3. The deep vadose zone was simulated by use of an impermeable surface film over the test region. Evaporative cooling and subsurface heterogeneities were key factors that impacted the rate and extent of desiccation.

Following the active portion of the test, the project team plans to monitor rewetting of the desiccated zone over a five year period, which is a key factor in the overall remedy performance in terms of mitigating contaminant transport. Laboratory testing and field

data were collected to understand and quantify the effects of desiccation and provide input to future evaluation of soil desiccation as a potential vadose zone remedy. This data, including physical samples retrieved from the actual test site, will be used to evaluate the effectiveness and scale up capabilities within a comprehensive test report.

Pore Water Extraction Test: Another desiccation technique that reduces pore water in the soil is pore water extraction, which utilizes an extraction well with a screened interval spanning the target region in combination with high vacuum applied within the well, nominally 215 cm (85 in) water column. This vacuum can pull contaminated sediment pore water into the screened well where it is then pumped to the surface. The attraction of this technology is that contamination is removed. At this time, CH2M HILL Plateau Remediation Company is planning a pilot test of this technology north of the B-Farm in the 200 East Area where there are high concentrations of mobile uranium in the perched water/pore water that are slowly migrating into the aquifer.

Soil Wicking: This desiccation technique utilizes a super absorbent polymer that would be placed in a well screened at the target zone. The polymer absorbs moisture from the surrounding sediment. Laboratory testing to date shows that this technique can remove as much as 80% of the available moisture. Similar to pore water extraction, this technique will remove contaminants from the soil when the polymer is removed from the well. An additional advantage of this technology is that new absorbent (polymer) can be installed to continue the moisture removal process.

INTRODUCTION

During the Hanford Site's plutonium production era, some 1.7 trillion L (450 billion gallons) of liquid effluents were discharged into the vadose zone (subsurface) at the Hanford Site. Concentrated waste was discharged into engineered surface structures and allowed to percolate into the vadose zone. The most dangerous waste was stored in 177 underground tanks. Some of this waste has been released to the vadose zone. Today, the Site's largest inventory of subsurface contamination lies beneath the Central Plateau, and area of 200 square kilometers (75 square miles) that includes approximately 800 waste sites and 900 facilities that operated to extract and purify plutonium. The byproducts of this activity were effluents contaminated to varying degrees with chemicals and radionuclides. This practice resulted in large-scale contamination to the vadose zone and groundwater underlying the Central Plateau. Much of this contamination remains in the vadose zone and has the potential to contaminate groundwater in the future.

The deeper section of the vadose zone, herein termed the deep vadose zone, poses unique problems for remediation by the very nature of the vadose zone itself. The physical structure, layering of sediments, subsurface emplacement of wastes, geochemical characteristics, and biogeochemical properties of the geologic framework affect subsurface contaminant movement and distribution. A lack of knowledge quantifying key processes affecting contaminant migration challenges scientists' ability to reasonably predict the location and fate of contaminants under both natural or remediation conditions.

The geohydrologic contrast between sediment types, plus crosscutting and discontinuous geologic features such as stratigraphic facies changes, sediment orientation, fractures, and clastic dikes can impact lateral and/or vertical contaminant movement. The degree of complexity may be pronounced on a local scale, such as near a waste site or beneath a tank farm, and be far less influential on a broader field scale.

Additionally, the heterogeneous nature of the Central Plateau vadose zone confounds detailed understanding of the distribution and extent of contamination. Because of the thickness of the vadose zone, thorough characterization using traditional sampling and analysis is extremely high in cost. Much of the contamination is too deep to apply traditional remediation techniques that are used for surface waste (removal actions) making alternative remediation approaches necessary. These issues and others combine to make the deep vadose zone at Hanford one of the most challenging remediation problems within the DOE complex today. In situ treatment and surface barrier technologies offer promise for immobilizing contaminants in place, and in some cases, technology is being proposed that will remove some contaminants from the deep vadose with minimally intrusive techniques.

For these reasons, treatability testing is being performed by the Deep Vadose Zone (DVZ) project team within the Soil and Groundwater Remediation Project (S&GRP), within the CH2M HILL Plateau Remediation Company (CH2M HILL). These treatability tests demonstrate the innovative/first of a kind approach that CH2M HILL is using to address cleanup challenges within the deep vadose region. The treatability testing is being performed first by performing numerical modeling to address uncertainties associated with technology and employing the technology in the deep vadose zone and lab scale testing of the technology that would be used ultimately to design the field scale application. These studies were performed by the Pacific Northwest National Lab (PNNL) under contract to CH2M HILL, followed by development of a field Pilot Test for those technologies maturing within the lab environment and showing the ability to effectively scale up to perform field testing.

