Field Applications of *In Situ* Remediation Technologies: Permeable Reactive Barriers
Field Applications of *In Situ* Remediation Technologies:
Permeable Reactive Barriers

U.S. Environmental Protection Agency
Office of Solid Waste and Emergency Response
Technology Innovation Office
Washington, DC 20460
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Notice
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Introduction

A permeable reactive barrier (PRB) contains or creates a reactive treatment zone oriented to intercept and remediate a contaminant plume. It removes contaminants from the groundwater flow system in a passive manner by physical, chemical or biological processes. Some PRBs are installed as permanent or semi-permanent units across the flow path of a contaminant plume. Some PRBs are installed as in situ reactors that are readily accessible to facilitate the removal and replacement of reactive media. Most have the reactive media installed or created in intimate contact with the surrounding aquifer material.

This report summarizes information about the use of PRBs for groundwater remediation at 47 sites in the United States, Canada, and selected locations abroad. PRB sites included were identified by the Remediation Technologies Development Forum (RTDF) Permeable Reactive Barriers Action Team members, and information was provided by the points-of-contact listed. The U.S. Environmental Protection Agency’s (EPA) Technology Innovation Office has prepared this document to assist potential PRB users in making more informed decisions related to their respective sites.

Complete profiles of these sites are available on the Remediation Technologies Development Forum/Permeable Reactive Barriers Action Team’s Internet site (www.rtdf.org/public/permbar/prbsumms/default.cfm).

In addition to the site-by-site information included (pages 9-23), charts and graphs at the end of this section of the report summarize overall statistics concerning the sites profiled. For example, Figure 1 (page 4) shows that PRBs were used for full-scale cleanup at most of the sites profiled and provides a breakdown of these sites by the category of contaminants treated. Figure 2 (page 4) shows the breakdown of U.S., Canadian, and European sites profiled by contaminant groups. Figure 3 (page 5) illustrates that the profiles are almost evenly divided between Federal and private-sector sites, and Figure 4 (page 5) shows the types of barriers used at these sites. Figure 5 (page 6) illustrates that, while zero-valent iron (Fe°) was the most frequently used reactive medium, a variety of other media or media mixtures are available and have been used in PRBs.

Internet versions of the PRB profiles are updated periodically as new information is received. Profile information for PRB sites that are currently not in the database may be submitted on-line at www.rtdf.org/public/permbar/prbsumms/default.cfm by clicking on the “Submit New Profile” button at the top of the page.

The RTDF/PRB Action Team was established in 1995. Its members include representatives from government, academia, and the private sector working as partners to further public and regulatory acceptance of PRBs for remediating chlorinated solvents, metals, radionuclides, and other groundwater pollutants.
Figure 1

PRB Sites by Scale and Contaminant

![Bar chart showing the number of PRB sites by scale and contaminant category.](chart1)

Figure 2

Profiled PRB Sites by Location and Contaminant

![Bar chart showing the number of profiled PRB sites by location and contaminant category.](chart2)
Figure 3

PRB Sites by Private and Government Sectors

Private
21

Federal (U.S.)
26

Figure 4

PRB Sites by Type of Barrier

- Funnel and Gate
- Continuous Trench
- Reactor Vessel(s)
- Continuous Wall
- Multiple Segments/Panels
- Trench and Gate
Figure 5

**PRB Sites by Reactive Medium Used**

- Zero-valent Iron
- Iron and Sand
- Iron and Gravel
- Iron Sponge
- Iron and Wood Chips
- Granular Cast Iron
- Activated Carbon
- Catalyzed Hydrogen
- Zeolite
- Sodium Dithionite
- Organic Carbon
- Limestone
- Oxygen
- Copper Wool
- Steel Wool
- Amorphous Ferric Oxide
- Phosphate
### Abbreviations Used in This Document

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Definition</th>
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<tbody>
<tr>
<td>AFO</td>
<td>amorphous ferric oxide</td>
</tr>
<tr>
<td>As</td>
<td>arsenic</td>
</tr>
<tr>
<td>bgs</td>
<td>below ground surface</td>
</tr>
<tr>
<td>BHC</td>
<td>alpha-hexachlorobenzene</td>
</tr>
<tr>
<td>Bq</td>
<td>Becquerel</td>
</tr>
<tr>
<td>BTEX</td>
<td>benzene, toluene, ethylbenzene, xylene</td>
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<tr>
<td>CaCO3</td>
<td>calcium carbonate</td>
</tr>
<tr>
<td>CB</td>
<td>cement bentonite</td>
</tr>
<tr>
<td>Cd</td>
<td>cadmium</td>
</tr>
<tr>
<td>Cr&lt;sup&gt;+&lt;/sup&gt;</td>
<td>chromium, chromate</td>
</tr>
<tr>
<td>Cu</td>
<td>copper</td>
</tr>
<tr>
<td>DCA</td>
<td>dichloroethane</td>
</tr>
<tr>
<td>DCB</td>
<td>dichlorobenzene</td>
</tr>
<tr>
<td>DCE</td>
<td>dichloroethylene</td>
</tr>
<tr>
<td>DCM</td>
<td>dichloromethane</td>
</tr>
<tr>
<td>DDD</td>
<td>(ClC&lt;sub&gt;6&lt;/sub&gt;H&lt;sub&gt;4&lt;/sub&gt;)&lt;sub&gt;2&lt;/sub&gt;CHCHCl&lt;sub&gt;2&lt;/sub&gt;; an insecticide with properties similar to DDT</td>
</tr>
<tr>
<td>DDT</td>
<td>C&lt;sub&gt;14&lt;/sub&gt;H&lt;sub&gt;9&lt;/sub&gt;C&lt;sub&gt;15&lt;/sub&gt;; a water-insoluble crystalline insecticide</td>
</tr>
<tr>
<td>DNAPL</td>
<td>dense nonaqueous-phase liquid</td>
</tr>
<tr>
<td>DSM</td>
<td>Deep Soil Mixing</td>
</tr>
<tr>
<td>Eh</td>
<td>Electrochemical Potential</td>
</tr>
<tr>
<td>Fe&lt;sup&gt;0&lt;/sup&gt;, ZVI</td>
<td>zero-valent iron</td>
</tr>
<tr>
<td>FeCO3</td>
<td>iron carbonate</td>
</tr>
<tr>
<td>Fe[OH]&lt;sub&gt;2&lt;/sub&gt;</td>
<td>iron hydroxide</td>
</tr>
<tr>
<td>FeS</td>
<td>iron sulfide</td>
</tr>
<tr>
<td>Freon 11</td>
<td>trichlorofluoromethane</td>
</tr>
<tr>
<td>Freon 13</td>
<td>trichlorotrifluoroethane</td>
</tr>
<tr>
<td>Freon 113®</td>
<td>1,1,2-Trichloro-1,2,2-trifluorothane</td>
</tr>
<tr>
<td>ft</td>
<td>foot, feet</td>
</tr>
<tr>
<td>g</td>
<td>gram, grams</td>
</tr>
<tr>
<td>gpm</td>
<td>gallons per minute</td>
</tr>
<tr>
<td>HC</td>
<td>hydrocarbon</td>
</tr>
<tr>
<td>HDPE</td>
<td>high-density polyethylene</td>
</tr>
<tr>
<td>in</td>
<td>inch, inches</td>
</tr>
<tr>
<td>K</td>
<td>Kelvin</td>
</tr>
<tr>
<td>kg</td>
<td>kilograms</td>
</tr>
<tr>
<td>L</td>
<td>litre</td>
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<tr>
<td>MCB</td>
<td>chlorobenzene</td>
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<tr>
<td>MCL</td>
<td>Maximum Contaminant Level</td>
</tr>
<tr>
<td>mg</td>
<td>milligram, milligrams</td>
</tr>
<tr>
<td>Mn</td>
<td>manganese</td>
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<tr>
<td>mV</td>
<td>millivolts</td>
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<tr>
<td>Mo</td>
<td>molybdenum</td>
</tr>
<tr>
<td>Ni</td>
<td>nickel</td>
</tr>
<tr>
<td>O&lt;sub&gt;2&lt;/sub&gt;</td>
<td>oxygen</td>
</tr>
<tr>
<td>OU</td>
<td>operable unit</td>
</tr>
<tr>
<td>PAH</td>
<td>polynuclear aromatic hydrocarbon</td>
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<tr>
<td>Pb</td>
<td>lead</td>
</tr>
<tr>
<td>PCE</td>
<td>perchloroethylene, tetrachloroethylene</td>
</tr>
<tr>
<td>pCi</td>
<td>picoCuries</td>
</tr>
<tr>
<td>PO&lt;sub&gt;4&lt;/sub&gt;</td>
<td>bone char phosphate</td>
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<tr>
<td>PRB</td>
<td>permeable reactive barrier</td>
</tr>
<tr>
<td>s, sec</td>
<td>second, seconds</td>
</tr>
<tr>
<td>Symbol</td>
<td>Substance</td>
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</tr>
<tr>
<td>Se</td>
<td>selenium</td>
</tr>
<tr>
<td>Sr-90</td>
<td>strontium</td>
</tr>
<tr>
<td>Tc</td>
<td>technetium</td>
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<tr>
<td>TCA</td>
<td>trichloroethane</td>
</tr>
<tr>
<td>TCE</td>
<td>trichloroethylene</td>
</tr>
<tr>
<td>U</td>
<td>uranium</td>
</tr>
<tr>
<td>V</td>
<td>vanadium</td>
</tr>
<tr>
<td>VC</td>
<td>vinyl chloride</td>
</tr>
<tr>
<td>VOC</td>
<td>volatile organic compound</td>
</tr>
<tr>
<td>yd</td>
<td>yard, yards</td>
</tr>
<tr>
<td>Zn</td>
<td>zinc</td>
</tr>
<tr>
<td>µg</td>
<td>microgram, micrograms</td>
</tr>
</tbody>
</table>
## Site Profile Summary

