

	<p>Welcome to ITRC's Internet Training: <i>"Permeable Reactive Barriers for Chlorinated Solvent, Inorganic, and Radionuclide Contamination"</i></p>
<p align="center"> "Design Guidance for Application of Permeable Barriers to Remediate Dissolved Chlorinated Solvents" Prepared for Air Force Research Lab/Enviroics Directorate (AL/EQ), Tyndall AFB, Florida by BATTELLE, Columbus, Ohio </p> <p align="center"> "Regulatory Guidance for Permeable Barrier Walls Designed to Remediate Chlorinated Solvents" & "Regulatory Guidance For Permeable Reactive Barriers Designed to Remediate Inorganic and Radionuclide Contamination" by Permeable Reactive Barrier Wall Team of the ITRC </p> <div style="display: flex; justify-content: space-between; align-items: center;">  <div data-bbox="706 871 982 913"> www.itrcweb.org </div>  </div>	


This training is designed to introduce state regulators, environmental consultants, site owners and community stakeholders to three documents created by the ITRC's Permeable Reactive Barrier Walls Technical Team and the Remediation Technologies Development Forum (RTDF) Bioremediation Consortium titled, "Regulatory Guidance for Permeable Barrier Walls Designed to Remediate Chlorinated Solvents", "Regulatory Guidance for Permeable Reactive Barriers Designed to Remediate Inorganic and Radionuclide Contamination" & "Design Guidance for Application of Permeable Barriers to Remediate Dissolved Chlorinated Solvents". The training focuses on the basic information one needs to determine and document the conditions necessary to effectively apply a permeable reactive barrier to a contaminated zone to be an effective part of remediating chlorinated solvents, radionuclides and other inorganic compounds in ground water. It provides a framework, that is, how to think about permeable reactive barriers based on science. The information contained in this manual and presentation is based on research activities of the RTDF and from experience and knowledge of the participating members.

ITRC – Interstate Technology and Regulatory Council (www.itrcweb.org)

EPA-TIO – Environmental Protection Agency – Technology Innovation Office (www.clu-in.org)

ITRC Course Moderator:

Mary Yelken (Western Governors' Association/ITRC – myelken@westgov.org)



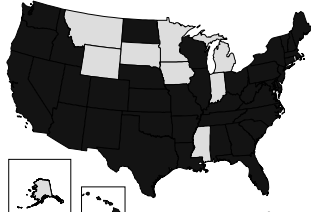
ITRC – Shaping the Future of Regulatory Acceptance

ITRC Internet Training Courses

- ★ Natural Attenuation
- ★ EISB (Enhanced In Situ Bioremediation)
- ★ Permeable Reactive Barriers (basic and advanced)
- ★ Diffusion Samplers
- ★ Phytotechnologies
- ★ ISCO (In Situ Chemical Oxidation)
- ★ Constructed Treatment Wetlands
- ★ Small Arms Firing Range Characterization and Remediation
- ★ Systematic Approach to In Situ Bioremediation


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Citizen Stakeholders


www.itrcweb.org

The bulleted items are a list of ITRC Internet Training topics – go to www.itrcweb.org and click on “internet training” for details.

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ITRC originated in 1995 from a previous initiative by the Western Governors’ Association (WGA). In January 1999, it affiliated with the Environmental Research Institute of the States, ERIS is a 501(c)3 nonprofit educational subsidiary of the Environmental Council of States (ECOS). ITRC receives regional support from WGA and the Southern States Energy Board (SSEB) and financial support from the U.S. Department of Energy, the U.S. Department of Defense, and the U.S. Environmental Protection Agency.

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	<h2><i>Meet the Instructors</i></h2>
	<p>★ <u>Matthew Turner</u></p> <ul style="list-style-type: none"> • NJ Dept. of Environmental Protection • 401 E. State St. • Trenton, NJ, 08625 • T 609-984-1742 • F 609-633-1454 • mturner@dep.state.nj.us
	<div style="display: flex; justify-content: space-between;"> <div data-bbox="479 630 876 945"> <p>★ <u>Arun Gavaskar</u></p> <ul style="list-style-type: none"> • Battelle • 505 King Ave. • Columbus Ohio 43201 • T 614-424-3403 • F 614-424-3667 • gavaskar@battelle.org </div> <div data-bbox="876 630 1282 945"> <p>★ <u>Scott Warner</u></p> <ul style="list-style-type: none"> • Geomatrix Consultants, Inc. • 2101 Webster St, 12th Fl • Oakland, Ca 94612 • T 510-663-4269 • F 510-663-4141 • swarner@geomatrix.com </div> </div>
	<p>3</p>

Matthew Turner has a B.S. in Biology and a M.S. in Environmental Science. With 15 years experience in the environmental field, he is currently employed by the New Jersey Department of Environmental Protection as a Case Manager in the Site Remediation Program. He is a member of the Interstate Technology and Regulatory Council Workgroup where he has served as the leader of the Permeable Barrier Wall Subgroup since 1997. He is also a participant in the Remediation Technology Development Forum's Action Team on Permeable Reactive Barriers.

Scott Warner is a Principal Hydrogeologist at Geomatrix Consultants, Inc. with 14 years experience and expertise in hydrogeology, geochemistry, and innovative soil and groundwater treatment technologies. He has B.S. in engineering geology from U.C.L.A. and M.S. in geology from Indiana University, Bloomington. Mr. Warner has provided consultation to the U.S. Department of Energy, the U.S. Department of Defense, the U.S. Environmental Protection Agency, and many private companies on innovative remediation technologies, including the use of bioremediation, permeable reactive barriers, and related technologies. He has also provided expert witness work with respect to litigation involving environmental remediation and geochemistry. He also leads Geomatrix focus groups on VOC/DNAPL remediation, and arsenic in groundwater. Mr. Warner is a steering committee member of the Remediation Technologies Development Forum, Permeable Barriers Subgroup, and is a lead developer and instructor for the USEPA-sponsored permeable reactive barriers short course.

Arun Gavaskar is a Research Leader/Group Leader in the Environmental Restoration Department at Battelle, Columbus, Ohio. He has a background in chemical engineering and environmental technology, and has worked for thirteen years in the remediation and industrial pollution prevention areas. His current research interests include the remediation of a variety of groundwater, soil, and sediment contaminants, namely, DNAPL and dissolved-phase chlorinated solvents, heavy metals, and PCBs/dioxins. He also co-chaired the Second International Conference on Remediation of Chlorinated and Recalcitrant Compounds at Monterey, California in May 2000.

	<i>Permeable Reactive Barriers for Chlorinated Solvent, Inorganic, and Radionuclide Contamination</i>
<p>Presentation Overview</p> <ul style="list-style-type: none"> ✓ Overview of PRB Tech. ✓ PRB Application Methodology <ul style="list-style-type: none"> ✓ Conceptual Design ✓ Site Characterization ✓ Treatability Testing ✓ Questions and answers ✓ PRB Application Methodology (cont.) <ul style="list-style-type: none"> ✓ PRB Design ✓ Emplacement & Permitting ✓ Monitoring ✓ Questions and answers ✓ Links to additional resources ✓ Your feedback 	<p>Logistical Reminders</p> <ul style="list-style-type: none"> ✓ Phone Audience <ul style="list-style-type: none"> • Keep phone on mute • * 6 to mute your phone and again to un-mute • Do NOT put call on hold ✓ Simulcast Audience <ul style="list-style-type: none"> • Use  at top of each slide to submit questions

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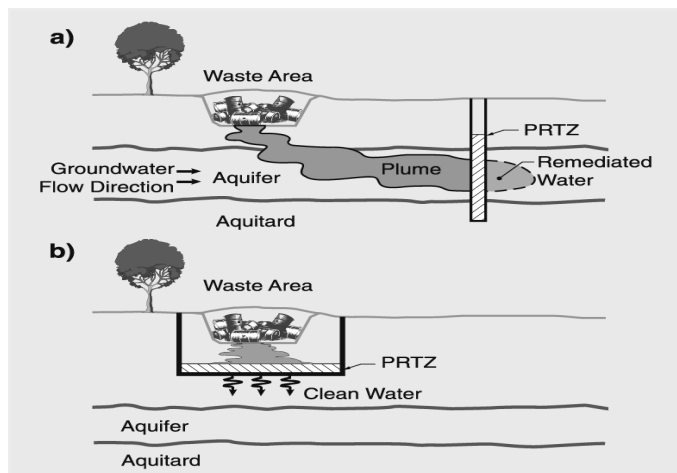
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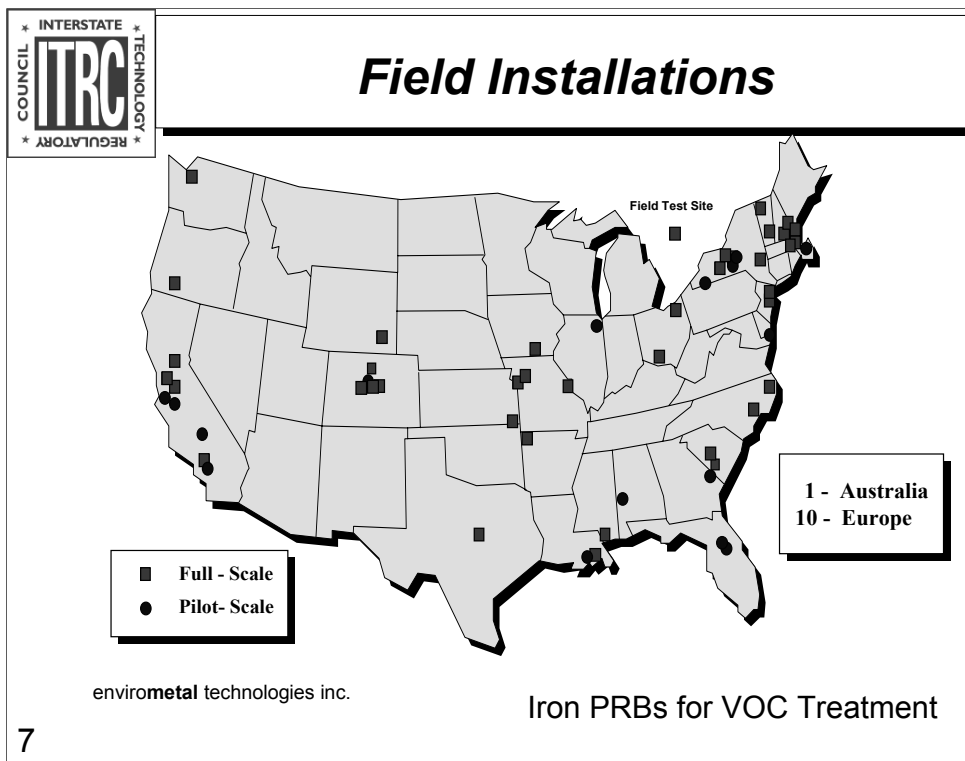


