COST AND PERFORMANCE REPORT

In Situ Permeable Reactive Barriers for Contaminated Groundwater at Fry Canyon, Southeastern Utah

January 2000

EPA
U.S. Environmental Protection Agency
Office of Solid Waste and Emergency Response
Technology Innovation Office

SITE INFORMATION

IDENTIFYING INFORMATION:

Site Name: Fry Canyon

Location: Southeastern Utah

TREATMENT APPLICATION

Type of Action: Field Demonstration

Period of Operation: September 1997 - Ongoing (Performance data for first year of demonstration, September 1997 to September 1998)

Quantity of Material Treated during Application [1, 4, 7]: 33,000 cubic feet (approximately 200,000 gallons) of groundwater total (the amount of groundwater treated by each PRB has not been calculated at this time. However, tracer tests have been conducted and the results will be analyzed over the next six months and used to refine the estimate of the volume of groundwater treated by the PRBs.)

BACKGROUND [1, 2, 3, 5, 7]

Historical Activity that Generated Contamination at the Site: Uranium ore milling

Waste Management Practice That Contributed to Contamination: Sub-surface drainage from abandoned mill ponds

Site History:

Fry Canyon, located in southeastern Utah (approximately 60 miles west of Blanding, Utah), is the site of an abandoned uranium ore milling operation and copper leach operation. Unreclaimed tailings, leach pads, and leach ponds used in these operations are located at the site. From 1957 to 1960, COG Minerals Corporation (COG) conducted uranium upgrading (concentrating) operations at the site. An estimated 50,000 tons of uranium ore from a nearby mine were processed by crushing and grinding the ore to minus 6-mesh, then sending it to a jig to separate the higher grade products (containing 0.20 to 4.20% uranium) from the waste sand tailings (containing about 0.02% uranium). Approximately 40,000 tons of sand tailings were generated from these operations. In 1962, the Besinare Company acquired the site from COG and conducted copper leach operations from 1962 to 1968. Sulfuric acid was used to leach copper from the mined ore. Tailings from the leaching operation was contained in ponds, and approximately 45,000 tons of tailings remain at the site. The Utah Department of Health, Bureaus of Radiation Control and Solid and Hazardous Waste, conducted site visits to Fry Canyon in 1984 and 1986. Water samples from Fry Creek contained up to approximately 300 ug/L or uranium.

The land is currently managed by the Bureau of Land Management (BLM). The site was selected by the U.S. Environmental Protection Agency (EPA) in cooperation with the U.S. Geological Survey (USGS), the U.S. Department of Energy (DOE), BLM, and the Utah Department of Environmental Quality, for a field demonstration of permeable reactive barriers (PRBs) to assess their performance in removing uranium from groundwater. Fry Canyon was selected for the demonstration based on the results of an investigation that considered a number of factors favoring a long-term field demonstration for PRBs. The favorable characteristics identified at Fry Canyon included uranium concentrations in the groundwater above 3,000 μg/L; shallow groundwater; no cleanup activities planned for the site during the field demonstration; and a moderate climate and a relatively flat topography.

The purpose of the ongoing field demonstration is to evaluate the effectiveness of three types of reactive materials (phosphate, zero valent iron, and amorphous ferric oxyhydroxide) in removing uranium from groundwater. As discussed in the system design section of this report, there are several elements of the design of this demonstration that would not be applicable to a remedial system. For example, based on the characteristics of the site, it was more desirable for the demonstration to install the PRBs within the plume rather than downgradient.

Prior to constructing the PRBs, extensive laboratory investigations were conducted to evaluate the various reactive materials for each type of PRB and to select the specific reactive materials for the Fry Canyon demonstration. The PRBs were constructed side-by-side to allow all three types of materials to be evaluated during the demonstration period.

Regulatory Context: The field demonstration is being conducted as part of a multi-agency effort to evaluate the effectiveness of PRBs in treating uranium-contaminated groundwater. The demonstration was intended to evaluate the effectiveness of the three types of PRBs.

