HEAP LEACHING TECHNOLOGY
Moving the frontier for treatment
Applications in Niger and Namibia

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HEAP LEACHING OF URANIUM ORES

- **Interest on heap leaching of uranium ores motivated by expected increased participation of low grade ore treatment in future uranium production**
- **Significant reduction in CAPEX and energy costs by avoiding grinding, agitation tank reactors and filters**
- **Large experience and best practices transfer from conventional copper heap leaching operations**
- **Recent advances in bio-leaching by using archea and other thermophile bacterial strains open opportunities for the treatment of black shale deposits**
- **Actual operation at Somair and the Imouraren Project in Niger, together with Trekkopje Project in Namibia show AREVA's confidence on this technology**
- **Present extremely low uranium price situation (< 30 US$/lb U) has temporarily slowed and delayed further development and application of this technology**
- **Learnings and experience from operational practice and from R&D activities should help in facing challenges associated to future market demands for safe, efficient and clean uranium production**

CONTENTS

THE HEAP LEACHING UNIT OPERATION

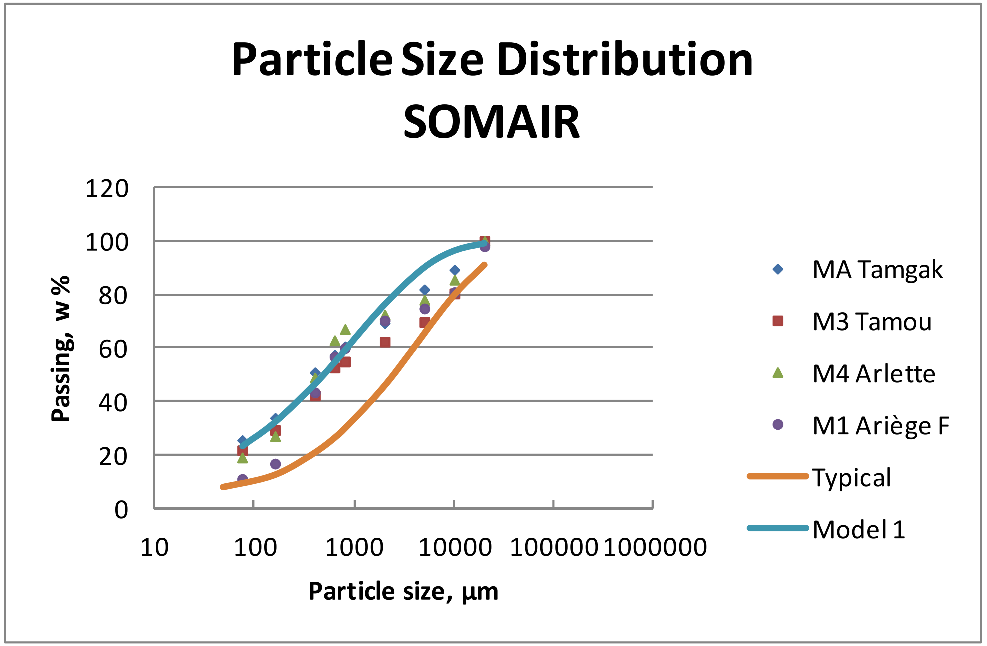
THE HEAP REACTOR

- Non confined auto-supported packed bed reactor
- Non flodded bed solution flow pattern
- Bed packing : agglomerated ore particles
- Agglomeration is key to ensure:
  - heap stability
  - ore bed permeability under non flooded bed liquid flow condition
  - enhanced initial reagent distribution all over heap height

Areva / M Ascani

THE AGGLOMERATION QUALITY

- **The amount of water and possible reagents required to produce a good agglomerate depends on particle size distribution (PSD), particularly on the amount of fines (<150µm)**
- **The PSD is a characteristic response of the ore to blasting and crushing operations**
- **The PSD of spheres can be characterized by the mean diameter D_{mean} and by the "Uniformity Coefficient" C_U describing the spread or standard deviation**
- **The PSD defines the apparent density (ρ_{App}) and therefore, the porosity (ε)**



$$D_{mean} = (D_{16} + D_{50} + D_{84}) / 3$$

$$C_U = D_{60} / D_{10}$$

$$\varepsilon = 1 - \rho_{App} / \rho_S$$

BUT, …..

