Metallurgical Testwork to Support Development of the Kintyre Project

Mark Maley[1], Marina Fainerman-Melnikova[1], Mervin Ovinis[1], Karin Soldenhoff[1], Bob Ring[1], Eric Paulsen[2] & David Maxton[2]

26 June 2014

ANSTO Minerals[1], Cameco[2]

ANSTO Minerals

- Studied processing of uranium ores for over 30 years;
- Extensive variety of deposits:
  - 6 operating mines in Australia (3 open, 3 closed)
  - 15 potential mines in Australia
  - 14 operating and potential mines outside Australia (mainly Southern Africa)
- Fundamental and diagnostic leach studies
- Detailed geometallurgical studies

ansto Minerals

KINTYRE URANIUM DEPOSIT

- Discovered in 1985 by CRA (Rio Tinto)
- Acquired in 2008 by Cameco/Mitsubishi JV (70/30)

ansto Minerals

KINTYRE URANIUM DEPOSIT

- 55 Mlb U_3O_8 @ 0.58% average grade

- Uranium present mainly as:
  - Uraninite (UO_2)
  - Coffinite ($(USiO_4)_{1-x}(OH)_{4x}$) – lesser amounts

- High in carbonates
  - Ankerite ($Ca(Fe,Mg,Mn)(CO_3)_2$)
  - Dolomite ($CaMg(CO_3)_2$)

ansto Minerals

Metallurgical Testwork

History

- Acid Leach Pilot Plant operated at ANSTO in 1997
  - Ore upgraded to 2% U_3O_8 by radiometric sorting and gravity separation
  - 7 campaigns
  - Direct uranium precipitation yielded on-spec product

- Alkaline Leaching subsequently investigated by Cameco, but acid route selected

ansto Minerals

Metallurgical Testwork

Objectives of Work Discussed Today

- Optimisation of leach conditions
  - Maximise U extraction
  - Minimise acid and oxidant consumption
- Evaluate leaching of variability samples
- Effect of ore type and leach conditions on settling, filtration and rheology
- Neutralisation and radionuclide deportment in tailings
- Solvent Extraction Pilot Plant
  - Evaluation of ammonia and strong acid stripping