SITE LOGISTICS/CONTACTS

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MATRIX DESCRIPTION

MATRIX IDENTIFICATION

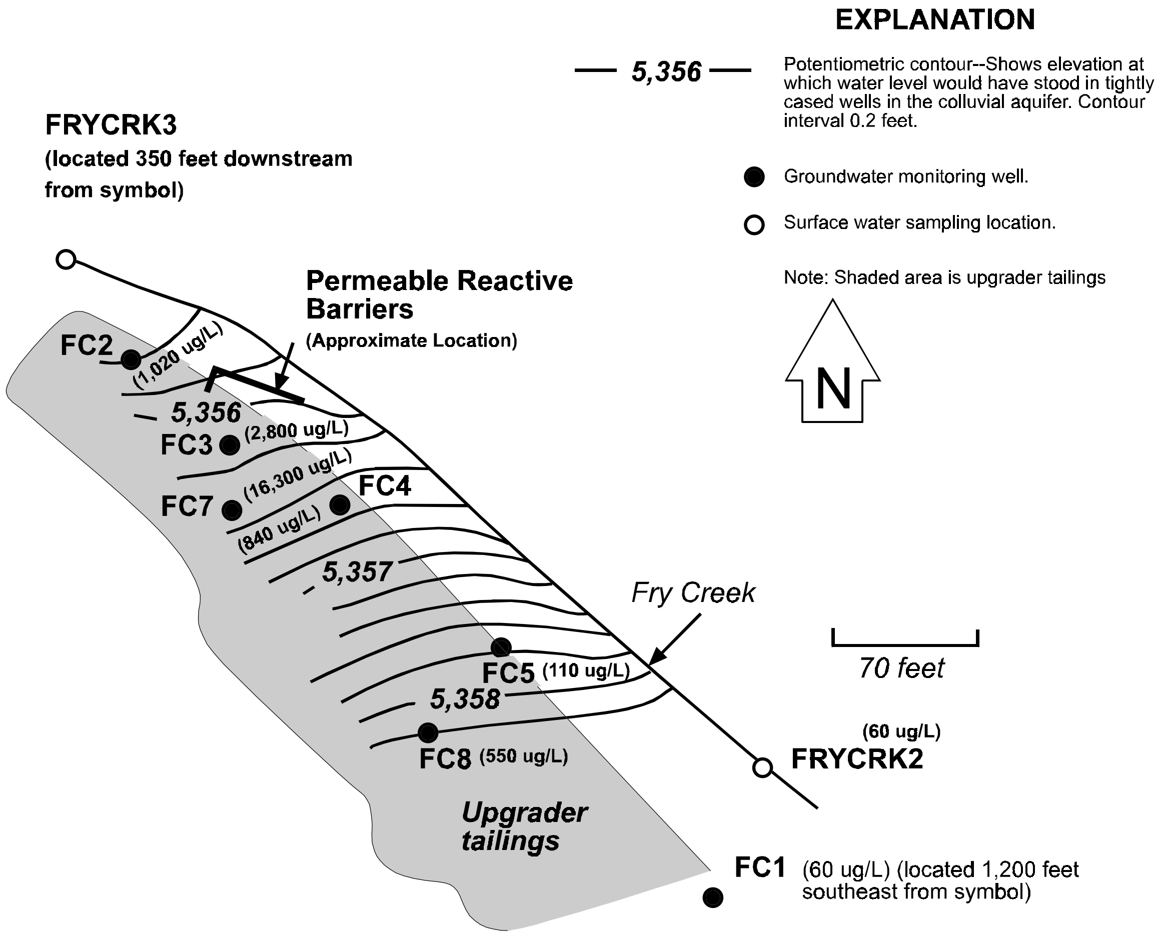
Type of Matrix Processed Through the Treatment System: Groundwater

CONTAMINANT CHARACTERIZATION [1, 2]

Primary Contaminant Groups: Radionuclides (uranium)

Concentrations of uranium in groundwater prior to installation of the PRBs were measured in seven locations, as shown in Figure 1. The uranium concentrations in groundwater ranged from 60 μg/L to 16,300 μg/L, with the highest concentration in well FC7.

Figure 1. Pre-installation ground- and surface-water sampling sites and potentiometric surface of the colluvial aquifer during October 1996, Fry Canyon, Utah [1]



Elevated levels of iron and manganese were detected in groundwater samples. The median concentrations were 90 μg/L for iron and 180 μg/L for manganese.

MATRIX CHARACTERISTICS AFFECTING TECHNOLOGY COST OR PERFORMANCE [1,2]

The demonstration area of the site lies within a sedimentary stream valley, bordered by Fry Creek. Colluvial deposits as thick as 18 ft, consisting of silt to gravel size particles derived from sandstone and shale formations that are upslope and upgradient from the site, are underlain by sandstone bedrock (Cedar Mesa Sandstone member). The water table is located approximately 8 feet below ground surface (bgs).

The underlying colluvial aquifer ranges in depth from 1 to 6 feet, with the saturated thickness in the areas of the PRBs ranging from 2 to 5 ft. The hydraulic properties of the aquifer were estimated from field and laboratory measurements. The estimated rate of groundwater flow is in the range of 0.2 - 2.5 ft/day, with the transmissivity estimated to range from 10 to 200 ft^2/day. The results of laboratory measurements indicated that the hydraulic conductivity ranges from 55 to 85 ft/day and that the porosity is 12.6%. The aquifer is recharged by subsurface inflow from Fry Creek upstream of the site, by runoff from the sandstone upslope of the site, and by precipitation. The groundwater discharges into Fry Creek. As shown in Figure 1, the direction of the groundwater flow is generally northwest, following the flow of the stream.

The vertical and lateral extent of the stream channel deposits in the area of the demonstration site are limited by the erosion surface on the Cedar Mesa Sandstone member. Laboratory measurements conducted by USGS (Grand Junction Project Office) indicate that the hydraulic conductivity ranges from 0.003 ft/day (unfractured portion of the formation) to 0.03 ft/day (deeper, fractured portion of the formation). Because the hydraulic conductivity of the sandstone is up to 1,000 times smaller than that of the colluvial aquifer, the sandstone formation is likely to be an impediment to flow in the shallow groundwater system. In addition, the presence of Fry Springs at the site is an indication that the sandstone transmits groundwater through bedding-plane fractures; therefore, it is possible that some groundwater could move between the sandstone and the channel deposits.