**NOTE:** Sites with more than 1 type of contaminant are listed under each appropriate contaminant category.

<table>
<thead>
<tr>
<th>Name</th>
<th>Location</th>
<th>Installation Date</th>
<th>Contaminants</th>
<th>Construction Type</th>
<th>Design/Installation Cost</th>
<th>Reactive Media</th>
<th>Results</th>
<th>Point of Contact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aircraft Maintenance Facility</td>
<td>Southern OR</td>
<td>1998</td>
<td>TCE</td>
<td>Funnel and Gate</td>
<td>$600 K</td>
<td>Fe⁰</td>
<td>Only 60% degradation rate in groundwater; pursuing other measures</td>
<td>Dave Weymann</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Tel: 503-624-7200 Fax: 503-620-7658 Email: <a href="mailto:dweymann@emconinc.com">dweymann@emconinc.com</a></td>
<td></td>
</tr>
<tr>
<td>Caldwell Trucking</td>
<td>Northern NJ</td>
<td>1998</td>
<td>TCE</td>
<td>Hydraulic Fracturing, Permeation Infilling</td>
<td>$1.12 M</td>
<td>Fe³</td>
<td>Effective treatment of upgradient concentration; part of plume migrated around barrier; conductivity decreased with time</td>
<td>John Vidumsky</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Tel: 302-892-1738 Fax: 302-892-7641 Email: <a href="mailto:john.e.vidumsky@usa.dupont.com">john.e.vidumsky@usa.dupont.com</a></td>
<td></td>
</tr>
<tr>
<td>Copenhagen Freight Yard</td>
<td>Copenhagen, Denmark</td>
<td>1998</td>
<td>cis 1,2-DCE, trans-DCE, TCE, PCE, VC</td>
<td>Continuous Trench</td>
<td>$235 K</td>
<td>Fe³</td>
<td>Concentrations of contaminants reduced to non-detectable level</td>
<td>Peter Kjeldsen</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Tel: +45 45251561 Fax: +45 45932850 Email: <a href="mailto:pk@er.dtu.dk">pk@er.dtu.dk</a></td>
<td></td>
</tr>
<tr>
<td>F.E. Warren Air Force Base</td>
<td>Cheyenne, WY</td>
<td>1999</td>
<td>TCE, cis 1,2-DCE, VC</td>
<td>Trench Box</td>
<td>$2.617 M</td>
<td>Fe⁰ and Sand</td>
<td>VOC concentrations increased in groundwater moving around south end of PRB and in area under PRB</td>
<td>Ernesto J. Perez</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Tel: 307-773-4356 Fax: 307-773-4153 Email: <a href="mailto:Ernesto.Perez@ren.af.mil">Ernesto.Perez@ren.af.mil</a></td>
<td></td>
</tr>
<tr>
<td>Federal Highway Administration Facility</td>
<td>Lakewood, CO</td>
<td>1996</td>
<td>TCA, 1,1-DCE, TCE, cis 1,2-DCE</td>
<td>Funnel and Multiple Gate</td>
<td>$1 M</td>
<td>Fe³</td>
<td>Viscous concentrations increased in groundwater moving around south end of PRB and in area under PRB</td>
<td>J.H. Woll</td>
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<tr>
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<td></td>
<td></td>
<td>Tel: 303-716-2106 Fax: 303-969-5903 Email: <a href="mailto:jhwoll@road.cflhd.gov">jhwoll@road.cflhd.gov</a></td>
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<td>Name</td>
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<td>Contaminants</td>
<td>Construction Type</td>
<td>Design/Installation Cost</td>
<td>Reactive Media</td>
<td>Results</td>
<td>Point of Contact</td>
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<tr>
<td>Former Dry-Cleaning Site</td>
<td>Rheine, Westphalia, Germany</td>
<td></td>
<td>PCE, cis 1,2-DCE</td>
<td>Continuous Wall</td>
<td>$160 K</td>
<td>Fe⁰ Iron Sponge</td>
<td>significant reduction in concentration of contaminants</td>
<td>Dr. Martin Wegner Tel: 49-5131-4694-55 Fax: 49-5131-4694-90 Email: <a href="mailto:wegner@mullundpartner.de">wegner@mullundpartner.de</a></td>
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<tr>
<td>Former Industrial Site</td>
<td>Brunn am Gebirge, Austria</td>
<td>1999</td>
<td>PAH, Phenols, BTEX, HC, TCE, cis 1,2-DCE</td>
<td>Adsorptive Reactors with Hydraulic Barrier</td>
<td>$750 K</td>
<td>Activated Carbon</td>
<td>effective in forcing groundwater to enter PRB; level of contamination varies with groundwater level</td>
<td>Peter Niederbacher Tel: 43-2243-22844 Fax: 43-2243-22843 Email: <a href="mailto:niederbacher@geol.at">niederbacher@geol.at</a></td>
</tr>
<tr>
<td>Former Manufacturing Site</td>
<td>Seattle, WA</td>
<td>1999</td>
<td>PCE, TCE, cis 1,2-DCE, VC</td>
<td>Funnel and Gate</td>
<td>$350 K</td>
<td>Fe⁰ Iron Filings</td>
<td>treatment efficiencies ranged from 65-99%; natural attenuation reducing concentrations before water reaches canal</td>
<td>Barry Kellems Tel: 206-324-9530 Fax: 206-328-5581 Email: <a href="mailto:barry.kellems@hartcrower.com">barry.kellems@hartcrower.com</a></td>
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<tr>
<td>Former Manufacturing Site</td>
<td>Fairfield, NJ</td>
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<td>1,1,1-TCA, PCE, TCE</td>
<td>Continuous Trench</td>
<td>$875 K</td>
<td>Fe⁰</td>
<td>concentrations at center of plume decreased to near detection levels; pH increased, Eh decreased</td>
<td>Stephen Tappert Tel: 973-383-2500 Fax: 973-579-0025 Email: <a href="mailto:stappert@trccos.com">stappert@trccos.com</a></td>
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<tr>
<td>Name</td>
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<td>Contaminants</td>
<td>Construction Type</td>
<td>Design/Installation Cost</td>
<td>Reactive Media</td>
<td>Results</td>
<td>Point of Contact</td>
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<tr>
