RESEARCH AND APPLICATION OF

PERMEABLE REACTIVE BARRIERS

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Preface

This document is an attempt to compile worldwide research efforts and applications in the field of permeable reactive barriers (PRB). The listing will evolve as input is received. Apologies are made for any inadvertent omissions or errors. Typically, many people are responsible for a project; however, for simplicity, a single contact is provided for each project.

Research projects are organized by the type of contamination treated (organics or inorganics) and by the type of reaction process (sorption, precipitation, substitution, or degradation), and then by the specific material. Field projects are organized by state, province, or country.

A PRB is defined by the Remediation Technology Development Form (RTDF) Action Team on Permeable Barriers as "a passive in situ treatment zone of reactive material that degrades or immobilizes contaminants as ground water flows through it." Projects that appear to fit this definition are included.

This compilation was updated by S. Morrison.

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Acronym List

AFB	Air Force Base
AFCEE	Air Force Center for Environmental Excellence
AFO	Amorphous ferric oxyhydroxide
ANL	Argonne National Laboratory
BNL	Brookhaven National Laboratory
BTEX	Benzene, toluene, ethylbenzene, xylene
cVOC	Chlorinated volatile organic compound
DCE	Dichloroethylene
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
ETI	EnviroMetal Technologies, Inc.
GAC	Granular activated carbon
GE	General Electric
GJO	Grand Junction Office
LANL	Los Alamos National Laboratory
LLNL	Lawrence Livermore National Laboratory
ORC	Oxygen release compound
ORNL	Oak Ridge National Laboratory
PCB	Polychlorinated biphenyl
PCE	Perchloroethylene
PNNL	Pacific Northwest National Laboratory
PRB	Permeable reactive barrier
SNL	Sandia National Laboratory
SRS	Savannah River Site
TCE	Trichloroethylene
UMB	Ultramicrobacteria
USBLM	U.S. Bureau of Land Management
USBM	(former) U.S. Bureau of Mines
VC	Vinyl chloride
VOC	Volatile organic compound
ZVI	Zero-valent iron

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Laboratory Research Projects

A compilation of laboratory research on PRBs is provided in this section. The section is organized by the contaminant group (inorganic or organic), by the type of the principal reaction thought to be operative, and finally by material type. Institutions (with contact in parentheses) that have conducted research in the area are listed along with the contaminants that were investigated.

Inorganics-Sorption or Substitution Barriers

Activated Alumina

DuPont (J. Whang): Arsenic

Activated Carbon

DOE, GJO (S. Morrison): Molybdenum and uranium.

DOE, ORNL (W. Bostick): Technetium and uranium

Bauxite

DuPont (J. Whang): Arsenic

Exchange Resins

DOE, ORNL (W. Bostick): Technetium and uranium

Ferric Oxides and Oxyhydroxides

DOE, GJO (S. Morrison): Molybdenum and uranium.

DOE, ORNL (W. Bostick): Mercury and uranium.

DuPont (J. Whang): Arsenic.

University of Waterloo (D. Blowes): Arsenic, phosphorus, and selenium.

Magnetite

DOE, GJO (S. Morrison): Molybdenum and uranium.

DOE, ORNL (W. Bostick): Aluminum, barium, cadmium, manganese, mercury, nickel, and uranium.

Peat, Humate, Lignite, Coal

DOE, GJO (S. Morrison): Molybdenum and uranium.

DOE, LANL (D. Janecky): Uranium.

DOE, ORNL (W. Bostick): Uranium.

DOE, ORNL (B. Gu): Chromium.

DuPont (J. Whang): Arsenic.

University of New Mexico (B. Thomson): Arsenic, lead, sulfate, uranium.

Phosphates

DOE, GJO (S. Morrison): Molybdenum and uranium.

DOE, ORNL (W. Bostick): Technetium and uranium.

Ohio State University (S. Traina): Lead.

UFA Ventures (J. Conca): Cadmium, lead, and zinc.

USGS, Menlo Park (J. Davis): Uranium.

Titanium Oxide

DOE, GJO (S. Morrison): Molybdenum and uranium.

Zeolite

DOE, ORNL (W. Bostick): [Zeolite and FeS_2] Aluminum, barium, cadmium, manganese, mercury, nickel, uranium. [Zeolite & FeOOH] Mercury.