TREATMENT SYSTEM DESCRIPTION

PRIMARY TECHNOLOGY

Permeable Reactive Barrier (PRB)

SUPPLEMENTAL TECHNOLOGY TYPES

None

SYSTEM DESCRIPTION AND OPERATION

System Description [1, 2, 7]

The Fry Canyon site was used to field test three categories of PRB materials: (1) phosphate (PO_4) which is hypothesized to remove uranium through precipitation of an insoluble uranyl phosphate phase, (2) zero-valent iron (ZVI) which is thought to reduce uranium to a +4 oxidation state and subsequently removes the uranium by precipitation, and (3) amorphous ferric oxyhydroxide (AFO) which removes uranium by adsorption to the iron hydroxide surface.

The selection of materials for the demonstration and the design and installation of the three PRBs and the monitoring network are described below.

Selection of Materials for the Demonstration

Laboratory investigations were conducted by USGS and DOE to select the specific reactive material to be used for the demonstration at Fry Canyon. The factors that were considered in selecting the materials included (1) availability, (2) cost, (3) permeability relative to the surrounding aquifer material, (4) structural strength/resistence to compactive crushing when placed in the ground, (5) extent, rate, and duration of uranium removal, (6) mobility in terms of the tendency of the material to move with the groundwater, (7) potential for re-release of uranium, and (8) possible detrimental effects on groundwater quality (e.g., pH change or release of iron or phosphate).

Extensive laboratory investigations were conducted to evaluate a number of materials for each category of PRB (details of these investigations can be found in Reference 1). The following is a summary of the basis for selecting the materials to be used for the Fry Canyon demonstration.

- PO_4 - Phosphate rock, bone meal, bone meal charcoal, and pelletized bone charcoal were evaluated using batch and column experiments. Of these, bone-meal materials were found to be the most effective in removing uranium. Bone-char pellets (charred bone meal with aluminum phosphate binder) were selected because the high hydraulic conductivity allows its use in a PRB without dilution (bone meal powders required dilution with inert course material to obtain adequate barrier permeability)

- ZVI - Eleven ZVI materials were evaluated including several types of ZVI filings, pellets, and foam aggregates. Batch and column tests as well as hydraulic conductivity measurements were performed. Foam pellets (foamed aluminosilicate-bound pellets) were selected because this material had suitable hydraulic conductivity, high uranium removal, and high compaction strength.

- AFO - Because AFO is not commercially available in a form that can be used in PRBs, laboratory investigations were performed to develop a suitable form of AFO for use in the demonstration. Batch, column, and hydraulic conductivity tests also were performed. AFO slurry mixed with gravel (1:2 volume/volume) was selected because this material had suitable hydraulic conductivity, high uranium removal, and high compaction strength. This material, however, contained only 2% (by weight) reactive iron and the PRB was expected to last only for six months.

<u>PRB Design and Installation</u>

The three PRBs were installed side-by-side and operated concurrently. As shown in Figure 2, a funnel and gate design was used consisting of three permeable gates (one for each PRB), separated by impermeable funnels of plywood covered with HDPE plastic sheeting. In addition, impermeable walls of bentonite or HDPE-covered plywood were installed on each end to help funnel the groundwater into the PRBs. Each PRB was keyed, along with each of the impermeable funnels, into the bedrock (Cedar Mesa Sandstone formation) beneath the colluvial aquifer. A 1.5-foot layer of pea gravel was placed on the upgradient side of the PRBs to facilitate uniform flow of groundwater into the PRBs.

A backhoe was used to dig a trench, which was then scraped down to the bedrock. Boxes constructed of angle iron and plywood were used as frames for the construction of the PRBs within the trench, along with trench boxes designed to protect the workers from cave ins. Reactive material was placed in the box, along with the monitoring wells (see below). The ZVI foam pellets and the bone char pellets were used as received on site (no mixing with sand or gravel was required). The AFO slurry (13% AFO) was mixed with gravel (1 part slurry to 2 parts gravel by volume) prior to placing in the box frame. The boxes were designed such that after filling with the reactive material, the frame and two of the plywood side sheets remained in place (providing support for the PRB), while the other two sheets of plywood were removed allowing groundwater to flow through the PRB. Following construction, the trench boxes were removed and the PRBs backfilled with native material. The ground surface was then graded to level, and the wells were pumped to remove fine particulates that were introduced during construction.

