Field Studies to Assess Biostimulation for Remediation of Radionuclides and Heavy Metals at an *in situ* Leach Mine Site

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School of Energy Resources

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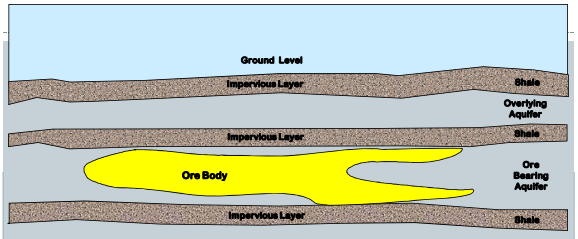
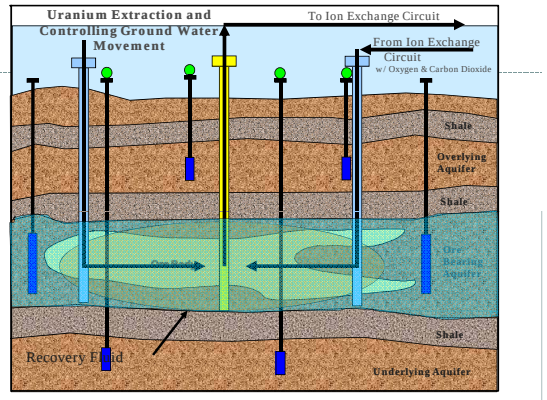
Geology and Wellfield Development



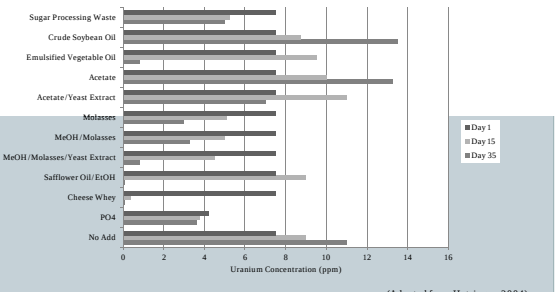
- The ore occurs at depths of several hundred feet, the extent is determined by surface drilling.
- Ore is typically confined by impervious shale.
- After deposit delineated, an extraction plan is prepared and grids of injection and production wells are installed.



Traditional Restoration Strategies

- Reverse Osmosis Water Sweeps
  - Remove extra mining lixiviant, TDS
  - Remove some Uranium (VI)
- Chemical Treatments
  - Attempt to reestablish reducing environment
    - i.e. Hydrogen Sulfide or Sodium Sulfide
- Very expensive, large consumptive water loss
- Evidence of rebound after treatment-U not valence reduced
- Can bio-stimulation improve the efficiency of restoration?

Previous Smith Ranch Highland Trial



(Adapted from Hatzinger, 2004)

Microcosm Experiment Objectives

- Examine potential biostimulants for their efficacy in promoting biological reduction of Uranium (VI) in SRH system
  - Tryptone
  - Safflower oil with Methanol
- Determine effective measurements to demonstrate biological reducing situations
  - Water chemistry analyses
  - Carbon-isotopic analyses
  - Uranium-isotopic analyses
  - Microbial community analyses

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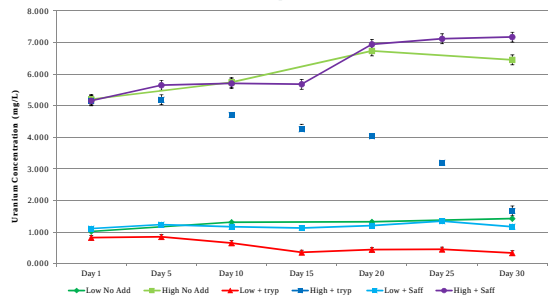
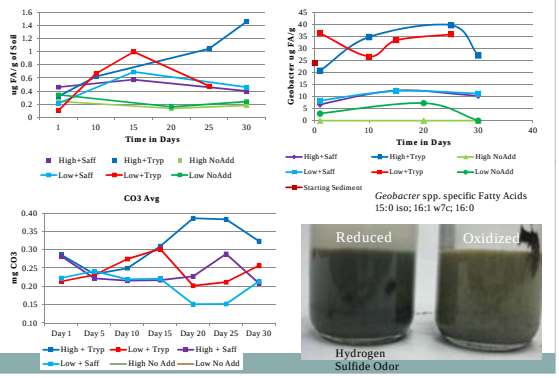
Soluble Uranium Results



