

**REMEDICATION OF GROUNDWATER CONTAMINATED WITH ORGANICS AND
RADIONUCLIDES – AN INNOVATIVE APPROACH EASES TRADITIONAL
HURDLES**

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ABSTRACT

Traditional approaches to the remediation of contaminated groundwater, such as pump-and-treat, have been used for many years for the treatment of groundwater contaminated with various organics. However the treatment of groundwater contaminated with organics and radionuclides has been considerably more challenging. Pump-and-treat technologies are generally not well suited for the treatment of groundwater contaminated with both organics and radionuclides for the following reasons:

- Technologies such as air stripping may remove organics, but are not effective at removing radionuclides
- Radiological contamination may be transferred to above ground piping, pumps, and equipment. Survey and release of the internals of this equipment is extremely difficult.
- Many local health departments strictly prohibit the re-injection of groundwater with detectable radiological contamination
- Treatment for radionuclides, such as ion exchange, can produce significant volumes of waste that can be difficult and/or expensive to disposition

Safety and Ecology Corporation (SEC) was recently faced with these challenges while designing a remediation system for the remediation of TCE-contaminated groundwater and soil at the RMI Extrusion Plant in Ashtabula, OH. Under contract with RMI Environmental Services (RMIES), SEC teamed with Regensis, Inc. to design, implement, and execute a bioremediation system to remove TCE and associated organics from groundwater and soil that was also contaminated with uranium and technetium. The SEC-Regensis system involved the injection of Hydrogen Release Compound (HRC), a natural attenuation accelerant that has been patented, designed, and produced by Regensis, to stimulate the reductive dechlorination and remediation of chlorinated organics in subsurface environments. The compound was injected using direct-push Geoprobe rods over a specially designed grid system through the zone of contaminated groundwater. The innovative approach eliminated the need to extract contaminated groundwater and bypassed the restrictive limitations listed above. The system has been in operation for roughly six months and has begun to show considerable success at dechlorinating and remediating the TCE plume and in reducing the radionuclides into insoluble precipitants.

The paper will provide an overview of the design, installation, and initial operation phase of the project, focusing on how traditional design challenges of remediating radiologically contaminated groundwater were overcome. The following topics will be specifically covered:

- A description of the mechanics of the HRC technology
- An assessment of the applicability of the HRC technology to contaminated groundwater plumes and other potential remediation opportunities
- A discussion of how the implementation of the HRC technology eased permitting issues and other challenges of remediating groundwater contaminated with radionuclides and organics
- An overview of the remedial design and installation of the design including the inputs required to design the remediation system
- A summary of results achieved to date and a forecast of future results
- A discussion of future needs and lessons learned

INTRODUCTION

The U.S. Department of Energy faces environmental remediation and waste management challenges resulting from over 50 years of nuclear weapons research and production. More than 10,500 sites contaminated with hazardous-substances have been identified. The DOE legacy of contaminant plumes includes 2500 billion liters of contaminated groundwater and 200 million cubic meters of contaminated soil.

The volume, extent, broad distribution, and complexity of DOE's contaminated soils and groundwater pose a unique and formidable challenge: to develop scientifically sound characterization, remediation, performance assessment, and long-term monitoring technologies that are cost-effective and result in acceptable risk to human health and the environment. *In situ* approaches to restoration and containment, including bioremediation, are methods of choice over excavation and pump-and-treat for a number of key reasons:

- Technologies such as air stripping may remove organics, but are not effective at removing radionuclides
- Radiological contamination may be transferred to above ground piping, pumps, and equipment. Survey and release of the internals of this equipment is extremely difficult.
- Many local health departments strictly prohibit the re-injection of groundwater with detectable radiological contamination
- Treatment for radionuclides, such as ion exchange, can produce significant volumes of waste that can be difficult and/or expensive to disposition
- Contamination is widely dispersed in the environment, is present in relatively dilute concentration, or is otherwise inaccessible because of its depth or its location beneath structures.

Environmental restoration is complicated by the diversity of subsurface environments at contaminated sites across the DOE complex. These sites are located in arid, non-arid, cold, and hot climates and include a diversity of geological settings and depositional environments with unique conditions that must be understood and managed for bioremediation or other restoration methods to be effective. In addition, DOE's history of developing, manufacturing, and managing nuclear materials and weapons resulted in environmental contamination with complex and exotic mixtures of compounds. The costs associated with remediating many of DOE's largest plumes of contaminated groundwater and sediments have not been determined, but estimates to clean up DOE's contaminant soils, sediments, and groundwater range from tens to hundreds of billions of dollars.