DOE, PNNL (K. Cantrell): Strontium-90

New Mexico Tech. (R. Bowman): [Zeolite and surfactant] Arsenic, chromium, lead, selenium.

Inorganics-Precipitation Barriers

Biota

DOE, INEL (C. Turick): Chromium.

University of New Mexico (B. Thomson): Arsenic, sulfate, and uranium.

University of Waterloo (D. Blowes): Chromium, sulfate, and vanadium.

Dithionite

DOE, PNNL (J. Fruchter): Chromium.

Ferrous Hydroxide, Ferrous Carbonate, Ferrous Sulfide

DOE, GJO (S. Morrison): Molybdenum and uranium.

DOE, ORNL (W. Bostick): Mercury, technetium, and uranium.

DuPont (J. Whang): Arsenic.

University of Waterloo (D. Blowes): Chromium

Hydrogen Sulfide Gas

DOE, Hanford/DOE, Sandia (E. Thornton): Chromium.

Lime, Flyash

DOE, GJO (S. Morrison): Molybdenum and uranium.

University of New Mexico (B. Thomson): Uranium.

Limestone

DOE, GJO (S. Morrison): Molybdenum and uranium.

DuPont (J. Whang): Arsenic.

University of New Mexico (B. Thomson): Arsenic, cadmium, selenium, sulfate, and uranium.

University of Waterloo (D. Blowes): Phosphorus [mixture of limestone and metal oxide].

USBM (G. Watzlaf): Testing anoxic limestone in PRBs at 21 sites to control acid mine drainage.

Miscellaneous [$Mg(OH)_2$, $MgCO_3$, $CaCl_2$, $CaSO_4$, $BaCl_2$]

DOE, GJO (S. Morrison): Molybdenum and uranium.

DuPont (J. Whang): Arsenic.

Zero-Valent Metals

DOE, GJO (S. Morrison): Arsenic, manganese, molybdenum, selenium, and uranium.

DOE, ORNL (N. Korte): Technetium.

DOE, ORNL (W. Bostick): Aluminum, barium, cadmium, manganese, mercury, nickel, technetium, and uranium.

DOE, PNNL (K. Cantrell): Chromium, molybdenum, strontium, technetium, and uranium.

EPA, Ada (R. Puls): Chromium.

University of New Mexico (B. Thomson): Arsenic, selenium, molybdenum, sulfate, and uranium.

University of Waterloo (D. Blowes): Arsenic, chromium, and selenium.

Inorganics-Degradation Barriers

Biota

University of New Mexico (B. Thomson): Nitrate

University of Waterloo (D. Blowes): Nitrate.

Zero-Valent Metals

University of New Mexico (B. Thomson): Nitrate.

Organics-Degradation Barriers

Ferrous Minerals

GE (T. Sivavec): cVOC.

Oxygen Release

University of Waterloo (D. Smyth): Fuel hydrocarbons.

Ultramicrobacteria

DOE, LLNL (R. Knapp): TCE.

Zero-Valent Metals

DOE, GJO (S. Morrison): TCE

DOE, ORNL (W. Bostick): cVOC.

DOE, ORNL (N. Korte): cVOC, PCB.

DuPont, (S. Shoemaker): cVOC.

EPA, Athens (N. Wolfe): Chlorinated pesticides, cVOC.

GE (T. Sivavec): cVOC.

Monsanto (R. Orth): cVOC.

Oregon State University Graduate Center (P. Tratnyek): cVOC, and nitroaromatics.

U.S. Air Force, Armstrong Laboratory (D. Burris): cVOC.

University of Central Florida (D. Reinhart): cVOC.

University of Waterloo (R. Gillham): cVOC.

University of Wisconsin (G. Eykholt): cVOC.

Organics-Sorption Barriers

Zeolite/Activated Carbon/Clays

DOE, ORNL (N. Korte): TCE.

New Mexico Tech (R. Bowman): BTEX and TCE.

Tyndall AFB (D. Burris): Organic contaminants.

Auxiliary Technologies

Emplacement Technologies

AFCEE (E. Marchand): Used a driven hollow mandrel and jet grouting to emplace PRBs of ZVI at Cape Canaveral, FL.

DOE, GJO (S. Morrison): Laboratory studies of introduction of amorphous ferric oxyhydroxide using ferric chloride injection.