The "as built" volume of reactive material was: PO_4 - 67.2 ft^3; ZVI - 77.7 ft^3, and AFO - 67.2 ft^3. As shown in Figure 3, each PRB was about 3 feet wide and 3 to 4 feet long. The design thickness (depth) of each wall (reactive zone) was 5 feet; however, because of materials settling after removal of the trench boxes, the actual depths were PO_4 - 3.2 ft, ZVI - 3.7 ft, AFO - 3.2 ft. As a result, the water table was about 1.9 feet above the top of the PO_4 PRB and the saturated zone above the PRB had to be backfilled with native materials that were less permeable than the reactive materials. However, in a remediation application, the highest projected elevation of the water table must be below the top of the barrier to ensure that all groundwater is treated.

During installation, several problems were encountered which required the design to be modified in the field.

Figure 2. Schematic diagram showing the funnel and gate design used for the installation of PRBs, Fry Canyon, Utah [1]

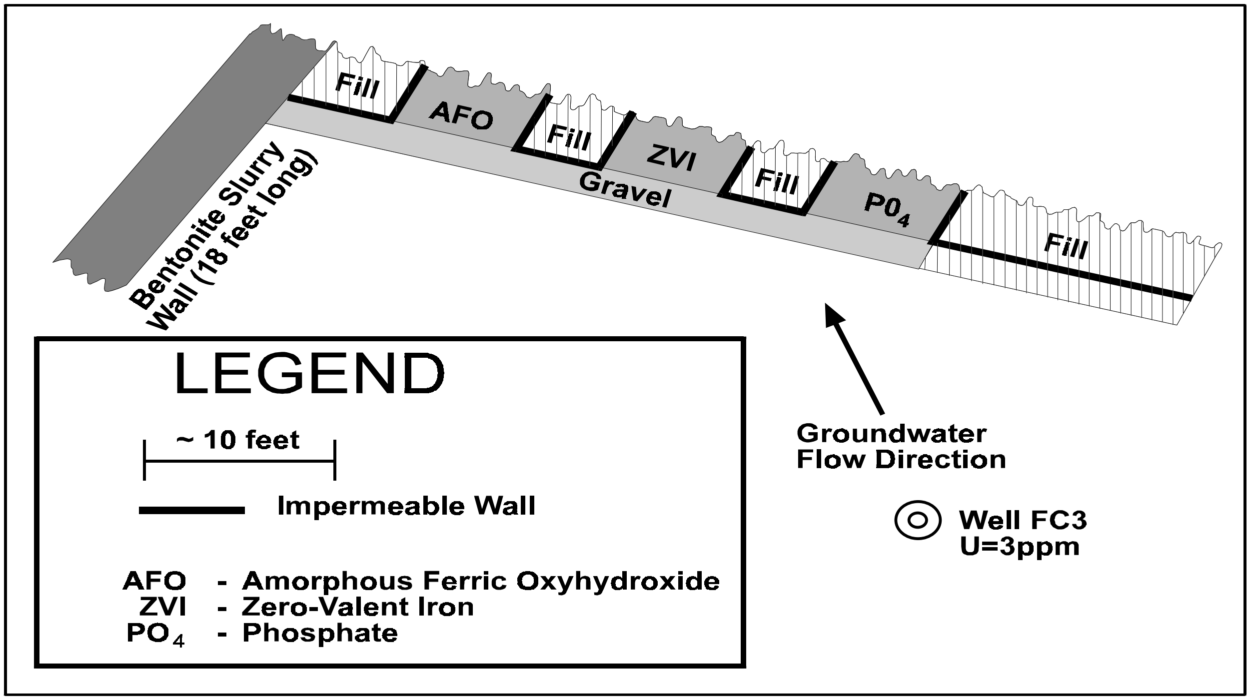
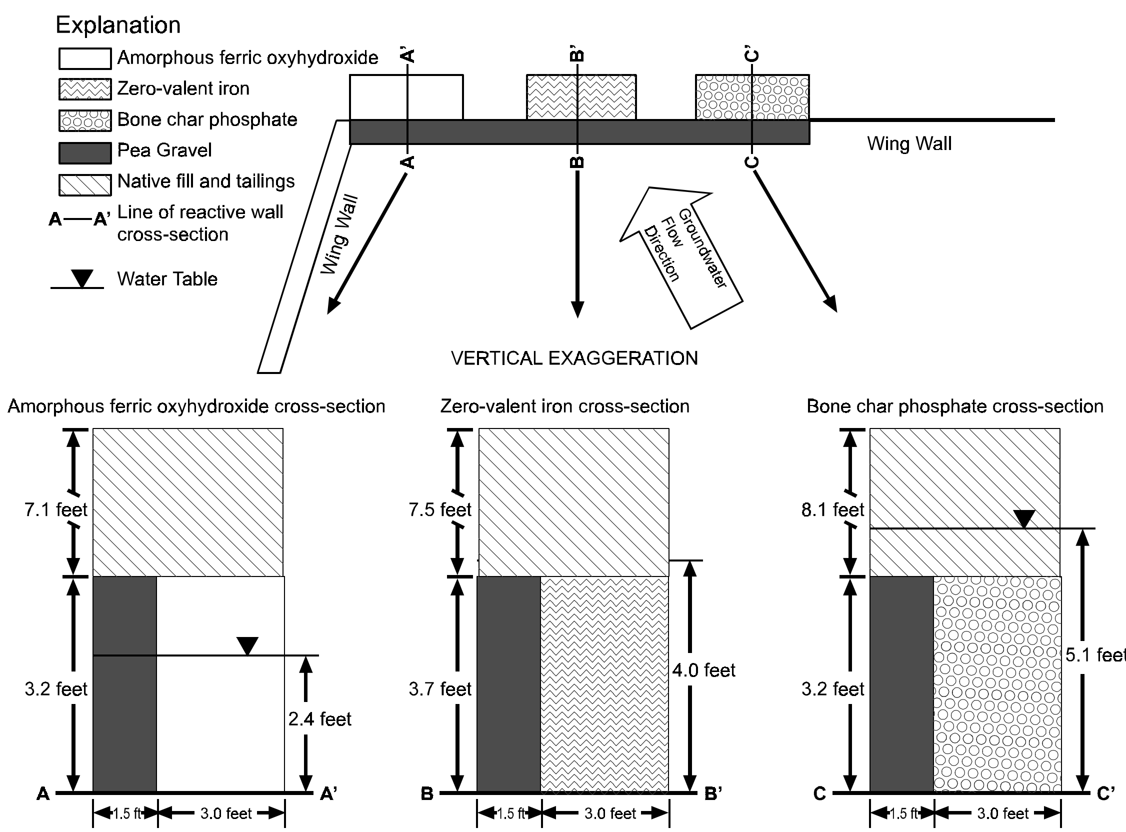


