Joseph Harrington, VP, Mining & Metals
Guaranteed Business Solutions
ARCADIS Technology

- US Pat. 5,632,715 Immobilization of heavy metals in waste stacks/zones
- 5,710,361 Immobilization in earth materials (CIP of 715)
- 6,196,765 Inhibiting AMD by displacing oxygen in rock heaps (includes underground workings)
- 6,350,380 In Situ Treatment of pit lakes
- 5,554,290 In Situ Reactive Zones
Metals Patents (‘361 & ‘715)

• Claimed process is one action step:
  – **Add a microbial nutrient**
  – Can be conveyed in a **treatment liquid**
    • Either percolated, injected, pooled
  – Can be conveyed in a **waste liquid**
    • Such as a tailings deposition line, recirculated waste water or land application disposal
  – Must be at a concentration and in a form that stimulates bacteria to generate microbial sulfides, which reacts with a metal to form MeS, and inhibits one or more (same or other) metals’ migration.
• Microbial nutrient not limited to carbohydrates, and sulfate is not required to be added
Sweetwater Uranium Mine Pit Lake

- 1.3 billion gallons contained in 60 acre pit lake
- 0.3 billion gallons contained in backfill zone
- 16 years filling (1983)
- Regional groundwater sink
- Regulated under WY livestock/wildlife standards
Remediation Objectives

• Selenium
  – 453 ppb vs site standard 50 ppb
  – 98% selenate (HSeO$_3^-$)
• Uranium
  – 8.4 mg/L vs. site standard 5 mg/L
  – U$^{6+}$ (UO$_2^{2-}$) carbonate species
• Stable ecosystem
Monitoring

- In Situ
  - pH
  - temperature
  - redox
  - dissolved oxygen
- Water quality
  - selenium, uranium, TOC
  - nitrate, sulfate, bicarbonate, iron, and manganese
Limnology: Lake Mixing

Day 0 = September 9, 1999
Treatment: October 19-23, 1999
Oxidation-Reduction Potential

Volts

1.5 meters
6 meters
11 meters
14 meters

Pit Lake During Treatment

- Denitrification (fine bubbling observed during week 1)
- Reddish color/foam related to selenium reduction (week 2)
- Reddish color/foam related to selenium reduction (week 3)
- Lake tan to brown color, uraninite precipitation (week 4)
Selenium Treatment Progress

Se^{6+} + 6 \text{ electrons} \Rightarrow \text{Se}^{0} (s)

Treatment Goal = 0.05 mg/L
Elemental Selenium Formation

Sweetwater Pit Lake
4 weeks post-treatment

Close up
Pit Lake Uranium Results

Treatment phase: 10/99 to 1/00

Post-closure monitoring began January 2000

U⁶⁺ +2 electrons => U⁴⁺ (UO₂(s))

Treatment Goal = 5 mg/L
Algae Organic Carbon Productivity
(Shown by Diurnal Fluctuations in Surface Water Dissolved O₂)

\[ 6 \text{CO}_2 + 6 \text{H}_2\text{O} + \text{sunlight} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6 \text{O}_2 \]
Newmont – San Luis Pit Backfill/G. W.
Sulfate and Metals Precipitation at San Luis

• In situ sulfate reduction began July 2000
• Sulfate removal from 1,500 to less than 250 was primary goal
• Iron was initially reductively dissolved by sulfide (initial iron concentration was less than 1 mg/L)
• Dissolved iron provided the metal with which sulfate was removed to a solid phase:
  \[ \text{Fe}^{2+} + \text{HS}^- \rightarrow \text{FeS}↓ + \text{H}^+ \]
Sulfate Reduction

Sulfate (mg/L)

BF-7R
BF-10
BF-12

Jun-00
Sep-00
Dec-00
Mar-01

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Production of Sulfide

Sulfide (mg/L)

BF-7R
BF-10
BF-12

Jun-00
Sep-00
Dec-00
Mar-01

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Precipitation of Copper

Copper (mg/L)

13-Jul-00 11-Sep-00 10-Nov-00 9-Jan-01
Iron: Reductive Dissolution and Re-Precipitation
Brewery Creek Heap Treatment

• Cyanide additions to the 9MM ton heap leach occurred from 1997 – 12/01

• Nutrient phosphate was added upon leach cessation to enhance native organisms to couple ammonia oxidation to metals reduction and biomass formation

• Bioreductants were then added throughout the summer 2002 to further reduce metals in microenvironments and these precipitated metals were encapsulated within the heap

• Water quality attained Water License land application standards in late summer – 2002 and 50,000 m³ were discharged to surface
Biomass Formation
Cyanide and Ammonia

- WAD CN
- Ammonia (mg/L)

Graph showing the concentration of Cyanide and Ammonia from November 2001 to November 2002.
Copper and Nickel

Copper, Nickel (mg/L)

Nov-01 Mar-02 Jul-02 Nov-02

Ni
Cu

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Mercury

Mercury (mg/L)

ARCADIS
Bioreduction in Infiltration Field
Newmont Hollister Mine, Leach Pad Drainage Treatment
Infiltration Field Development

Vegetation

Heap

Dosing Tank

Organic Carbon Tank
Automated Dosing Detail

- 8,000 gallon alcohol tank
- All dosing systems battery operated
- Battery recharged by solar energy
- Tank refilled once per 3-5 years
Leachate Disposal Injection Technology

- Drainage from gold heap leach treated by adding organic carbon and infiltration into a leach field.
- This leach field has successfully disposed of the heap drainage at 10 gpm for 4 years without impact to GW.
- Samples taken 40 feet below the infiltration field indicate no impact of constituents of concern to waters of the State of Nevada.

<table>
<thead>
<tr>
<th>Species</th>
<th>Heap</th>
<th>40’ below leach field</th>
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<tbody>
<tr>
<td>WAD CN</td>
<td>0.34</td>
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<td>Nitrate</td>
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<tr>
<td>pH</td>
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<td>8.2</td>
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ARCADIS Sites & Experience

• 130 Sites across US and Europe creating sulfate-reducing conditions in situ

• Species treated include divalent metals, sulfate analogs, radionuclides (U, Tc, Po, Pu), Chlorinated solvents (TCE, PCE, 1,2 cis DCE, CT)

• Subsequent encapsulation in iron sulfide matrix can prevent mobilization of arsenic, uranium and amphoteric species that are unstable in changing pH or [HS⁻] conditions.

• ARCADIS places itself at risk and guarantees water quality improvements based on this extensive portfolio of experience, and can provide substantial financial assurance and bonding through the application of these cutting edge technologies for mine sites throughout North America