INNOVATIVE TECHNOLOGY
Summary Report

DOE/EM-0557

Permeable Reactive Treatment (PeRT) Wall for Rads and Metals

Subsurface Contaminants Focus Area

Prepared for
U.S. Department of Energy
Office of Environmental Management
Office of Science and Technology

September 2000

INNOVATIVE TECHNOLOGY
Summary Report

Permeable Reactive Treatment (PeRT) Wall for Rads and Metals

OST/TMS ID 2155

Subsurface Contaminants Focus Area

Demonstrated at
Monticello Mill Tailing Site
Monticello, Utah

INNOVATIVE TECHNOLOGY
Summary Report

Purpose of this document

Innovative Technology Summary Reports are designed to provide potential users with the information they need to quickly determine whether a technology would apply to a particular environmental management problem. They are also designed for readers who may recommend that a technology be considered by prospective users.

Each report describes a technology, system, or process that has been developed and tested with funding from DOE's Office of Science and Technology (OST). A report presents the full range of problems that a technology, system, or process will address and its advantages to the DOE cleanup in terms of system performance, cost, and cleanup effectiveness. Most reports include comparisons to baseline technologies as well as other competing technologies. Information about commercial availability and technology readiness for implementation is also included. Innovative Technology Summary Reports are intended to provide summary information. References for more detailed information are provided in an appendix.

Efforts have been made to provide key data describing the performance, cost, and regulatory acceptance of the technology. If this information was not available at the time of publication, the omission is noted.

All published Innovative Technology Summary Reports are available on the OST Web site at http://ost.em.doe.gov under "Publications."

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SECTION 1
SUMMARY

Technology Summary

Problem

Organic and inorganic contamination of groundwater is widespread at Department of Energy (DOE), Department of Defense (DOD), other federal, and industrial sites. Contamination at a majority of these sites is present in shallow, unconfined aquifers, which may impact human health and the environment. Although there are many treatment methods, for organic contamination, relatively few technologies are effective in treating inorganic contamination, such as metals and radionuclide, in situ. Because metals are commonly adsorbed to clays and organic matter in an aquifer, groundwater pump and treat technology can be expensive and ineffective. Desorption of these metals into the aquifer is a long-term issue, difficult to address.

How It Works

A permeable reactive treatment (PeRT) wall, also referred to as a permeable reactive barrier, is a zone of reactive material that is placed in a contaminated aquifer so that the concentrations of dissolved inorganic contaminants are reduced as the groundwater passes through the material (Figure 1). The reactive material can be emplaced directly in the path of groundwater flow via trenching or injection or as a reactive liner in a landfill.

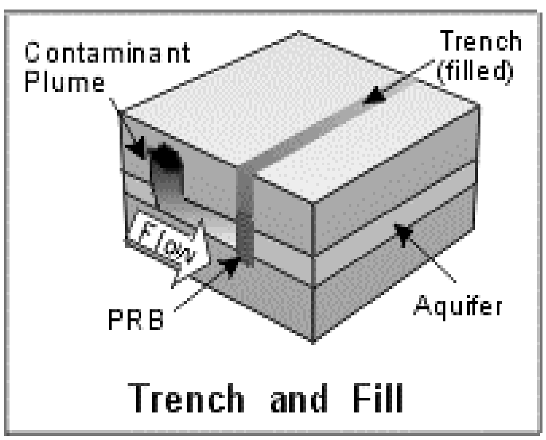

Figure 1. Schematic cartoon of a permeable reactive barrier.

Permeable reactive barriers can be emplaced as a continuous reactive barrier or as a funnel and gate system, where a permeable "gate" contains the reactive material and impermeable materials are emplaced on either side to "funnel" groundwater towards the gate. The entire remediation system is passive and works by creating a strongly reducing environment.

A key issue in the design of an effective permeable reactive barrier is the ability to key into an impermeable formation or aquitard to prevent migration of groundwater below the engineered barrier. Barrier design is based upon groundwater flow velocity and volume, ensuring an effective contact time to allow for the reaction to occur, while preventing mounding behind the wall.

The most common reactive material used in permeable barriers is zero-valent iron (ZVI). ZVI provides a reducing environment that facilitates reductive dechlorination of chlorinated organics (i.e. solvents) or alters redox-sensitive metals so they are immobilized by a precipitation reaction (DOE 1999a). Because iron and manganese are commonly released from the ZVI into the groundwater, an air sparging system can be used to control dissolved iron and manganese concentrations in the groundwater at the downgradient side of the gate.

PeRT wall technology is relatively young, with the first walls installed in the mid-1990's. The application of PeRT wall technology to treat metals and radionuclides is even newer (EPA 2000).

Potential Markets

- DOE, DOD, and other federal or private-sector facilities with groundwater contaminated with uranium and/or other metals sensitive to reduction (such as arsenic, manganese, selenium, vanadium, chromium, or lead)
- Particularly applicable to markets with a shallow, unconfined aquifer with a significant horizontal gradient and a continuous aquitard at a depth that is reachable by excavation (typically less than ~10 meters below grade)

Advantages Over Baseline

- The PeRT wall is a passive treatment system; it produces less waste than active remediation (e.g. pump and treat or extraction systems), as the contaminants are immobilized or altered in the subsurface.
- The initial capital costs for installation of a PeRT wall are greater than that of the pump-and-treat baseline, but the passive system has dramatically lower operations and maintenance costs and a lower life-cycle cost.
- After installation, the PERT wall is not evident at the surface, other than monitoring well heads or covers.
- Estimated life-time treatment effectiveness from a single installation may be greater than 100 years; however the effectiveness of the wall may be reduced over time due to the formation of precipitates.