<td>Chlorinated Solvents - Full Scale</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Haardkrom Site</td>
<td>Kolding, Denmark</td>
<td>1999</td>
<td>TCE, CR&lt;sup&gt;+&lt;/sup&gt;</td>
<td>Continuous Trench</td>
<td>$358 K</td>
<td>Fe&lt;sup&gt;0&lt;/sup&gt;</td>
<td>design not effective in controlling contaminants along PRB; working on resolving problems</td>
<td>Peter Kjeldsen  Tel: +45 45251561 Fax: +45 45932850 Email: <a href="mailto:pk@er.dtu.dk">pk@er.dtu.dk</a></td>
</tr>
<tr>
<td>Industrial Site</td>
<td>SC</td>
<td>1997</td>
<td>TCE, cis 1,2-DCE, VC</td>
<td>Continuous Trench</td>
<td>$400 K</td>
<td>Fe&lt;sup&gt;0&lt;/sup&gt;</td>
<td>consistent decrease in concentration levels downgradient; upgradient levels remain variable</td>
<td>Steven Schroeder  Tel: 864-281-0030 Fax: 864-287-0288 Email: <a href="mailto:steve.schroeder@rmtinc.com">steve.schroeder@rmtinc.com</a></td>
</tr>
<tr>
<td>Industrial Site</td>
<td>Coffeyville, KS</td>
<td>1996</td>
<td>TCE, 1,1,1-TCA</td>
<td>Funnel and Gate</td>
<td>$400 K</td>
<td>Fe&lt;sup&gt;0&lt;/sup&gt;</td>
<td>concentration in iron zone below MCLs; no determination made of groundwater velocity through system</td>
<td>Greg Somermeyer  Tel: 970-493-3700 Fax: 970-493-2328 Email: <a href="mailto:gsomermeyer@thermoretec.com">gsomermeyer@thermoretec.com</a></td>
</tr>
<tr>
<td>Industrial Site</td>
<td>Belfast, Northern Ireland</td>
<td>1995</td>
<td>TCE, cis 1,2-DCE</td>
<td>Slurry Wall Funnel in situ reaction vessel</td>
<td>$375 K</td>
<td>Fe&lt;sup&gt;0&lt;/sup&gt;</td>
<td>overall 99.7% reduction in contaminant levels through reaction vessel</td>
<td>Dale Haig  Tel: 44-115-9456544 Fax: 44-115-9456540 Email: <a href="mailto:Dhaigh@GOLDER.com">Dhaigh@GOLDER.com</a></td>
</tr>
<tr>
<td>Intersil Semiconductor Site</td>
<td>Sunnyvale, CA</td>
<td>1995</td>
<td>TCE, cis 1,2-DCE, VC, Freon 113®</td>
<td>Funnel and Gate</td>
<td>$1 M</td>
<td>Fe&lt;sup&gt;0&lt;/sup&gt;</td>
<td>concentrations below cleanup goals in wells within wall; groundwater contained on site until mounding dissipates</td>
<td>Carol Yamane  Tel: 415-434-9400 Fax: 415-434-1365 Email: <a href="mailto:cyamane@geomatrix.com">cyamane@geomatrix.com</a></td>
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<tr>
<td>Name</td>
<td>Location</td>
<td>Installation Date</td>
<td>Contaminants</td>
<td>Construction Type</td>
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<td>Reactive Media</td>
<td>Results</td>
<td>Point of Contact</td>
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<tr>
<td>Kansas City Plant</td>
<td>Kansas City, MO</td>
<td>1998</td>
<td>cis 1,2-DCE, VC</td>
<td>Continuous Trench</td>
<td>$1.5 M</td>
<td>Fe⁰</td>
<td>samples from wells north and south of PRB indicate inconsistencies in levels; high zone of conductivity; PRB rendered ineffective upon ordered resumption of pumping well</td>
<td>Steve Cline  Tel: 423-241-3957 Fax: 423-576-8646 Email: <a href="mailto:qc2@ornl.gov">qc2@ornl.gov</a></td>
</tr>
<tr>
<td>Lowry Air Force Base</td>
<td>CO</td>
<td>1995</td>
<td>TCE</td>
<td>Funnel and Gate</td>
<td>$530 K</td>
<td>Fe⁰</td>
<td>chlorinated hydrocarbons degraded within first ft of wall; all analytes degraded 2 ft into wall</td>
<td>William A. Gallant  Tel: 303-452-5700 Fax: 303-452-2336 Email: <a href="mailto:gallabil@versar.com">gallabil@versar.com</a></td>
</tr>
<tr>
<td>Rocky Flats Environmental Technology Site (East Trenches Plume)</td>
<td>Golden, CO</td>
<td>1999</td>
<td>TCE, PCE, Carbon tetrachloride, Chloroform, cis 1,2-DCE, Methylene chloride</td>
<td>Reaction Vessels</td>
<td>$1.3 M</td>
<td>Fe⁰ and Pea Gravel</td>
<td>except for methylene chloride, concentrations routinely non-detectable</td>
<td>Annette Primrose  Tel: 303-966-4385 Fax: 303-966-5180 Email: <a href="mailto:Annette.Primrose@rfets.gov">Annette.Primrose@rfets.gov</a></td>
</tr>
<tr>
<td>Rocky Flats Environmental Technology Site (Mound Site)</td>
<td>Golden, CO</td>
<td>1998</td>
<td>VC, 1,1-DCE, cis 1,2-DCE, TCE, PCE, U, Chloroform Carbon tetrachloride,</td>
<td>Reaction Vessels</td>
<td>$590 K</td>
<td>Fe⁰</td>
<td>concentrations non-detectable in effluent samples; U concentration below stream standards; low cost, effective technology</td>
<td>Annette Primrose  Tel: 303-966-4385 Fax: 303-966-5180 Email: <a href="mailto:Annette.Primrose@rfets.gov">Annette.Primrose@rfets.gov</a></td>
</tr>
<tr>
<td>Name</td>
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<tr>
<td>Seneca Army Depot Activity</td>
<td>Romulus, NY</td>
<td>1999</td>
<td>TCE, cis 1,2-DCE</td>
<td>Continuous Trench</td>
<td>$450 K</td>
<td>Fe(^3) and Sand</td>
<td>100% removal of TCE; removal of cis 1,2-DCE less than expected - will require added iron</td>
<td>Michael Duchesneau&lt;br&gt; Tel: 781-401-2492&lt;br&gt; Fax: 781-401-2492&lt;br&gt; Email: <a href="mailto:michael.duchesneau@parsons.com">michael.duchesneau@parsons.com</a></td>
</tr>
<tr>
<td>Shaw Air Force Base</td>
<td>Sumter, SC</td>
<td>1998</td>
<td>TCA, DCA, DCE, VC</td>
<td>Continuous Wall Trenches</td>
<td>$1.065 M</td>
<td>Fe(^3), Iron Filings</td>
<td>significant reductions in TCA, DCA and DCE; VC increases at PRB, but biodegrades sufficiently</td>
<td>Richard Roller&lt;br&gt; Tel: 803-895-9991&lt;br&gt; Fax: 803-895-5103&lt;br&gt; Email: <a href="mailto:richard.roller@shaw.af.mil">richard.roller@shaw.af.mil</a></td>