Documentation of the Desiccation Pilot Test will evaluate overall test success and the ability to scale this technology up to large production scale applications for considerations of cost and schedule should this treatment technology be chosen for the Record of Decision (ROD) remedial actions.

At this time, the active portion of the Desiccation Pilot Test has been completed and in a five year monitoring period to look at vertical and horizontal recharge from surrounding moist sediments. During the portion of the Desiccation Pilot Test, two additional desiccation-based technologies were observed and evaluated in the laboratory setting through testing and modeling, one of which is now being prepared for field testing. Those subset technologies are Pore Water Extraction, and Soil Wicking.

NOMENCLATURE

ALARA	as low as reasonably achievable
bgs	below ground surface
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act of 1980
CHPRC	CH2MHill Plateau Remediation Company
DOE	U. S. Department of Energy
DPHP	Dual Probe Heat Pulse
DVZTTP	Deep Vadose Zone
DVZTTP	Deep Vadose Zone Treatability Test Plan
EPA	U. S. Environmental Protection Agency
ERT	Electrical Resistivity Tomography
GPR	Ground Penetrating Radar – Cross Hole Radar
HDU	Heat Dissipation Units
PWX	Pore Water Extraction
RL	U. S. Department of Energy, Richland Operations Office
ROD	Record of Decision
SAP	Sample Analysis Plan
scfm	standard cubic feet per minute
S&GRP	Soul and Groundwater Remediation Project
TCP	Thermocouple Psychrometers

DESICCATION TESTING (CHARACTERIZATION AND PILOT TESTING)

<u>Desiccation Characterization Test:</u> The desiccation field test was divided into two distinct field applications. First, a characterization test was performed to understand soil characteristics and lithology in the target test zone. Under this characterization test, well 299-E13-65 was drilled to enable the collection, measurement, and analysis of grab and core sediment samples to augment data previously collected from adjacent well 299-E13-62 (as shown in Figure 1). Sediment sampling and laboratory analysis of

borehole sediments were conducted to provide the vertical distribution of mobile contaminants, moisture content, and major solutes in the vadose zone pore water to support groundwater remediation planning related to final site cleanup. The total and water-leachable concentrations of key contaminants of concern (COC), especially technetium-99 and uranium-238 in the sediments as a function of depth and their distances from inactive disposal facilities, were also collected to augment the conceptual site model for the BC Cribs and Trenches Area. Water extracts taken from the sediments were used for electrical conductivity (EC), common cation and anion concentrations, pH, and alkalinity. Pore-water ionic strength was calculated based on the concentrations of major cations and anions. The total and water-leachable concentrations of key contaminants will be used to update contaminant-distribution conceptual models and to provide more data for improving baseline risk predictions and remedial alternative selections.