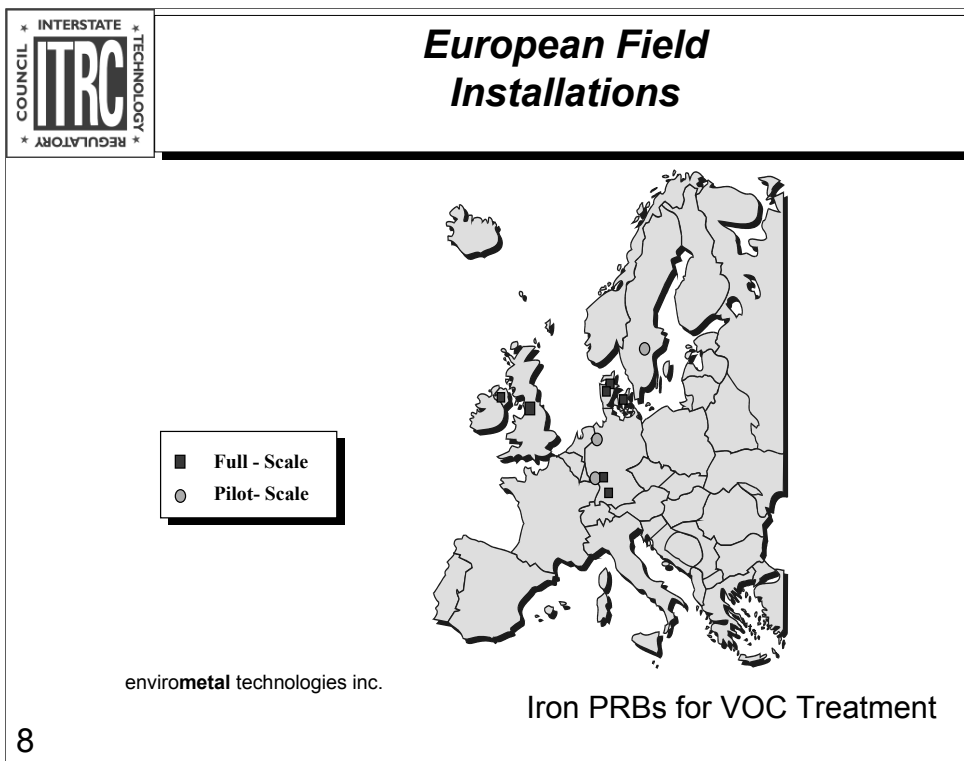
ITRC Regulatory Documents

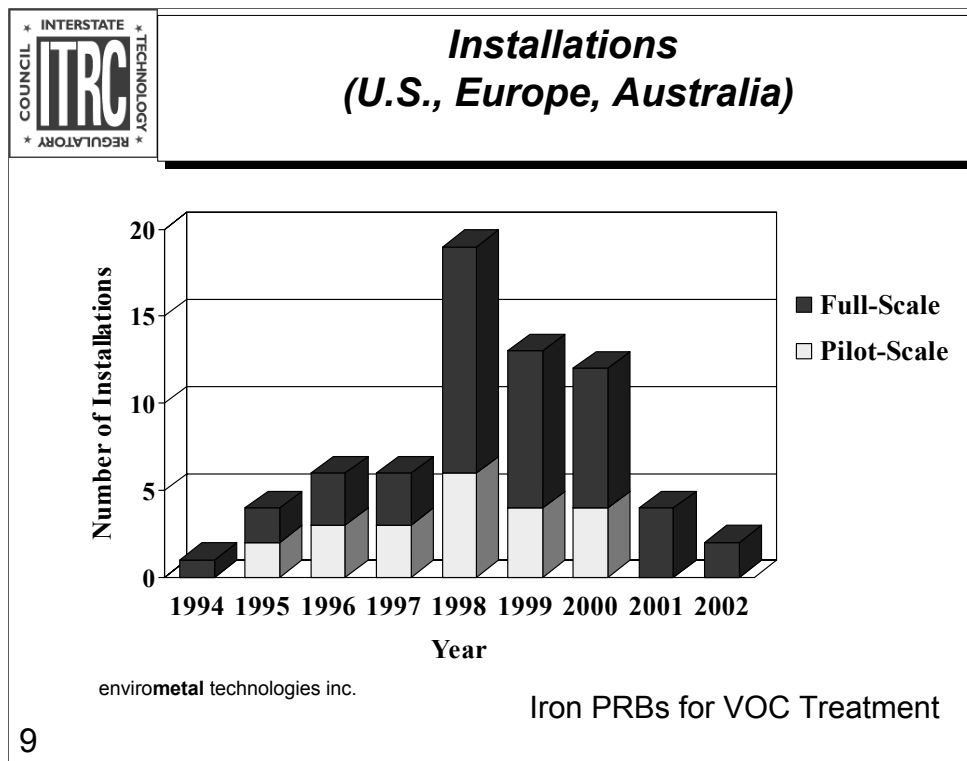
- ★ ITRC Documents can:
 - **Provide Information on PRB deployment**
 - **Identifies regulatory & stakeholder issues**
 - **Provides technical & regulatory & design guidance**
 - **Builds technical and regulatory consensus**
 - **Streamlines regulatory approval process**
 - **Educates stakeholders, regulators, technology implementers**

What Is A Permeable Reactive Barrier?







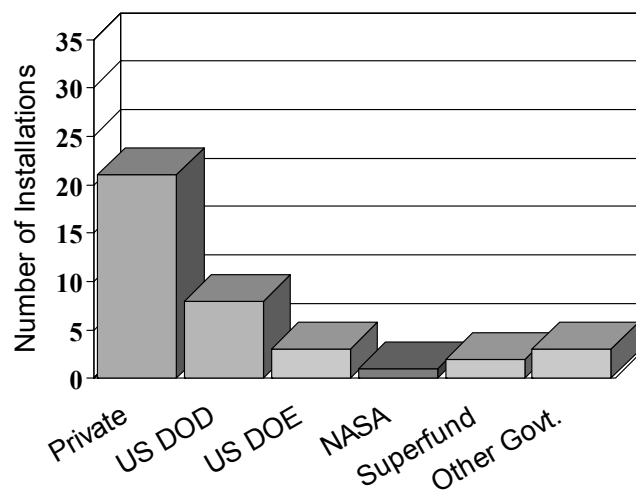


As the PRB Technology has become more accepted pilot studies are not as likely to be required. Although the number of PRB implementations has dropped in the last couple of years the length and tonnage of the systems has increased.

