In Situ Monitoring of the Ten-Year Old PRB at CFB Borden, Ontario

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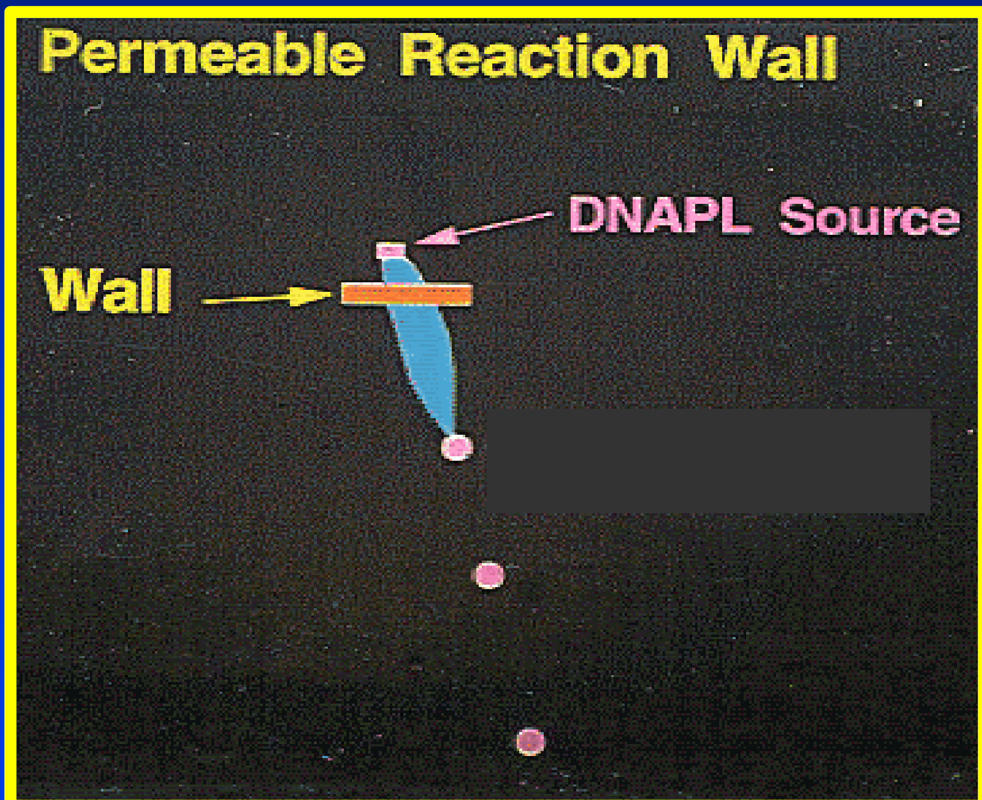
PRB Uncertainty

- long-term effectiveness due to corrosion and precipitates
- precipitates
  - reduce porosity
  - coat iron surface reducing transfer of electrons
- predictive methods, mainly laboratory columns
- limited empirical evidence !

Waterloo Permeable Reactive Wall
Field Trial 1991

- CFB Borden, Ontario, Canada
- unconfined sand aquifer
- groundwater flow velocity: 9 cm/day (0.3 ft/day)
- wall 4-6 m (13-20 ft) bgs, ∇ 2.5 m (8.2 ft) bgs
- contaminants: TCE - 253 mg/L
  PCE - 43 mg/L
- reactive wall (20 m^3, 706 ft^3)
  - 22% Kanmet iron (local Ontario foundry)
  - 78% coarse sand

Proof of Concept
(Borden Field Trial, 1991)



