# Application of United Nations Framework Classification – 2009 (UNFC-2009) for Uranium Resources

MINTEK
A global leader in mineral and metallurgical innovation

## Uranium Ore Processing

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# CONTENT

Novel technologies developed and implemented by Mintek in South Africa since the 1940's; during the 1980's and today applicable to the expected future "new wave" of U production

- Mineralogy and impact on processing options
- Ore preparation and waste rejection
- Leaching
- Extraction
- Product recovery




# MAJOR URANIUM MINERALS

- Uraninite $(U^{4+}_{1-x},U^{6+}_{x})O_{2+x}$

- Coffinite $U(SiO_4)_{1-x}\ (OH)_{4x}$

- Brannerite $UTi_2O_6$

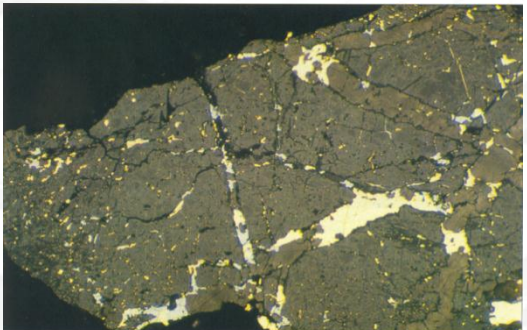
- Davidite $U_6Ti_{15}(O,OH)_{36}$

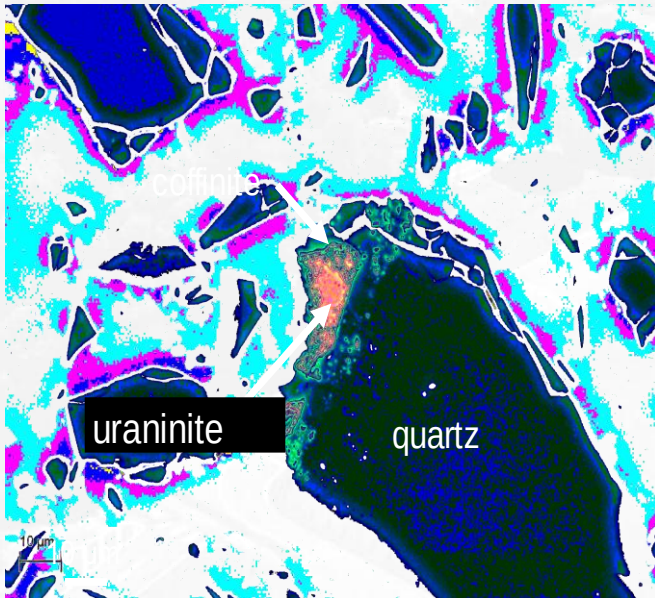
- Betafite $U_{2-x},Nd_2O_6(O,OH_x)$

- Carnotite $K_2(UO_2)(VO_4)_2.3H_2O$

# URANIUM MINERALOGICAL ANALYSIS

- Most important factors to consider before choosing a processing route:
  - Elemental composition of U-bearing and gangue minerals
  - Size of U particles
  - U liberation
  - U association with gangue minerals
  - Nature of the gangue





# TYPICAL METALLURGICAL FLOWSHEET

Ore preparation, waste rejection and U upgrading

↓

Leaching

↓

Liquid/Solid Separation

↓

Uranium extraction/ upgrading

↓

Product recovery (Precipitation to form yellow cake)

# ORE SORTING DEVELOPMENTS

- **Traditionally radiometric sorting**
  - Only viable at very coarse particles in mineralogy allows
  - High grade ores
  - Suppliers no longer use these sorters

- **Mintek investigated other sorting technologies**
  - Near infrared
  - Optical sorting
  - X-Ray transmission sorting

- **XRF most effective technology**
  - Depends on mineralogy of distinct host rock and waste minerals liberated at coarse size

# ORE SORTING

- **Major Advantages**
  - Dry processing
  - Crushing coarser
  - Lower reagent costs due to upfront waste rejection

→ **No Water**
→ **Less Energy**
→ **Lower OPEX**

- **Disadvantages**
  - Only competitive up to 30mm particle size
  - Bottom size determined by throughput economics
  - Not feasible for disseminated ores