Figure 3. Location and dimensions of PRBs after construction, Fry Canyon, Utah [1]



- The planned design called for the gates to intercept the groundwater flow at right angles. However, during the initial trench excavation, an unanticipated occurrence of a large bedrock “nose” of the Cedar Mesa Sandstone formation was encountered that required rotation of the trench orientation. This resulted in the gate structure of each PRB intercepting the groundwater about 35 degrees from perpendicular.

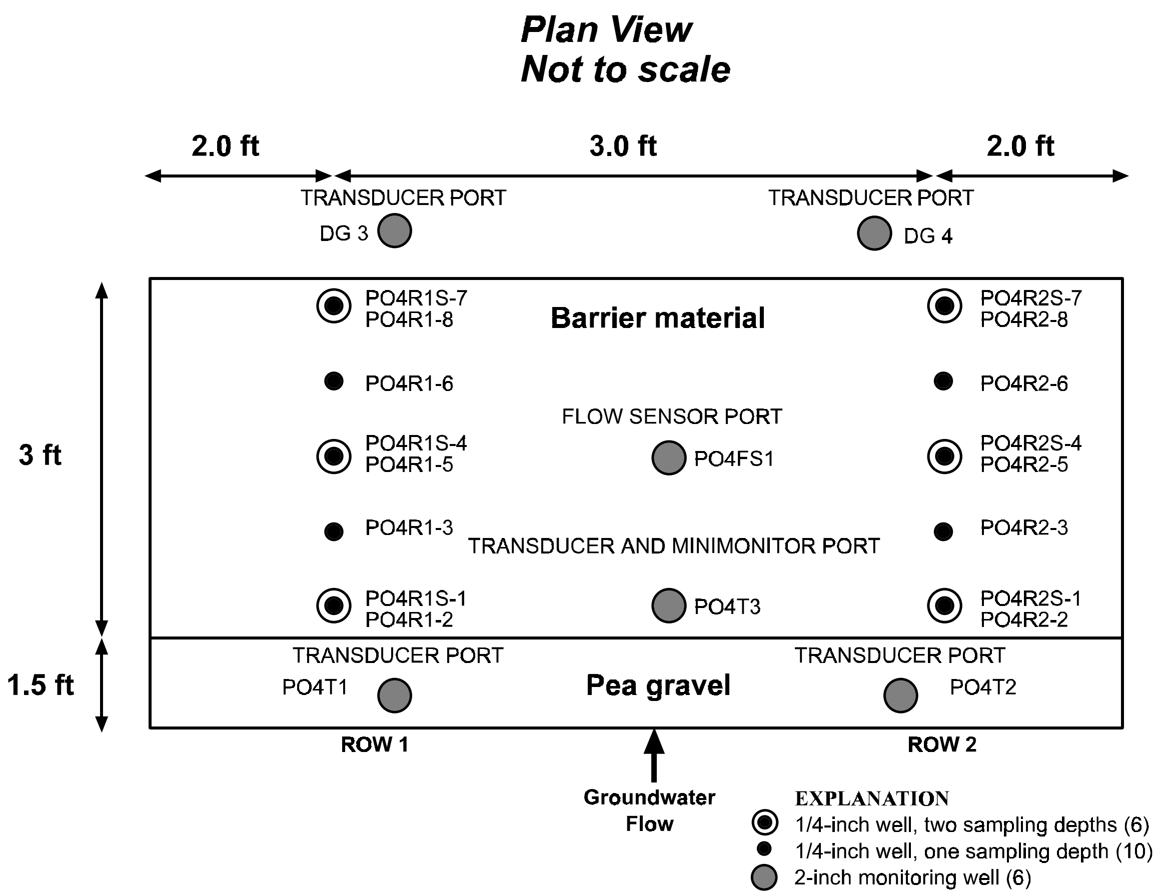
- The planned use of bentonite for the impermeable barriers for both wing walls had to be modified. During construction of the east wing wall, the slurry could not be contained while the gate structures were being constructed. The slurry was removed and the wing wall was constructed using plywood and plastic sheeting. The slurry was reused for the west wing wall after sufficient native soil was placed in the area to contain the slurry.