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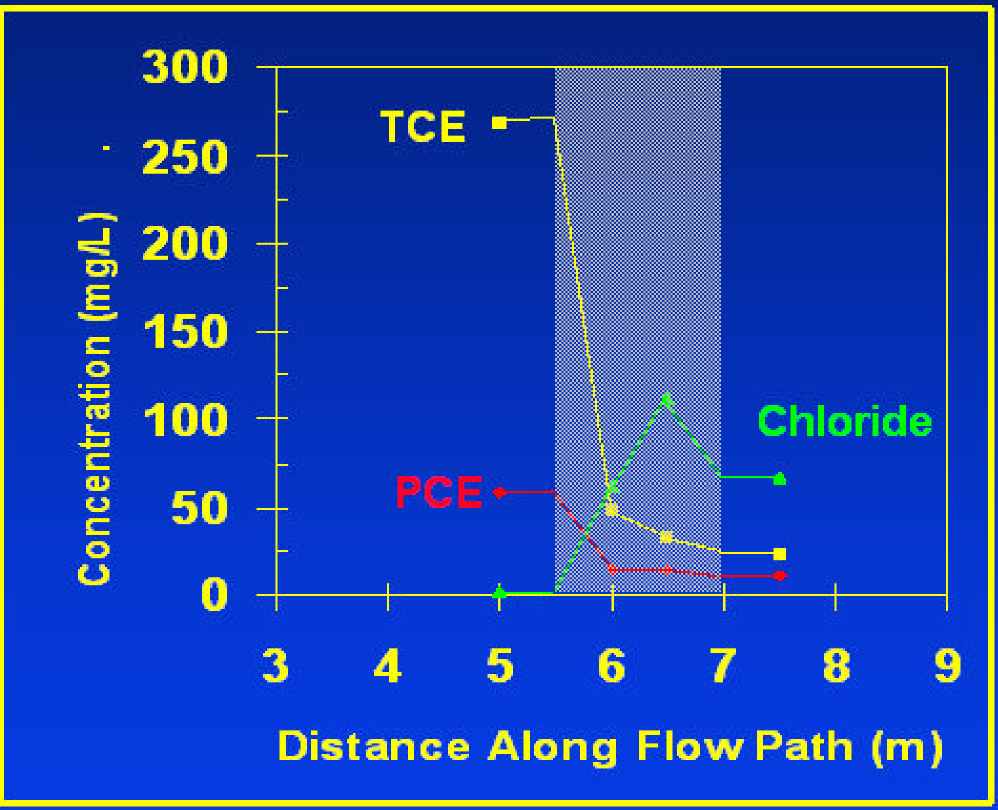
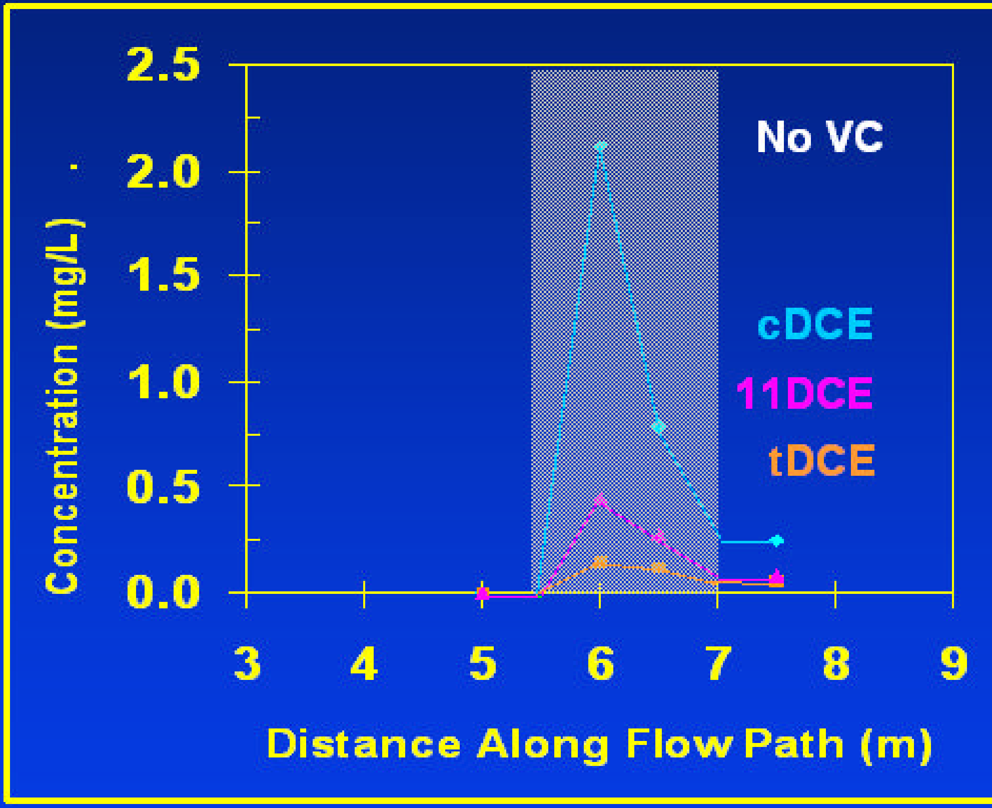
Performance