2002 data – as of March 2002

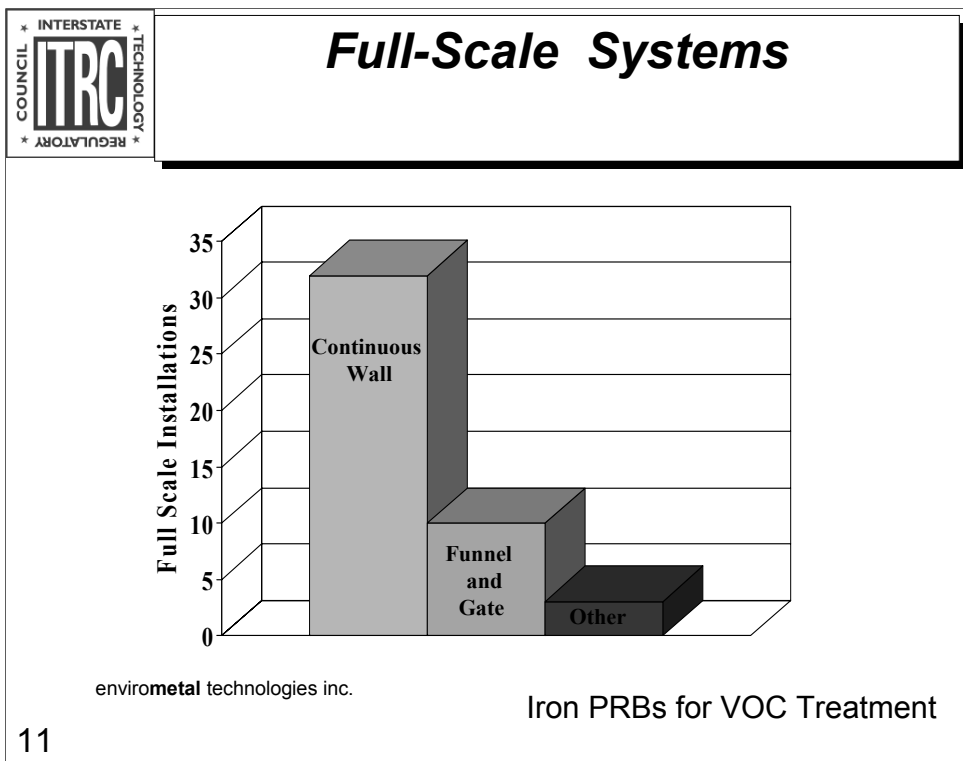


US Full Scale PRB Applications



envirometal technologies inc.

Iron PRBs for VOC Treatment





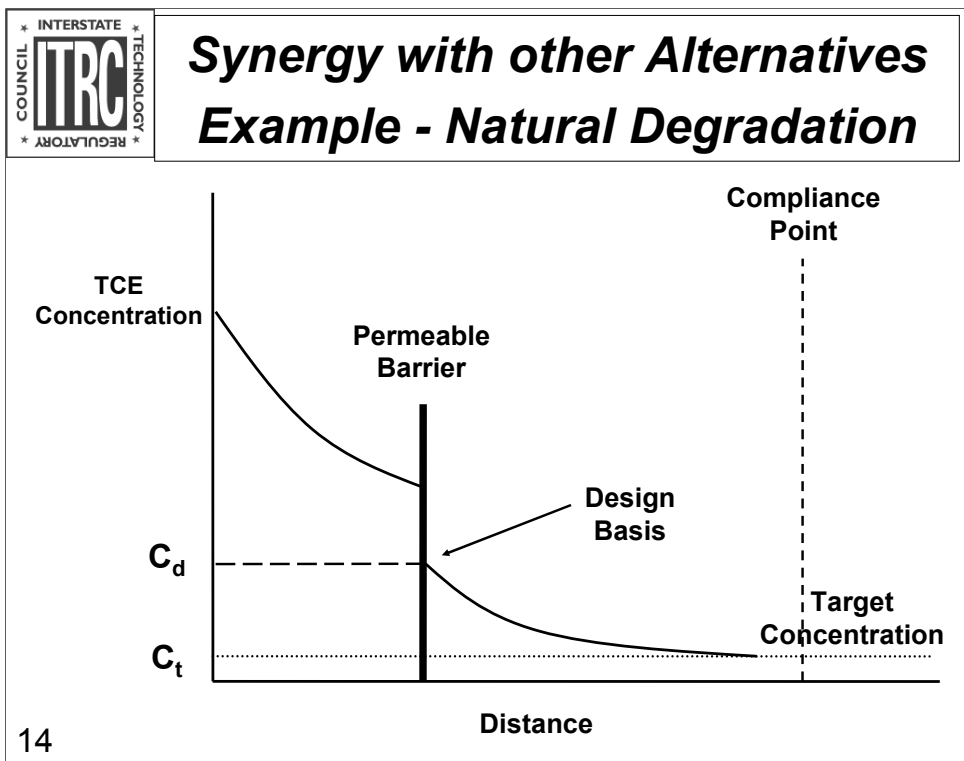
Advantages Of Permeable Barriers

- ★ **Treatment occurs in the subsurface**
- ★ **Typical treatment is passive**
- ★ **Potentially lower operation and maintenance costs**
- ★ **Allows full economic use of a property**
- ★ **No above ground structures or routine day-to-day labor attention required**
- ★ **Monitoring can be focused**



Treatment Mechanisms

- ★ **pH Control**
- ★ **Chemical Precipitation**
- ★ **Oxidation-Reduction Reactions**
- ★ **Zero-Valent Metal Induced Dehalogenation**
- ★ **Biological Degradation Reactions**
- ★ **Sorption Reactions**





Common Terminology

★ Treatment Matrix / Reactive Media-

- zone of material that promotes treatment

★ Hydraulic control system

- routes affected groundwater through the treatment zone
- prevents migration around treatment zone
- provides the affected groundwater with sufficient residence time in the treatment zone



Reactive Media Selection Guidance

Treatment Material and Treatable Contaminants

Treatment Material	Target Contaminants	Status
Zero-Valent Iron	Halocarbons, Reducible metals	In Practice
Reduced Metals	Halocarbons, Reducible Metals	Field Demonstration
Metals Couples	Halocarbons	Field Demonstration
Limestone	Metals, Acid Water	In Practice
Sorptive Agents	Metals, Organics	Field Demonstration, In Practice
Reducing Agents	Reducible Metals, Organics	Field Demonstration, In Practice
Biological Electron Acceptors	Petroleum Hydrocarbons	In Practice, Field Demo



Permeable Reactive Barrier Composed of Fe(0)



Journal of Environmental Engineering, June 1998



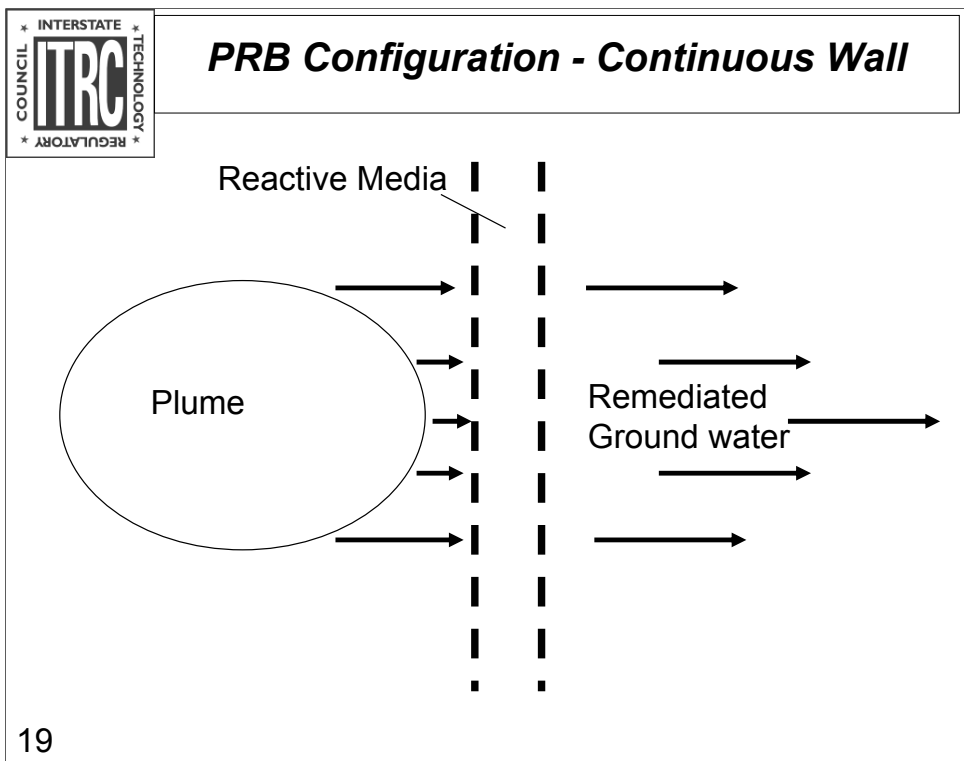
Contaminants Treated by the Most Common Reactive Medium -- Iron