- The plan to visually inspect the seal between the no-flow barrier and underlying bedrock was complicated by the fact that the bedrock surface was not flat. As such, it was difficult to assure a consistent seal.

Monitoring Network Design

Figure 4 shows the monitoring network design for the PO_4 PRB. Identical designs were used for all three walls. As shown in Figure 4, each PRB contains a total of 22 monitoring wells. There are 16 1/4-inch sampling wells, including six multi-level wells (used to monitor changes in water quality at different depths) and six 2-inch monitoring wells - two upgradient, two downgradient, and two within the wall to monitor groundwater velocity and water quality. In addition, there are 4 pressure transducers in each PRB.

Figure 4. Monitoring well placement and sample site identification for the PO_4 PRB [1]



Within each PRB the 16 1/4-inch wells are configured into two parallel "rows" - Row 1 and Row 2. Groundwater sample results are reported by row number and used to assess potential variation in performance within the PRB.

System Operation [1,2]

The demonstration began in September 1997 and is ongoing. Data are available for the first year of operation (through September 1998, see Treatment Performance Data Section).

The estimated quantity of groundwater treated between September 1997 and September 1998 was 33,000 cubic feet total for all three PRBs. The volume was based on an estimate that the quantity of water entering and exiting the capture zones for the PRBs was 90 cubic ft/day.

The volume of water passing through each PRB has not been estimated at this time. Computer simulations along with tracer tests are currently being conducted to refine the estimate of the volume of groundwater treated.

The PRBs have been operational 100% of the time since September 1997. No maintenance has been required during the first year of operation.

OPERATING PARAMETERS AFFECTING TECHNOLOGY COST OR PERFORMANCE

The following operating parameters affect cost and performance for this technology [7].

Parameter	Value
Estimated Range of Groundwater Velocity through PRBs	0.2 - 2.5 ft/day (actual groundwater velocity in each PRB will be confirmed by tracer tests)

TIMELINE [1]

The timeline for this demonstration project is presented below.

Start Date	End Date	Activity
9/96	4/97	Site characterization and laboratory investigations of reactive material conducted
9/97		Installation of three PRBs completed
9/97	9/98	PRBs operated for one year; groundwater sampled seven times
9/98	ongoing	PRB operation continues

TREATMENT SYSTEM PERFORMANCE

TREATMENT PERFORMANCE GOALS [1]

The objective of the demonstration project is to evaluate the use of three types of PRBs in controlling the migration of radionuclides (uranium) and metals in groundwater. The demonstration includes five phases: (1) characterization of the site; (2) laboratory testing to determine operating parameters; (3) design of the field demonstration; (4) installation and operation of the PRBs to evaluate performance; and (5) using results to determine effectiveness and to develop cost estimates for commercialization.

PERFORMANCE DATA ASSESSMENT [1, 4]

During the first year of operation, the groundwater was sampled seven times and analyzed for uranium. For each PRB, samples were collected for each of the two “rows” of wells within the PRB (see Figure 4). In addition, samples were collected from the 2-inch monitoring wells down-gradient from each PRB and analyzed for chemicals of interest and parameters such as iron and pH to evaluate the potential effects on water quality caused by the leaching of barrier materials. For example, high iron or manganese concentrations from the ZVI PRB could have negative impacts on down-gradient water quality.

Table 1 summarizes data on the percentage of uranium removed by each type of PRB from September 1997 to September 1998. Percent removal was calculated as follows - influent concentration - effluent (treated) concentration divided by influent concentration. For the calculations, the effluent concentration was measured 1.5 ft down-gradient from the gravel/PRB interface. As shown in the table, the ZVI PRB removed the greatest percentage of uranium of the three PRBs. The ZVI PRB removed more than 99.9% of the uranium from both rows of monitoring wells during all seven sampling events.

Table 1. Percentage of input uranium concentration removed by each of the permeable reactive barriers from September 1997 through September 1998, Fry Canyon, Utah [1]

Date	PO_4 barrier, row 1	PO_4 barrier, row 2	ZVI barrier, row 1	ZVI barrier, row 2	AFO barrier, row 1	AFO barrier, row 2
SEP 1997	99.7	94.4	>99.9	>99.9	95.3	87.4
OCT 1997	94.8	71.9	>99.9	>99.9	94.9	81.4
NOV 1997	89.4	71.6	>99.9	>99.9	93.6	65.1
JAN 1998	79.2	61.8	>99.9	>99.9	85.9	60.1
APR 1998	96.7	77.4	>99.9	>99.9	77.8	47.5
JUN 1998	98.3	88.6	>99.9	>99.9	81.9	66.7
SEP 1998	>99.9	92.0	>99.9	>99.9	87.4	37.4

The next best performance was observed for the PO_4 PRB. The overall percentage of uranium removed by the PO_4 PRB ranged from about 62% to 94% in row 2 and 79% to 99.9% in row 1. Initially, the PO_4 PRB removed more than 99% of the uranium. The removal rate then decreased to 60 to 70% in January 1998, then increased to greater than 92% as of September 1998.

