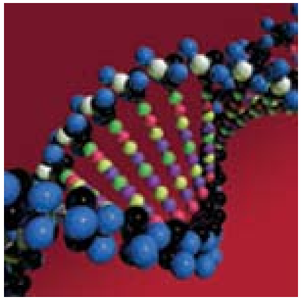
Advanced Diagnostic Tools: Applications To Site Design, Management and Expedited Resolution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Presentation Overview

- Shifts in the Regulatory Landscape and Remediation Technologies
- Descriptions of Diagnostic Tools
- Applications of Diagnostic Tools in Site Design, Management & Closure Strategies

Elements of Expedited Closure Practice

- Some Drivers of a Paradigm Shift
  - Many problems have no realistic solution
  - Asymptotes are a form or purgatory (or worse)
  - Not enough money in the U.S. to clean it up
  - Recognition that resources have limits – need to practice “triage”
  - Remediation should be “sustainable” - what is collateral damage?
- Objective
  - Continue to evolve more sensible management paradigms with provisional emphasis on MNA to reduce active costs
  - Note: Progress being made; the advent of RBCA as an inspiration

Evidence for Regulatory Change?

Source: National Academy of Sciences Report –

Contaminants in the Subsurface: Source Zone Assessment and Remediation

Proposed New Metrics to Judge Success

Physical objectives include mass removal, concentration reduction, mass flux reduction, reduction of source migration potential, plume size reduction, and changes in toxicity of residuals.

Other objectives relate to risk reduction and cost minimization.

Shifts in Remediation Technology

What is the next evolutionary step?

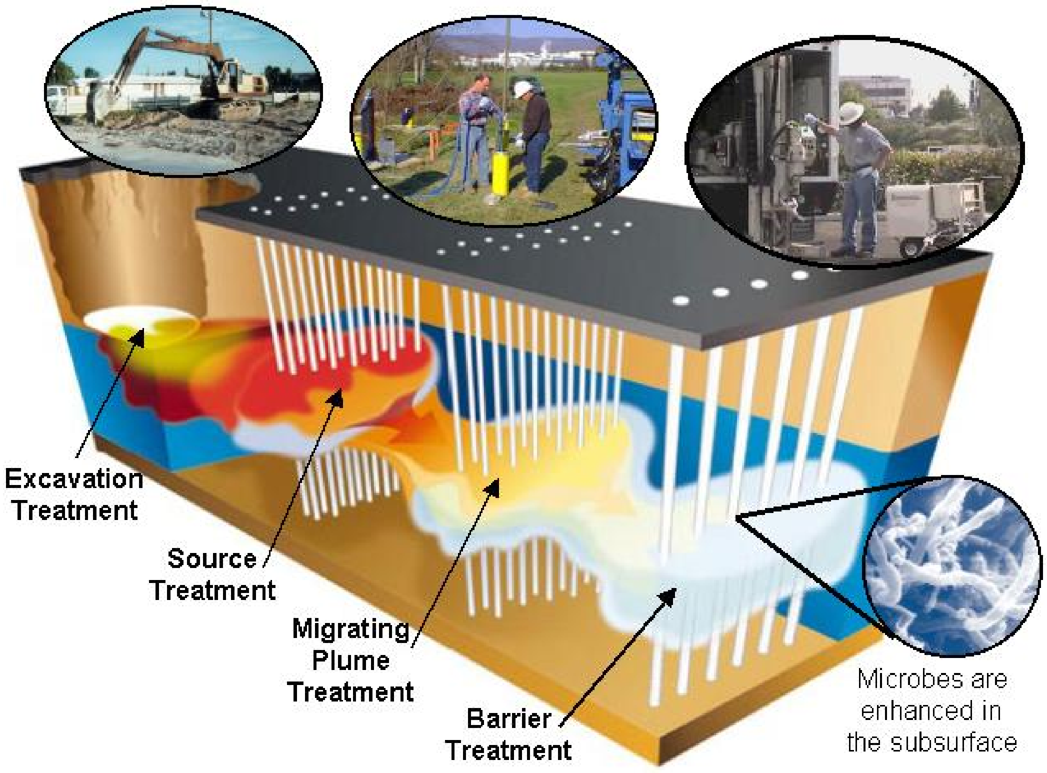
- Phase I. Mechanical and energy intensive operations such as pump and treat, DPE, SVE, and air sparging. OK to a point.

- Phase II. Rise of the *in-situ* technologies, such as bioremediation, in-situ chemical oxidation and chemical reduction (ISCO/ISCR)

Chemical Oxidation (ISCO)	**Chemical Reduction (ISCR)**
Biological Oxidation (Aerobic Bio)	**Biological Reduction (Anaerobic Bio)**

Visualizing In Situ Technology

- INJECT / EMPLACE
- Electron Acceptors
- Electron Donors
- Chemical Oxidants
- Chemical Reductants
- Microbes



Courtesy of Regenesis

Shifts in Remediation Technology

Phase III

- The “next wave” overlays advanced diagnostic technologies from biotechnology, chemistry and geophysics to optimize remedial design and management.
- Ultimately we seek to integrate the “new lines of evidence” from these diagnostic tools in concert with risk assessment to get more reasonable regulatory responses such as MNA
- What are some of the tools in an advanced site resolution program?

Expedited Site Resolution Matrix

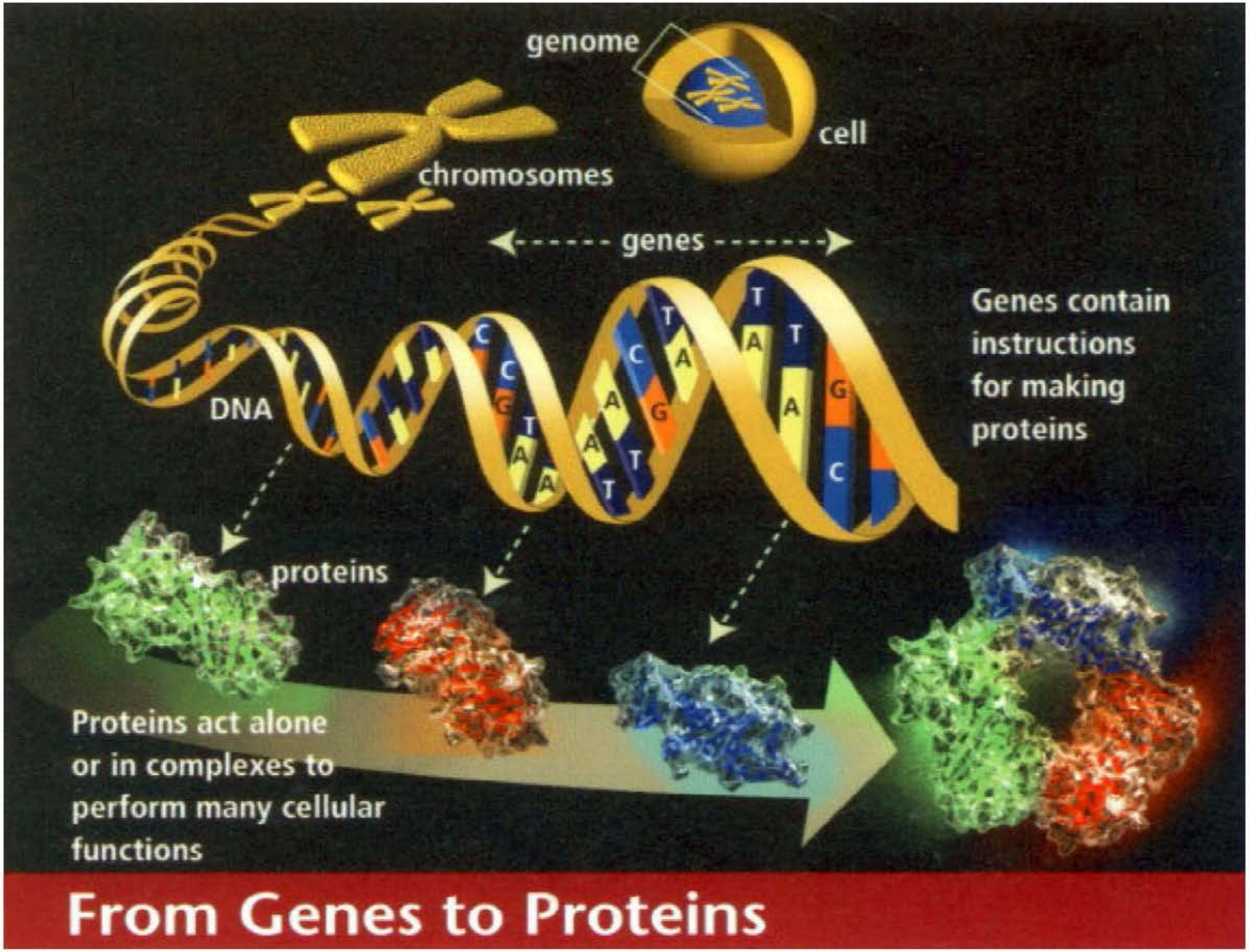
Tools & Processes

Applications	Biotechnology	Advanced Chemistry	Advanced Geotechnical	Risk Analysis	F & T Models	Sustainable Remediation	Financial Instruments
Eval.							
Design							
Mgmt.							
Closure							