DOE, Hanford (S. Phillips): Field high/low pressure injection in soil/tailings/ spoils/rock.

DOE, LANL: DuPont (D. Janecky): Silica and polymer gels used in small field trenches to support reactive materials.

DOE, ORNL (D. Watson): Demonstration of a buried cement vault with removable drums of reactive media.

DOE, PNNL (K. Cantrell): Laboratory studies of injection of colloidal zero-valent iron.

DOE, PNNL (J. Fruchter): Injection of dithionite to contain contaminants.

DOE, SNL (B. Dwyer): Small-scale field demonstrations of emplacement of reactive materials (GAC, Zeolite, ZVI, cement slag) by jet grouting. Placed in a clean area but contaminants were added.

DOE, Westinghouse Hanford (E. Thornton): Laboratory studies of H_2S injection.

DuPont (R. Landis): Demonstration of jet grouting to emplace ZVI at a clean area at DuPont's Parlin, NJ, site.

EMCON (D. Marcus): Used hydraulic fracturing with ZVI propants to emplace a PRB.

University of Waterloo (J. Cherry): Sealed sheet pilings to direct ground water flow into the zone of interest (development of funnel & gate systems).

University of Waterloo (D. Smyth): Demonstrating removable cassettes for PRBs.

University of Waterloo (R. Wilson): Use of unpumped walls to emplace PRBs.

Reactive Material Development

Cercona (R. Helferich): Developed porous foamed reactive materials.

DOE, GJO (S. Morrison): Developing reactive materials for treating metals and radionuclides in PRBs.

DOE, ORNL (N. Korte): Developing enhanced ZVI by plating with palladium.

EPA, Ada (R. Puls): Investigated the buffering effect of mixing native soils with ZVI.

GE (T. Sivavec): Tested the performance of nickel-coated ZVI to degrade cVOC.

University of Waterloo (R. Gillham): Developed enhanced ZVI by plating with nickel.

Modeling

Colorado State University (C. Shackelford): 1-D modeling of biodegradation PRBs.

Delta Research Corp. (M. Thurston): Developed "RACER" code for costing PRBs.

DOE, GJO (S. Morrison): Coupled hydrogeochemical modeling of PRBs.

Golder Associates (G. Hocking): Vertical ground fracturing to emplace PRBs.

SUNY Buffalo (A. Rabideau): Developing a numerical modeling approach to simulate long-term performance of PRBs.

U.S. Navy (B. Schwartzman): Developing the "SUCCESS" code for costing PRBs.

University of Tübingen, Germany (G. Teutsch): Hydraulic geochemical economical modeling of sorption PRBs.

University of Waterloo (D. Smyth): 3-D modeling of PRB plume capture.

University of Waterloo (R. Starr): Model simulations of funnel and gate PRBs.

Verification

EnviroMetal Technologies, Inc. (R. Focht): Using bromide tracers in pilot tests to determine flow paths.

EnviroMetal Technologies, Inc. (J. Vogan): Examining long-term performance by coring existing PRBs.

GE (T. Sivavec): Conducting laboratory column tests to determine tendency for fouling of ZVI.

University of Waterloo (S. O'Hannesin): Examined long-term performance of Borden site.

University of Waterloo (E. Reardon): Use of hydrogen gas generation to interpret corrosion rates of ZVI.

Field Demonstrations

British Columbia

Vancouver: Compost/gravel was installed to promote microbial activity in a PRB to reduce concentrations of copper and zinc. Contact: D. Blowes.

California

Chico: Resting-state microbes were injected into a TCE plume, 30-m deep to form a microbial PRB. Contact: R. Knapp

Emoryville: Molasses was injected to form a PRB to degrade TCE and precipitate Cr in a biobarrier at an abandoned manufacturing facility. Injection was initiated in April 1997. Contact: S. Suthersan.

Fort Bragg: A funnel-and-gate system was installed at a lumber mill to treat petroleum hydrocarbons, chlorinated solvents, and phenols. The system treats 20 gpm and is 625 feet long. Each of four gates is made of 4-foot diameter culverts with a 4-foot thick bed of GAC. Contact: K. O'Brien.