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O'Hannesin & Gillham, 1998

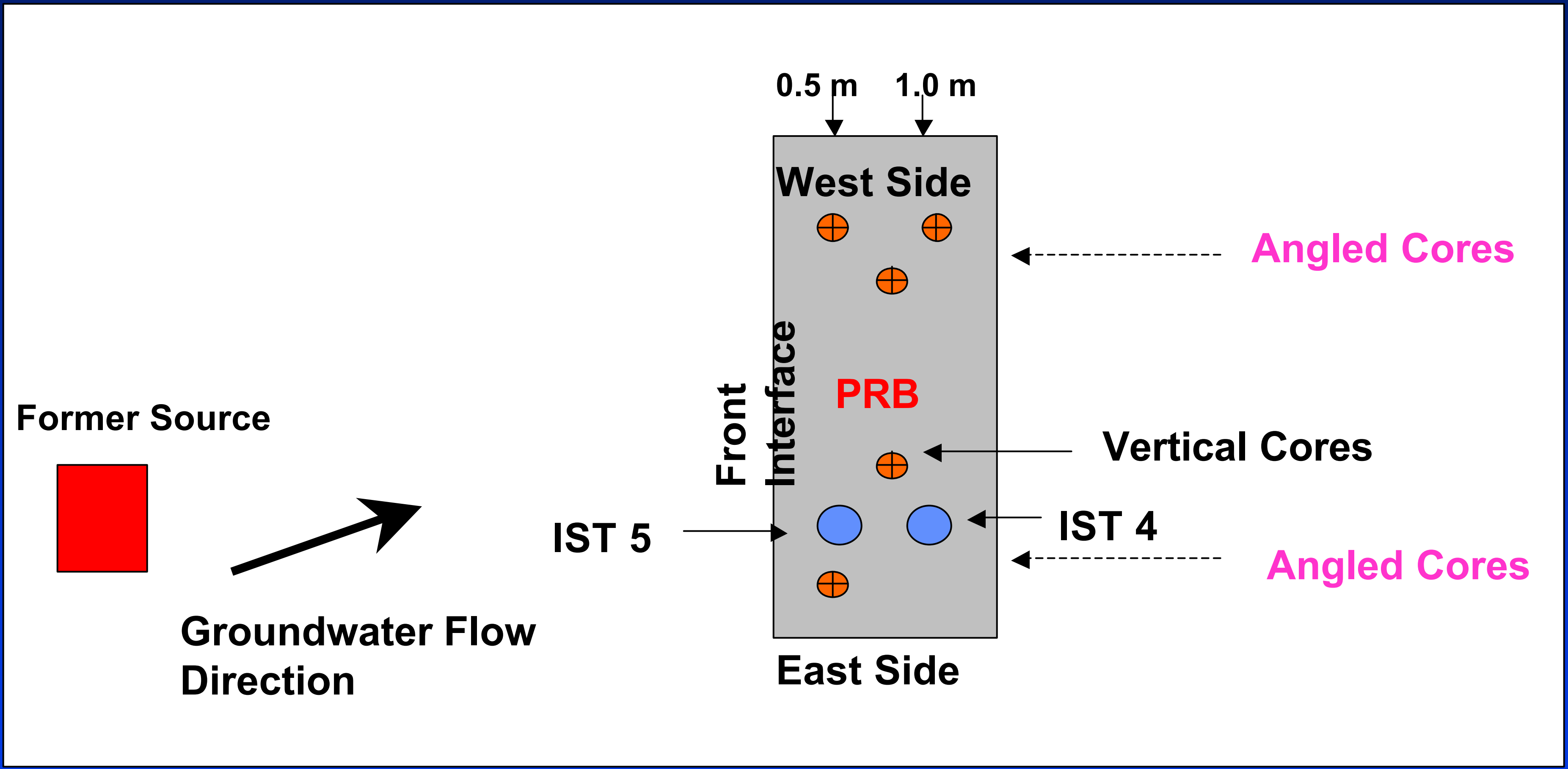
Waterloo Permeable Reactive Wall
5 Year Field Trial Results

- 5 years of consistent performance
- 90% TCE and 86% PCE removal
- breakdown products degraded
- complete remediation possible with increased iron
- trace amounts of calcium / iron carbonates and iron oxides
- very low microbial activity

Is the Waterloo PRB Still Effective After 10+ Years ? (1991-2001)

- assessment of iron reactivity by comparing TCE half lives in both lab and field
- evaluation of core material
  - K, biological activity and precipitates
- 1996 source removed by permanganate
  - effects on iron in PRB

Plan View



0.5 m
1.0 m
West Side
Angled Cores
Front
Interface
PRB
Former Source
Vertical Cores
IST 5
IST 4
Angled Cores
Groundwater Flow
Direction
East Side