Safety and Ecology Corporation (SEC) recently faced these challenges when designing a system for remediating TCE-contaminated soil at the Reactive Metals Incorporated (RMI) site in Ashtabula, OH.

SITE HISTORY AND DESCRIPTION

The RMI Titanium Company Extrusion Plant, located on the east side of Ashtabula, Ohio, approximately one mile south of Lake Erie and immediately south of Fields Brook, extruded ferrous and non-ferrous metals, including uranium. RMI previously utilized a small wastewater evaporation pond near the north boundary of the site for disposal of spent sodium nitrate process containing trace amounts of uranium and technetium-99 from 1963 until 1984. An unauthorized disposal of TCE into the pit before 1972 is the suspected reason for the TCE contamination. The groundwater contamination plume extends about 100 feet north of the former evaporation pond. The pond has since been closed. Groundwater monitoring in the vicinity of the pond has documented the presence of trichloroethylene (TCE), uranium, and technetium-99 (Tc-99).

PROJECT SCOPE AND OBJECTIVES

The primary objective of the project was to design and implement a bioremediation system to reduce trichloroethylene (TCE) contamination in soil in the area of the former pond to a level below 22.6 mg/kg. Additionally, the remediation of all referenced volatile organic compounds (VOCs) must be reduced to a total Hazard Index (HI) ≤ 1 .

The CAMU is located within a radiologically contaminated area; however radionuclide concentration reduction is not required by the scope of work. Although contamination consists mainly of TCE, additional chlorinated solvents, including vinyl chloride (VC), dichloroethylene (DCE), and perchloroethylene (PCE), are present at lower levels. Additionally, low levels of uranium (U) and technetium (Tc-99) are present in the the groundwater and soil.

Table 1, below, lists the applicable contaminants of concern (COC) for the site and the respective cleanup goal for each.

Table I. Bioremediation acceptance criteria.

COC	Soil GCN (mg/kg)	Maximum Concentration (mg/kg)	Observed Concentration (mg/kg)
TCE	22.6	1620	
VC	0.212	0.095	
1,1-DCE	0.524	ND	
1,2-DCE	27.7	0.587	
PCE	45.5	2.67	

In addition to achieving the single contaminant levels for each COC specified above, the total HI for all COCs must be \leq one. The HI represents the sum of the final concentration (FC) divided by the GCN for all COCs and is calculated as follows:

$$HI = [(FC_{TCE}/GCN_{TCE}) + (FC_{VC}/GCN_{VC}) + (FC_{1,1-DCE}/GCN_{1,1-DCE}) + (FC_{1,2-DCE}/GCN_{1,2-DCE}) + (FC_{PCE}/GCN_{PCE})]$$

REMEDIATION ACTIVITIES

Remediation design was further complicated by the presence of U and Tc-99 in the subsurface as any extracted groundwater could not be re-injected without treatment to remove the radionuclides. Above ground pumps and pipes could become contaminated with the radionuclides and survey and release of these components is very difficult because of inaccessible surfaces. SEC chose to design and install an in-situ bioremediation system to accelerate natural attenuation, remediate the VOCs present in the site, and mitigate the hurdles associated with traditional remediation technologies.

SEC teamed with Regenesis to design a remediation system that used Hydrogen Release Compound© (HRC), a food-grade bioremediation agent, to degrade TCE and its associated daughter products. HRC is a proprietary polylactate ester specially formulated by Regenesis for the slow-release of lactic acid upon hydration. When HRC is introduced into the subsurface, various indigenous organisms help to uncouple lactic acid from HRC. Consequently, fermentative anaerobic microbes metabolize the lactic acid, making the aquifer anaerobic and producing hydrogen in the process. Microorganisms capable of biological dehalogenation can then use this hydrogen to displace chlorine atoms from the contaminant molecules. Hydrogen serves as the electron donor and chlorinated hydrocarbons (such as TCE) serve as the electron acceptor in the process. As the contaminant accepts the electron, a chlorine molecule is displaced. In this manner, the contaminant is broken down from perchloroethane (PCE) to TCE to dichloroethane (DCE), to vinyl chloride (VC), and finally to ethane.

