Primary Extraction

IAEA - INT2019
Interregional Workshop on Case Study of Conventional Uranium Production: from Exploration to Closure
October 14 to 18th, 2019, Prague, Czech Republic
Agenda

• Uranium Market Fundamentals
• Cost of Production around the Globe
• Where are the World’s Uranium Resources
• Current Mining Methods and costs
• Production capacity of the Athabasca Basin
• What are some potential new mines in Canada
Uranium Market Fundamentals

- The greatest sensitivity when assessing most uranium deposits is in understanding what market conditions will be by the time you are able to bring the deposit into production (5 to 10-year time lag).

- Compared to other metal groups, the price of uranium has been challenging over the past ten years. Gold and base metals are near or above their ten year average price, but uranium remains well below it’s average ten year price range.

- Challenging market post-Fukushima
World Production & Consumption

Source: BMO Capital Markets, WNA UxC
Australia has the largest amount of U resources, based on USD $130 per kg of U. However the “quality” of the resources in terms of grade and cost sensitivity to the price of uranium must be taken into account.
Production method

<table>
<thead>
<tr>
<th>Method</th>
<th>tonnes U</th>
<th>%</th>
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<tbody>
<tr>
<td>In situ leach (ISL)</td>
<td>29,248</td>
<td>55%</td>
</tr>
<tr>
<td>Underground &amp; open pit (except Olympic Dam)</td>
<td>20,745</td>
<td>39%</td>
</tr>
<tr>
<td>By-product</td>
<td>3,505</td>
<td>7%</td>
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Canada which is in the top 3 for Uranium Resources and production has not yet used ISR as a primary extraction method

(table is from WNA)
Uranium Mining Methods

Uranium is currently mined in one of four ways:

- In-situ leach mining – ISL [also ISR or solution mining]
- Underground with tunnels, galleries etc.
- Open pit, including surface excavations
- Heap Leach

In 2018 about 6% of mined uranium production was as a by-product from the mining of other minerals

Olympic Dam, Australia (photo courtesy of BHP)
Uranium Mining Methods:
In-situ Leach Mining (ISL)

- Sometimes may be called solution mining or ISR (in situ recovery)
- Can be acid or alkali leach solution
- Very small volume of waste generation
- Limited surface disturbance

Beverley ISL mine, Australia
Uranium Mining Methods: In-situ Leach Mining (ISL)
In-situ Leaching (ISL): Advantages

• Lower Capital Cost to first production
• Shorter lead time to production
• Lower radiation exposure
• Lower surface disturbance and no tailings pond
• No crushing or grinding required
• Lower cost for decommissioning
In-situ Leaching (ISL): Disadvantages

- Limited application due to need for specific geological features
- Ore deposit must be soluble
- Risk of ground water contamination
- Potential lower recovery of reserves
Ore Extraction

Underground mine (UG)

Where orebodies are deeper, underground mining is usually employed, involving construction of access shafts and tunnels but with less waste rock removed and less environmental impact.

Choice of mining method:

· Shape of the deposit
· Size of the deposit
· Distribution of uranium ore. Selective or non selective mining method

Important phases of underground mining:

• Ventilation: All underground mines are ventilated, but in uranium mines, extra care is taken with ventilation to minimize the amount of radiation exposure and dust inhalation.
• Ground support
• Water extraction
Underground mining

- Much smaller waste rock production volumes, frequently very little at the surface
- Smaller infrastructure footprint at the surface
- May be possible to dispose of much of the waste underground as backfill in the workings

McArthur River Uranium Mine, Canada (photo courtesy of Cameco Corporation)
Uranium Mining Methods: Underground

Note:

- Main access shaft
- Ventilation shafts
- Underground network
- Small waste piles at surface
Uranium Mining Methods: Open Pit

Open pit / surface excavations

- Relatively large footprint at the surface
- Manage stockpiles of waste rock, sub-economic ore and/or overburden
- Waste water, drainage and seepage
- May be a possibility for in-pit disposal of tailings
Open Pit Mine

Rössing (Namibia)
Heap Leach Mining

Another consideration for mining and extraction of uranium is heap leaching

- Geotechnical characteristics
- Hydraulic characteristics
- Geochemical characteristics
- Kinetics – steady state conditions
- Recovery of uranium may be lower than conventional methods
Heap Leaching

Somair (Niger)

Trekopje (Namibia)
Sample of Uranium Mine Production Costs

Sample of global production costs\(^{(1)}\)

<table>
<thead>
<tr>
<th>Mine Location</th>
<th>Cost per lb (U_3O_8)</th>
</tr>
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<tbody>
<tr>
<td>Karatsau (Kazatomprom)</td>
<td>US$8.90/lb</td>
</tr>
<tr>
<td>Phoenix/Wheeler (Denison)</td>
<td></td>
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<tr>
<td>Adateau (Kazatomprom)</td>
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<tr>
<td>Muyunkum/Yorkuduk (Orano)</td>
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<tr>
<td>Arrow (NeoGen)</td>
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<tr>
<td>Inkai ( Cameco)</td>
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<tr>
<td>McArthur River (Cameco)</td>
<td></td>
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<tr>
<td>Olympic Dam (BHP)</td>
<td></td>
</tr>
<tr>
<td>Gryphon/Wheeler (Denison)</td>
<td>US$22.82/lb</td>
</tr>
<tr>
<td>Cigar Lake (Cameco)</td>
<td></td>
</tr>
<tr>
<td>Four Mile (General Atomic)</td>
<td></td>
</tr>
<tr>
<td>Rabbit Lake (Cameco)</td>
<td></td>
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<tr>
<td>Nichols Ranch (Energy Fuel)</td>
<td></td>
</tr>
<tr>
<td>Rossing (CNMC)</td>
<td></td>
</tr>
<tr>
<td>Open Pit</td>
<td></td>
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</tbody>
</table>