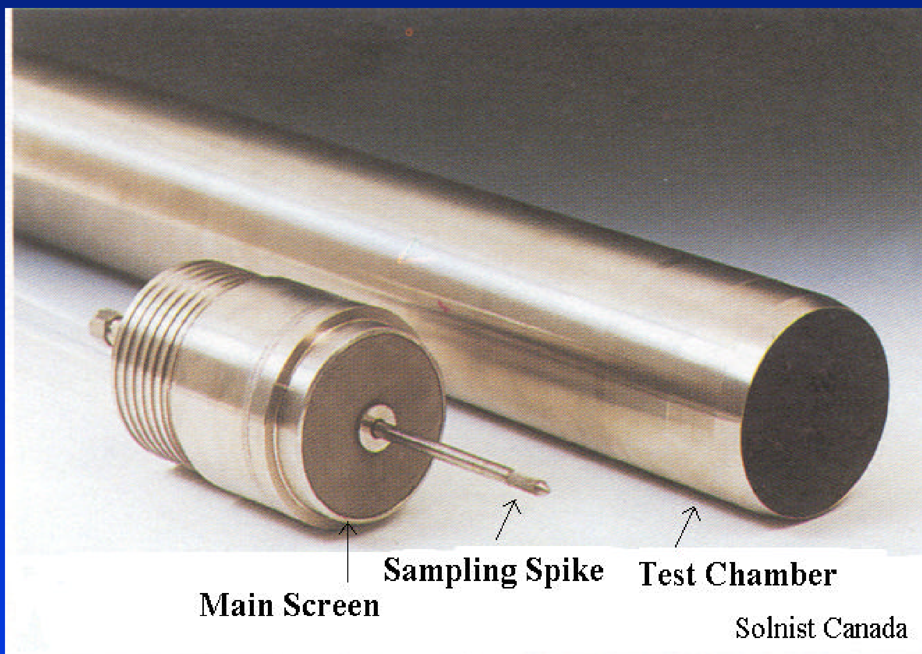
Cores - Vertical and Angled

- iron %, K, microbial activity and precipitates
- laboratory column testing

Laboratory Column Testing using Core Material

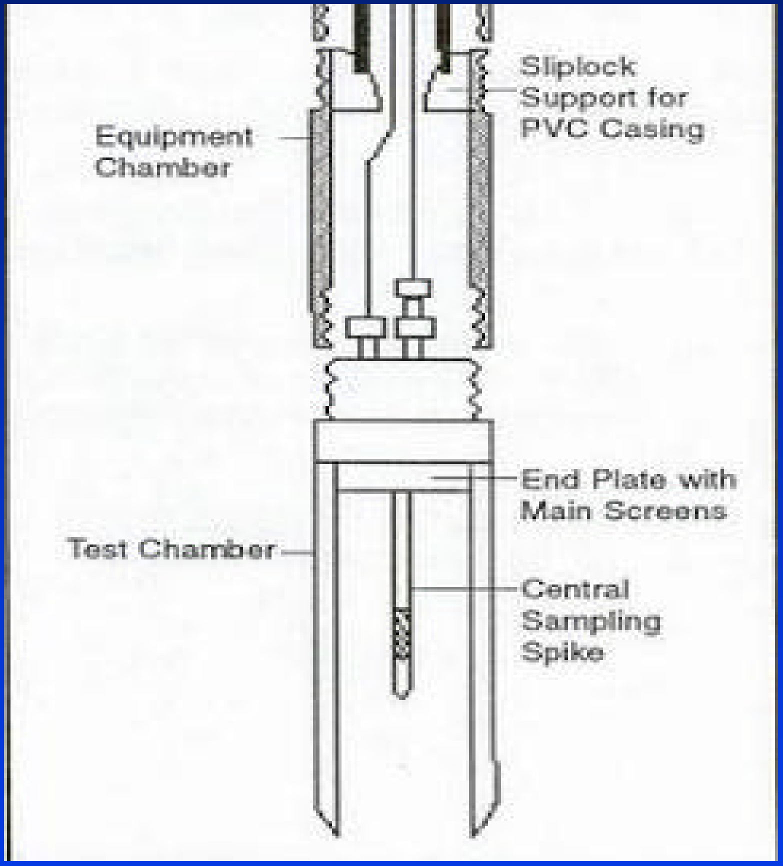
- 10-20 cm h, 3.8 cm ID
- V = 15 to 25 cm/day, Temp = 10°C
- TCE 10 mg/L, >30 pv
- 1 control column original material
- 4 columns with angled core samples
- 3 columns with vertical core samples

In- Situ Tester (IST) Device
Developed at Waterloo (1990)



- **allows field comparison with laboratory columns and with field results from 5 years ago**
- **isolates 5L aquifer**
- **allows for in-situ solute loading and sampling to characterize chemical reactions**

Operation of In-Situ Tester



- installed with hollow stem drill rig
- groundwater is withdrawn using a pump into a Teflon bag
- groundwater is amended with chemicals of interest
- solution pumped back into device
- samples collected over time

Field Testing

- testers installed 0.5 and 1.0 m distance at 5.2 m bgs
- bromide 50 mg/L
- TCE 10 and 250 mg/L
- samples collected over 17 days
- material also used in column testing

Kanmet Iron Source

- waste foundry material
- no commercially available source available in 1991
- only contained 30% iron
- non-magnetic material silica sand
- SA = 0.37 m^2/g
- pptes – magnetite and hematite