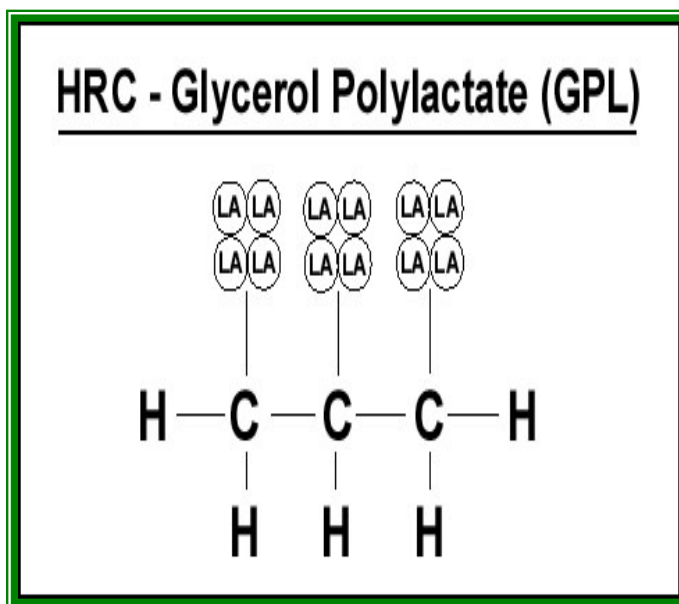


Figure 1. Structure of HRC

SEC developed a three-phased approach to remediation to achieve GCNs for soil and groundwater contaminants within the three-year project performance period. The overall design of the SEC's remedial approach is based on the division of the site into zones, based on the depth and concentration of contaminants, and the injection of HRC in a grid-based design in each of the zones.

HRC CHEMISTRY

The use of HRC is widely accepted as being very low cost. It has been successfully applied at over 300 sites to date. Results of HRC application to treat contaminated aquifers are widely published.

The HRC material is simply injected with a Geo-Probe rig, leaving nothing behind in the way of piping or wells. Once in place, HRC slowly releases hydrogen over a period of greater than 12 months, maintaining low dissolved hydrogen concentrations that optimize the rapid dechlorination of the contaminant. With HRC, no application wells are required, and no piping is necessary. There are no monthly reapplication requirements with HRC, and no system operation and maintenance is needed.

When HRC is introduced into the subsurface, various indigenous organisms help to uncouple lactic acid from HRC. Consequently, fermentative anaerobic microbes metabolize the lactic acid, making an aquifer anaerobic and producing hydrogen in the process. Microorganisms capable of biological dehalogenation then can use the hydrogen. The hydrogen serves as the electron donor and the chlorinated hydrocarbon (such as TCE) serves as the electron acceptor. As the contaminant accepts the electron, a chlorine molecule is displaced. In this manner, the contaminant is broken down (i.e. conversion of perchloroethane (PCE) to trichloroethane (TCE) to dichloroethane (DCE) to vinyl chloride (VC) to ethene.