Leach Testwork

Automated – Computer controlled pH and ORP

Leach Optimisation Program

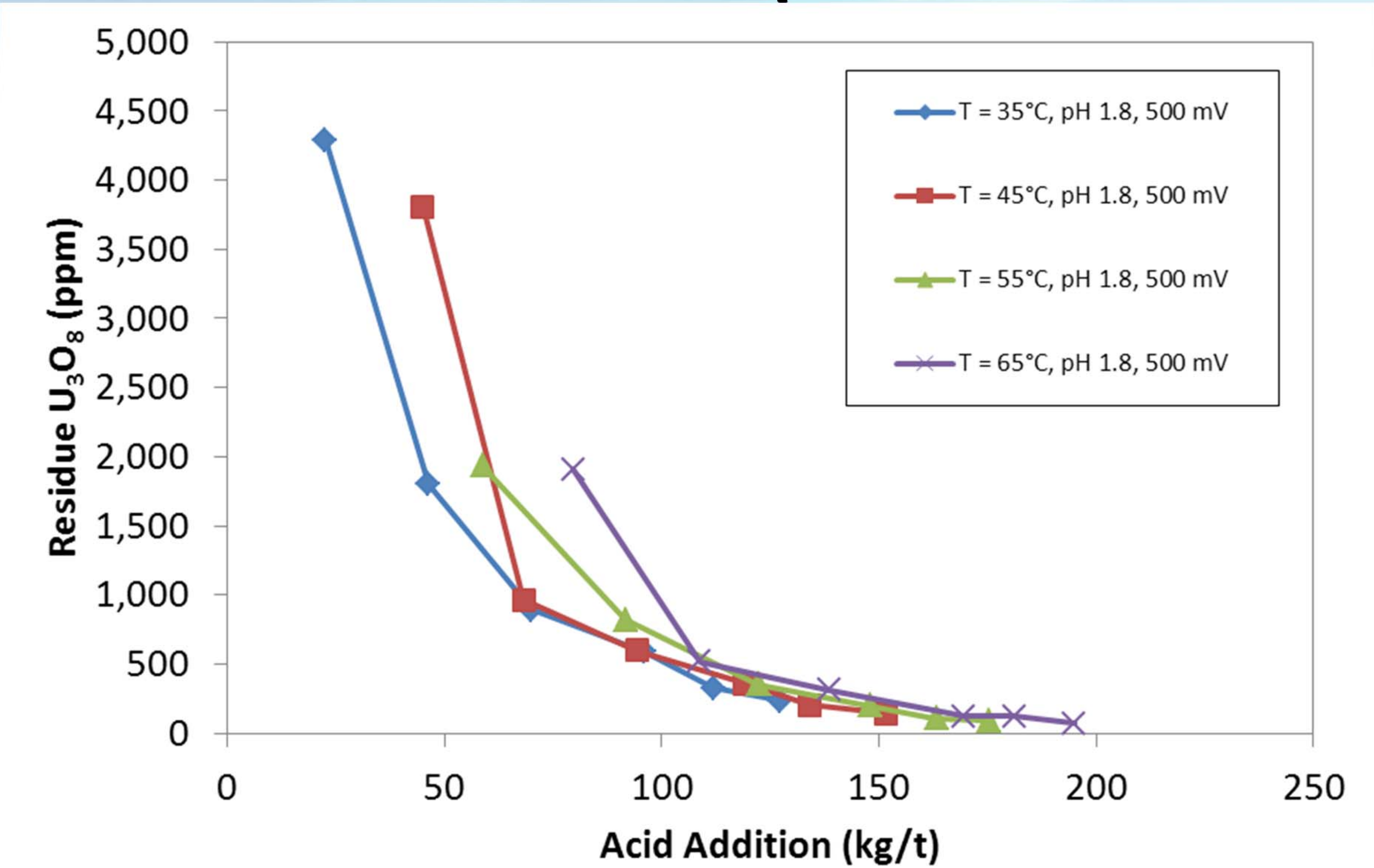
- Composite sample prepared to represent average of U and CO_3 in orebody

Species	wt%	Species	wt%
CO_3	**9.55**	**Mg**	7.3
Ca	3.03	**Si**	25.6
Fe	8.2	**U_3O_8**	**0.52**

- Leach Testwork:
  - 50 wt% solids
  - 18 h leach time
  - $NaMnO_4$ as oxidant
- Variables investigated:
  - Temperature 35-65°C
  - pH 1.8-2.5
  - ORP 450-550 mV (vs. Ag/AgCl)
  - P_{80} 250-710 μm