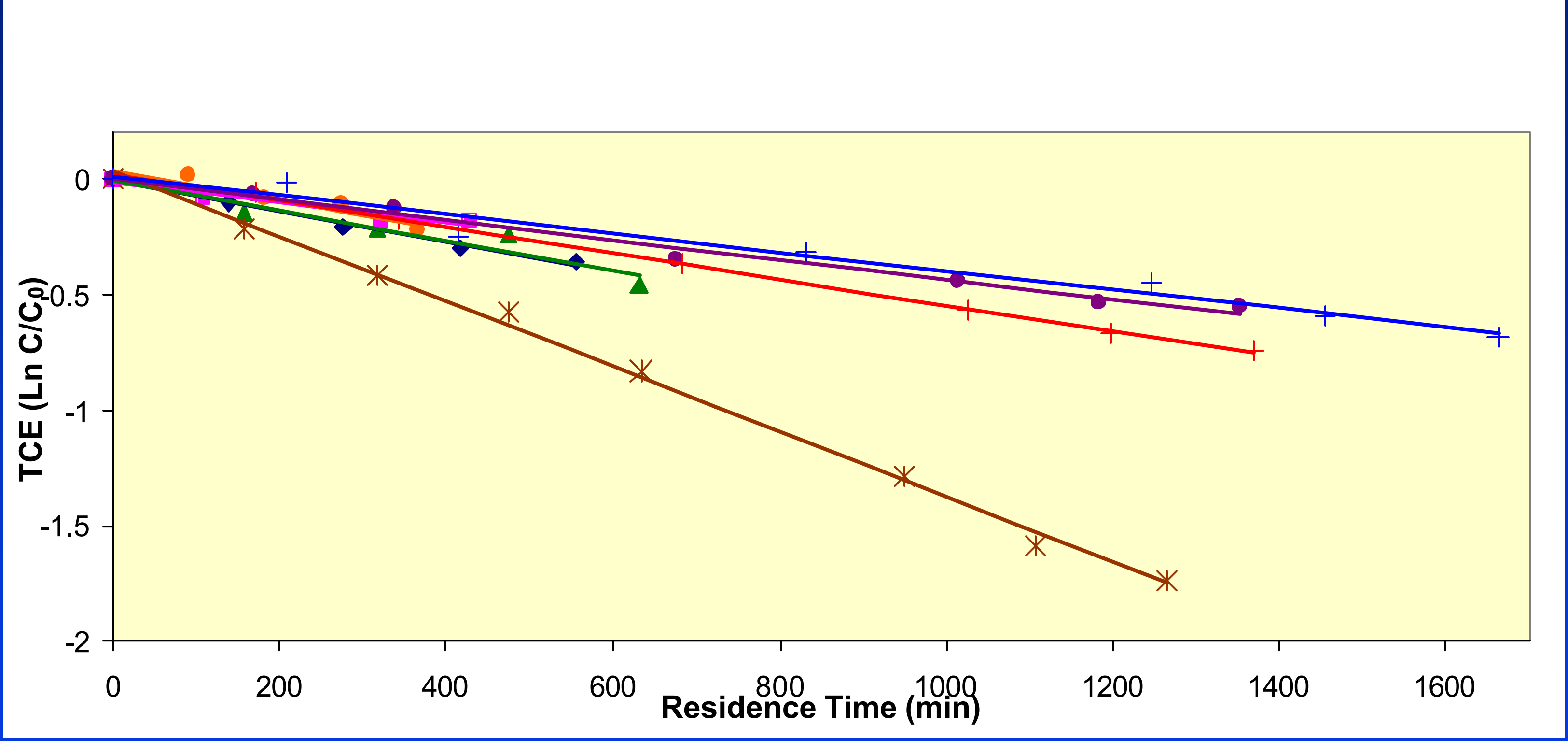
Core Precipitates Results

- carbonate analyses indicated a 19.4% total porosity loss within the wall
- reduced from the original 33% to 27% over 10 yrs
- pptes: Fe(OH)3, calcite, dolomite and sulphide minerals
- bottom 20 cm of wall influenced by permanganate evidence of MnO_2, MnOOH and $MnFeCO_3$

Core Results

Parameter	Years	Aquifer	PRB
Hydraulic Conductivity	10 yr	2×10^{-3} cm/sec	2×10^{-3} to 1×10^{-2} cm/sec
	5 yr	7.2×10^{-3} cm/sec	4.4×10^{-2} cm/sec
Lipid Biomass		10^5 cells/g	10^6 cells/g
Anaerobic Microbial Counts		3 – 70 CFU/g	10^2 – 10^3 CFU/g

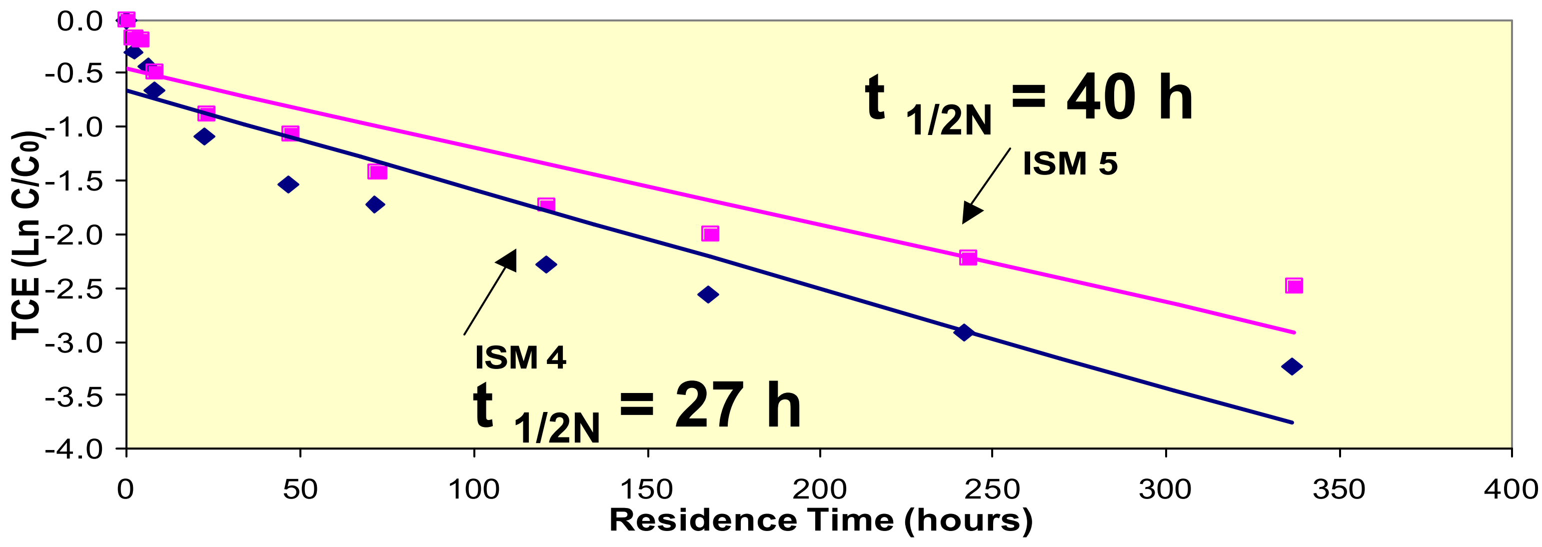
7 Lab Columns: Core Material TCE 10 mg/L (10°C)



