

Paladin Energy Limited

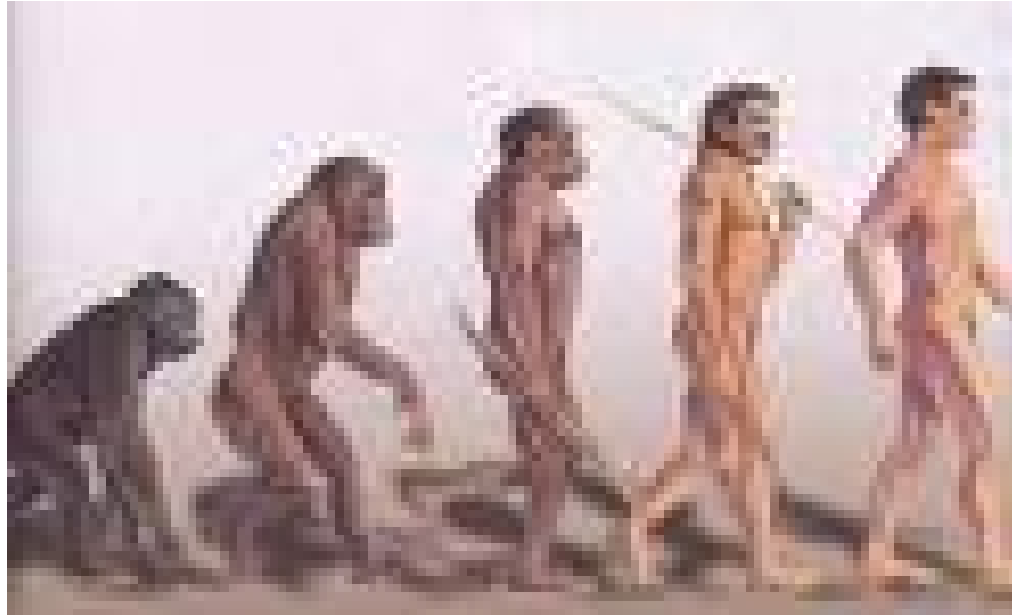
Merrill Ford

The Evolution of Uranium Extraction Technology

MINTEK's 75th Anniversary Conference
4 June 2009



Evolution and Uranium



Age of the Earth

- Rate of cooling
- Radiometric dating

Radiometric decay



Discovery of Uranium

”Up to the present 17 individual metallic substances have been acknowledged, gentlemen. However, it is my purpose today to increase this by one more.”

1789 – Martin Klaproth

- **1841 – Eugene Peligot first produced uranium metal**
- **Use in colouring glass with green fluorescence, yellow & orange glazes and sepia photograph prints**



Uranium Uses



Radioactivity

- **1896 – Henri Bequerel**
 - Start atomic science
- **St Joachimstal mine**
 - Silver, cobalt, lead, arsenic, bismuth
- **Pitchblende “waste”**
 - 1st uranium extraction process
- **Marie and Pierre Curie**
 - Polonium and radium

