Laboratory Tests and Field Investigations of DNAPL Source Zone Remediation Using Granular Iron

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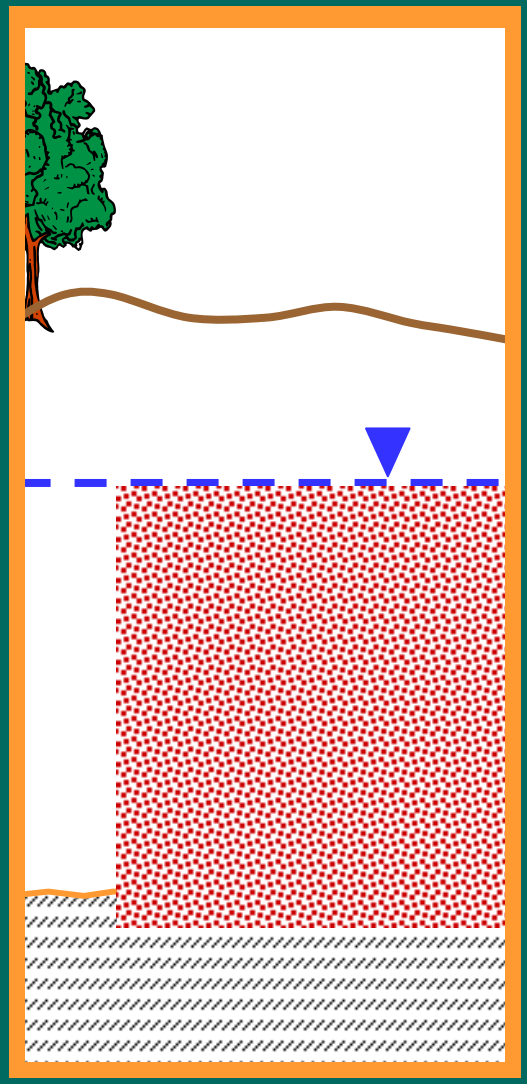
DNAPL Remediation Using Isolation Technology and Granular Iron

- Soil-mixing augers used to mix iron-bentonite slurries *in situ*
- Bentonite
  - Initially, a lubricant and viscosifer to facilitate injection
  - Subsequently, reduces hydraulic conductivity of mixed zone
- Mixing homogenizes contaminated region
- Contaminant diffuses to iron surface within mixed zone where dechlorination takes place



Research Objectives

- To determine, through laboratory testing, whether mixing granular iron, bentonite and saturated materials contaminated with free-phase chlorinated ethenes would prove an effective remediation method
- To demonstrate the concept in a field setting, to evaluate the remediation potential and installation method

Experiments

1. Preliminary Batch Experiment

2. Field Demonstration

3. Laboratory Experiment

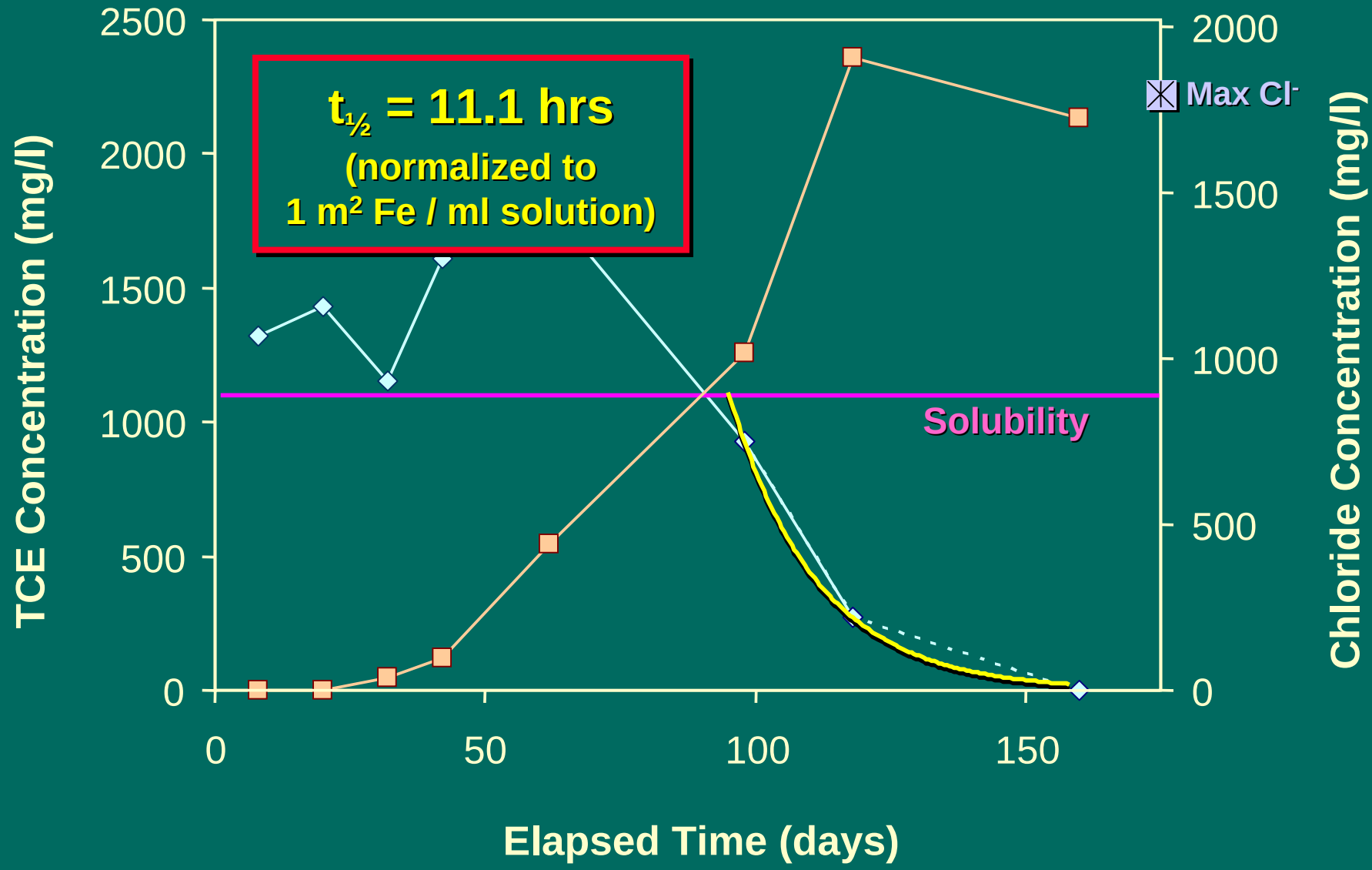
Experimental Preparation

Hypovials contained: **(Wt%)**

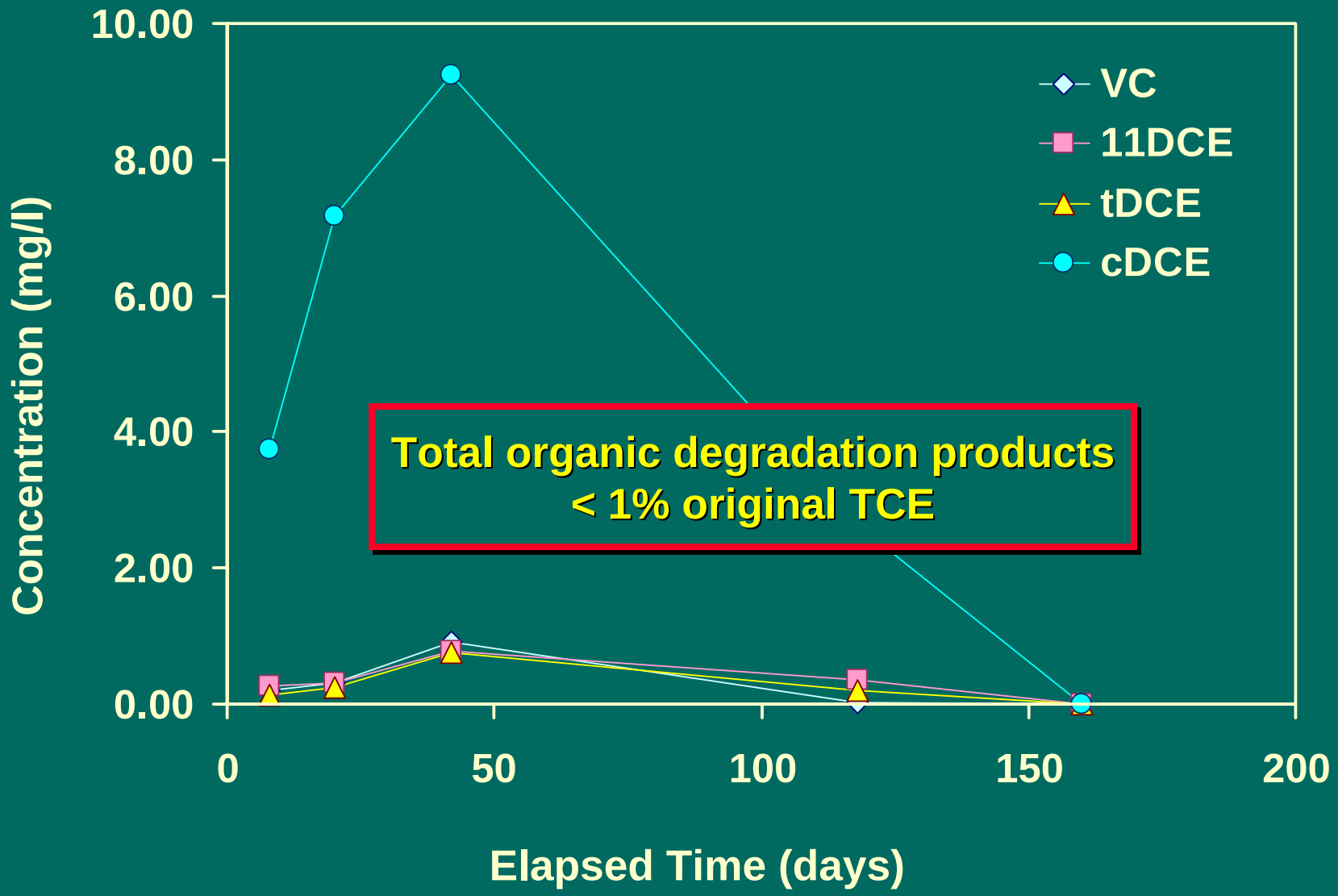
Master Builders Iron (med-fine):	1.3	g	(5%)
Baroid Benseal® Bentonite:	3.5	g	(12%)
Borden Sand:	23.5	g	(83%)
Distilled water:	49.3	mL	(average)
Free-phase TCE:	0.11	g	(2x solubility)