Physical Lab/Field Applications
"Virtual" Applications
Frameworks

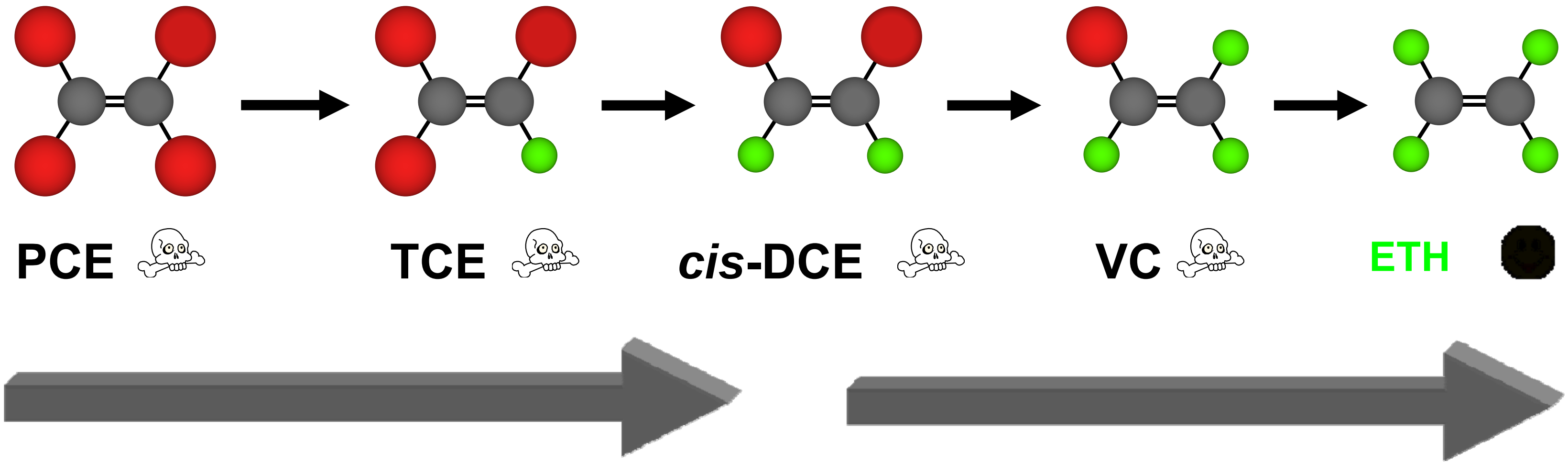
New Approaches in Site Management

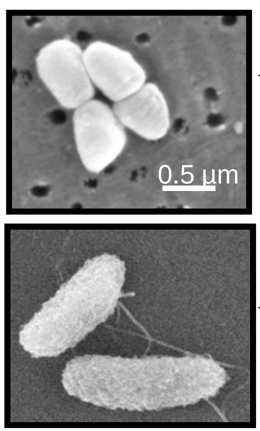
- Advanced Diagnostics
  - Molecular Biological Tools (MBTs)
    - DNA probes to ID key organisms and their catabolic functions
    - Other gene products, e.g., lipid analysis for general community profile
  - Specialized Chemical Analysis
    - SIP/CSIA (proof/rates of attenuation, plume dynamics)
    - Field based analytical measurements – “better, faster, cheaper”
  - Advanced Geophysical and Modeling Tools
    - Real time data collection and imaging; also new models (i.e., BioBalance)
    - Remote sensing and signaling



From DOE: Genomes to Life

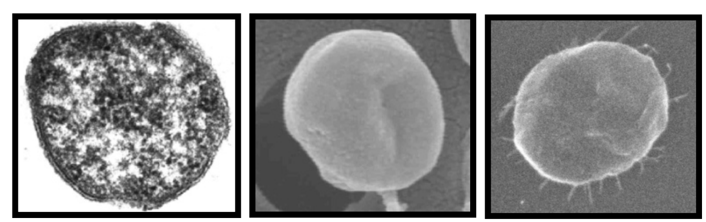
Taxonomic and Functional ID





Desulfuromonas spp.
Sulfurospirillum spp.
Dehalobacter spp.
Desulfitobacterium spp.
Geobacter spp.
etc.

Dehalococcoides spp.



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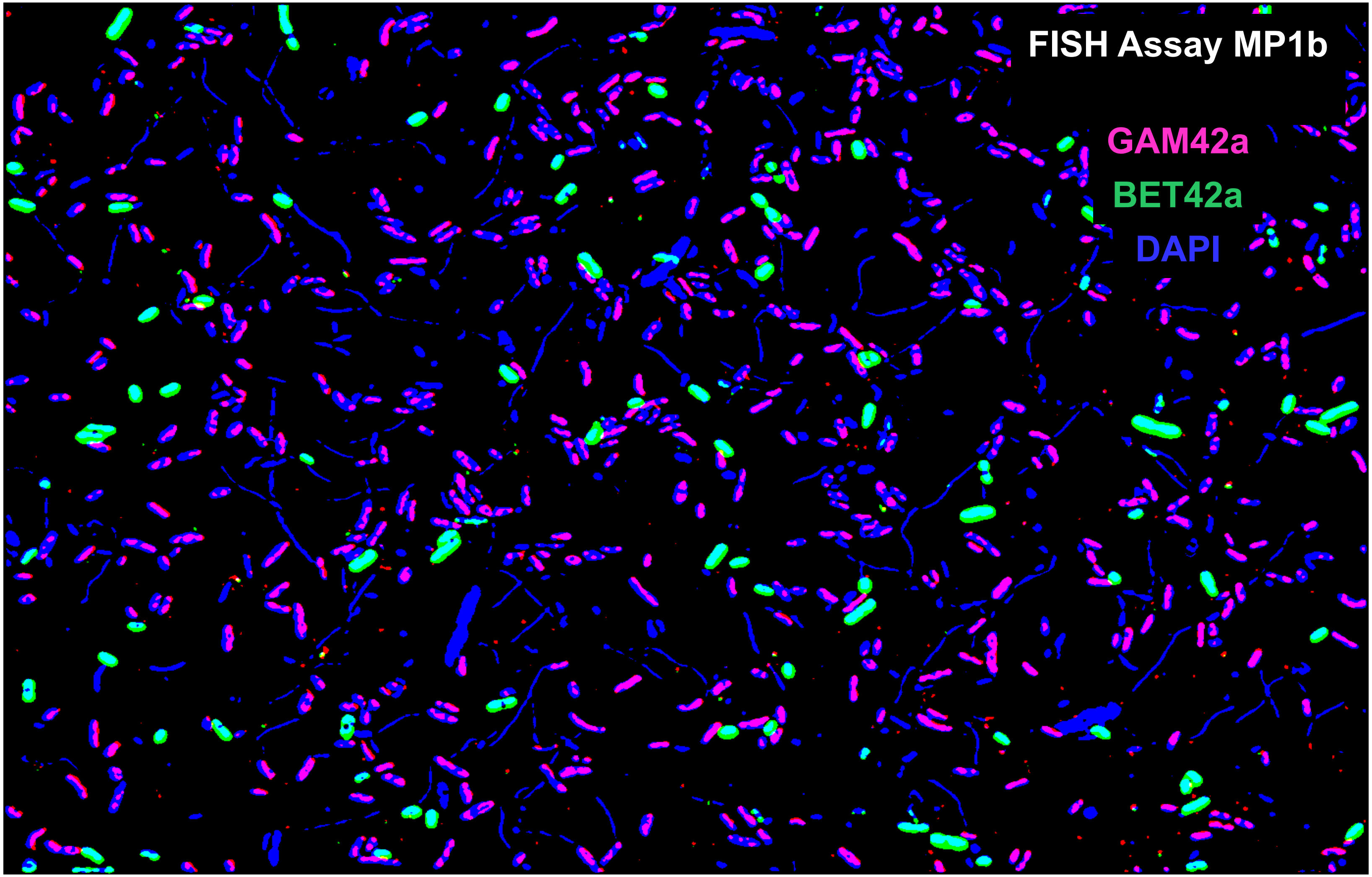
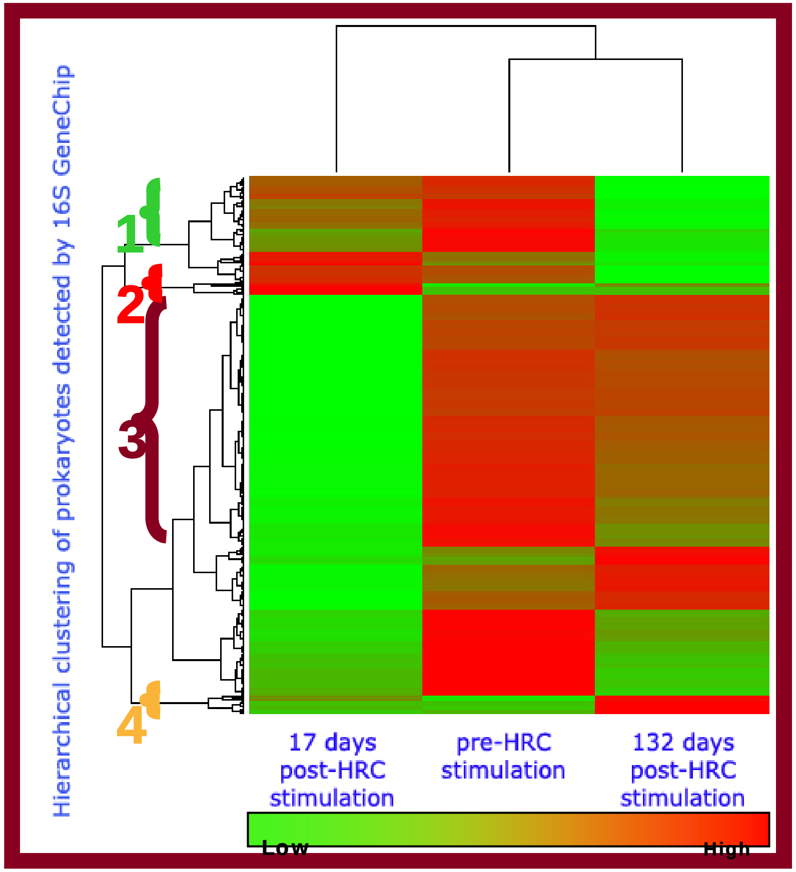
Fluorescence In-Situ Hybridization



