THE UNIVERSITY OF MELBOURNE

Melbourne Energy Institute

MEInetwork23 Seminar #2:

Uranium mining and refining

Speaker: **Dr Neilesh Syna,**
Senior Hydrometallurgist, ANSTO

Moderator: **Assoc Prof Kathryn Mumford,**
Head of Department, Chemical Engineering

8 June 2023

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MEI*network*23 Seminar Series

Seminar topic	Month
Crude oil and product supply chains - Nicholas James, VIVA Energy	*Recording available online*
Uranium mining and refining	**8 June**
Energy commodity trading	6 July
New energy commodities and critical minerals	10 August
Fiscal policy to support future energy commodity exports	7 September

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Australian Government | ANSTO

Uranium mining and milling to UOC

Neilesh Syna, ANSTO Minerals

Kathryn Mumford, Melbourne Energy Institute

MEI*network*23

8 June 2023, Melbourne, VIC

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Science. Ingenuity. Sustainability.

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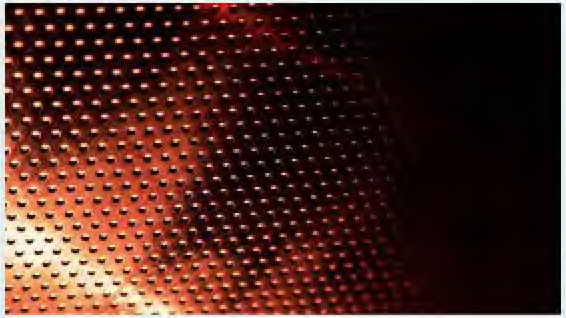


Silicon Irradiation

Science. Ingenuity. Sustainability.

Minerals Business Unit

60+ personnel

with engineering, metallurgy, mineralogy, chemistry experience

40+ years experience

providing practical solutions and innovative technology to industry

20+ global client locations

supported by our unique capabilities and facilities

Plan

Background

Fast Facts

Short Break with Questions

Different processing routes

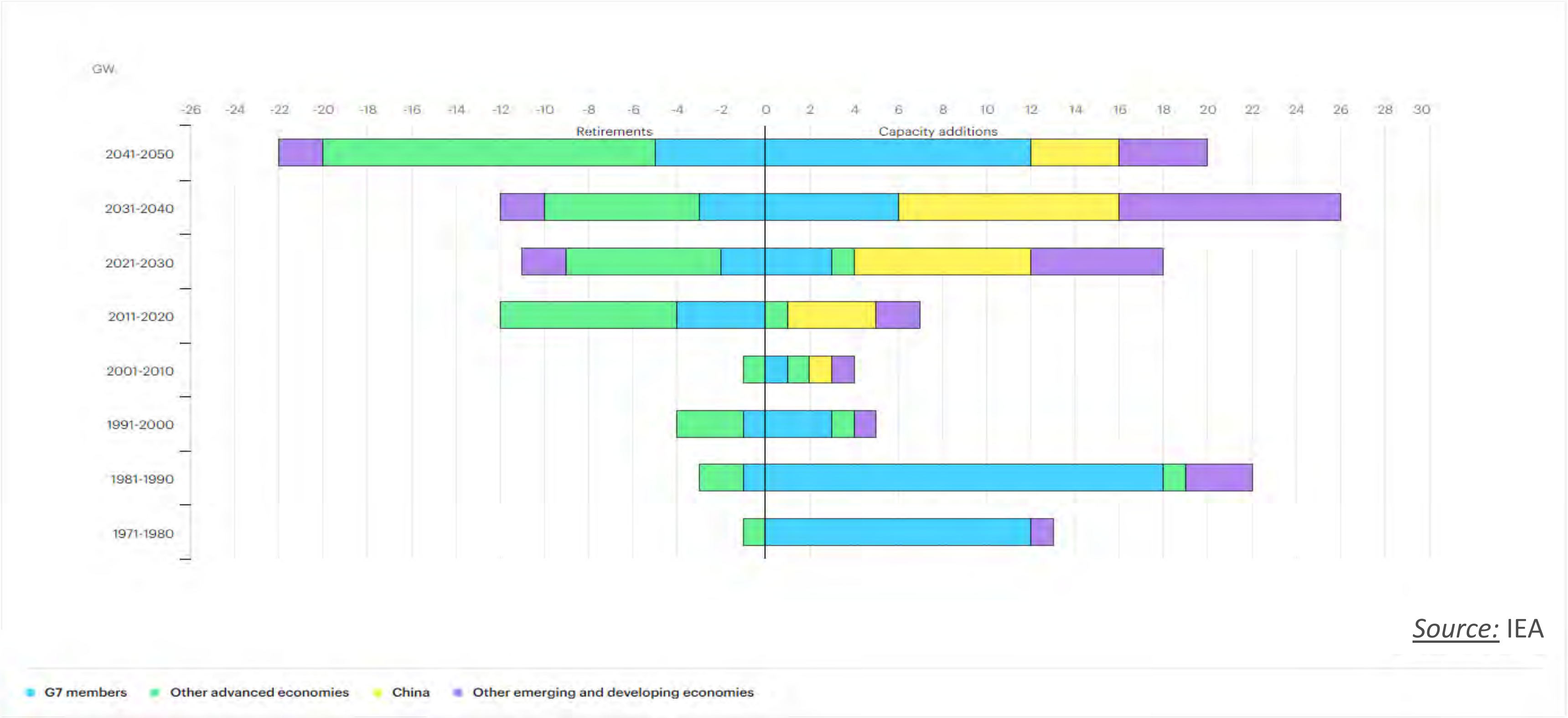
Short Break with Questions

Recent innovations

Australia operations & projects

Future challenges & opportunities

Nuclear power generation



Source: IEA

Source: World Nuclear Association

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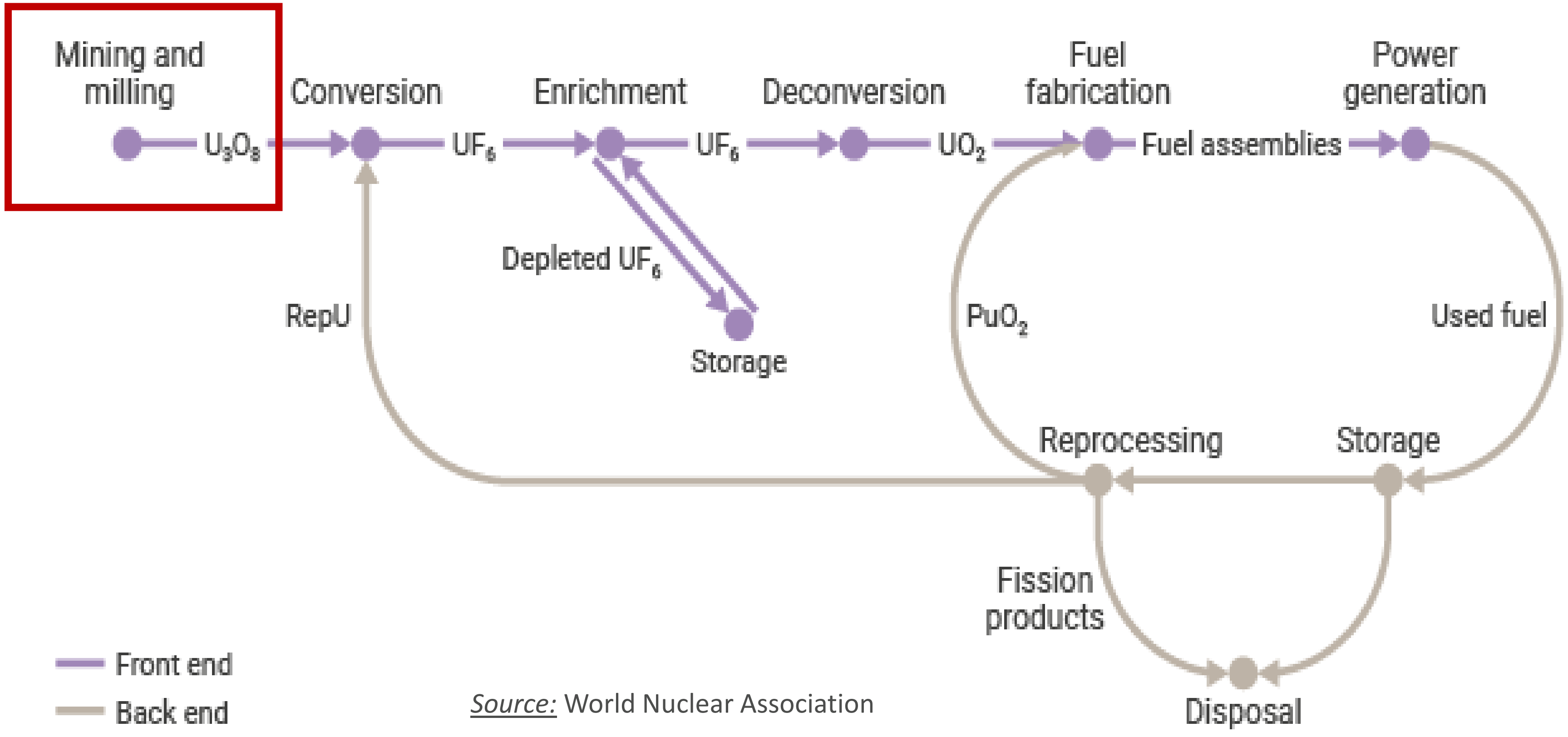
Nuclear fuel cycle

- Exploration, Mining and Milling to produce Uranium Oxide Concentrate (UOC)
- Conversion to UF_6
- Enrichment of ^{235}U isotope
- Fuel (UO_2) fabrication
- Power generation
- Spent fuel storage
- Reprocessing (U and Pu recovery)
- Waste storage and disposal



Source: World Nuclear Association

Uranium market pricing


Source: BHP

- Spot contracts
- Long-term contracts
- Financial instruments active in spot market

LT price (~US$60-80) crucial to incentivise new mine development

Source: Cameco Corp.