The apparent increase in uranium removal in the PO_4 PRB was thought to be as a result of treated water leaking from the ZVI PRB into the PO_4 PRB, rather than improved performance by the PO_4 PRB. (Tracer tests did not confirm leakage from the ZVI to the PO_4 PRB; rather they showed that ZVI gets water pretreated by PO_4.) Data show that the dissolved iron concentrations have consistently increased in the PO_4 PRB. These data, along with the fact that the hydraulic gradient is nearly flat within the pea gravel, indicated that there is possible unintentional water movement between barriers. However, newer information has showen that this is no longer a possibility, and that there is no leakage between the ZVI and PO_4 barriers. It appears that the increased efficiency in the PO_4 barrier is the result of anoxic conditions caused by the release of PO_4.

The AFO PRB showed the lowest uranium removal rate among the three types of PRBs. The percent removal for the AFO barrier ranged from about 77% to 95% in row 1 and 37% to 87% in row 2. The data from row 1 show that while the AFO removed more than 90% of the uranium from September to November 1997, the removal rate dropped to below 90% through September 1998. The removal rate for row 2 was consistently below 90%, and was only about 37% as of September 1998. The performance of the AFO PRB was likely affected by variations in pH because uranium adsorption by AFO has been documented to have a strong pH dependence. Data on the pH of the groundwater indicates that the removal rate for uranium by the AFO PRB was inversely proportional to increases in pH (see discussion below). Also, the AFO barrier had higher contaminant levels and was designed to operate for only six months, with fifty times less reactive material than in the other barriers.

Water quality data for the first year of operation are summarized below:

- Water temperature measurements followed a seasonal cycle in all three PRBs, ranging from about 9 to 19 degrees Celsius during the year.

- Data on the pH values in water samples indicated that the pH range for water samples from the PO_4 PRB were similar to those in the upgradient well (6.5 to 7.5). However, the pH of water samples from the ZVI and AFO PRBs were higher than the upgradient well. The pH values ranged from about 9.2 to 9.7 for the ZVI PRB and from about 7.6 to as high as 9.0 for the AFO PRB. The elevated pH in the ZVI water samples was attributed to iron corrosion.

- For the ZVI PRB, the dissolved oxygen (DO) concentrations were below 0.10 mg/L (the lower reporting limit) during the first seven months of operation, then increased to between about 0.25 to 0.3 mg/L for the remainder of the year. DO concentrations for the PO_4 PRB ranged from about 0.4 mg/L to 3.7 mg/L and for the AFO PRB from about 0.75 mg/L to 2.75 mg/L. The oxidation-reduction potential for the PO_4 PRB varied from -300 to 300 millivolts and for the AFO PRB from -100 to 400 millivolts. The ZVI PRB values ranged from -600 to -400 millivolts. Also, the alkalinity (Ca) decreased, indicating a reduction in porosity.

The low levels of DO in the ZVI PRB are consistent with the consumption of oxygen during iron oxidation during dissolution of the ZVI evident by increased pH levels and high ferrous iron dissolved concentrations. In addition, this may lead to the formation of iron hydroxide precipitates that may passivate the barrier material. Data on ferrous iron concentrations in water samples from the ZVI PRB indicate that dissolution of ZVI is occurring. It is unclear whether formation of iron hydroxide precipitates occurs that may coat the metallic iron surface and affect the redox potential and the performance of the PRB. However, no impact on uranium removal has been observed during the first year of operation.

Other factors relevant to performance consider barrier longevity, including plugging, iron dissolution and re-precipitation (not discussed further in this report).

PERFORMANCE DATA COMPLETENESS [1]

Data were available for each of the seven groundwater sampling events conducted during the first year of operation (September 1997 to September 1998) for each of the PRBs. For each PRB, data are available on uranium concentrations and removal efficiency and on other water quality parameters.

PERFORMANCE DATA QUALITY

Quality assurance (QA) samples (process blanks and field duplicates) were collected and analyzed from September 1997 to September 1998 and during pre-installation activities. With the exception of one field duplicate sample collected during January 1998, where uranium was 11.5% higher than the routine sample, all duplicates were within ± 10% margin of error.

TREATMENT SYSTEM COST

COST DATA [1,4]

Data about the actual cost of each phase of the demonstration were provided by the EPA and USGS team members for this demonstration. Table 2 summarizes the actual costs of the demonstration project for the following activities - Phase 1 - site selection, characterization, and PRB material testing; Phase 2 - PRB design; Phase 3 - PRB installation.; and Phase 4 - PRB operation. In addition, information is provided on how the costs of full-scale projects could differ from the costs of the demonstration project.

