TCE Fate & Transport Project

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Briefing

PGDP Citizens Advisory Board

Steve Hampson, Associate Director

KRCEE

for

PGDP TCE FT Project Team

June 19, 2008

TCE Fate & Transport Project

4 Project Phases

Phase I - Data Evaluation

Phase II – Aerobic Degradation Investigation

Phase III – Stable Carbon Isotope Investigation

Phase IV – Abiotic Degradation Evaluation

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Phase I - Data Evaluation

- Completed
- Screening to ID most-likely TCE attenuation processes
- Determination of TCE degradation rate in RGA
  - Utilized Existing NWP Data
  - Calculated as "half-life"*
  - Range of Half-Life Rates from 4 – 26 years

*half-life = time required for present concentration to be reduced by 50%

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Phase II – Aerobic Degradation Investigation

Status of Activities

- Completed Scoping Document (May '07)
- Completed Sampling (December '07)
- Completed Microbiological, Stable Carbon Isotope & Geochemical Laboratory Analyses (April '08)
- SRNL Report due July 1, 2008
- KRCEE White Paper due July 15, 2008

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Phase II – Aerobic Degradation Investigation

Goals

1. To identify biological degradation mechanisms active in the RGA (degradation by bacteria)
2. Provide DOE with recommendations for future Biological Degradation Investigation(s)

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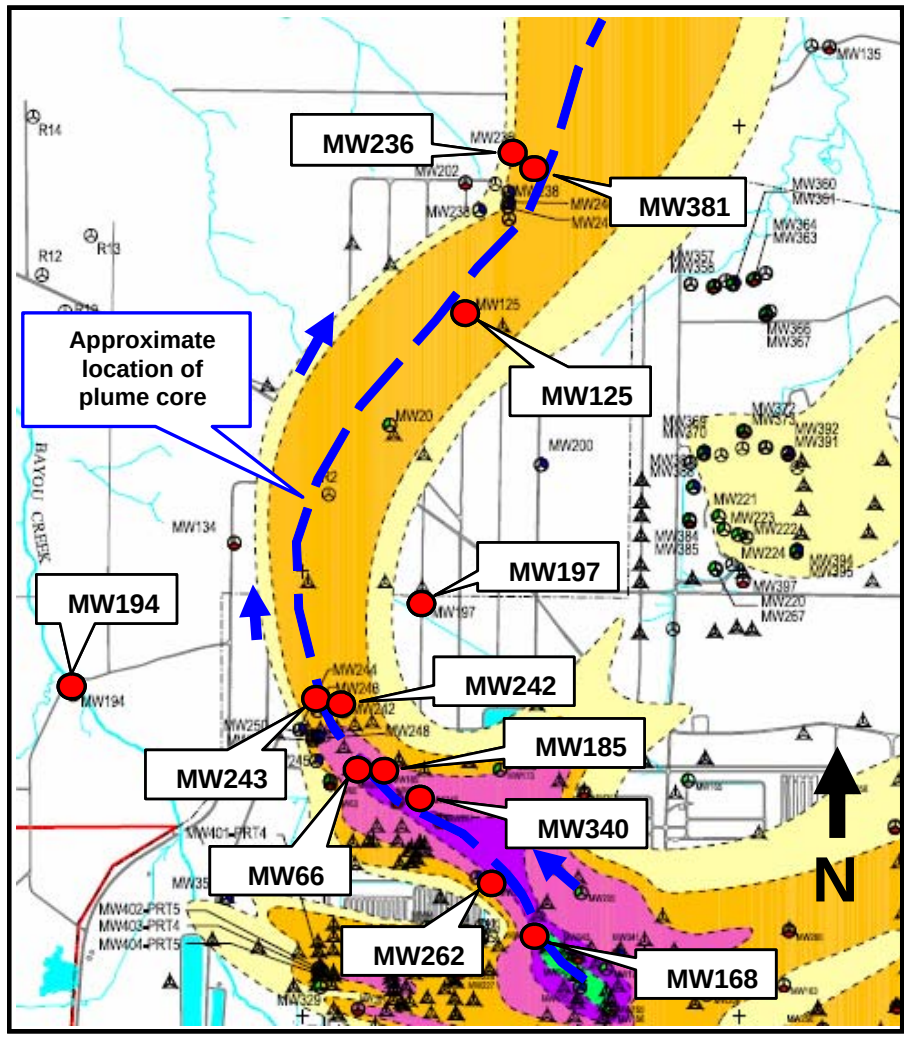
Phase II – Aerobic Degradation Investigation