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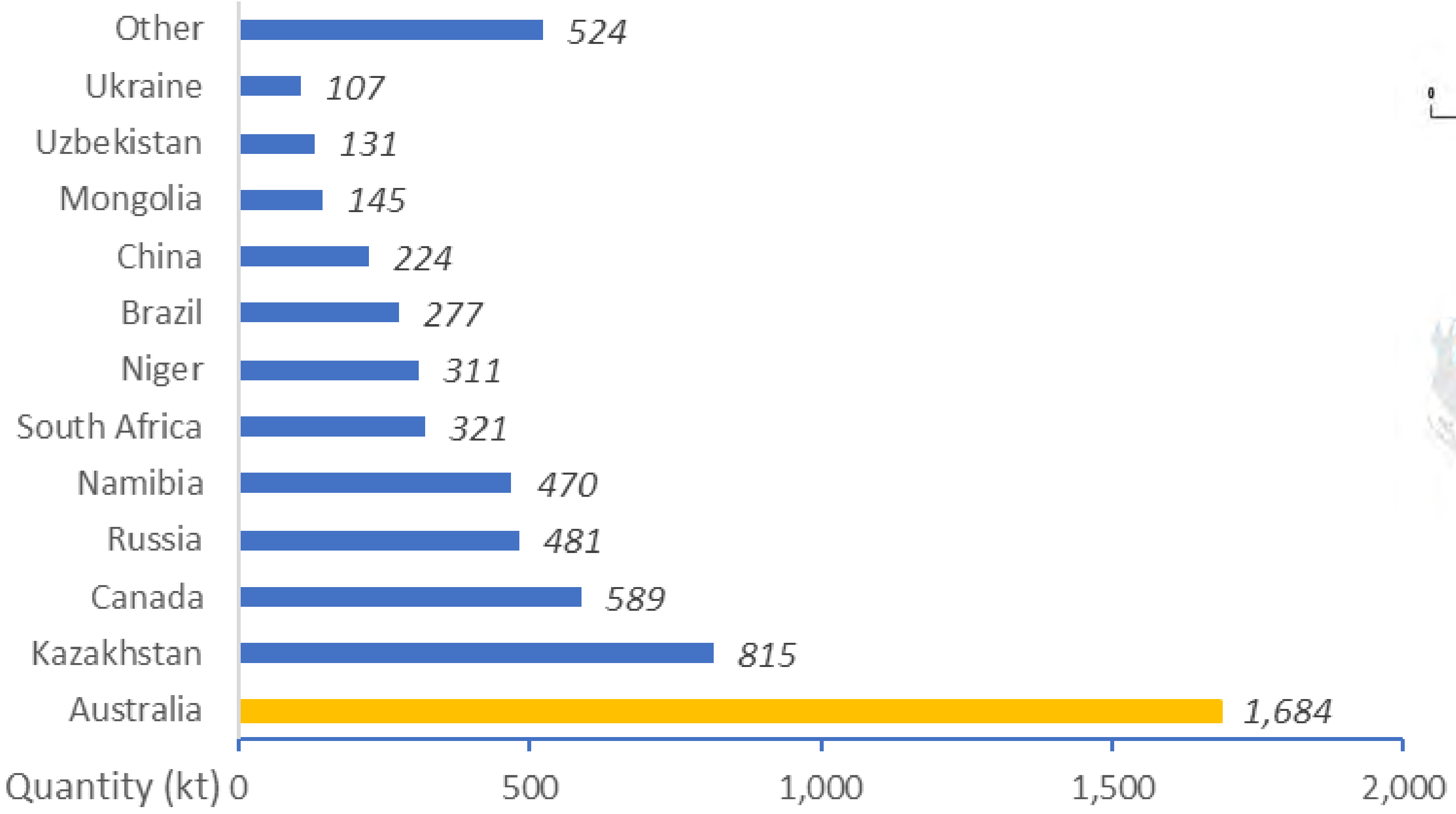
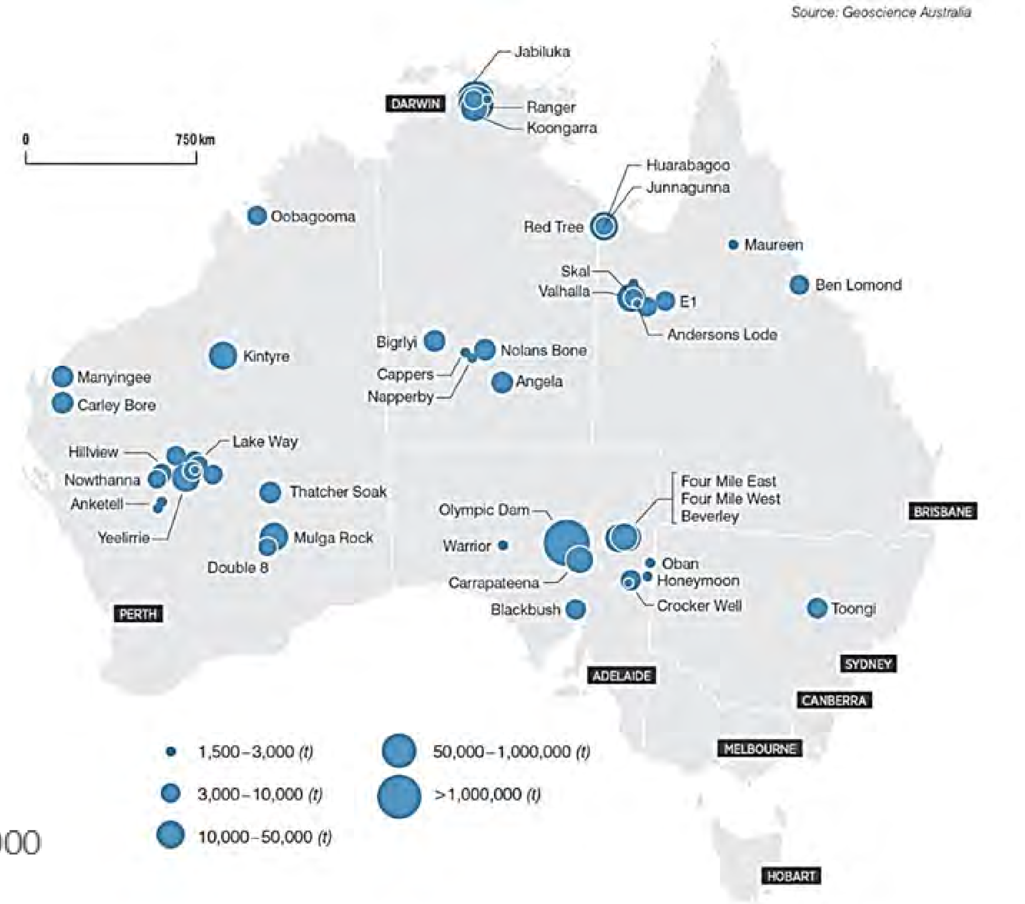
Resources (2021)



