Field Investigations of Lactate-Stimulated Bioreduction of Cr(VI) to Cr(III) at Hanford 100H

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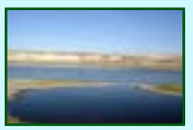
http://esd.lbl.gov/ERT/hanford100h/

Hypothesis



Lactate (HRC) injection into chromium-contaminated groundwater through an injection well will cause bioreduction of chromate [Cr(VI)] and precipitation of insoluble species of [Cr(III)] on soil particles, probably catalyzed at oxide surfaces at the field scale.

Objective

To perform field investigations to assess the potential for immobilizing and detoxifying chromium contaminated soils and groundwater using bioremediation at Site 100H at Hanford.

Specific Goals

- Designing a field test to measure the effect of lactate biostimulation on microbial community activity, redox gradients, transport limitations, and other reducing agents in comparison with our previous NABIR laboratory work.
- Establishing the rates and conditions that may cause areoxidation of Cr(III) to Cr(VI) following biostimulation
- Providing design criteria for full-scale deployment on in situ Cr(VI) bioreduction via lactate stimulation for use at DOE sites

Types of Research Performed

•Drilled and equipped two new boreholes a field site

• Evaluated pre-test (background) conditions.

• Developed an initial conceptual model of background conditions

• Microbial and lactate-induced treatability studies.

• Geophysical characterization and monitoring

• Hydraulic measurements.

• Evaluated causes for the incomplete Cr(VI) bioreduction and potential Cr(III) reoxidation

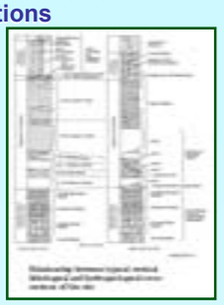
Cr(VI) Bioremediation using lactate/polylactate (HRC™)

- Hydrogen Release Compound (HRC™), when injected into chromium contaminated groundwater, will generate electron donors like lactate and hydrogen for microbial production of reducing conditions, which, in turn, stimulate the rapid precipitation of a Cr(III) solids
- Cr(VI) can also be directly reduced to Cr(III) by some bacteria, when HRC is supplied as an electron donor
- HRC also stimulates microbial reduction and production of species that can chemically reduce Cr(VI) to Cr(III) like Fe(II) and hydrogen sulfide.
- The reduction process caused by adding lactate (produced by HRC) and its breakdown products, causes the microbial population to remove the oxygen, nitrate, sulfate and other competing electron acceptors, which, in turn, depresses the redox potential in the aquifer, affecting the transformation of Cr(VI) species to Cr(III) species, which are precipitated on soil particle surfaces.

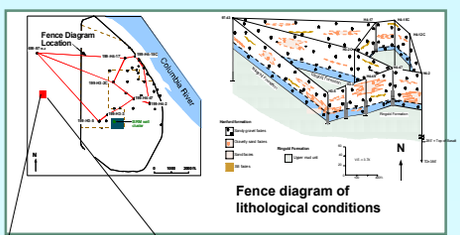
Factors affecting Cr(VI) Bioremediation

Aquifer geochemistry (inorganic common anions and cations, Eh, pH, temperature and DO), nitrate, oxidation conditions caused by recharge of infiltrating water or water from the river and the presence of manganese oxide.

Hanford 100H Site Geological, Hydrological, and Geophysical Conditions



Distribution of chromium in groundwater, Hanford100D and 100H areas, 1994



Fence diagram of lithological conditions

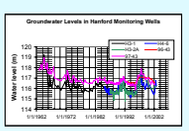
Field site

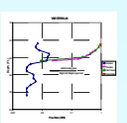
Photographs of cores (diameter is 4 in.), Well 699-94-44

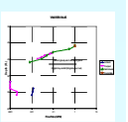
38.5 ft
Hanford gravelly sand

54 ft
Ringold silt

Hydrological Measurements

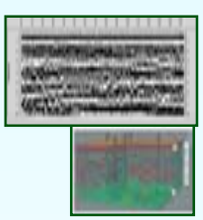


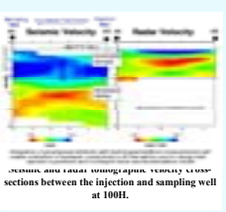




Concentration measurements (PNNL data)

Geophysical measurements



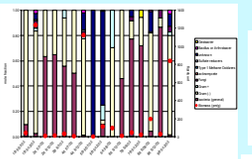


Surface GPR measurements for mapping geologic data

Seismic and radar tomographic velocity cross-sections between the injection and sampling well at 100H.

Surface GPR imaging at Hanford 100H
- Mapping water table
- Assessing spatial variability
- Delineating key interfaces between hydrostratigraphic units

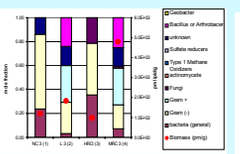
Results of Laboratory Microbial and Treatability Study of Cr(VI) Biostimulation



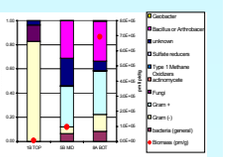
Types of Microbial Analyses:
- Phospholipid fatty acid analyses (PLFA),
- Terminal restriction fragment length polymorphisms (TRFLP),
- Clone libraries,
- Direct cell counts, and
- 16s rDNA microarray analysis

Phospholipid fatty acid (PLFA) analysis of sediments (Well 699-94-45). Left vertical axis: fractions of constituent microrganisms. Right vertical axis: viable biomass concentration (picomole/g).