Lab Column: Core Material TCE 10 mg/L (10°C)

- half lives normalized ($t_{1/2N}$) to 1 m^2/mL to compare on equal iron content
- control column (fresh iron), $t_{1/2N}$ = 3 h
- 7 core columns $t_{1/2N}$ ranged: 2.2 to 5.6 h
- not a significant decline in reactivity over 10 years

IST Field Results
TCE 10 mg/L (10°C)



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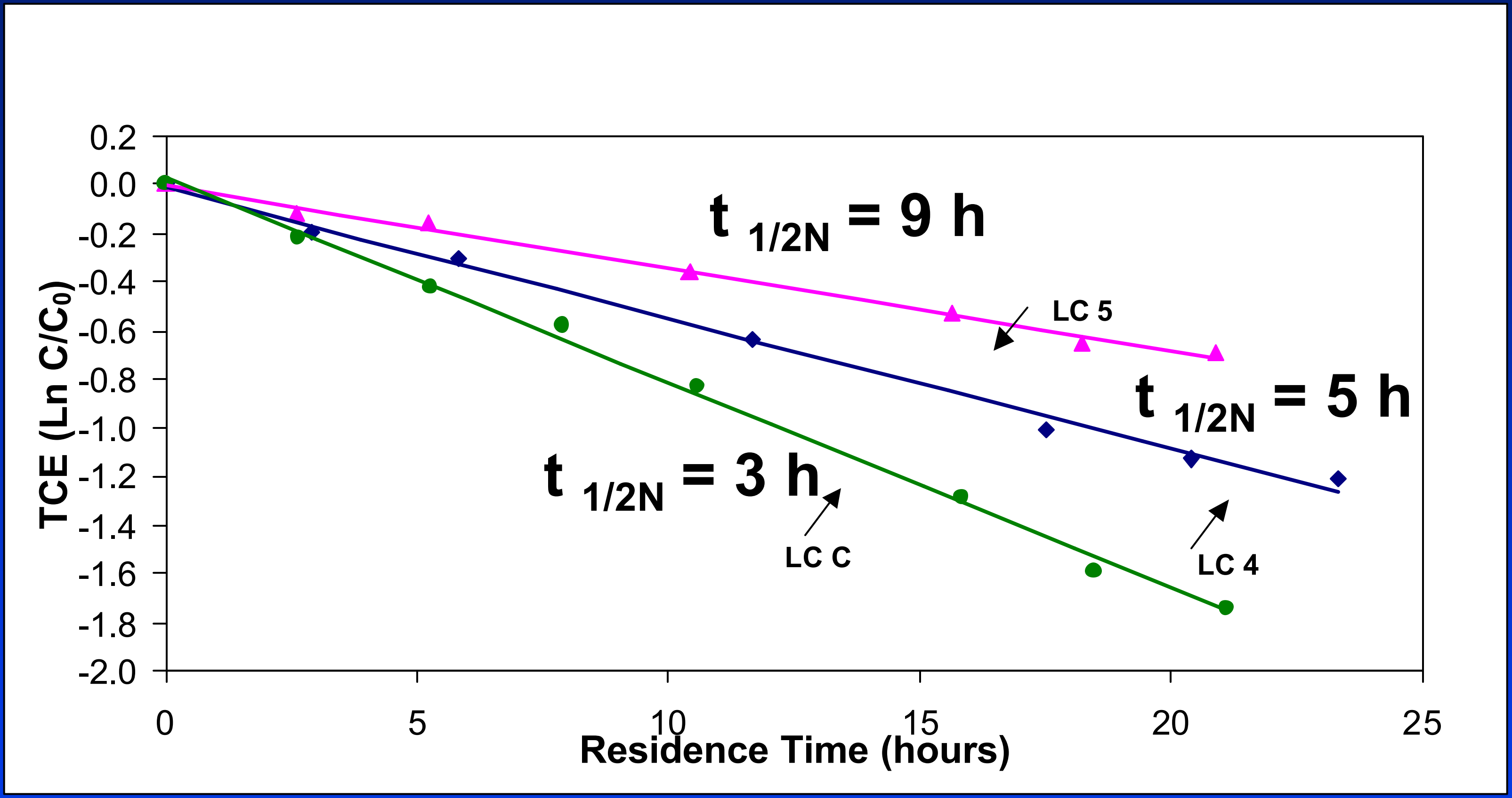
Lab Column: IST Material
TCE 10 mg/L (10°C)