Moffett Field: A PRB containing ZVI was emplaced using a sheet piling box in April 1996 to treat cVOC. The gate is 10 feet wide by 6 feet thick. Contact: C. Reeter.

Mountain View: A 44-foot PRB containing ZVI was installed in September 1995 at an industrial facility to treat DCE. Contact: J. Vogan.

Newbury Park: ZVI was emplaced by hydraulic fracturing to treat chlorinated VOCs and chromium. Contact: D. Marcus.

Unspecified location: Two PRBs (one with 6 wells, the second with 4 wells) were formed using ORC socks to control BTEX at a pipeline leak site in California. Contact: S. Koenigsberg.

Valley Wood Treating, Turlock (planned): A PRB will be emplaced by injecting a reductant around the margins of a chromium plume. Contact: J. Rouse.

Colorado

DOE, Durango: Four PRB cells were installed at a DOE uranium mill tailings disposal site. The cells use ZVI (steel wool and Cercona foam bricks) to treat uranium, molybdenum, and nitrate seeping from the disposal cell. Contact: D. Metzler.

Lowry AFB: Sheet pilings were used to install a 10-foot wide gate of ZVI with 30 feet of funnel to treat cVOC. The wall was installed January 1996. Contact: E. Marchand

DOE, Rocky Flats (planned): A 270-foot wall with 2 gates of ZVI will be installed to treat cVOCs, metals, and uranium. Contact: N. Castaneda.

Delaware

Dover AFB (planned): A PRB to treat cVOCs with ZVI is planned. Contact: M. Mikula.

Florida

Cape Canaveral AFS: A PRB using Peerless -8 +50 ZVI was emplaced using a hollow mandrel driven to 45 feet. The wall is 70 feet long about 4 inches thick. A second PRB with the same configuration (70' of wall) was emplaced using a driven beam with jet grouting and Peerless -50 mesh ZVI. Contact: E. Marchand.

Kennedy Space Center (planned): A site has been selected to demonstrate the emplacement of ZVI by deep soil mixing. The PRB will treat cVOCs. Contact: J. Quinn.

Kansas

Coffeyville: A funnel-and-gate system was installed in January 1996 to treat cVOCs. The 25-foot-wide gate contains ZVI and has 1,000 feet of slurry wall as a funnel. Contact: J. Vogan.

Missouri

DOE, Kansas City: A ZVI wall, 6 ft x 150 ft is being installed 25 ft into groundwater 8 ft thick. TCE and degradation products. Contact: P. Keary.

New Hampshire

Somersworth Landfill: A caisson (8-foot diameter, 40-foot depth) was used to emplace ZVI to treat cVOCs. Contact: J. Vogan.

New Jersey

DuPont's Parlin Plant: Jet grouting was used to emplace columns and "thin diaphragms" of ZVI. This test was conducted at a clean site, no contamination was treated. Contact: R. Landis.

Unspecified Industrial Site: An ORC PRB was emplaced to treat BTEX. Ten wells were used over a 275-foot span. Contact: S. Koenigsberg.

Wayne: A large (8-foot diameter, 9-foot high) tank was installed at the SGL Printed Circuits site in November 1994 to treat cVOCs. Contact: R. Gillham.

New Mexico

Belen: Twenty wells were loaded with ORC socks at a former service station to control BTEX migration. The PRB is about 70 feet wide. Contact: S. Koenigsberg.

New York

Unspecified industrial site: A funnel-and-gate system was installed in May 1995 to treat cVOCs. The gate is 12-feet wide, 3.5 feet thick, and 15 feet deep. It has 30 feet of sheet piling funnel. Contact: J. Vogan.

Ohio

DOE, Portsmouth Plant: A ZVI test facility was constructed in February 1996 to treat cVOCs fed from a horizontal well connected to a contaminant plume. Contact: K. Wiehle.

Ontario

Canadian Forces Base Borden: A trench with ZVI was constructed to degrade TCE in ground water plume. This was the first PRB with ZVI. It ran for 5 years with negligible loss of performance. Contact: R. Gillham.

Nickel Rim Site: A PRB containing compost and wood chips mixed with pea gravel was installed in August 1995. The PRB was emplaced by cut and fill excavation and is treating acid mine drainage (sulfate, iron, pH). Contact: D. Blowes.