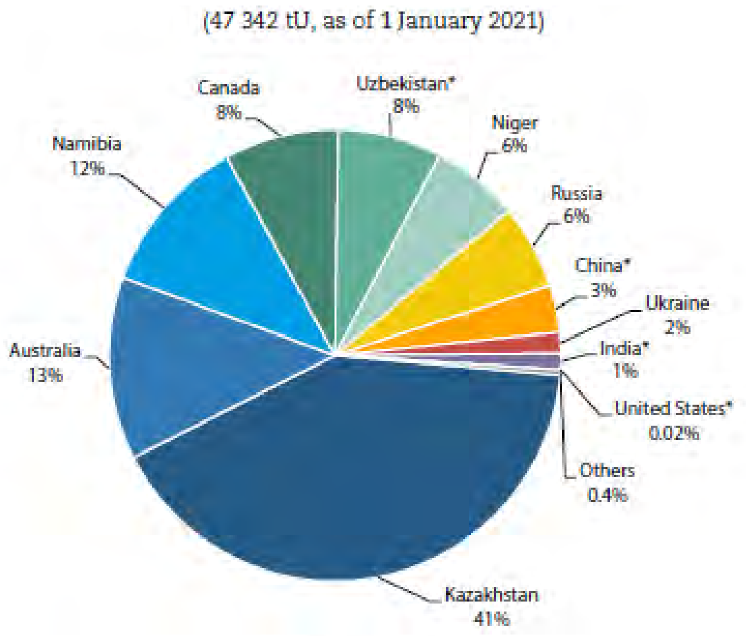


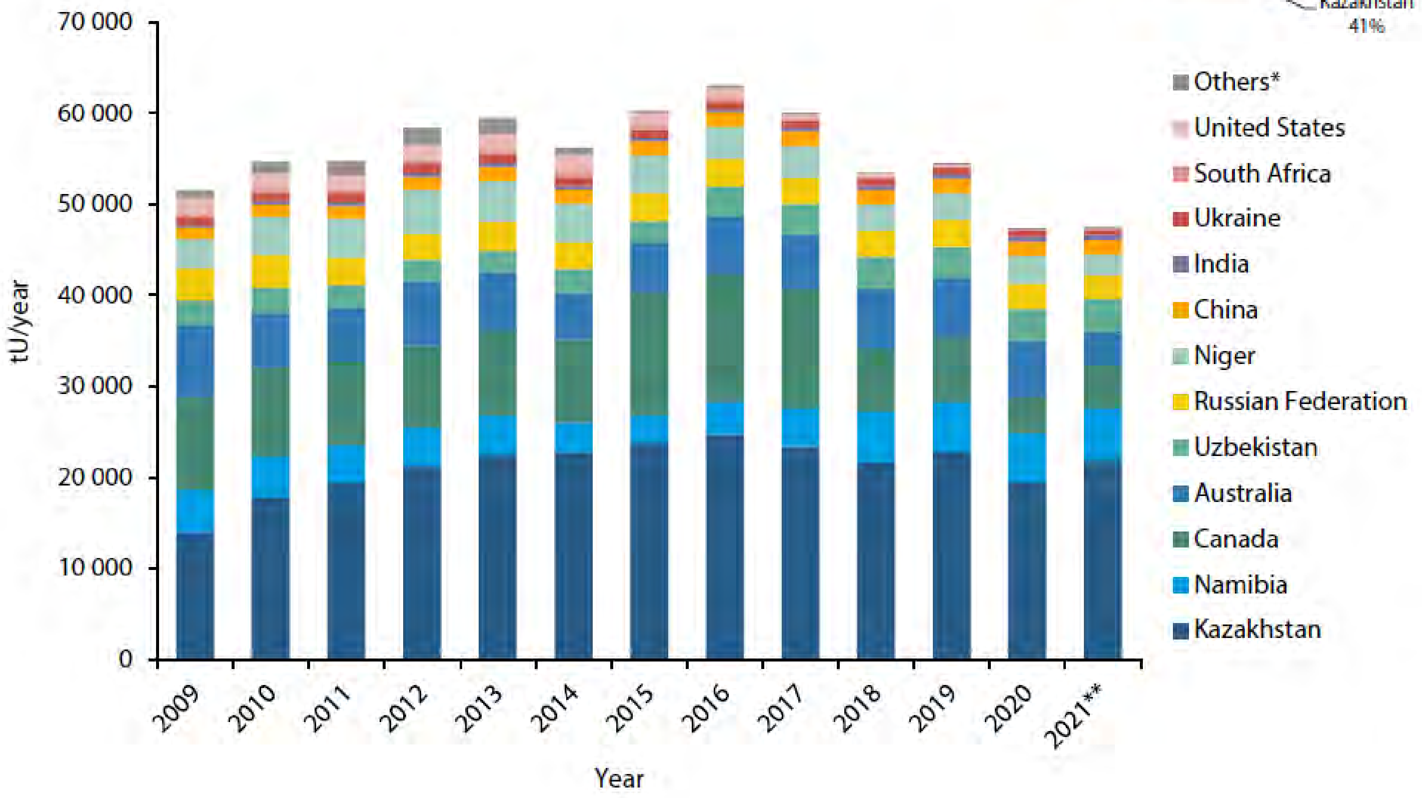
Source: World Nuclear Association

UOC production (2020)

- 17 countries (Australia is 2nd)
- 7 countries accounted for 94%
- From the deserts of Africa, through the plains of Central Asia to the arctic tundras of Canada

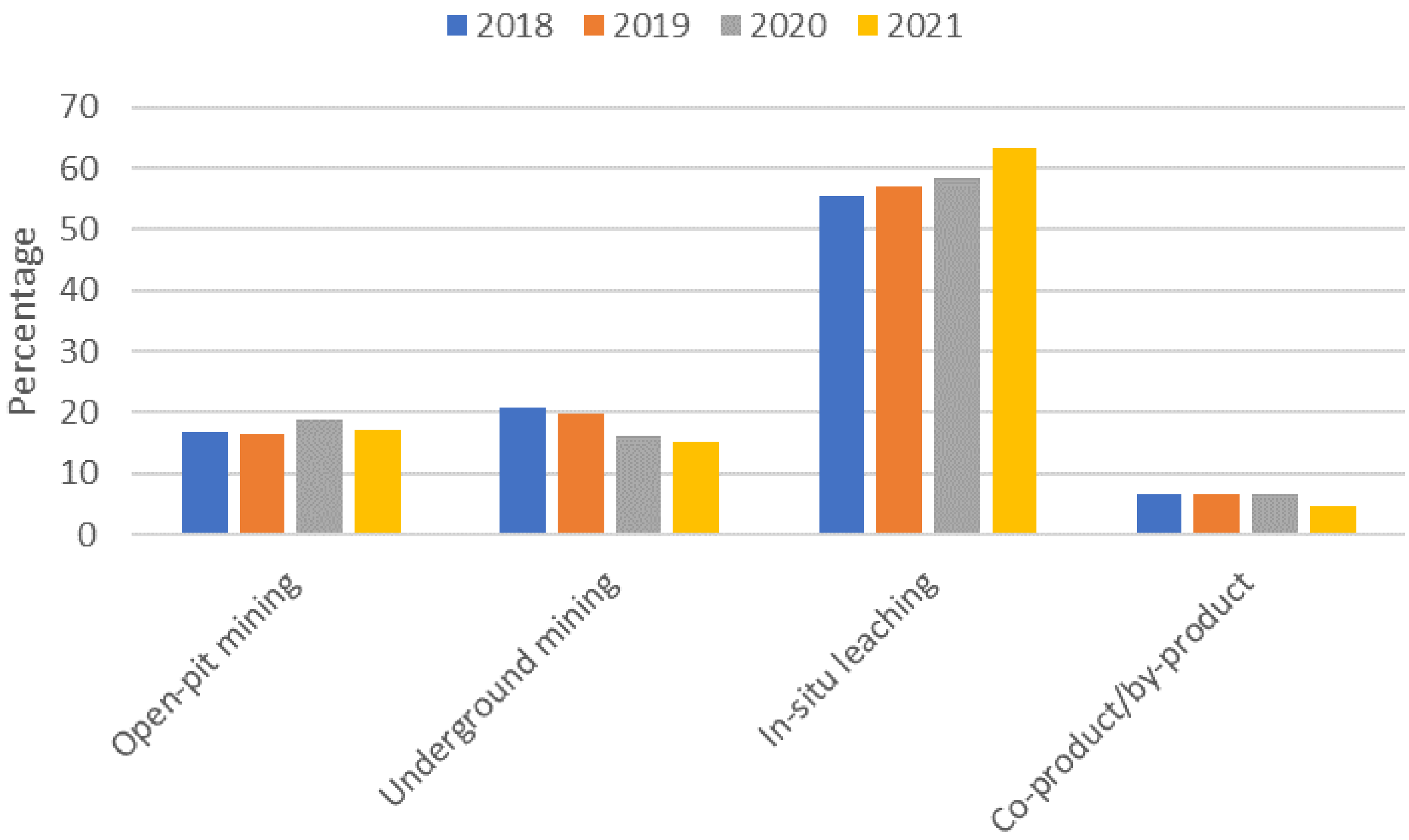
Source: OECD U Red book (2022)





Methods of production (2021)

- Open pit, underground, in-situ leach and co-/by-product
- In-situ leach is the largest and continues to grow (underground mining in decline)
- Co-/by-production typically from gold, base metals (copper and nickel) and phosphate operations



Source: World Nuclear Association

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Producers (2021)

- 10 companies market 94% of global mine production
- 80% of global production concentrated within 6 companies
- 5 are State Own Enterprises

Source: World Nuclear Association and OECD U Red Book (2022)

Break Time: Questions?

Process selection

Dependent upon:

- Resource
- Mining method
- Ore mineralogy
- U grade
- Geographical location
- Economics
- Laws and regulations
- Schedule, . . .

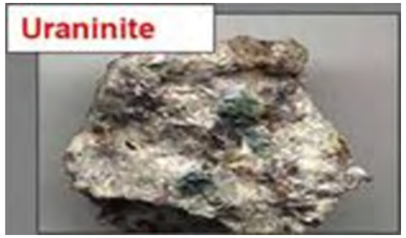
Mineralogy

Mineralisation:

- Vanadates
- Carbonates
- Oxides
- Phosphates
- Arsenates
- Sulphides,
- Molybdates, . . .

Principle Uranium minerals:

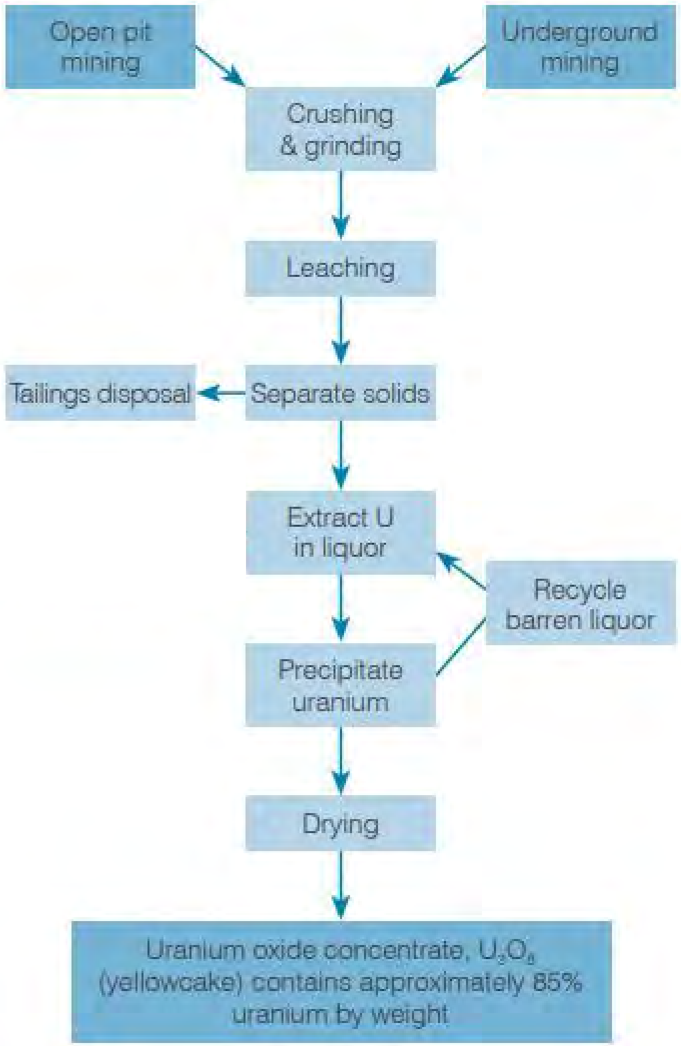
- Pitchblende
- Uraninite
- Carnotite
- Coffinite
- Brannerite
- Torbenite
- Wulfenite, . . .



