Overview of Results from the Integrated Field-Scale Subsurface Research Challenge Site (IFRC) at Rifle, Colorado

Phil Long, Pacific Northwest National Laboratory and the Rifle IFRC Research Team

ERSP PI Meeting, Lansdowne, VA 22 April 2009
Co-Principal Investigators:
Field Experiments, geophysics, Geochemistry: Ken Williams
Microbiology:
  Proteomics: J. Banfield, Mary Lipton, Bob Hettich, Nathan Verberkmoes
  In-field microarray: D.P. Chandler
  Stable Isotope Probing: Lee Kerkhof
  Lipid analysis, qPCR: Aaron Peacock
Uranium Sorption: Jim Davis
Column Experiments: Peter Jaffe
Mineralogy: Ravi Kukkadapu
Natural bioreduction: Aaron Peacock
Modeling: Steve Yabusaki

Key Collaborators:
Gene expression, metagenomes: D. Lovley
Geophysics, RTM, isotopes: S. Hubbard, Carl Steefel, Mark Conrad et al., LBNL SFA
Hydrology: Frank Spane
Sedimentology/geostatistics: Chris Murray
Database: Roelof Versteeg

Field Site Manager: Dick Dayvault  DOE Site Representative: Rich Bush
Metal Reducing Bacteria

Geobacter uraniireducens, Isolated from the Rifle Site and a Member of the Subsurface Clade I Geobacter

Lovley et al., 1991; Suzuki et al., 2002; Suzuki et al., 2003; Gu and Chen 2003; Anderson et al., 2003; Singer et al., 2007

Acetate structure

\[
\text{CH}_3\text{COO}^-
\]

\[
\text{Fe}^{2+} \rightarrow \text{Fe}^{3+}
\]

\[
\text{U}^{4+} \rightarrow \text{U}^{6+}
\]
The Rifle Integrated Field Research Challenge Site: *Goals and Objectives*

**Overall Goal:** develop a mechanistic understanding of subsurface mobility of uranium at the field scale, with emphasis on on bioreduction of U(VI)

- The ability to manipulate (extend) Fe reduction during *in situ* biostimulation
- Determine the effect of bioreduction on U(VI) sorption
- Understand and enhance post-biostimulation U removal from groundwater
- Estimate rates of unstimulated bioreduction at the Rifle IFRC
- Combine desorption and bioreduction to enhance extent of U remediation and stability of bioreduced products
- Reactive transport models that enable prediction for a broad range of alluvial aquifers
Rifle Site History

~1924 Original vanadium mill

~1957 Uranium mill (shut down Dec 1957)

~1960

Fall 1967
Well 655: Ten Years of U(VI) Conc. Data
Well 655: Ten Years of U(VI) Conc. Data

- **Date:** 2/1/97, 10/29/99, 7/25/02, 4/20/05, 1/15/08, 10/11/10

- **U(VI) Concentration (μM):**
  - MCL
  - UMTRA Standard

The graph shows the variation of U(VI) concentration over time, with data points indicating fluctuations around the MCL and UMTRA Standard levels.
Overlay of U(VI) Concentrations (mg/L)

<table>
<thead>
<tr>
<th>Hydrologic Parameters</th>
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<tbody>
<tr>
<td>Saturated Thickness</td>
<td>2.4 to 3.4 m</td>
</tr>
<tr>
<td>Hydraulic Conductivity</td>
<td>5 to 20 m/d</td>
</tr>
<tr>
<td>Porosity</td>
<td>0.15 to 0.35</td>
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<tr>
<td>Pore Velocity</td>
<td>0.3 to 0.5 m/d</td>
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<table>
<thead>
<tr>
<th>Water Chemistry</th>
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<tbody>
<tr>
<td>Uranium</td>
<td>~0.7 – 1.5 uM</td>
</tr>
<tr>
<td>pH</td>
<td>~7.0 – 7.2</td>
</tr>
<tr>
<td>Alkalinity</td>
<td>~7-10 meq/L</td>
</tr>
<tr>
<td>ORP</td>
<td>-150 to 250 mV</td>
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<tr>
<td>Dissolved Oxygen</td>
<td>0.1 to 0.7 mg/L</td>
</tr>
<tr>
<td>Fe(II)</td>
<td>15 to 50 uM</td>
</tr>
<tr>
<td>Nitrate</td>
<td>2 to 3 uM</td>
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<tr>
<td>Sulfate</td>
<td>8 to 11 mM</td>
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<tr>
<td>Sulfide</td>
<td>0.03 to 0.5 uM</td>
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</table>
Note: The La Quinta experiment runs in parallel with active biostimulation experiments to assess natural rates U(VI) bioreduction, focusing on naturally bioreduced zones in the subsurface at the site.
GEOCHEMICAL RESULTS: Big Rusty-Winchester
U(VI) comparison
Sediment colors pre- and post-biostimulation