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Comparison of TCE Reactivity 10 mg/L

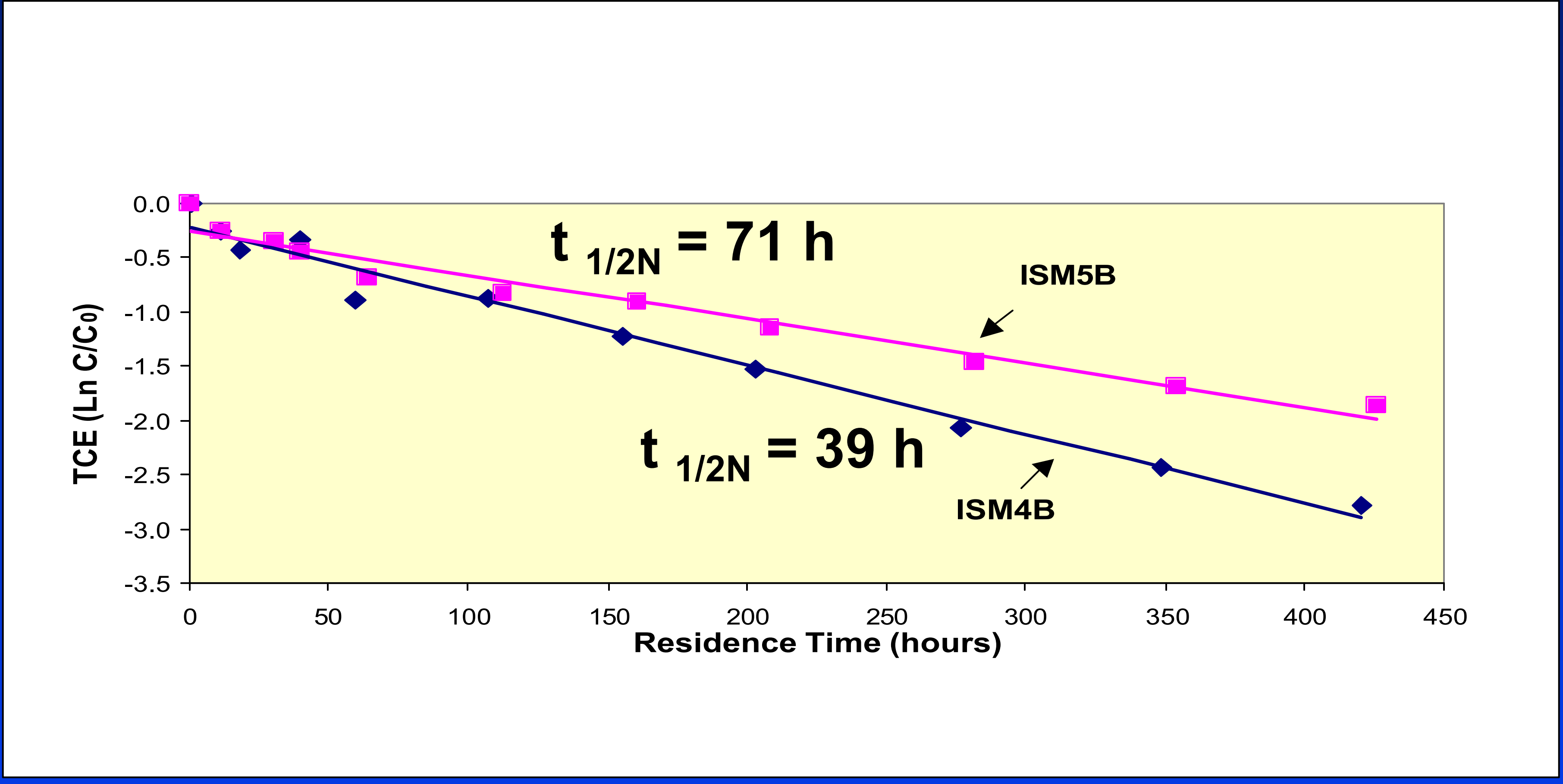
	0 - 10 cm distance In PRB	30 - 50 cm distance In PRB	100 cm distance in PRB
Lab Core Material	1.6 x lower	1.1 x lower	1.0
Lab IST Material	--	2.9 x lower	1.6 x lower