*53% reduction in Low + Tryp; 68% reduction in High + Tryp

Evidence of Microbial Activity

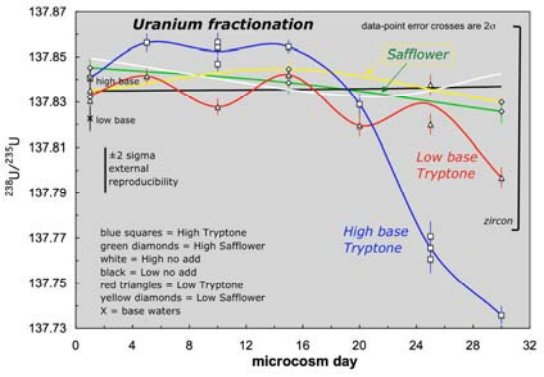


Geobacter spp. specific Fatty Acids
15:0 iso; 16:1 w7c; 16:0

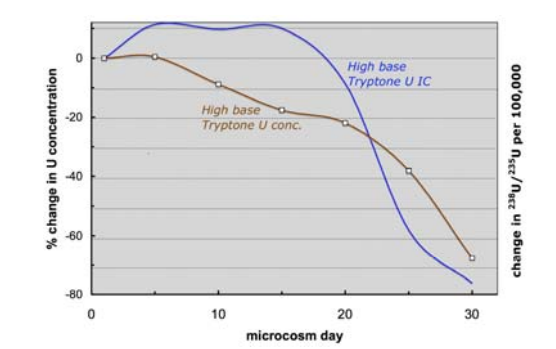
Hydrogen Sulfide Odor

Uranium Isotope Analysis Methods

- Isotopic fractionation correlates to valence reduction
- Samples of monitoring waters
- Sample load ~100 nanograms (10^{-9} gm) U
- Spiked with $^{233}U/^{236}U$ tracer
- Purification on ion exchange columns
- Sample/blank ~10,000
- Multi-collector, inductively-coupled plasma, mass spectrometry (MC-ICP-MS)



U concentration and isotopic fractionation-High Tryptone



Other Issues/Unanswered Questions from Microcosm Study

- How much tryptone is required to stimulate growth and reduction of uranium (VI)?
- Where in mining process would this type of biostimulation be the most beneficial?
- Do the monitoring metrics hold up in a continuous flow system?

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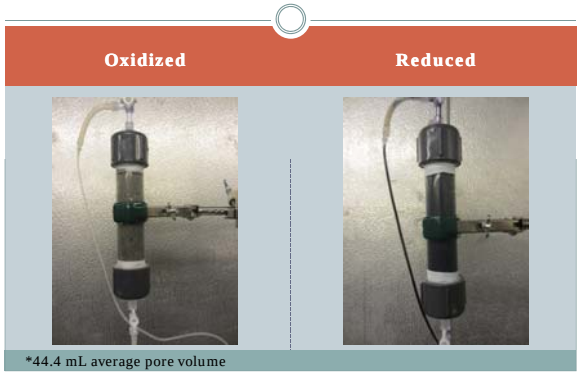
Column Study Design

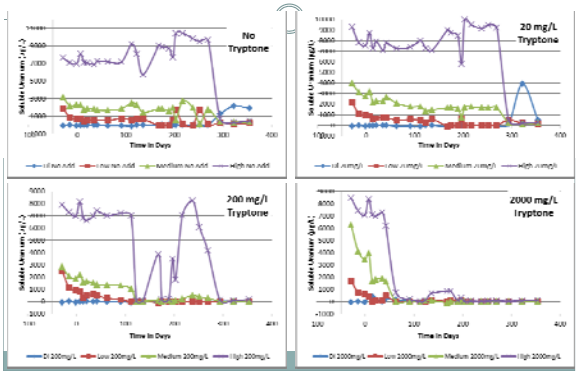
- Study was setup in a 4x4 system
  - 4 levels of tryptone stimulation
    - 2000 mg/L
    - 200 mg/L
    - 20 mg/L
    - No tryptone control (No Add)
  - 4 types of water
    - High TDS/U (7-8 ppm U)
    - Medium TDS/U (2-3 ppm U)
    - Low TDS/U (~1 ppm U)
    - Deionized control
- 16 total columns – 4 per syringe pump