Periodically, hypovials were sacrificed to measure aqueous concentrations of TCE and potential degradation products

TCE and Chloride Concentrations



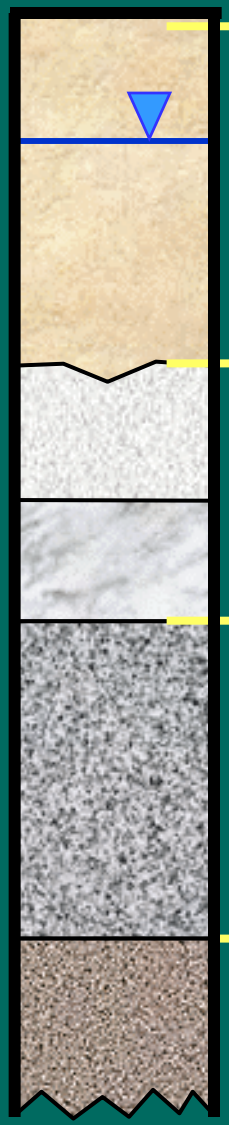
Organic Degradation Products



Field Demonstration: Objectives

- To determine whether mixing slurries of granular iron and bentonite into contaminated geological material promotes *in situ* removal of DNAPL
- To test the feasibility of producing uniform iron/bentonite/soil/DNAPL mixtures

CFB Borden: Geology



Surface Aquifer (Beach sand)

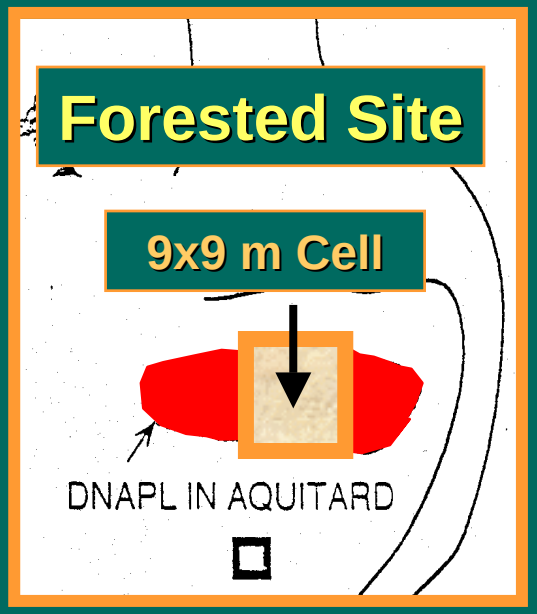
Upper Aquitard (Silty clay)

Stiff Blocky Texture

Soft Plastic Texture

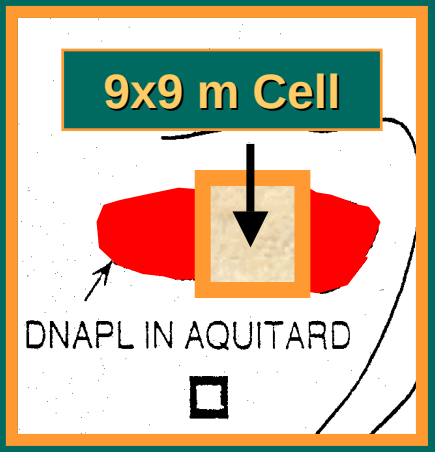
Lower Aquitard (Diamict)

Lower Aquifer (Silty sand)



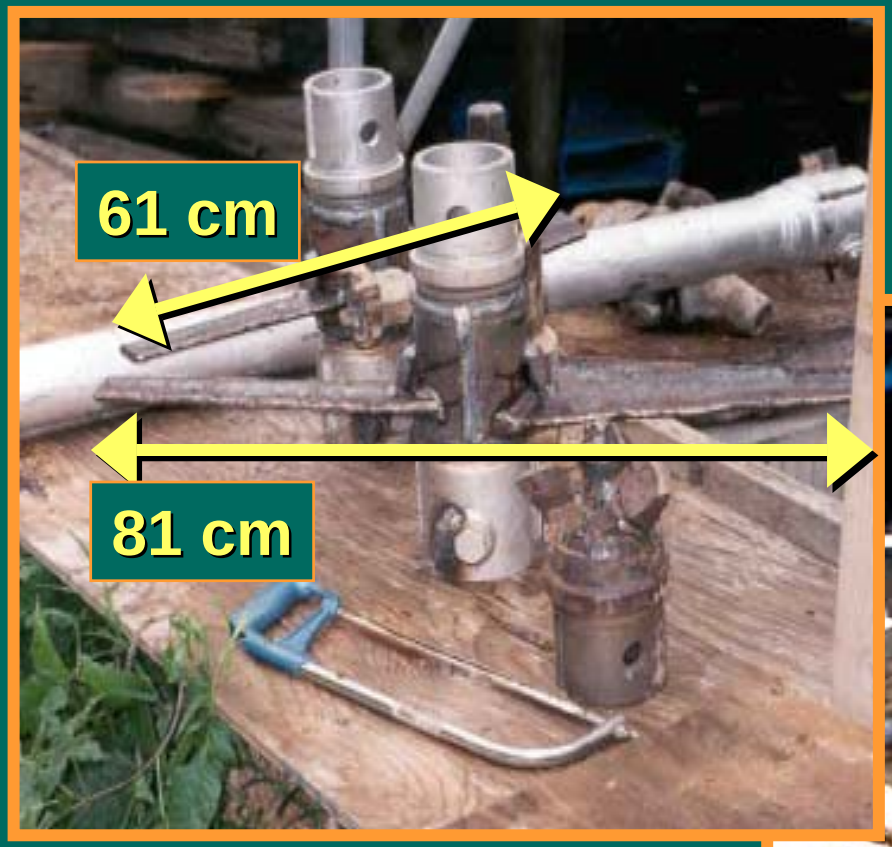
Site History

- 1991 9x9m sheet-piling cell constructed in Borden aquifer and keyed into aquitard
  - 771 L PCE released to monitor migration
  - 39 days later – PCE was found in aquitard
- 1991-3 425 L DNAPL removed
- 1998 $KMnO_4$ experiment