**Pre-biostimulation**

**Post-biostimulation**
(Sulfate reduction)
GEOCHEMICAL RESULTS: Big Rusty-Winchester
U(VI) comparison
Heat map of Geobacter proteins from ground water during acetate amendment - Big Rusty, 2008

Lipton and Callister, PNNL
Little Rusty Location and Well Layout
Rifle IFRC Presentations

- **3:30 PM** Overview of Results from the Integrated Field-Scale Subsurface Research Challenge Site (IFRC) at Rifle, Colorado. Phil Long
- **3:45 PM** Assessing the Prospects for Metals Remediation During Prolonged Acetate Amendment: Results from the "Big Rusty" Field Experiment. Ken Williams
- **4:10 PM** Evolving Geochemical Conditions Drive Changes in Geobacter Physiology During Stimulated Early-Stage Uranium Bioremediation. Jill Banfield
- **4:30 PM** Uranium Release from Contaminated Sediments at the IFRC Site in Rifle, CO. Jim Davis
- **4:55 PM** Estimating the in situ Rates of Natural Bioreduction of U(VI) at the Rifle IFRC Site. Aaron Peacock
- **5:15 PM** Reactive Transport Modeling: Closing the Knowledge Gaps for Uranium in Biostimulated and Naturally Bioreduced Alluvial Aquifers. Steve Yabusaki
Rifle IFRC Posters (Boards 39 to 47)

- Microbial growth, activity, and succession in response to electron donor amendment at the Rifle IFRC: I. Results from field experiments. Lucie N’Guessan, et al.
- Microbial growth, activity, and succession in response to electron donor amendment at the Rifle IFRC: II. Results from column, and batch experiments. Peter Jaffe, et al.
- Proteomic assessment of Geobacter physiology during field-scale uranium bioreduction. Kim Handley, et al.
- Geophysical approaches for monitoring in situ bioreduction of U(VI) during Fe-reducing and sulfate reducing conditions. Kenneth H. Williams, et al.
- Estimating the in situ rates of natural bioreduction of U(VI) at the Rifle Integrated Field-Scale Subsurface Research Challenge (IFRC) Site. Aaron Peacock, et al.
- Uranium desorption from contaminated sediments at the IFRC site Rifle, CO: from batch to field. Patricia Fox, et al.
- Sedimentology, mineralogy and geochemistry of the Rifle IFRC alluvial sediments: implications for in situ bioremediation and long-term behavior of U(VI) in groundwater, Ravi Kukkadapu et al.
- Reactive Transport Modeling of In situ biostimulation experiments at the Rifle IFRC: progress to date and remaining knowledge gaps. Steve Yabusaki et al.
Collaborator Presentations/Posters

- Lovley Posters: Tues. Miletto et al. (Gene expression), #36; Wed. Fang et al. (*In silico* modeling #28)
- LBNL SFA Posters: Wed. Hubbard Overview #5; Steefel #8
- SLAC SFA Poster: (Wed. Bargar #10A), Biogenic Uraninite stability presentation Thursday 9:00 AM
- Steefel: Modeling presentation (Thursday 10:30 AM)
- Hatfield: U flux presentation (Tuesday); Poster Wed #23
- Student poster Jenny Druhan et al. Sulfur isotopes, Wed #27
- Student poster Valerie Stucker et al U flux measurement resins, Wed # 38
- Rob Sanford et al. Poster: Tues: Uranium isotopic shifts with bioreduction during 2007 Winchester
- Brad Tebo et al. Poster (Tues: Mn oxidation of U(IV)-- used Rifle sediments for batch and column experiments.
Additional Information

- Rifle IFRC Website: [http://ifcrifle.pnl.gov/](http://ifcrifle.pnl.gov/)
- Annual report copies available at poster session