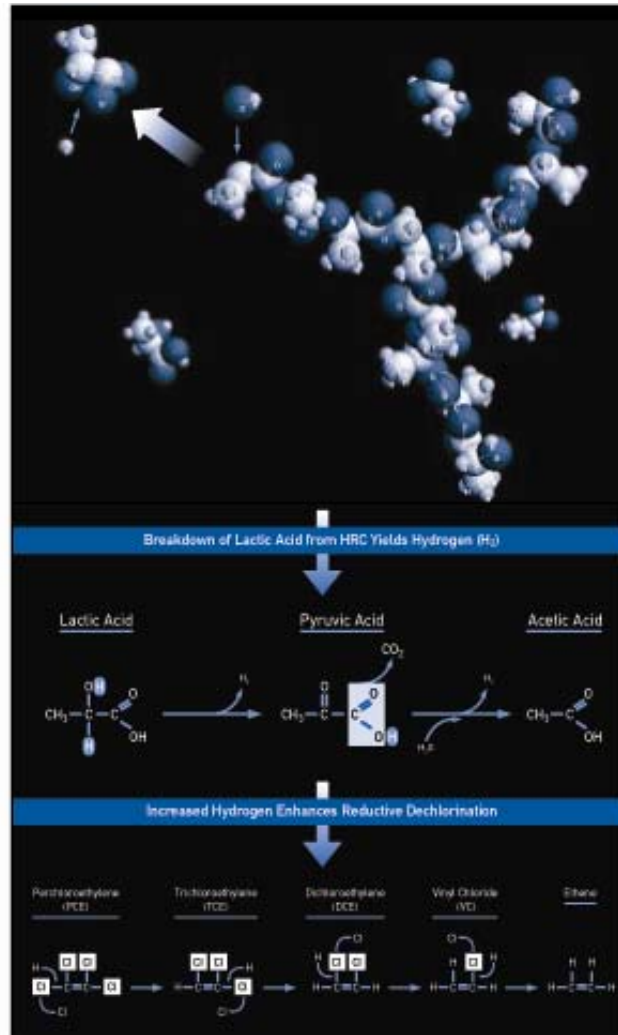


Figure 2.
Breakdown of Lactic acid by HRC

By providing a long-lasting, time-released hydrogen source, HRC can enhance anaerobic reductive dechlorination. The following are some key advantages of HRC.

- **Low maintenance and low cost** – unlike actively engineered systems, continuous mechanical operation and maintenance is eliminated, dramatically reducing overall operation and maintenance costs
- **Constant and persistent hydrogen source** – HRC is a semi-solid material that will remain where emplaced and generate highly diffusible hydrogen slowly over time. A continuous, highly diffusible hydrogen source increases the effectiveness of contact, containment and remediation, especially in low hydraulic conductivity aquifers.
- **Diffusion of HRC**- Laboratory and field work indicate that lactic acid will move by diffusion alone about 10 ft./yr regardless of aquifer matrix material.
- **Enhanced desorption of chlorinated hydrocarbons (CH)** – the continuous hydrogen source provided by HRC can reduce dissolved-phase CH concentrations. This creates a larger concentration gradient that, in turn, facilitates desorption of CHs from the soil matrix

- **Favored dechlorination over possible competing methanogenic activity** – Results from several university studies suggest that there is competition for hydrogen between the reductive dechlorinators and methanogens. While methanogen survival is favored under elevated hydrogen conditions, reductive dechlorinators are best supported in conditions of more moderate hydrogen concentration, such as when HRC is used.

INJECTION DESIGN PARAMETERS

The overall design of the HRC injection is based on a mass balance between the mass of contaminants in the dissolved phase and the sorbed phase and the mass of HRC required to treat the contaminants. A number of additional demand factors and safety factors are built into the mass balance.

Site TCE concentrations in the groundwater ranged from <0.001 mg/L to 1600 mg/L. Soil contamination levels also ranged quite dramatically over the site. Soil dTCE concentrations range from <10 ppm to over 1600 ppm.

SEC's approach estimated the total mass of TCE and associated chlorinated hydrocarbons (in grams) present in the subsurface, and used this mass to stoichiometrically calculate the mass of HRC required to reduce the TCE into ethane and ethene. The total mass of TCE and other contaminants is equal to the dissolved phase contaminant concentrations and the sorbed phase contaminant concentrations.

In addition to the overall mass of contamination, additional properties and factors must be considered. These additional parameters must be estimated or measured and factored into the design to accurately determine the mass of electron donor needed to both satisfy the demand factors and to enhance the reductive dechlorination of the target contaminants. These additional factors include:

- **Basic Site Characteristics** – In order to effectively design the system, SEC and Regenesys input the basic site characteristics such as width and depth of the plume, thickness of the contaminated zone, porosity, hydraulic gradient and conductivity into the design model. These characteristics determine the depth of injection and the injection point spacing, and evaluate flow dynamics for the grid.
- **Dissolved-Phase Groundwater Concentrations** - The Dissolved phase concentrations were determined from previous sampling data and are representative of an entire hydrogeologic cycle, rather than a one-time monitoring event.
- **Sorbed Phase Contaminant Mass**. Generally the mass of contaminant bound to the saturated soil matrix is a multiple of the total dissolved contaminant mass. The mass of contaminant sorbed to the aquifer matrix is a function of the bulk density of the aquifer matrix, the fraction of organic carbon in the matrix (foc), and the contaminant partitioning coefficient (Koc).
- **Competing Electron Acceptor (CEA) Concentrations** - The concentrations of dissolved competing electron acceptors such as oxygen, nitrate, ferric iron, and sulfate have an effect on the amount of HRC required to enhance bioremediation. CEA concentrations in the CAMU are fairly high, perhaps resulting from the area's former use as an evaporation pond, and a concentration of nitrate in the soil. Hydrogen from HRC is used to reduce these CEAs and create redox conditions that are conducive to reductive dechlorination. CEA concentrations were calculated from the previous sampling data and are representative of an entire hydrogeologic cycle, rather than a one-time monitoring