ansto Minerals

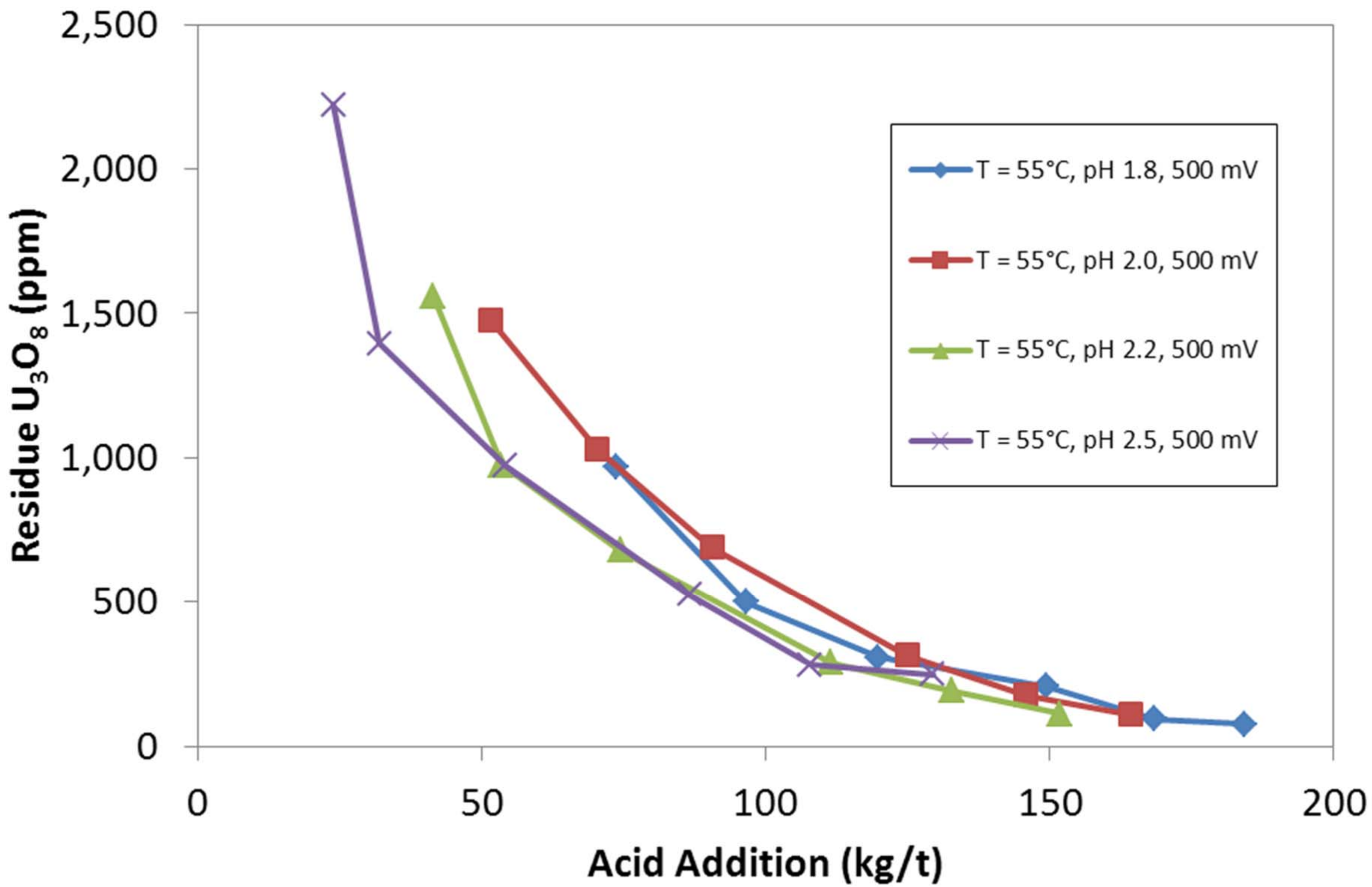
Effect of Temperature



- U leached at varying rates, but final extractions similar
- 55^{o}C selected as optimum temperature