Source: Mindat

Conventional process

1. Mining
2. Crushing & grinding
3. Leach
4. Solid-liquid (S/L) separation
5. Purification & enrichment
6. Precipitation & dewatering
7. Drying & calcination
8. Packaging & transport
9. Waste treatment



Source: World Nuclear Association

1. Mining | 2. Crushing & grinding | 3. Leach | 4. S/L separation | 5. Purification & enrichment | 6. Precipitation & dewatering | 7. Drying & calcination | 8. Packaging & transport | 9. Waste treatment

Source: Energy Resources Australia

Open-pit mining

- Near surface ores (< 100 m)
- Requires heavy equipment for soil and waste rock removal before ore access
- Pros:
  - Better ventilation, less costly than UG
- Cons:
  - Huge footprint, expensive remediation

Source: Cameco Corp

Underground mining

- Deep orebodies (> 100 m)
- Requires vertical shafts to ore depth followed by creation of tunnels, ramps and chambers
- Pros:
  - Smaller footprint, less waste
- Cons:
  - Expensive operation and remediation

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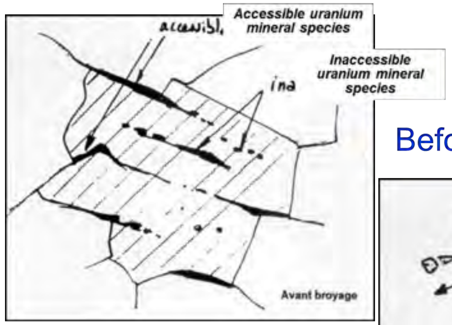
- Objective: minerals liberation through size reduction
- Crushing of mine ore
  - 1.5 m ➲ > 20 mm
- Very energy intensive (65-80% of total process energy usage)
- Only 1-2% is effectively used, what bout the rest?
  - Noise and heat
  - Materials transfer, . . .



Before

After

Gyratory crusher

High Pressure Grinding Rollers

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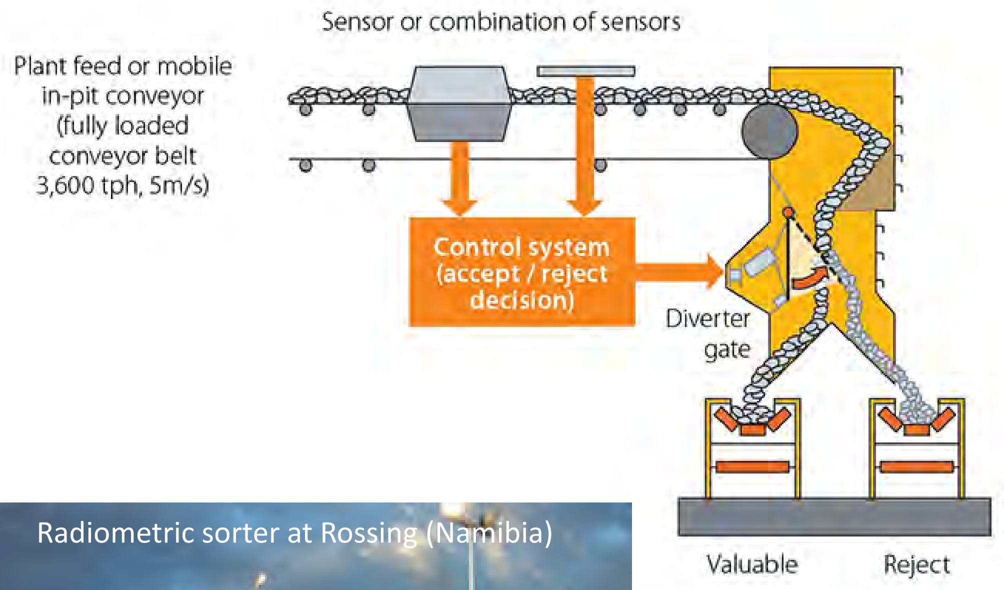
- Crushed ore storage prior to beneficiation and/or grinding circuits
- Options of open or covered storage
- Ensures undisrupted feed to downstream process units

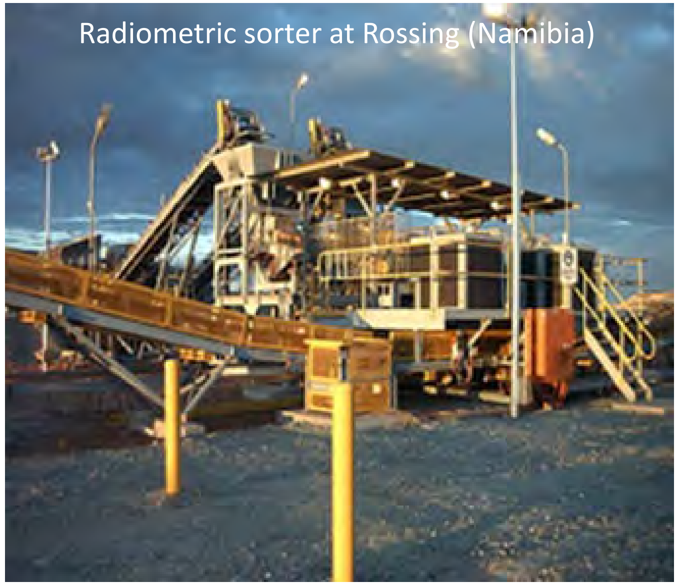
Somair (Niger)

Cominak (Niger)

Source: Orano

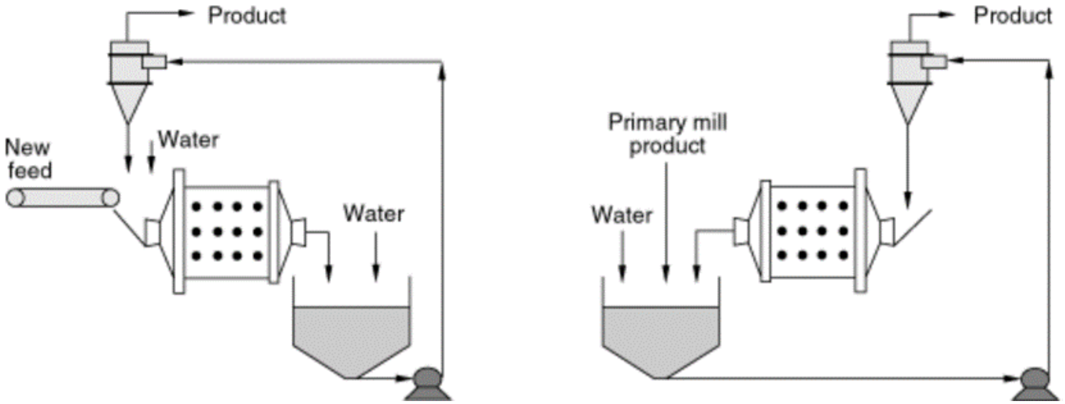
- Crushed ore enters beneficiation circuit
- Objective: Increase U grade whilst reducing tonnage treated
- Available techniques include:
  - Sizing
  - Gravity spirals
  - Magnetic & electrostatic
  - Flotation
  - Sorting
- Very few U ores are amenable to the above techniques except for (radiometric) sorting
  - Rossing (Namibia)





Source: Applied Sorting Technologies

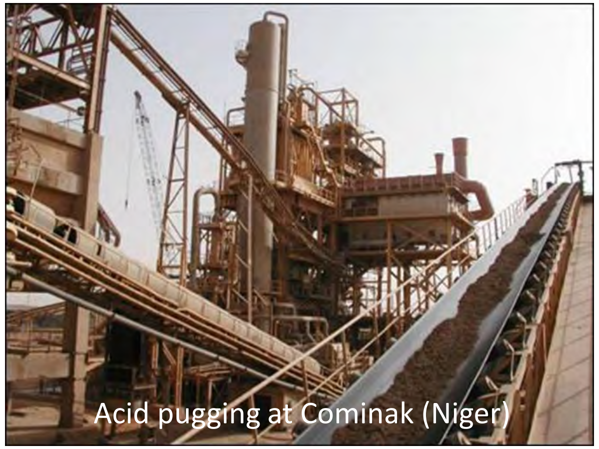
- 2nd stage **grinding** circuit:
  - (Autogenous/Semi-autogenous) mills, > 100 µm
  - (Ball/Rod) mills, > 30 µm
  - (Stirred/Tower/ISA) mills, >1 µm
- Operated either wet or dry
- Use grinding media (metallic or ceramic balls)
- Typically operated in closed loop arrangement



Source: Energy Resources Australia

Source: Orano

- Objective: Chemical dissolution (leach) of U minerals & limiting gangue dissolution
- Reagent choice of:
  - Acid (most common)
  - Alkaline (for high acid consuming ores, e.g. carbonates)
- Variables include:
  - Mineralogy, grade, time, temperature, . . .
- Options:
  - Dynamic leach (vat, Pachuca, agitated tank, autoclave)
  - Heap leach
  - In-situ leach



Source: Orano

Source: Orano

- <u>Objective:</u> Separation of U bearing liquor from leach solids for further processing
- Variables include:
  - Leach method, clay content, particle size, water availability, solution grade, costs, . . .
- Options:
  - Thickening followed by filtration (belt, drum, pressure, . . .)
  - Counter-current decantation (CCD)
  - Resin-in-Pulp (RIP)

Belt filter at Cominak (Niger))

Source: Orano

Thickener at Langer Heinrich (Namibia)

Source: Paladin Energy

CCD at Langer Heinrich (Namibia)

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- Objective: Purification & concentration of U from contaminants
- Variables include:
  - Solution flow, grade, pH, impurities, . . .
- Options:
  - Solvent extraction (SX)
    - Mixer settlers, pulsed columns
  - Ion exchange (IX) resins
  - Resin-in-Pulp (RIP)

Source: Energy Fuels Inc.