event. These concentrations were input into the model to determine a conservative HRC dose amount that would satisfy the CEAs and dechlorinate the contaminants.

- **Microbial Demand Factor** - In addition to the contaminant and CEA demand for HRC, subsurface microbes will use some of the lactic acid as a source of energy or structural carbon. Therefore, when designing an initial or re-injection of HRC, these competing microbial processes must be taken into account. Sampling for the additional demand factor can be very difficult. SEC chose to rely on Regenesys' overly conservative demand factor of 3.
- **Additional Demand Factor** - Additional demand factor is used for uncertainty about the potential sinks for electron donor, and can be thought of as a contingency. SEC chose to use a factor of 2 for additional demand for preliminary design purposes. It will become better defined after the initial injection and monitoring.

SEC's overall design to remediate the contaminated soil involved the division of the site into five zones based on concentration of contaminants and depth of contaminants. Specific HRC injection doses were then calculated for each of the five zones. Between the zones, the depth of injection, injection point spacing, and pounds injected per foot varied with the depth and levels of contaminants. Three separate injection events, spaced approximately one year apart were scheduled to remediate the high concentrations of contaminants. The three injection events are summarized below in Table II:

Table II. Summary of injection events.

Injection Event	Dates	Number of Injection Points	Amount of HRC Injected (lbs.)
1	4/02 – 5/02	165	25,896
2	4/03 – 5/03	49	11,790
3	5/04	49	8,370

Figure 3, below shows the injection point layout for the first injection event. This event was completed on May 22, 2002.

