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OPPORTUNITIES FOR PRODUCING URANIUM WITHOUT DEVELOPING A NEW MINING OPERATION

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ABSTRACT

The current low uranium price trend makes it very difficult to justify new conventional uranium mining operations. The most common strategy to avoid conventional mining is to search for deposits amenable to in-situ leaching. However, another approach is to recover uranium as a by-product from existing or future operations producing other commodities.

Uranium has been commercially recovered as a by-product from copper concentrates and tailings, gold ores and tailings, phosphoric acid, polymetallic leach solutions, copper leaching solutions and rare earth leach solutions.

Representative commercial operations are reviewed, and current project developments and future prospects are discussed.

Keywords: Uranium, Low Uranium Price, Avoidance of Mining, By-Product Uranium Opportunities, Commercial Operations

By-Product Uranium – An Alternative Approach to New Mines

- Challenges confronting new uranium mining projects include low uranium price, escalating costs, tightening of environmental regulations, and growing community opposition.
- The most common strategy to avoid conventional mining is to search for deposits amenable to in-situ leaching.
- However, another approach is to recover uranium as a by-product from existing or future operations producing other commodities.
- In addition to avoiding the significant challenges of new mines, advantages include relatively low capex and opex, no dedicated uranium ore handling and comminution facilities, addition of another revenue stream, ability to regulate output to match market demand without shutting down, reduced environmental impact, and less closure and remediation issues.

Outline

This presentation reviews past and present uranium by-product processes and technology developments including:

- Uranium from gold ores and tailings.
- Uranium from copper sulphide concentrates and tailings.
- Uranium from phosphoric acid.
- Uranium from polymetallic leach solutions.
- Uranium from copper leach solutions.
- Uranium from rare earth leach solutions.

Uranium from Gold Ores and Tailings

- Numerous plants for the recovery of uranium as a by-product from the treatment of pyritic gold ores and tailings have operated in South Africa since 1952, making use of the close association of gold, pyrite and uranium (typically present as uraninite). Has been applied to old tailings heaps as well as fresh ore.
- The process has generally used sulphuric acid followed by IX, SX or IX/SX (referred to as Bufflex in South Africa and ELUEX in North America).
- Initially, uranium facilities were conveniently used to treat the residues from existing gold cyanidation operations. Reverse leaching (uranium ahead of gold) was introduced to avoid IX resin poisoning with cobalticyanide and also proved beneficial for gold recovery.
- Flotation has been included in various configuration for upgrading, and to provide a feed for by-product sulphuric acid generation.
- AngloGoldAshanti Vaal River Operations are treating dumps and tailings for gold and uranium recovery – only current operation in South Africa.

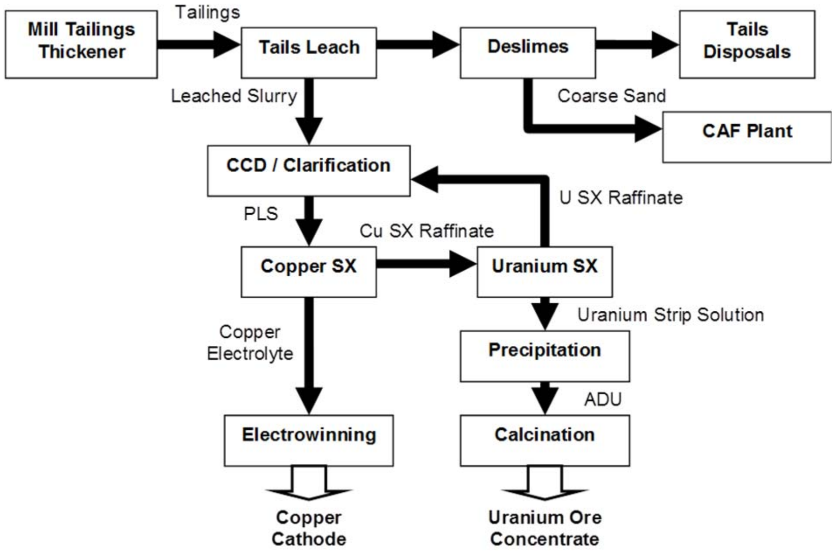
Uranium from Copper Sulphide Concentrates and Tailings

Olympic Dam Operation, BHPB, South Australia:

- Typical ore 1.8% Cu and 0.06% U3O8.
- Production 200,000 t/a Cu and 4,100 t/a U3O8 from 9 M t/a ore.
- Uranium minerals are uraninite with some brannerite and coffinite.
- Copper sulphide floatation at 75 micr. results in 85-90% uranium to tails and 10-15% to concentrate.
- Both concentrates and tails are leached for uranium recovery.
- Concentrate leaching was included to reduce uranium to an acceptable level.
- Tails leach was included to reduce uranium content and maximize overall recovery.
- Copper is recovered by SX/EW followed by uranium with SX, precipitation and calcining.
- Heap bio-leaching is currently being developed for a projected expansion.