ansto Minerals

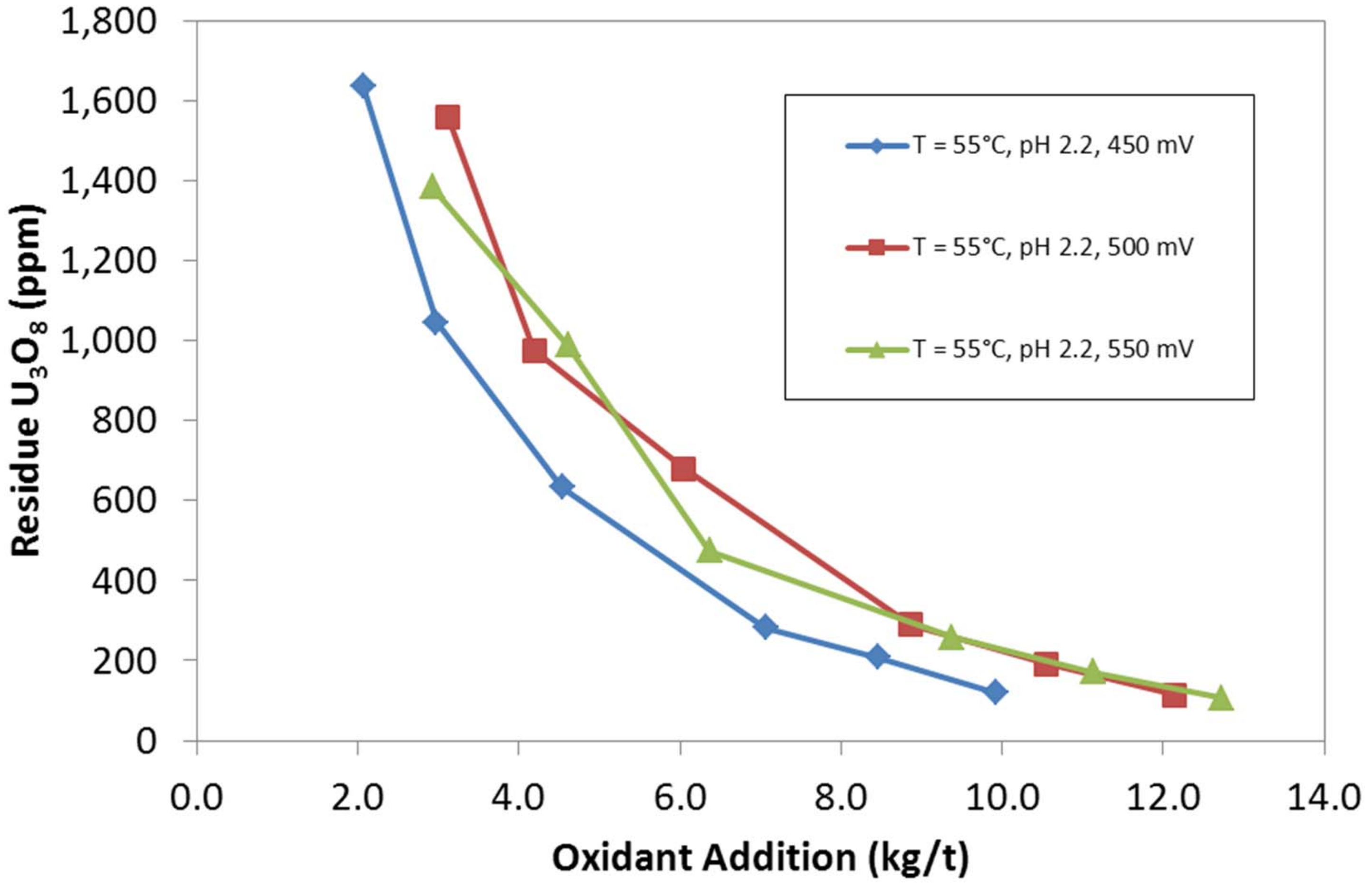
Effect of pH



- Final U extractions similar at all pHs except 2.5
- pH 2.2 selected as optimum

ansto Minerals

Effect of ORP



- 450 mV selected as optimum ORP
- U present mainly as Uraninite – leaching not driven by ORP as long as Fe^{3+} concentration is sufficiently high

