ISL uranium production historical review and current status
ISL versus conventional mining
Acid versus alkaline ISL
ISL cost considerations
Principal criteria and parameters for ISL mining
ISL production forecast and resources availability

Acknowledgements and references:
- ISL was developed independently in the former Soviet Union (Ukraine 1959, Uzbekistan) and the U.S.A using similar engineering and technological approaches.

- ISL mining ramp up in the USSR (Kazakhstan, and Uzbekistan) and USA.
- New ISL mines in Bulgaria, Czechoslovakia and China.
- Period of major sandstone type deposits discoveries worldwide.

- Stagnation period.
- New small ISL projects in Russia, Australia.
- ISL production at existing mines in Kazakhstan, Uzbekistan.
- ISL mines closure in the USA, Europe.

- ISL mining boom in Kazakhstan (8 new mines).
- New ISL mines in Uzbekistan, USA, Russia, Australia.

- New ISL mines in: Kazakhstan (Kharasan, Akbastau, Semizbai).
- USA (Lost Creek, Nichols Ranch, Willow Creek).
- Australia (Four Mile).
- Russia (Khiagda).
- Uzbekistan (Sugraly, N. Kenimekh, Alendy).
**Historical uranium production by deposits types and mining methods**

- **U mining from sandstone type deposits** - 52% of the 2011 world total
- **ISL U production share increased from 20% in 2005 to 47% in 2013:**
  - **Kazakhstan is the world top uranium producer since 2009**
  - **Kazakhstan 2013 ISL production 22,000tU - a 37% of world total**
  - **Other 2013 ISL production in Uzbekistan, Russia, USA, China, Australia - 5,750tU (10% of total)**
Kazakhstan 2013

Uranium ISL production and resources by companies

Kazakhstan 2013 U Production by companies

Kazatomprom 11,849, 56%
Uranium One, 4,387, 21%
Areva, 1,881, 9%
CNNC, 599, 3%
Japanese, 163, 5%

Kazakhstan 2013 U Resources by companies

Kazatomprom attributable production* in Kazakhstan - 56%, Uranium One - 21%, followed by Areva and Cameco
Kazatomprom attributable resources* in Kazakhstan - 53%, Uranium One and Cameco - 15% each, followed by Areva, Japanese and Chinese companies

*- attributable by JV share (not marketing)
Unique Chu-Sarysu Uranium province:

- Area 40,000 sq.km
- Eight deposits with 900,000tU initial resources hosted in Upper Cretaceous and Palaeogene sediments
- Main deposits – Budenovskoe, Inkai, Mynkuduk, Moinkum
- 13 operating mines with 20,000tU aggregated annual production capacity
# World top seven ISL uranium mines with annual capacity above 1,500tU

<table>
<thead>
<tr>
<th>Mine</th>
<th>Karatau</th>
<th>Akbastau</th>
<th>South Inkai</th>
<th>Inkai</th>
<th>South Moinkum</th>
<th>Tortkuduk</th>
<th>Central Mynkuduk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deposit</td>
<td>Budenovskoe site 2</td>
<td>Budenovskoe sites 1,3,4</td>
<td>Inkai , site 4</td>
<td>Inkai 1,2,3</td>
<td>Muyunkum</td>
<td>Muyunkum North</td>
<td>Mynkuduk</td>
</tr>
<tr>
<td>Owners</td>
<td>50% Kazatomprom, 50% Uranium One</td>
<td>50% Kazatomprom, 50% Uranium One</td>
<td>70% Uranium One, 30% Kazatomprom</td>
<td>60% Cameco, 40% Kazatomprom</td>
<td>51% Areva, 49% Kazatomprom</td>
<td>51% Areva, 49% Kazatomprom</td>
<td>100% Kazatomprom</td>
</tr>
<tr>
<td>Resources, KtU</td>
<td>56</td>
<td>41</td>
<td>48</td>
<td>153</td>
<td>35</td>
<td>24</td>
<td>52</td>
</tr>
<tr>
<td>Production capacity, tU/year</td>
<td>2,000 (to 3,000)</td>
<td>2,000</td>
<td>2,000</td>
<td>2,000 (to 4,000)</td>
<td>1,500</td>
<td>2,500</td>
<td>2,000</td>
</tr>
<tr>
<td>2013 production, tU</td>
<td>2,114</td>
<td>1,495</td>
<td>2,030</td>
<td>2,030</td>
<td>1,437</td>
<td>2,563</td>
<td>1,800</td>
</tr>
<tr>
<td>Full production cost, $/lbU3O8*</td>
<td>21</td>
<td>29</td>
<td>31</td>
<td>31</td>
<td>25</td>
<td>36</td>
<td></td>
</tr>
<tr>
<td>2013 cash cost $/lbU3O8**</td>
<td>11</td>
<td>13</td>
<td>18</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
</tbody>
</table>