Demonstration Summary

A PeRT wall using ZVI was installed at the DOE's Monticello Mill Tailings Site (MMTS), a former uranium and vanadium ore-processing mill in Monticello, Utah, in June 1999.

The ZVI PeRT wall is part of Interim Remedial Action under a federal Record of Decision (ROD) as part of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) for Operable Unit (OU) III. As such, the Remedial Action has gone through laboratory and field treatability studies to develop the funnel-and-gate system design and to determine the most effective manufactured ZVI form to reduce contaminants of concern to acceptable levels.

The PeRT wall consists of two impermeable walls on the north and south of the reactive media gate. The reactive gate is made up of three sections of materials: (1) an upstream gravel with a ZVI pre-treatment zone; (2) a middle portion of granular ZVI; and (3) the downstream gravel pack with an air-sparging system.

Design of the PeRT wall was based upon previous site investigation data to determine the bedrock profile and the groundwater chemical and physical characteristics. The MMTS site contains an alluvial, unconsolidated aquifer containing mostly sand with minor amounts of gravel and clay. The alluvial aquifer fills a narrow valley at the site. The PeRT wall was installed in the alluvium and was keyed into the underlying bedrock across the entire valley. Groundwater flows through the reactive gate and down the valley in the alluvial aquifer.

The reactive gate was constructed by driving sheet pilings in a box-like geometry into the underlying impermeable bedrock, then excavating the unconsolidated alluvium, and replacing it with the reactive material in the gate. The impermeable walls were constructed by trenching and filling with a soil/bentonite slurry mixture.

Over sixty groundwater monitoring wells were installed up-gradient, within, and down-gradient of the reactive gate and also in up-gradient and down-gradient locations from the impermeable funnel walls to evaluate wall performance.

Key Results

- The PeRT wall was effective in reducing elevated levels of uranium, vanadium, selenium, and arsenic in groundwater down-gradient of the barrier to non-detectable levels, once the contaminated groundwater had passed through the permeable reactive gate containing ZVI. This performance is likely to be superior to that obtained using a pump and treat system.
- Both iron and manganese were expected to be present at elevated concentrations in the reactive media effluent exiting the gate. Concentrations of both iron and manganese in the groundwater down-gradient of the gate were lower than predicted by treatability studies.
- Key to the success of the PeRT wall design was a pretreatment zone, consisting of mostly gravel with minor amounts of ZVI, at the leading edge of the gate. This zone initiated the reduction reactions within a very porous media that would not be likely to clog.

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Other

All published Innovative Technology Summary Reports are available on the OST Web site at http://ost.em.doe.gov under “Publications.” The Technology Management System (TMS), also available through the OST Web site, provides information about OST programs, technologies, and problems. The OST/TMS ID for Permeable Reactive Treatment (PeRT) Wall for Rads and Metals is 2155.

SECTION 2
TECHNOLOGY DESCRIPTION

Overall Process Definition

A permeable reactive barrier can be designed as (1) a continuous wall containing reactive material or (2) a funnel-and-gate system, where the funnel consists of two impermeable walls that direct groundwater flow to the central reactive-material gate. Permeable reactive barriers have been used in a number of locations to treat both organic-and inorganic-contaminated groundwater in shallow, unconfined aquifers.

Keys to design of an effective barrier system include:

- presence of an impermeable aquitard below the aquifer (a low-permeability bedrock formation or thick, continuous clay unit); and
- a significant horizontal gradient in the unconfined aquifer.

The funnel walls of a funnel-and-gate system are made of an impermeable material, typically a bentonite or cement slurry, which is placed in a narrow trench that is almost perpendicular to the flow of groundwater (about a 75 degree angle facing up-gradient is typical). Actual angle of intersection with groundwater flow is determined based on many site-specific characteristics, including groundwater flow gradient, groundwater velocity, permeability of the aquifer materials, topography of both the ground surface and the basal aquitard, and contaminant distribution.

The design of the permeable gate is also based on many site-specific features, including contaminant type, desired treatment efficiency, remediation goals, and groundwater characteristics. The permeable gate can vary in thickness and composition. In all cases, the reactive material design must take into account the concern about impact on barrier effectiveness due to reduced permeability that may occur as a result of mineral precipitation.

Groundwater modeling and laboratory and field treatability studies are required to properly design the PeRT wall. By using existing characterization data for the site, an optimal design based on the specific site hydrology can be developed (DOE 1999b). At MMTS, such studies provided information to design the wall. Increases in dissolved iron and manganese in the groundwater down-gradient of the wall were predicted. An air-sparging system was designed for the down-gradient portion of the wall to precipitate iron and manganese from the groundwater as iron oxyhydroxide.

The MMTS project utilized a funnel-and-gate barrier design (Figure 2). The entire bottom of the wall is keyed into bedrock, which varies from 4 to 8 meters below ground surface, thereby guiding the groundwater to move through the reactive gate. At MMTS, ZVI was selected as the reactive media because of its particular ability to reduce the metals of concern, particularly uranium. Uranium, as an example, will precipitate as the mineral uraninite or an amorphous precursor when contacted by ZVI.