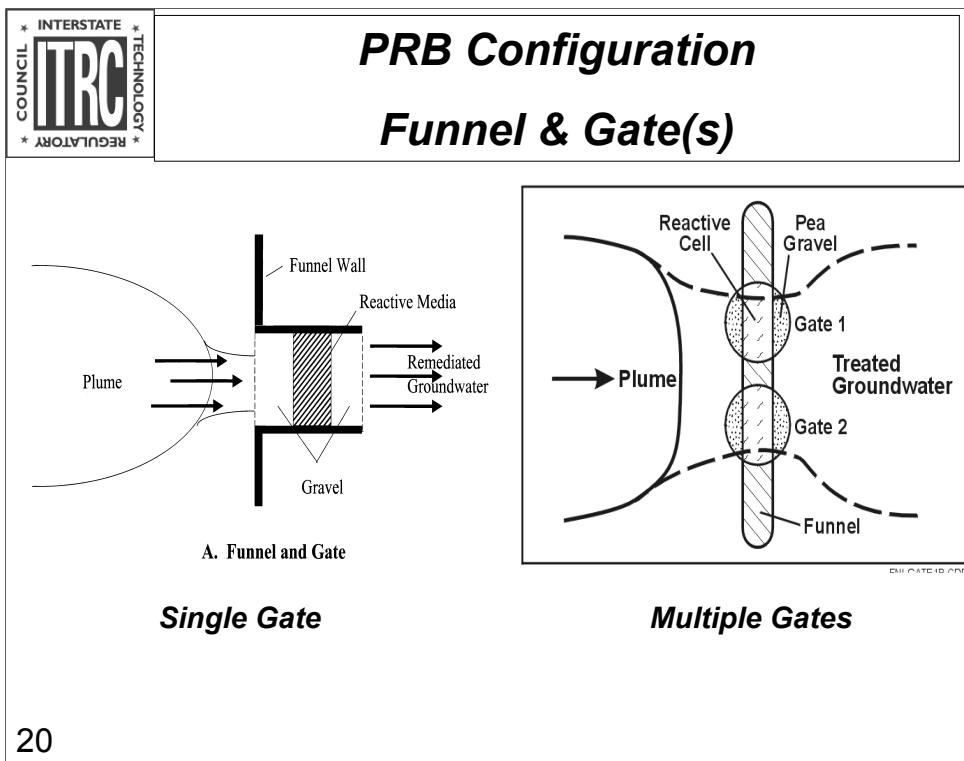
★ Inorganics:

- Cr, As, Hg, Cd, U, Tc
Nitrate, Sulfate

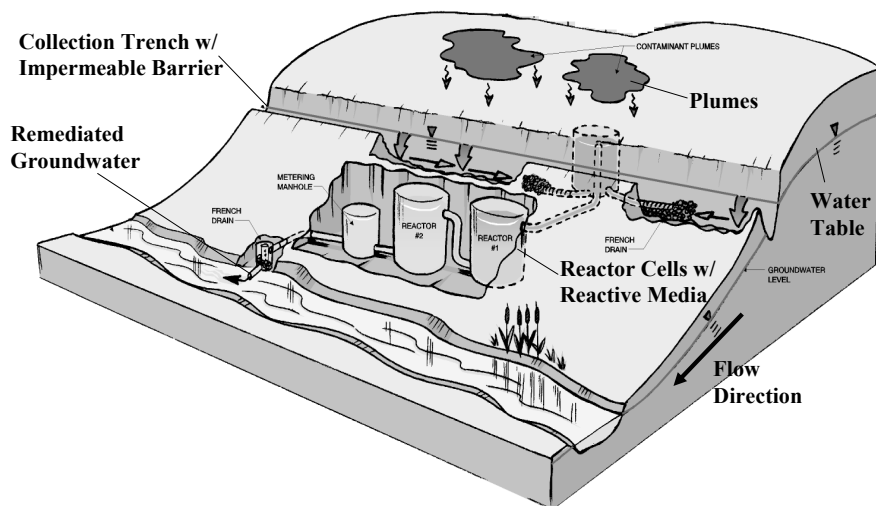
★ Organics:

- Chlorinated Methanes (CT)
Chlorinated Ethanes (TCA)
Chlorinated Ethenes (TCE)
Nitroaromatics (TNT, RDX)