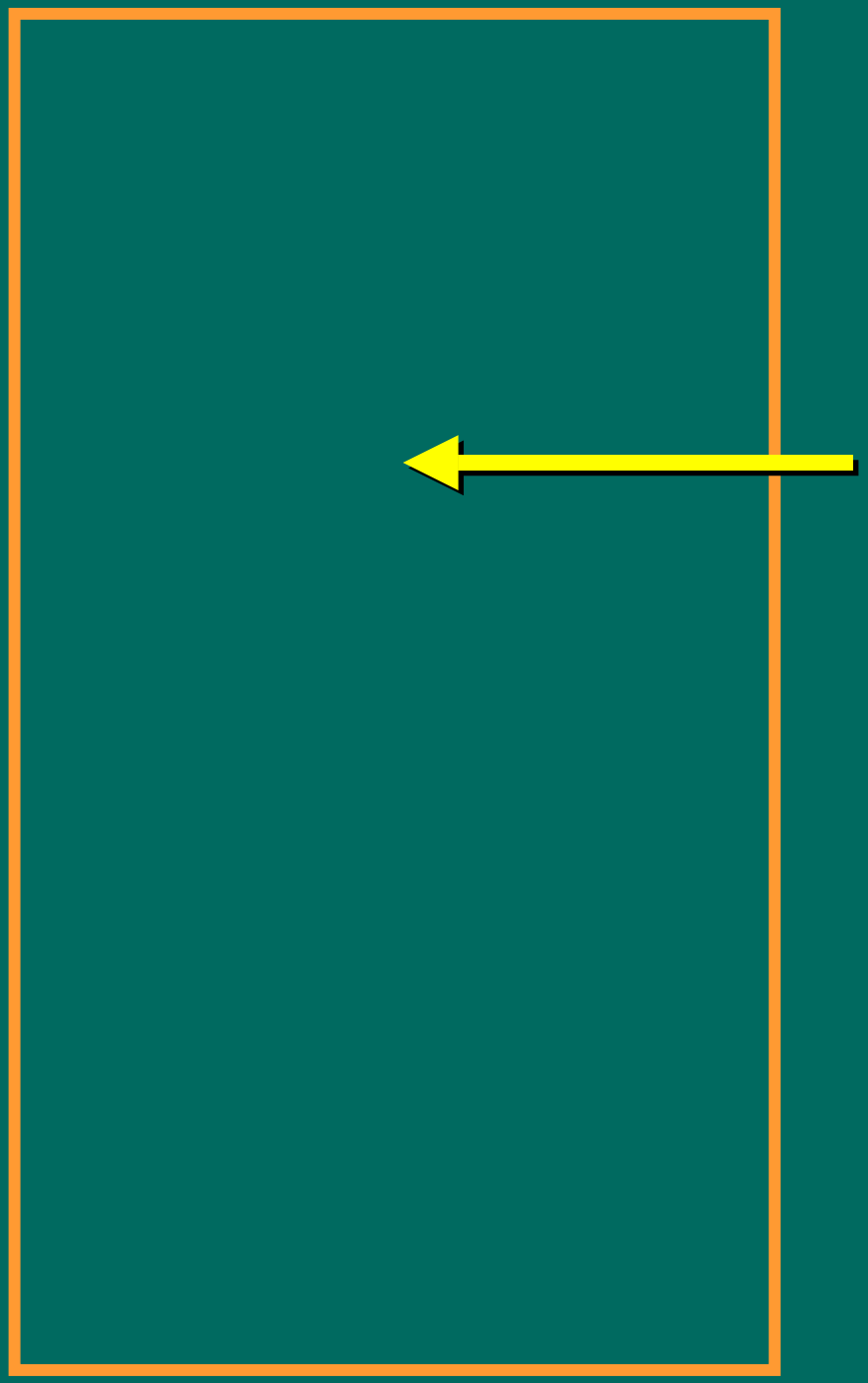


Estimated PCE remaining 1998:
350 L (200 L in aquifer and 150 in aquitard)

