PRBs in the UK:
New Agency Guidance
Monkstown ZVI &
New Sequential Reactors

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Guidance on the Design, Construction, Operation and Monitoring of Permeable Reactive Barriers

National Groundwater & Contaminated Land Centre report NC/01/51

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Entec (UK) Ltd

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Technical Advice
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✓ Change in UK Legislation
✓ Change in UK Remediation
✓ Route to Commercial Use
✓ Ca. >£100M impact?
## Detailed 1-day Guidance Seminars
**PRB-Net & First Faraday**

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Definition

“A Permeable Reactive Barrier is an engineered treatment zone of reactive material(s) that is placed in the subsurface in order to remediate contaminated fluids as they flow through it.

A PRB has a negligible overall effect on bulk fluid flow rates in the subsurface strata, which is typically achieved by construction of a permeable reactive zone, or by construction of a permeable reactive ‘cell’ bounded by low permeability barriers that direct the contaminant towards the zone or reactive media”
Why produce this guidance?

- Provide Agency, consultants and remediation contractors with good practice guidance;
- Underpin an Agency Enforcement Position on the regulation of PRBs
- Encourage the effective use of sustainable remediation techniques, including PRBs.
Key principles (1)

- PRB should be selected when it is the ‘best practicable technique’;
- Guidance applies to a wide range of contaminants and PRB designs;
- Framework for development and justification of PRB design, monitoring regime and decommissioning arrangements.
Key principles (2)

• Design
  – Treatability tests
  – Pilot scale trials
  – Modelling
    • Hydraulic effects
    • Residence time and reactivity
    • Geochemistry and longevity assessment
• Decommissioning
PRB Licensing requirements

• Where treatment of contaminated groundwater takes place it requires a Waste Management Licence (site licence) or PPC Permit, unless:
  – Exclusion (e.g. not controlled waste)
  – Exemption (e.g. subject to a discharge consent - Reg 16, WMLR94)

• Agency may take an Enforcement Position
  – Works Instruction 4/98
  – As amended to include PRBs
What does the EP not extend to?

• Borehole arrays (e.g. ORC™, HRC™, nutrient injection etc) - *in situ* bioremediation;

• Air-sparge / bio-sparge (including sparge curtains);

• Soil solidification / stabilisation;

• treatment of waste soil
  – all MPL

• Low permeability clay / sorption barriers ***
  – Not licensable activity

• *Technical Guidance*: May be helpful to above treatments.
Framework for guidance

Stage 1: Screening
- Preliminary assessment
- Is a PRB a viable option?

Stage 2: Design
- SI, pilot studies and design
- Refine conceptual model and design PRB

Stage 3: Implementation
- Construction
- Installation of PRB

Stage 4: Operation, maintenance & monitoring
- Verification and monitoring
- Does PRB manage risks?
- Does PRB clog?
- Decommissioning
PRB installations in the British Isles
7 PRBs + 12 Soil Mix installed
10 in Feasibility stages (includes new patents for treatments)

- Zero-valent Iron ($\text{Fe}^0$)
- Biological barrier mine water
- Granular Activated Carbon (GAC)
- New patented treatment CS$_2$
- Sequential Abiotic / Biologic
- Phyto hydraulic-control PRB
- Soil Mix ‘PRB’ (12 known)
- PRB at proposal / trial stage

Sites not identified on map
Continuous Wall

USA more popular

Long-term will it be a source term?

Funnel and Gate

UK more popular

Can be cleaned out.

(Reproduced courtesy of EnviroMetal Technologies Inc)
Operation

Maintenance

Monitoring

Decommissioning
Monitoring objectives:

- Performance assessment
  - Outflow concentrations / flux
    - test against remedial objectives
    - validate PRB effectiveness
    - PRB deterioration (fouling)
  - Hydraulic controls
    - By-pass flow
    - impacts on GW flow regime
- Test conceptual model
Monkstown ZVI Site

CL: AIRE TDP Report 4 – Operation

QUB Report in prep on Maintenance and Decommissioning plan
PRB implementation in Belfast/N.Ireland
TCE Concentrations in Reactor Monitoring Well (excluding RB5)

Date

TCE Concentrations (ug/l)

RB4
RB3
RB2
RB1

2002: Nortel approached QUB for long-term R&D
Experimental Setup - GC-MS/IRMS

Mass abundances

44: $^{12}$C$^{18}$O$_2$ 98,42
45: $^{13}$C$^{16}$O$_2$ 1,095
45: $^{13}$C$^{16}$O$^{17}$O 7,7$\times$10$^{-2}$
46: $^{12}$C$^{16}$O$^{18}$O 0,402
46: $^{13}$C$^{16}$O$^{17}$O 8,6$\times$10$^{-4}$
46: $^{12}$C$^{17}$O$_2$ 1,5$\times$10$^{-5}$

He

He

vent
combustion chamber

nafion

IRMS

MS

GC
TCE Degradation with Fe\textsuperscript{0} - Products

Belfast iron, control # 1, 143 hours

Retention Time

TIC
Mass 15 - 150
n-Hexane (Int. Std.)