High Density Microarray Analysis



Hierarchical clustering and heatmap plot of 16S GeneChip analysis of microbial community sub-families detected during chromate bioremediation. PCA groups are indicated by brackets.

Bacteria and Archaea Detected

Grouped according to response to HRC during chromate remediation

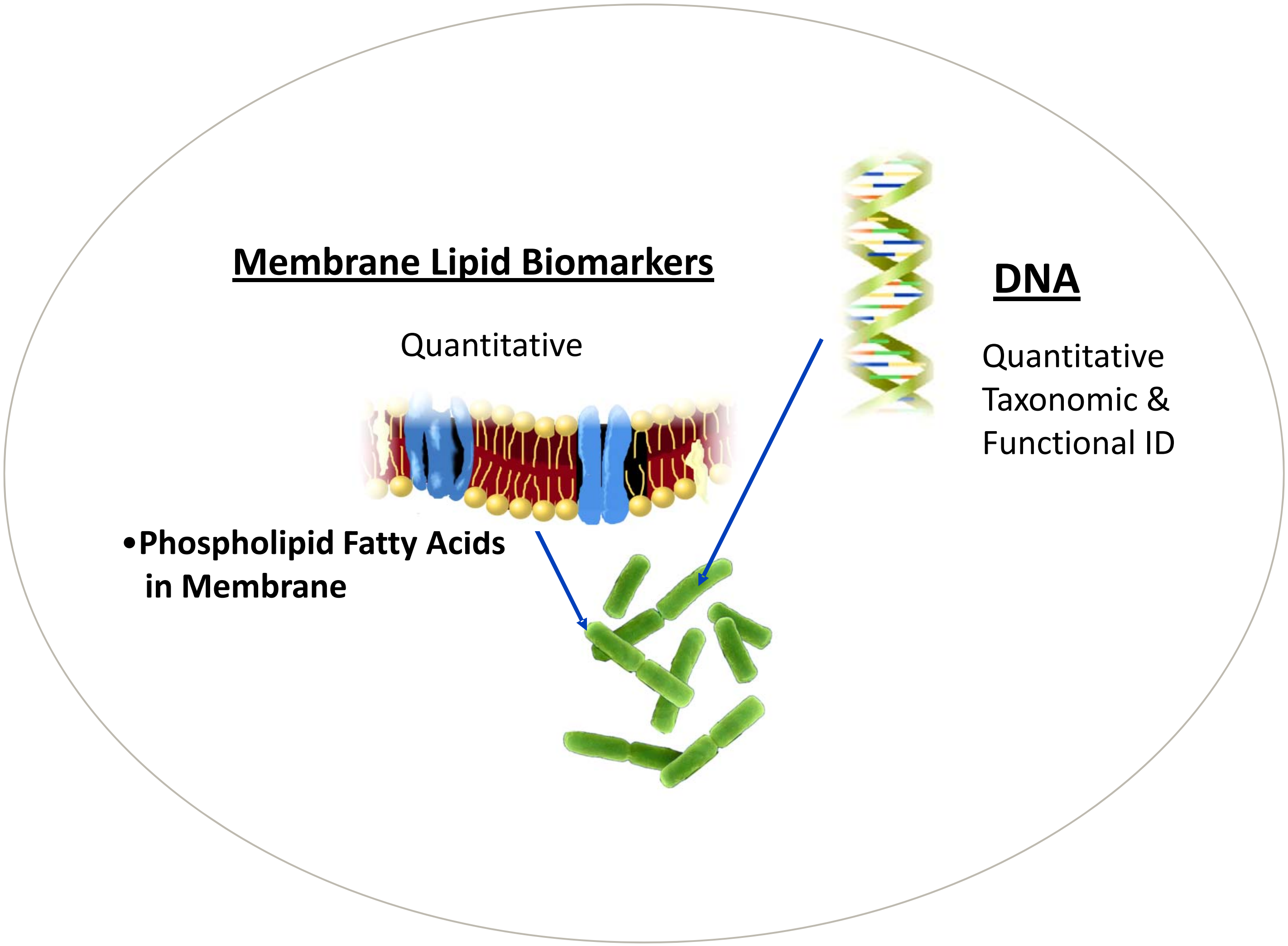
Group1 organisms decline
Pseudomonas, Burkholderia (Denitrifiers)
Acidithiobacillus, Thiothrix (Sulfur oxidizers)
Leptothrix (Iron oxidizer)

Group2 organisms increase then decline
Acidovorax, Thauera (denitrifiers)
Flavobacteria (aerobes, use glycerol)

Group3 organisms decline then return
Mainly oligotrophic bacteria

Group 4 organisms increase in late stages
Legionella, Chlamydophila, Flectobacillus.

Other Molecular Biological Tools



Courtesy of Microbial Insights

Expedited Site Resolution Matrix

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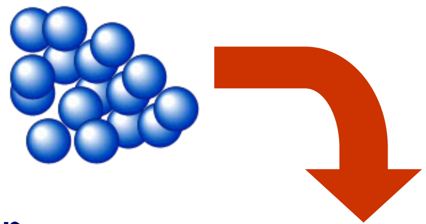
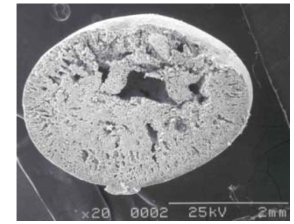
Physical Lab/Field Applications
"Virtual" Applications
Frameworks