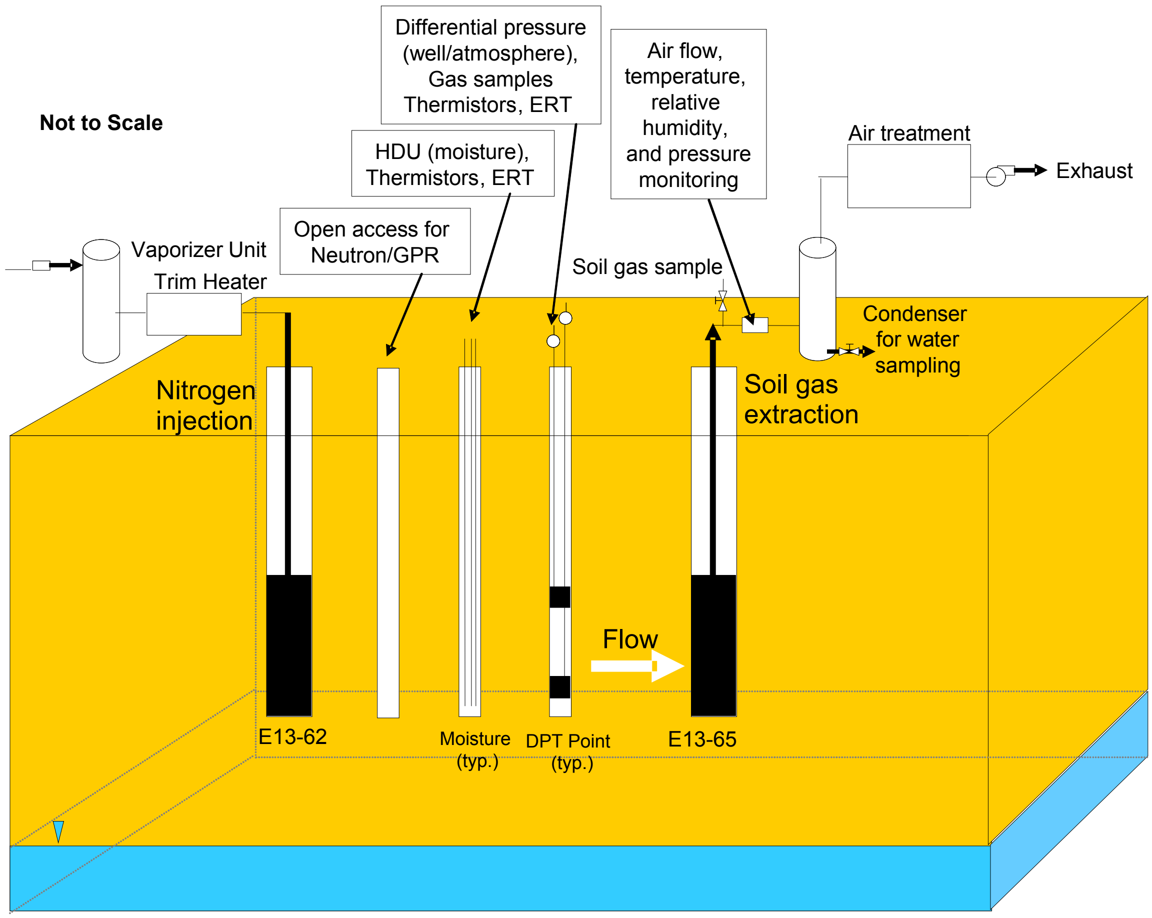

Figure Error! No text of specified style in document. **Schematic of Pilot Test (Phase 2 of the field test performance)**

The characterization test for this project was used to gather data on soil moisture content, temperature in the desiccation region during operation, and sediment air permeability. Additionally, a variety of potential in situ sensors were evaluated to determine their applicability for the Pilot Test as well as other future deep vadose activities. The characterization test was performed during June and July of 2009 and yielded information on soil gas transmissivity and soil permeability that helped optimize the overall project design and monitoring for the Desiccation Pilot Test.

An Expert Panel was contracted by the Deep Vadose Zone project as an outgrowth of a 2004 request by the Regulators to identify a path forward to identify tools to address Tc-99 and U contamination in the deep vadose zone. Charter for the Panel was to overview the project plan and design, monitoring and equipment operation, and provide overall guidance based on their collective expertise. Panel members provided expertise in vadose zone transport, infiltration control, hydrology, geochemistry, instrumentation, and geology, and came from academia, government laboratories, industry, and consulting.

The Deep Vadose Zone project team found the panel recommendations to be invaluable. The most significant recommendation ultimately changed the basic design of the pilot test. This adaptation was to operate a single soil gas extraction well associated with the dry gas injection well (a dipole system), which reduced the number of monitoring locations required, eliminated drilling three of the four extraction wells originally planned, and greatly simplified test data evaluation. .

Desiccation Pilot Test: A number of instruments were emplaced in situ for monitoring the desiccation test: 1) thermistors, 2) heat dissipation units (HDU), 3) thermocouple psychrometers (TCP), 4) humidity probes, and 5) dual probe heat pulse (DPHP) sensors. These instrument clusters were installed in ten boreholes, resulting in excess of 700 underground instruments that were used to monitor the Desiccation Pilot Test. The signals from these instruments were used to monitor sediment moisture content changes. In addition to these instruments, cross-hole radar (GPR), neutron moisture logging, and electrical resistance tomography (ERT) were used to monitor sediment moisture content changes. Prior to the performance of the field test, baseline measurements using GPR, logging, and ERT techniques were tested. For ERT, this field information was coupled with laboratory data that evaluates the change in conductance versus moisture content as the sediment was dried. Soil gas and condensate samples were gathered during the performance period of the Desiccation Pilot Test in accordance with the sample analysis plan (SAP).

The active phase of desiccation was operated almost continually for a period of just over six months. We are now continuing to monitor instruments and perform periodic geophysical characterization to examine horizontal and vertical rebound of moisture in the desiccated region. This monitoring period is nominally scheduled for five years.