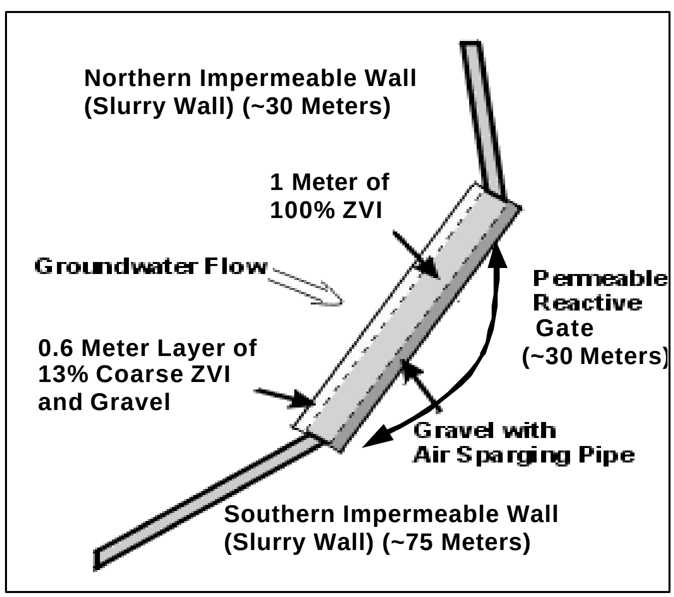


Figure 2. Diagram of PeRT wall construction at MMTS.

$$Fe^{0}\ (ZVI) + UO_2(CO_3)_2^{2-} + 2H^{+}$$
$$Fe^{2+} + 2HCO_3^{-} + UO_2\ (uraninite)$$

Chemical reduction by ZVI affects the entire aqueous system and not just the contaminants; some undesired effects need to be considered when designing a PeRT wall. As an example, H+ is consumed during reduction and can lead to an increase in pH. Increases in pH can lead to precipitation of metal-carbonate or metal-hydroxide minerals that could significantly reduce the permeability of a PeRT wall. Increases in pH can also occur due to other chemical processes, such as the reduction of dissolved oxygen or the direct reduction of aqueous protons. Thus, the potential for mineral precipitation due to increasing pH is limited only by the availability of the metals or carbonate and the rates of the reactions. Precipitation of calcite ($CaCO_3$), siderite ($FeCO_3$), and ferrous hydroxide [$Fe(OH)_2$] have been observed in laboratory experiments with ZVI. Generation of hydrogen gas has also been observed. Although hydrogen gas is used by some microbes as an electron donor, no detrimental (or positive) effects of hydrogen gas on PeRT walls have been confirmed or reported (DOE 1999a).

System Operation

Once the PeRT wall is emplaced, there is little operation or maintenance to conduct. Groundwater monitoring to measure the effectiveness of the PeRT wall is likely to be required for all installations; monitoring should include sampling of wells placed both up-gradient and down-gradient from the PeRT wall. At MMTS the monitoring-well network also included installation of wells within the PeRT wall itself.

Operating and maintenance for PeRT walls might include removal of precipitates from or periodic replacement of the reactive media.

SECTION 3
PERFORMANCE

Demonstration Plan

The PeRT wall was deployed at MMTS to chemically reduce the concentrations of the contaminants of concern in the surficial aquifer at the site to levels deemed acceptable by the regulatory agencies.

The MMTS site (Figure 3) is a former uranium-and vanadium-processing site, which operated from the mid-1940s until 1960. The site was placed on the National Priority List (NPL) in 1989 because of potentially elevated risks associated with contaminated materials related to past milling activities. The DOE, U.S. Environmental Protection Agency (EPA) and the State of Utah have entered into a Federal Facilities Agreement (FFA) that specifies DOE as the lead agency and gives oversight authority to EPA and the State. This site is currently being remediated in accordance with CERCLA. The PeRT wall was installed as part of the Interim Remedial Action included in the Operable Unit Three Record of Decision (OU III ROD).