Study Area
&
Well Locations



= TCE contaminant plume in Regional Gravel Aquifer

= NWP GW Flow is to NW from MW168 to MW66

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Phase II – Aerobic Degradation Investigation

Background

1. The RGA is an aerobic "oxygen rich" aquifer
   - Dissolved Oxygen present in groundwater (throughout aquifer)
   - Under the right conditions, Aerobic "oxygen loving" microbes via process of Co-metabolism destruct TCE

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Phase II – Aerobic Degradation Investigation

Background

2. Co-metabolism occurs in aerobic environments when a microbe produces enzyme(s) capable of TCE destruction
   - The microbe does not use TCE as a food source
   - The microbe does not benefit from the enzymatic destruction of TCE
3. Microbes are utilizing other substances for respiration/metabolism

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Phase II – Aerobic Degradation Investigation

Background

4. Aerobic microbes metabolize (oxidize) naturally occurring and man-made (anthropogenic) sources of organic material
5. Many sources of naturally available organic material
    - Organic material deposited with aquifer sediment
    - Decaying plant matter
    - Decaying microbial biomass

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Phase II – Aerobic Degradation Investigation

Background

6. Aerobic microbes, thru their metabolic processes, add oxygen (oxidize) to organic compounds
7. Addition of oxygen into the organic substances occurs via enzyme reactions ("oxygenase" enzymes)
8. Oxygenase enzymes fortuitously destroy TCE
9. Enzyme destruction of TCE produces end-products carbon dioxide, chloride, and water
10. No harmful intermediate/end products (such as vinyl chloride in anaerobic degradation)