** Uranium One 2013 Annual Report
Lower capital and operational costs:
- low power consumption,
- less equipment required,
- reduced labor costs per unit produced
- low restoration cost

Economic uranium recovery from low grade ores (200 to 800ppm);

Reduced period of project development and start-up;

Reduced radiation exposure and lower environmental impacts

Greatly reduced solid wastes (no rock damps, tailings)

ISL advantages versus conventional mining
ISL uranium mines:

- 30 of 52 currently operating U mines (58%)
- 20 of 28 in the category below $40/lb (72%)
- Total ISL mines production capacity is 42kt U (110 Mlbs U₃O₈)
- 29kt U (75 Mlbs U₃O₈) is the capacity of ISL mines in below $40/lb cost
13 of 14 mines with the lowest specific CAPEX are ISL mines
10 of such mines are in Kazakhstan
$80M is an average CAPEX estimation for 1,000tU capacity ISL mine (including $48M for processing plant)
Acid Leach Advantages

- Higher degree of uranium recovery (70-90% versus 60-70%);
- Favorable leaching kinetics (at 80% recovery, the number of pore volumes of leach solution circulated is 3-4, compared to 10-12 for alkaline solutions);
- A comparatively short leaching period of 3-5 years for acid (depending on the wellfield size, ore permeability, well pattern, etc.);
- Possibility of natural attenuation of the remaining leach solution;
- Radium is not recovered and requires no special restoration;
- Lower capital and operational project costs (next slide)

Alkaline Leach Advantages

- Uranium leaching from carbonate-bearing ores (i.e. CO2 content over 1.5-2.0%) (acid increases chemical costs and make the process non-economic);
- Lower risk of pore plugging by newly formed gypsum and gas bubbles;
- Lower concentration of dissolved solids in leaching solutions;
- No corrosion in materials and equipment (pumps).
Acid Versus Alkaline ISL Costs for a 1000t U annual capacity mine

Operating Costs

- Miscellaneous
- G&A expenses
- Personnel
- Wells construction
- Reagents, Supplies, Energy

Capital Costs

- Mobile equipment
- Buildings, infrastructure
- Reagents first load
- Processing plant equipment
- Processing plant construction
- Initial well field

<table>
<thead>
<tr>
<th></th>
<th>Acid</th>
<th>Alkaline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating cost, $/lb U3O8</td>
<td>12</td>
<td>26</td>
</tr>
<tr>
<td>Operating costs total, $M</td>
<td>27</td>
<td>58</td>
</tr>
<tr>
<td>Capital costs, $M</td>
<td>56</td>
<td>85</td>
</tr>
</tbody>
</table>

Alkaline ISL – main reasons for higher costs:

- Lower flow rate per recovery well
- Lower U concentration in pregnant solutions
- Smaller distance between recovery in injection wells (higher drill costs)
- Higher costs for aquifer restoration

Aquifer natural restoration after acid ISL due to residual solution dilution and reaction with the hosting environment

Case of environmental monitoring after pilot test at Irkol deposit (Kazakhstan)

- Four main parameters monitored (pH, sulphate ion, nitrate ion, Uranium)
- ISL exposed area decreased in 50% during four years
- Complete restoration occurred within 12 years
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lithology</td>
<td>Sands, and gravels (clay fraction below 30%)</td>
</tr>
<tr>
<td>Ore productivity</td>
<td>Above 1 kgU/m²</td>
</tr>
<tr>
<td>Depth of ore body</td>
<td>Below 900m</td>
</tr>
<tr>
<td>Aquifer thickness</td>
<td>1 to 30m</td>
</tr>
<tr>
<td>Carbonate content (CO₂)</td>
<td>Not exceed 2 %</td>
</tr>
<tr>
<td>Hydrogeology</td>
<td>Water confining beds above and below aquifer, no hydraulic connection</td>
</tr>
<tr>
<td>TDS</td>
<td>Below 10 g/dm³</td>
</tr>
<tr>
<td>Water table level</td>
<td>Above the mineralization</td>
</tr>
<tr>
<td>Hydraulic conductivity (permeability)</td>
<td>Above 1 m/day</td>
</tr>
<tr>
<td>Transmissivity</td>
<td>Above 10 m²/day</td>
</tr>
<tr>
<td>Environmental issues</td>
<td>No potable water supply</td>
</tr>
</tbody>
</table>

*- IAEA-TECDOC-1239, Manual of acid in situ leach uranium mining technology.
How to improve major ISL technical parameters?