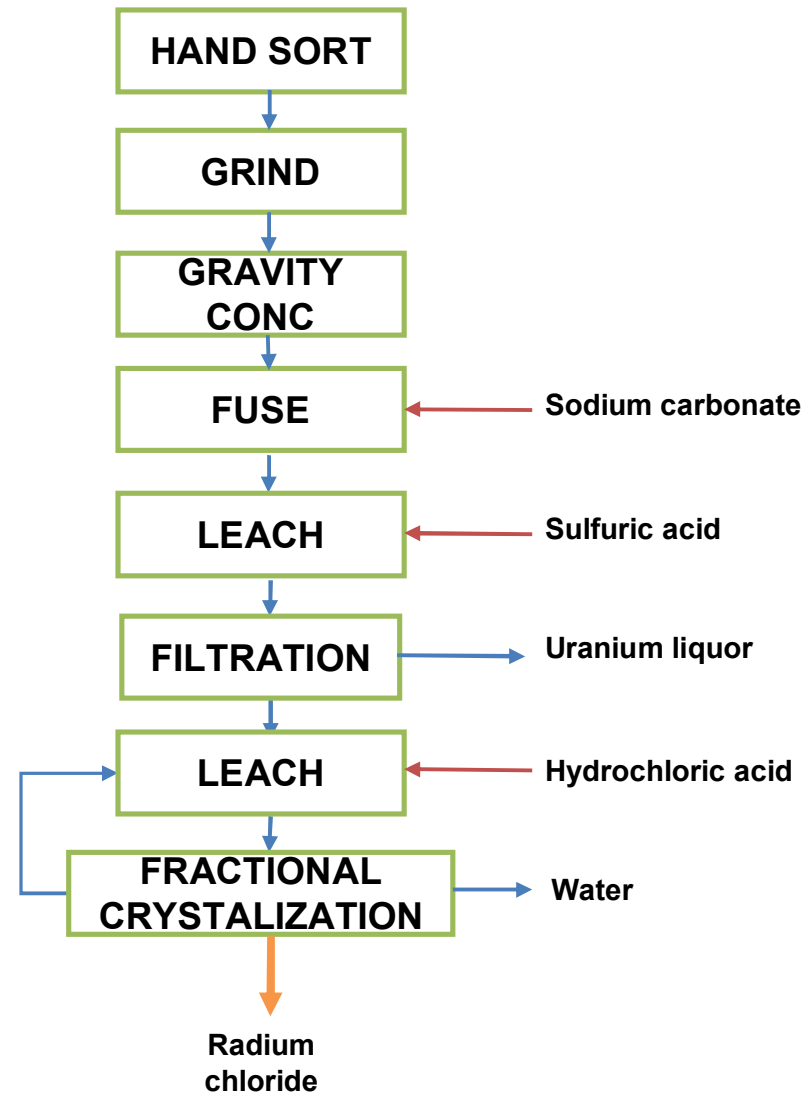


Radium Extraction



Radium Extraction

- **1909 – St Joachimstal**
 - US\$ 10 million per gram
- **1913 - Colorado carnotite**
 - US\$ 150 000 per gram
- **1915 – Shinkolobwe**
 - Union Miniere du Haut Katanga
 - 68% U_3O_8
 - Refinery at Olen, Belgium
 - US\$ 70 000 per gram



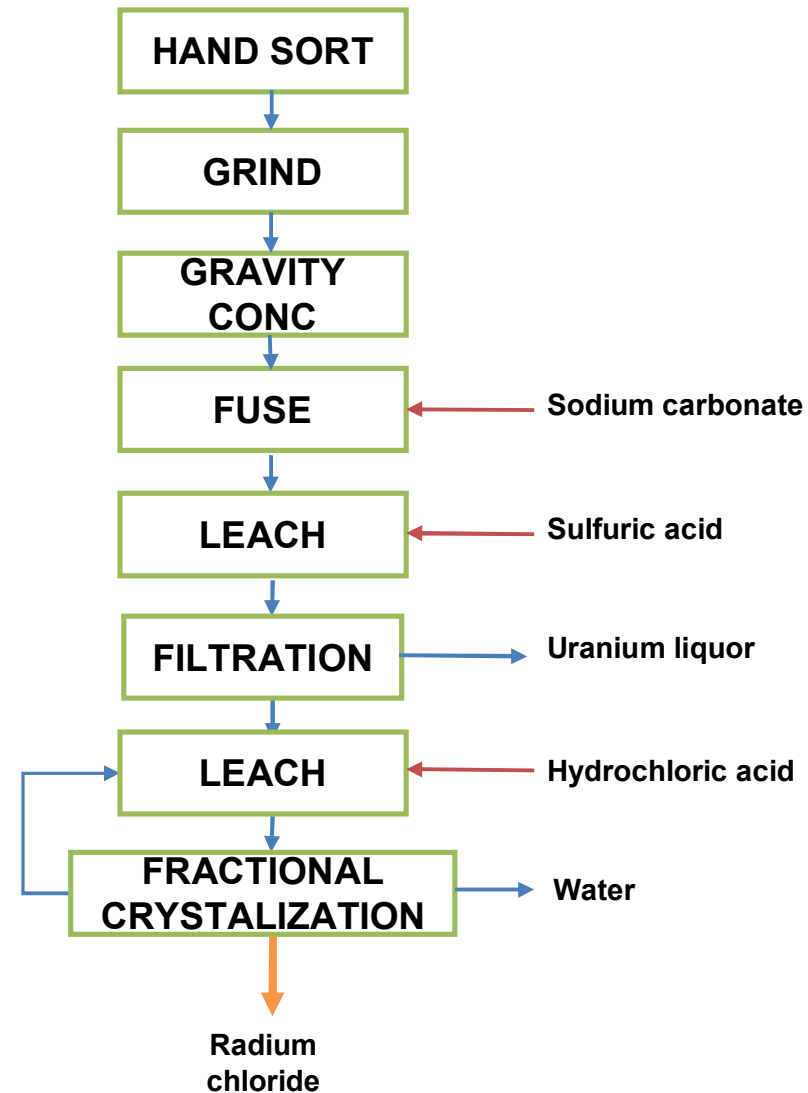
Shinkolobwe - 1922

- The most powerful rock ever found – 7 ton uranium



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- **1930 – Great Bear Lake**
 - Refinery at Port Hope
 - US\$ 25 000 per gram
- **1940 – End of Radium**



1934

- **Establishment of the Government Metallurgical Laboratory in Johannesburg**
- **Discovery of artificial radioactivity by Irene Joilet-Curie**
- **Observation of fission by Enrico Fermi (but not understood until 1938)**
- **1939 – Concept of “chain reaction” confirmed**
- **Realization that ^{235}U was the fissile isotope in uranium**
- **1941 – Manhattan project initiated**