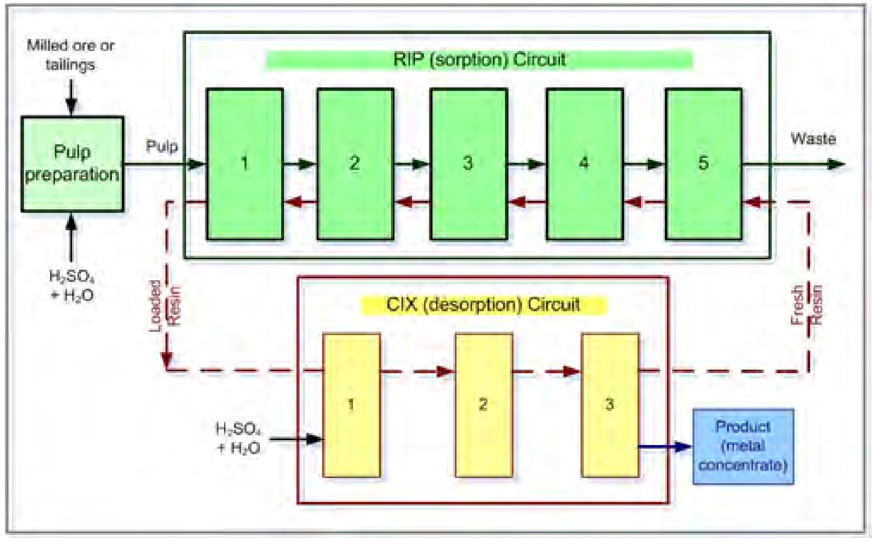
Source: BHP

Source: Dow

Source: Heathgate Resources

Resin-in-pulp (RIP)

- Negates the need for S/L step before contact
- Process pulps with 50wt% solids
- Coarser resin beads retained in baskets
- Consists of 2 (adsorption and desorption) circuits
- Higher CAPEX but lower OPEX (over standard IX)
- Issues with resin fracture and U loss



Source: Ion Exchange Australia

RIP at Kayelekera (Malawi)

Source: Lotus Resources

- Objective: **Transform** U from solution to solid phase by increasing solution pH
- Variables include:
  - Solution flow, environmental regulations, reagent availability, temperature, converter requirements,
- Reagent options include:
  - Ammonia, peroxide, caustic, lime or milk of magnesia
- Tank precipitation (either in batches or continuously) followed by filtration
- Step can be repeated to further reject more impurities (Mg, Na, Zr, etc.)
- Converters prefer UO_4 or U_3O_8 concentrates

Stirred tanks at Cominak (Niger)

Belt filter at Cominak (Niger)

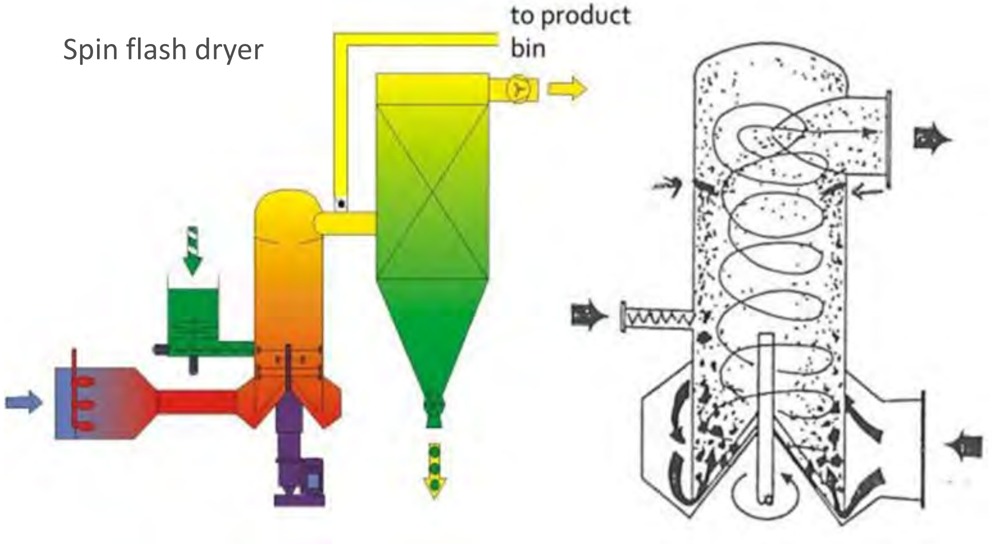
Source: Orano

- <u>Drying objective:</u> **Displace** water from wet cake and crystalline water
- Variables include:
  - Precipitate type, temperature, . . .
    - e.g. peroxide precipitate at 150 - 480°C

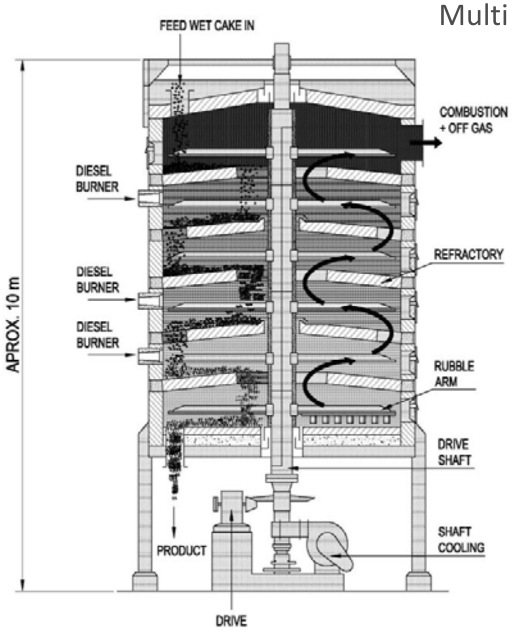
      $UO_4.2H_2O \leftrightarrow UO_4 + 2H_2O$
- <u>Calcination objective:</u> **Convert** to final product
- Variables include:
  - Product type, temperature, . . .
    - e.g. ammonia precipitate (ADU) at 650 - 800°C

      $9(NH_4)_2U_2O_7 \leftrightarrow 6U_3O_8 + 14NH_3 + 15H_2O + 2N_2$

Spin flash dryer



Multi hearth furnace



<u>*Source:*</u> Adelaide Control Equipment

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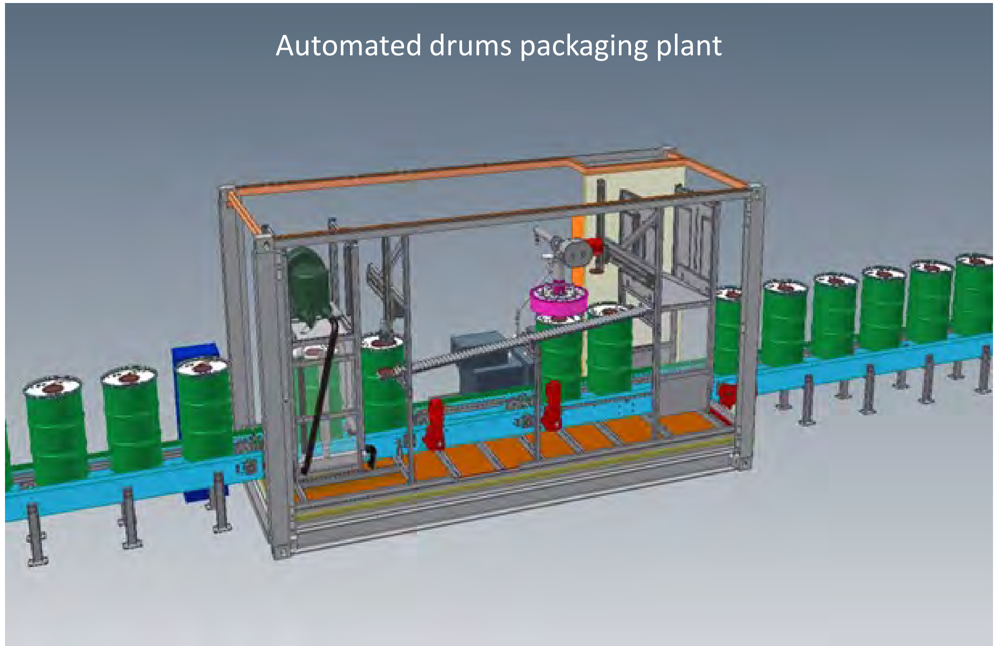
- Objective: **Package** end product for delivery to converters (chosen by customers)
- Automated to minimise radioactive contamination and exposure


Automated drums packaging plant

Source: Adelaide Control Equipment


Package plant and shipment for transport at Cominak (Niger)

Source: Orano

- Uranium oxide (U_3O_8) is sold via both contract and spot market
- Each sale is controlled through the U3O8 specification
  - Some converters have their own specification
  - An increasing number use ASTM C967 (for naturally occurring uranium, minimum 65 % U or 85 % U3O8)
- Limits:
  - Without penalty: impurities up to indicated level attract no cost penalty
  - Without rejection: above this the consignment can/will be rejected
  - In between: Sliding scale of cost, based upon element and concentration, subtracted from the unit price.
- Why U-234 limit?
  - Remember natural abundance U-234 is 0.0055 % (55 ppm)
  - U-234 absorbs neutrons and affects the breeding properties of the fuel
  - Shortens life of fuel rods
  - Shorter half life means heightened exposure control
  - Compensate by increasing U-235 content in fuel (issues, plus cost)

ASTM C967 – 13

TABLE 1 Impurities and Maximum Concentration Limits

Impurity	Maximum Concentration Limit (Mass %, Uranium Basis)[A]	
	Limit Without Penalty[B]	Limit Without Rejection[C]
As	0.05	0.10
B	0.005	0.10
Ca	0.05	1.00
Carbonate	0.20	0.50
F	0.01	0.10
Halogens[D]	0.05	0.10
Fe	0.15	1.00
Mg	0.02	0.50
Moisture[E]	2.0	5.0
Mo	0.10	0.30
P	0.10	0.70
K	0.20	3.00
Si(calculated as SiO_2)	0.50	2.50
Na	0.50	7.50
S	1.00	4.00
Th	0.10	2.50
Ti	0.01	0.05
V	0.06	0.30
Zr	0.01	0.10
^{234}U	56[F]	62[F]