Olympic Dam Copper/Uranium Hydromet Flowsheet

(Ref: WMC presentation, ALTA 2003)



Olympic Dam Copper/Uranium Complex

(Ref: WMC presentation, ALTA 2003)

Uranium From Copper Sulphide Concentrates & Tailings (Cont.)

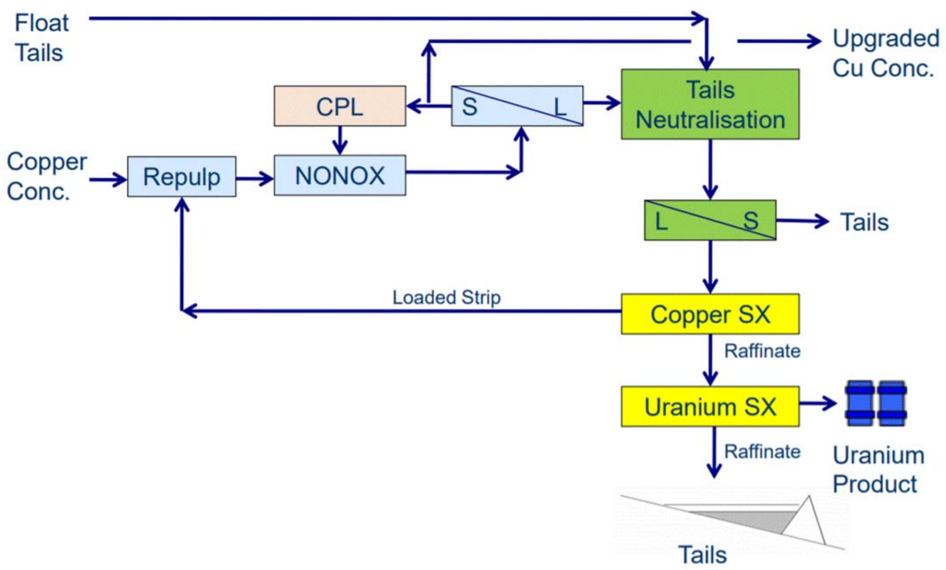
(Ref: Orway/Alchemides presentation,
Recovery of Uranium from Unconventional Sources, IAEA, 2006)

Copper Concentrate Upgrading Processes:

- OMC (Orway Mineral Consultants), Perth, Australia, have developed a process for the recovery of uranium from copper concentrates.
- The objective is to reduce the uranium content in the product to meet marketing and shipment specifications as well as to yield a valuable by-product.
- The process involves:
  - Copper pressure leaching with low intensity pressure oxidation.
  - NONOX autoclave leach where a metathesis reaction replaces iron with copper to form copper sulphide minerals.
  - Copper concentrate is upgraded, and uranium is recovered by SX from solution.
- Ausenco have developed a similar process.

OMC Process Flowsheet

(Ref: OMC/Alchemides presentation, IAEA Technical Meeting, 2014, courtesy OMC)



Uranium From Copper Sulphide Concentrates and Tailings (Cont.)

Palabora Operation, South Africa:

- Operated 1971-2001.
- Uranium was recovered from a heavy minerals gravity concentrate produced from the copper sulphide flotation tails at a grind size of 50% passing 75 microns.
- Ore contained 0.004% U_3O_8.
- Production was about 100 t/a U_3O_8.
- Uranium mineralization was uranothorianite.
- Gravity circuit comprised desliming, Reichert cones and shaking tables.
- A hot nitric acid leach at 70°C was used to avoid leaching zirconium present as Baddeleyite (ZrO_2).

Uranium From Phosphoric Acid

- Phosphate rock has an average uranium content of 50 to 200 ppm; typical uranium extraction is 85-90% into phosphoric acid.
- Typical uranium in phosphoric acid 150-175 ppm U_3O_8.
- 13,000 t/a U_3O_8 could in principle be recovered each year from approx. 400 existing phosphoric acid plants worldwide.
- Numerous commercial plants have operated in USA (8 plants in Florida, Louisiana), Canada, Belgium, Jordan, Kazakhstan, Spain, Israel, Taiwan and China.
- No known current commercial operations.
- Previous projects used SX based processes.
- PhosEnergy Process using IX is under development by Urtek, Australia.