Uranium Finds its Role

- **Eldorado - Great Bear Lake**
- **1941 first 8 t uranium concentrate ordered.**
- **1942 order from US Army increased to 60 t, then 400 t then 900 t.**
- **1200 t of Shinkolobwe concentrate from New York Harbour sent to Port Hope for refining**



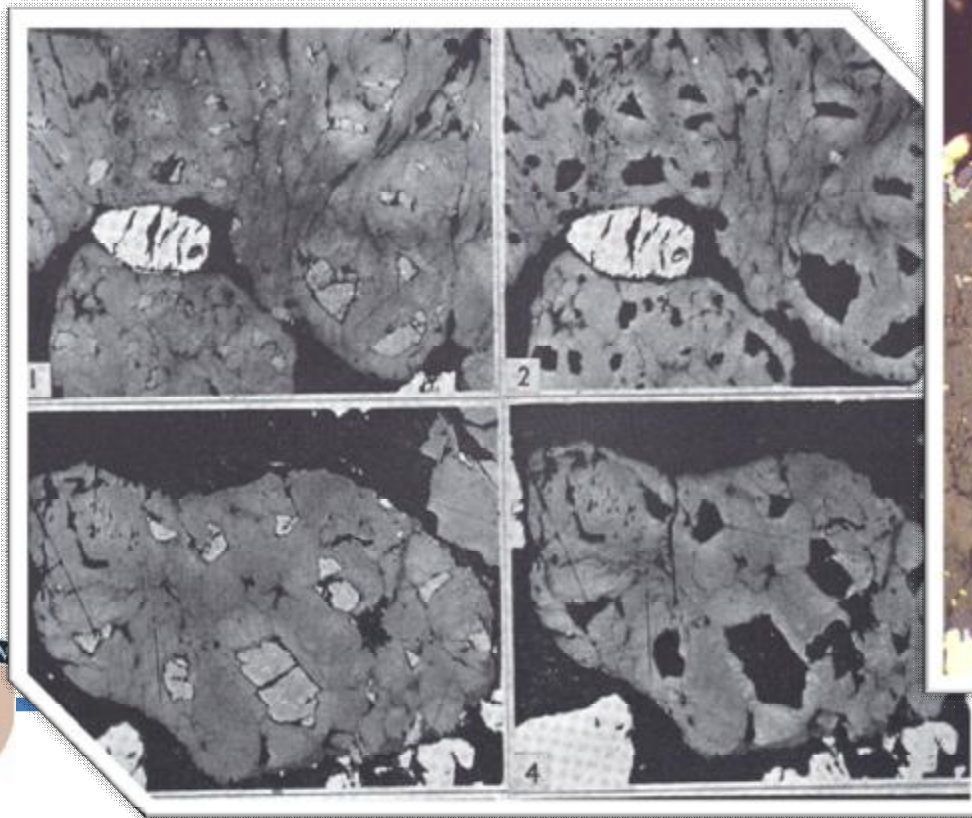
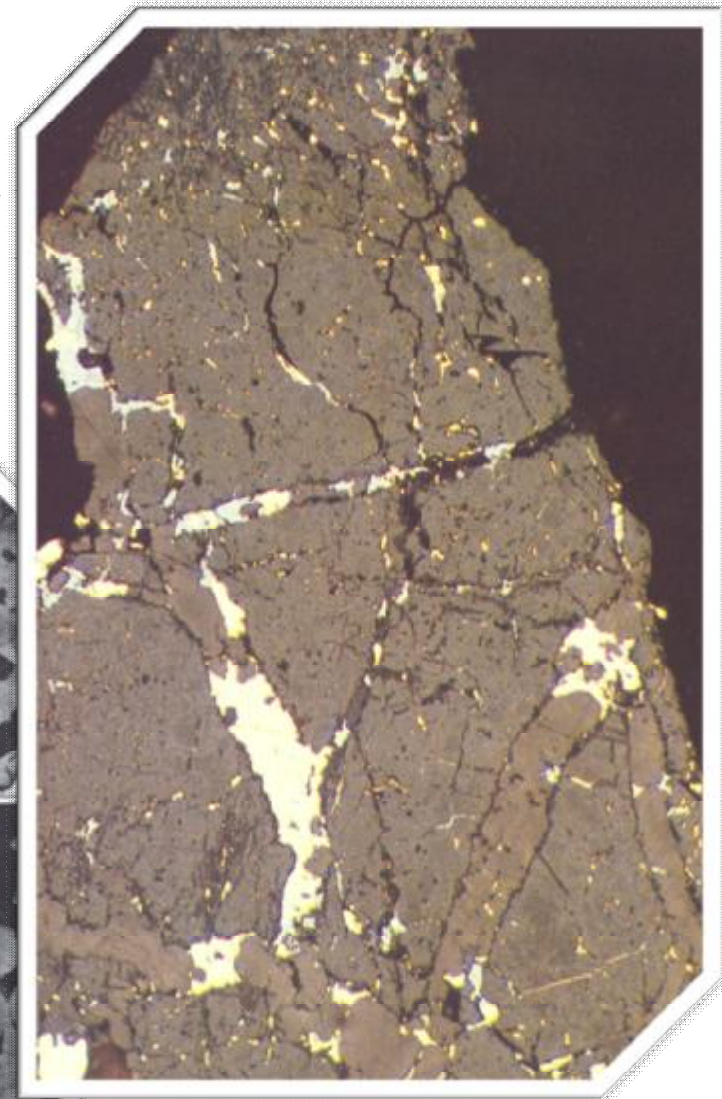
South Africa finds its Role