</tr>
<tr>
<td>Somersworth Sanitary Landfill</td>
<td>Somersworth, NH</td>
<td>2000</td>
<td>PCE, TCE, cis 1,2-DCE, VC</td>
<td>Continuous Wall</td>
<td>$2.2 M</td>
<td>Fe(^3) and Sand</td>
<td>groundwater monitoring indicates PRB working as designed</td>
<td>Tom Krug&lt;br&gt; Tel: 519-822-2230&lt;br&gt; Fax: Email: <a href="mailto:tkrug@geosyntec.com">tkrug@geosyntec.com</a></td>
</tr>
<tr>
<td>Vapokon Petrochemical Works</td>
<td>Sonderso, Denmark</td>
<td>1999</td>
<td>PCE, TCE, TCA, DCA, DCE, DCM, BTEX</td>
<td>Funnel and Gate</td>
<td>$940 K</td>
<td>Fe(^3)</td>
<td>most compounds degraded at expected rates; daughter products degraded in anoxic plume; upgradient concentrations increased possibly due to low velocities</td>
<td>Peter Kjeldsen&lt;br&gt; Tel: +45 45251561&lt;br&gt; Fax: +45 45932850&lt;br&gt; Email: <a href="mailto:pk@er.dtu.dk">pk@er.dtu.dk</a></td>
</tr>
<tr>
<td>Watervliet Arsenal</td>
<td>Watervliet, NY</td>
<td>1999</td>
<td>VOCs</td>
<td>Continuous Trench</td>
<td>$391 K</td>
<td>Fe(^3) and Concrete Sand</td>
<td>monitoring indicates walls meeting projected goals</td>
<td>Grant A. Anderson&lt;br&gt; Tel: 410-962-6645&lt;br&gt; Fax: 410-962-7731&lt;br&gt; Email: <a href="mailto:grant.a.anderson@nab02.usace.army.mil">grant.a.anderson@nab02.usace.army.mil</a></td>
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<tr>
<td>Alameda Point</td>
<td>Alameda, CA</td>
<td>1997</td>
<td>cis 1,2-DCE, VC, TCE, BTEX</td>
<td>Funnel and Sequenced Gate</td>
<td></td>
<td>Fe⁹, O</td>
<td>excellent results for VOCs at high concentrations; almost complete degradation at low concentrations; biosparg zone supported aerobic degradation of VC &amp; cis 1,2-DCE</td>
<td>Mary Morkin Tel: 925-943-3034 ext. 203 Fax: 925-943-2366 Email: <a href="mailto:mmorkin@geosyntec.com">mmorkin@geosyntec.com</a></td>
</tr>
<tr>
<td>Area 5, Dover Air Force Base</td>
<td>Dover, DE</td>
<td>1998</td>
<td>PCE, TCE, DCE</td>
<td>Funnel and Gate</td>
<td>$800 K</td>
<td>Fe⁹</td>
<td>PRB functioned as designed, capturing plume and reducing contaminants below target levels; iron zone more efficient than pyrite zone in removing DO</td>
<td>Alison Lightner Tel: 850-283-6306 Fax: 850-283-6064 Email: <a href="mailto:alison.lightner@tyndall.af.mil">alison.lightner@tyndall.af.mil</a></td>
</tr>
<tr>
<td>Borden Aquifer</td>
<td>Ontario, Canada</td>
<td>1991</td>
<td>TCE, PCE</td>
<td>Continuous Trench</td>
<td>$30 K</td>
<td>Fe⁹</td>
<td>PRB reduced TCE by 90% and PCE by 86%; low calcium carbonate after 5 years indicates at least another 5 yrs of operation</td>
<td>Stephanie F. O'Hannesin Tel: 519-746-2204 Ext. 235 Fax: 519-764-2209 Email: <a href="mailto:sohannesin@eti.com">sohannesin@eti.com</a></td>
</tr>
<tr>
<td>Cape Canaveral Air Station</td>
<td>Cape Canaveral, FL</td>
<td>1998</td>
<td>TCE, DCE, VC</td>
<td>Continuous Walls with Overlapping Panels</td>
<td>$809 K</td>
<td>Fe⁹</td>
<td></td>
<td>Jerry Hansen Tel: 210-536-4353 Fax: 210-536-4330 Email: <a href="mailto:jerry.hansen@hqafcee.brooks.af.mil">jerry.hansen@hqafcee.brooks.af.mil</a></td>
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<tr>
<td>DuPont</td>
<td>Oakley, CA</td>
<td></td>
<td>Carbon tetrachloride, Chloroform, Freon 11, Freon 113</td>
<td>Vertically Oriented Hydraulic Fracturing</td>
<td>$1.15 M</td>
<td>Granular cast iron</td>
<td>No problems except at recovering an intact core of emplaced PRB at 120 ft.; alternative methods being explored</td>
<td>Stephen H. Shoemaker Tel: 704-362-6638 Fax: 704-362-6636 Email: <a href="mailto:Stephen.H.Sheomaker@DuPont.com">Stephen.H.Sheomaker@DuPont.com</a></td>
</tr>
<tr>
<td>DuPont</td>
<td>Kinston, NC</td>
<td>1999</td>
<td>TCE</td>
<td>Continuous Jetted Wall with Overlapping Panels</td>
<td>$200 K</td>
<td>Granular Fe⁰</td>
<td>TCE mass reduced by 95%; 13 of 16 geoprobe locations indicate non-detectable levels of TCE; negotiating with state to shut down pump &amp; treat system affecting velocity through PRB</td>
<td>Richard C. Landis Tel: 302-892-7452 Fax: 302-892-7641 Email: <a href="mailto:Richard.C.Landis@DuPont.com">Richard.C.Landis@DuPont.com</a></td>
</tr>
<tr>
<td>Launch Complex 34, Cape Canaveral Air Force Station</td>
<td>Cape Canaveral, FL</td>
<td>1999</td>
<td>TCE, trans DCE, cis 1,2-DCE</td>
<td>Vibrating Caissons filled with Fe⁰, followed by Deep Soil Mixing</td>
<td>$220 K</td>
<td>Fe⁰</td>
<td>TCE and daughter products non-detectable within wall and declining in downstream wells, except for VC</td>
<td>Debra R. Reinhart Tel: 407-823-2156 Fax: 407-823-5483 Email: <a href="mailto:reinhart@mail.ucf.edu">reinhart@mail.ucf.edu</a></td>
</tr>
<tr>
<td>Massachusetts Military Reservation CS-10 Plume</td>
<td>Falmouth, MA</td>
<td>1998</td>
<td>PCE, TCE</td>
<td>Hydraulic Fracturing</td>
<td>$160 K</td>
<td>Fe⁰</td>
<td></td>
<td>Robert W. Gillham Tel: 519-888-4658 Fax: 519-746-1829 Email: <a href="mailto:rwgillha@sciborg.uwaterloo.ca">rwgillha@sciborg.uwaterloo.ca</a></td>
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**Chlorinated Solvents - Pilot Scale**
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<th>Name</th>
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<th>Point of Contact</th>
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</thead>
<tbody>
<tr>
