“Heap Leach Design for Success – A Case Study”

Low-Grade Uranium Dump and Heap Leach Technical Meeting

March 29 – 31, 2010

International Atomic Energy Agency
Nuclear Fuel Cycle & Materials Section
Vienna International Center, Wagramer Strasse 5
Vienna, Austria

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OBJECTIVES

- Present a CASE STUDY of a small, but very efficient, low-grade (0.04%) uranium heap leach,
- Discuss some of the procedures and disciplines applied, and then
- Present some improvements to heap leaching that have occurred the last 30 years, which
- Clearly have great potential to contribute to modern day uranium heap leaching.
Some Observations from 35+ years of experience with HL

1. “A heap leach is only as good as its conceptual design is correct”, and that

2. “It is an inefficient process made efficient with the judicious use of time and space”, and finally,

3. “The result of not paying attention to all the details is about a 10% to 20% under-performance relative to the projected production.”
Bluebird Copper Mine –
Circa 1975

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Bluebird Mining Technique
Bluebird Heap Construction
The Very Reliable
OLD RELIABLE

Circa 1972
Old Reliable – Final Terracing
Big Mike – Post Blast
Naturita Uranium Tailings Site
~550,000 mt @0.043% $U_3O_8$

Circa 1976
Process Development Test Work

• Resource Evaluation

• Comprehensive Preliminary Testing Program
  • Column Testing

• Key Design Issues
Key Findings

• *Fines highly segregated, and*

• *related to moisture content,*

• *therefore, blending would be critical.*

• *Strong acid cure best means of controlling pH*
Key Findings, (cont.)

• **Too high of moisture in agglomerates reduces permeability, and most importantly**

  • **that the leached residue was not free-standing at a low level of saturation.**

  • **The acid-cure solubilized most of the uranium in agglomeration, leading**
Key Findings, (cont.)

- to a three-stage leaching (washing) scheme.

- Pilot SX tests indicated a high volume of “crud”, leading to,

- an activated carbon adsorption treatment of the PLS
Particle Size Distribution

Naturita Head Sample

Particle Size Distribution (Wet Sieved Head Sample)

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$U_3O_8$ Mass Distribution

Naturita Head Sample

% $U_3O_8$ by Fraction in Feed

% $U_3O_8$

Particle size ($\mu m$)

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# Column Test Conditions

<table>
<thead>
<tr>
<th>Sample</th>
<th>Naturita Tailings</th>
<th>Durango Tailings</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Column Dimensions:</strong></td>
<td>150 mm dia. x 6 m D</td>
<td>2.4 m dia. x 6 m D</td>
</tr>
<tr>
<td>% $U_3O_8$:</td>
<td>0.044%</td>
<td>0.046%</td>
</tr>
<tr>
<td>% $V_2O_5$:</td>
<td>0.31%</td>
<td>0.47%</td>
</tr>
<tr>
<td>% Moisture:</td>
<td>6.5</td>
<td>11.9</td>
</tr>
<tr>
<td>$H_2SO_4$, kg/t:</td>
<td>50.5</td>
<td>58</td>
</tr>
<tr>
<td><strong>Cure time, hrs:</strong></td>
<td>18</td>
<td>8 days</td>
</tr>
<tr>
<td><strong>Cure Temp, C:</strong></td>
<td>15.5 - 35</td>
<td>35+</td>
</tr>
<tr>
<td><strong>Wash Solution, pH:</strong></td>
<td>1.0 - 1.5</td>
<td>1</td>
</tr>
<tr>
<td><strong>Wash Solution, temp.:</strong></td>
<td>Ambient</td>
<td>Ambient</td>
</tr>
<tr>
<td><strong>Irrigation rate:</strong></td>
<td>3 to 5 L/hm²</td>
<td>3 to 6 L/hm²</td>
</tr>
</tbody>
</table>

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% $\text{U}_3\text{O}_8$ Recovery

![Graph showing % Recovery vs. kl Solution/t Ore for different Ore sizes](image)
**PLS grade**