- **1944 – paper by RA Cooper on uranium in Witwatersrand gold ores unearthed**
- **Samples sent to USA for analysis**
- **Dr Davidson the Chief Geologist of the Atomic Energy Division of the Geological Survey of Great Britain concluded:**
 - **“Present evidence appears to indicate that the Rand may be one of the largest low-grade uranium fields in the world”**
- **Prof Taverner felt it was doubtful whether the deposits would have attracted serious attention if grade recognized**
- **Bigger samples requested**
- **Beginning of a journey from which South Africa would emerge as the world leader in the extraction of uranium from low-grade deposits**



Mineralogy

- Uraninite with pyrite & gold inclusions
- G Smits
- Thucolite before & after leaching
- WR Liebenberg



Ore Dressing

- **Pre-concentration process believed to be essential for economics**
- **20-30% uranium recovered by flotation of thucolite**
- **MIT reported up to 80% recovery with oleic acid flotation, but needed pure water and no iron**
- **Gravity recovered up to 10% if not overground**



Uranium Leaching

- **Excellent dissolution of gold and uranium in concentrate with chlorine, but reagent consumption too high**
- **Leaching of complete gold plant residue with sulfuric acid and ferric sulfate was successful**
- **Auto-oxidation with SO_2 to generate Fe^{3+} and H_2SO_4 selected, but did not scale up**
- **Pyrolusite was cheap and readily available as oxidant**
- **Calcine from roasting pyrite introduced for some plants as extra source of iron**
- **Extraction improved with increasing leach temperature and acid concentration**
- **Animal glue suitable as a flocculent for filtration**