Ethene
Ethane
Propene
Propane
1-Butene
c-Butene
t-Butene
VC
Pentenes
c-DCE
TCE

Belfast iron, control # 1, 143 hours

TCE Degradation with Fe\textsuperscript{0} - Products

Belfast iron, control # 1, 143 hours
TCE Degradation Fe⁰ – GC-MS/IRMS

Belfast iron, control # 1,

\[ \delta^{13}C_{VPDB} = \frac{^{13}C / ^{12}C_{(sample)} - ^{13}C / ^{12}C_{(std)}}{^{13}C / ^{12}C_{(std)}} \cdot 1000 \text{ [‰]} \]
TCE Degradation with Fe$^0$ – Isotopes

9 independently performed experiments with different reaction rates and different types of iron

Enrichment factor $\varepsilon$ (similar to a Rayleigh-type fractionation)

$$\varepsilon = \frac{1000 \cdot \ln \frac{10^{-3} \cdot \delta^{13}C_{TCE} + 1}{10^{3} \cdot \delta^{13}C_{TCE (0)} + 1}}{\ln f}$$

$\varepsilon = -10$
Belfast Iron - Rates

\[ -\frac{d[TCE]}{dt} = k_{obs}[TCE] \]

\[ K_{obs} = 0.037 \, \text{h}^{-1} \]
\[ K_{obs} = 0.065 \, \text{h}^{-1} \]
\[ K_{obs} = 0.136 \, \text{h}^{-1} \]

Fastest rate = old iron in the reactor
Belfast Iron - QUB EM Images

Control

Center

Entrance

× 300

× 300

× 50

× 3000

× 3000

× 4500
Monitoring objectives:

- Performance assessment
  - Outflow concentrations / flux (Gate)
    - tested against remedial objectives
    - validated PRB effectiveness
    - PRB deterioration (fouling) not threat
  - Hydraulic control (Funnel)
    - By-pass flow – none noted
    - impacts on GW flow regime - negligible
  - Test conceptual model
BROWNFIELD REDEVELOPMENT
QUB Project for Biologic PRB at Portadown

Portadown Gas Works
- Hydrogeology & Modelling
- BioGeochemistry
- Microbial Ecology
- Microbial Genetics
- Full-scale implementation
- Evaluation

Up to 1500 existing gasworks sites in the UK still requiring remediation
Desk Study
• Location in Northern Ireland

The Upper Bann Catchment

Lough Neagh
Portadown
Mourne Mountains
Old Landfill

Spoil from factory

Gasworks

Petrol Stations
Site Investigation
Portadown Gasworks Site Investigation
Example GC-MS of a soil extract from made ground contaminated with aliphatic compounds.
3-D Multi-level information
Geochemistry of groundwater on site is controlled by nitrate – ammonia microbial processes and therefore very little H₂S is formed.
Microbiological Investigation
Conceptual Geologic Framework
Site Lithologies

[Diagram showing the site lithologies with depth (AOD) and distance (m) from a river. The diagram includes labels for FG11, FG10, FG9, and K5, and the river is marked with a dotted line.]

Lithologies:
- FILL
- ALLUVIUM
- BOULDER CLAY
- ABLATION TILL
- FLUVIO GRAVEL
- WATER TABLE

Depth markers:
- 0 m
- 5 m
- 10 m
- 15 m
- 20 m
- 25 m
- 30 m

Distance markers:
- 500 m
- 1000 m
- 1500 m
- 2000 m

Site locations:
- A
- B
- FG11
- FG10
- FG9
- K5

River:
- RIVER

[Photograph of a person working at the site.]
Hydrogeologic Framework
Final Flow Field Pre-Works

Note the effect of underground structures on pathlines.

(off-site migration of plume encountered where modelled predicted)
Modelled contaminant plumes distribution within made ground after 100 years, source - Tar well

- Phenanthrene mg/L
- 2-methylnaphthalene mg/L
- Naphthalene mg/L
- Mineral oil (benzene) mg/L

Source: Tar Well in Aquifer 2, 500mg/l constant contamination
Pre Excavation Modelled Results

Fit of Observed and Modelled Water Table at Site
Reactor Placement to Intercept Plume
Laboratory Feasibility Study
Treatability study using actual site water
Columns at QUB

1-D Flux and Rate Experiments
2-D Biologic Treatment Feasibility Study
Rates of BTEX removal for the lab-scale reactor were used in full-scale designed to ensure adequate residence time and hence removal of contaminated substances. (Note: Microtox indicates toxicity is removed after only 1 week of pilot scale operation.)