# FLOTATION DEVELOPMENTS ON HIGH GRADE ORES

- High grade ores such as Springbok flats
- Development phase
- Removing carbonates by selective flotation

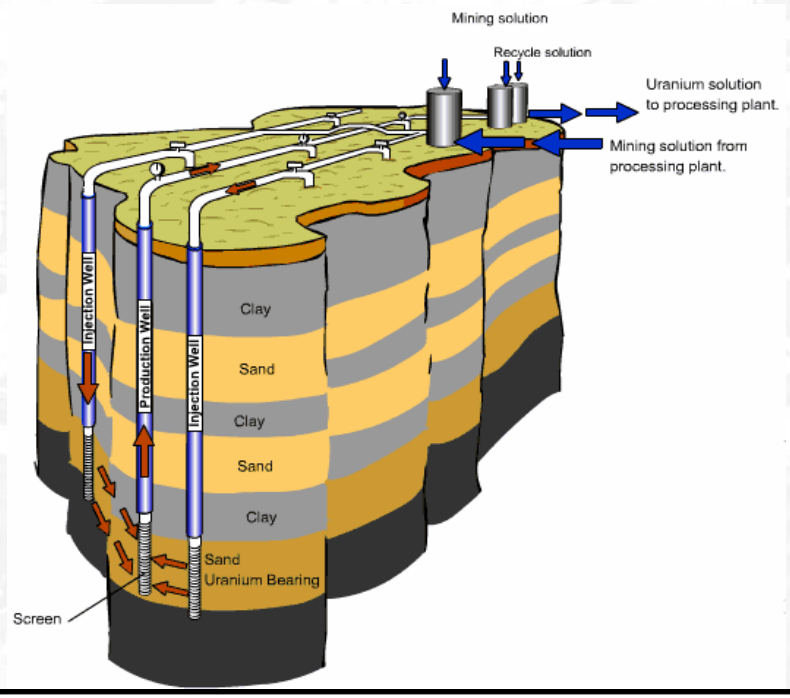
**Reduce acid consumption in leach**
**Lower reagent costs**
**Lower CAPEX**
**Lower OPEX**

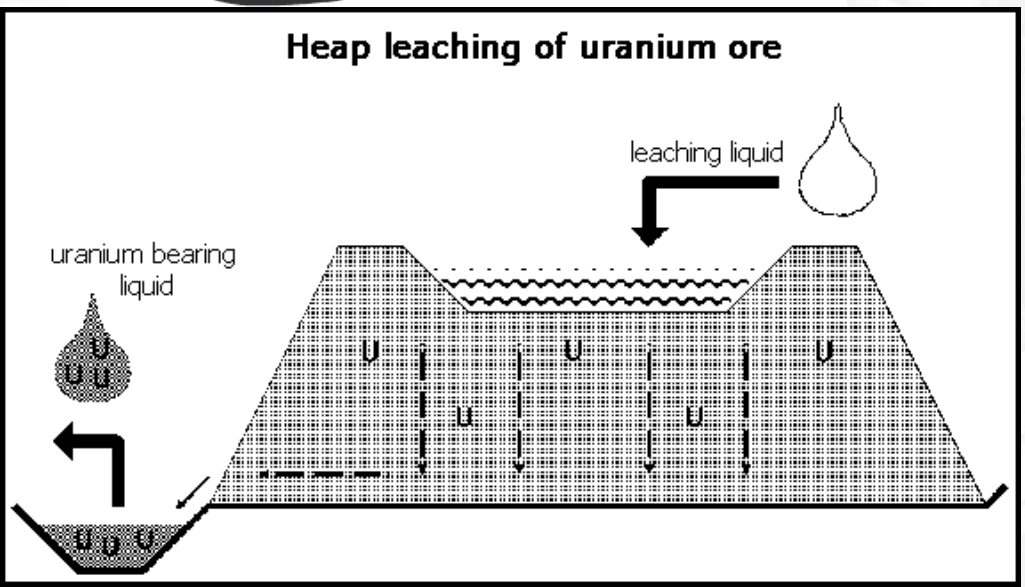
# FLOTATION DEVELOPMENTS ON LOW GRADE ORES