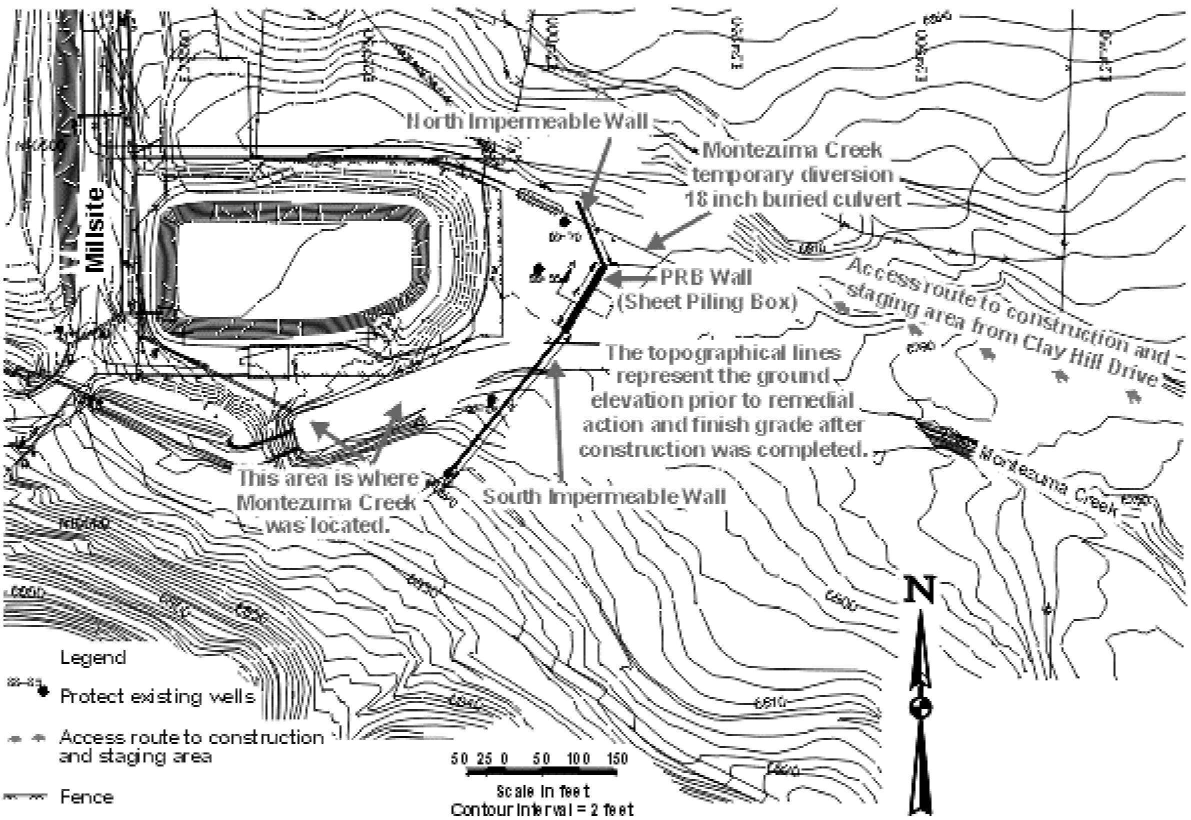


Figure 3. Map of Monticello Mill Tailings site.

At the site, contaminated groundwater flows through a shallow alluvial aquifer that is underlain by impermeable bedrock present at a depth of 4 to 8 meters. The groundwater is naturally funneled through a zone of less then 150 meters width. The major contaminants of concern in groundwater at MMTS are uranium, vanadium, arsenic, selenium, manganese and lead-210 (the final daughter product in the radioactive decay of uranium-238).

Results

PeRT Design Parameters

As part of the Interim Remedial Action, laboratory and field Treatability Studies were conducted to support the barrier design and determine the most effective ZVI form. Through these studies, theoretical treatment efficiency and optimal parameters for porosity, packing density, and residence time were calculated.

Several reactive materials were originally evaluated during the initial bench and column treatability studies using actual groundwater from the MMTS site, but ZVI was found to be most effective at removing the site-specific contaminants. Field column tests were performed to evaluate (1) the removal of contaminants by ZVI from five suppliers; (2) iron and manganese mobilization from the ZVI;
(3) changes in hydraulic conductivity; (4) the concentrations of contaminants of concern after ZVI treatment; and (5) rates of reaction (DOE 1999a).

It was found that ZVI in any of the tested forms would be effective in achieving the removal of the targeted contaminants. However, iron and manganese were found to be released by ZVI treatment of the MMTS groundwater. An air-sparging unit on the down-gradient side of the gate was added to precipitate the iron and manganese as oxyhydroxides to reduce dissolved concentrations in groundwater (Figure 4).

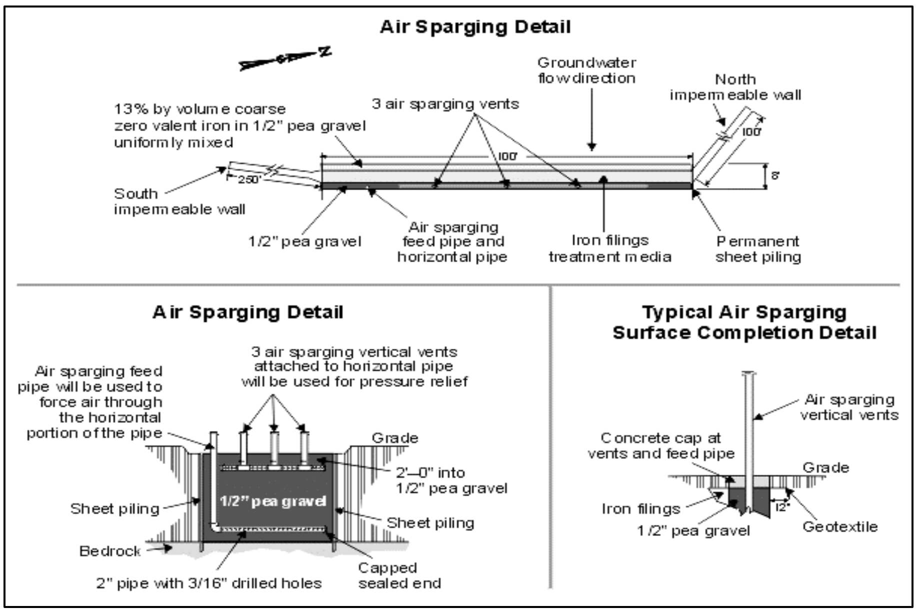
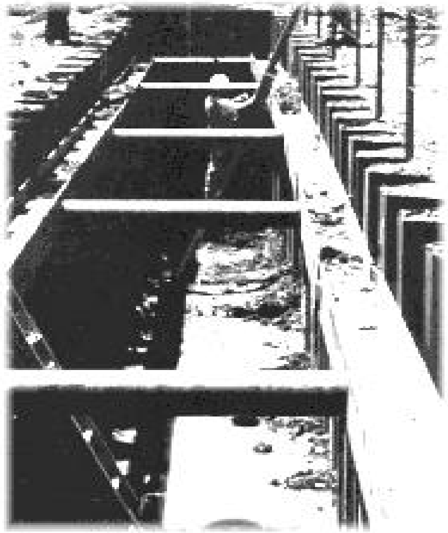


Figure 4. Air sparging addition to the PeRT wall.