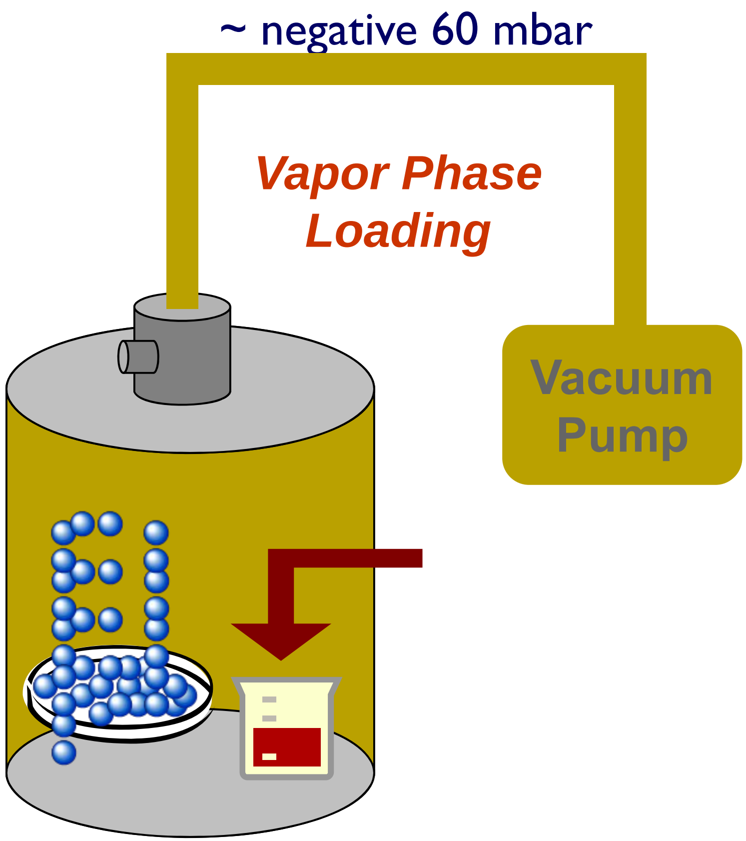
Baited Bio-Traps

Bio-sep Beads enriched with amendments



Interior of Bio-Sep Bead

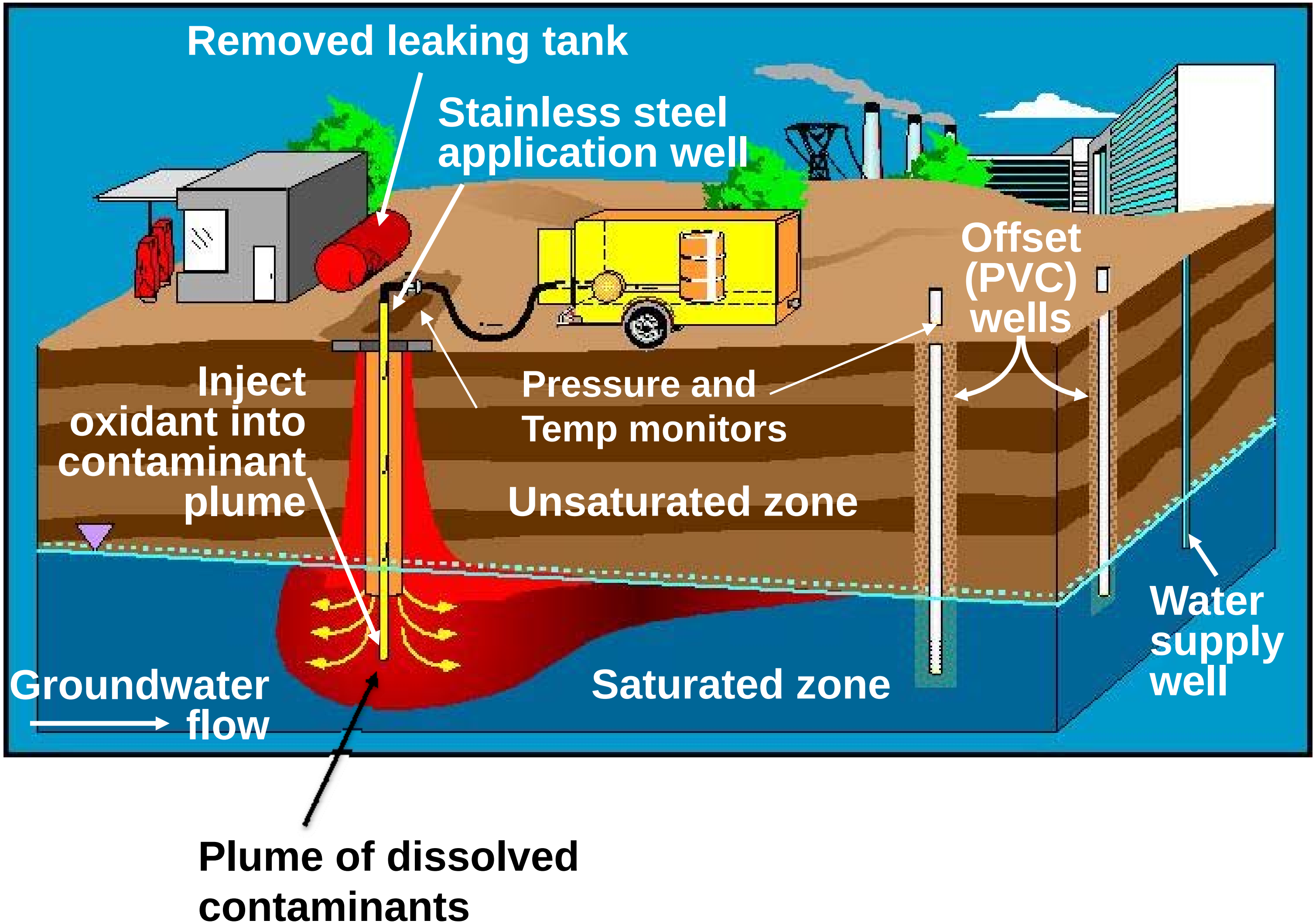




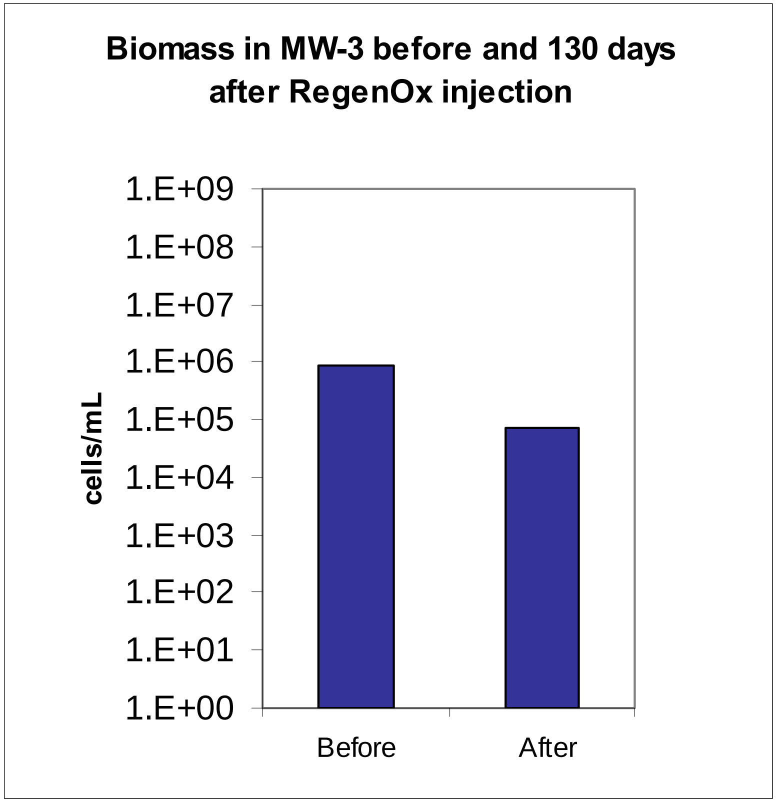
Amendments Include:

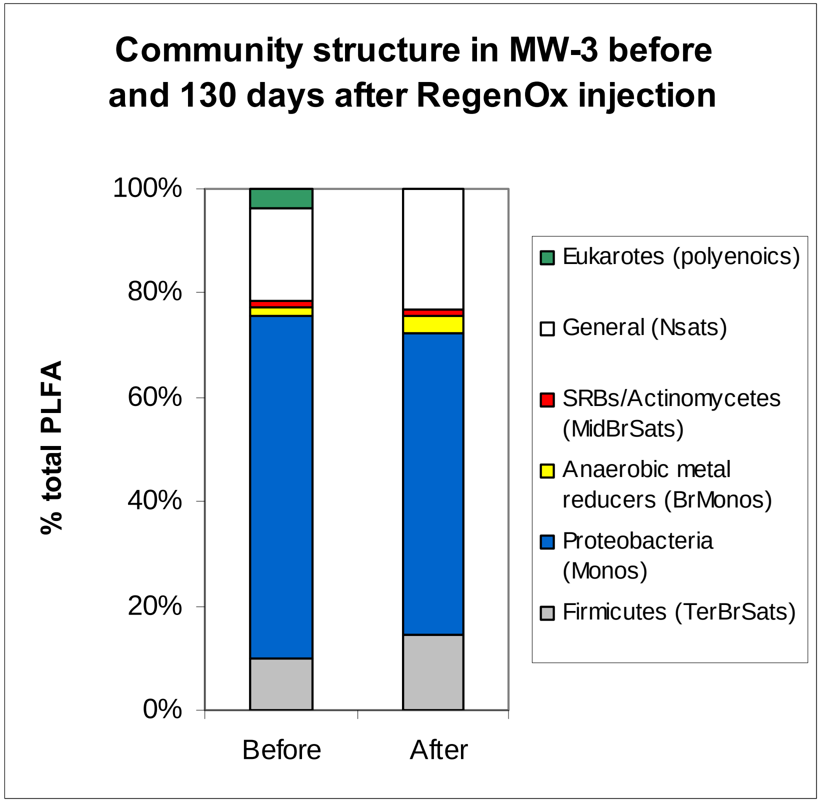
- Electron Donors
    - Organic Acids
    - Whey
    - HRC
    - EOS
    - Molasses
    - Other
- Electron Acceptors
- Nutrients