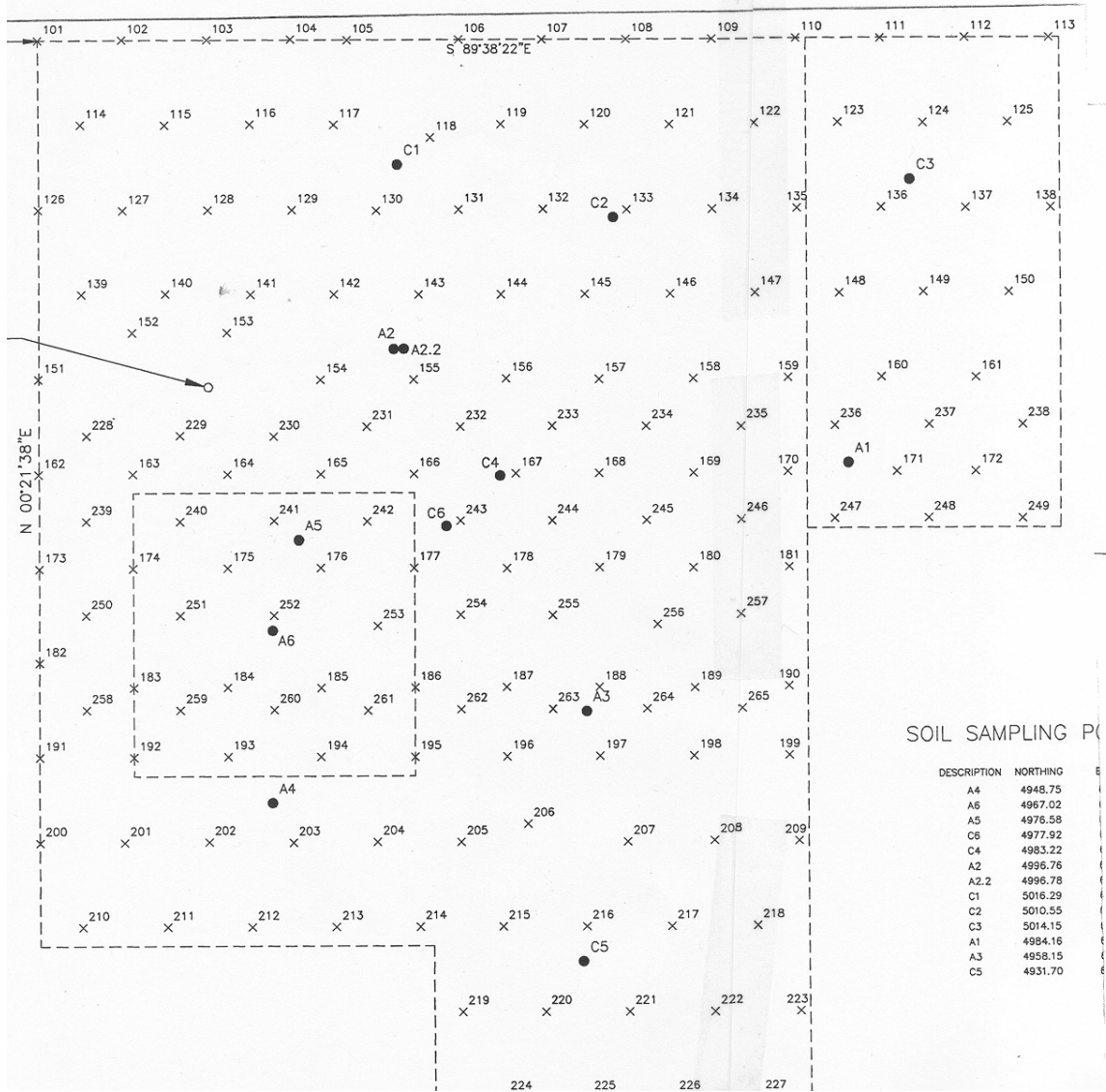


Figure 3. Injection point layout for initial HRC injection.

INJECTION OF HRC

Injection of HRC eased traditional permitting issues associated with treating contaminated groundwater. As mentioned earlier, the HRC method does not require groundwater extraction or re-injection. As a result, there was no discharge needed, no waste water generated, no treatment required, and no handling of contaminated liquids as a result of remediation. Because HRC is manufactured as a food-grade product, many of the problems associated with injection of chemicals into the groundwater were greatly eased. Below is a general summary of the overall injection procedure:

- The containers of HRC are heated to approximately 95 degrees Fahrenheit in a hot water bath
- A direct push unit is set up over the specified injection point with the specified Geo-Probe rods (generally a 1.25-inch O.D./0.625-inch I.D. rod) and subassemblies
- The drive rods are advanced through the surface

- The drive rod assembly is pushed to the desired depth
- The expendable tip is dropped from the rod
- The pre-heated HRC is poured into the pump hopper and homogenized in the hopper using the pump's mixing and recirculation features
- The HRC is pumped through the delivery system through the rod into the subsurface.
- Using the pump's stroke counter and the appropriate conversion factors, the appropriate volume of HRC per injection location is calculated
- While slowly withdrawing single lengths of drive rod, the pre-determined amount of HRC is pumped into the aquifer along the desired treatment interval.
- An appropriate seal, such as bentonite, is installed above the HRC material
- The drive rods are removed and cleaned, as necessary
- These steps are repeated until all injection points have been used to deliver HRC to the subsurface



Figure 4. HRC injection – (1) Buckets are heated in a water bath; (2) HRC is transferred to the injection pump hopper; (3) The rod is driven to the required depth; (4) HRC is pumped through the rod as it is extracted.

CONFIRMATORY SAMPLING AND ANALYSIS

Monitoring of selected wells is being conducted to monitor and validate the HRC-based enhancement of reductive dechlorination and subsequent remediation. Additionally, collection and analysis of soil samples provides a method to monitor bioremediation success. Table III, below, summarizes the types of analyses that will be performed to gauge and track bioremediation success.