- **0re particles are not spheres !!**
- **And they are randomly packed**

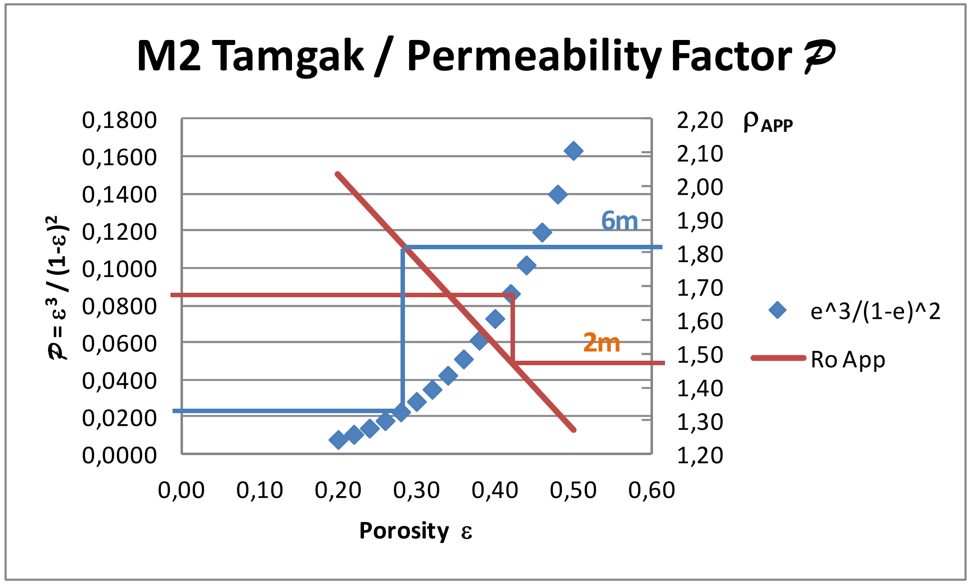
Typical refers to PSD encountered at copper heap leach operations

SOLUTION FLOW THROUGH ORE BED

- Non flooded bed gravity flow leading to the so called "Thin Layer (TL) Leaching" concept (Rauld et al, SME-AIME, Louisiana, March 1986)
- Specific discharge flow v° and hydraulic conductivity K related by:

$$v° \text{ [cm/sec]} = K\,[(\theta - \theta^*)/(\theta_s - \theta^*)]^3 = \kappa\, g\, \rho/\mu\, [(\theta - \theta^*)/(\theta_s - \theta^*)]^3$$

- The difference ($\theta - \theta^*$) is the excess of liquid retained by the ore agglomerates referred to θ^*, which is the liquid retained once the flow has been stopped (at the end of drainage). θ_s is the liquid retention under flooded bed condition.



- The intrinsic permeability κ depends on ore PSD and on ore packing characteristics within the ore bed:

$$\kappa = \kappa' D_P^2 \; [\varepsilon^3 / (1-\varepsilon)^2]$$

- Somair typical values are:

$H = 6$ m
$K = 0.0125$ cm/sec
$v° = 3$ L/hm^2

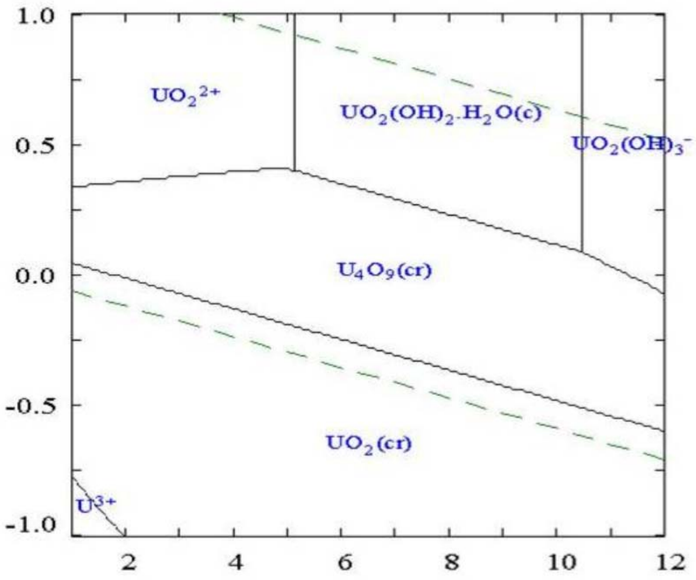
THE REACTION SYSTEM

- **Ore mineralogy and solution chemistry**

$$UO_3 + 2\ HCO_3^- + CO_3^{2-} = UO_2(CO_3)_3^{4-} + H_2O$$

$$UO_3 + 2\ H^+ + 3\ SO_4^{2-} = UO_2(SO_4)_3^{4-} + H_2$$

$$UO_2 + 2\ Fe^{+3} + 3\ SO_4^{2-} = UO_2(SO_4)_3^{4-} + 2\ Fe^{+2}$$



- **Impurity dissolution**

$$V_2O_5 + 2\ OH^- = 2\ VO_3^- + H_20$$

$$CaSO_4 + CO_3^{2-} = CaCO_3 + SO_4^{2-}$$

$$2\ FeO.OH + 6\ H^+ = 2\ Fe^{3+} + 4\ H_2O$$

$$Al_2O_3 + 6\ H^+ = 2\ Al^{3+} + 3\ H_2O$$

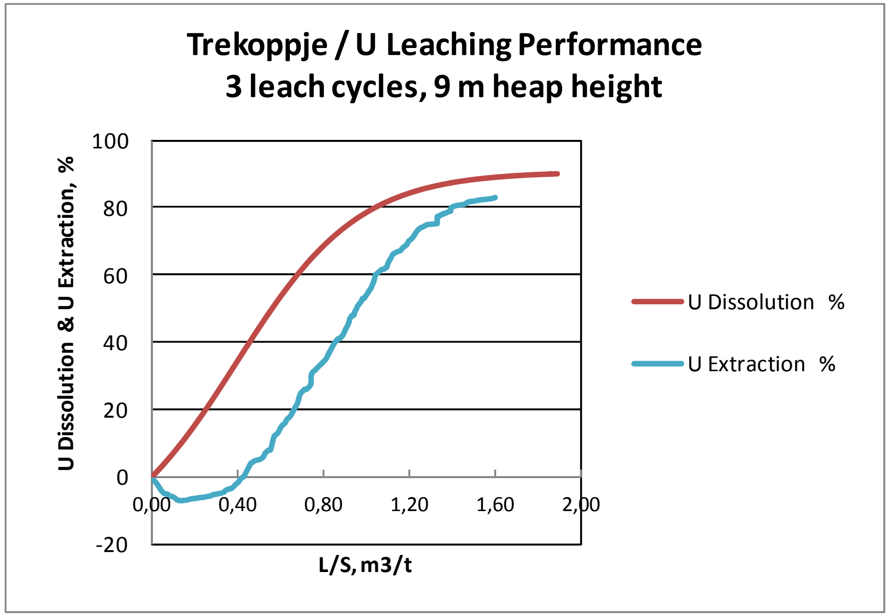
$$CaCO_3 + 2\ H^+ = CaSO_4 + CO_2 + H_2O$$