Typical ISCO Project



ISCO Impacts on Microbial Ecology





Courtesy of Regenesis

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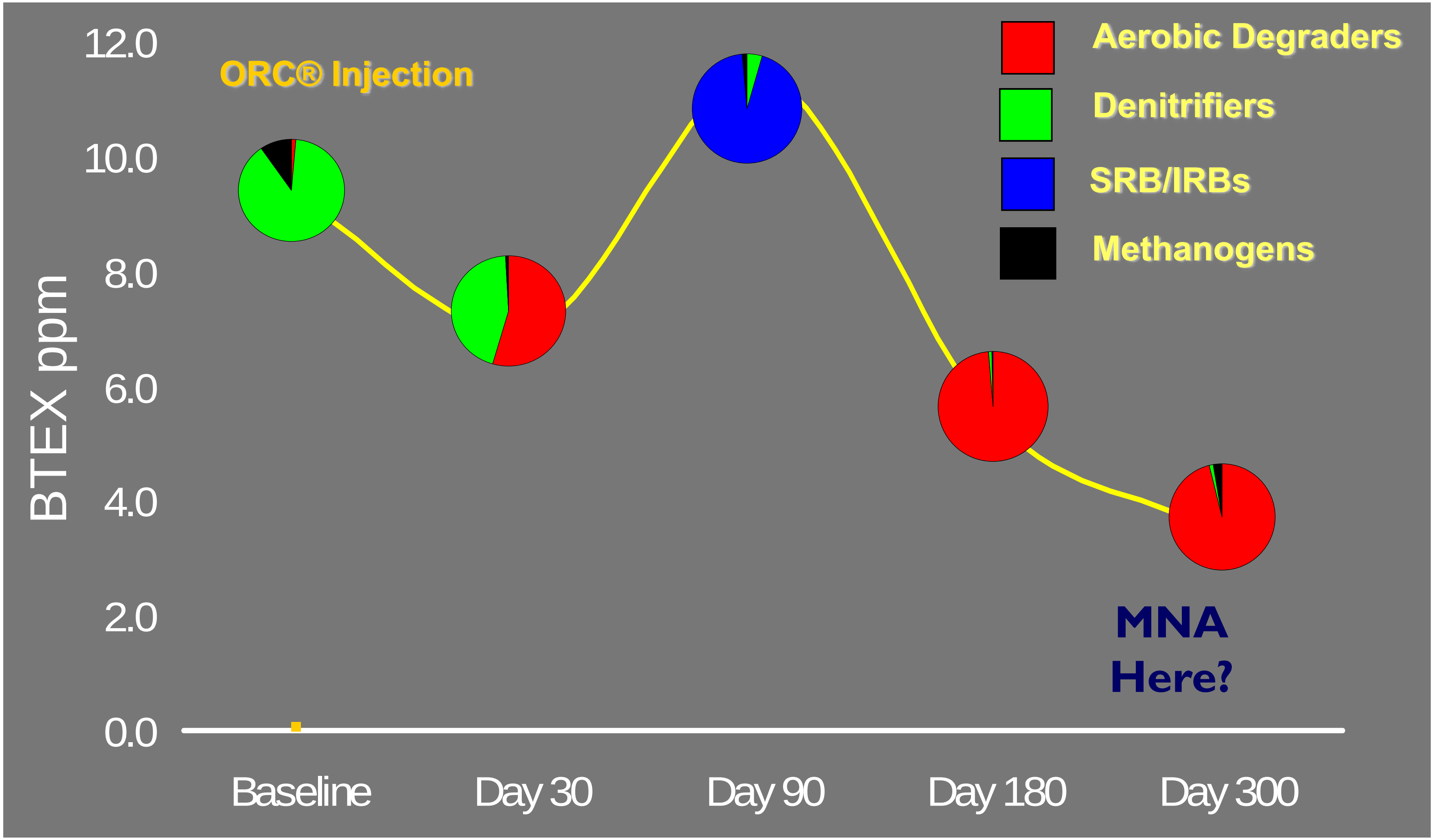
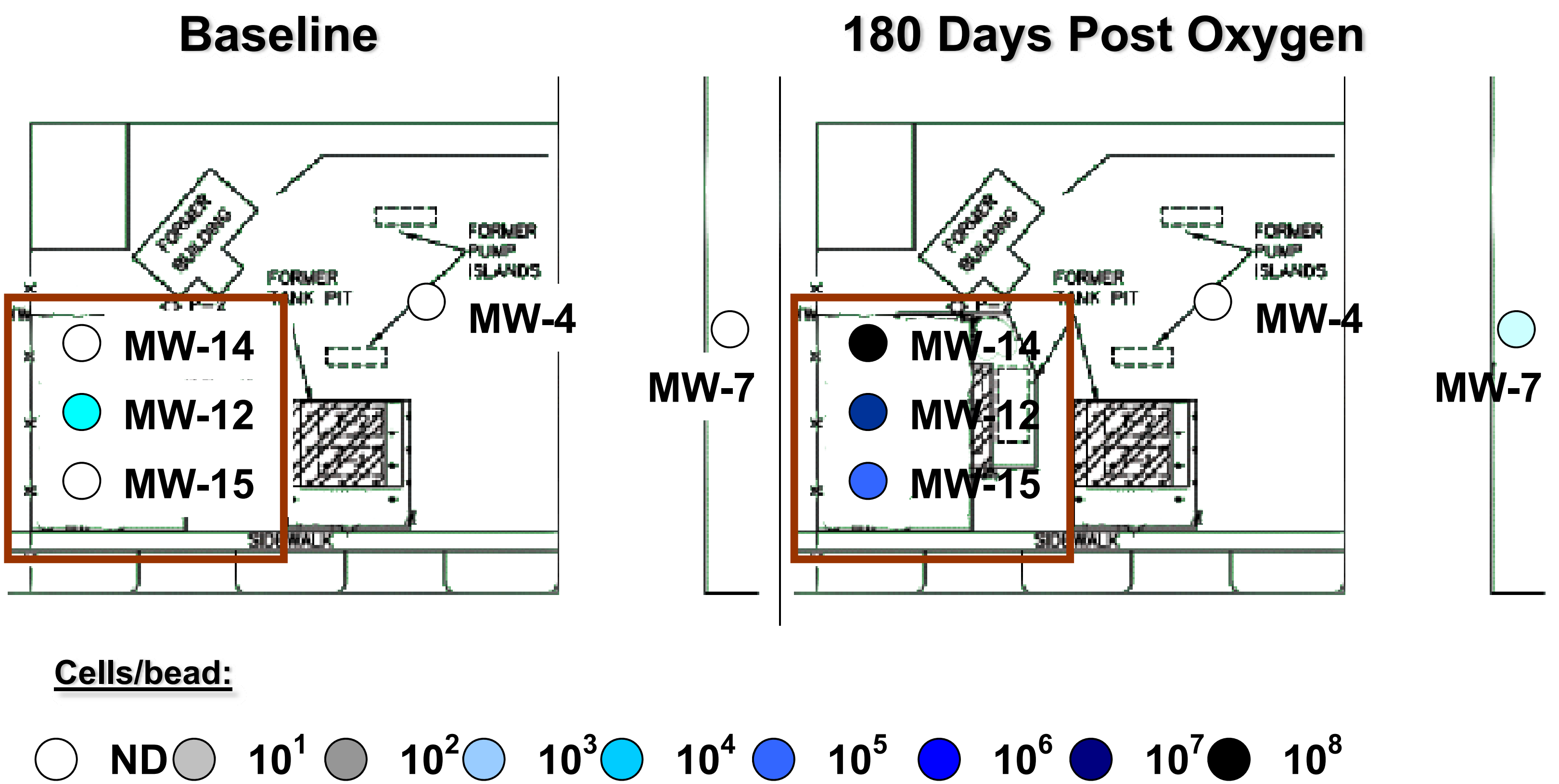
Showing Proper Microbial Transitions



Courtesy of Microbial Insights

Showing Abundance of Hydrocarbon Degrading Enzymes



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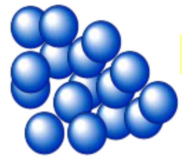
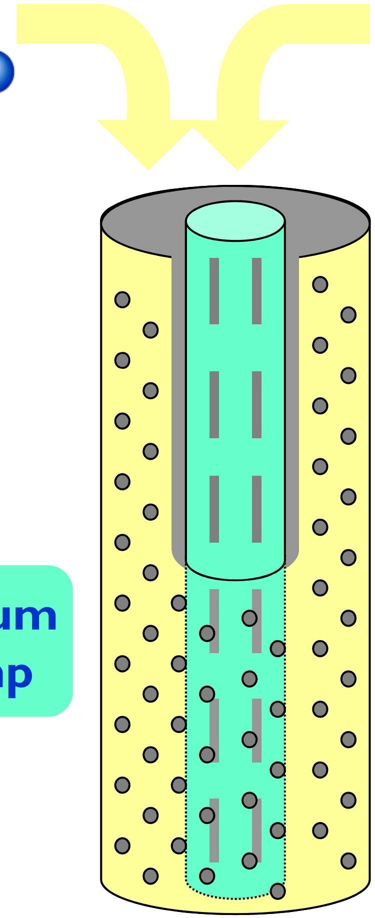
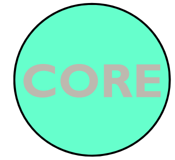
Bio-Trap Sampler: SIP Design