Strathroy: Seven wells loaded with ORC socks were used to control BTEX at a former service station site. The PRB is about 7 feet wide. Contact: S. Koenigsberg.

Pennsylvania

Unspecified location: Molassis was injected to treat BTEX and cVOC at a truck leasing and race car repair facility in Pennsylvania in September 1997. Contact: S. Suthersan.

South Carolina

DOE, Savannah River Site: An interceptor trench was constructed to capture a metal-bearing (Cr, Fe, Al, Sulphate, Ni) plume. Various options have been evaluated for a reactive material to be used to form a PRB. Contact: W. Nate Ellis.

DOE, Savannah River Site: One cell was installed July 1997 and another cell in this F4. GeoSiphon Cell TCE Carbon Tetrachloride granular ZVI siphon from GW (2-5 ft deep) through cell (8 gpm) and discharge to river. Contact: W. Nate Ellis.

Tennessee

DOE, ORNL: A field demonstration funnel and gate was emplaced at the S-3 ponds at the Y-12 plant using replaceable media in 55 gallon drums, ZVI and peat moss. Also, a 220 foot trench was constructed using ZVI and pea gravel. Contact: E. Phillips.

DOE, ORNL: A PRB demonstration at ORNL used zeolite in a canister to treat Cs and Sr. The canisters are fed by gravity flow from a French drain. The system was installed in November 1994. Contact: E. Phillips.

Texas

Alameda, Naval Air Station: A ZVI funnel and gate PRB to treat cVOCs in 8-foot-thick aquifer was installed in December 1996. Contact: R. Yee.

Unspecified Locations

A trench was filled with limestone and used as an emergency measure to contain an acid (metals) spill. Referenced in Gillham and Burris (1992).

Twenty-two anoxic limestone drains were installed by the USBM to control acid mine drainage. Contact: G. Watzlaf.

Utah

Fry Canyon: Three PRBs were emplaced September 1, 1997 using a trackhoe and trench box at an abandoned uranium upgrader facility to treat uranium in ground water. Each PRB was 7 feet wide, 3 feet thick, and extend to a depth of about 15 feet. Each PRB had a different material: (1) AFO mixed with pea gravel, (2) Cercona foamed ZVI pellets, and (3) Cercona bone charcoal. Contact: E. Feltcorn.

Hill AFB: Above ground canister tests were conducted in 1994. Contact: D. Wray.

Washington

DOE Hanford Site-Zeolite Barrier (planned): Plans have been made to install a PRB containing zeolites to contain a strontium-90 plume that is heading toward the Columbia River. Contact: D. Olson.

DOE Hanford Site - Dithionite: 21,000 gallons of sodium dithionite was injected in September 1995. The dithionite reduces iron minerals to form a PRB to contain a Cr(VI) plume. Contact: A. Tortoso.

Remediation Projects

California

Sunnyvale: A ZVI funnel and gate system was installed to treat a TCE plume. This system, operational February 1995, was the first commercialized PRB using ZVI. Contact: S. Warner.

Colorado

Denver Federal Center: A funnel-and-gate system was installed using 4 gates with ZVI to treat cVOC. Each gate is 40 feet wide and 2 to 6 feet thick using a total of 580 tons of ZVI, and the depth is 45 feet. The emplacement used gates of sheet piling boxes separated by sheet piling over a total length of 1,200 feet. Contact: P. McMahon.

Ireland

Belfast: A PRB using a vertical reactor shell (16 feet high) was installed at an industrial site in December 1995. The system is treating cVOCs using ZVI. Contact: J. Vogan.

Massachusetts

Massachusetts Military Reservation: Project addresses a 180-foot deep PCE plume. An attempt was made to drive sheet piling but was unsuccessful in achieving the desired depth. A vertical fracturing emplacement of the ZVI is planned this FY. Contact: E. Pescle.

North Carolina

Elizabeth City Coast Guard Site: A PRB using ZVI to degrade TCE and precipitate Cr was emplaced using a continuous trencher in June 1996. The gate is 150 feet wide, 2 feet thick and 25 feet deep. Contact: R. Puls.

Utah

DOE, Monticello Site (planned): A funnel and gate PRB to treat metals and radionuclides is being designed as an IRA for the CERCLA site. Emplacement is scheduled for November 1998. Laboratory tests are in progress. Contact: V. Cromwell.

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