The test used standard commercial air movers and nitrogen gas delivery systems. The nitrogen gas injection well and the soil gas exhaust/removal well were monitored for temperature, pressure, flow and moisture (see Figure 2). A series of boreholes were established as part of baseline preparation for operation of the Pilot Test and were also monitored for temperature, moisture, and pressure differential between the monitoring locations. Exhausted soil gas was monitored for temperature, humidity and flow rate. All data from the in situ sensors and instruments and above-ground equipment/systems were transmitted to data loggers in the field and from there to a computer in the operations/instrument trailer.

The design injection rate for the Pilot Test was nominally 300 standard cubic feet per minute (scfm) of nitrogen gas. The nitrogen gas system injected conditioned nitrogen gas into well 299-E13-62 at a temperature of 68 degrees Fahrenheit plus or minus 2 degrees. The extraction well was located approximately 12 m (40 ft) away from the injection well. Soil gas extraction was at 100 scfm.

Figure 2 Desiccation Test Site / Rattlesnake Mountain

Both the extraction and injection wells were screened from 9.1 to 15.3 m (30 to 50 ft) bgs in order to establish air flow between these two wells. The exhaust system also utilized a high efficiency filter and record sampler to monitor the system as part of the air emissions plan.

Moisture (water) was the only constituent requiring removal and was the focus of this project. Although there is no requirement for the removal of co-contaminants, monitoring and sampling was required in accordance with the SAP and was also established in the air emissions plan, both of which were regulatory documents approved by the U.S. Environmental Protection Agency (EPA). The data collected from this test will be used to support additional modeling that would be required design a full scale remedy, should this technology be chosen as a remediation method. The data, modeling, and sample analysis from post test sampling of the test region will be provided in a test report to be issued late FY2012. While the test data suggest the results exceeded expectations for targeted change in water flux, remedy solutions using this technology should consider coupling this technology with other remedy methods such as construction of a surface barrier to preclude introduction of annual precipitation that could prematurely undo the benefit of desiccation.

PORE WATER EXTRACTION

The Pore Water Extraction (PWX) phenomenon was encountered at the BC Cribs waste site by CH2M HILL personnel during characterization testing that was performed as part of the Deep Vadose Desiccation Characterization Test performed in the late spring of 2009. During the performance of the Desiccation Characterization Test, establishment of significant pressure differential to understand the soil gas transmissivity characteristics resulted in high extraction flows rates. Rates were obtained out of the extraction well in excess of 400 scfm. Corresponding vacuum pressures in excess of 215 cm (85 in.) of water column were achieved. The project had expected water removal via an evaporative model that left the contaminants behind. However, significant contamination was observed in the condensate collection vessel. Due to the high flow rates negative pressure, pore water was actually stripped from the soil into the screened section of the extraction well and entrained in the exhausted soil gas (calculated to be around 65 mph). The attractiveness of this phenomenon was that instead of leaving the contaminants locked in place using technologies such as desiccation, we could remove significant quantities of contaminants with minimal intrusion into the subsurface. In effect, this was closer to a remediation technique rather than a “lock it up and leave it” approach.

Subsequently, PNNL was requested by DOE to perform modeling to determine conditions required and area of influence that could be achieved with a vacuum applied for the purpose of removing contaminated pore water from sediment. Based on these modeling results provided by PNNL, it became evident that PWX can occur in the Hanford Formation (a sandy/silt loam region that can be a few hundred feet thick) under specific conditions, but that application of the PWX process in high moisture content regions of the Cold Creek Unit (a high carbonate tight silt lens region underneath the Hanford formation that ranges in thickness from several feet to tens of feet) would produce the highest yields.

Using the results of the modeling study, the PWX field test site selection was broken into two independent tests: One for the Cold Creek Unit to test the optimal conditions for PWX and one for the Hanford Formation to validate PWX occurrence and potential application under sub-optimal conditions. For this reason, the site selection process reviewed sites that were previously well characterized to ensure the soil characteristics within each of these regions were suitable to meet the necessary conditions to achieve the pore water extraction. The selection process reviewed both the positive and negative issues associated with each site reviewed by the selection team. The resulting conclusions from this site selection process was to recommend a field test adjacent the B tank farms in the Cold Creek Unit (existing well 299-E33-344) within the perched water region to remove mobile uranium and Tc-99 present in the pore water. The BC Cribs and Trenches site within the cribs discharge portion was recommended as the field test site in the Hanford Formation to evaluate pore water and Tc-99 removal from high moisture content Hanford formation silt lenses. This site is adjacent to the Desiccation Pilot Test site and will utilize the same infrastructure (power, data collection systems, and extraction and monitoring equipment) that were used to monitor the Desiccation Pilot Test. This “Hanford Formation” pore water extraction test is scheduled to be performed in fiscal year 2014.