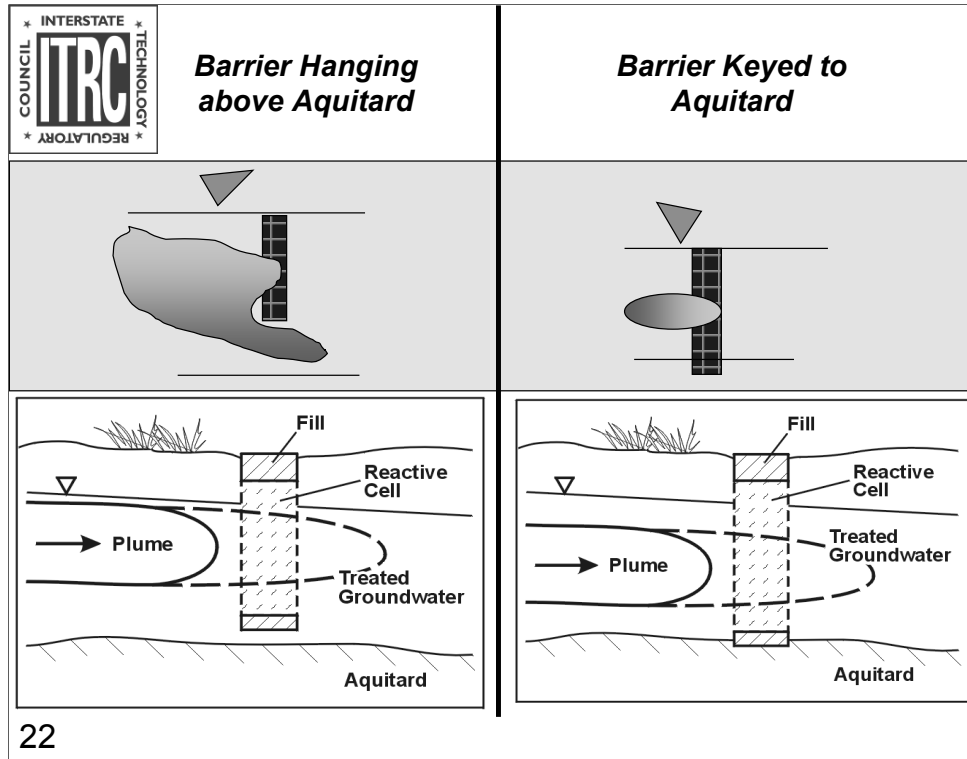


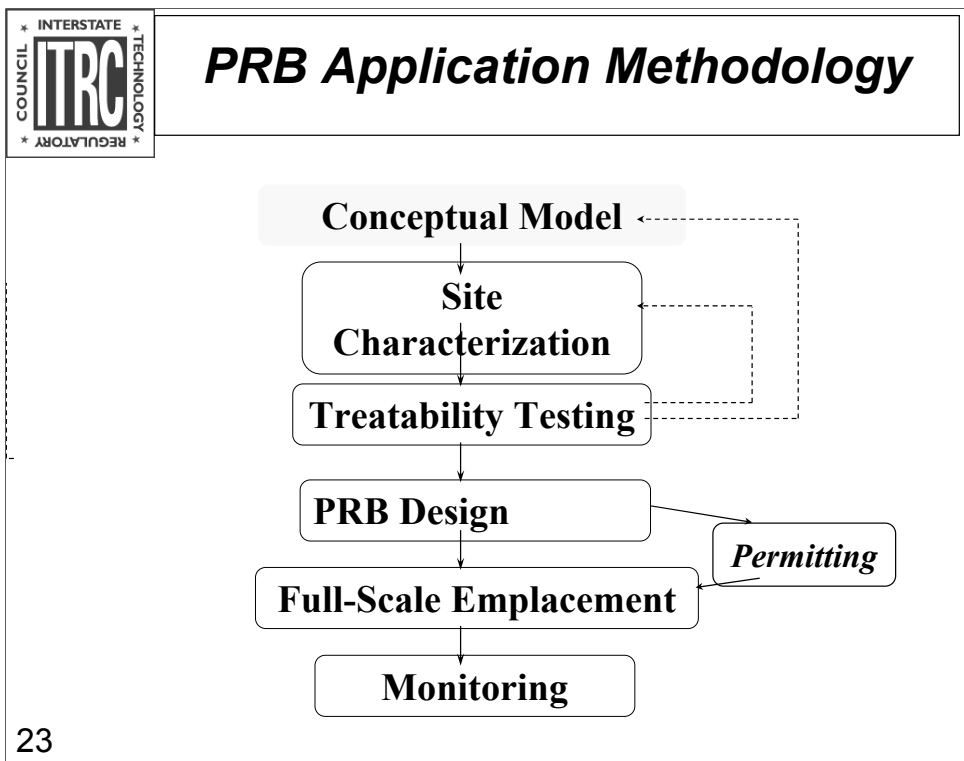


PRB Configuration - Passive Collection with Reactor Cells



USDOE Rocky Flats Mound Site Plume, Tetra Tech EM, Inc. 1998

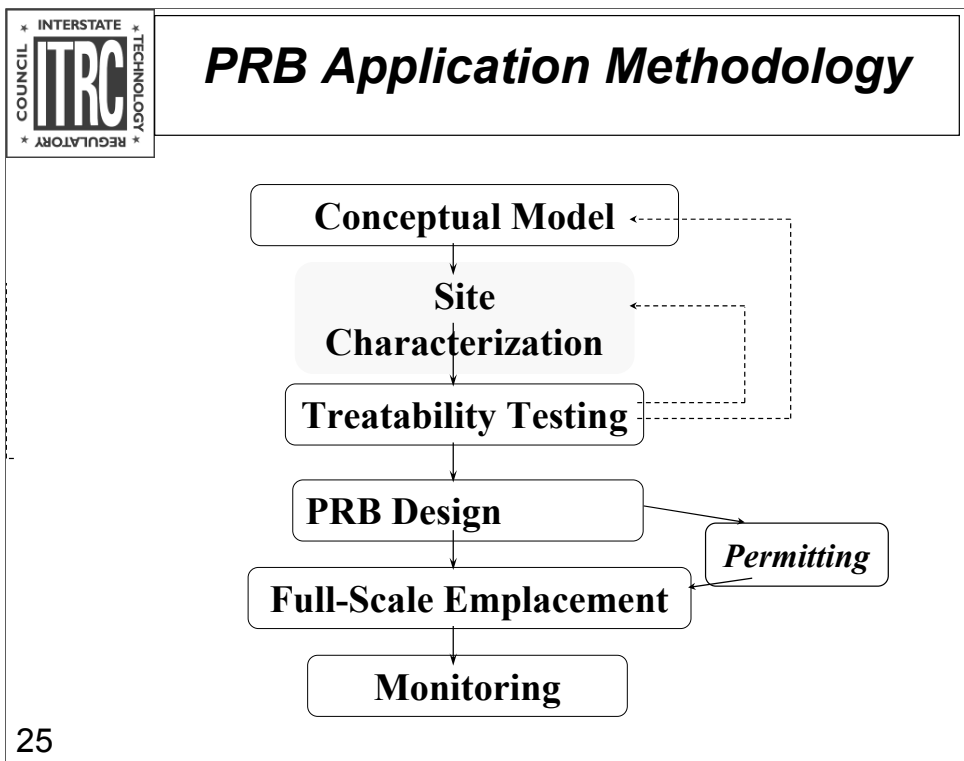






Conceptual Model
***(Using available information to determine if a
PRB is suitable at a given site)***

- ★ **The suitability of a contaminated site for PRB treatment is affected by the following factors:**
 - **Contaminant type**
 - **Plume size and distribution in 3 dimensions**
 - **Depth of aquitard**
 - **Geotechnical considerations**
 - **Constructibility**
 - **Groundwater flow characteristics**
 - **Ground water geochemistry**





Site Characterization and Design Information

★ Need to Know

• Composition of the Groundwater

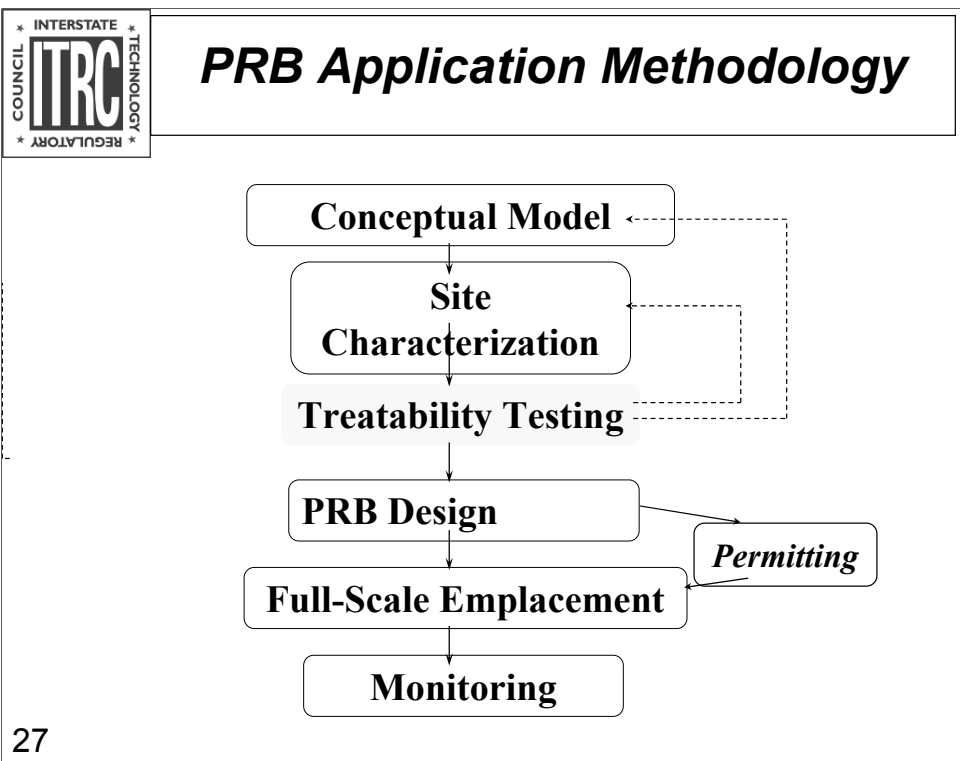
- Types and concentrations of contaminants
- Plume distribution
- Geochemistry of groundwater (e.g., pH, DO, Ca, etc.)

• Hydrogeology of the Affected Aquifer

- Stratigraphy
- Groundwater flow velocity and direction

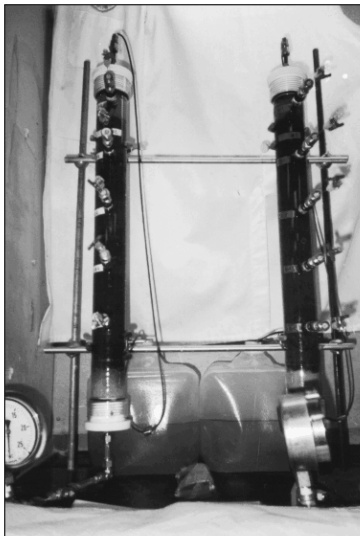
★ Used to

- **Select the appropriate reactive media,**
- **Conduct treatability tests, and**
- **Design the thickness of the wall**





Treatability Testing for Reactive Media Selection and Design Information Gathering



★ **Batch tests**

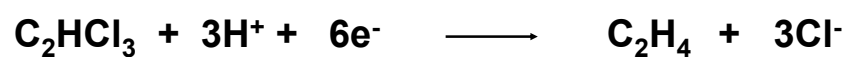
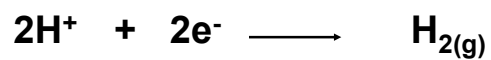
- Quick screening of multiple reactive media

★ **Column tests**

- Final selection of reactive media
- Obtaining design information (contaminant half-lives or reaction rates)

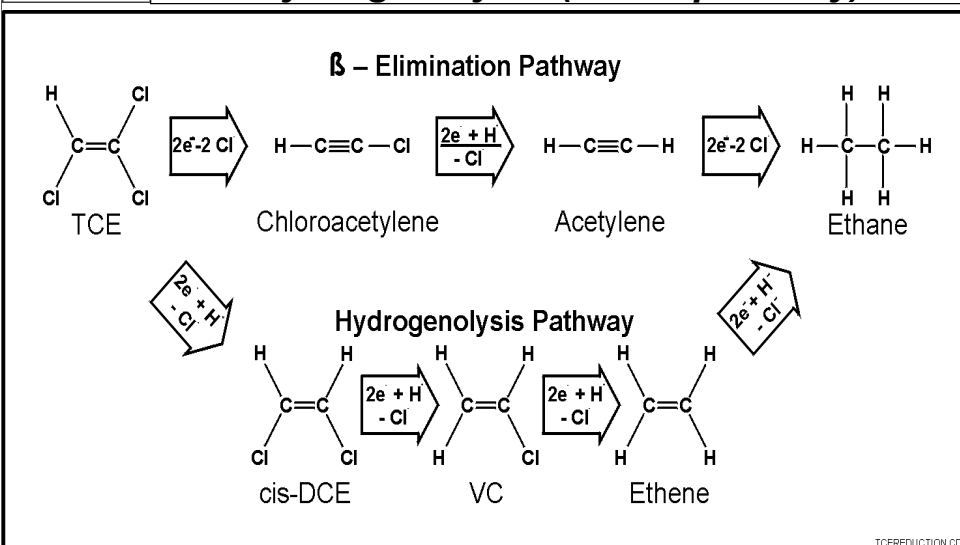


***Degradation of CVOCs with Iron
- A strong reducing agent (electron donor)***





Degradation of CVOCs with Iron - Beta-elimination (major pathway) and Hydrogenolysis (minor pathway)



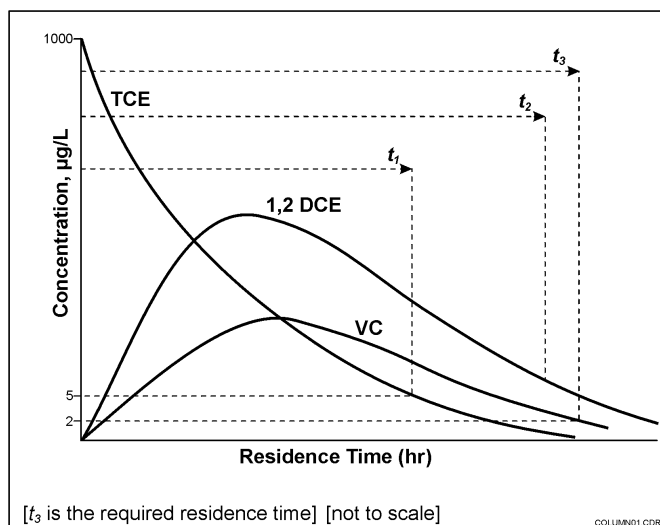


***Using column test results and site
characterization information to determine
PRB thickness***

- ★ **Half-lives (or reaction rate constants) of the contaminants for a given reactive medium**
 - Based on column tests
 - Used to determine residence time in the reactive medium to reduce contaminants to target levels
- ★ **The flow-through thickness of the reactive cell**
 - Is determined by residence time requirement and estimated groundwater velocity through the reactive cell
 - Adjusted for groundwater temperatures and the potentially lower field bulk *density* of the reactive medium