PeRT Wall Construction

- Construction on the funnel-and-gate system occurred from June to July 1999 (DOE 1999b). The reactive gate was constructed by driving steel pilings down into bedrock forming a rectangular box approximately 30 meters long by 2.3 meters wide (Figure 5). The native geologic materials inside the box, including a minimum of 0.3 meters of bedrock aquitard, were excavated and removed (Figure 6). The box was then filled with a reactive medium of ZVI and gravel pack up-gradient, 100 % pure ZVI in the center, and gravel pack alone down-gradient of the ZVI (Figure 7). After the reactive materials and gravel were placed in the box, the sheet pilings were removed to allow groundwater to flow through the reactive portion of the wall.



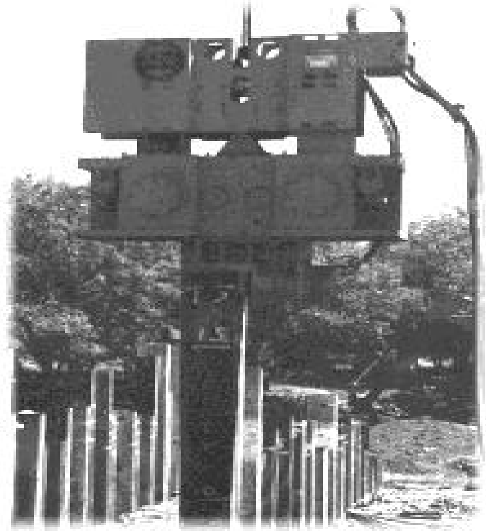


Figure 5. Reactive gate construction **Figure 6. Excavation of native soils.**

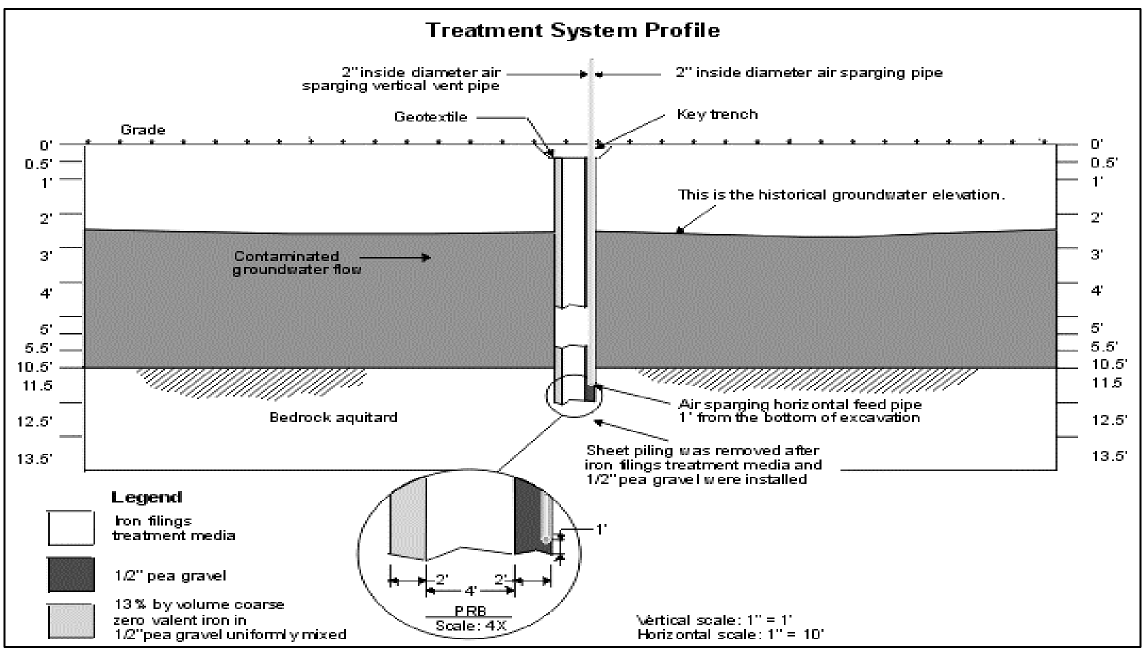


Figure 7. Cross-sectional view of reactive media, showing air sparging pipe.

- The up-gradient gravel pack is ~0.6 meters wide, composed of 13 percent by volume ZVI (–4/+20 mesh) mixed uniformly with ½ inch gravel. The purpose of the up-gradient gravel layer is to initiate precipitation in this more permeable zone. Results from treatability tests conducted in 1998 indicated that most precipitation occurs in the first several centimeters of a ZVI barrier. This key design feature addresses the long-term performance issue related to reduction in hydraulic conductivity from chemical precipitation. It is intended to extend the longevity of the PeRT wall.