Table 2. Summary of Actual Costs for Field Demonstration at Fry Canyon [1, 4, 7]

Project Phase and Approximate Duration	Tasks	Cost (1996$)*	Full-Scale Cost Considerations
Phase 1: March 1, 1996 to March 15, 1997	Project planning Site selection Laboratory testing of reactive materials Selection of reactive materials Regulatory permitting Site health and safety plan for site characterization Site characterization	280,000	Costs of this phase for a full-scale project could be less because: (1) the site already would be selected, (2) existing information on type and performance of reactive material will decrease laboratory testing time, and (3) site characterization activities will likely be complete.
Phase 2: March 16, 1997 to August 15, 1997	Design of PRB structures Design of monitoring network Logistical planning Analysis and awarding of subcontracts Development of health and safety plan for construction phase	148,000	Costs for this phase for a full-scale project would be less because: (1) the demonstration included three PRBs whereas a full-scale project would only include one; and (2) the costs to design the monitoring network for the demonstration was relatively large because of the extent of the system to monitor three PRBs. A full-scale PRB would likely not require this extensive of a system.
Phase 3: August 20, 1997 to September 4, 1997	Purchasing and shipment of material, supplies, and equipment Excavation of trench Installation of monitoring network Placement of reactive material and backfilling/recontouring operations	246,000	Costs for this phase for a full-scale may be higher than for the demonstration because of the following factors that made the installation of the three PRBs relatively cost effective: (1) depth to groundwater was less than 15 feet; (2) average saturated thickness was less than 5 feet; (3) tailings and overburden removed during trench excavation did not require special handling; and (4) the total length of the three PRBs was only 21 linear feet
Phase 4: September - ongoing	Operation and maintenance (O&M) of the PRBs (primarily sampling and analysis)	Information not available	The O&M costs for the demonstration, which requires sampling and analysis of the extensive monitoring system for three PRBs, are relatively expensive. O&M for a full-scale would likely be less expensive as the number of wells, frequency of samples, and chemical constituents monitored, would be less than what is required for a demonstration. Full-scale sampling and analysis was estimated to be about $55,000 to $60,000 per year.

* Cost figures include indirect costs incurred by DOE and USGS.

OBSERVATIONS AND LESSONS LEARNED

The results of the first year of the demonstration showed that the ZVI PRB was the most effective of the three reactive materials tested, consistently removing more than 99% of the uranium from the groundwater. While the removal rate for the PO_4 PRB varied throughout the year, decreasing to as low as 62%, as of September 1998, the uranium removal rate for the PO_4 PRB at the end of one year of operation was greater than 92%. The AFO PRB initially removed greater than 90% of the uranium from the groundwater, but dropped to as low as 37% after the first year of operation. In addition, the AFO PRB showed the greatest variation in performance across the barrier, with the highest removal rate for row 1 of 87% and the lowest rate for row 2 of 37%.

The researchers from EPA and USGS identified several lessons learned to date and suggested solutions for full-scale installations of PRBs for site remediation. These include:

- The uneven surface of the underlying confining unit made it difficult to insure that each PRB gate structure and no-flow barrier was in direct contact with the underlying confining unit to avoid the possibility that the contaminated groundwater could bypass the reactive material. A possible solution would be to use a more powerful track hoe capable of excavating into the underlying confining unit and the use of pumps with capacity that exceeds the groundwater inflow, to allow for visual inspection of the seal between the PRB and the confining unit.

- There were several problems in using a pre-mixed bentonite slurry for the construction of the no-flow barriers including difficulty in controlling the movement of the slurry from the wing walls to the gate structures of each PRB. A possible solution would be to use non-hydrated bentonite chips that could be placed where needed and hydrated in place with groundwater.

- Measurement of groundwater flow during pre-installation characterization and after PRB emplacement is critical; this information is needed for PRB design and to monitor changes in PRB hydraulic conductivity after emplacement.

- During installation of the PRBs, a large bedrock nose was encountered that caused the PRBs to be rotated such that groundwater entered into the gate structures at an oblique angle rather than perpendicular, as designed. To prevent this problem, a more detailed view of the bedrock topography is needed during site characterization.

- The concentration of reactive iron placed in the AFO barrier was approximately 50 times less than the concentrations of reactive materials placed in the other two gates. If an AFO-based material could be manufactured that has a higher concentration of reactive iron and has suitable compaction and permeability properties, it might be competitive with other reactive materials.

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7. Comments on Fry Canyon Report. 1999. From David Naftz, Chris Fuller, and Stan Morrison, USGS, to Richard Weisman, Tetra Tech EM Inc. November 23.

ANALYSIS PREPARATION

This case study was prepared for the U.S. Environmental Protection Agency's Office of Solid Waste and Emergency Response, Technology Innovation Office. Assistance was provided by Tetra Tech EM Inc. under EPA Contract No. 68-W-99-003.