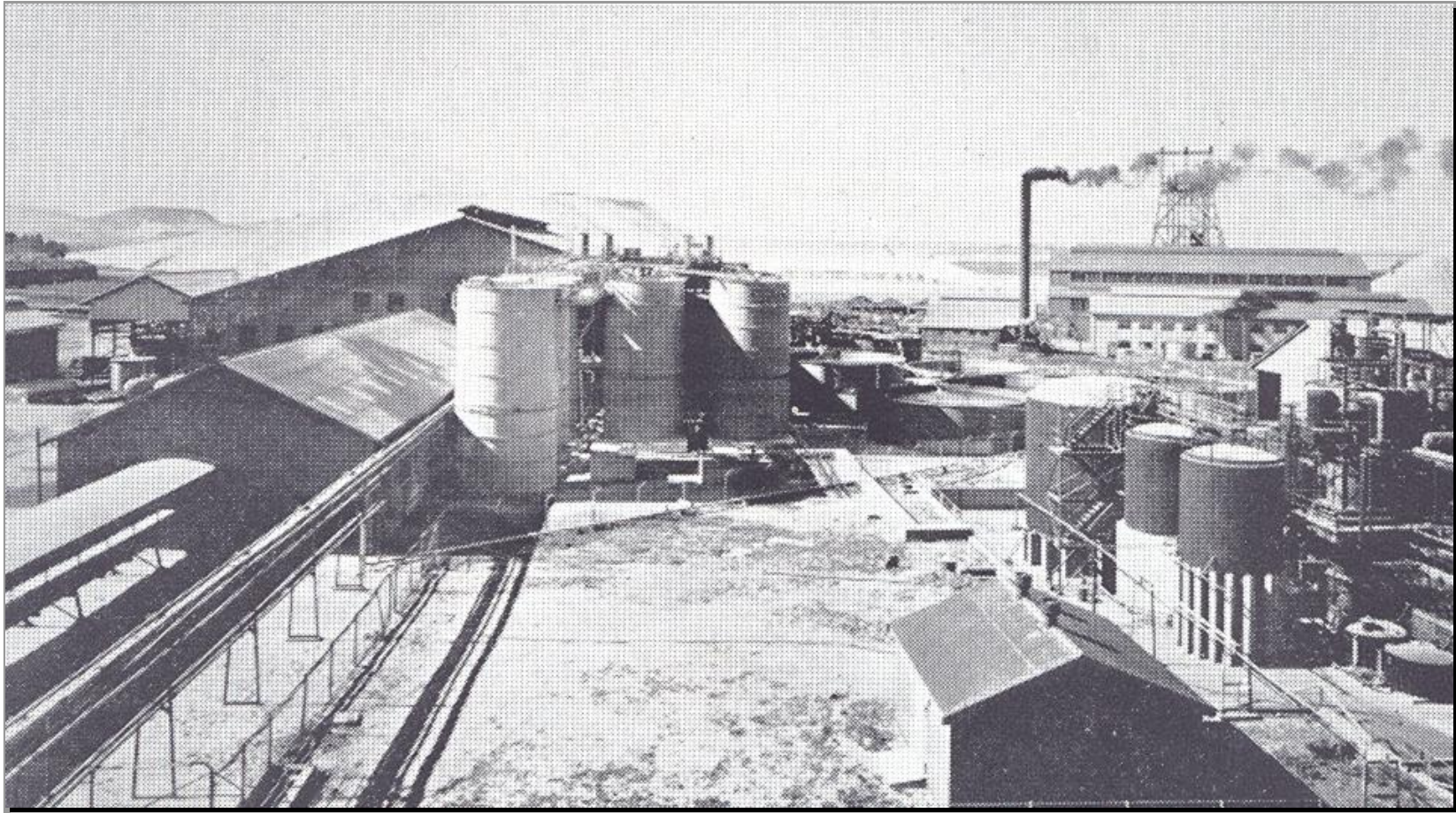


Uranium Recovery

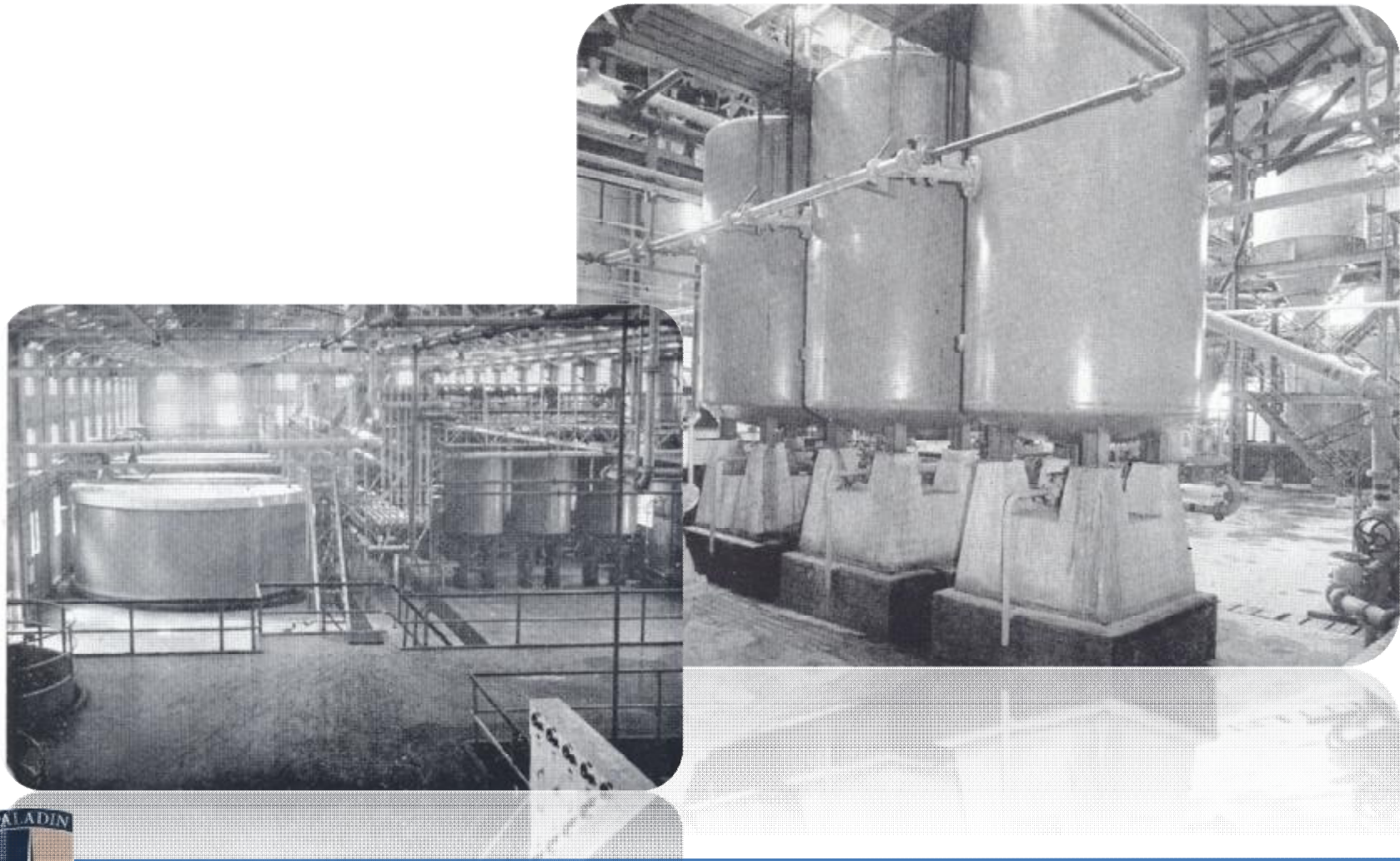
- **Traditional precipitation with lime or magnesia produced unacceptably low grade precipitates**
- **More success with copper uranium phosphate precipitation**
- **Superseded by strong base anion exchange resin**
 - **Cation resin tried but unselective**
 - **Anion selective and eluted with acidified nitrate, chloride and sulfate**
 - **Ammonium nitrate eluate treated with ammonia to precipitate ADU and recycled to elution**
 - **Fixed bed process developed**
- **Resin poisons identified as cobalti-cyanide and polythionates**
 - **Life testing rig showed marked differences in resins**
 - **Pilot-plant resin lost one third capacity after 10 cycles**
 - **Led to reverse leach process and caustic resin regeneration step**