Relative to control column

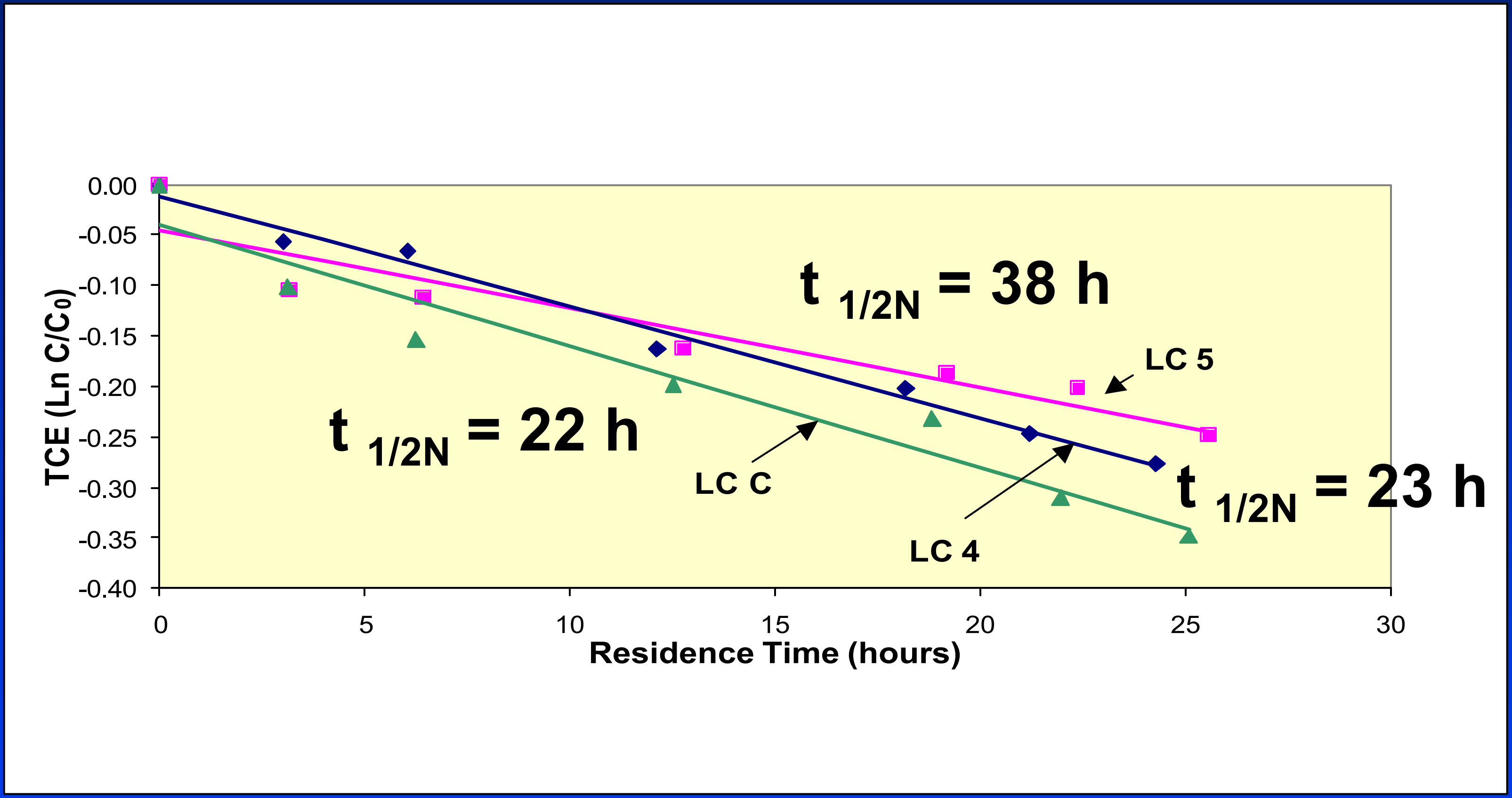
Comparison: TCE 10 mg/L

- factor 5 difference between IST and laboratory results at each location
- maybe due to role of mass transport limitations in IST with low iron contents and low concentrations
- lab column controlled by advective flow
- IST by diffusion due to concentration gradients

IST Field Results
TCE 250 mg/L (10°C)



Lab Column: IST Material
TCE 250 mg/L (10°C)



Comparison of TCE Reactivity 250 mg/L

	30 - 50 cm distance in PRB	100 cm distance in PRB
Lab IST Material	1.8 x lower	1.1 x lower
Field IST Results	1.8 x lower (t1/2N=71 h)	--- (t1/2N=39 h)

Comparison of Half Lives For TCE 250 mg/L

10 Years IST	5 Years Field
2 x higher than lab column	2 x higher than lab column
138 hours (average IST)	142 hours

IST Conclusions

- promising approach for reactivity in PRBs
- may be used at different locations/depths
- deviation from 1^{st} order kinetics at low concentrations may be due to mass transfer limitations with low iron content but may be less dominant in 100% iron PRBs
- IST may give more accurate results than laboratory columns

Conclusions

- 0 – 30 cm evidence of precipitates
- precipitates mainly $CaCO_3$ and $Fe(OH)_3$
- reduction in reactivity
  - 0 to 30 cm: 1.7 x less reactivity
  - 50 to 100 cm: 1.1 x less reactivity
- K is equal or one order of magnitude greater than aquifer

Conclusions

- microbial activity only slightly elevated
- no indication of biofouling
- after 10 yrs wall is still reactive suggesting it could last for several more years
- provides encouraging indicator of long-term performance