The Cold Creek Unit test site north of B-Farms is now being prepared to perform the PWX test starting in fiscal year 2012. The test depth at this site is about 220 feet below ground surface. It is also the location of a perched water zone. The collection of water at this location is the result of planned and unplanned radiological discharges from the tank farms and surrounding cribs just outside the tank farms. This tight silt lens above the aquifer has slowed down this highly saturated plume of contaminants. For this reason, the test has been broken down into three phases. Phase one (this was initiated on August 30, 2011) will perform the gravity collection of contaminated perched water. Based on recharge rate of the well between pumping cycles, and lowering of the perched water level, we plan to calculate total volume of perched water. Second, we will install a vacuum system on the well to increase the perched water collection rate. Third, following removal of the perched water, this zone will have transitioned from fully saturated to non-saturated. At this stage of testing, we will continue to pull vacuum on this well to strip pore water from this tight sediment region and pump it the surface via a sump pump which will provide continued moisture and contaminant removal.

SOIL WICKING

The Deep Vadose Treatability Test Project Team worked on evaluating the use of retrievable absorbent materials that could be deployed in a borehole as a concept for vadose zone remediation. With appropriate design, these absorbent materials could be replaced once it reaches its holding capacity over time. Extraction of pore water directly removes contaminants from the vadose zone. This also lowers the moisture content which will act to reduce the rate of vertical migration of water through the vadose zone. Application of the adsorbent process is expected to draw water primarily from finer grained portions of the vadose zone where the water saturation is high enough to support pore water movement.

PNNL was tasked to perform scoping studies and laboratory tests to evaluate the potential influence of the absorbent process. Laboratory experiments were performed to evaluate and quantify the potential for vadose zone pore water extraction using borehole absorbent materials. The experimental matrix included variations in the following parameters:

- Adsorbent material types (Super Absorbent Polymers {SAP})
- Sediment particle size (silt, silty sand, fine sand, coarse sand)
- Initial sediment moisture content

The initial column experiments utilized emplacement of a layer of polymer on top of unsaturated porous media. These column experiments showed the potential of the SAPs to extract up to 80% of the initially emplaced water against gravity into the sorbent over a test period of up to four weeks. The next column experiments performed were configured with the sorbent being emplaced between layers of unsaturated porous media. The extraction percentages over four weeks of contact time were similar for both packings. No obvious differences were observed for the four tested SAPs.

Additional testing was performed using a larger flow cell in which the absorbent was packed in a woven nylon sock that was subsequently placed between perforated metal plates, mimicking a well configuration. The initially emplaced sock was exchanged after one week of contact time and replaced by a fresh sock. The results of this experiment show that the sorbent was able to continuously extract water from the porous media, although the rate decreased over time.

The tested sorbents all demonstrated a distinct capacity to extract water from unsaturated porous media. It was observed that water removal from the porous media slowed down as a function of time because both the water saturation and relative permeability adjacent to the sorbent decreased. Additionally, the test performing the exchange of the sorbent using a sock validated a sustained capillary pressure gradient towards the sorbent over time (the test time for this experiment was 14 days).

These tests only investigated the proof-of-principle for water removal by absorbent material. While initial results yielded significant reductions in the percentage of water from these unsaturated sediments, additional testing is needed to evaluate these SAPs to perform with a variety of soil types and extended durations to evaluate the full potential/extent of moisture removal as well as the area (radius) of influence these SAPs would have within specific soil sediment types. The attraction of this technology, similar to pore water extraction, is the ability to remove contaminants from the vadose zone with minimal disturbance. A significant added benefit over pore water extraction is the significant reduction in infrastructure (no surface equipment or power needed) and minimal labor resources needed to maintain this process.

CONCLUSIONS

Desiccation technologies offer significant potential to provide practical remediation technologies in an environment that is impractical to perform traditional excavation/removal type of actions typical within the nuclear industry. While there are other promising deep vadose technologies in development that to some degree are minimally intrusive, desiccation concepts offer remediation strategies that are easily implementable, and some even offer the added benefit of source term reduction from the target regions selected. These technologies are however limited largely to regions of the vadose zone that are unsaturated. While these technologies utilize standard industrial equipment (off the shelf) and can be easily implemented, these technologies can also be coupled to improve reliability in the overall remedy (i.e. use of PWX or soil wicking prior to dry air desiccation). This approach would yield reduced source term in the contaminated target regions, coupled with significant reduction in water flux, serving to both reduce source term available to the aquifer, and the speed at which it can get to the aquifer.

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