**Main ISL capital intensive cost parameters**
- Drilling and wellfield construction (65 - 85% of CAPEX costs)
- Reagents (acid) consumption (30% of OPEX)

**Main ISL operating parameters**
- Uranium concentration in pregnant solutions
- Recovery wells flow rates
- Acid consumption

**Innovations to increase wells productivity**
- Effective drilling technique and wells construction (casing, material, pump, screen, packing)
- Optimal wellfield pattern configuration and spacing between recovery and injection wells
- Wells damage control and work over

**Innovations in leaching effectiveness and modelling**
- Geological, hydrological and ISL process 3D modelling
- New generation of PFN logging tool
- Using effective reagents and oxidants to reduce acid consumption and increase productivity
Aggregated U production in 2012 – 2030 estimated at 1.5 MtU, which is 24% of total known resources and 40% of resources below US$80/kgU category

U resources of primary uranium mines will be decreased more than two fold by 2030, more than a half of remaining U resources are in the Olympic Dam (copper is main product)

After 2020, uranium market may face shortage of low cost U resources.
Ramp up ISL U production to 2018
Decline of ISL U production after 2020 due to resources depletion and mine closure
Higher cost resources will be developed in future
It is expected that new deposits will be discovered in the coming years which will lead to additional low cost resources for ISL mining

Historical exploration expenditures versus uranium prices

- Historical correlation between exploration expenditures and uranium prices
- Current low uranium prices don’t promote investments in U exploration
- 90% of U deposits were discovered more than 35 years.
- The era of easy discoveries is over
- Recent discoveries were promoted by U market activation in mid 2000s (before Fukusima)

- Current depressed U market is not favorable for uranium exploration and new developments
How to discover uranium deposit for ISL mining?
Major exploration stages and costs

- Average historical discovery cost (in 1945-2003) for 9 major countries $1.82kgU (The Red Book retrospective, OECD 2006)
- The current inflated discovery cost is ~ $20kgU
- The medium size U deposit (20ktU) discovery cost is $40M
- Another $30M for resources and reserves delineation and estimation
- $80M - CAPEX for a 1,000tU capacity ISL mine
- Total costs $150M

Exploration requires special knowledge and expertise
- Specific complex of exploration criteria must be identified during each stage: paleoclimate reconstruction, tectonics, lithology, hydrogeology, radiology, geochemistry, alteration.
- Advanced geophysical surveying focused on stratigraphic, hydrogeological and tectonic modelling
Regions favorable for new sandstone type deposits for ISL mining

**U deposits tonnage**

- **> 200,000 t**
- **100,000 - 200,000 t**
- **20,000 - 100,000 t**

- USA: Wyoming, Texas basins
- Kazakhstan: Chu Sarysu basin
- South and Central Africa: Karoo basin
- South America: Parana basin
- China and Mongolia: Cretaceous basins
- South Australia: Frome basin
- Russia: Vitim region - Buryatia
- South and Central Africa: Karoo basin
- South America: Parana basin
- China and Mongolia: Cretaceous basins
- South Australia: Frome basin
- Russia: Vitim region - Buryatia
Good Luck in uranium exploration and in ISL mining!
# Major exploration stages for the sandstone types uranium deposits (after I. Pechenkin)

<table>
<thead>
<tr>
<th>Stages</th>
<th>Regional metallogeny study</th>
<th>Regional Prospecting</th>
<th>Detailed prospecting</th>
<th>General exploration</th>
<th>Advanced exploration</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Main target</strong></td>
<td>To identify areas favorable for redox front zones</td>
<td>To identify redox front zones and areas favorable for uranium deposits</td>
<td>Redox front zone delineation, Speculative resources evaluation</td>
<td>Deposit discovery, Inferred resources estimation</td>
<td>Mineralization delineation, resources estimation</td>
</tr>
<tr>
<td><strong>Scale</strong></td>
<td>1:2,500,000 to 1:1,000,000</td>
<td>1:500,000 to 1:200,000</td>
<td>1: 100,000</td>
<td>1: 50,000</td>
<td>1: 25,000</td>
</tr>
<tr>
<td><strong>Drill spacing</strong></td>
<td>No</td>
<td>12.8 x 6.4-3.2km</td>
<td>6.4-3.2x km</td>
<td>3.2-1.6x0.2-0.1km</td>
<td>1.6-0.8x0.2-0.05km</td>
</tr>
</tbody>
</table>

Specific factors and criteria for each stage: paleoclimate, tectonic, lithology, hydrogeology, radiology, hydrodynamics, geochemistry, microbiology, alteration.
Athabasca Basin Historic Exploration Expenditures vs Resource Discovery

Expenditures are in dollars of the day.