- Low grade Witwatersrand gold tailings (CIL tailings)
- Uranium, sulphide sulphur, un-leached gold
- Flotation of sulphides followed by oxidation to free Au for leaching - **Mintek patent in process**
- Increase U grade and recovery

**Reduce cyanide consumption**
**Lower reagent costs**
**Meets environmental requirements**
**Lower CAPEX**
**Lower OPEX**

# LEACHING OF URANIUM ORES




- Atmospheric leaching
- Pressure leaching
- In-situ leaching: suitable for the permeable ore bodies & underlying rocks which provide a barrier to solution
- Heap leaching – acidic, alkaline, bacterial

# LEACHING

- **Acid leaching**
  - Alkali-consuming ores (e.g. pyrite)
  - Witwatersrand Ores
  - $UO_3 + H_2SO_4 \rightarrow [UO_2(SO_4)_3]^{4-}$
  - Acid consumption depends on gangue minerals not U grade
  - **Typical oxidants:** $MnO_2$, sodium chlorate, ferric, $H_2O_2$, oxygen, air/$SO_2$
  - **Main impurities:** Fe, Al, Mg, Ca, V, Mo, Cu, Cl, $NO^{3-}$, Si

# LEACHING

- **Alkaline leaching**
  - Acid-consuming ores (e.g. calcite)
  - $UO_3 + NaCO_3 \rightarrow [UO_2(CO_3)_3]^{4-}$
  - Sodium or ammonium carbonate – lixiviants
  - Less efficient and slow
  - Mineralogy can affect efficiency
  - Oxidant is required
  - Relatively pure PLS
  - **Main impurities:** V, $Cl^-$, $NO^{3-}$ & $SO4^{2-}$)

# PROCESS DESIGN CONSIDERATIONS

## Leaching conditions influence design of downstream process

### Influencing parameters:

- Type of lixiviant used
- Severity of leach
- Co-extraction of impurities (level & type of impurities)
- PLS grade

### Influenced parameters:

- CAPEX, OPEX (reagents, equipment, energy, etc.)
- Plant construction material (i.e. chloride level-stress corrosion)
- Selection and design of downstream process (SX, IX, IX/SX, ppt, etc)
- Environment and safety requirements with associated costs

# HEAP LEACH DEVELOPMENTS ON LOW GRADE ORES

- **Hydrodynamic performance critical for heap leach to function optimally**

- **Mintek investigating characterisation of crushed ore for heap leach in 1m column cells**
  - Stacking profiles
  - Hydrodynamic properties (pore pressure and conductivity, moisture content)

# HEAP LEACH TESTING FACILITIES AT MINTEK

# HEAP LEACH DEVELOPMENTS ON LOW GRADE ORES

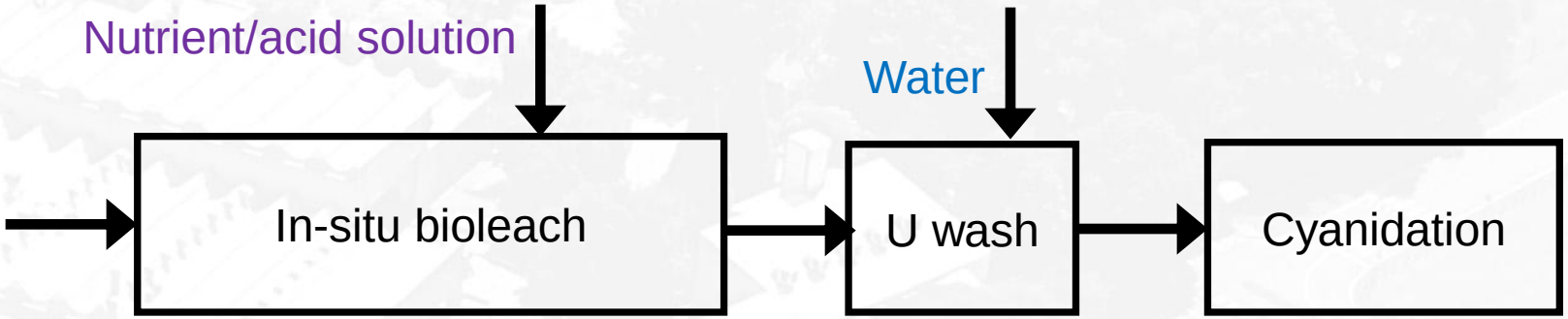
- **Refractory minerals deemed difficult to leach** (brannerite, Ti-rich coffinite) – Karoo sandstone
- Acid consumption high due to presence of **carbonates** (calcite and dolomite)
- Investigating **acid ferric leaching**
- Improve rate and extent of uranium dissolution
  - Increased acid dosages during agglomeration
  - Curing duration