SX Based Processes

- SX extractants used:

D2EHPA:	di(2-ethyl-hexyl) phosphoric acid
TOPO:	tri-octyl phosphine oxide
MOPPA:	mono-octyl-phenyl phosphoric acid
DOPPA:	di-octyl-phenyl phosphoric acid
OPPA:	di-octyl pyrophosphoric acid
CPE:	capryl pyrophosphoric acid

- Oak Ridge National Laboratory, Tennessee played a major role and developed the D2EHPA-TOPO (most commonly used) and MOPPA-DOPPA processes.
- Arafura Resources have developed a process for recovery of uranium and removal of Iron from phosphoric acid containing HCl, using one proprietary solvent named FEU, for their Nolans Rare Earths-Uranium project in Australia (Ref: Arafura-Bateman paper, ALTA 2010).

IX Based Processes

- IX processes have been tested (e.g. chelating resins; resin impregnated with D2EHPA-TOPO) by a number of organizations in the 1970s and 1980s to reduce cost, avoid the phase disengagement problems in SX, avoid post-treatment of the acid, and improve environmental impact and safety. No commercial plants eventuated.
- ANSTO, Australia, have carried out more recent testwork and found that extraction of uranium with aminophosphonic (chelating) resins is a good option, extracting both U(VI) and U(VI) at 30% P_2O_5.

PhosEnergy Process

- New IX based process, a joint development between PhosEnergy Limited (27%), a wholly owned subsidiary of Uranium Equities Ltd, and Cameco Corporation (73%) through Colorado registered Urtek, LLC.
- Developed in association with ANSTO, Lucas Heights, Australia.
- Said to be a simpler and lower cost than previous processes with high recovery and improved environmental impact.
- Large scale pilot plant program has been completed, and a modular demonstration plant was operated at the site of a US-based fertilizer producer in 2015, connected directly to their Filter Grade Acid (FGA) stream achieving >92% recovery.
- A prefeasibility study indicated that, while the operating costs of the process were very attractive, the capital cost was too high for depressed uranium market conditions. A programme of work was initiated to reduce capital and/or operating costs

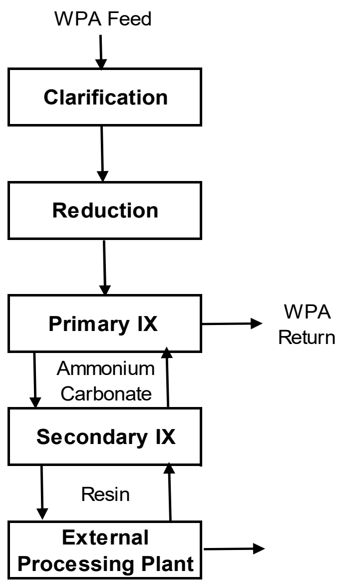
PhosEnergy Process (Cont.)

- An electro-reduction process was developed to reduce ferric iron to ferrous to avoid iron loading on the resin without chemical addition.
- A two-stage IX system is included. Aminophosphonic resin is used for primary IX with ammonium carbonate elution, while a conventional strong-base resin is used in secondary IX.
- The loaded secondary resin is sent to an external processing plant for elution and product recovery.

References:

- Uranium Equities Presentation, AUSIMM 2009 Uranium Conference.
- Inception Group Presentation, AUSIMM 2013 Uranium Conference.
- PhosEnergy Financial Report – 31st December 2016.

PhosEnergy Process Flowsheet



Uranium From Polymetallic Leach Solutions

- Talvivaara Heap Bioleaching Operation, Finland .
- Recovers nickel, cobalt, zinc and copper by heap bioleaching.
- Ore contains 15-25 ppm uranium and the leach solution 25 ppm.
- Uranium recovery circuit using SX was installed to produce 350 tpa U_3O_8.
(Ref: Outotec-Cameco presentation, ALTA 2012).
- Operation was initiated by the Talvivaara Mining Co. in 2008 following a successful 17,000 tonne pilot heap program. The subsequent commercial operation suffered major technical, environmental and economic problems, and closed in late 2014. It was restarted by new owners Terrafame in August 2015.
- Challenges include sub-zero winter operation and a net positive solution balance due to rainfall and melting snow, and long leach cycle time
(Ref: Terrafame presentation, ALTA 2017).

Talvivaara Heap Bioleaching Operation

(Ref: Talvivaara/Cameco/Outotec paper, ALTA 2012)

Uranium From Copper Leach Solutions

Agitated Tank and Dump Leaching Operations

- Copper ores contain 1-500 ppm U; mostly < 15.
- Copper leach solutions contain 1-40 ppm U – higher end of range generally is for recirculating leach systems, especially from heap and dump leaching.
- Difficult to project equilibrium uranium content in recirculating leach systems and replenishment after a uranium extraction system is in operation.
- Two commercial plants operated in USA in 1970s/1980s - Twin Buttes, Anamax, Arizona (tank leaching of oxide ore), and Bingham Canyon, Kennecott, Utah (dump leaching of low grade sulphide ore).
- Both used eluex (IX/SX) systems for uranium recovery, followed by ammonia precipitation, dewatering and calcining.