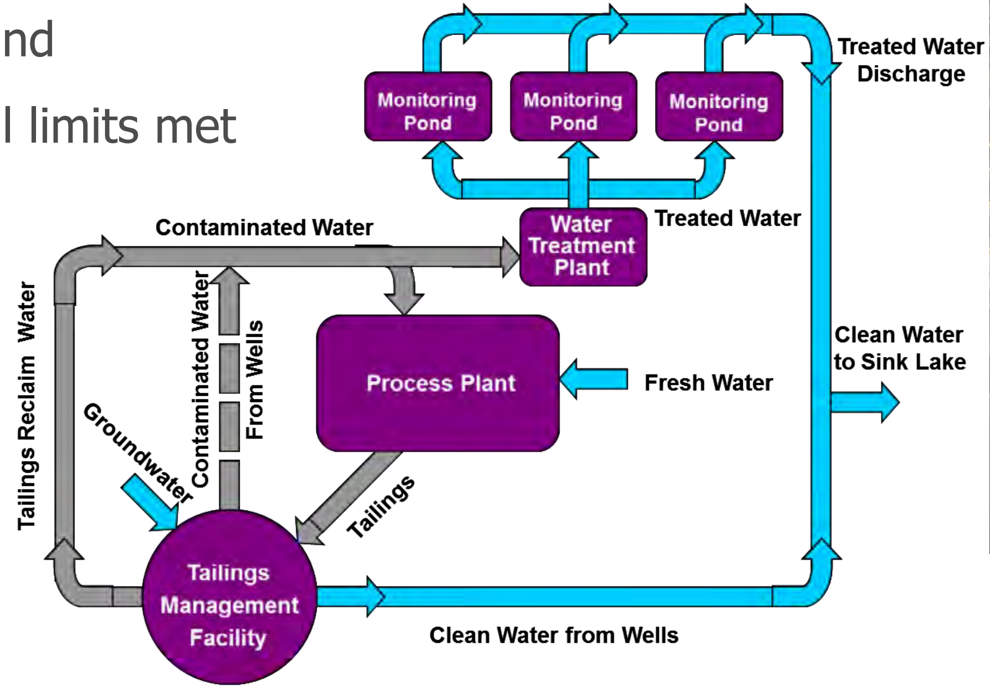
Source: ASTM

- Objectives:
  - Disposal of **solid tailings** compliant to local laws
  - Disposal of **liquid effluents** by immobilising **environmental contaminants** (heavy metals and radioactive) and ensuring local limits met for **water discharge**
    - e.g. $Fe^{3+} + 3OH^{-} \rightarrow Fe(OH)_3$


Dry storage at Cominak (Niger)


Wet storage at McClean Lake (Canada)

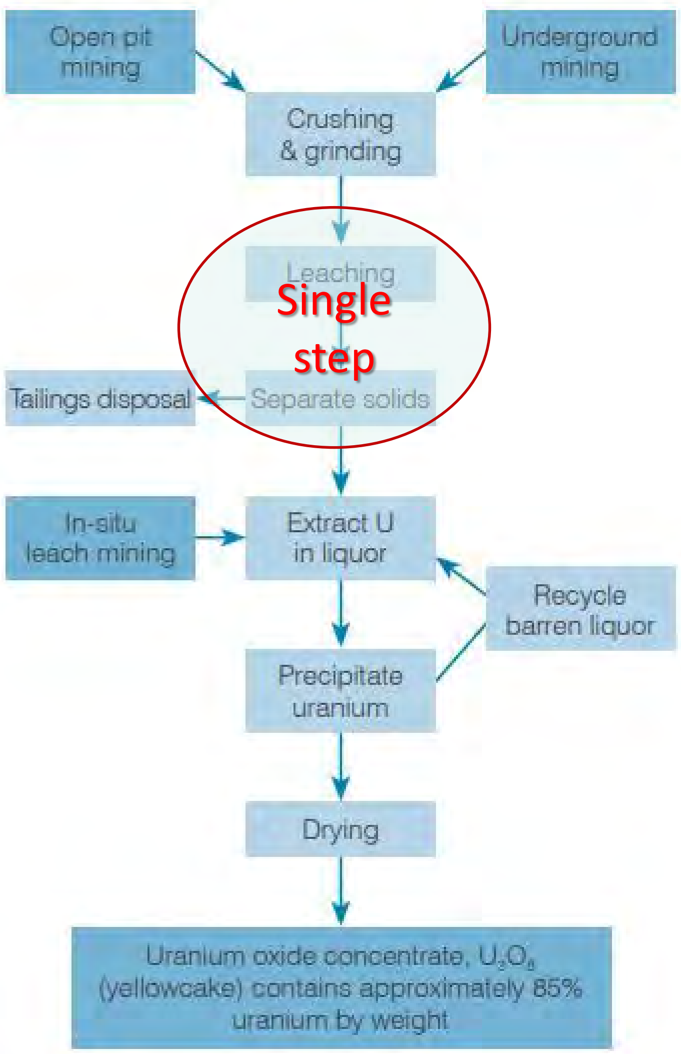
Source: Orano




Water treatment plant at McClean Lake (Canada)

Heap leach process

1. Mining
2. Crushing & agglomeration
3. Heap leach
4. Purification & enrichment
5. Precipitation & dewatering
6. Drying & calcination
7. Packaging & transport
8. Waste treatment



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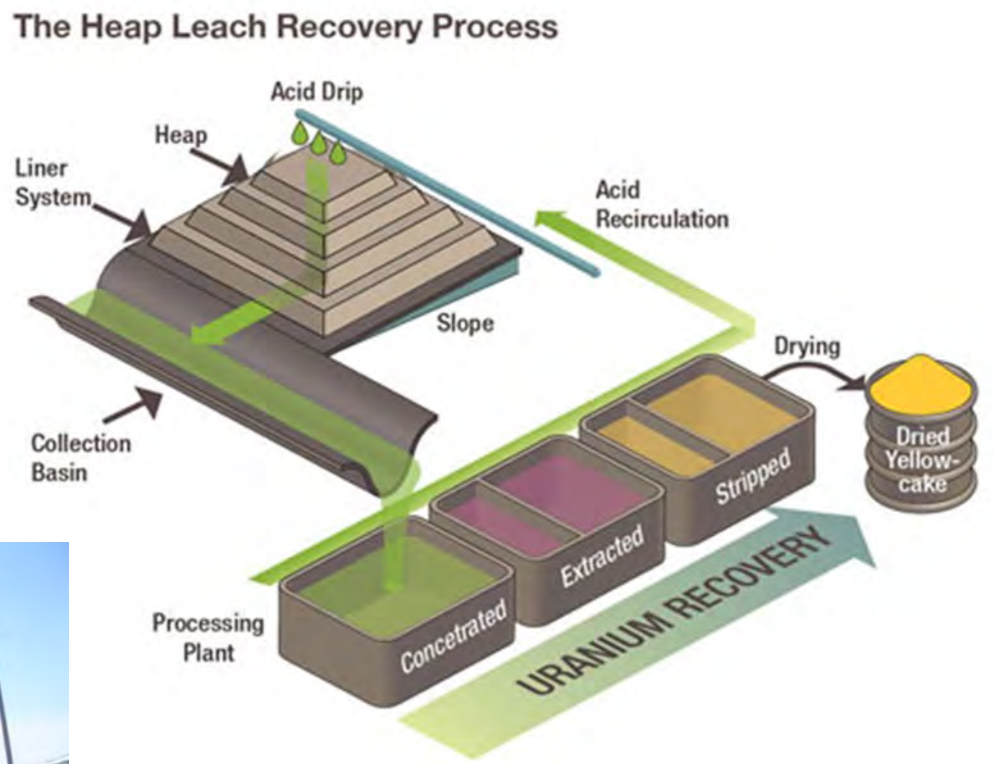
Heap leach process

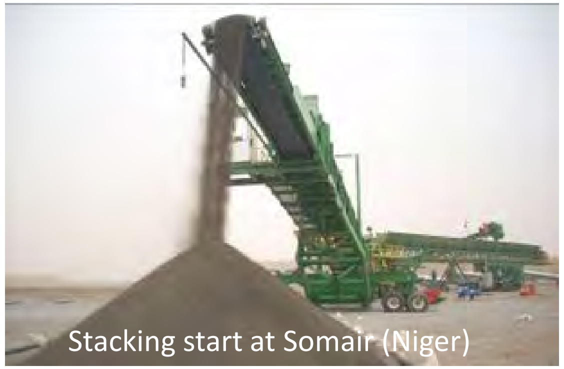
- Suitable for low grade ores
- Ores crushed and agglomerated with reagents then built into heaps and irrigated with leach solution
- Leach solution recovered from collection basin
- Slow reaction rate (3 – 9 m)
- Moderate CAPEX with low OPEX
- SX or IX used for U recovery
- Used in Niger & Finland



Source: Nuclear Regulatory Commission


Agglomeration at Somair (Niger)

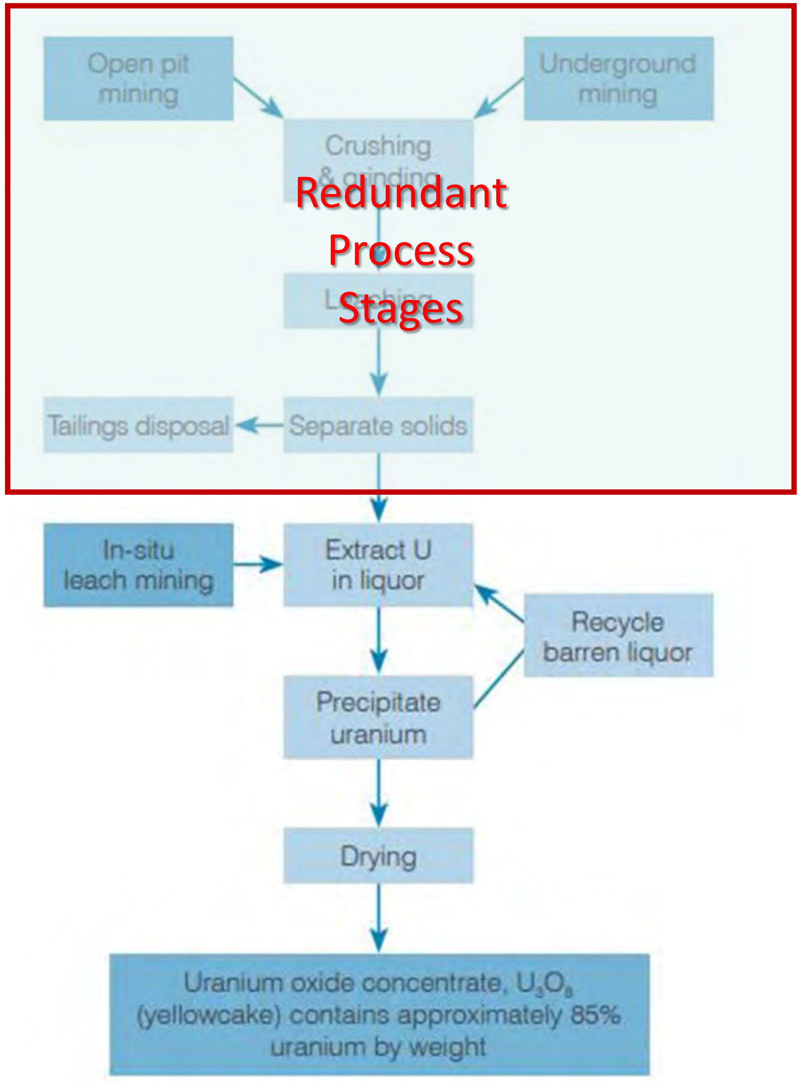
Source: Orano


Stacking start at Somair (Niger)