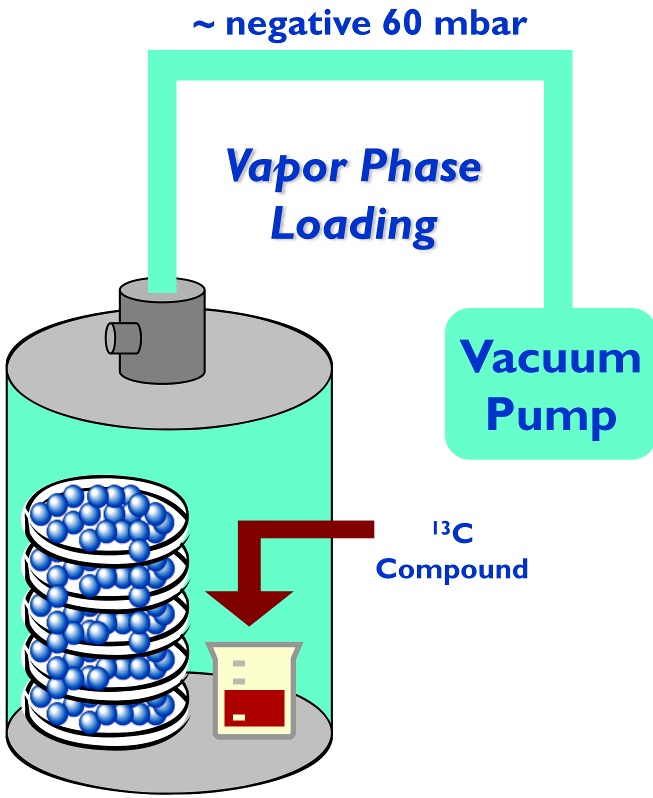
Annular space loaded with ^{13}C enriched Bio-Sep Beads







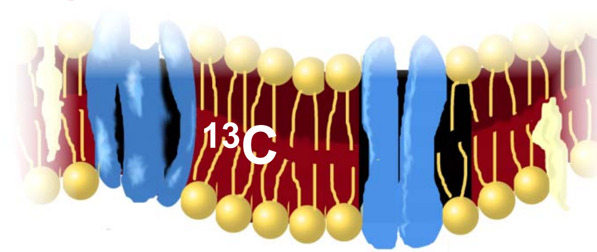
Core area is used for the slow diffusion of amendments into the annular space



<u>Amendments Include:</u>

- E Donors
- E Acceptors
- Nutrients
- Other

13C incorporated into membrane as proof of natural attenuation



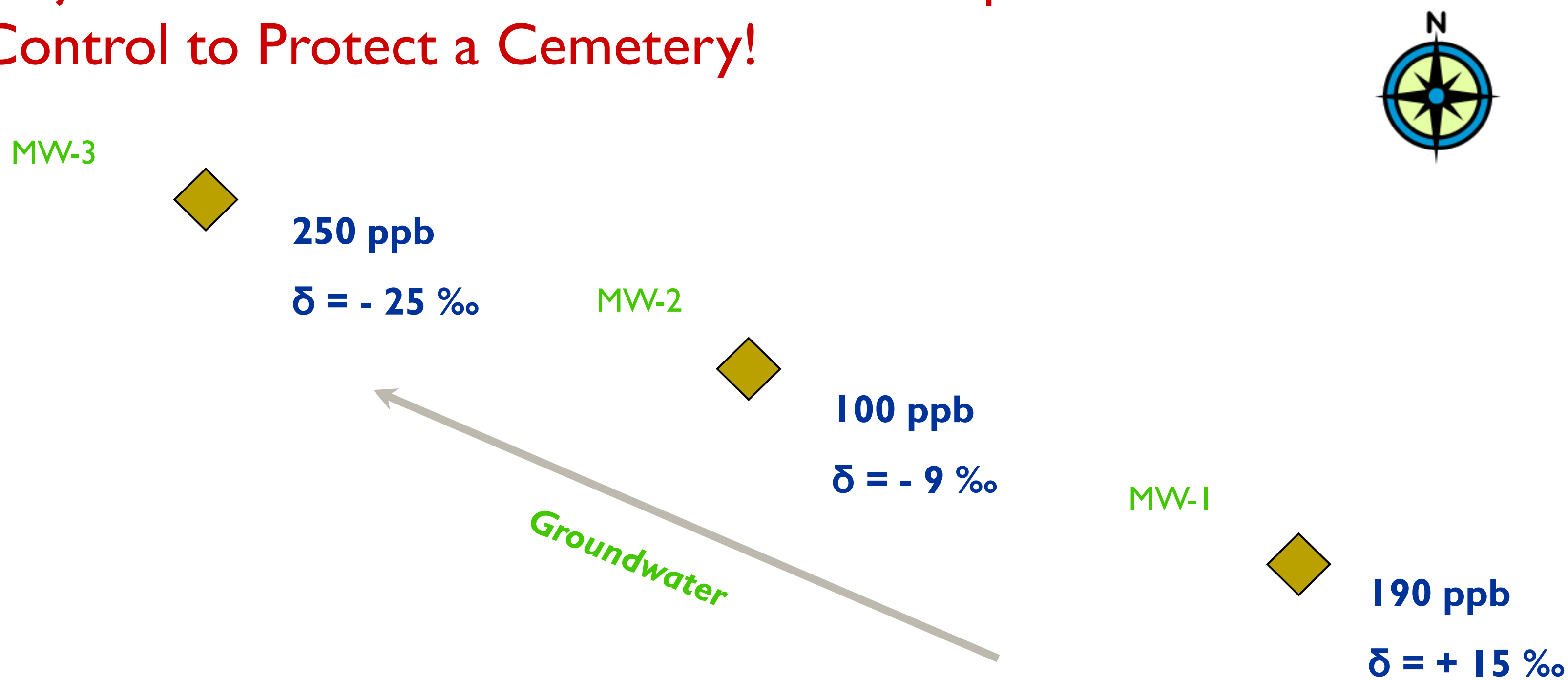
Compound Specific Isotope Analysis

CSIA

- A very powerful new tool in remediation science (but not science in general)
- Looks at ratios of naturally occurring isotopes such as 13C/12C for carbon
- Results of isotopic shifts in time are indicative of biological and chemical action

CSIA for MNA at a Site in Michigan

Objective: Avoid Multi-Million Dollar Pump and Treat Plume Control to Protect a Cemetery!



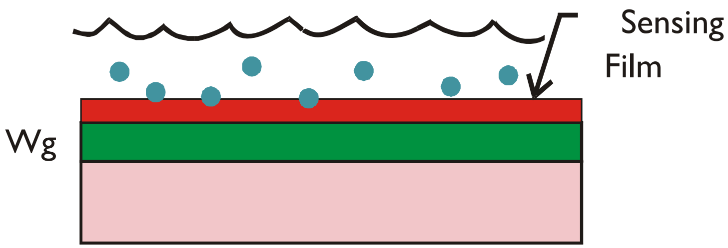
Compound Specific Isotope Analysis (CSIA) of TCE

More positive values = greater TCE degradation

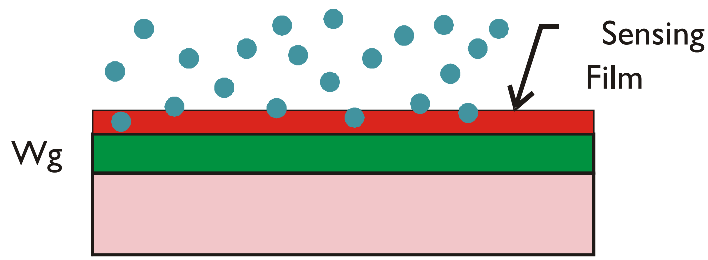
Values are in 'Del C" in ppth: a measure of an isotopic shift that is indicative of bond breaking degradation processes