# IN-SITU BIOLEACHING DEVELOPMENTS ON LOW GRADE ORES

- **Witwatersrand CIL Tailings**

- **Tailings dumps compacted, water and air permeabilities are low**

- **Suitable for in-situ bioleaching**
  - Irrigation with dilute acid solution to reduce pH
  - Suitable for bacterial oxidation instead of $MnO_2$
  - Tailings washed after time to recover uranium



# IN-SITU BIOLEACHING ON LOW GRADE ORES

- **Advantages of BioLeaching over acid-ferric leaching of uranium**

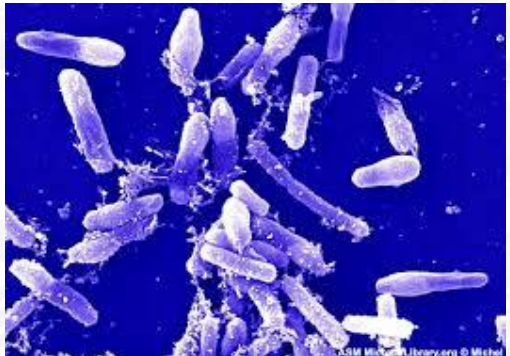
**Lower acid consumption**
**Reduced heating requirements**
**Lower environmental impact due to bacteria performing as oxidant**
**Lower OPEX**

# BIOLEACHING DEVELOPMENTS ON LOW GRADE ORES

- Novel flowsheets for incorporating bioleaching into uraninite extraction from pyritic flotation concentrates – Witwatersrand ores

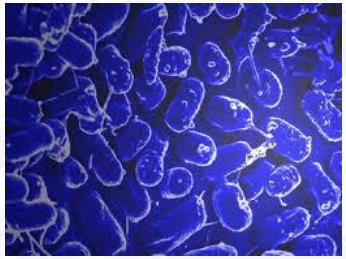
- **Biological and chemical leaching together**
  - Bio-oxidation of pyrite for the production of ferric
  - Sulphuric acid generated in process

- **Split feed system bioleaching system**
  - Pyrite leached in autoclave and uranium subjected to bacterial leach



# SPLIT FEED SYSTEM BIOLEACHING

- **Limitations**
  - Perform better at smaller particle sizes
  - Perform better at lower sulphide concentrations
  - Slower leaching kinetics
  - Limited by feed solids concentration that could be tolerated by micro-organisms
  - Narrow critical temperature range required for biological environment
  - Not currently economically viable since U tenor (leach liquor composition) in solution below the 100mg/L required




# URANIUM IN SOLUTION => “YELLOW CAKE”

**Uranium ore leaching**

**Pregnant leach liquor**

***Depending on $U_3O_8$ grade, impurities levels, physical characteristics of liquor, complexity of S/L separations, etc.***