Stacking completed at Somair (Niger)

In-situ leach process

1. ISL involves drilling, well preparation & cell irrigation
2. Purification & enrichment
3. Precipitation & dewatering
4. Drying & calcination
5. Packaging & transport
6. Waste treatment



Source: World Nuclear Association

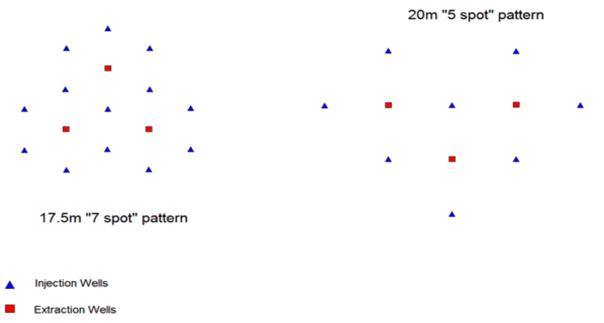
In-situ leach process

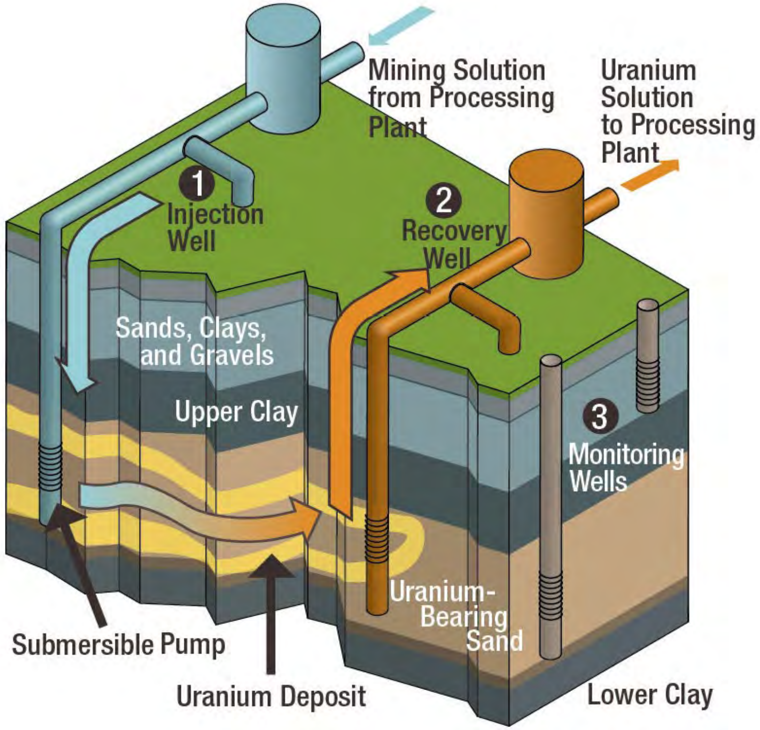
- Suitable for ore bodies sandwiched between clay layers)
- Reagents injected into ore body (18-24m)
- Leach solution is pumped out for U recovery
- Monitoring wells check for chemical escapes
- Low CAPEX and low OPEX
- Little waste generation & minimal surface ground disturbance
- IX used for U recovery


Drilling at Tortkuduk (Kazakhstan)

Source: Orano


Production well at Tortkuduk (Kazakhstan)





Source: Nuclear Regulatory Commission


Well field at Smith Ranch-Highland (USA)

Source: Cameco Corp.

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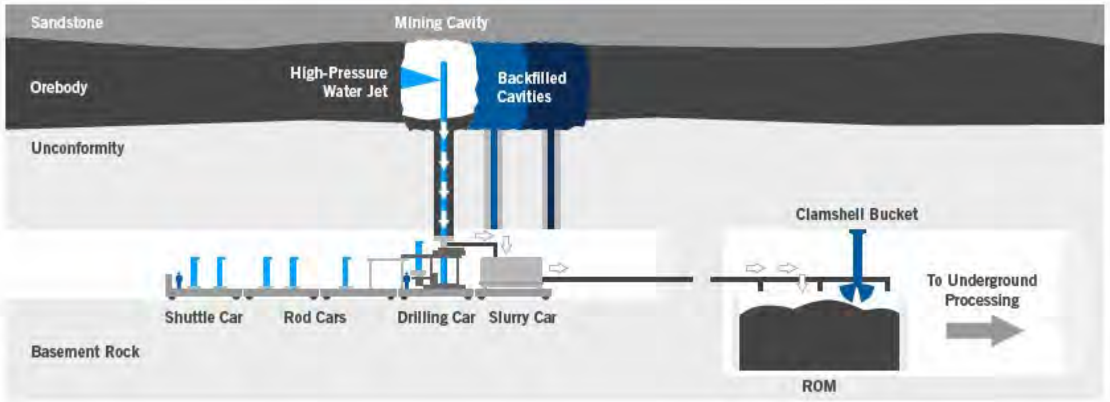
Break Time: Questions ?

Recent innovations in mining

Jet boring



Source: Cameco Corp.

- UG mining technique used at Cigar (Canada)
- Freezing the ore and surrounding rocks using chilled brine (-40ºC) in large pipes
- Production tunnel created for jet boring system entry
- Pilot hole drilled through orebody then jet boring nozzle inserted
- High pressure water jet extracts ores
- Places workers UG

SABRE

Source: Orano

- Surface Access Borehole Resource Extraction
- Non-entry surface based mining technique
- Benefits of:
  - Economics (flexibility and scalability)
  - Safety (health and injury minimised)
  - Environmental (small footprint and lower water and energy demand)
- Potential for Midwest project (Canada)

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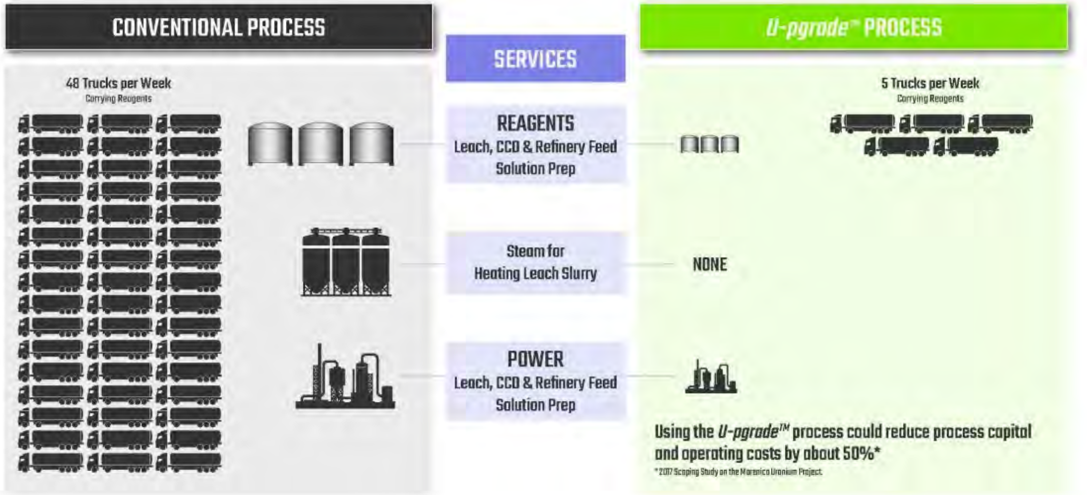
Recent innovations in processing

Abrasion based beneficiation technique

Source: DISA Technologies LLC



Source: Elevate Uranium

- 2 proponents
  - U-pgrade™ (Elevate Uranium) and High Pressure Slurry Ablation technique, HPSA (DISA Technologies LLC)
- Uses the forces of abrasion, elastic compression and rebounding
- Benefits of:
  - Lower mine haulage
  - Lower milling costs (throughput, reagents, energy)
  - Better environmental outcomes (lower (mill) tailings and cleaner (mine) waste dumps)
- Tested using Colorado (USA) sandstones and Namibian calcretes

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Recent innovations in processing

Nanofiltration

Source: BMS Engineers

- Filtration technique employing membranes under high pressure
- Applied for reagent recovery
- Used at Langer Heinrich (Namibia) & Kayelekera (Malawi)

Saline IX (ANSTO)

Source: Boss Resources

- Ideal for locations with saline (Cl) water
- High capacity Strong Base Anion (SBA) resin binds strongly to U
- Patented U elution method developed
- To be applied at the restart of Honeymoon (SA)

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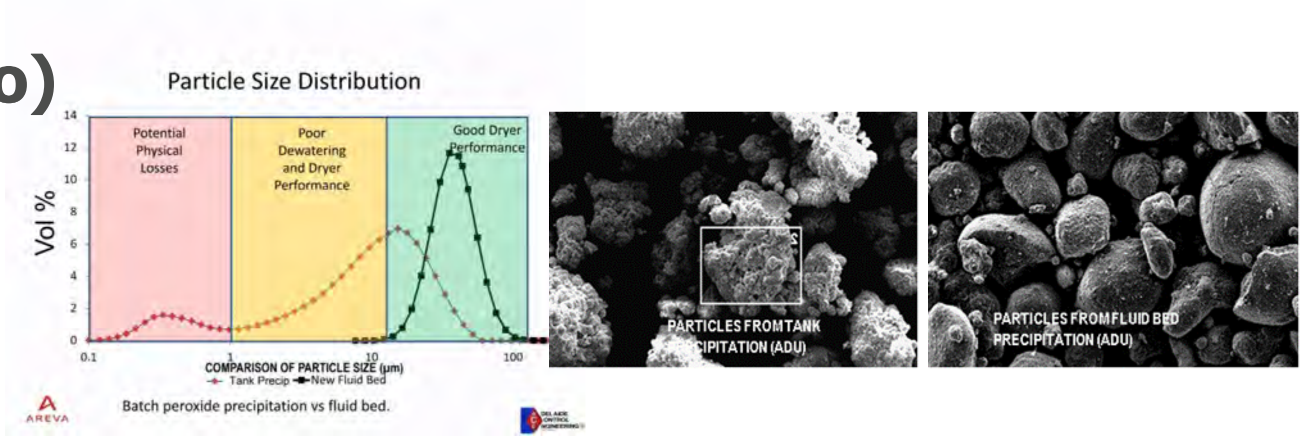
Recent innovations in processing