9x9 m Cell
Borden, ON


61 cm
81 cm

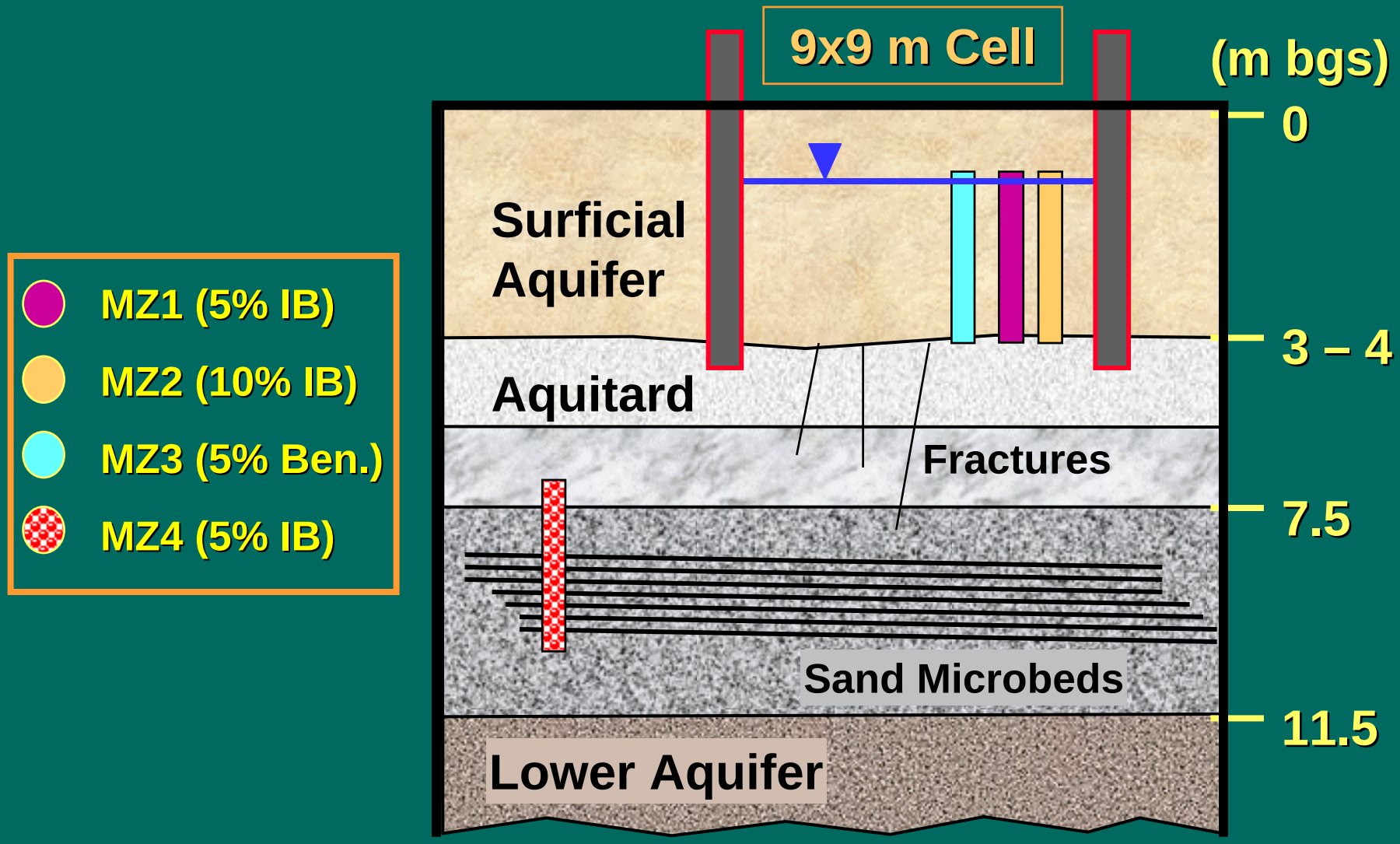
Iron-Bentonite (IB) Slurry



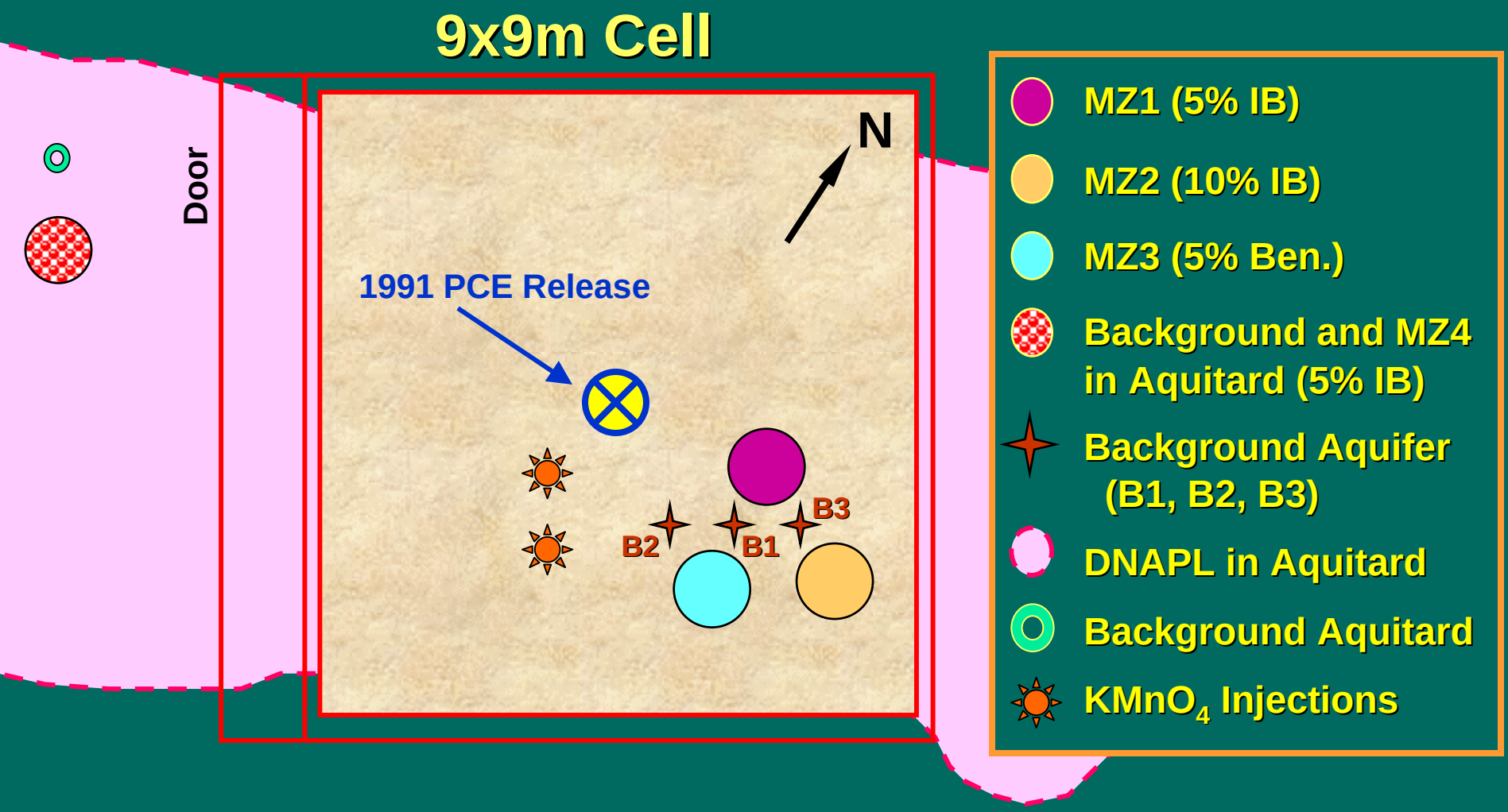
Iron-Bentonite Mixing Process

- IB slurry delivered to subsurface through drill rods
- Mixing blades were raised and lowered several times to homogenize region
- Tapered blades prevented materials from surfacing

Location of Mixed Zones



Location of Mixed Zones: Plan View



Field Sampling & Analyses

Coring at Site

- Soil samples were stored in methanol and acetonitrile

Laboratory Analyses

- GC/ECD analyses for PCE and TCE
- GC/PID analyses for VC and DCE isomers
- Combination electrode for Cl^- analyses

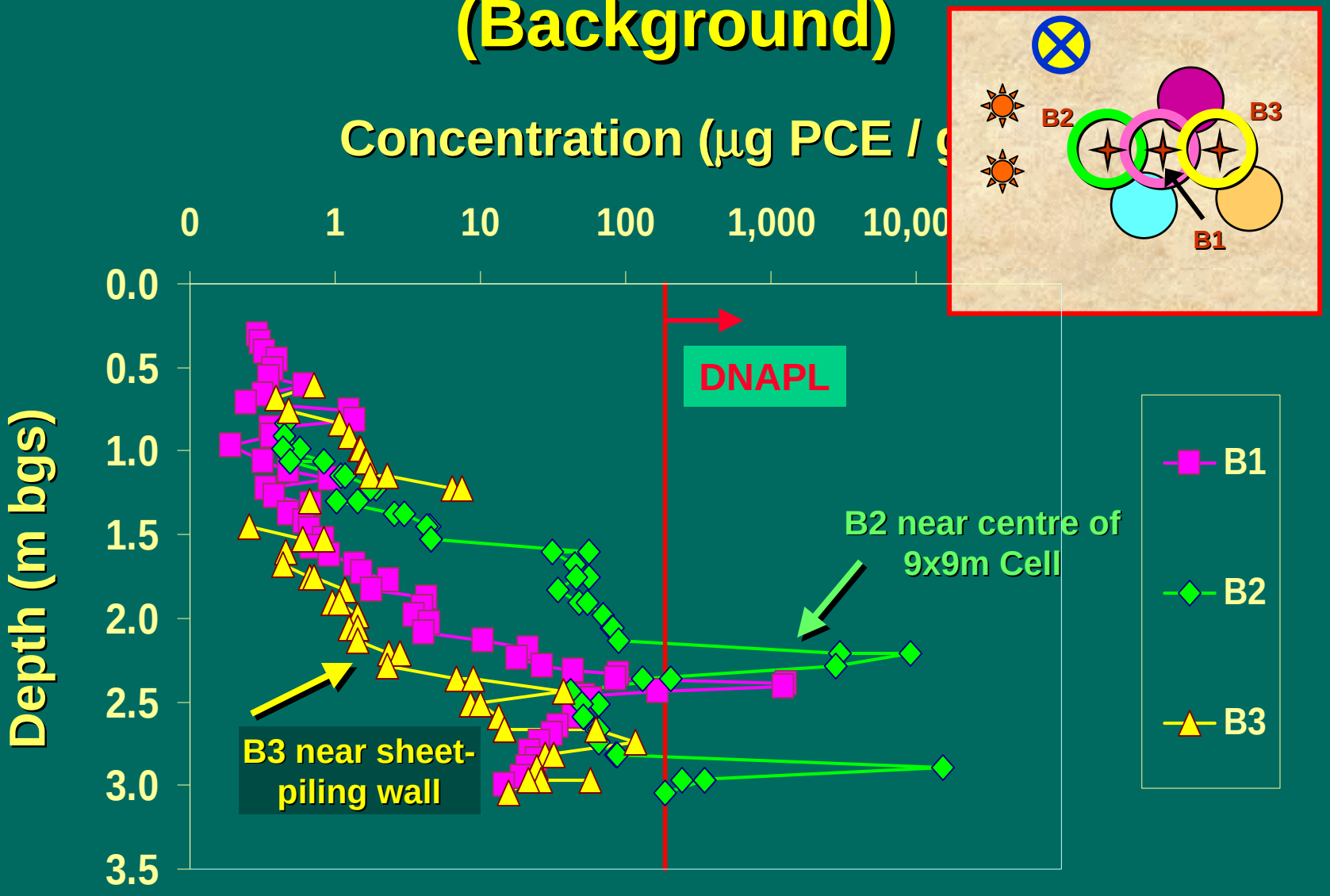
Iron Distribution in Aquifer

Mixing Zone 2

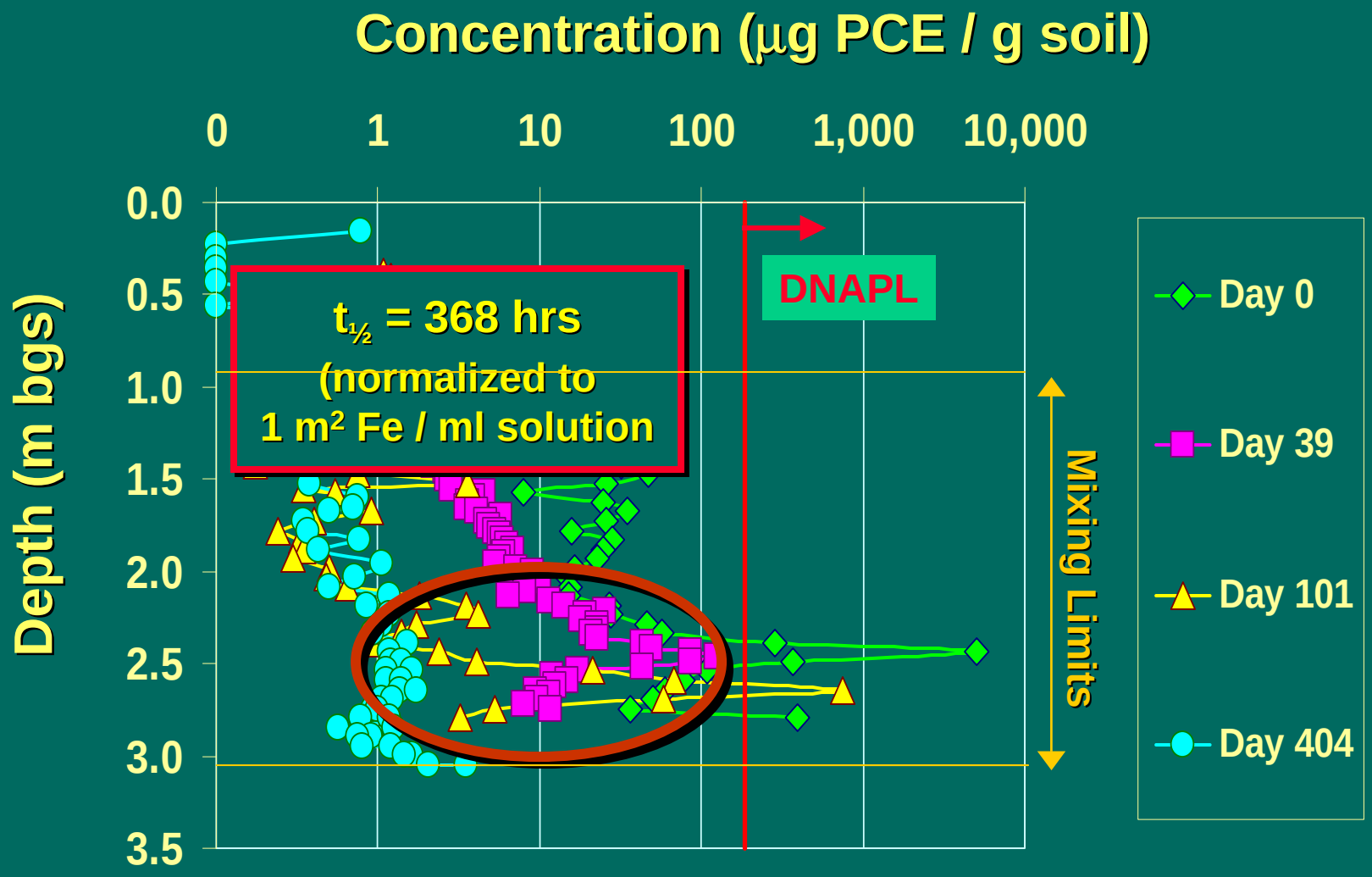
(10% Iron-bentonite)