![Graph showing PLS grade](image-url)
Staged-Washing Circuit

From tailings preparation by truck and distributing conveyor

Raffinate Leach | middlings Leach | pregnant Leach | curing Area

Acid

Raffinate Solution Pond | middlings solution Pond | pregnant Solution Pond

0.01-0.03 gpl $U_3O_8$ ph 1.8
0.2-0.3 gpl $U_3O_8$ ph 1.8

Pregnant solution to SX Plant
0.7-1.0 gpl $U_3O_8$ ph 1.9 - 2.1

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Naturita Tailings Site
Reclaiming and Blending Strategy
Ore Preparation Site
Ore breaking and Blending
Ore Preparation Site
Reclaiming and Agglomerator Feed
Ore Preparation Site
Agglomerator
Modified Vat Loading
Spreader Conveyor
Modified Vat Loading
Spreader Conveyor
First Vat Under Leach
Flood Irrigation
Flood Irrigation
Three-Stage Solution Collection
Three-Stage Solution Ponds

- Raffinate
- Middling, and
- PLS
Naturita Process Site
Circa 1979

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SX Mixer / Settlers
$U_3O_8$ Extraction Mixer
Yellowcake Press
Yellowcake slurry
Yellowcake slurry transport tankers
Leach Performance

Mass Balance

Extraction and Washing Efficiency
## Uranium Mass Balance

### Mass Balance:

<table>
<thead>
<tr>
<th>Mass Balance</th>
<th>$U_3O_8$</th>
<th>% Distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total kg to Leach</td>
<td>235,021</td>
<td>100.0</td>
</tr>
<tr>
<td>Total acid soluble kg to Leach*</td>
<td>202,004</td>
<td>86.0</td>
</tr>
<tr>
<td>Actual kg solublized by acid cure**</td>
<td>185,496</td>
<td>78.9</td>
</tr>
<tr>
<td>kg in Residue</td>
<td>49,525</td>
<td>21.1</td>
</tr>
</tbody>
</table>

### Accountability:

<table>
<thead>
<tr>
<th>Accountability</th>
<th>Amount</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production (kg)</td>
<td>173,161</td>
<td>73.7</td>
</tr>
<tr>
<td>Soluble loss in Heap (kg)</td>
<td>5,227</td>
<td>2.2</td>
</tr>
<tr>
<td>Bleed stream losses (kg)</td>
<td>2,149</td>
<td>0.9</td>
</tr>
<tr>
<td>Carbon filter cake (kg)</td>
<td>186</td>
<td>0.1</td>
</tr>
<tr>
<td>Clay liner losses (kg)</td>
<td>1,921</td>
<td>0.8</td>
</tr>
</tbody>
</table>

| Total Accountable extracted (kg)         | 182,644  | 77.7|
| Solublized (kg) not accounted for        | 2,852    | 1.2 |

* Hot sulfuric acid digestion residue of 0.006% $U_3O_8$

** Based on washed leached residue assay of 0.009% $U_3O_8$
Uranium Extraction Efficiency

Total acid soluble $U_3O_8$ to Leach 202,004
Actual kg solublized by acid cure 185,496
Soluble values left in residue 5,227

$U_3O_8$ Extraction Efficiency $\frac{185,496}{202,004} = 91.8\%$

$U_3O_8$ Washing Efficiency* $\frac{185,496 - 5,227}{185,496} = 97.2\%$

* Based on average wash water concentration of 0.035 g/L $U_3O_8$
Lessons Learned

• *Time, temperature and dry bulk density have significant impact on permeability,*

• *Mass flow characteristics of ore and agglomerates is a critical design parameter,* and

• *Design of solution distribution system with respect to temperature and uniformity of distribution critical.*
Current Opportunities

Materials Handling

Geotechnical Considerations

Hydraulic Characterization

Computer Modeling
Material Handling

High Volume Mobile
Grasshopper/Radial Stacking

High Volume Spreader / Reclaiming
Radial Stacking

Courtesy: Terra Nova Technologies, Inc.
Santee, CA
www.tnt.inc.com

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Spreader / Reclaim – Dynamic “Race-track” Design