Wave Guide Sensing

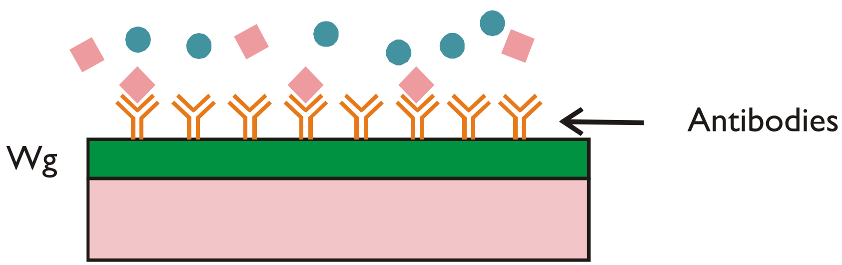
Analytes in Solution



Analytes in Air



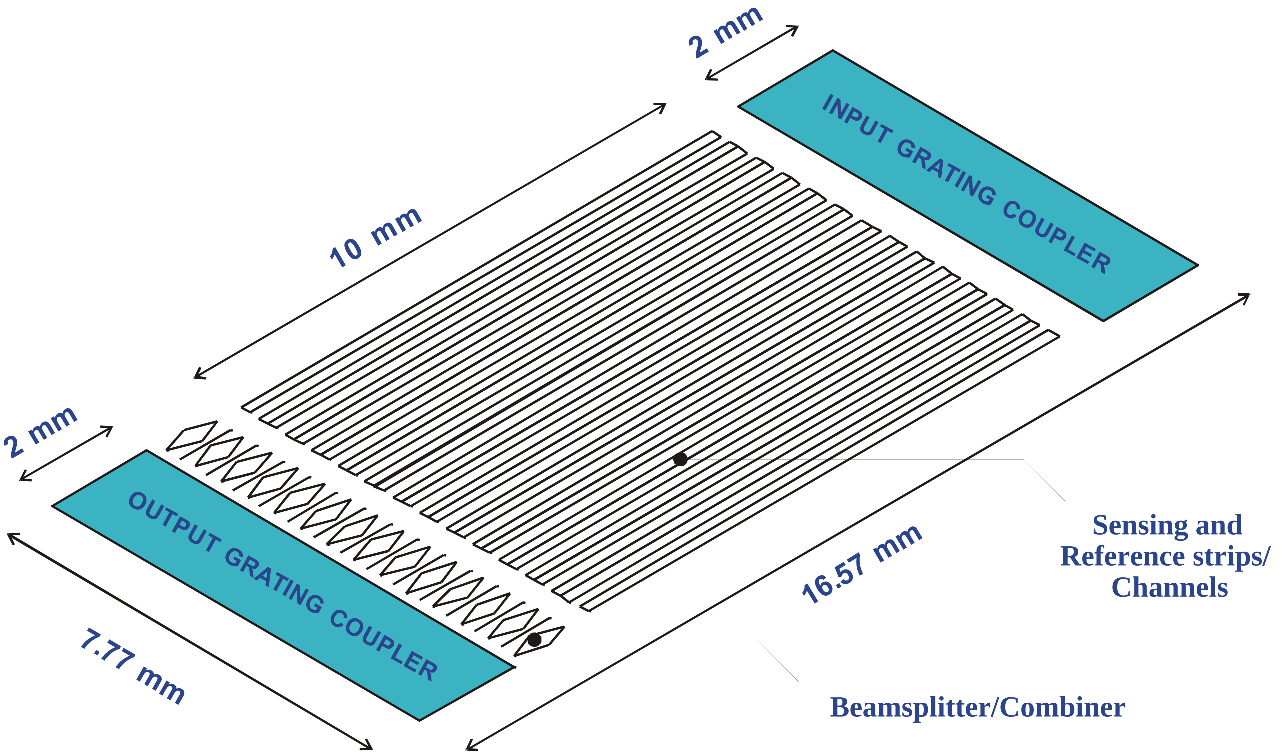
Bioconjugate Reactions



Probing at the waveguide surface allows the sensor to work either in air or water. The coating can be tailored to respond broadly to a class of analytes or can be made very chemically specific, as in an antibody-antigen interaction.

Courtesy of David Gottfried – GTRI

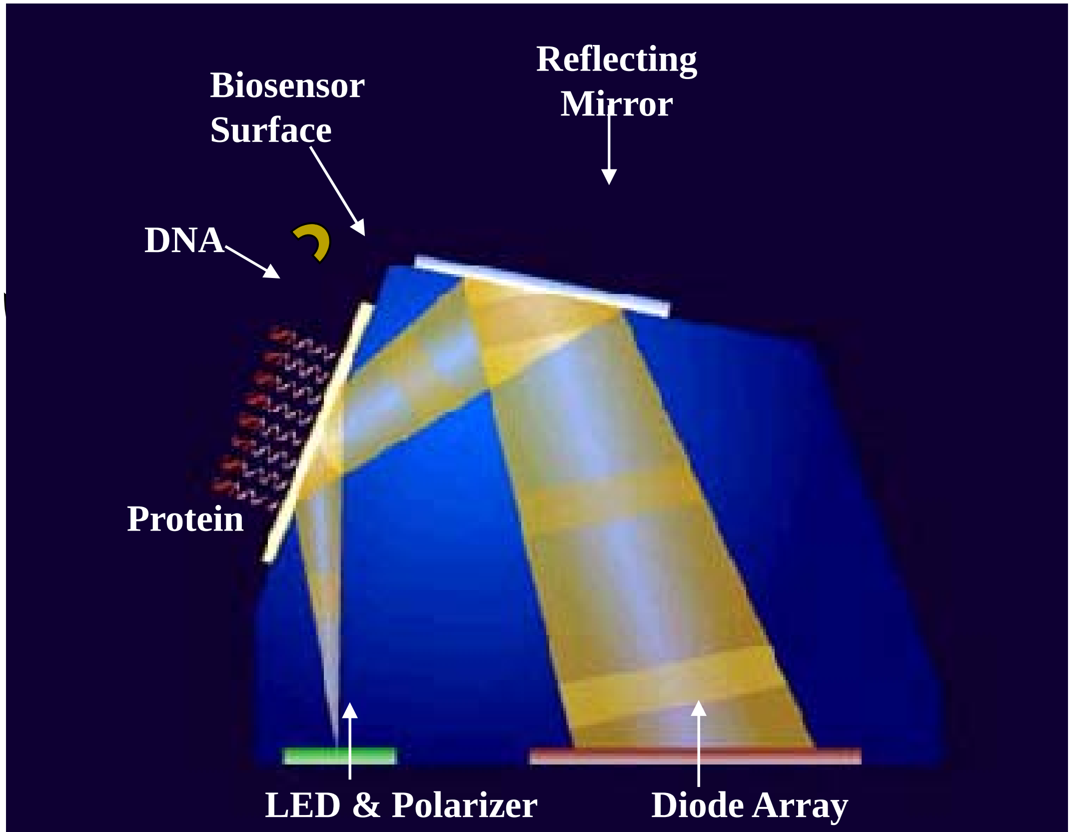
13 Sensing Interferometers on a Chip



Several of these interferometers can be assembled on a single waveguide to allow multiple analyte sensing. Recent detector improvement will allow for up to 50 interferometers on the same size chip less than 1 cm wide.

Spreeta Detection Device (Texas Instruments)

DNA/Protein Complex on Gold Surface



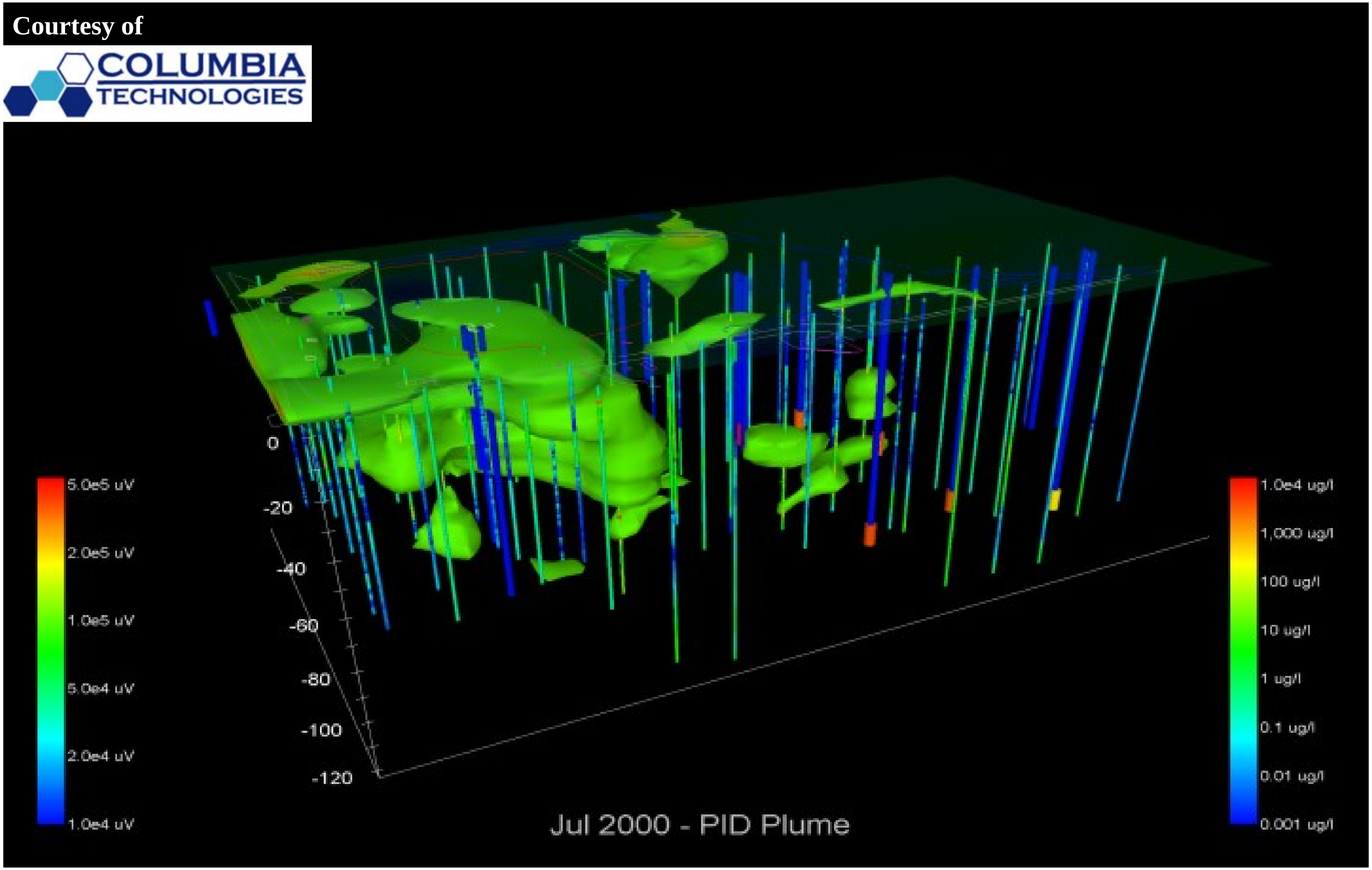
The angle/intensity of incident light detected is dependent on amount of material bound to the biosensor surface.