**Ion exchange** → **Solvent extraction** → **Precipitation**

***“yellow cake”***

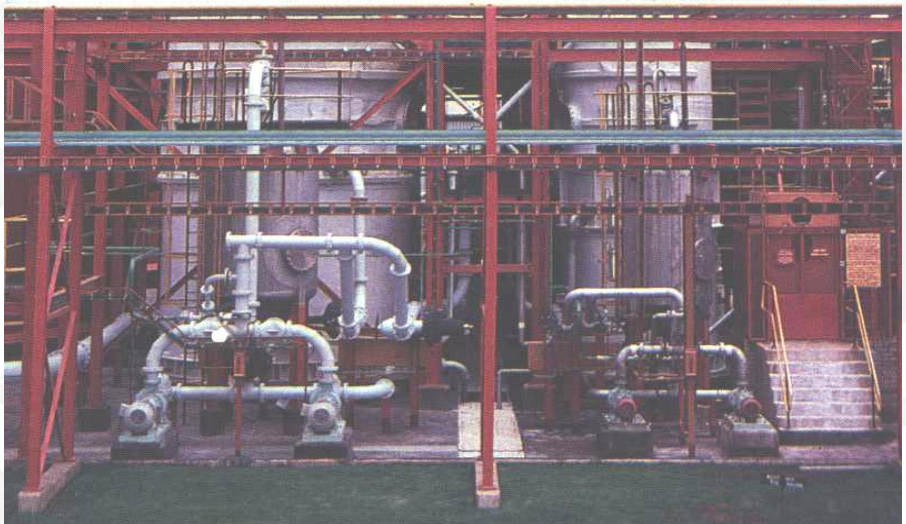
# ION EXCHANGE / SOLVENT EXTRACTION

- IX and SX – used to upgrade uranium prior to yellow cake precipitation
- SX for high grade streams (>800mg/L)
- IX for low grade streams

# EXTRACTION DEVELOPMENTS OVER THE YEARS

- Fixed bed IX with precipitation of ammonium diurate (ADU)
- Bufflex process – IX and SX on eluate from IX
  - Much higher grade of ADU
- Purlex process – SX only
- NIMCIX™ – Continuous fluidised bed ion exchange
  - Major advantage: Can handle 200-300g/L suspended solids in feed
- Resin-in-Pulp (RIP)

# NIMCIX & RIP



# RESIN-IN-PULP TECHNOLOGY

- **Major Advantages**
  - Minimal or no upstream Solid/Liquid separation required
  - Can handle up to 60% solids
  - Lower wash water requirements
  - Improvement of overall metal recoveries
  - Lower discharge metal concentrations => decrease of problems associated with wastes disposal - Environmentally acceptable
  - Economically viable
  - Can be retrofit to existing U plants
  - Feasible for U < 800 mg/L

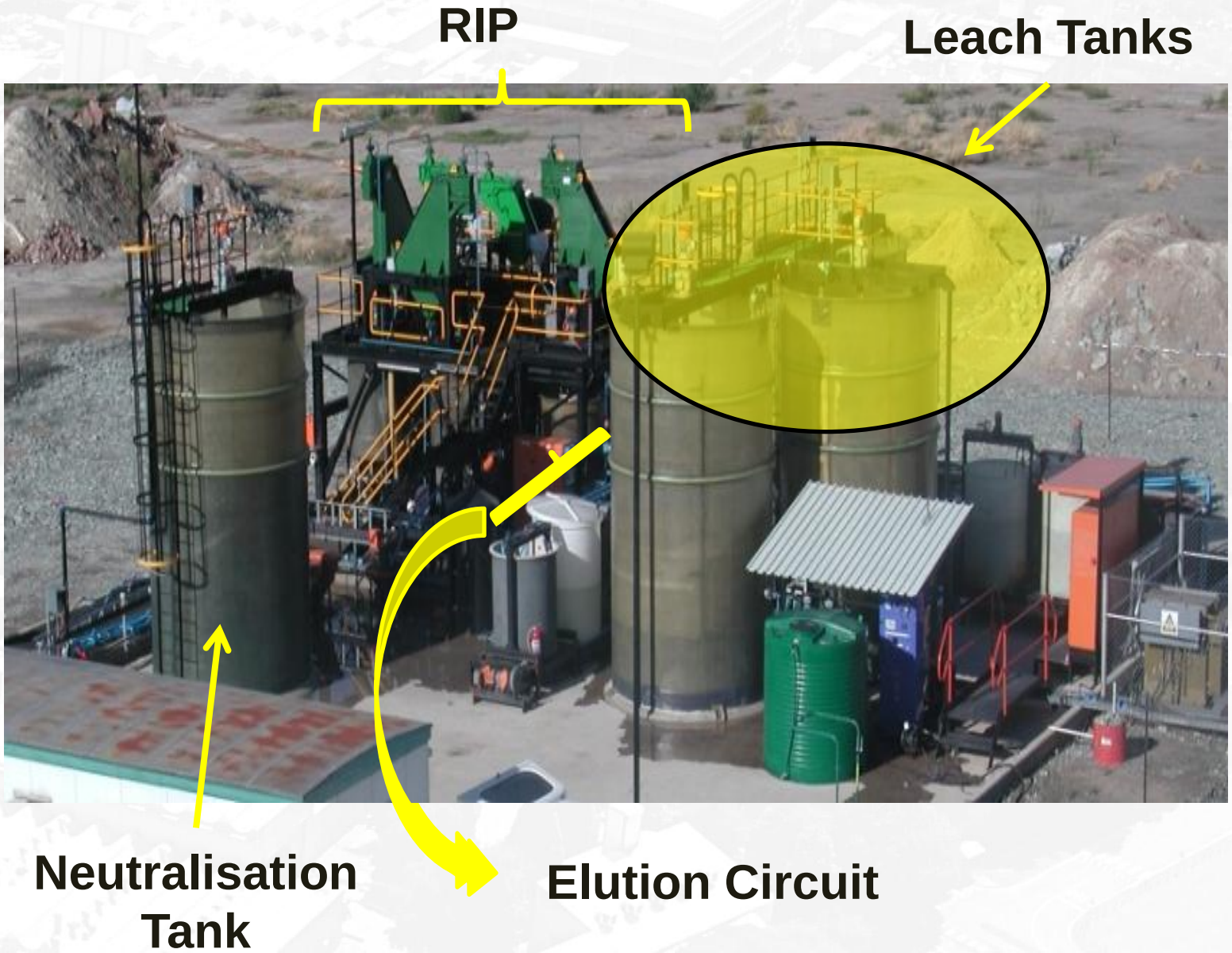
- **Main Disadvantage**
  - Resin loss and durability
    - Mintek can assist with resin selection
    - Process optimisation prior to RIP can handle impurities
  - Silica fouling and impact on OPEX
    - Design to limit uranium losses