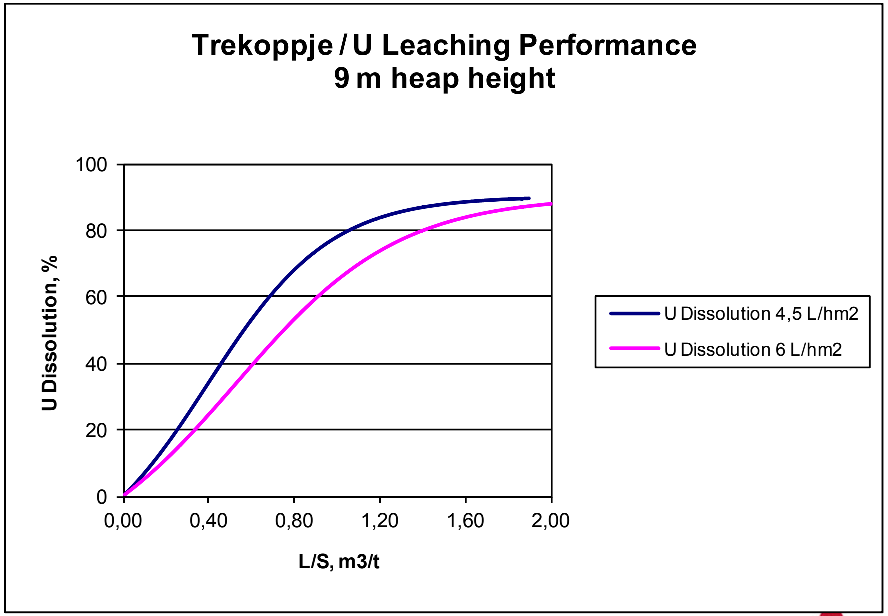
- **Dissolution kinetics controlled by mass transport phenomena, but mainly by reagent supply to the ore solution reaction inter-phase**
  - **Volume application rate is 3 orders of magnitude lower at heap leaching as compared to agitation leaching**
  - **Reagents concentration profiles along heap height**

Operating condition	**Unit**	**Heap**	**Agitation**
Specific flow rate	L/hm2	5	9730
Volume application rate	m3/td	0,011	12,7
Solid-liquid contact time	h	900	0,79
Solution residence time	h	389	4,8
Total leaching time	h	2160	4

LEACHING PERFORMANCE

- **Need to distinguish between extraction and recovery**
- **Multiple leach cycles lead to large and slow solution inventory changes**
- **Increased heap height helps in improving $[U]_{PLS}$, but compromises leaching time**
- **Increased specific flow rate reduces time but also reduces $[U]_{PLS}$**



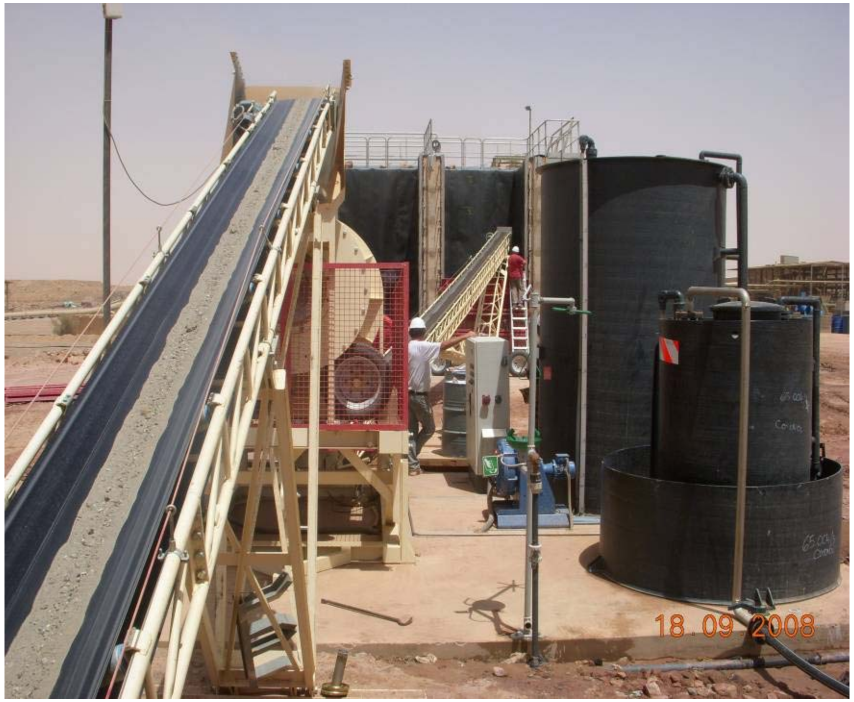


TESTWORK PROGRAM DEMANDS

- Heap Leaching processes set up require many lab scale tests in columns and pilot tests
  - Dedicated Equipments
  - Large number of columns
  - Time for tests
  - CAPEX and OPEX for these tests

