

# Problems connected with use of Permeable Reactive Barriers for groundwater treatment

D. Jirasko

*Czech Technical University, Prague, Czech Republic*

**ABSTRACT:** The one of the most significant environmental problems in the last decades becomes the contamination of the soil and groundwater. The contamination can comprise the substantial risk for the environment and for human health. This paper concerns with one of the promising innovative in situ remediation method - Permeable Reactive Barriers (PRB). The aim is to very briefly summarize the basic knowledge about this method, point out possible problems from the geo-environmental point of view.

## 1 INTRODUCTION

At the beginning of the 90s was developed the new remediation method – the method of Permeable Reactive Barriers (PRB). The method belongs to the group of the passive in situ remediation methods and it seems to be very useful alternative to the Pump and Treat method, which can be very often rather expensive, too lengthy or not too effective.

The principle of the treatment of contaminated soil with the PRB method lies in digging out the trench (perpendicularly to the groundwater flow), which is afterwards filled with suitable permeable reactive material (See figure 1). The contaminated groundwater flows through the reactive media where treatment processes occur.

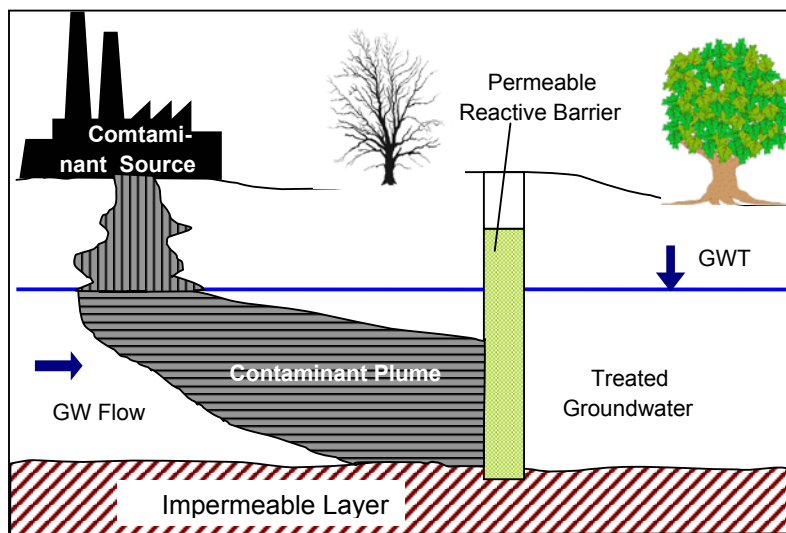


Figure 1. Principle of groundwater remediation by using PRB

The reactive materials either immobilise or transform (biologically or abiotically) the pollutants, such that the treated groundwater down hydraulic gradient of the PRB should not represent risk to water resources or other receptors.

The Definition of Permeable Reactive Barriers according to the EPA 1998:  
 “An emplacement of reactive materials in the subsurface designed to intercept a contaminant plume, provide a flow path through the reactive media, and transform the contaminant(s) into environmentally acceptable forms to attain remediation concentration goals downgradient of the barrier.”

## 2 PERMEBLE REACTIVE BARRIER DEMONSTRATION

### 2.1 Configuration of PRB

Basically, two configurations of PRB can be used (See figure 2):

- Continuous wall – It allows the flow of the contaminant plume through the reactive wall in whole width of the plume.
- Funnel and gate system – consists of impermeable walls which are embedded to the impermeable subsoil. The walls direct the contaminant plume at the permeable window, which is filled with suitable reactive material and where the treatment reactions arise.

Another option of PRB is using of reactive vessels (reactors). The constituent vessels are filled with reactive media, connected by pipes and they are flowed through vertically. (See figure 3).

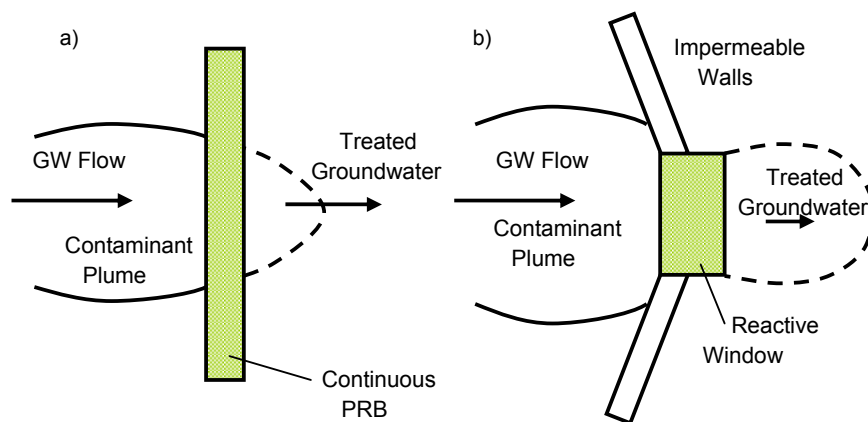


Figure 2. Two basic configurations of the permeable reactive barriers: a) continuous wall, b) funnel and gate system