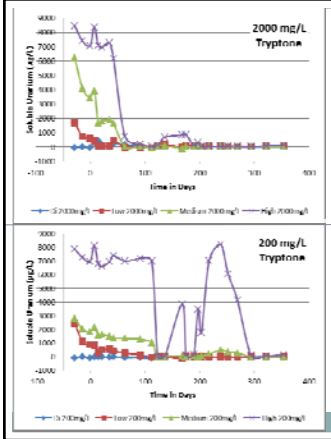
Visually Observable Changes



*44.4 mL average pore volume

Soluble Uranium Concentration Results





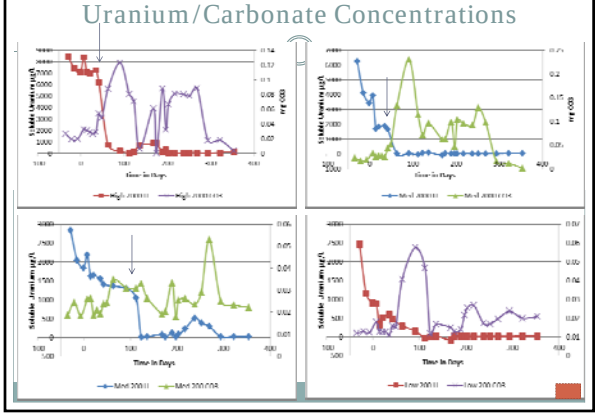
2000 mg/L Treatment

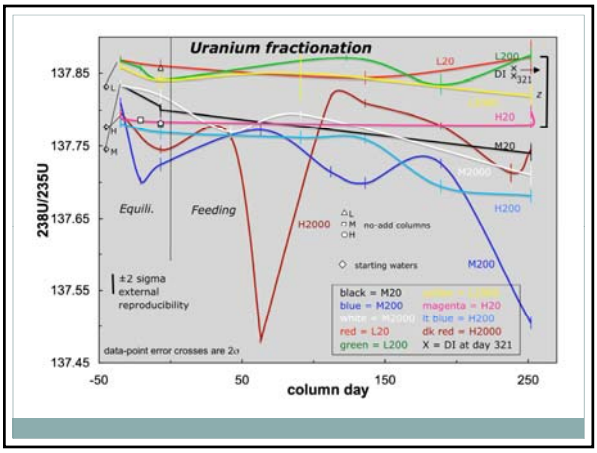
- 99.3% reduction in High 2000 treatment
- Consistent reduction beginning at ~Day 42
- Synchrotron data demonstrates high U(IV) presence in sediment

200 mg/L Treatment

- 82.6% reduction in Medium 200 treatment
  - Beginning at ~Day 112
- Despite initial reduction, clear rebound in High TDS/U water

Uranium/Carbonate Concentrations





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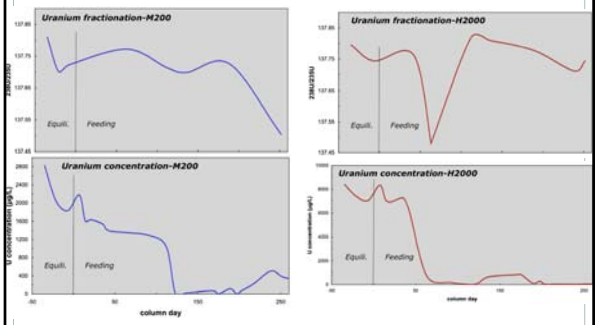
Uranium Fractionation/Concentrations