# MINTEK DEVELOPMENTS IN RIP TECHNOLOGY

- Metal Recovery through Ion Exchange **(MetRIX™)** technology
- Developed by Mintek and TENOVA in 1980's for base metals
- MetRIX™ technology revived for uranium recovery from low-grade sources in 2007
  - Truly continuous system
  - Independent resin and pulp flows – optimal metallurgical performance
  - Shorter resin residence time - limits resin fouling
  - Lower CAPEX (Resin inventory 30-40% of carousel system)
  - Easy integration to existing plants

# METRIX™ RIP SECTION OF THE PLANT

# METRIX™ DEMONSTRATION PLANT



# MINTEK DEVELOPMENTS IN RIP TECHNOLOGY

- **Major resin developments:**
  - Larger, more durable resin produced
  - Mintek resin durability evaluation techniques:
    - Pilot plant and laboratory scale tests

- **Resin replacement from MetRIX™ plant operated at Harmony:**
  - Resin replacement cost attributed <1% to plant OPEX

# RIP PILOT PLANT

# RIP DEMONSTRATION PLANT

# SOLVENT EXTRACTION

Mixer-settler contactors

Bateman Pulse Column

# SOLVENT EXTRACTION DEVELOPMENTS

- Karoo sandstone deposits with coffinite, uraninite and pitchblende
  - Mo concentrations in feed high - Selective extraction
  - Presence of calcite and sulphide minerals – Acid and base consuming
- Direct precipitation (after leaching)
- Precipitation from eluate (after SX, IX)

**Improved U dissolution**
**Reduced acid consumption in leach**
**Lower reagent costs**
**Lower OPEX**

# FLOWSHEET EXAMPLES

- Uranium One, Klerksdorp: CCD ➔BPC SX ➔ADU
- Ezilweni: CCD➔NIMCIX➔SX➔ADU ppt
- Langer Heinrich: CCD ➔Clarification ➔FBIX ➔Ppt
- Vaal River South: CCD ➔NIMCIX ➔MS SX ➔ ADU
- Trekkopje: Heap leach ➔ NIMCIX ➔ SDU
- Kayelekera: RIP ➔ direct ppt
- AngloGold Ashanti: South Uranium upgrade, Kopanang extension: NIMCIX / RIP

# SUMMARY

- **No fixed flowsheet choice**

- **Key drivers:**
  - Mineralogy
  - Reagent consumption
  - Uranium grade & impurities level
  - Ability to upgrade
  - CAPEX & OPEX

- **Process selection criteria:**
  - Throughput
  - Selectivity
  - Costs

# Thank You

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