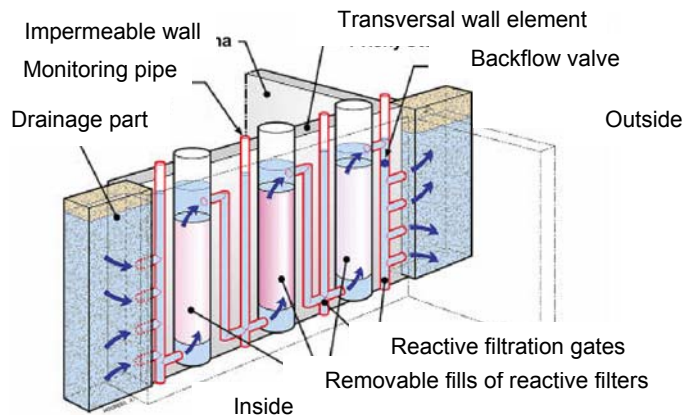


Figure 3. The reactive vessels (Řičica 2000)

## 2.2 Choice of appropriate reactive media and processes of decontamination

The choice of suitable reactive media depends on many factors, from which the most important is chemical composition of the contaminant.

The suitability of reactive media is determined on base of laboratory tests. There are used in principle the following chemical or physical processes:

- **Sorption.** Sorption is the process of removal contaminant from solution with using adsorption, absorption, ion exchange to the reactive media. The most often used media is granular activated carbon, zeolites, peat for removal of organic compounds and heavy metals.
- **Precipitation.** Precipitation is transformation of contaminants to the insoluble solid forms which are captured in the reactive media. For example by increasing of pH arise the reduction of some metals which are precipitated in the form of hydroxides or sulfites.
- **Degradation.** Chemical or biological (aerobic or anaerobic) reactions which leads to the decay of contaminant to the less harmful compounds. The example of chemical degradation can be oxidation of zero valent iron  $Fe^0$ , which results in the dehalogenization of chlorinated hydrocarbons. The example of aerobic biological degradation is artificial aeration, which helps to decay volatile organic hydrocarbons BTEX (benzene, toluene, ethylbenzene, and xylene).

The detailed description of reactive media for different types of contaminants concerns for example the report PEREBAR 2000, EPA 1998 and others. The brief summary of the remediation processes states Suthersan (1997). See table 1.

Table 1. Options of decontamination processes of reactive walls

Contaminant	Process of decontamination				
	Air stripping	Biol. degradation	Adsorption	Oxidation	Reduction
Chlorinated hydrocarbons	X	X	X	X	X
Aromatic hydrocarbons	X	X	X	X	
Chlor. aromatic hydrocarbons		X	X	X	
Alcohol, ketone, phenol		X		X	
Dissolved metals		X			
1.4 dioxan				X	

## 3 DESIGN OF PERMEABLE REACTIVE BARRIERS

In this chapter I would like to describe the basic principles of PRB design. It is evident that PRB design is very complicated interdisciplinary problem and it is necessary to cooperate with experts from different professions. The main task of chemists is to find and test the suitable reactive media and to define the sufficient residence time in order to occur the removal reactions. The column and batch tests are necessary to do.

The main task of geotechnical engineer is to design configuration, shape, dimensions, size, and thickness of permeable reactive wall with respect of minimal residence time. The whole contaminant plume has to pass through the reactive wall in order to capture the entire contaminant. The most important tool in this design is hydro-geological model.

### 3.1 Dimensions of PRB

The dimensions of PRB are derived by desired level of contaminant concentration, which depends on the residence time of contaminant in the reactive media i.e. on the groundwater velocity in the reactive wall.

In the continuous reactive wall will groundwater velocity and hydraulic gradient approximately same as in the surrounding aquifer. (It holds good in case the wall is more or same per-

meable as in the aquifer  $k_{f, PRB} > k_{f, aquifer}$ ). The contaminant plume will spread same way as without the reactive wall.

The impermeable walls of the funnel and gate configuration of PRB concentrate the contaminant plume flow to the permeable window. It causes decreasing of flow x-section i.e. increasing of hydraulic gradient and groundwater velocity. Therefore it needs thicker reactive media in order to keep the required residence time. The size of the reactive gate has to be enough in term of too high backwater height.