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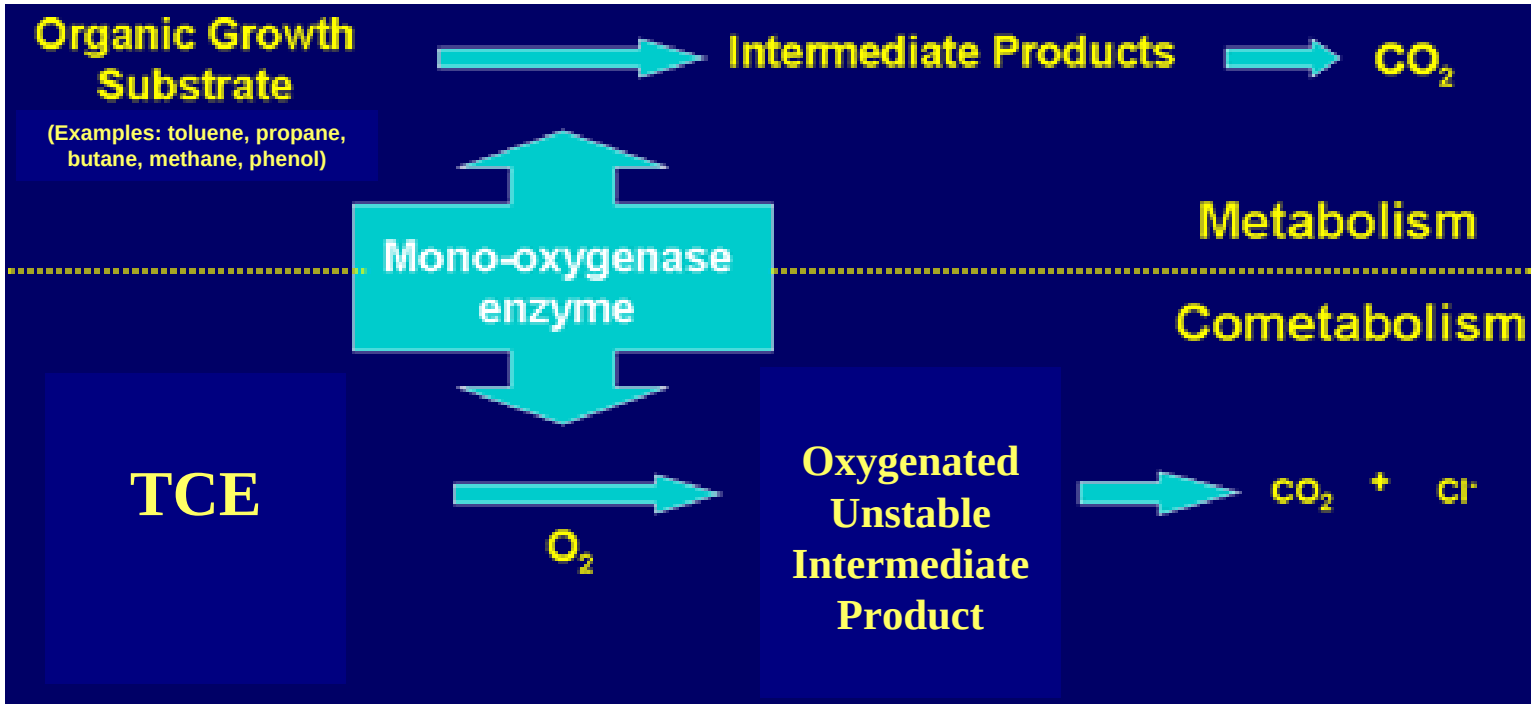
Phase II – Aerobic Degradation Investigation

Microbial metabolic process on top of diagram



Co-metabolism process on bottom of flow diagram

(Source – http://wrhsrc.oregonstate.edu/briefs/brief_8.htm)

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Phase II – Aerobic Degradation Investigation

Background

Pseudomonas putida

(Known to metabolize toluene in soil)

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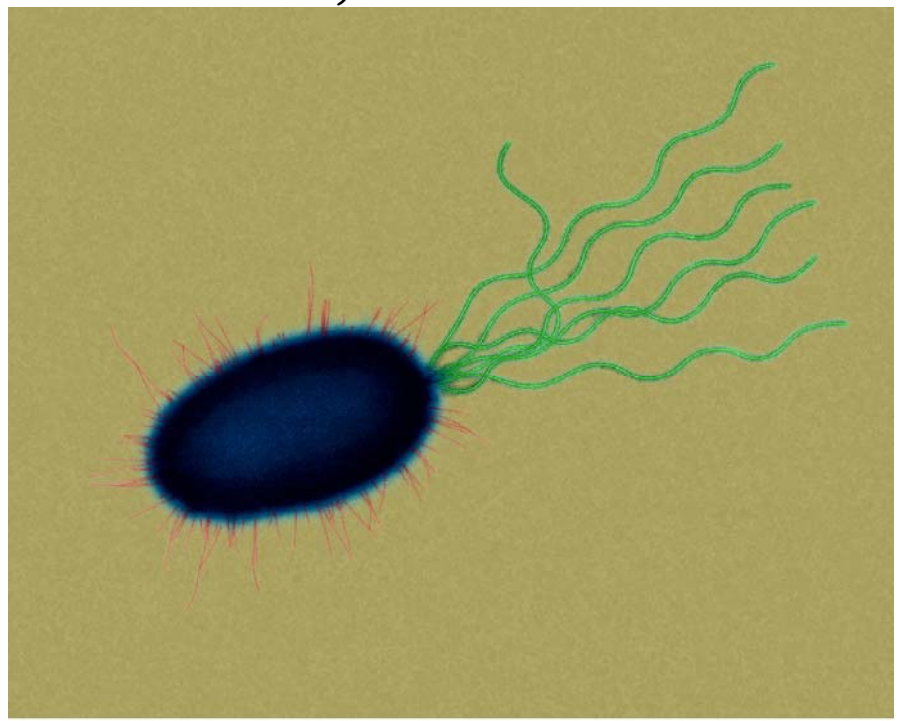