Anamax Twin Buttes, Arizona

- Used grinding/agitated tank sulphuric acid leaching/CCD/SX/EW for treating oxidized copper ore.
- Uranium IX was inserted ahead of copper SX – avoided fouling of resin with residual SX extractant.
- IX circuit was a Himsley continuous countercurrent fluidized bed system.
- IX was followed by a conventional tertiary amine SX system using conventional mixer-settlers, followed by ammonia precipitation, dewatering and calcination.
- Uranium IX feed solution flow was 1,400 m^3/h.
- Initial feed grade was 32 ppm U3O8 due to accumulation in the circuit. Dropped to 12-15 after 3 months of operation. (Design was for 7 ppm.)
- Design production rate was about 66 t/a U_3O_8. Came on stream 1981.
- Average uranium extraction efficiency was 83%.

Kennecott Bingham Canyon, Utah

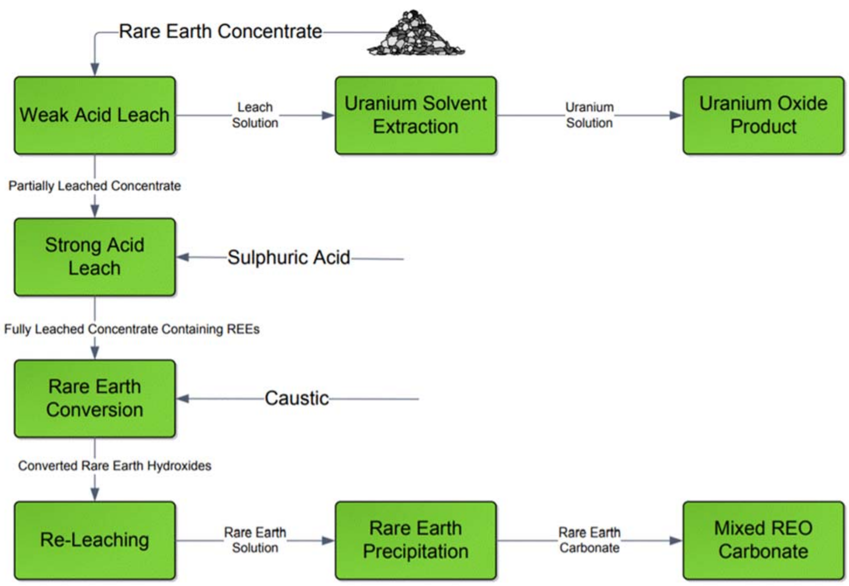
- Kennecott operated a large scale dump leach operation for low grade copper sulphide ore in which copper was recovered by cementation with scrap iron using Kennecott cones.
- Uranium plant was owned and operated by Wyoming Minerals, a subsidiary of Westinghouse.
- IX circuit used a Chemical Separation Higgins Loop continuous countercurrent pulse moving bed system.
- SX was with D2EHPA/TOPO and used mixer-settlers followed by sodium carbonate stripping, sulphuric acid redissolution, ammonia precipitation, dewatering and calcination.
- Uranium IX feed solution flow was 1,520 m^3/h.
- Design production rate was 63.5 t/a 66 t/a U_3O_8.
- Operated 1979 – 1988.

Uranium From Rare Earth Leach Solutions

- There have been commercial operations in the past, e.g. Rhone-Poulenc, Texas, USA.
- Commercial operations are reported in China.
- Tested for a number of current projects under development, e.g. Kvanefjeld in Greenland, by Greenland Minerals and Energy, Australia. FS released in 2015.
  - Claimed to be world's largest undeveloped resource of rare earth elements and uranium (>1 Billion tonnes defined, <20% of project area evaluated).
  - Primary product stream of high-purity critical rare earth concentrates (Nd, Pr, Eu, Dy, Tb, Y), with by-products of U_3O_8, lanthanum and cerium, zinc and fluorspar.
  - Production of uranium 512 tpa U_3O_8 equivalent.
  - Uranium recovery process: SX, SDU precipitation, acid redissolution, peroxide precipitation, drying of UO_4 product.

Kvanefjeld Project Simplified Refinery Flowsheet

(Ref: Greenland Minerals and Energy Paper, ALTA 2015)



Conclusions

- Recovering uranium as a by-product offers an alternative strategy to establishing new mines which involve significant challenges.
- In addition to avoiding the significant challenges of new mines, advantages include relatively low capex and opex, no uranium ore handling and comminution, addition of another revenue stream, ability to regulate output to match market demand without shutting down, reduced environmental impact, and less closure and remediation issues.
- Opportunities include both existing operations and future projects.
- A variety of by-product processes have been proven on a commercial scale.