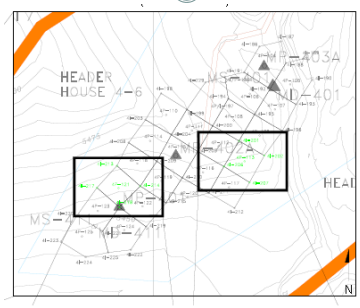
Conclusions of Column Study

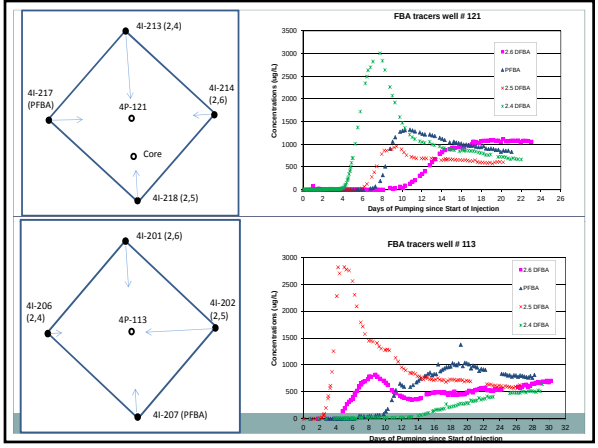
- Tryptone was effective at promoting microbial growth and reduction of uranium in a continuous flow system
  - Clogging due to stimulation not observed
  - 2ooo mg/L of tryptone shown effective at 7-8 mg/L uranium
  - 200 mg/L of tryptone shown effective at 2-3 mg/L uranium
  - 20 mg/L did not display reduction different from No Add control
- Monitoring metrics:
  - Carbonate concentration syncs well with uranium reduction activity
  - Uranium isotopic fractionations syncs well with uranium reduction activity
    - $^{238}U/^{235}U$ fractionation very sensitive to changes in U concentration, including increases

Field Trial Experiment Objectives

- Evaluate tryptone for its ability to promote biological reduction of Uranium (VI) in a field situation
- Continue monitoring metrics to determine effective measurements to demonstrate biological reducing situations
  - Water chemistry analyses
  - Carbon-isotopic/carbonate analyses
  - Uranium-isotopic analyses
  - Microbial community analyses
- Demonstrate biostimulation practicality
  - To ease some regulatory questions from previous efforts

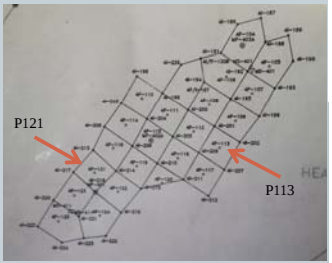
Field test for bio-stimulation





Field Trial at SRH

- Tryptone stimulation with longer-term monitoring in one field pattern in Mine Unit 4 at SRH
  - Stimulated P121 well pattern with tryptone (~80 mg/L)
    - 200kg total
  - Well pattern P113 used as control pattern
- Tryptone added Sept-Oct 2014



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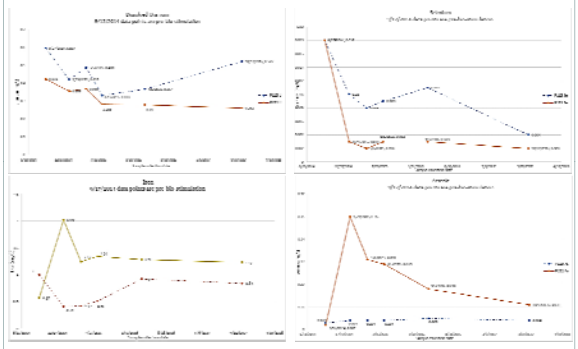
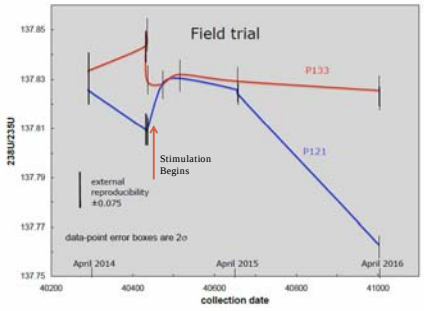
Measured Concentrations



Uranium Fractionation



Conclusions of Field Trial

- Reducing environment:
  - Overall, data suggest a reducing environment in stimulated well pattern P121
    - Selenium & uranium concentrations decrease
    - Arsenic & iron (ferrous) concentrations increase
  - Uranium isotopic fractionation is significant in stimulated environment
- Most recent data may suggest increased stability of reduced uranium in the stimulated pattern
  - More data necessary

Field Trial Thoughts, Future Directions

- Tryptone quantity added was likely too low
  - Only ~40% of the low value suggested based upon column data
- Was this the proper point in restoration to bioremediate?
  - Didn't clog any wells
  - In-lab studies show reduction at higher levels, plus bottom level in microcosms was close to 0.4ppm
- What makes tryptone effective?
  - Carry-on lab trial is providing insight

Acknowledgements

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