⇒ well-mixed but not homogenized

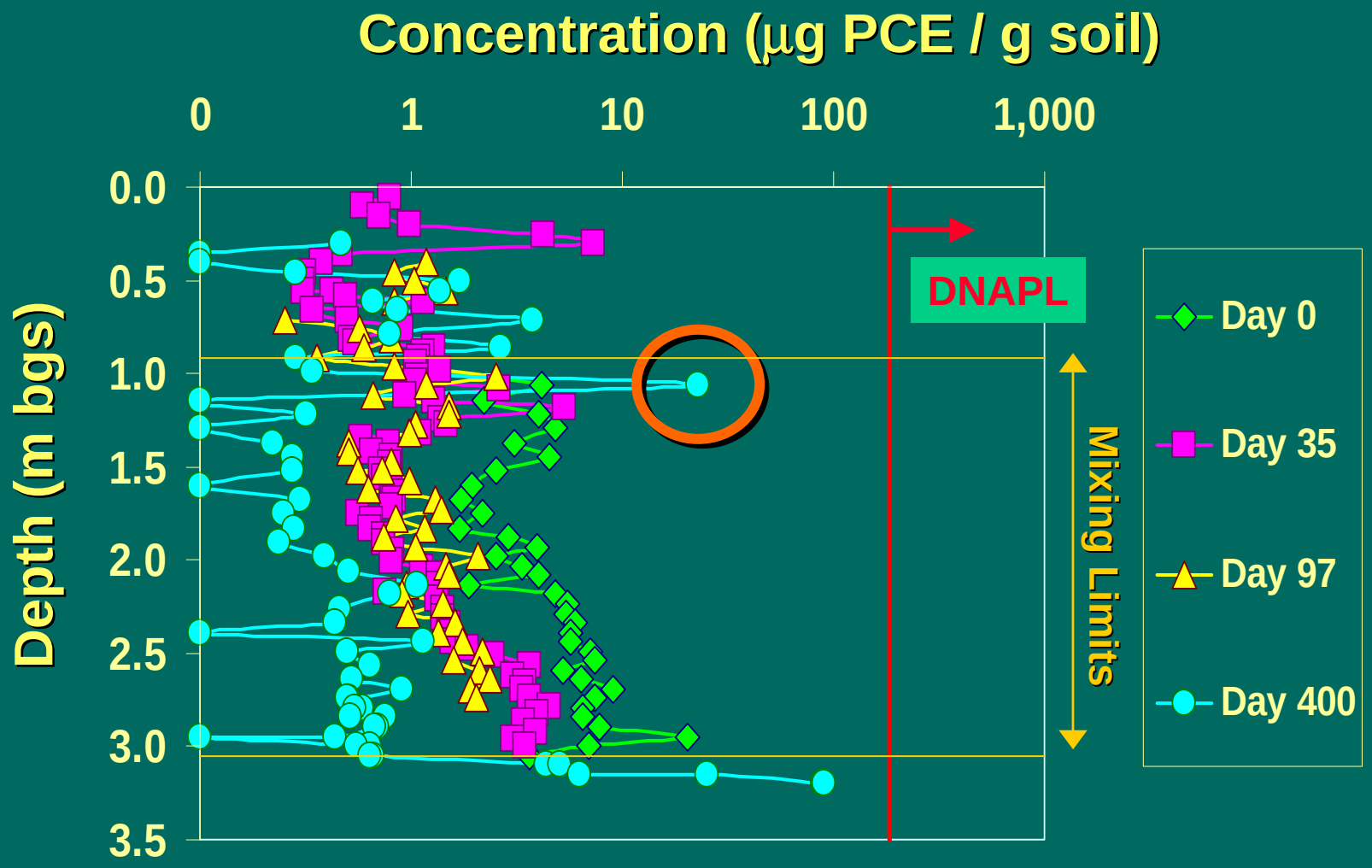
Aquifer PCE Concentrations (Background)



Mixing Zone #1 PCE Concentrations
(5% Iron-bentonite)

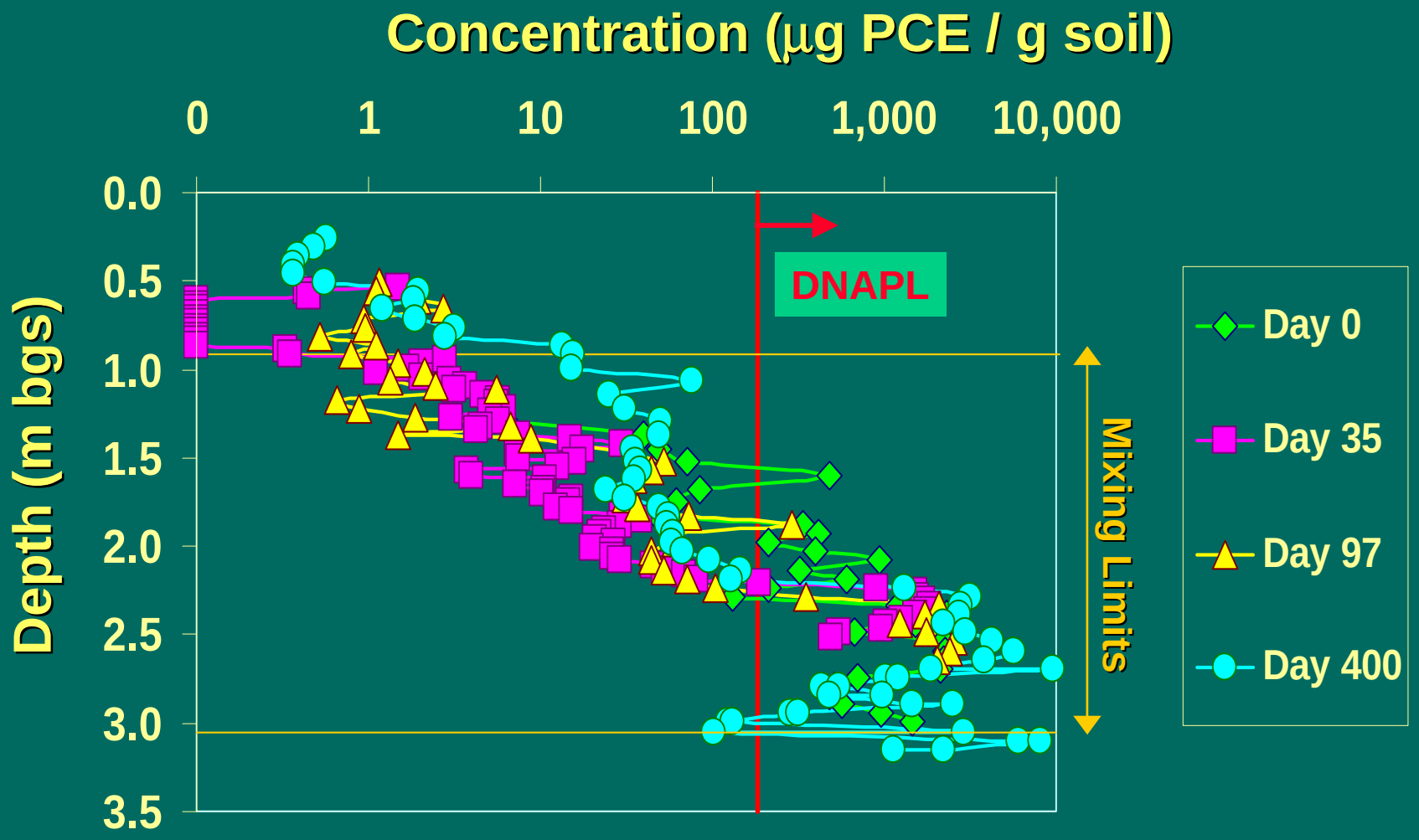


Mixing Zone #2 PCE Concentrations
(10% Iron-bentonite)



Mixing Zone #3 PCE Concentrations

(Control - 0% Iron, 5% Bentonite)



Degradation Products in the Aquifer

TCE and DCE isomers

- Total DCE in iron-mixed zones < 0.5 μg VOC / g soil
- TCE was detected in background and mixed-zones