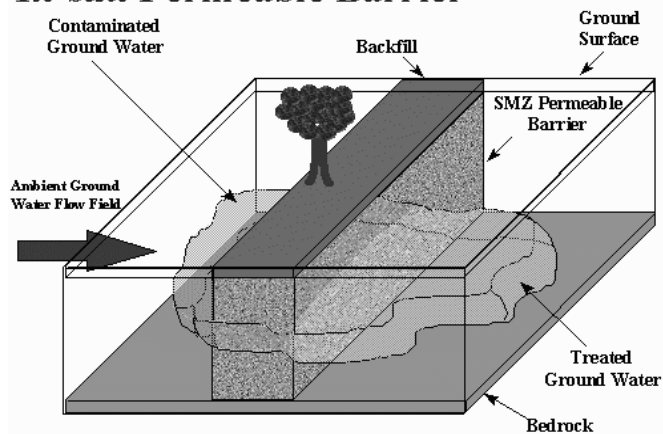
Sizing the PRB for the Byproducts



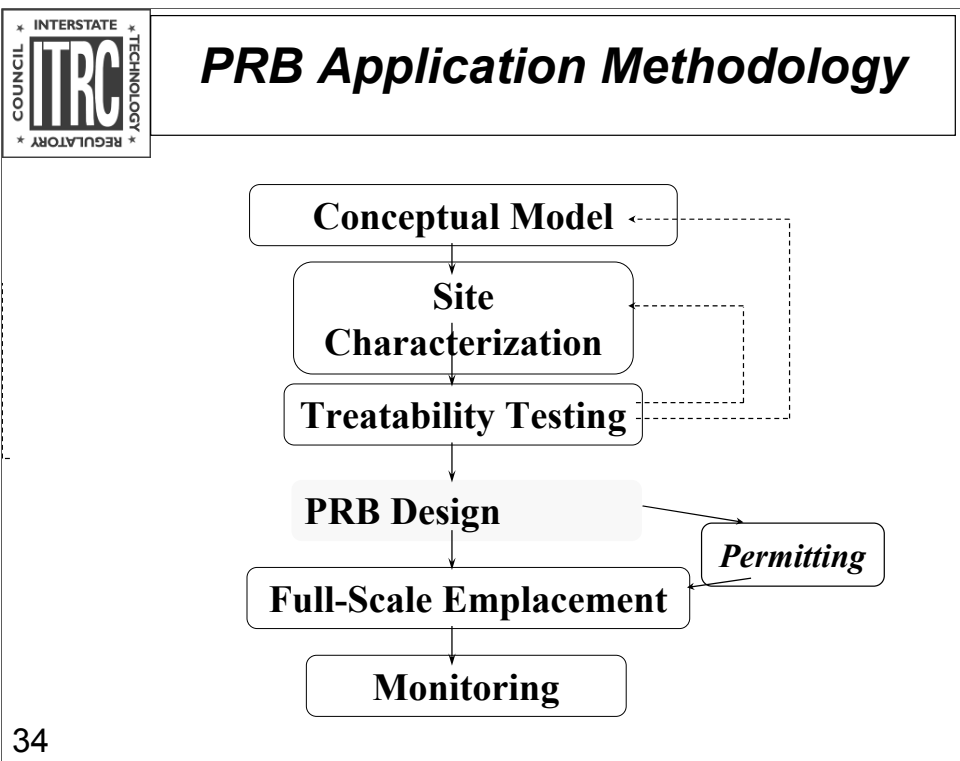
- ★ Do column feasibility study.
- ★ Compare results to MCLs.
- ★ Select t_c for the last byproduct CoC to reach its MCL (e.g., t_3).

Question & Answers

In-situ Permeable Barrier



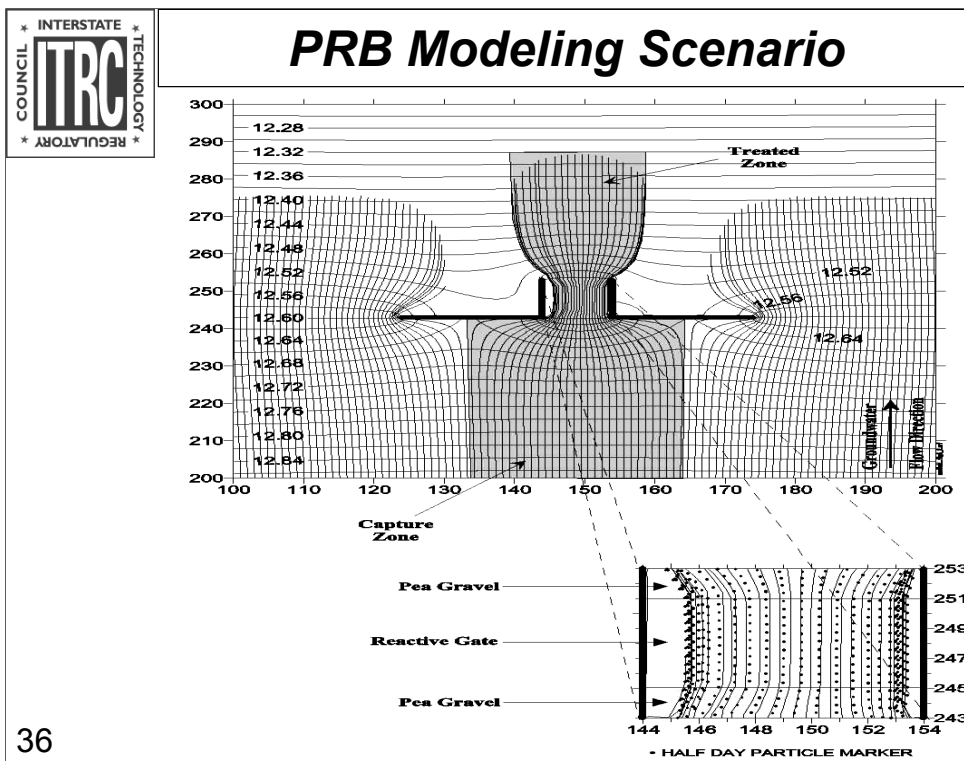
Oregon Graduate Institute and New Mexico Tech





PRB Design Objectives and Role of Groundwater Modeling

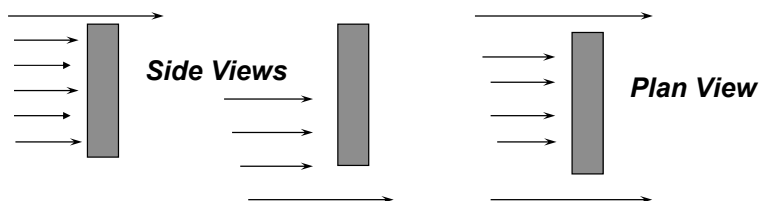
- ★ **Determine suitable location, orientation, and configuration of PRB**
- ★ **Determine required thickness of PRB (for specified residence time)**
- ★ **Determine required width of PRB (for specified capture zone)**
- ★ **Plan monitoring well locations and frequencies**



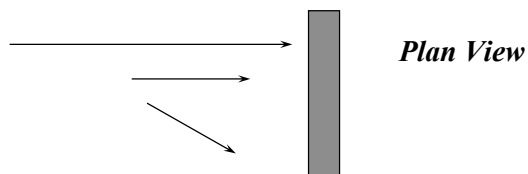


Addressing Groundwater Flow Uncertainties Through Modeling

- ★ The plume could pass over, under, or around the PRB



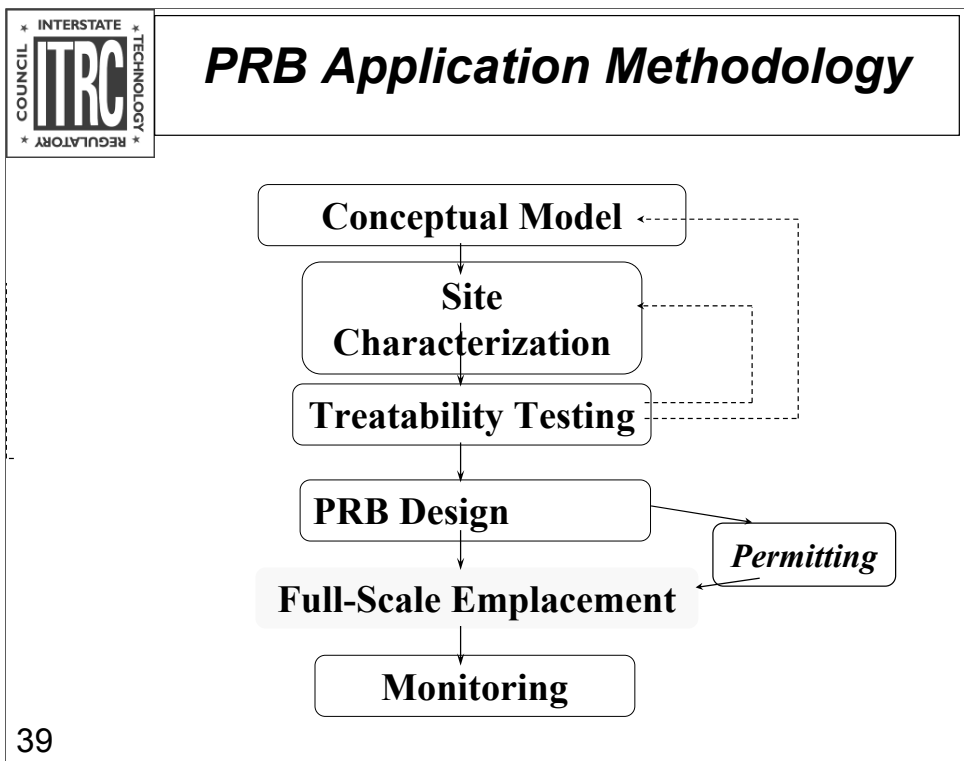
- ★ Flux may be non-uniform creating variable velocity conditions and shifting hydraulic gradient directions