The thickness of PRB wall can be estimated according the following equation (Carey et al.2002):

$$b = v \cdot t_{res} \cdot SF \quad (1)$$

where  $b$  = thickness of PRB wall (m),  $v$  = groundwater velocity in the reactive media (m/d),  $t_{res}$  = required residence time (d),  $SF$  = safety factor.

$$v = \frac{K \cdot i}{n_p} \quad (2)$$

where  $K$  = hydraulic conductivity of reactive media (m/d),  $i$  = hydraulic gradient across PRB,  $n_p$  = porosity of reactive media.

The treatment processes can be very often described by the first order decay reactions. For this case is possible to estimated the residence time in the reactive media:

$$t_{res} = \left[ \frac{-\ln \frac{C_t}{C_0}}{k} \right] \quad (3)$$

where  $t_{res}$  = required residence time (d),  $C_t$  = target concentration downgradient of the PRB (mg/l),  $C_0$  = contaminant concentration entering the PRB (mg/l),  $k$  = reaction rate ( $d^{-1}$ ) (typically derived from analysis of laboratory column tests for a first order reaction).

The interesting solution can be used for case of groundwater contaminated by Light Non-Aqueous Phase Liquid (LNAPL) substance, which flows on the top of groundwater table. There is possible to use the „Hang-up“ PRB (Vaniček 2002). See figure 4. This alternative is appropriate in case there is accurate knowledge about hydrogeology and contaminant behaviour.

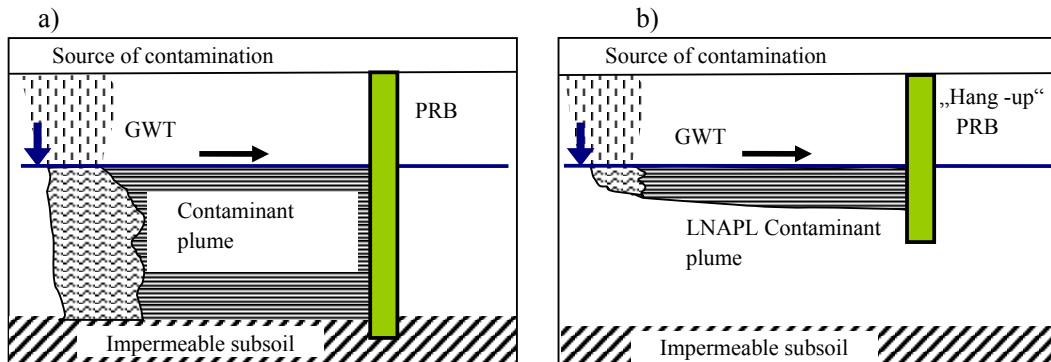


Figure 4. Alternatives of permeable reactive walls a) embedded wall, b) „Hang -up“ wall

### 3.2 *Influence on hydro-geological regime*

The significant questions are: How the PRB will influence the hydrology in the aquifer? How much the groundwater table will increase? How the groundwater flow will change the direction and the groundwater velocity? What will happen if the reactive media loses the permeability in the future due to the fouling processes? How the contaminant will spread in the time and space? These questions can help to answer the hydraulic model.

### 3.3 *Hydraulic modelling*

Hydraulic model is one of the most important tool for design of permeable reactive barriers. It includes two parts: groundwater flow and transport of contaminant. At present there are available many 2D and 3D models. At the Geotechnical department of Czech Technical University is used software package GMS, which consists of several programs for groundwater flow and reactive and non-reactive transport of contaminants.( MODFLOW, MODPATH, MT3D, RT3D, SEAM3D, SEEP2D, FEMWATER).

Hydraulic modelling is necessary for the following reasons (ITRC 1999):

- Determine an approximate location and configuration of the permeable reactive barrier with respect to groundwater flow, plume movement, and flow velocity through the ISTZ,
- Determine the dimensions of the permeable reactive barrier and ISTZ,
- Estimate hydraulic capture zone,
- Determine location and sample frequency of monitoring wells,
- Evaluate the hydraulic effects of potential losses in porosity, flow bypass, underflow, overflow, or flow across aquifers.

## 4 CONCLUSIONS

The Permeable reactive barrier method seems as a very promising and advantageous method in the wide field of remediation methods and there are still many questions for the further research.

### 4.1 *The problems for future research*

I would like to use the advantage of 3D hydraulic models and create parametrical study for the funnel and gate system PRB with focus on influence of groundwater regime in the aquifer for different shapes of PRB - study the flow around PRB, increasing of groundwater table, overflow. The other part should be simulation of a crack in the PRB wall and observation of the contaminant spreading. The next interesting problem for further investigation is simulation of clogging and bio-fouling influence to the reduction of permeability and function of PRB. The other branch of study is investigation of the influence of diffusion and dispersion on the contaminant transport and behaviour of LNAPL contaminants and their spreading.