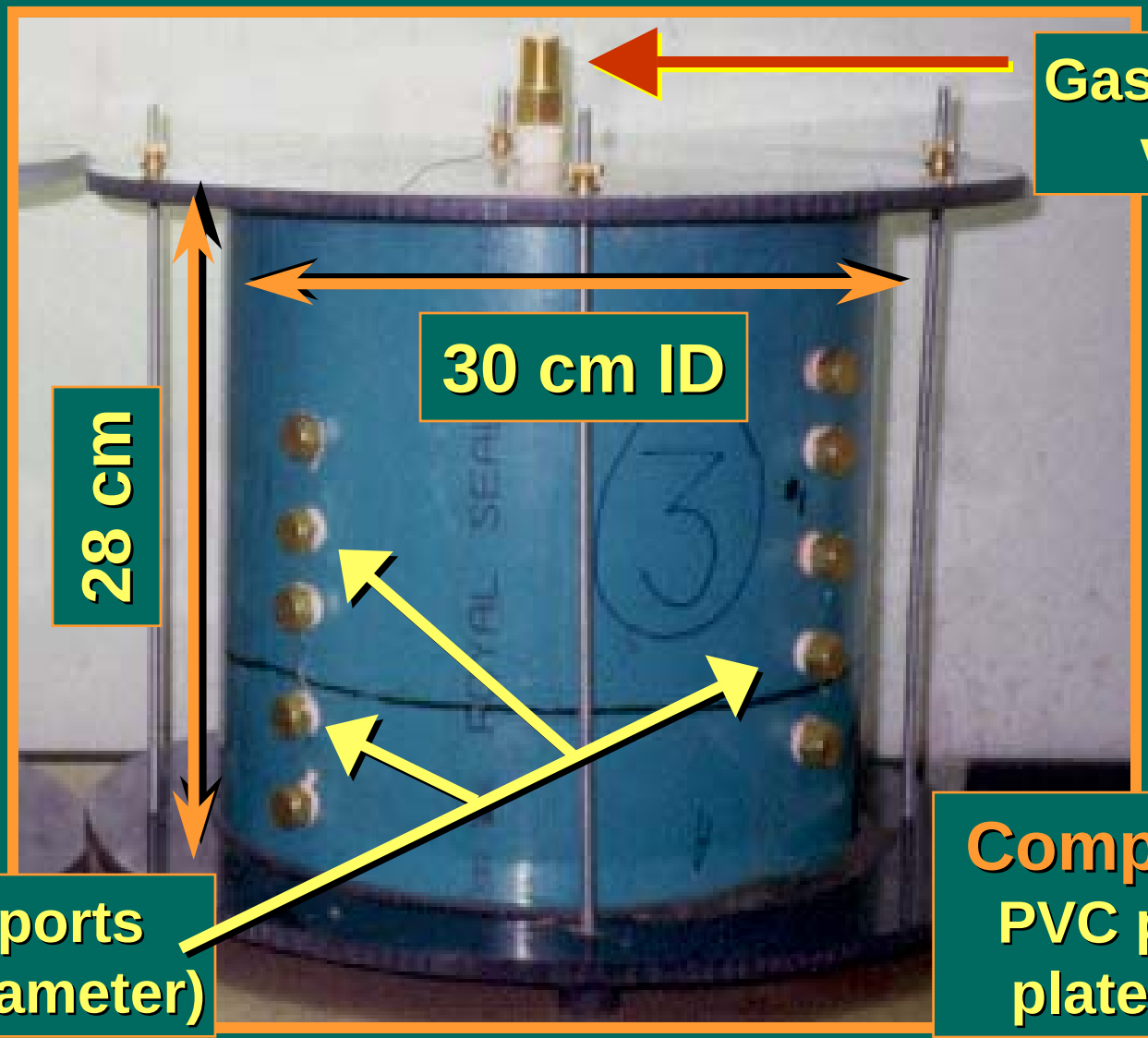
Chloride

- Uncontaminated aquifer measures 1-3 mg/L
- Background cores in 9x9m Cell 100-300 mg/L
- Amounts detected in iron-mixed zones did not correspond to PCE degradation
  - Possibly due to nearby $KMnO_4$ experiment
- Therefore, could not confirm PCE degradation

Cell Experiment: Objectives

- Examine DNAPL disappearance using a substantial amount of free-phase PCE, and under conditions in which the degradation process could be examined more reliably than the field demonstration

Construction



Composition:
PVC pipe and plate welded

Assembly

- Borden sand, Baroid Benseal® bentonite, and Master Builder medium-fine granular iron
- Distilled water mixed until saturated
- Free-phase PCE (dyed red with Sudan IV)
- Cell was packed and sealed as quickly as possible

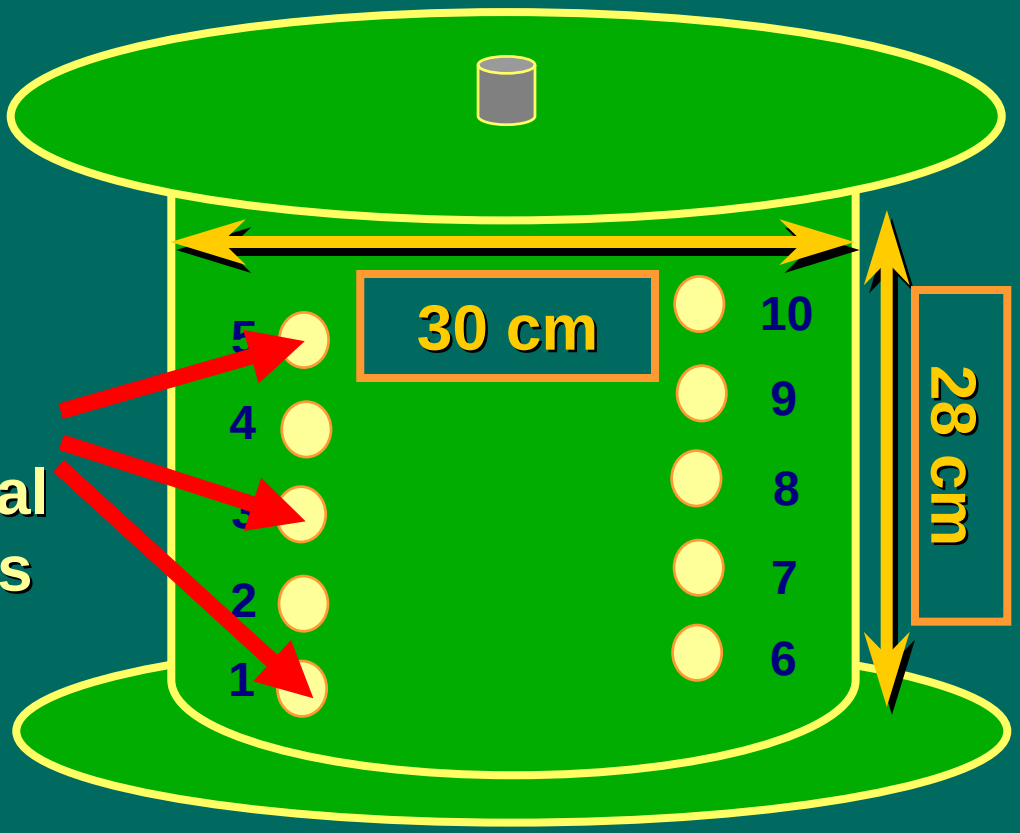
Cell Contents (by volume)

Cell	Borden Sand (Volume %)	Bentonite (Volume % when wet)	Iron (%)	PCE (% pore space)	Porosity of Cell[a]
1 (control)	95	5	0	6% (0.5 L)	0.48
2	90	5	5	8% (0.5 L)	0.35
3	85	5	10	7% (0.5 L)	0.40