<td>Moffet Federal Airfield</td>
<td>Mountain View, CA</td>
<td>1996</td>
<td>TCE, cis 1,2-DCE, PCE</td>
<td>Funnel and Gate</td>
<td>$540 K</td>
<td>Fe⁹</td>
<td>principal contaminants reduced to below maximum levels within 2-3 ft of gate</td>
<td>Chuck Reeter Tel: 805-982-0469 Fax: 805-982-4304 Email: <a href="mailto:creeter@fesc.navy.mil">creeter@fesc.navy.mil</a></td>
</tr>
<tr>
<td>SAFIRA Test Site</td>
<td>Bitterfeld, Germany</td>
<td>1999</td>
<td>Benzene, MCB, o-DCB, p-DCB, TCE, cis 1,2-DCE, trans 1,2-DCE</td>
<td>Vertical Well Shafts and Horizontal Wells</td>
<td>11 M Deutsch Mark</td>
<td>Hydrogen-activation Systems with and without Paladium Catalyst</td>
<td>pilot tests indicate promising results; project ends 6/02, expected to be extended</td>
<td>Dr. Holger Weiss Tel: +49-341-235-2060 Fax: +49-341-235-2126 Email: <a href="mailto:weiss@pro.ufz.de">weiss@pro.ufz.de</a></td>
</tr>
<tr>
<td>Savannah River Site TNX Area</td>
<td>Aiken, SC</td>
<td>1997</td>
<td>TCE, cis 1,2-DCE, CT, Nitrate</td>
<td>GeoSiphon Cell</td>
<td>$119 K (phase I)</td>
<td>Fe⁹</td>
<td>Phases I &amp; II indicate that changing siphon line accelerates flow rates inducing accelerated cleanup; use limited to areas of shallow ground water</td>
<td>Mark Phifer Tel: 803-725-5222 Fax: 803-725-7673 Email: <a href="mailto:mark.phifer@srs.gov">mark.phifer@srs.gov</a></td>
</tr>
<tr>
<td>U.S. Coast Guard Support Center</td>
<td>Elizabeth City, NC</td>
<td>1996</td>
<td>Cr⁶, TCE</td>
<td>Continuous Trench</td>
<td>$675 K</td>
<td>Fe⁹</td>
<td>Cr continues to be removed as expected; TCE, cis 1, 2-DCE, and VC below MCL for most wells; plume seems to have dipped after wall installation</td>
<td>Robert W. Puls Tel: 580-436-8543 Fax: 580-436-8706 Email: <a href="mailto:puls.robert@epa.gov">puls.robert@epa.gov</a></td>
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<tr>
<td>X-625 Groundwater Treatment Facility, Portsmouth Gaseous Diffusion Plant</td>
<td>Piketon, OH</td>
<td>1996</td>
<td>TCE</td>
<td>Horizontal Well</td>
<td></td>
<td>Fe³</td>
<td>TCE reduced to below 5 µg/L; hydraulic conductivity of iron media reduced due to mineral precipitation</td>
<td>Thomas C. Houk  614-897-6502 Fax: 614-897-3800 Email: <a href="mailto:uk9@ornl.gov">uk9@ornl.gov</a></td>
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<td><strong>Metals &amp; Inorganics - Full Scale</strong></td>
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<td>100D Area, Hanford Site</td>
<td>Hanford, WA</td>
<td>1997</td>
<td>Cr⁶⁺</td>
<td>Injection</td>
<td>$480 K (wall- $5 M)</td>
<td>Sodium dithionite</td>
<td>aqueous chromate reduced below 8 µg/L; plan calls for remaining cells to be treated</td>
<td>Jonathan S. Fruchter  509-376-3937 Fax: 509-372-1704 Email: <a href="mailto:john.fruchter@pnl.gov">john.fruchter@pnl.gov</a></td>
</tr>
<tr>
<td>Chalk River Laboratories</td>
<td>Ontario, Canada</td>
<td>1998</td>
<td>Sr-90</td>
<td>Wall and Curtain</td>
<td>$300 K</td>
<td>Clinoptilolite (zeolite)</td>
<td>PRB retained 100% of contaminant since installed; leakage beneath steel cut-off wall compensated for by controlling flow</td>
<td>David R. Lee  613-584-8811 Ext. 4710 Fax: 613-584-1221 Email: <a href="mailto:leed@aesc.ca">leed@aesc.ca</a></td>
</tr>
<tr>
<td>Former Mill Site</td>
<td>Monticello, UT</td>
<td>1999</td>
<td>U, As, Mn, Se, V</td>
<td>Funnel and Gate</td>
<td>$800 K</td>
<td>Fe³</td>
<td>PRB effective in reducing contaminants; concentration of iron increases as groundwater passes through the PRB</td>
<td>Don Metzler  970-248-7612 Fax: 970-248-6040 Email: <a href="mailto:d.metzler@gjo.doe.com">d.metzler@gjo.doe.com</a></td>
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<tr>
<td>Haardkrom</td>
<td>Kolding, Denmark</td>
<td>1999</td>
<td>TCE, CR&lt;sup&gt;+&lt;/sup&gt;</td>
<td>Continuous Trench</td>
<td>$358 K</td>
<td>Fe&lt;sup&gt;3&lt;/sup&gt;</td>
<td>design not effective in controlling contaminants along PRB; working on resolving problems</td>
<td>Peter Kjeldsen Tel: +45 45251561 Fax: +45 45932850 Email: <a href="mailto:pk@er.dtu.dk">pk@er.dtu.dk</a></td>
</tr>
<tr>
<td>Nickel Rim Mine Site</td>
<td>Sudbury, Ontario, Canada</td>
<td>1995</td>
<td>Ni, Fe, Sulfate</td>
<td>Cut and Fill</td>
<td>$30 K</td>
<td>Organic Curtain</td>
<td>decrease in concentration of all contaminants; PRB converted aquifer from acid-producing to acid-consuming</td>
<td>David W. Blowes Tel: 519-888-4878 Fax: 519-746-5644 Email:</td>
</tr>
<tr>
<td>Rocky Flats Environmental Technology Site (Solar Ponds Plume)</td>
<td>Golden, CO</td>
<td>1999</td>
<td>Nitrate, U</td>
<td>Reaction Vessels</td>
<td>$1.3 M</td>
<td>Fe&lt;sup&gt;3&lt;/sup&gt; and Wood Chips</td>
<td>although system does not collect and treat all groundwater in plume, surface water standards are met in nearby creek</td>
<td>Annette Primrose Tel: 303-966-4385 Fax: 303-966-5180 Email: <a href="mailto:Annette.Primrose@rfets.gov">Annette.Primrose@rfets.gov</a></td>
</tr>
<tr>
<td>Tonolli Superfund Site</td>
<td>Nesquehoning, PA</td>
<td>1998</td>
<td>Pb, Cd, As, Zn, Cu</td>
<td>Continuous Trench</td>
<td></td>
<td>Limestone</td>
<td></td>
<td>John Banks Tel: 215-814-3214 Fax: 215-814-3002 Email: <a href="mailto:banks.john-d@epa.gov">banks.john-d@epa.gov</a></td>
</tr>
<tr>
<td>Vapolon Petrochemical Works</td>
<td>Sonderso, Denmark</td>