West Rand Consolidated Uranium Plant

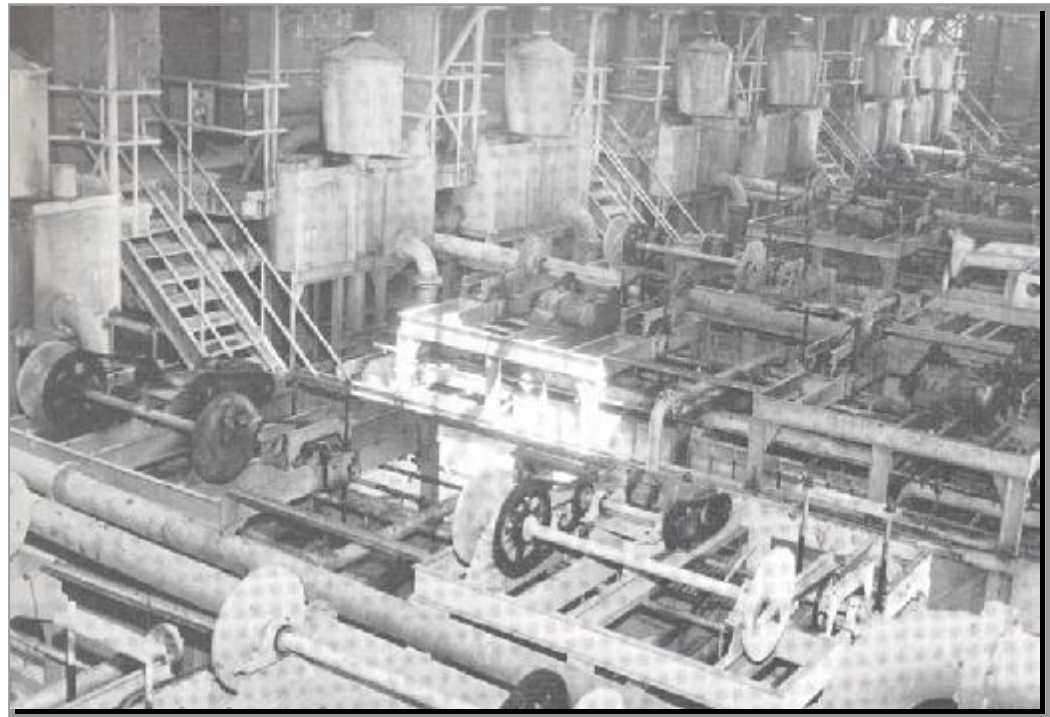


Ion exchange



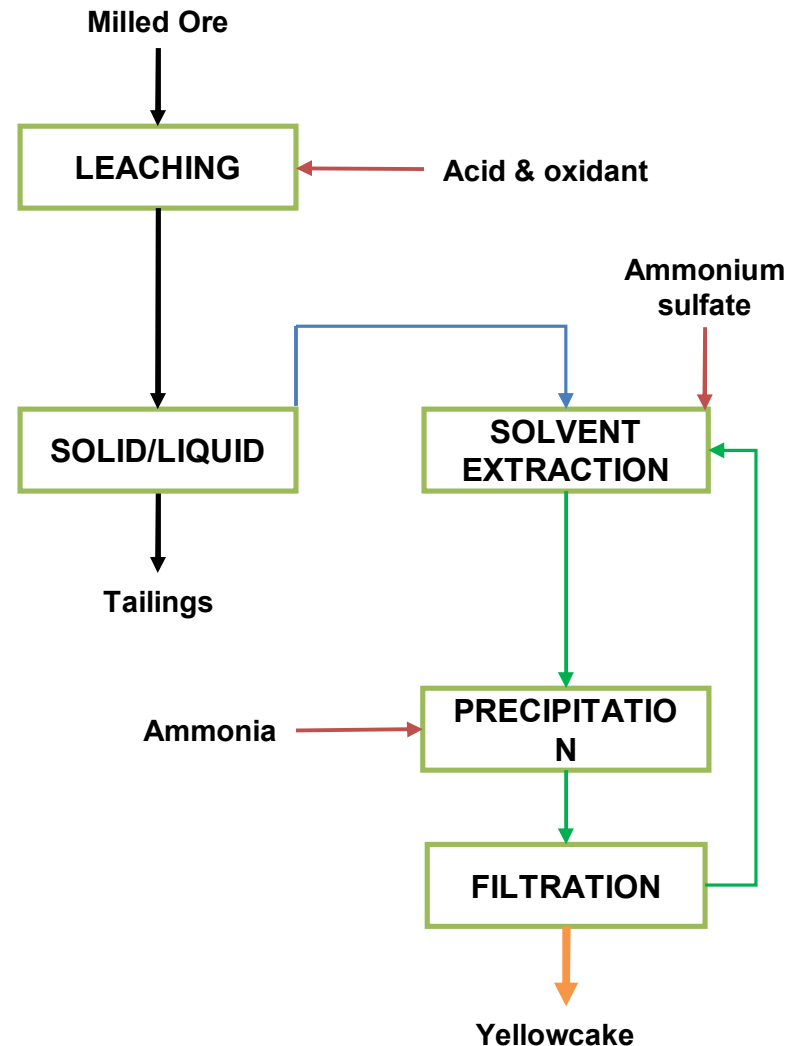
North American Variations

- Preference for CCD instead of filters
- Use of sodium chlorate as oxidant
- Elution
 - NaCl and H₂SO₄ elution precipitation with MgO
- Sand-slime split and RIP



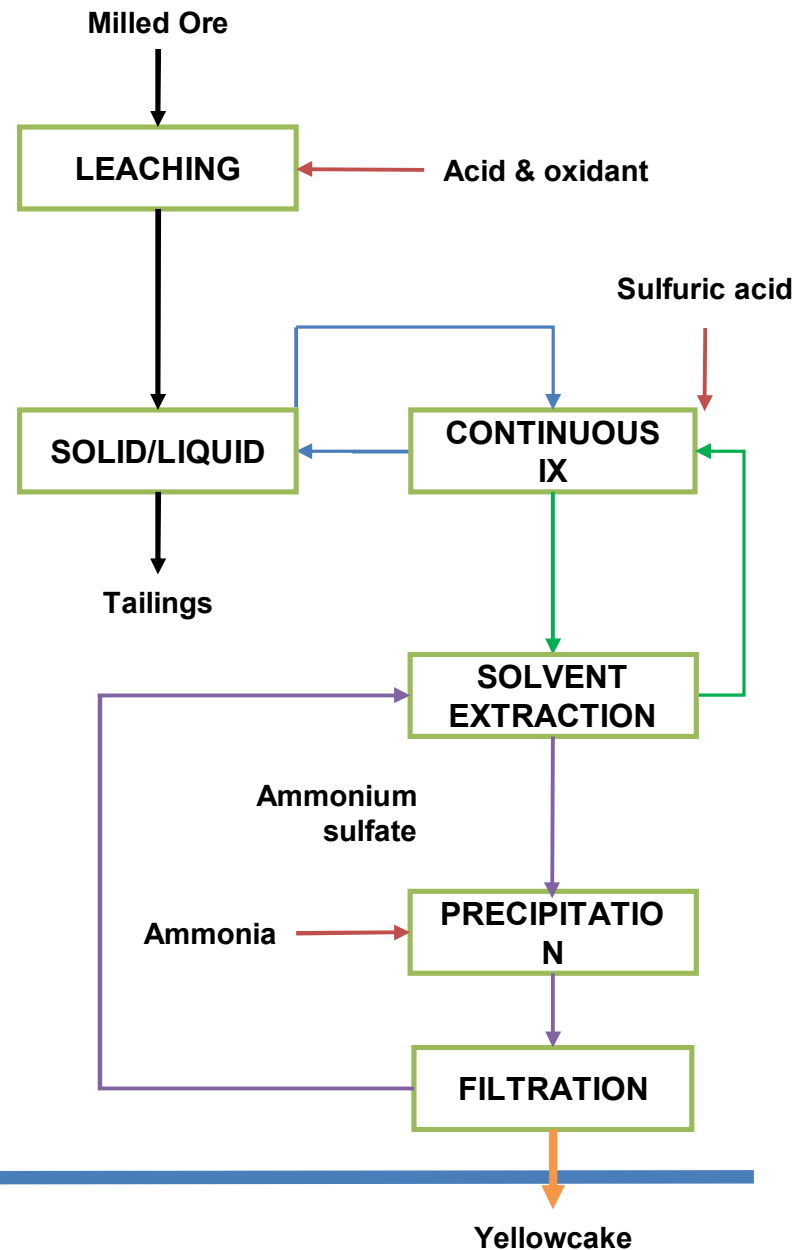
Solvent Extraction

- **1957 – Eluex introduced in USA**
- **Bufflex process developed in South Africa**
 - 1M H₂SO₄ as eluant
 - Scrubbing and regeneration
 - High purity uranium
 - Four plants implement
- **Purlex process**
 - Treat pregnant solution directly
 - 8 new plants immediately
 - 5 more by 1982
 - Americans, Australians and Canadians follow suit