Advances in Geophysical Testing & Modeling

- Advances include:
  - Use of membrane interface probes (MIPs) to direct investigation and treatment
  - Tomographic remote sensing capabilities
  - Multi-level sampling and imaging
  - “Better – Faster – Cheaper” field testing
  - New Fate and Transport Models

- Generates superior understanding of contaminant concentrations and distribution: “If you don’t know where you are going you will get there”

Visualizing Initial Conditions

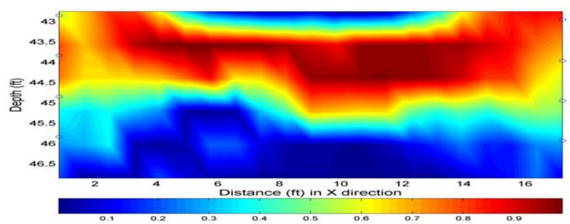


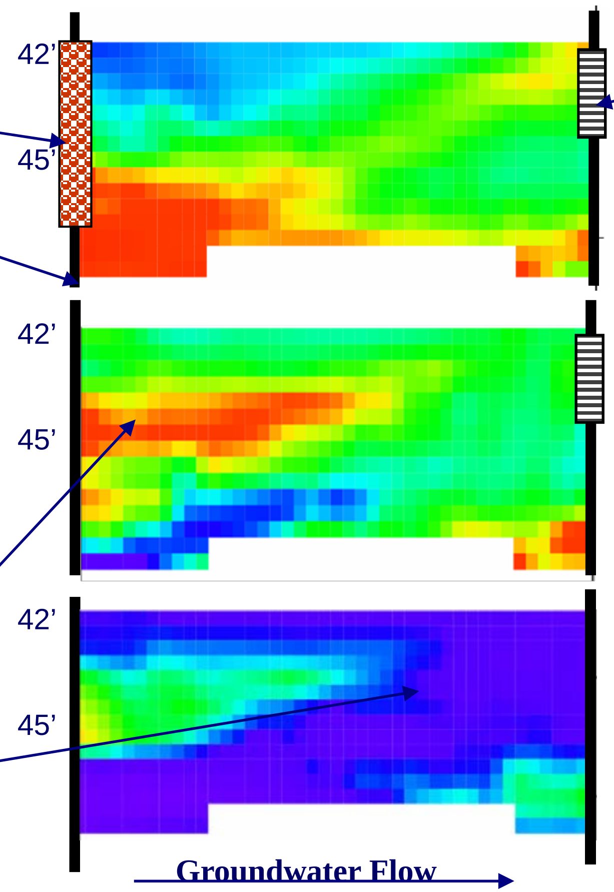
Post-HRC Injection “Tomography”

HRC Injection Zone

Pump

High K_{sat}



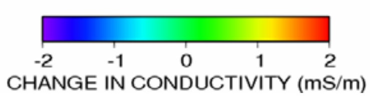


2 Days after HRC injection

3 DAYS

30 DAYS

Hypothesis: Reaction halo due to formation of precipitates



Courtesy of Charles Newell - GSI

Scenario #2: *Reduction in Source Mass and Source Flux*

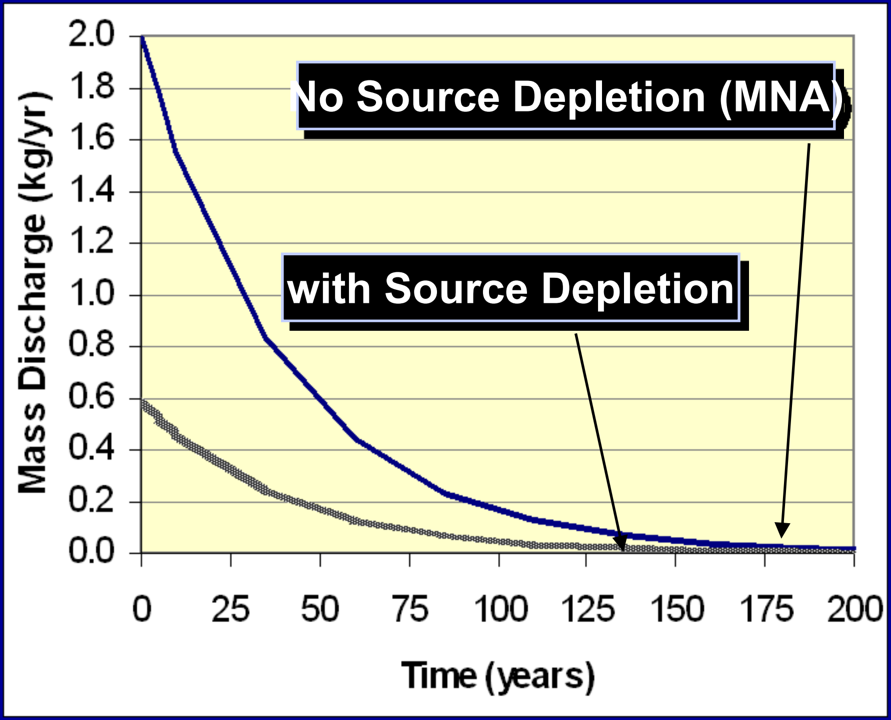
- What is the RTF if 70% of the mass and flux is removed and the remaining source decays at a first order rate?

$$RTF_{SD} = \left(\frac{M_O}{W_O}\right)\left(\frac{RF_M}{RF_W}\right)\left(-Ln\left(\frac{W_g}{W_O RF_W}\right)\right)$$

- If M_O=80 kg, W_O=2 kg/yr, W_g=0.02, RF_M=RF_W=0.3

RTF_{MNA} = 184 years

RTF_{SD} = 136 years



RTF_{SD}=Remediation Timeframe, M_O=Initial Source Mass, W_O=Initial Mass Discharge Rate, W_g=Goal Mass Discharge Rate, W_{SD}=Mass Discharge Rate following source depletion, k_s=source decay coefficient, RF_M=remaining fraction of mass, RF_W=remaining fraction of mass discharge rate

MNA via MBTs

Cost Differential in $K for Treatment options vs. MNA only and Actual Remedy

Options	Capital	O & M	Total	Δ MNA Δ Actual
MNA	29	1001	1030	
MNA + Source Treatment	252	1070	1322	-292
MNA + ST + Barriers with Substrate 1	838	1188	2026	996 704
MNA + ST + Barriers with Substrate 2	747	1279	2026	996 704
MNA + ST + Array Treatment with Substrate 2	2199	861	3060	2030 1738

From WSP Presentations - Consoil 2008 and AEHS SD 2007

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CONCLUSIONS

- The industry is moving/has moved away from capital and energy intensive methods in favor of *in-situ* remediation.

- Treatments utilizing *in-situ* methods are being increasingly supported by advanced diagnostic tools that employ biotechnology, advanced chemistry, novel geophysics and creative modeling.

- The suite of advanced diagnostic tools can be used to optimize site design and management. Also, “new lines of evidence” generated by these tools can be used to petition for a more cost effective site resolution.