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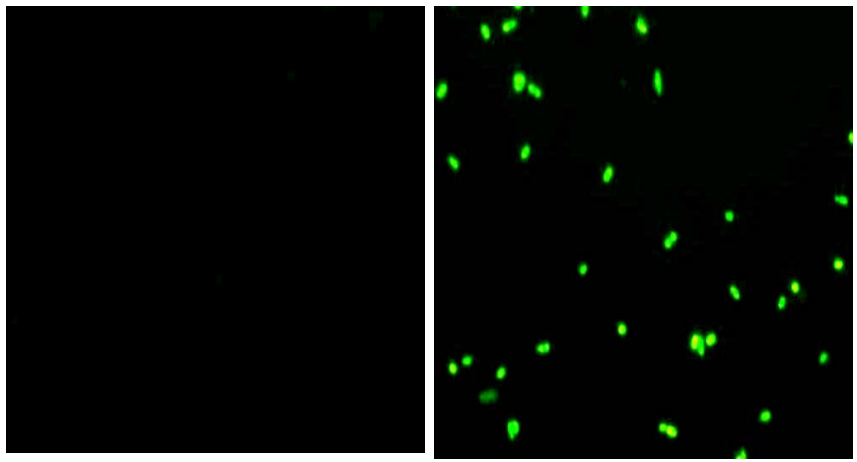
Phase II – Aerobic Degradation Investigation

Enzyme Activity Probes

Laboratory tools that evaluate the activity of the microbial oxygenase enzymes; cells appear fluorescent when the enzyme is active

No Probe With Probe



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Phase II – Aerobic Degradation Investigation

Monitoring Well	Aquifer Designation	Screened Interval Depth (ft bgs)	Qualitative data (6/4/7)		Toluene probes			Total –DAPI cells/mL
			sMMO probe Coumarin	Toluene probes	Quantitative data (fluorescent cells/mL)			
					3HPA	PA	Cinnamonitrile	
MW168	URGA	83 - 88	-	-	nd	$2.41x10^3$	nd	$1.90x10^5$
MW66		55 - 60	+	+++	$1.43x10^4$	$2.10x10^4$	$9.14x10^3$	$3.67x10^5$
MW194		47 - 52	+	+++	$3.13x10^3$	$9.52x10^3$	$1.20x10^4$	$1.76x10^5$
MW197		58 - 63	-	+	$1.73x10^4$	$6.28x10^4$	$2.23x10^3$	$1.59x10^5$
MW197 (resample)			na	na	$5.03x10^3$	$1.20x10^4$	$2.04x10^3$	$7.05x10^5$
MW185	MRGA	68 - 73	-	++	$1.79x10^4$	$1.37x10^4$	$1.95x10^3$	$9.75x10^5$
MW242		65 - 75	-	-	$3.57x10^3$	$1.24x10^3$	$8.85x10^3$	$7.76x10^5$
MW243		65 - 75	-	-	$3.29x10^3$	$4.61x10^3$	$1.32x10^3$	$4.27x10^5$
MW381		66 - 76	-	++	$6.14x10^4$	$3.52x10^4$	$5.51x10^3$	$9.66x10^5$
MW262	LRGA	90 - 95	+	+++	$1.35x10^4$	$1.36x10^4$	$2.79x10^4$	$3.52x10^5$
MW 262 (resample)			na	na	$1.05x10^4$	$1.22x10^4$	$5.71x10^3$	$2.84x10^5$
MW340		85.5 - 95.3	+	+	$3.63x10^2$	$9.57x10^3$	nd	$7.25x10^5$
MW236		69.5 - 79.5	+	+++	$3.24x10^4$	$5.26x10^4$	$9.28x10^3$	$8.84x10^5$
MW125		78 - 88	+	++	$1.39x10^4$	$6.37x10^4$	$2.03x10^4$	$7.99x10^5$