Namibia equipments

TESTWORK PROGRAM DEMANDS

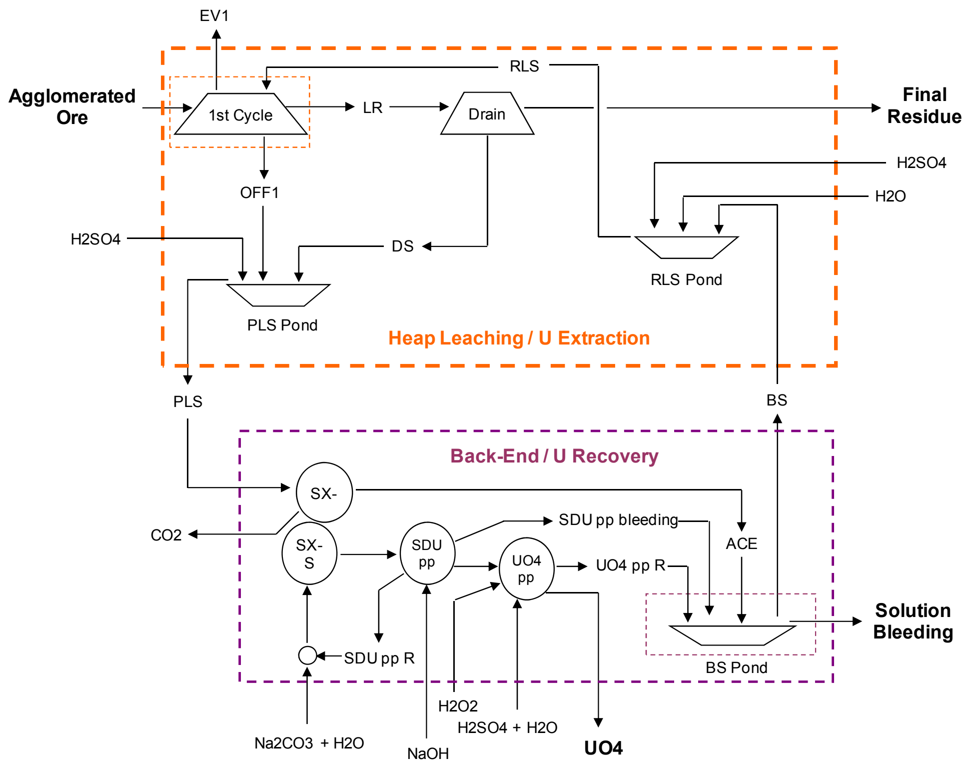


Niger equipments for Somaïr and Imouraren Projects

INTEGRATION OF THE HEAP IN THE URANIUM RECOVERY PROCESS

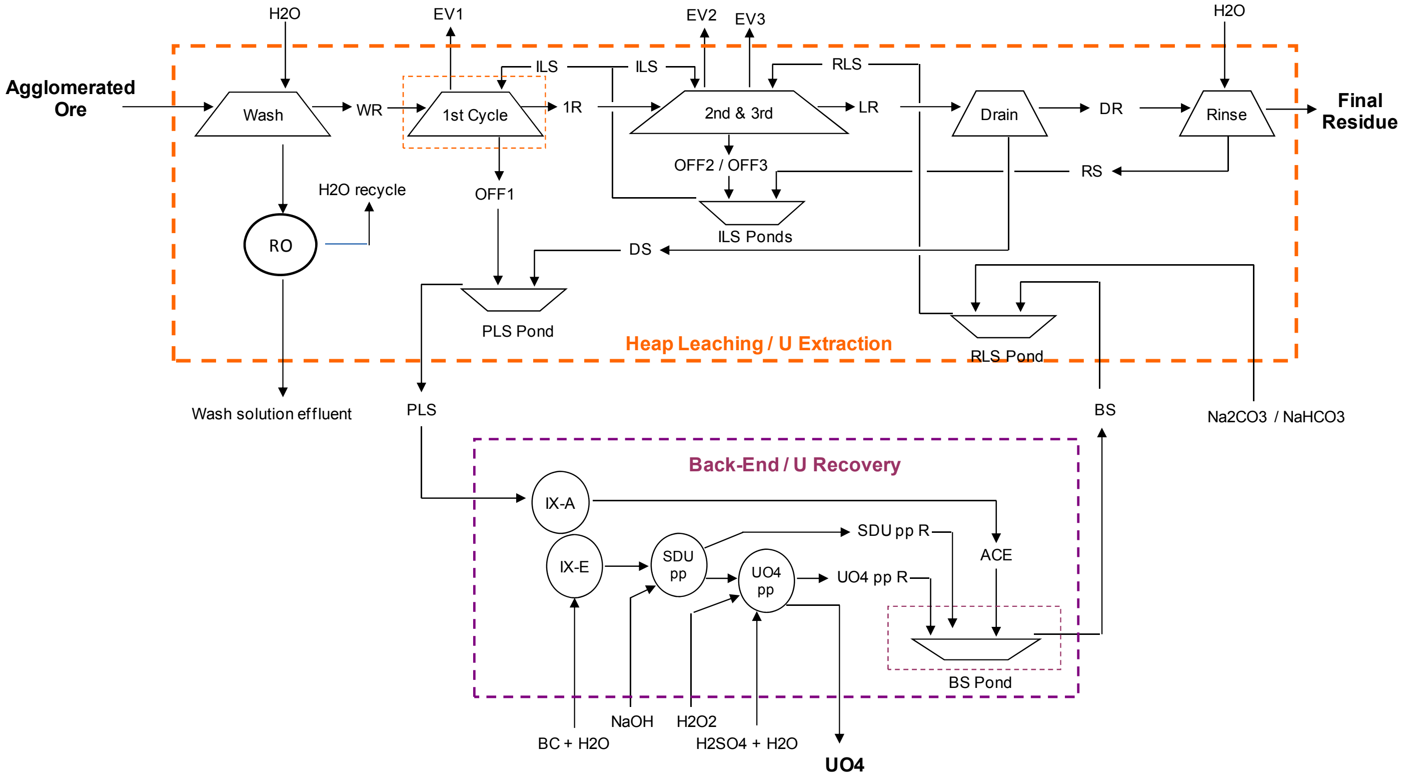
ACID HEAP LEACHING PROCESS

- Similar to Copper heap leaching operations
- Anionic amine as SX organic extractant reagent
- Typical impurity release with final residue. Solution bleeding depending on acid consumption and gangue mineralogy
- Possible regeneration of oxidant Fe^{+3} by bacterial activity



ALKALINE HEAP LEACHING PROCESS

- **Need of ore washing to minimize $[Cl^-]_{PLS}$ and $[SO_4^{2-}]_{PLS}$**
- **Three leach cycles to increase $[U]_{PLS}$ and to reduce PLS flow to IX**
- **Need of residue rinsing to minimize reagent losses**
- **Water balance very much affected by elution efficiency**



FINAL REMARKS

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- Uranium is being successfully extracted from low grade ores by heap leaching operations
- The response of the reaction system both at acid or alkaline leaching conditions is well know
- Proper characterization of ore feed is required to anticipate agglomeration quality, heap permeability and stability, and uranium dissolution kinetics and final recovery
- Many laboratory, bench scale tests and pilot plant demonstration at proper scale are necessary to provide suitable design parameters and to fit modeling efforts to actual results
- Large space for optimization opportunities to reduce ore throughput,

  water and reagents consumption
- Proper effluent solution management and control as well as proper residue disposal are required for safe and clean operation