Fluidised Bed Precipitation (Orano)


Fluidised bed precipitation at Tortkuduk (Kazakhstan)

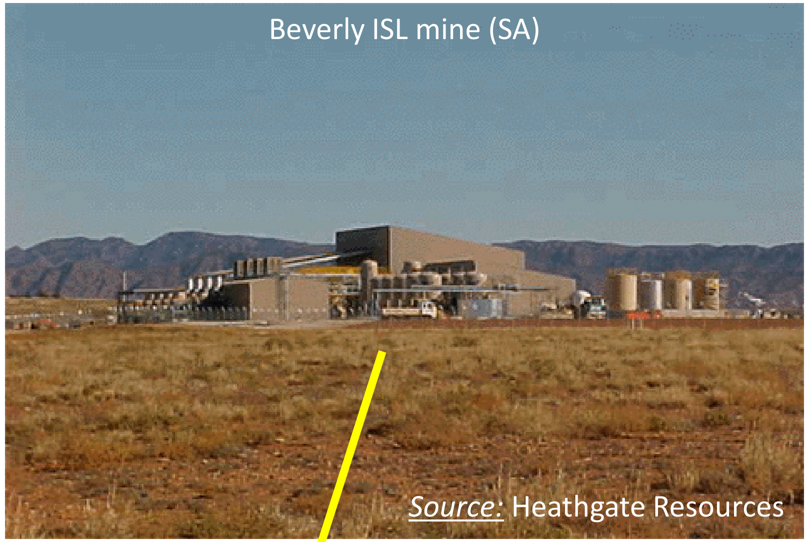
Source: Orano



Source: Adelaide Control Equipment

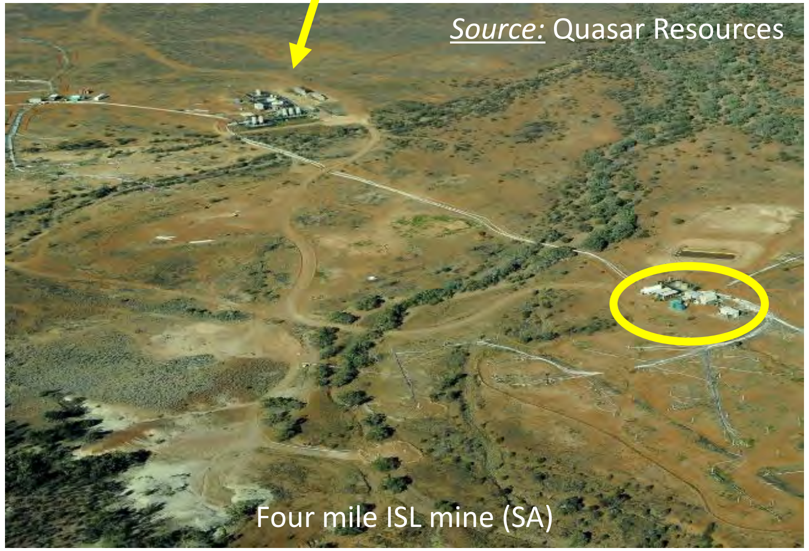
- Larger particles ➲ better S-L separation
- Less fines ➲ reduced dust generation
- Higher bulk density ➲ transport savings
- Used at KATCO JV (Kazakhstan) and Somair (Niger) operations

Australian operations (2021)



Beverly ISL mine (SA)

Source: Heathgate Resources



Source: Quasar Resources

Four mile ISL mine (SA)

Source: BHP

Olympic Dam UG Copper mine (SA)

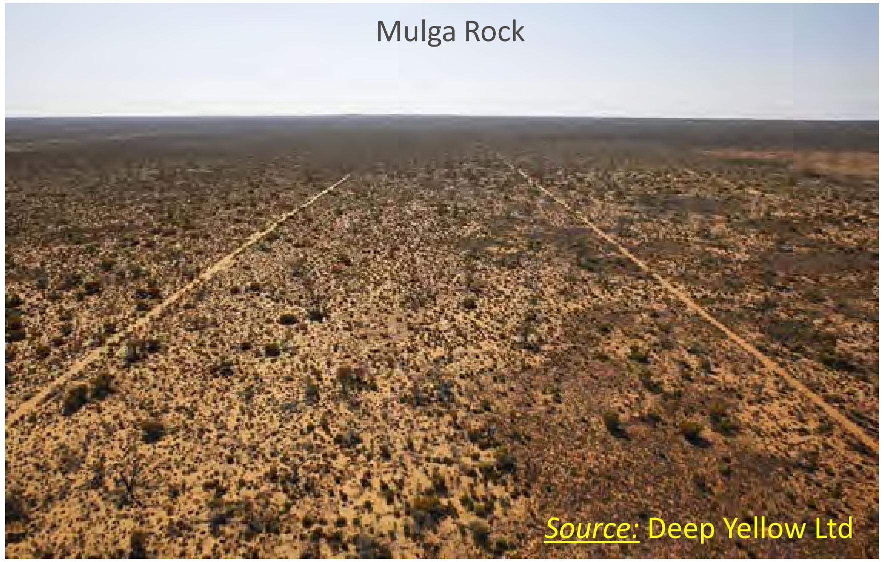
Source: Energy Resources Australia

Ranger OP mine (NT) – Rehab

Source: Boss Resources

Honeymoon ISL mine (SA) – Undergoing restart

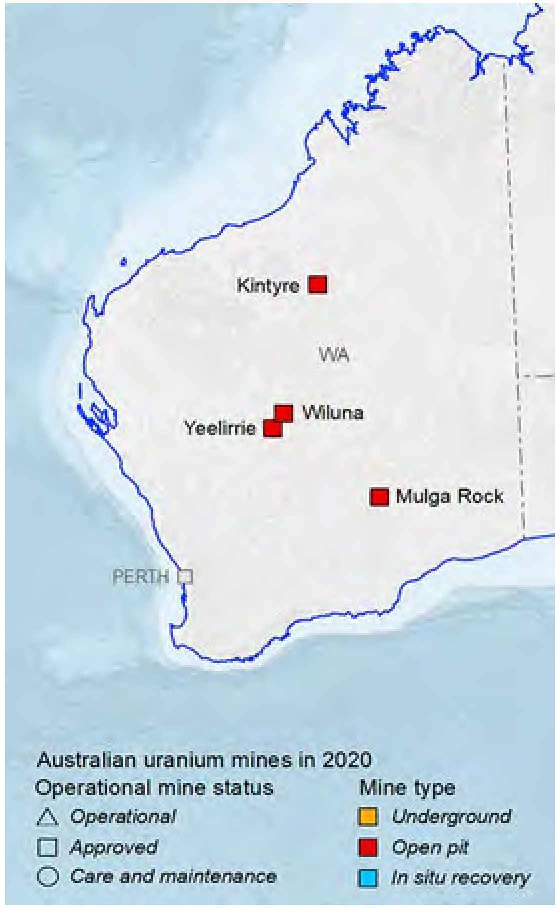
Australian projects (2021)


Mulga Rock

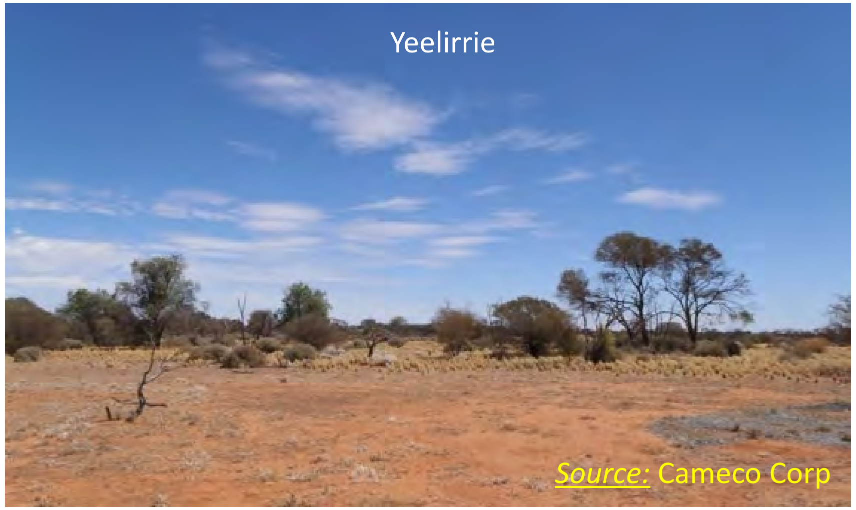
Source: Deep Yellow Ltd


Source: Toro Energy

Wiluna



Source: Geoscience Australia


Yeelirrie

Source: Cameco Corp


Source: Cameco Corp

Kintyre

Future challenges & opportunities

- Process & economics:
  - Treat lower grade ores and to reprocess old tailings
  - Produce U as a by-product (e.g. Au, Cu, REE, . . .) and/or produce by-products from U deposits (e.g. Co, Ni, V, Sc, Re, . . .)
  - Adopt and integrate alternative process technologies (e.g. bioleach, . . .)
- Safety: Provide safe work conditions & reduce worker exposure,
- Environment: Reduce impacts & consider sustainable development.
- Laws and Regulations: Adapt to changing landscape
- Social licence: Transparent engagement with local population and the wider public

ANSTO

Thank you.
Questions ?

Australian Government

ANSTO

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