a) Estimated using amount of water used to saturate cell

Sampling Procedure

Cored from side:
Shallow, Central and Deep ports



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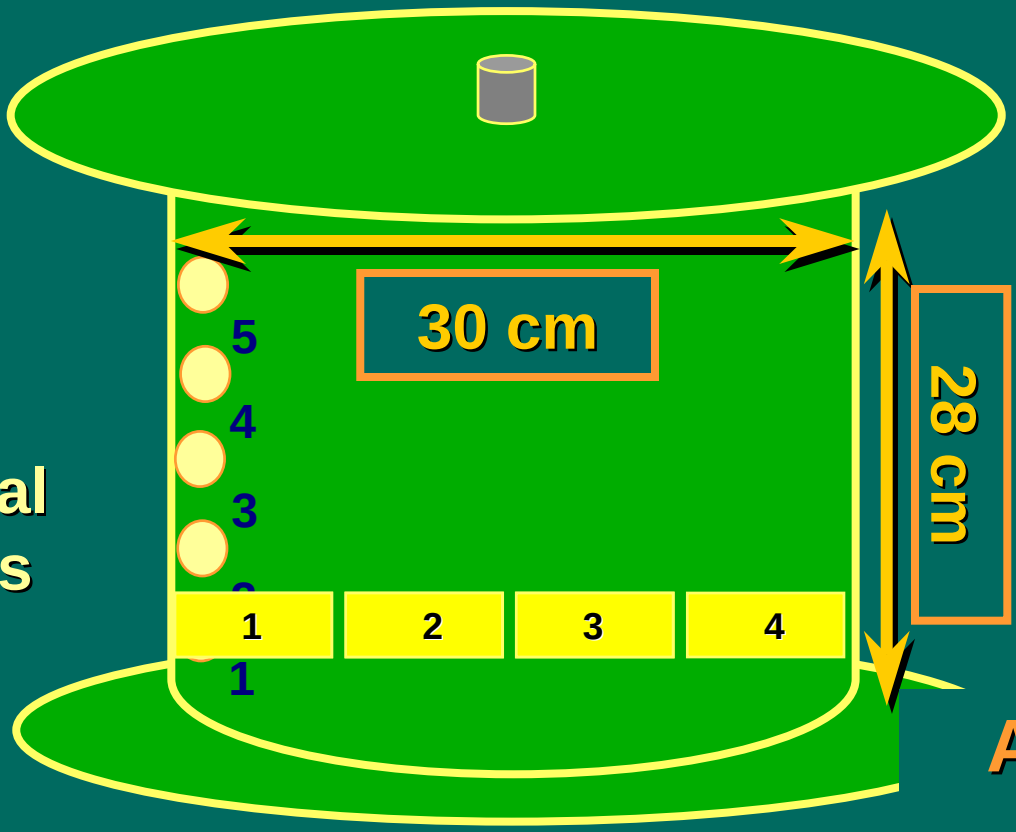
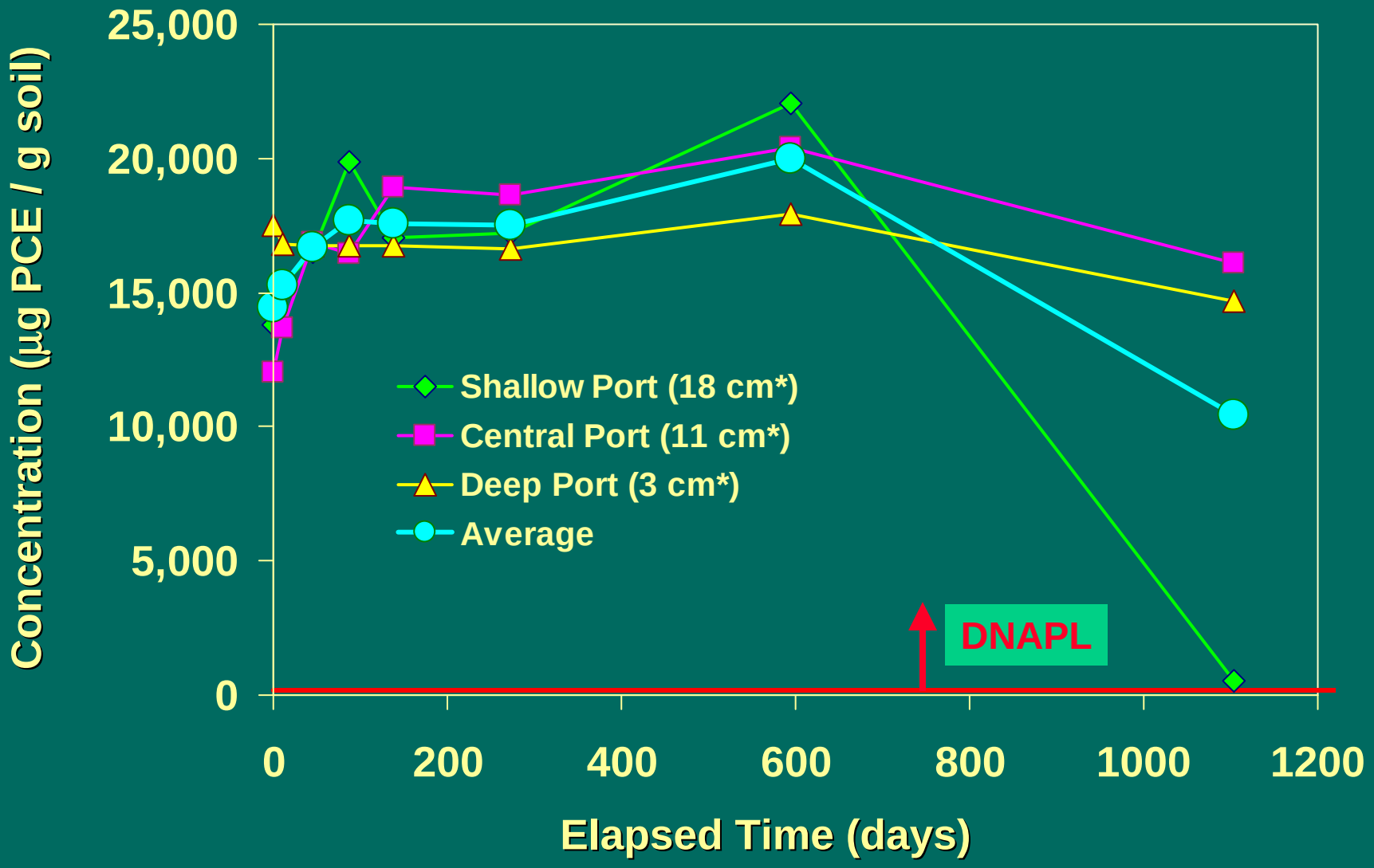


Analyses:
PCE, TCE
DCE isomers
Vinyl Chloride
Chloride

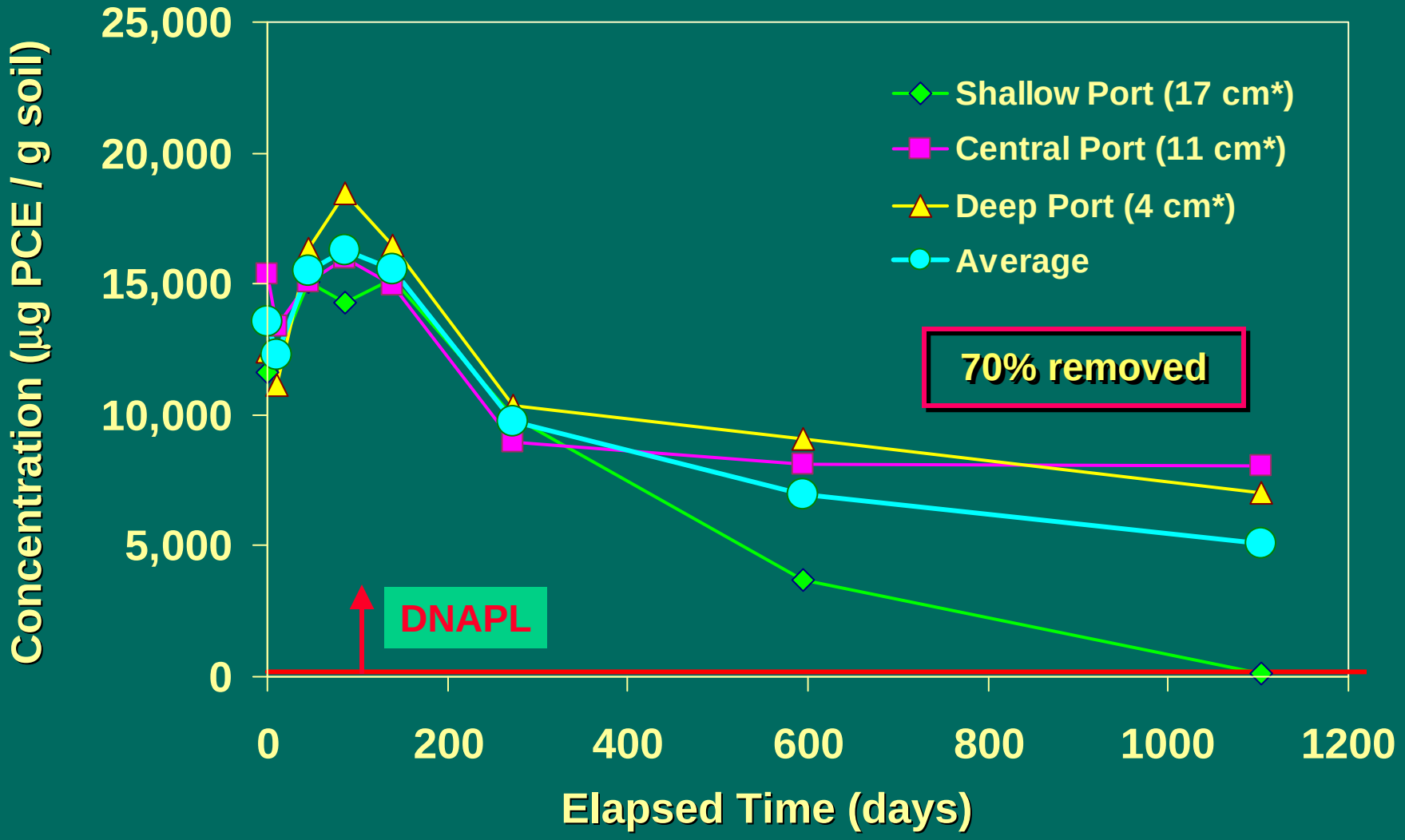
4 samples taken from each port:
1st & 3rd stored in methanol
2nd & 4th stored in acetonitrile