- The center section of the reactive gate contains 100 percent ZVI (-8/+20 mesh). Approximately 4,480 cubic meters of ZVI with a loose-filled weight density of 115 pounds per cubic foot were used. The hydraulic conductivity of this material (saturated for 24 hours using a Falling Head Method) is 3.58 x 10^{-2} centimeters per second. This section of the wall was designed to serve as the main treatment area, ensuring contaminant removal to acceptable levels over an extended period of time. ZVI dissolution calculations (assuming minimal clogging) indicate that the ~1.2 meter layer of ZVI at MMTS will last more than 100 years.
- The downstream gravel pack is ~0.6 meters wide, composed of ½ inch gravel and includes an air-sparging system constructed of perforated polyvinyl-chloride pipe (Figure 4).
- The impermeable walls, which funnel contaminated ground water to the reactive gate for treatment, are ~80 meters in length to the south and ~30 meters in length to the north. They were installed using a slurry-wall construction method. The bentonite content of the soil/bentonite mix was 4 percent (Figure 8).

Figure 8. Impermeable wall construction.

- Once the PeRT wall was in place, an extensive monitoring well network was installed in August 1999 to evaluate the performance of the PeRT wall as shown on Figure 9.

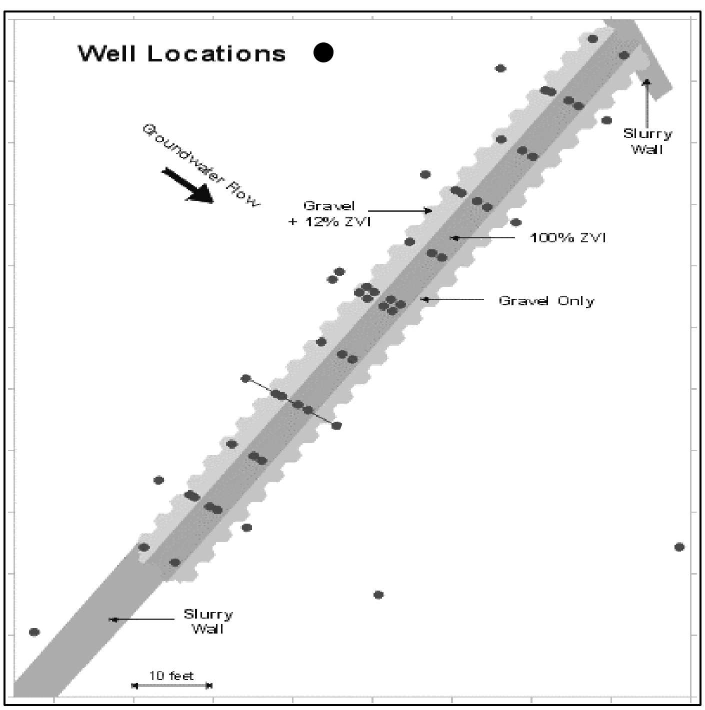


Figure 9. PeRT wall monitoring well locations.

Groundwater Quality

Five rounds of groundwater sampling have occurred since the wall was installed: one each in September, October, and November 1999 and one each in January and April of 2000 (in conjunction with the OU III quarterly sampling event). Sampling is expected to continue on a quarterly basis until July 2001, after which the wells will be sampled as part of the OU III program.

Average concentrations of the contaminants of concern entering the reactive gate in September through November and exiting the gate in April 2000 are shown in Table 1. Analytical results from all five rounds of groundwater sampling indicate that concentrations in groundwater of arsenic, selenium, uranium and vanadium exiting the PeRT wall are below reporting limits. Therefore, the PeRT wall has been effective in reducing contaminant concentrations in groundwater at MMTS. In addition, concentrations of molybdenum were reduced to near non-detectable levels within the PeRT wall. In some cases, concentrations of metals have begun to increase on the down-gradient side of the wall, probably because of desorption of previous absorbed contaminants due to flushing by "clean" water.

Table 1. Average contaminant concentrations in groundwater entering/exiting the PeRT wall

Contaminant of Concern	Entrance Concentration (Sept - Nov 1999)	Exit Concentration (April 2000)
Uranium	700 µg/L	<0.41 µg/L
Vanadium	400 µg/L	<0.77 µg/L
Arsenic	10 µg/L	<0.2 µg/L
Selenium	40 µg/L	<2.0 µg/L

pci/L - pico curies/Liter
µg/L - micrograms/Liter

Source: EPA 2000

As predicted from the treatability studies, concentrations of iron increase as groundwater passes through the PeRT wall. Concentrations of iron exiting the wall are lower than predicted levels and are well within the acceptable human health and ecological risk ranges for iron. Concentrations of manganese have not been altered significantly. The pH in the wall has increased more than predicted (to as much as pH9) thus controlling the release of iron and manganese to acceptable levels. Hence, there has been no need to utilize the down-gradient air-sparging system.

SECTION 4
TECHNOLOGY APPLICABILITY AND ALTERNATIVES

Competing Technologies

The baseline groundwater treatment technology is pump and treat, which is a well-documented remediation strategy. However, data show this approach has been mostly inadequate to restore groundwater to regulatory levels and that operating costs are predicted to be 10 to 20 times the capital costs.

Other competing technologies for remediation of inorganics include:

- Soil flushing;
- Deep soil mixing
- In situ redox manipulation

In addition to other technologies, there are competing reactive barrier systems using the following reactive media for treatment of inorganics.

Sorption

- Peat
- Ferric oxyhydroxide
- Bentonite
- Zeolites and modified zeolites
- Chitosan beads

Precipitation

- Hydroxyapatite
- Dithionite
- Lime or limestone

Although considerable design details have already been developed through field- and pilot-scale applications for these reactive media, many have not been deployed in a full-scale mode, but remain as laboratory studies (GWRTAC 1996).