Ion Exchange

- **NIMCIX Technology**
 - Unclarified pregnant liquor
 - Low reagent consumption
 - High purity product
 - Benefits of scale
 - Half resin inventory of FBIX
- **Eight CIX plants built worldwide**



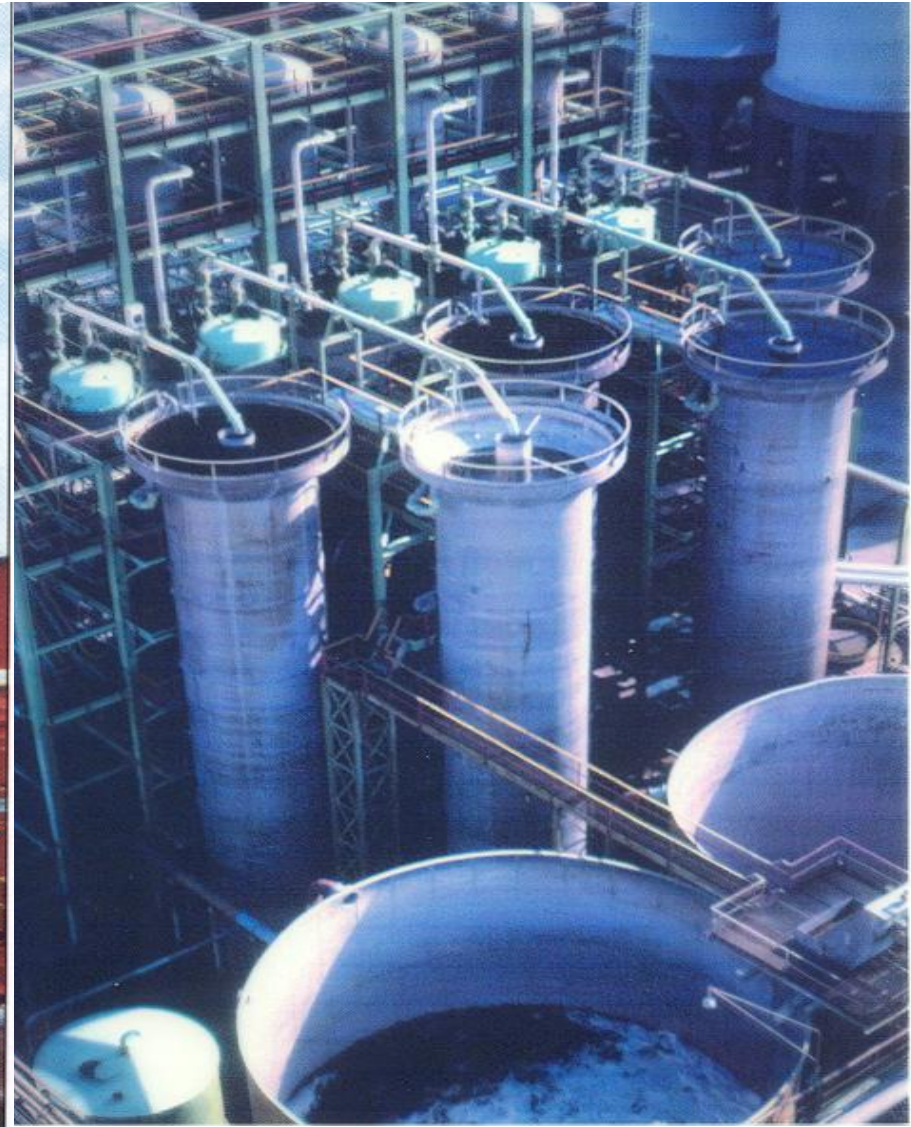
Demonstration Plant at Blyvooruitzicht



Chemwes



Vaal Reefs South



Resin-in pulp

- **1980's – Mintek development**
 - Minimize resin degradation
 - External interstage screening
 - Small contactors, same level
 - Golden Jubilee plant
- **Advantages**
 - Eliminates solid-liquid separation
 - Higher resin loading
 - Lower soluble loss
- **Kayelekra**
 - Commissioned 2009



Conclusions

Today's uranium extraction processes are underpinned by technology first tried or developed by Mintek and its predecessors in collaboration with the South African mining industry.

- **Whole ore treatment**
- **Ferric leaching and its chemistry**
- **Analytical techniques suitable for routine use**
- **Fixed bed ion exchange**
- **Bufflex and Purlex solvent extraction**
- **Continuous ion exchange (NIMCIX)**
- **High density resin in pulp**