Cell 1 (Control)
PCE Concentrations



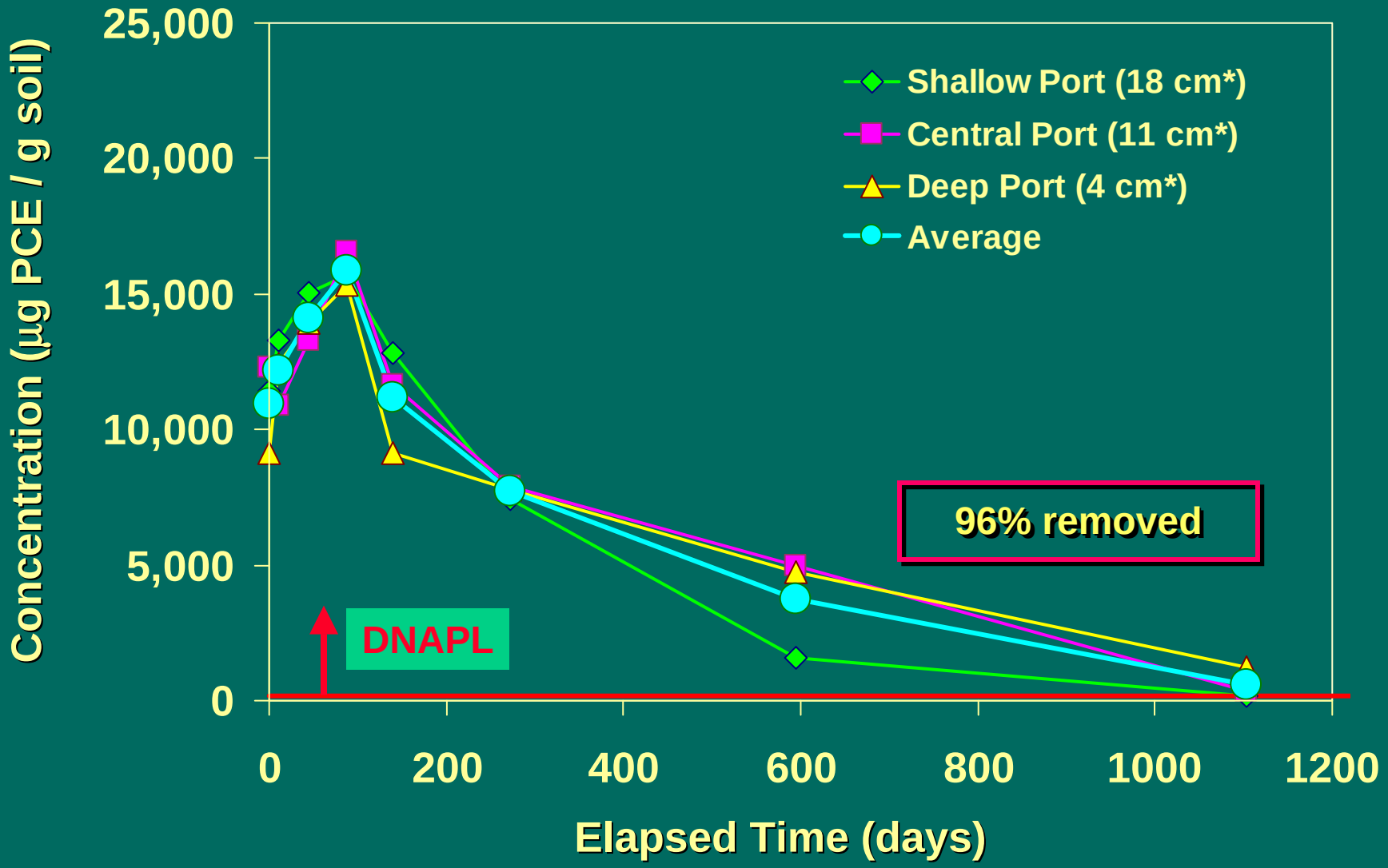
* Port height above base

Cell 2 (5% Fe)
PCE Concentrations



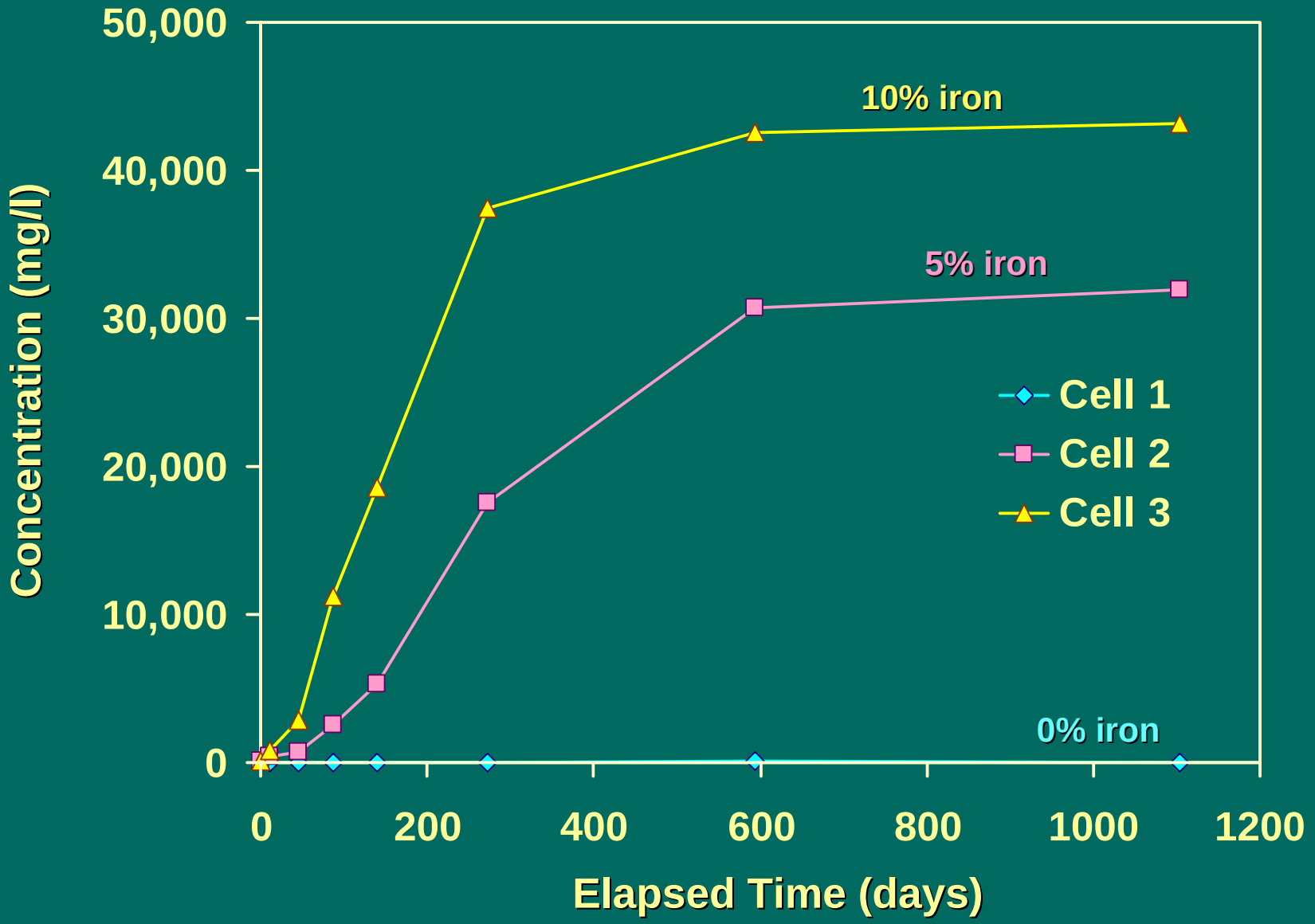
* Port height above base

Cell 3 (10% Fe)
PCE Concentrations



* Port height above base

Chloride Concentrations



Organic Degradation Products

- Total degradation products measured less than 1% of original PCE added to cells
- TCE was main product detected (<100 μg/g soil)
- DCE isomers generally less than 2 μg/g soil, but showed regular trends
- VC only detected briefly in cells with iron
  - None detected at end of experiment

Conclusions: Laboratory Experiments

Batch experiment:

- Batch experiment showed that concept is viable
- Half-life was relatively low, possibly due to continuous mixing of hypovials

Cell experiment:

- Experiment using larger cells showed removal of more significant amounts of free-phase PCE

Conclusions: Field Demonstration

- Degradation of PCE was apparent, despite limited DNAPL and irregularity of degradation products
- Longer half-life due to static conditions of test
- Field testing at a larger scale with commercial soil-mixing equipment appears to be warranted

Acknowledgements

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