Table III. Parameters used to track the progress of HRC-mediated remediation

Parameter	Lab or Field Analysis	Methodology	Data Use
Chlorinated VOCs and GCN-listed compounds	Lab	EPA 8021 (on-site) EPA 8260 (off-site)	Track Bioremediation progress by observing contaminant levels versus time
pH, Dissolved Oxygen (DO); Oxidation-Reduction Potential (ORP); Temperature	Field	Field Test Kit (HACH sensION 156 Portable Ion Multi-Parameter Meter or equivalent)	Track aquifer properties to determine if anaerobic conditions are being produced and reductive dechlorination conditions are favorable
Total Organic Carbon (TOC)	Lab	EPA 415.1 or EPA 9060	TOC in the aquifer matrix influences contaminant migration, sorption and desorption and biodegradation rates.
Metabolic Acids (including lactic, pyruvic, acetic, propionic and butyric) – generated from HRC release	Lab	Various	Track the distribution of HRC in the aquifer to assess if the design ensures sufficient coverage
Total and dissolved Fe and Mn	Lab	EPA 6000 with filtered and unfiltered samples	Indicative of reductive conditions in aquifer that facilitate reductive dechlorination
Nitrate	Lab	EPA 353.1 or 9056	Substrate for microbial respiration in depleted oxygen environments
Sulfate	Lab	EPA 375.3 or 9056	Substrate for microbial respiration in depleted oxygen environments.
Carbon Dioxide, Methane, Ethane, Ethene	Lab	ASTM D1945	Track Bioremediation progress

In addition to the analyses listed above in Table IV, groundwater samples will be analyzed for uranium and Tc-99, alkalinity, and other anions and cations to assess the effects of HRC on bio-reduction of radionuclides. Although reduction of these radionuclides is outside the scope of the bioremediation project, previous studies indicate that these radionuclides become less available in reducing environments, and concentrations fall.

SUMMARY OF RESULTS TO DATE

To date, four groundwater sampling and two soil sampling (including baseline) events have been performed. The results of these sampling events indicate that subsurface conditions are being

altered by the injection of HRC and remediation of TCE is occurring. Results also indicate that radionuclides are being bioreduced and made less available by the injection of HRC. Table IV below, shows a summary of the analytical results achieved to date

Table IV. Results of soil and groundwater sampling performed.

Groundwater Sampling Event				
	Baseline	Q1	Q2	Q3
Date	4/22/02	6/20/02	9/5/02	11/20/02
Parameter				
TCE (ug/L)	142,533	153,781	155,064	137,108
PCE (ug/L)	0	0	0	0
1,1-DCE (ug/L)	98	0	0	0
1,2-DCE (ug/L)	0	0	0.146	2438
VC (ug/L)	140	0	0	0
pH	7.4	7.3	7.0	7.2
DO (mg/L)	5.4	3.9	4.8	7.0
ORP (mV)	118.5	92.9	190.3	190.5
Soil Sampling Event				
	Baseline	A1		
TCE (ug/L)	308,076	157,690		
PCE (ug/L)	2.2	5.79		
1,1-DCE (ug/L)	64.5	0.84		
1,2-DCE (ug/L)	0	2,782		
VC (ug/L)	259.1	984		

BENEFITS OF THE SYSTEM

The advantages of the SEC-Regeneration system arise not only from the efficacy of the HRC-enhanced natural attenuation but also from the absence of long-term operations and maintenance costs. Specific advantages include:

- **No installation of injection wells:** HRC (and ORC, if needed) were be injected through direct-push Geo-Probe injection rods. The small diameter rods are more effective for introducing the chemical to the subsurface and much less expensive than traditional injection wells. Additionally, the use of Geo-Probe rods eliminates the need to permit, plug, or abandon new wells.
- **HRC is routinely approved for injection without having to go through the UIC Permit Process.** HRC is generally approved through the use of a UIC Permit Exemption. In fact, HRC has been utilized at hundreds of sites the formal UIC Permit Process.
- **No pumping or extraction of groundwater necessary.** In addition to its proven track record, the single greatest advantage of the HRC system for this application is that it eliminates the need for any extraction of groundwater. This advantage offers multiple benefits because it:
 - *Eliminates the probability of the contamination of remediation equipment-* Traditional approaches that use an extraction methodology rely on pumps, pipes and above-ground support systems. These systems may become internally contaminated, and survey of the internal surfaces is extremely difficult. Because

the HRC system does not involve these support apparatus, the potential for contamination of equipment is eliminated.