Technology Applicability

Initial results from monitoring of the MMTS PeRT wall indicate that the ZVI reactive material is effective in treating groundwater contaminated with uranium and vanadium, as well as several other metals and inorganics.

Because site conditions at MMTS are similar to those at other sites where uranium and vanadium ore-processing activities occurred, it is conceivable that application of the ZVI PeRT wall at other DOE UMTRA locations would be quite appropriate. ZVI's ability to treat metals other than uranium and vanadium make it likely to be utilized at other federal or commercial locations.

Patents/Commercialization/Sponsor

DOE OST (EM-50) sponsored the development of PeRT wall technology (formerly called Chemical Barrier Technology) at the MMTS starting in 1992. Laboratory results were favorable; however, the technology was not demonstrated in the field at that time because of major scheduling issues involving the relocation of the tailings.

Research, demonstration, and deployment of PeRT walls have evolved rapidly since the early development efforts by EM-50. Six sites have installed commercial PeRT walls as a final remedy for groundwater remediation. In addition, six demonstration projects are operating. Except for one (in Durango, CO), all of these PeRT walls are located at a non-DOE site.

Of these operating PeRT walls, only three have addressed inorganic contaminants (other than the one at MMTS): Durango, CO, Elizabeth City, NC and Fry Canyon, UT.

- At Durango, a PeRT wall of ZVI has been successfully treating groundwater contaminated with uranium.
- At Elizabeth City, a successful demonstration of a PeRT wall using ZVI led to emplacement of a full-scale PeRT wall for remediation of chromium and halogenated hydrocarbons.
- At Fry Canyon, a PeRT wall has been installed by the U.S. EPA, U.S. Geological Survey, the U.S. Bureau of Land Management and the DOE Grand Junction Office as a joint-agency effort to field-test three separate treatment media (amorphous ferric oxyhydroxide, ZVI, and phosphates). Monitoring results indicate that all three treatment materials at the Fry Canyon site have been effective in removing uranium from the groundwater (DOE 1997).

It is unclear as to whether the funnel-and-gate system requires licensing. University of Waterloo claims to hold a patent on the funnel-and-gate system, but the application was for treatment of organic contaminants. The MMTS project has utilized consultants from the University of Waterloo and their spin-off company, Envirometal, to assist with design and monitoring.

MACTEC has applied for a patent for the air-sparging system designed to treat elevated levels of iron and manganese that may be generated by the PeRT wall.

SECTION 5
COST

Methodology

Costs detailed below for the MMTS PeRT wall are actual. Costs for installation of permeable barriers at other sites were collected from GWRTAC (1996).

Cost Analysis

The capital cost summary for the MMTS ZVI PeRT wall and several other full-scale ZVI PeRT wall installations is presented in Table 2 below. Construction costs for the installations below are assumed to include actual construction costs and not design activities or treatability studies. Dollar amounts are rounded to the nearest thousand.

Table 2. Capital cost summary for treatment walls

Location	Dimensions	Contaminants	Cost ($)		
			Construct.	Media	Total
MMTS ZVI PeRT wall – Monticello, UT	30 m and 73 m slurry walls on opposite sides of a 31.5 m long, 2 m wide reactive cell, 3.5 to 7 m deep	Uranium, vanadium, arsenic, lead-210, selenium, manganese	1,052,000	144,000	1,196,000
Sunnyvale, CA	75 m slurry wall on either side of 12 m long treatment section 1.2 m wide, 6 meters deep, 3.5 m vertical.	VC, cis-1,2-DCE, and TCE	550,000	170,000	720,000
Moffett Federal Air Field, CA	6.5 m long interlocking sheet piles on either side of 3.2 m wide, 3.2 m thick, 8.2 m deep reaction cell	TCE	---	---	300,000
Elizabeth City, NC	45 m long, 5.5 m deep and 0.6 m wide ZVI wall	TCE, chromium	220,000	200,000	420,000
New Hampshire	400 m long wall with several gates, 9 m deep	TCE, VC, cis-1,2-DCE	1,200,000	900,000	2,100,000
Michigan	90 m long with 3 gates, 6 m deep	TCE	300,000	135,000	435,000
Canada	45 m long with 2 gates; 4.5 m deep	TCE	130,000	52,500	182,500

m – meter
cis-1,2-DCE – 1,2-dichloroethylene
TCE – trichloroethylene
VC – vinyl chloride

Source: GWRTAC 1996

The total costs through November 1999 for the PeRT wall at MMTS are presented in Table 3 (DOE 1999).

Table 3. MMTS PeRT Wall project costs (November 1999)

Cost Element	Total
Qualification Strategy (includes review of previous data, design, characterization. Treatability studies, and project management)	$453,800
Implementation Strategy (includes construction prep, emplacement of PeRT wall system, site restoration, monitoring for 2 years)	$1,195,600
Deployment Strategy (includes communication transfer, deployment at other sites)	$19,400
Grand Total	$1,668,800

Source: DOE 1999

Cost Conclusions

Although initial capital costs are significant, PeRT wall technology is much less costly in the operations phase. Total life-cycle costs for PeRT wall technology are significantly less than those of a baseline pump-and-treat system. It is believed that PeRT wall technology can account for a ten-fold reduction in life-cycle costs (Carpenter 2000).