<td>1999</td>
<td>PCE, TCE, TCA, DCA, DCE, DCM, BTEX</td>
<td>Funnel and Gate</td>
<td>$940 K</td>
<td>Fe&lt;sup&gt;3&lt;/sup&gt;</td>
<td>most compounds degraded at expected rates; daughter products degraded in anoxic plume; upgradient concentrations increased possibly due to low velocities</td>
<td>Peter Kjeldsen Tel: +45 45251561 Fax: +45 45932850 Email: <a href="mailto:pk@er.dtu.dk">pk@er.dtu.dk</a></td>
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<tr>
<td>Bodo Canyon</td>
<td>Durango, CO</td>
<td>1995</td>
<td>As, Mo, Se, U, V, Zn</td>
<td>Collection Drain Piped to</td>
<td>$380 K</td>
<td>Fe&lt;sup&gt;0&lt;/sup&gt;, Copper Wool, Steel Wool</td>
<td>only 1 of 4 PRBs ran for 3 years reducing concentrations of wide variety of contaminants</td>
<td>Don Metzler Tel: 970-248-7612 Fax: 970-248-6040 Email: <a href="mailto:d.metzler@gjo.doe.com">d.metzler@gjo.doe.com</a></td>
</tr>
<tr>
<td>U.S. Coast Guard Support Center</td>
<td>Elizabeth City, NC</td>
<td>1996</td>
<td>Cr&lt;sup&gt;6+&lt;/sup&gt;, TCE</td>
<td>Continuous Trench</td>
<td>$675 K</td>
<td>Fe&lt;sup&gt;3+&lt;/sup&gt;</td>
<td>Cr continues to be removed as expected; TCE, cis 1,2-DCE, and VC below MCL for most wells; plume seems to have dipped after wall installation</td>
<td>Robert W. Puls Tel: 580-436-8543 Fax: 580-436-8706 Email: <a href="mailto:puls.robert@epa.gov">puls.robert@epa.gov</a></td>
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<td>Alameda Point</td>
<td>Alameda, CA</td>
<td>1997</td>
<td>cis 1,2-DCE, VC, TCE, BTEX</td>
<td>Funnel and Sequenced Gate</td>
<td>Fe&lt;sup&gt;0&lt;/sup&gt;, O</td>
<td></td>
<td>excellent results for VOCs at high concentrations; almost complete degradation at low concentrations; biosparging zone supported aerobic degradation of VC &amp; cis 1,2-DCE</td>
<td>Mary Morkin Tel: 925-943-3034 ext. 203 Fax: 925-943-2366 Email: <a href="mailto:mmorkin@geosyntec.com">mmorkin@geosyntec.com</a></td>
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<tr>
<td>East Garrington</td>
<td>Alberta, Canada</td>
<td>1995</td>
<td>BTEX</td>
<td>Trench and Gate</td>
<td>$67.2 K</td>
<td>O₂</td>
<td>plume captured and treated; no contaminants detected off-site</td>
<td>Marc Bowles Tel: 403-247-0200 Fax: 403-247-4811 Email: <a href="mailto:mbowles@calgary.komex.com">mbowles@calgary.komex.com</a></td>
</tr>
<tr>
<td><strong>Nutrients - Full Scale</strong></td>
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<tr>
<td>Y-12 Site, Oak Ridge National Laboratory</td>
<td>Oak Ridge, TN</td>
<td>1997</td>
<td>U, Tc, Nitric acid</td>
<td>Funnel and Gate, Continuous Trench</td>
<td>$1 M</td>
<td>Fe⁸</td>
<td>efficient and cost-effective method of removing this combination of contaminants</td>
<td>Baohua Gu Tel: 423-574-7286 Fax: 423-576-8543 Email: <a href="mailto:b26@ornl.gov">b26@ornl.gov</a></td>
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<td><strong>Nutrients - Pilot Scale</strong></td>
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<td>Savannah River Site TNX Area</td>
<td>Aiken, SC</td>
<td>1997</td>
<td>TCE, cis 1,2-DCE, Nitric acid, Carbon tetrachloride</td>
<td>GeoSiphon Cell</td>
<td>$119 K (phase I)</td>
<td>Fe⁸</td>
<td>Phases I &amp; II indicate that changing siphon line accelerates flow rates inducing accelerated cleanup; use limited to areas of shallow ground water</td>
<td>Mark Phifer Tel: 803-725-5222 Fax: 803-725-7673 Email: <a href="mailto:mark.phifer@srs.gov">mark.phifer@srs.gov</a></td>
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<td><strong>Radionuclides - Full Scale</strong></td>
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<tr>
<td>Former Mill Site</td>
<td>Monticello, UT</td>
<td>1999</td>
<td>U, As, Mn, Se, V</td>
<td>Funnel and Gate</td>
<td>$800 K</td>
<td>Fe⁸</td>
<td>PRB effective in reducing contaminants; concentration of iron increases as groundwater passes through the PRB</td>
<td>Don Metzler Tel: 970 248-7612 Fax: 970-248-6040 Email: <a href="mailto:d.metzler@go.doe.com">d.metzler@go.doe.com</a></td>
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<td>Name</td>
<td>Location</td>
<td>Installation Date</td>
<td>Contaminants</td>
<td>Construction Type</td>
<td>Design/Installation Cost</td>
<td>Reactive Media</td>
<td>Results</td>
<td>Point of Contact</td>
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<tr>
<td>Rocky Flats Environmental Technology Site (Solar Ponds Plume)</td>
<td>Golden, CO</td>
<td>1999</td>
<td>Nitrate, U</td>
<td>Reaction Vessels</td>
<td>$1.3 M</td>
<td>Fe⁰ and Wood Chips</td>
<td>although system does not collect and treat all groundwater in plume, surface water standards are met in nearby creek</td>
<td>Annette Primrose Tel: 303-966-4385 Fax: 303-966-5180 Email: <a href="mailto:Annette.Primrose@rfts.gov">Annette.Primrose@rfts.gov</a></td>
</tr>
<tr>
<td>Y-12 Site, Oak Ridge National Laboratory</td>
<td>Oak Ridge, TN</td>
<td>1997</td>
<td>U, Tc, Nitric acid</td>
<td>Funnel and Gate, Continuous Trench</td>
<td>$1 M</td>
<td>Fe⁰</td>
<td>efficient and cost-effective method of removing this combination of contaminants</td>
<td>Baohua Gu Tel: 423-574-7286 Fax: 423-576-8543 Email: <a href="mailto:b26@ornl.gov">b26@ornl.gov</a></td>
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<td><strong>Radionuclides - Pilot Scale</strong></td>