- *Greatly reduces the volume of waste generated-* Many regulatory agencies have taken the position that re-injection of uranium or technetium-contaminated groundwater will not be allowed without treatment. Any extracted groundwater must therefore be treated or disposed. The HRC system does not produce any volume of contaminated groundwater requiring treatment or disposal, again resulting in significant cost-savings.
- *Eliminates the need for handling hazardous, radioactive, or mixed wastes-* Any groundwater extracted may be considered a radioactive, hazardous, or mixed waste. Those systems that extract any quantity of groundwater will require the handling of this waste. Handling of the waste will expose site workers, neighbors, and the environment to these hazards. Additionally, the possibility of spills of the material are inherent to the handling of the waste. The HRC methodology does not require the extraction of this material, and therefore eliminates the need for handling, exposure or spillage of the material.
- *Eliminates the need for treatment of extracted groundwater-* As there is no extracted groundwater, there is no need to treat the water. Again, this will result in a significant cost burden reduction.
- **Drastically reduced on-site power requirements.** Because the HRC method does not require any long-term operations or maintenance functions, the need for on-site power is greatly diminished.
- **HRC and ORC enjoy wide-scale acceptance by USEPA, State environmental agencies and other regulatory agencies.** HRC has been fully approved by EPA for injection into groundwater and has been approved and used at hundreds of sites across the country. HRC has received accolades from the New Jersey Department of Environmental Protection, the Canadian Environmental Technology Verification Program, and the state of Florida Department of Environmental Protection for its efficacy and cost-effectiveness.

LESSONS LEARNED

During the design, installation, and subsequent tracking of the bioremediation system, SEC has learned many valuable lessons. While each and every project has its own unique challenges, many potential problems can be anticipated and overcome during the design phase, when a comprehensive knowledge of lessons learned is applied to the planning. Below is a summary of lessons learned on the bioremediation project.

1. **Extensive baseline sampling should be performed before the final design of the remediation system is completed.** SEC relied on historical sampling information that had been performed over a period of 10 years to develop our remedial design. However, SEC's baseline sampling and analyses discovered somewhat different site conditions than were expected based on the historical information (higher concentrations of competing electron acceptors). If the baseline sampling had been performed several months before injection the newly discovered information could have been incorporated into a revised design with enough time to receive all necessary approvals. By the time the results of the baseline sampling were available, SEC had all but completed initial injection activities. Because SEC's system included three injection events, the

unexpected changes were incorporated into the design of a subsequent injection phase and will be accounted for during subsequent field activities.

2. **Prior to mobilization, contingency plans that anticipate potential problems with injection, should be developed and ready to implement.** The geohydrology of the site indicated that very tight clays were present. Significant concern was raised that the aquifer might not accept the HRC that was being injected and that the pump being used may not be powerful enough to overcome the low hydraulic conductivity clays in the subsurface. Because SEC had anticipated these concerns ahead of time, we had ordered a more powerful pump that we mobilized to the site and left in a standby position in case the original pump was not sufficient. Despite the tight clays, the original pump performed flawlessly and the contingency pump was not needed. However, should the original pump have not performed properly, field activities may have been delayed up to one week to order a replacement pump and have the pump inspected and surveyed into the area.
3. **Laboratories that perform non-traditional analyses can be difficult to find, and additional time should be provided to find labs to perform these analyses.** Because of the U and Tc-99 contamination, very few analytical laboratories (with radioactive materials licenses) were available to perform analysis of the samples. While many of the analyses involve traditional methodologies some of the analyses (metabolic gases and metabolic acids) required specialty methodologies. While several laboratories are able to perform these analyses, none of these laboratories have a radioactive materials license. The lab chosen to perform the analyses had to develop a methodology and procedure for the required analyses. The development of the procedure added additional cost and schedule. The methodology was not completed until after the second sampling event, leaving gaps in the data from previous sampling events.

CONCLUSION

Since initial injection of HRC, the site soil samples have shown an overall decrease in TCE concentrations of approximately 57%. Although site contaminant levels were over three times anticipated levels, the bioremediation system is proving to be quite successful. The bioremediation design is currently being revised to account for the higher-than-anticipated baseline contaminant concentrations. The revised design will utilize increased amounts of HRC to stimulate the remediation of the higher-than-anticipated concentrations of TCE and related compounds. This revised design will be implemented during the April 2003 injection event. It is anticipated that remediation rates will increase by as much as 10 times following the revised reinjection. The significant decrease in soil concentrations of TCE have been brought about with minimal site disturbance, minimal generation of secondary and remediation-derived wastes, and with no contamination of equipment or material.