When performing a cost comparison for installation of a PeRT wall as opposed to a pump-and-treat system at a specific site, the following factors should be considered:

- initial activities – identify what startup costs, including design and site characterization, may be associated with the project;
- mobilization costs – compare the costs of equipment and site support;
- treatment facility costs – contrast the differences between deployment costs, such as well installation, above-ground equipment, etc.;
- annual costs – identify the long-term costs for preparation of updated operations plans, continued monitoring, regulatory reviews;
- operating and maintenance costs – itemize cost for maintenance and upkeep of equipment; and
- decontamination and decommission – identify the estimated costs for closure of the system.

After consideration of each of these cost items, it is clear that the PeRT wall technology cost less over a life cycle as small as ten years. While it is now recognized that pump-and-treat systems will usually be operated for very long periods of time (in excess of thirty years), many of the PeRT walls being designed have an estimated life cycle (based on reactivity of ZVI) in excess of 50 to 100 years (DOE 1997). However, long-term performance is uncertain because walls have been installed for less that ten years.

SECTION 6
REGULATORY AND POLICY ISSUES

Regulatory Considerations

Implementation of a PeRT wall at a hazardous waste site requires the approval of appropriate state or federal regulatory agencies. The EPA has worked closely with the developers of the PeRT wall technology. Few states' regulations specifically address PeRT wall technology; the Interstate Technology Regulatory Cooperation Working Group, a state-led ad hoc group promoting the implementation of innovative technologies, has a permeable barrier technical group that has written guidance documents on the implementation of permeable barriers.

Potential considerations to be addressed as a part of any approval process involve site investigation, design, and monitoring issues, including those listed below:

- sufficient characterization of site geology, hydrology, contaminant distribution, and human health and environment risk factors to permit adequate design of the PeRT wall;
- ability of the proposed design to account for uncertainties inherent in subsurface investigations and application of in situ treatment technologies;
- ability of the proposed design to capture and adequately remediate the vertical and horizontal extent of the groundwater plume;
- monitoring to measure concentrations of by-products in groundwater potentially produced through treatment-wall reactions; and
- monitoring to characterize precipitate formation and wall clogging, which may limit effectiveness.

One regulatory advantage is that PeRT wall technology does not involve removal of groundwater from the subsurface. Therefore, it does not require permits for discharges of groundwater to the environment (GWRTAC 1996).

Safety, Risks, Benefits, and Community Reaction

Worker Safety

Exposure of workers to hazardous substances during installation and operation of the PeRT wall is likely to be lower than other treatment technologies due to minimal contact with contaminated materials. During wall installation, workers may contact contaminated soils. Specific exposures will be dependent upon the type of installation technology selected.

Environmental Impact

It is imperative that groundwater monitoring be conducted to ensure that releases that may result from the use of the PeRT wall technology do not impact offsite receptors. It is important to note, though, that impacts from PeRT wall installation are likely to be less than with other technologies due to the placement of the treatment materials in the ground (GWRTAC 1996).

Socioeconomic Impacts and Community Reaction

There will be minimal socioeconomic impact associated with the application of PeRT wall technology, as system installation will occur over a very short period of time and operations requirements are almost non-existent. Community reaction, however, will likely support the application of this passive technology, because it operates below ground, thus reducing potential community exposure to hazardous chemicals.

SECTION 7
LESSONS LEARNED

Implementation Considerations

The PeRT wall is ideal for sites where groundwater is channelized or contained in a constricted path. It is also ideal for unconfined, shallow aquifers (less than 10 meters below ground surface) with a significant aquitard underneath.

A particular concern with PeRT wall technology is the question of long-term performance. Loss of permeability over time as a result of chemical precipitation, microbial activity, gradual loss of media reactivity as the reactant is either depleted or coated by reaction by-products has been a major concern. Maintenance of a PeRT wall system might include removal of precipitates from or periodic replacement of the reactive media. Studies are currently underway to improve our understanding of the systems over long periods of time.

Access to the surface is required for PeRT wall installation if trenching is the selected mode for installation. If surface obstructions are present, the reactive material could be emplaced using directional drilling or injection via fractures.

ZVI materials are available in several inexpensive forms, which are commonly available from commercial vendors and have good structural and hydrodynamic properties. It is necessary to evaluate the most effective form of ZVI for a specific site, as groundwater chemistry can vary widely.

Technology Limitations and Needs for Future Development

A significant limitation for application of PeRT wall technology is the depth at which it can be installed and the cost escalation that occurs when emplacement is required at greater depths. Although quite cost-effective in shallow aquifers with near-surface aquitards, costs increase at depths that require significant sheet piling-emplacement or removal of soil materials using equipment larger than a commercial excavator. Besides generating a significant amount of additional waste materials, the ability to control the groundwater during emplacement of the system and the ability to conduct a quality installation at greater depths decreases significantly. Installation of ZVI through deep fractures is being investigated at DOE's Paducah Gaseous Diffusion Plant. Information from this demonstration will be utilized to improve our understanding of the technology's limitations and cost effectiveness.

Future technology development for PeRT walls needs to address loss of permeability in the reactive media over time and the potential creation of chemicals not desirable within the reactive barrier or as a reactant by-product down-gradient of the wall.

Technology Selection Considerations

It is necessary to fully assess site-specific characteristics to determine if groundwater contaminants and parameters lend themselves to implementation of PeRT wall technology.

- The project manager should be sure the site is fully characterized so that a good understanding of groundwater hydrology, geology, and contaminant chemistry distribution exists.
- Site characterization data must be utilized to create a robust design of the PeRT wall system.
- Treatability studies using groundwater samples from the affected site must be conducted to assist with selection of the reactive media that is most effective in treating the groundwater and will allow long-term operation of the system.

APPENDIX A
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