***Addressing longevity issues
-- Geochemistry factors that may limit the life of the
iron medium through loss of reactivity and/or plugging
(Requires long term monitoring of PRB)***

- ★ **Oxygen concentration**
 - high dissolved O_2 , increased $Fe(OH)_3$ precipitation (rust)
 - $Fe^0 + 1.5O_2 + 6H^+ > Fe(OH)_3 + 1.5H_2$
- ★ **Carbonate alkalinity**
 - precipitation of Fe, Ca, and Mg carbonates
- ★ **Sulfate concentration**
 - possible sulfide formation on iron





PRB Emplacement Methods

- ★ **Conventional Excavation (Backhoe)**
- ★ **Continuous Trencher**
- ★ **Caisson**
- ★ **Tremie Tube / Mandrel**
- ★ **Deep Soil Mixing**
- ★ **High Pressure Grouting (Jetting)**
- ★ **Vertical Hydraulic Fracturing**
- ★ **Geochemical Manipulation**



PRB Full-Scale Systems

★ Construction methods by end of 1999:



- **20 continuous reactive walls**

- conventional excavation
- continuous trencher
- hydrofracturing
- jetting

- **5 funnel and gate systems**

- slurry wall
- sheet piling
- HDPE impermeable wall

- **In Situ Reaction Vessels**

<div data-bbox="332 199 472 338"><div>INTERSTATE</div><div>COUNCIL</div><div>REGULATORY</div><div>TECHNOLOGY</div><div>ITRC</div></div>	<div data-bbox="594 212 1179 327"><h1>Conventional Excavation (Backhoe)</h1></div>
42	<div data-bbox="488 363 862 621"></div> <div data-bbox="488 667 862 919"></div> <div data-bbox="935 432 1255 747"><ul style="list-style-type: none">★ Intersil Site, Sunnyvale, Ca., 1995★ 30 Feet Deep★ Trench Gate (backhoe) and slurry funnel wall</div>



Caisson-Based Emplacement



(a)

★ Dover Air Force Base,
Dover, De., 1997

★ Keyed 40 ft (bgs) into
clay aquitard



(b)

★ Sheet pile funnel & two
8-foot diameter caisson
gates



Continuous Trencher (Elizabeth City Photo)



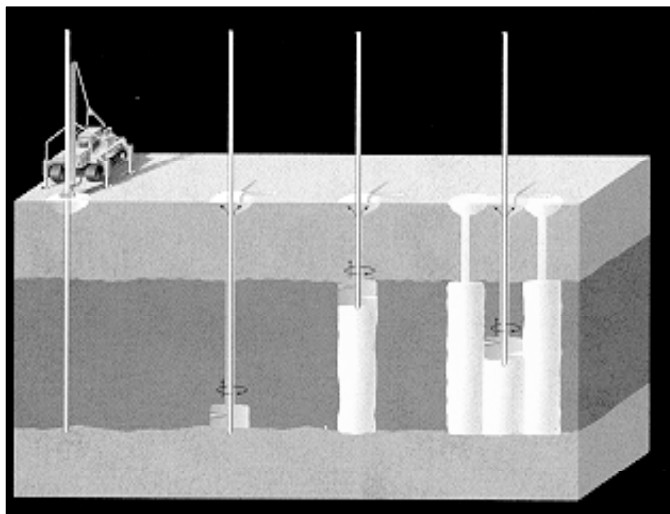
★Coast Guard site, Elizabeth City, NC 1996

★25 feet deep wall, hanging wall configuration

★Continuous wall using continuous trencher



Schematic of Jetting Process



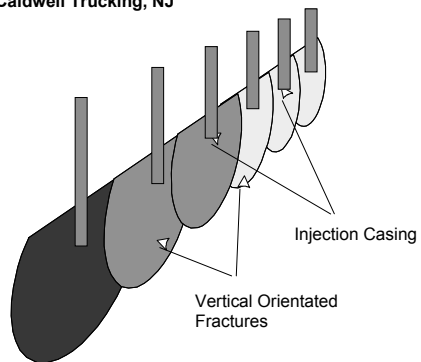
★ Travis Air Force Base, Ca. 1999

★ 50 feet deep; overlapping injection

★ iron slurry injected at high pressure through nozzles

Hydraulic Fracturing

◆ Caldwell Trucking, NJ



Source: Dupont Company

- ★Caldwell Trucking site, NJ
- ★vertical (overlapping) hydraulic fractures created
- ★fractures filled w/ iron slurry (3-4" thick barrier)