Notes: (1) Chart data, including all-in costs, have been derived from UxCo’s estimates of Worldwide Production Costs as of August 2019. Phoenix and Gryphon costs are per Denison’s Pre-Feasibility Study for the project, available at www.denisonmines.com or on SEDAR and EDGAR.
Canada’s Nuclear Industry

Source CNSC
The Infrastructure Rich Eastern Athabasca Basin

Denison Land Position as of June 30, 2018

- McArthur River Mine
- Cigar Lake Mine
- Waterbury Mill (Denison 66.51%)
- McClean Lake Mill (Denison 22.5%)
- Wheeler River (Denison 90%)
- Rabbit Lake Mill
- Key Lake Mine & Mill
- Waterbury Lake (All Season Highway / Haul Road)
- Provincial Power Grid

-钩-卡特 (Denison 80%)
- Hook-Carter (Denison 80%)
- All Season Highway / Haul Road
- Provincial Power Grid
Mines and Uranium Deposits in Canada

- Canada’s uranium reserves and resources are found in Saskatchewan around the Athabasca Basin.
- Unconventional underground mining methods currently being used at Cigar Lake and McArthur River as deposits mined in the sandstone generally require ground freezing.
- The Basin has three mills and three mines, but only one mine and one mill are currently being operated at 18 M lbs./year of production.
- The annual licensed capacity of the three mills in the Basin; Key Lake (25 M lbs.); Rabbit Lake (14 M lbs.) and McClean Lake (24 M lbs.); Total 63 M lbs.
- Peak Production in 2016/2017 of approximately 36 M lbs representing less than 60% of the total milling capacity in the Basin.
Cross-Section Showing Projection of various Uranium Deposits in the Athabasca Basin – Cigar Lake

Source: NexGen Energy Ltd.
Production rate of 18 M lbs/yr of U3O8 approximately 7 M tonnes of U
Cigar Lake Operation
(source Cigar Lake Technical Report)
Cross-Section Showing Projection of various Uranium Deposits in the Athabasca Basin – Arrow Deposit

Source: NexGen Energy Ltd.
NexGen Arrow Deposit

Delivering the Clean Energy of the Future
August 2019
Detailed metallurgical study resulted in process recovery increasing to 97.6% (versus 96% in the PEA).

In addition, the ammonia strip process envisioned in the PEA was updated to an acid strip process in the PFS, resulting in the complete elimination of ammonia in the processing facility. Elimination of ammonia from the processing facility will ultimately lead to improved effluent discharge performance.
All processed waste streams can be stored in an Underground Tailings Management Facility ("UGTMF"). The UGTMF will significantly reduce the surface footprint of the Rook I project and represents continued and ongoing reclamation during operations, allowing for industry leading environmental sensitivity.

PFS test work confirmed paste fill strength meet or exceed all requirements set in the original design for a potential Paste-Backfill to be used for underground stope stability.
Denison’s Phoenix Deposit

Source: NexGen Energy Ltd.
Bringing the world’s lowest cost uranium mining method to the jurisdiction hosting the world’s highest-grade uranium deposits

ISR Mining Process\(^{(1)}\):

1. Mining solution (also known as “lixiviant”) is pumped through a permeable orebody via injection well;
2. Lixiviant dissolves the uranium as it travels through the orebody;
3. Uranium rich mining solution (also known as uranium bearing solution or “UBS”) is pumped back to surface via recovery well;
4. UBS is sent to a processing plant on surface for chemical separation of the uranium and reconditioning of lixiviant;
5. Lixiviant is returned back to well field for further production.

Denison’s Phoenix Deposit

Artificial freeze cap replicates confining layer typically required for ISR mining operations

- Parallel cased holes drilled from surface and anchored into impermeable basement rock surrounding the Phoenix deposit
- Circulation of low-temperature brine solution through cased pipes will freeze groundwater in sandstone surrounding the deposit
- 10 metre thick freeze wall, together with basement rocks will encapsulate Phoenix deposit

✓ Eliminates common environmental concerns with ISR mining and facilitates controlled reclamation

Source: Denison Mines Corp
Summary

• Supply and demand fundamentals forecast an improving market, however, there is significant curtailed production capacity ready to restart if the right economic conditions emerge. This is an important consideration when evaluating market conditions.

• There is potential for some Tier One deposits to be developed even in today’s challenging price environment.

• Primary extraction using In-Situ Recovery is the dominant world extraction method; successful application in Canada’s Athabasca Basin may represent a fundamental shift in uranium mining economics.

• Mining companies are recognizing that environmental concerns with respect to waste rock and tailings are important social license issues which require creative approaches to deal with future projects.