Sample Number	Depth (ft)
1B	37.5-38.0
2A	40.5-41.0
3B	42.0-42.5
4A	43.0-43.5
5B	47.0-47.5
6A	50.0-50.5
7B	52.0-52.5
8A	55.0-55.5
9B	56.5-57.0

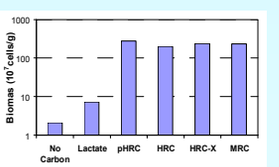


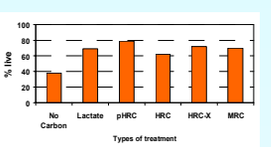
Results of PLFA analysis of the remediation-based enrichment of Hanford sediments: NC = no carbon; L = lactate; HRC = hydrogen release compound; MRC = metal remediation compound. All enrichments were exposed to 1000 ppb Cr(VI). Left vertical axis is fractions of constituent microorganisms, and right vertical axis is viable biomass, picomole/g.



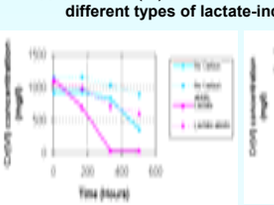
Results of PLFA analysis of R2A enrichment of Hanford sediments. Left vertical axis is fractions of constituent microorganisms, and right vertical axis viable biomass concentration, picomole/g.

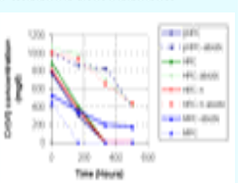
Biomass from direct microscopic cell counts in Hanford sediments after 3 weeks of incubation period





Decrease in Cr(VI) concentration with time as affected by different types of lactate-induced bioreduction





Lab experiments show that HRC in the pore space DRAMATICALLY reduces the seismic amplitude relative to that in groundwater

Key Intermediate Findings

• Microbial populations (<10^5 cells g^{-1}) in the viable soils are probably too low for direct enzymatic Cr(VI) reduction, but after biostimulation increased typically to more than 10^8 cells/g.

• We determined the presence of several types of bacteria, including *Bacillus/Arthrobacter and Geobacter* species. These bacteria are known to:
- withstand high concentrations of heavy metals,
- metabolize recalcitrant chlorinated compounds, and
- reduce or sorb hexavalent chromium.

• Injection of lactate/polylactate (HRC™) is an effective method for Cr(VI) bioreduction in ground water

• Because Cr(VI) reduction in sediments is diffusion-rate limited, a small fraction of Cr(VI) in groundwater could remain unreduced and continue moving with the regional flow.

• Cr(VI) bioreduction could occur along with Cr reduction by Fe(II).

• The presence of dissolved oxygen within the zone of fluctuations of the water table and the existence manganese oxides could cause a small portion of Cr(III) to reoxidize to Cr(VI).

• Determination of the efficacy of bioreduction of Cr(VI) is not sufficient, and what is required is the ability to predict and impose the conditions necessary to sustain the bioreduction.

• Biogeochemical transformations of redox-sensitive chemicals in soils can be strongly transport-controlled and localized.

• Cr(VI) can precipitate with Ca in localized zones, decreasing Cr(VI) mobility.

• The natural pH/Eh conditions of an aquifer favor the predominance of Cr(III) under equilibrium conditions.

• Understanding of hydraulic, geochemical, and microbial conditions necessary for maintaining complete bioreduction of Cr(VI) and a long-term stability of Cr(III) in soils is essential for designing effective strategies for reducing environmental risk.

Collaborators

• PNNL provides:
- Hanford site support and interaction with other Hanford site projects.
- A link to promote the public and regulatory acceptability of bioremediation for metals and radionuclides.

• Fluor Hanford performed drilling and coring

• Regenesis is the industry partner, lending their expertise in bioremediation products. http://www.regenesis.com/

Drilling of Well 699-94-44, May 2003.

Benefits to DOE

- Develop data and models for the redox chemistry of chromium in the subsurface environment, and information to support chromium remediation and treatment.
- In-situ chemical reduction of Cr(VI) in contaminated groundwater is expected to be a rapid and cost-effective remediation action.
- Anticipated cost savings are approximately 30-80% over accepted cleanup methods such as pump-and-treat.

Acknowledgement

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Victor Gruol (LBNL) and Bruce Bjornstad (PNNL) participated in field work

Selected Publications

Hazen, T.C., D. Joyner, S.Borglin, B.Faybishenko, J.Wan, T.Tokunaga, M.Conrad, C.Rios-Velazquez, J.Malave-Orengo, R.Martinez-Santiago, M.Firestone, E.Brodie, PE. Long, A.Willet, and S.Koenigsberg, Functional Microbial Changes During Lactate-Stimulated Bioreduction of Cr(VI) to Cr(III) in Hanford 100H Sediments, Abstract submitted to the Fourth International Conference "Remediation of Chlorinated and Recalcitrant Compounds, May 24-27, 2004.

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Project website: http://esd.lbl.gov/ERT/hanford100h/