### 4.2 *Advantages of PRB*

- After installation of PRB is site available for other use and activities.
- Possibility of application in urban area.
- Low acquisition and operational costs (EPA 2002).
- Lower influence to the groundwater regime (with comparison wit pump and treat method).
- Minimal exposure of persons with contaminant. Contaminant isn't pump to the surface.
- No requirements for building treatment plant and other technological buildings.
- Clean water isn't mixed with contaminated water (with comparison wit pump and treat method).

#### 4.3 Disadvantages of PRB

- Necessity to remove reactive media after finish of PRB operation
- Contaminated water is cleaned, but contaminated soil remains
- Clogging and fouling of reactive media, loosing of permeability.
- Possible reactive media replacement.
- Contaminant plume has to be exactly described and localized.
- Necessity to know detailed information about hydrology in the aquifer.

#### USEFUL INTERNET SOURCES:

Permeable reactive barrier network <http://www.prb-net.org>  
German Permeable Reactive Barrier Network "RUBIN" <http://www.rubin-online.de>  
Remediation Technologies Development Forum (RTDF) <http://www.rtdf.org>  
RTDF PRB Action Team <http://www.rtdf.org/public/permbarr/minutes/>  
EPA Clean-up Information System <http://www.clu-in.com>  
ESTCP Clean-up Projects <http://www.estcp.org/projects/cleanup>  
Powell Associates: Reactive Barriers <http://www.powellassociates.com/sciserv>  
Remediation with Iron Metal <http://cgr.ese.ogi.edu/iron>  
U.S. Department of Energy Grand Junction Office (GJO) <http://www.gjo.doe.gov/perm-barr>  
USGS Superfund Cleanup of Ground Water <http://wa.water.usgs.gov/pubs/fs/fs082-98>  
US Environmental Protection Agency <http://www.epa.gov>  
Federal Remediation Technologies Roundtable <http://www.frtr.gov>  
Groundwater Remediation Technologies Analysis Center <http://www.gwrtac.org>  
NATO CCMS: Pilot Studies, P007 <http://www.nato.int/ccms/pilot-studies/pilot007>  
CLAIRE Contaminated Land: Applications in Real Environments <http://www.claire.co.uk>  
CLARINET - Contaminated Land Rehabilitation Network for Environmental Technologies  
<http://www.clarinet.at>  
EU Project PIRAMID <http://www.piramid.org>  
Institute of Wastes Management <http://www.iwm.co.uk>  
European Groundwater and Contaminated Land Information System <http://www.eugris.org>  
International Association of Hydrogeologists <http://www.iah.org>  
Long-term Performance of Permeable Reactive Barriers <http://www.perebar.bam.de>

#### ACKNOWLEDGEMENT

*This paper was written with support of GAČR, reg. n.. 103/06/1257.*

#### REFERENCES

- EPA (2002): *Economic Analysis of the Implementation of Permeable Reactive Barriers for Remediation of Contaminated Ground Water*, EPA/600/R-02/034, 2002
- EPA (1998): *Permeable Reactive Barrier Technologies for Contaminant Remediation*. U.S. EPA Remedial Technology Fact Sheet, EPA 600/R-98/125., 1998
- Carey, M.A., Fretwell, B.A., Mosley, N.G., Smith, J.W.N.: *Guidance on the use of permeable reactive barriers for remediating contaminated groundwater*, National Groundwater & Contaminated Land Centre report NC/01/51, UK Environment Agency, Bristol, 2002
- IITRC (1999): *Regulatory Guidance for Permeable Reactive Barriers - Designed to Remediate Chlorinated Solvents*, Interstate Technology and Regulatory Cooperation Work Group-Permeable Reactive Barriers Work Team, 1999, <http://www.itrcweb.org>
- PEREBAR 2000: *Reactive Materials and Attenuation Processes for Permeable Reactive Barriers*, National Technical University of Athens, EVK1-CT-1999-00035, 2000
- Řiřica, J., Růžička, M.: *Reakční bariéry - vhodná sanační alternativa*. In: Sborník Sanační technologie III, Ekomonitor, Seč u Chrudimi, 2000, (In Czech)
- Sutherson, S.S.: *Remediation Engineering. Design Concepts*, CRC Lewis Publishers, New York, 1997
- Vaniček, I. : *Sanace skládek, starých ekologických zátěží*. Vydavatelství ČVUT Praha, 2002, (In Czech)