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<tr>
<td>Bodo Canyon</td>
<td>Durango, CO</td>
<td>1995</td>
<td>As, Mo, Se, U, V, Zn</td>
<td>Collection Drain Piped to Underground Treatment System</td>
<td>$380 K</td>
<td>Fe³, Copper Wool, Steel Wool</td>
<td>only 1 of 4 PRBs ran for 3 years reducing concentrations of wide variety of contaminants</td>
<td>Don Metzler Tel: 970-248-7612 Fax: 970-248-6040 Email: <a href="mailto:d.metzler@gjo.doe.com">d.metzler@gjo.doe.com</a></td>
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<td>Fry Canyon Site</td>
<td>Fry Canyon, UT</td>
<td>1997</td>
<td>U</td>
<td>Funnel and Gate</td>
<td>$170 K</td>
<td>Fe³, AFO, PO₄</td>
<td>3 barriers each using different media - Fe³ and PO₄ remove &gt;99% of incoming U; AFO PRB reached chemical breakthrough</td>
<td>David N. Naftz, PhD Tel: 801-975-3389 Fax: 801-975-3424 Email: <a href="mailto:dlnaftz@usgs.gov">dlnaftz@usgs.gov</a></td>
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<td>Name</td>
<td>Location</td>
<td>Installation Date</td>
<td>Contaminants</td>
<td>Construction Type</td>
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<td>Former Industrial Site</td>
<td>Brunn am Gebirge, Austria</td>
<td>1999</td>
<td>PAH, Phenols, BTEX, HC, TCE, cis 1,2-DCE</td>
<td>Adsorptive Reactors with Hydraulic Barrier</td>
<td>$750 K</td>
<td>Activated Carbon</td>
<td>effective in forcing groundwater to enter PRB; level of contamination varies with groundwater level</td>
<td>Peter Niederbacher  Tel: 43-2243-22844 Fax: 43-2243-22843 Email: <a href="mailto:niederbacher@geol.at">niederbacher@geol.at</a></td>
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<tr>
<td>Marzone Inc./Chevron Chemical Co</td>
<td>Tifton, GA</td>
<td>1998</td>
<td>BHC, beta-BHC, DDD, DDT, xylene, ethylbenzene, lindane, methyl parathion</td>
<td>Funnel and Gate</td>
<td>$750 K</td>
<td>Activated carbon</td>
<td>concentrations for effluent have been below detection levels</td>
<td>Annie Godfrey Tel: 404-562-8919 Fax: 404-562-8896 Email: <a href="mailto:godfrey.annie@epa.gov">godfrey.annie@epa.gov</a></td>
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<tr>
<td>Rocky Flats Environmental Technology Site (East Trenches Plume)</td>
<td>Golden, CO</td>
<td>1999</td>
<td>TCE, PCE, Carbon tetrachloride, Chloroform, cis 1,2-DCE, Methylene chloride</td>
<td>Reaction Vessels</td>
<td>$1.3 M</td>
<td>Fe⁰ and Pea Gravel</td>
<td>except for methylene chloride, concentrations routinely non-detectable</td>
<td>Annette Primrose Tel: 303-966-4385 Fax: 303-966-5180 Email: <a href="mailto:Annette.Primrose@rfets.gov">Annette.Primrose@rfets.gov</a></td>
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<tr>
<td>Rocky Flats Environmental Technology Site (Mound Site)</td>
<td>Golden, CO</td>
<td>1998</td>
<td>VC, 1,1-DCE, cis-1,2-DCE, TCE, PCE, Chloroform, U Carbon tetrachloride</td>
<td>Reaction Vessels</td>
<td>$590 K</td>
<td>Fe⁰</td>
<td>concentrations non-detectable in effluent samples; U concentration below stream standards; low cost, effective technology</td>
<td>Annette Primrose Tel: 303-966-4385 Fax: 303-966-5180 Email: <a href="mailto:Annette.Primrose@rfets.gov">Annette.Primrose@rfets.gov</a></td>
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<td><strong>Other Organic Contaminants - Full Scale</strong></td>
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<td>Vapokon Petrochemical Works</td>
<td>Sonderso, Denmark</td>
<td>1999</td>
<td>PCE, TCE, TCA, DCA, DCE, DCM, BTEX</td>
<td>Funnel and Gate</td>
<td>$940 K</td>
<td>Fe⁹</td>
<td>most compounds degraded at expected rates; daughter products degraded in anoxic plume; upgradient concentrations increased possibly due to low velocities</td>
<td>Peter Kjeldsen</td>
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<td>Tel: +45 45251561 Fax: +45 45932850 Email: <a href="mailto:pk@er.dtu.dk">pk@er.dtu.dk</a></td>
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<td>Petrochemical Works</td>
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<td>Watervliet Arsenal</td>
<td>Watervliet, NY</td>
<td>1999</td>
<td>VOCs</td>
<td>Continuous Trench</td>
<td>$391 K</td>
<td>Fe⁶ and Concrete Sand</td>
<td>monitoring indicates walls meeting projected goals</td>
<td>Grant A. Anderson</td>
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<td>Tel: 410-962-6645 Fax: 410-962-7731 Email: <a href="mailto:grant.a.anderson@nab02.usace.army.mil">grant.a.anderson@nab02.usace.army.mil</a></td>
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<td><strong>Other Organic Contaminants - Pilot Scale</strong></td>
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<td>SAFIRA Test Site</td>
<td>Bitterfeld, Germany</td>
<td>1999</td>
<td>Benzene, MCB, o-DCB, p-DCB, TCE, cis 1,2-DCE, trans 1,2-DCE</td>
<td>Vertical Well Shafts and Horizontal Wells</td>
<td>11 M Deutsch Mark</td>
<td>Hydrogen-activation Systems with and without Paladium Catalyst</td>
<td>pilot tests indicate promising results; project ends 6/02, expected to be extended</td>
<td>Dr. Holger Weiss</td>
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<td>Tel: +49-341-235-2060 Fax: +49-341-235-2126 Email: <a href="mailto:weiss@pro.ufz.de">weiss@pro.ufz.de</a></td>
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</tbody>
</table>
Lessons Learned