URGA: Upper Regional Gravel Aquifer

MRGA: Middle Regional Gravel Aquifer

LRGA: Lower Regional Gravel Aquifer

3HPA: 3-hydroxy-phenylacetylene --> probe for toluene oxidase and related activity

PA: Phenylacetylene --> probe for toluene oxidase and related activity

cinnamonitrile: probe for toluene dioxygenase and related activity

DAPI: 4',6-Diamidino-2-Phenylindole (double stranded DNA staining)

ft bgs– feet below ground surface

µg/L – micrograms per liter

pCi/L – picocuries per liter

cells/mL – per milliliter

Highlight denotes that the toluene probe response was considered moderate (fluorescent activity > $3x10^3$ cells/mL and < $8x10^3$ cells/mL) – see text for explanation

Highlight denotes that the sMMO probe was significantly above background or the toluene probe response was considered significant (> $8x10^3$ cells/mL fluorescent activity)

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Phase II – Aerobic Degradation Investigation

EAP Well Locations

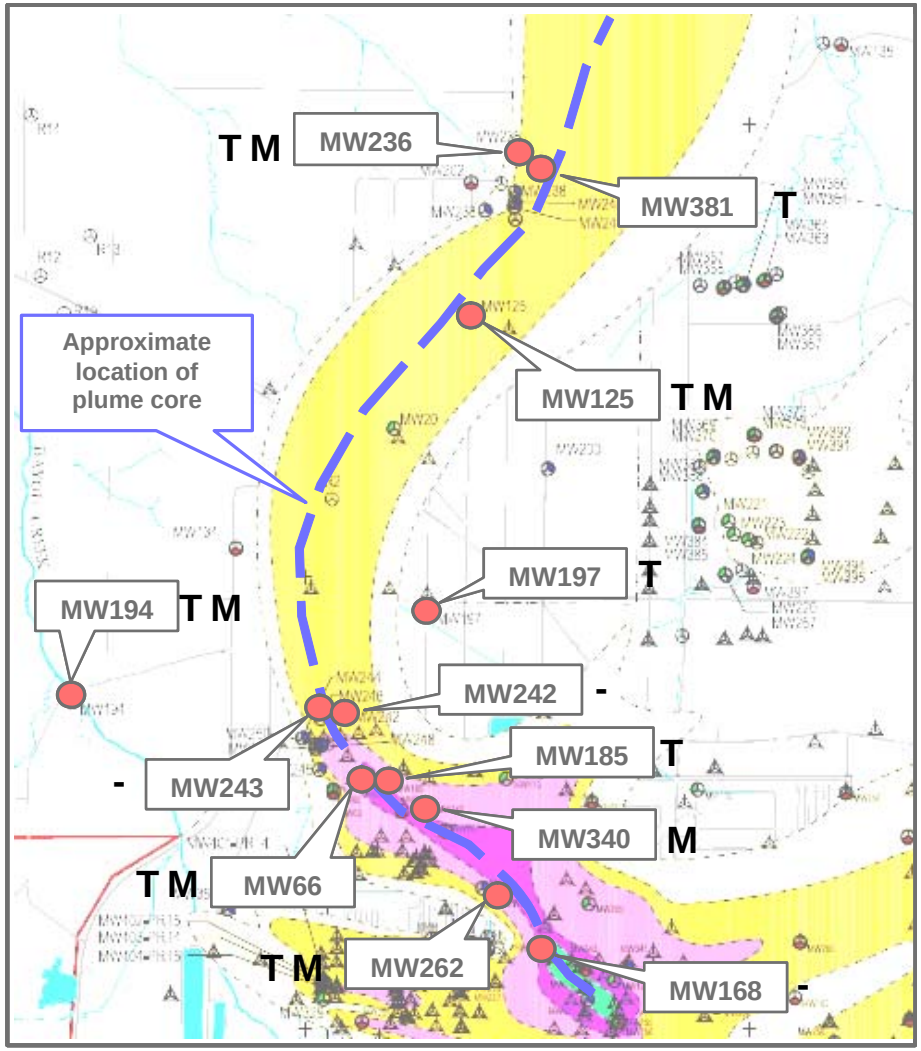
EAP Results Legend

T = positive for Toluene degrading enzyme

M = positive for Methane degrading enzyme

Blank = not ID'ed*

*not ID'ed in qualitative results and/or did not meet 10^4/mL quantitative criteria



Stable Carbon Isotope (SCI) Background

1. Carbon in TCE molecule
2. Carbon in TCE molecule contains stable* carbon isotopes carbon-12 (^{12}C) and carbon-13 (^{13}C)
3. The weight of a ^{13}C atom is greater than the weight of a ^{12}C atom

*"stable" indicates isotope does not undergo radioactive decay

Stable Carbon Isotope (SCI) Background

4. Ratio of carbon-13 to carbon-12 ($^{13}C/^{12}C$) is specific to every material containing carbon, including TCE source material
5. Microbes prefer to utilize the "lighter" ^{12}C isotope in metabolic processes
6. If biodegradation is occurring then the ratio of carbon-13 to carbon-12 ($^{13}C/^{12}C$) increases in the remaining TCE

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Phase III – Stable Carbon Isotope Investigation

Stable Carbon Isotope (SCI) Evaluation

1. Pair each up-gradient well with a down-gradient well along plume flowpath
2. Measure the ratio of carbon-13 to carbon-12 ($^{13}C/^{12}C$) in up-gradient well TCE