Tremie Tube / Mandrel



★ **Pilot Test at Cape Canaveral, Fl. 1997**

★ **43 feet deep, mandrel driven into ground at overlapping locations**

★ **granular iron tremied into hole (4" barrier)**



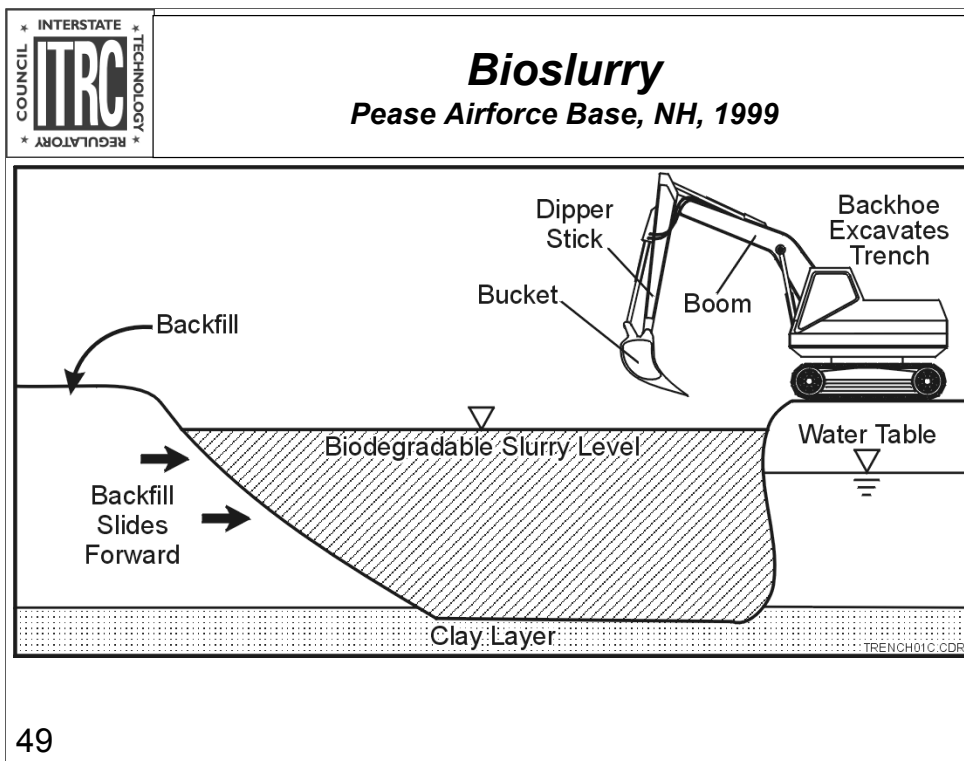
Deep Soil Mixing



★ Iron slurry fed through hollow stem augers

★ iron-soil mixture created in subsurface

★ overlapping penetrations





PRB Economics

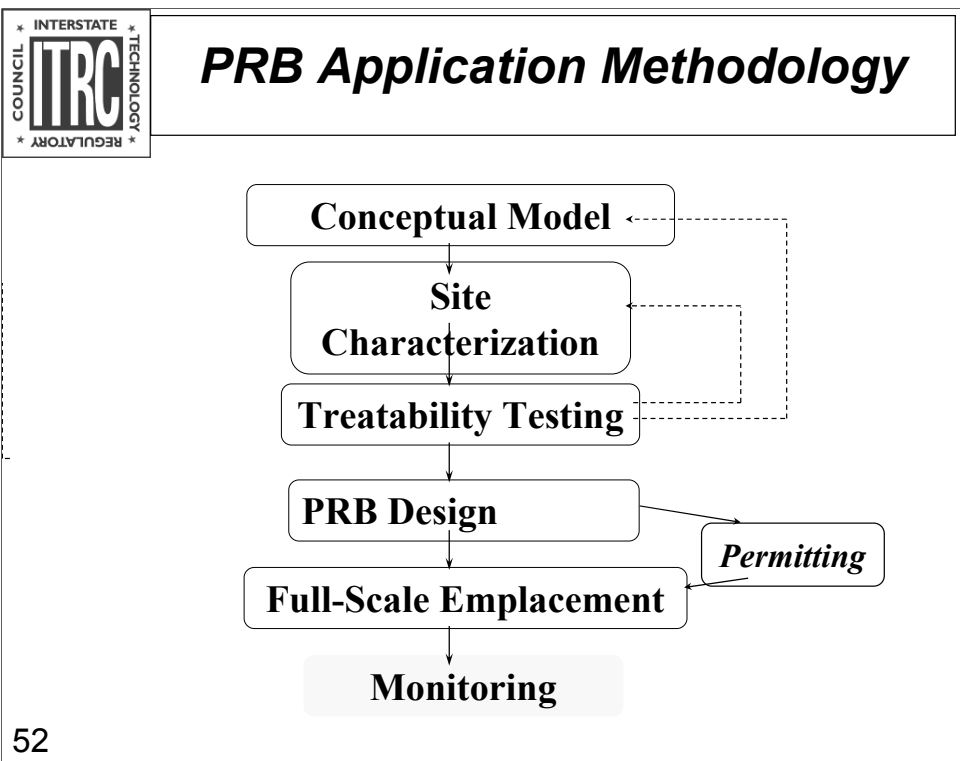
- ★ Capital Investment
 - Site Characterization/Treatability Test/Design
 - Reactive Medium and Construction
- ★ Annual O&M Costs
 - Monitoring
- ★ Reactive Medium Maintenance Cost (may be required in the future for reactive medium replacement or regeneration)
 - Frequency depends on longevity of reactive medium
 - Iron medium could last for several years



PRB Economics

Cost-Benefit Analysis

- ★ Present Value Analysis (PV)
 - **estimate long-term costs of PRB**
- ★ Multiple cost scenarios for varying life expectancies
- ★ Compare PV of PRB w/ PV of other options (rather than comparing Capital Investment and O&M Costs)
- ★ Evaluate Costs of PRB against Benefits
 - **No annual operating requirements**
 - **no above ground structures**
 - **no above ground waste streams**





Monitoring

★ Monitoring Comprised of Two Objectives

- Compliance Monitoring - regulatory requirements, monitoring for compliance with standard
- Performance Monitoring - ensure operation of wall as designed

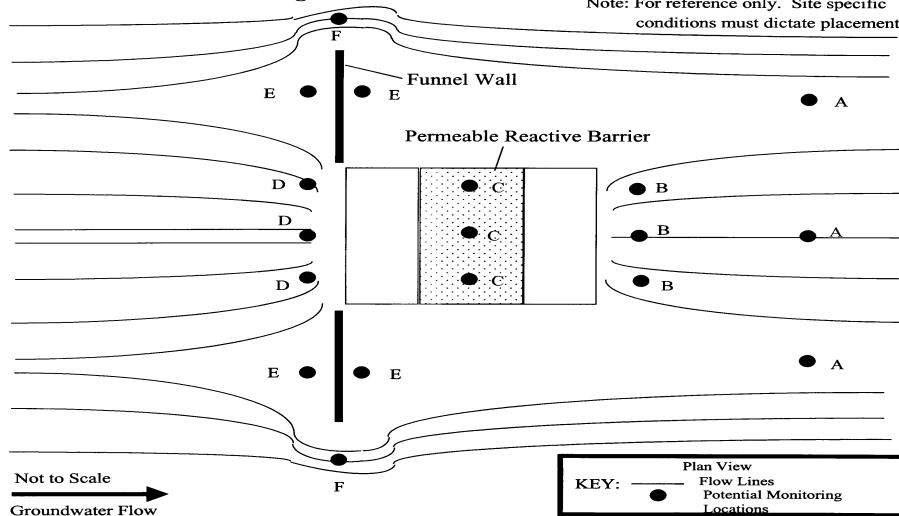
★ Sampling Procedures

- Low flow sampling method for collection of groundwater samples
- Collection of representative samples where the retention time within the reactive media is not altered

Hypothetical Monitoring Well Placement

Figure 2 Funnel and Gate

Note: For reference only. Site specific conditions must dictate placement.



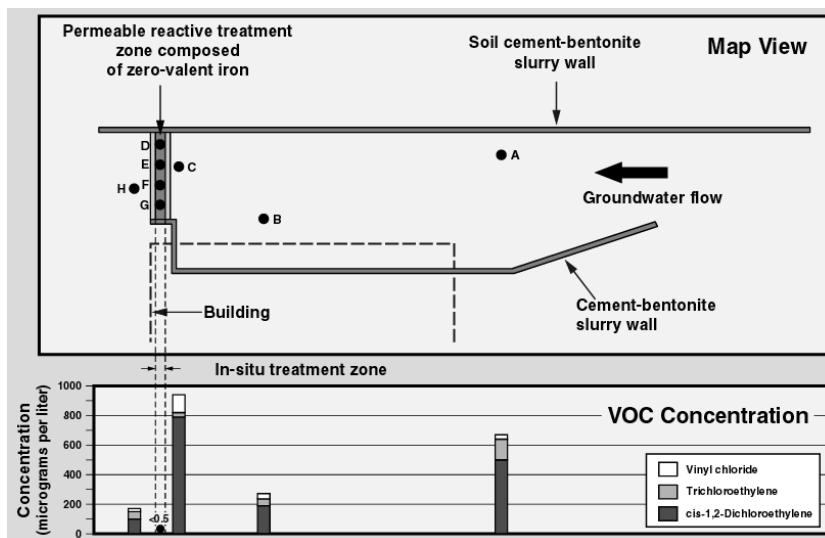


Monitoring Frequency

- ★ 1st quarter after installation - **Monthly**
- ★ 1-2 years after installation - **Quarterly**
- ★ Long term - **Quarterly** (may be modified/decreased based on performance)
- ★ Post Closure - **TBD** (based on closure method and parameters)



Monitoring Results - Sunnyvale, Calif.





Permitting

- ★ **NPDES** - triggered by excess generated groundwater
- ★ **UIC** - triggered by reactive media placement
- ★ **Air Quality** - triggered by emission generation during installation
- ★ **RCRA Land Disposal Restrictions** (LDRs) - triggered by waste generated during site investigation or PRB installation
- ★ **Other** site-specific permits may apply (i.e. wetlands)
"Thorough review of all site/state-specific permitting issues is necessary"



Maintenance and Closure

- ★ Operation and Maintenance Plan
 - **Contingency Sampling Plan** (necessary in the event the PRB fails to meet performance or compliance criteria)
 - **Reactive media restoration or replacement**
- ★ Closure plan
 - **Address whether the wall will remain in place or be removed after remediation goals have been met**



Stakeholder Issues


- ★ Long periods for treatment
- ★ Wall performance, & effectiveness
- ★ Reactive material disposal
- ★ Land access and deed restrictions
- ★ Radionuclide concentration



Summary and Lessons Learned

Technical Presentation Wrap-up w/ Q&A

- ★ ***A PRB is a cost-effective long-term viable alternative for treating contaminants (VOCs and metals) in situ (compared to pump and treat and other active remedies)***
- ★ ***The chemistry of treating VOCs using iron is well known***
- ★ ***PRBs are being installed to depths approaching 120 feet***
- ★ ***“Failures” in PRB performance have been due generally to failure of the hydraulic system: e.g., incomplete plume capture, residence time not maintained; incomplete site characterization***

	<h2><i>Thank You!</i></h2>
<div data-bbox="540 562 1089 682" style="border: 1px solid black; padding: 10px; display: inline-block; margin: 20px auto; width: fit-content;"> <p><u>Links to Additional Resources</u></p> </div> <p>For more information on ITRC training opportunities and to provide feedback visit: www.itrcweb.org</p> <p>61</p>	

Links to additional resources: <http://www.clu-in.org/conf/itrc/prb/resource.htm>

Your feedback is important – please fill out the form at: <http://www.clu-in.org/conf/itrc/prb/feedback.cfm>

The benefits that ITRC offers to state regulators and technology developers, vendors, and consultants include:

- helping regulators build their knowledge base and raise their confidence about new environmental technologies
- helping regulators save time and money when evaluating environmental technologies
- guiding technology developers in the collection of performance data to satisfy the requirements of multiple states
- helping technology vendors avoid the time and expense of conducting duplicative and costly demonstrations
- providing a reliable network among members of the environmental community to focus on innovative environmental technologies

•How you can get involved in ITRC:

- Join a team – with just 10% of your time you can have a positive impact on the regulatory process
- Sponsor ITRC's technical teams and other activities
- Be an official state member by appointing a POC (Point of Contact) to the State Engagement Team
- Use our products and attend our training courses
- Submit proposals for new technical teams and projects
- Be part of our annual conference where you can learn the most up-to-date information about regulatory issues surrounding innovative technologies