Courtesy: FLSmidth RAHCO
Spokane, WA
www.rahco.com
Spreader

Courtesy: FLSmidth RAHCO
Spokane, WA
www.rahco.com

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Reclalm Bucket wheel

Courtesy: FLSmidth RAHCO
Spokane, WA
www.rahco.com
Geotechnical Considerations

Modern Testing Methods


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# Geotechnical Considerations

<table>
<thead>
<tr>
<th>Material</th>
<th>Geotechnical Tests</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Underliner - Liner System</strong></td>
<td>- Particle size distribution</td>
</tr>
<tr>
<td></td>
<td>- Atterberg limits</td>
</tr>
<tr>
<td></td>
<td>- Specific gravity</td>
</tr>
<tr>
<td></td>
<td>- Moisture-density relationship</td>
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<tr>
<td></td>
<td>- Saturated hydraulic conductivity</td>
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<tr>
<td></td>
<td>- Direct shear/triaxial shear strength</td>
</tr>
<tr>
<td></td>
<td>- Interface shear strength with geomembrane</td>
</tr>
</tbody>
</table>

## Geotechnical Considerations

| Overliner - Liner System | - Particle size distribution  
|                         | - Atterberg limits            
|                         | - Specific gravity            
|                         | - Moisture-density relationship  
|                         | - Saturated hydraulic conductivity 
|                         | - Air permeability             
|                         | - Direct shear/triaxial shear strength 
|                         | - Interface shear strength with geomembrane |

# Geotechnical Considerations

<table>
<thead>
<tr>
<th>Ore</th>
<th>Geomembrane - Liner System</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Particle size distribution</td>
<td>- Liner load test</td>
</tr>
<tr>
<td>- Atterberg limits</td>
<td>- Interface shear testing</td>
</tr>
<tr>
<td>- Specific gravity</td>
<td></td>
</tr>
<tr>
<td>- One-dimensional compression</td>
<td></td>
</tr>
<tr>
<td>- Saturated hydraulic conductivity (under load)</td>
<td></td>
</tr>
<tr>
<td>- Load-percolation</td>
<td></td>
</tr>
<tr>
<td>- Soil-water characteristic curve</td>
<td></td>
</tr>
<tr>
<td>- Direct shear/triaxial shear strength</td>
<td></td>
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</tbody>
</table>


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Hydraulic Characterization

Density Profile

Hydraulic Conductivity

Air Conductivity
Density Profile

![Graph showing bulk density vs. ore depth for Good Ore and Poor Ore. The graph indicates that bulk density increases with increasing ore depth.]

Courtesy: A. Guzman, HydroGeoSense
Tucson, AZ

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Hydraulic Conductivity

![Graph showing solution application rate vs. liquid saturation for good ore and poor ore.](image)

**Solution application rate (L/hr/m²)**

- **Good Ore**
- **Poor Ore**

**Liquid Saturation (%)**

30, 40, 50, 60, 70, 80, 90, 100

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Courtesy: A. Guzman, HydroGeoSense
Tucson, AZ

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Air Conductivity

- **Good Ore**
- **Poor Ore**

Air application rate (L/hr/m²) vs Liquid Saturation (%)

Courtesy: A. Guzman, HydroGeoSense
Tucson, AZ

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Example of not paying attention to geotechnical and hydraulic characteristics of the ore
Hydrodynamic Monitoring

Electrical Resistivity Tomography (ERT)

% Moisture

Oxidation Reduction Potential (ORP)

Temperature
Hydrodynamic Monitoring
Hydrodynamic Monitoring

% Moisture
Computer Modeling

Empirical

Phenomenological

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Empirical Modeling

Typical Spreadsheet

Shrinking Core
Phenomological Modeling

Computational flow dynamic (CFD)
In Conclusion

Ensuring a successful HL operation and performance requires paying attention to many individual disciplines, some of which are:
Critical Disciplines

Properly characterizing the “leachable” resource

Testing representative sample(s)

Understanding the physical characteristics of the Ore, and finally

Studying Historic Operations
THANK YOU FOR YOUR ATTENTION 😊

International Atomic Energy Agency
Nuclear Fuel Cycle & Materials Section
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