The following lessons learned are based on a review of all of the site profiles. They are organized according to the major phases of the remediation process. Visit \texttt{www.rtdf.org/public/permbarr/prbsumms/default.cfm} and check the profiles indicated in parentheses for more detailed information.

\textbf{Site Characterization}

At least 5 sites reported that it is important to conduct extensive characterization in the pre-planning phase. Specifically, it is important to detail the hydrogeology (Kansas City, Fry Canyon), topography (Fry Canyon), seasonal conditions (Oak Ridge), and presence of or proximity to potential obstacles (Tonolli, Chalk River).

\textbf{Planning and Coordination}

Several sites reported that careful planning (F.E. Warren) and coordination are critical to the success of a PRB project. Planning factors that were addressed include site layout, sequencing of the work, and selection and placement of equipment and materials (Brunn am Gebirge, Fry Canyon). Three sites addressed the issue of structuring the project so that the methods and design are flexible enough to respond to changing conditions (Chalk River, Bodo Canyon, Tonolli).

At this stage, it is also important to coordinate plans with state agencies (Fairfield, NJ) and subcontractors (Chalk River). This ensures a better understanding of the project by all interested parties.

\textbf{Design and Construction}

\textit{Groundwater Geochemistry and Flow}

Groundwater geochemistry (FHWA) and velocity/flow are common concerns during the design and construction phases.

- Groundwater modeling is recommended as a design tool during this stage in order to avoid potential flaws (Watervliet).
- Awareness of the geochemistry can include the impact of high concentrations of inorganic compounds (Copenhagen) or affect of \( \text{O}_2 \) on microbial activity (Brunn am Gebirge).
- Groundwater velocity/flow can impact the time required to complete flushing (Industrial Site, SC) or the wall design and efficiency (Watervliet).
- The variability of velocities can affect monitoring and incomplete treatment (Seneca).
- When hydraulic conditions change seasonally, groundwater migration patterns may change (Oak Ridge).
- Reduced hydraulic conductivity of bedrock fractures coupled with shallow gradients in the vicinity of a PRB may result in a diversion of groundwater flow (Caldwell).
- Gravity flow may be considered the most effective when the natural contours of a hillside can be utilized (Rocky Flats), but groundwater at one site was reported to have moved laterally through reactive media before it moved downgradient (Monticello).

\textit{Reactive Media}

Some sites performed tests comparing a variety of reactive media (Bodo Canyon, Fry Canyon) to the most commonly used media, \( \text{Fe}^0 \). A number of sites had problems with hydraulic conductivity and incomplete treatment of contaminants attributed to the concentration (Seneca) and amount or distribution of reactive media (Chalk River, Caldwell).

\textit{Other Media or Materials}

Other media or materials in or around the PRB have been found to affect PRBs.
• A pea gravel zone upgradient of a PRB can result in precipitation of minerals and partial treatment of target contaminants (Intersil).
• The addition of phosphorous can increase the degradation rate (East Garrington).
• The presence of guar can increase biological activity (Oak Ridge). Guar gum gel introduced at low temperature and high pH may slow enzymatic degradation after placement in PRB (Caldwell).
• The use of bentonite slurry may make it difficult to control movement of slurry (Fry Canyon).
• The presence of chloride is not a good indication of effectiveness of dechlorination for all sites (Industrial Site, SC).

**Tools and Construction Methods**

The following observations were made regarding tools and construction methods:

• The use of appropriate tools and construction methods allow for better surfaces and flow patterns for groundwater (Fry Canyon).
• The system should be constructed to allow for gas venting (Bodo Canyon, Marzone).
• The length of trench box should be minimized to reduce slope failure (Rocky Flats).
• Backfill specifications should be rigorously followed (Rocky Flats).

**Other Considerations**

Other design and construction considerations might include:

• The impact of other remediation technologies. For example, groundwater flow and plumes at a site that has been subjected to pump and treat need time to return to non-pumping conditions (Kansas City).
• Daughter products may affect the width and retention time required to treat groundwater (Shaw).
• A funnel and gate system was selected at one site because it offered less impact on the surrounding community (Marzone).
• In placing monitoring wells, consideration should be given to no-flow areas (Fry Canyon) and the need for additional wells in areas with unanticipated variability in contaminant concentrations and groundwater velocity (Seneca).

**Operations and Maintenance**

Monitoring and testing of groundwater conditions, contaminants, reactive media, and materials during and after construction help ensure that the systems operate effectively. Therefore, it is important that operations and maintenance be carefully considered during site characterization, planning and design (Rocky Flats).

**Cost**

Observations on PRB costs include:

• Reaction vessels cost about 1/4 of a baseline pump and treat system (Rocky Flats).
• A continuous trench system is a cost effective installation with a high degree of confidence (Industrial Site, SC).
• The bio-polymer construction method is effective and economical for a large PRB (Somersworth).
• A wall and curtain construction performs well and involves relatively low cost for routine monitoring and adjustment (Chalk River).
Selected References


**Electronic Resources**


Strategic Environmental Research and Development Program (SERDP), [http://www.serdp.org/](http://www.serdp.org/)

Environmental Security Technology Certification Program (ESTCP), [http://www.estcp.org/](http://www.estcp.org/)

U.S. EPA/Kerr Lab - USCG Site, Elizabeth City, North Carolina, [http://www.epa.gov/ada/research/elim.html](http://www.epa.gov/ada/research/elim.html)


AATDF Canadian Forces Base Borden (Canada) and NAS Alameda (CA) sites, [http://www.ruf.rice.edu/~aatdf/pages/passive.htm](http://www.ruf.rice.edu/~aatdf/pages/passive.htm)


EnviroMetal Technologies Inc. (Ont., Canada) Field Reports, [http://www.eti.ca/](http://www.eti.ca/)


RUBIN (Reinigungswände und -barrieren im Netzwerkverbund), [http://www.rubin-online.de/](http://www.rubin-online.de/)