3. Measure the ratio of carbon-13 to carbon-12 ($^{13}C/^{12}C$) in down-gradient well TCE
4. Determine if the ratio of carbon-13 to carbon-12 ($^{13}C/^{12}C$) in down-gradient well is greater than that of up-gradient well

Stable Carbon Isotope (SCI) Results

- 70% of SCI well-pair comparisons showed an increase in the carbon-13 to carbon-12 ($^{13}C/^{12}C$) ratio in the downgradient well
- The increase in the carbon-13 to carbon-12 ($^{13}C/^{12}C$) ratio in the downgradient wells supports the occurrence of biodegradation along the plume flowpath
- Provides third line of evidence that biodegradation is occurring

Conclusions

- Three lines of evidence for occurrence of aerobic-cometabolic TCE degradation in RGA:

I. Decrease in concentrations of TCE along plume along plume flowpath (decrease > ^{99}Tc)
   - First-order degradation rate calculation

II. Positive Enzyme Activity Probe results provide evidence that co-metabolism is occurring & contributing to TCE degradation

III. Stable Carbon Isotope well-pair evaluations support occurrence of co-metabolism in Northwest Plume

Conclusions

- Aerobic co-metabolic degradation of TCE is occurring in the RGA
- Rate of TCE degradation in dissolved phase NWP is attributable in some degree to co-metabolism.

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Phase II – Aerobic Degradation Investigation

Aerobic BioDegradation Recommendations

1. Conduct study to quantify rate of co-metabolism
2. Expand characterization of Northwest Plume
3. Characterize biodegradation in Northeast and Southwest Plumes
4. Reflect range of degradation rates (half-lives) in groundwater modeling
5. Evaluate potential enhancements to environment to increase degradation rate

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Phase III – Stable Carbon Isotope Investigation

Status

1. DQO process completed
2. Applied DQO to evaluation of SCI data collected in support of Phase II Aerobic Investigation
3. Future activities to be scoped

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Phase IV – Abiotic Degradation Investigation

Status

1. Compiled existing site data related to abiotic degradation process from historical activities
2. Conducted preliminary literature review
3. Future activities to be scoped