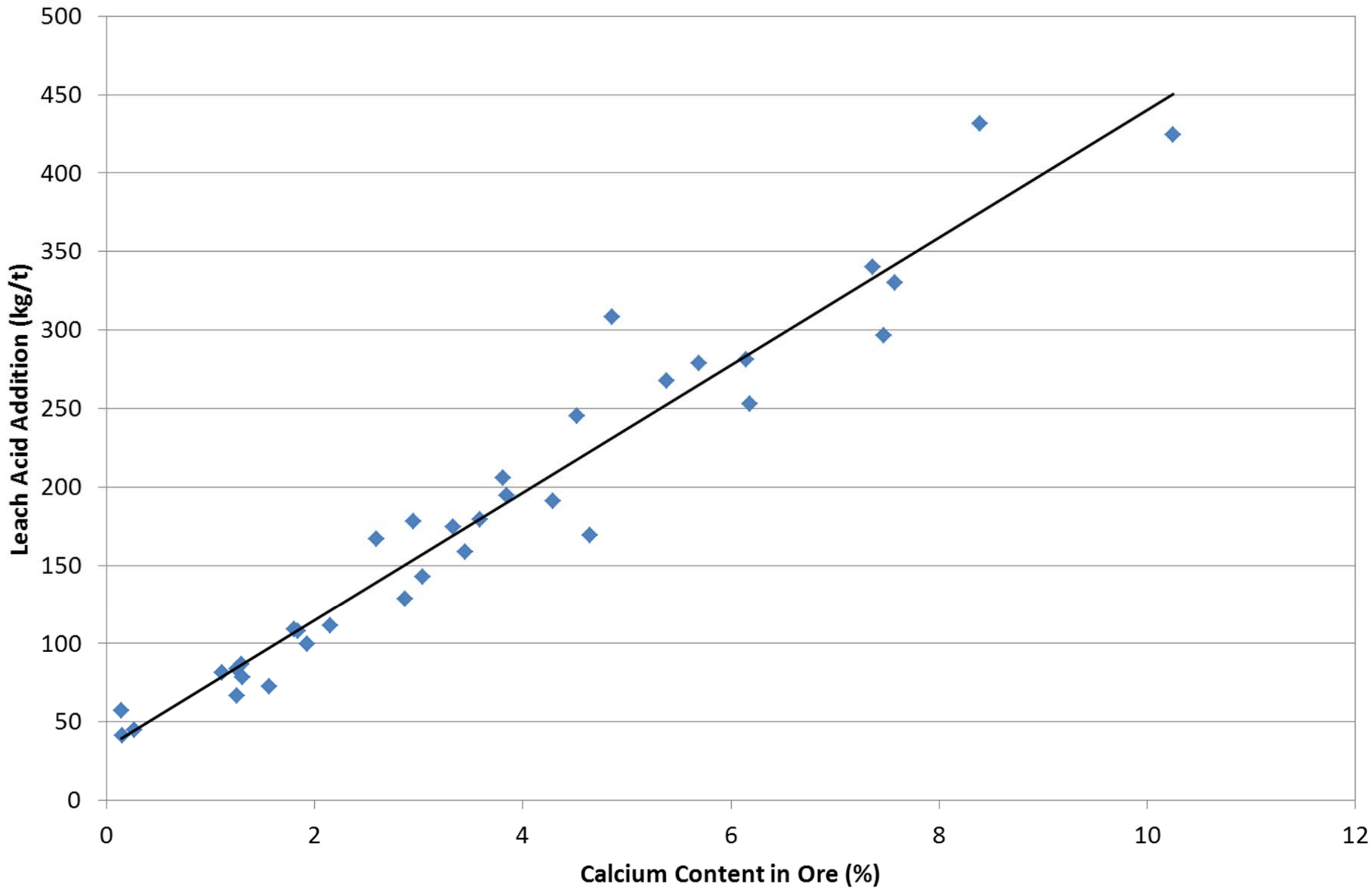
Variability Samples Leaching

- Performed under optimum conditions determined:
  - pH 2.2
  - ORP 450 mV
  - P_{80} 500 μm
  - 50 wt% Solids
  - 18 h Leach Time

	% U Extn.	Acid Addn. (kg/t)	Equiv. MnO_2 Addn. (kg/t)
Max	99.2	432	22.3
Min	86.2	42	2.8
Avg.	95.5	187	11.1

ansto Minerals

Variability Samples Leach Results



ansto Minerals

Other Work from Leaches

- QEMScan on leach feeds and residues
- Effect of ore type and particle size on settling and filtration rate
- Effect of solids density on rheology for feed and residue slurries and neutralised slurries
- Tailings Neutralisation and radionuclide deportment

Bulk Leaching

- 2000 kg of ore leached over three campaigns

Ansto Minerals

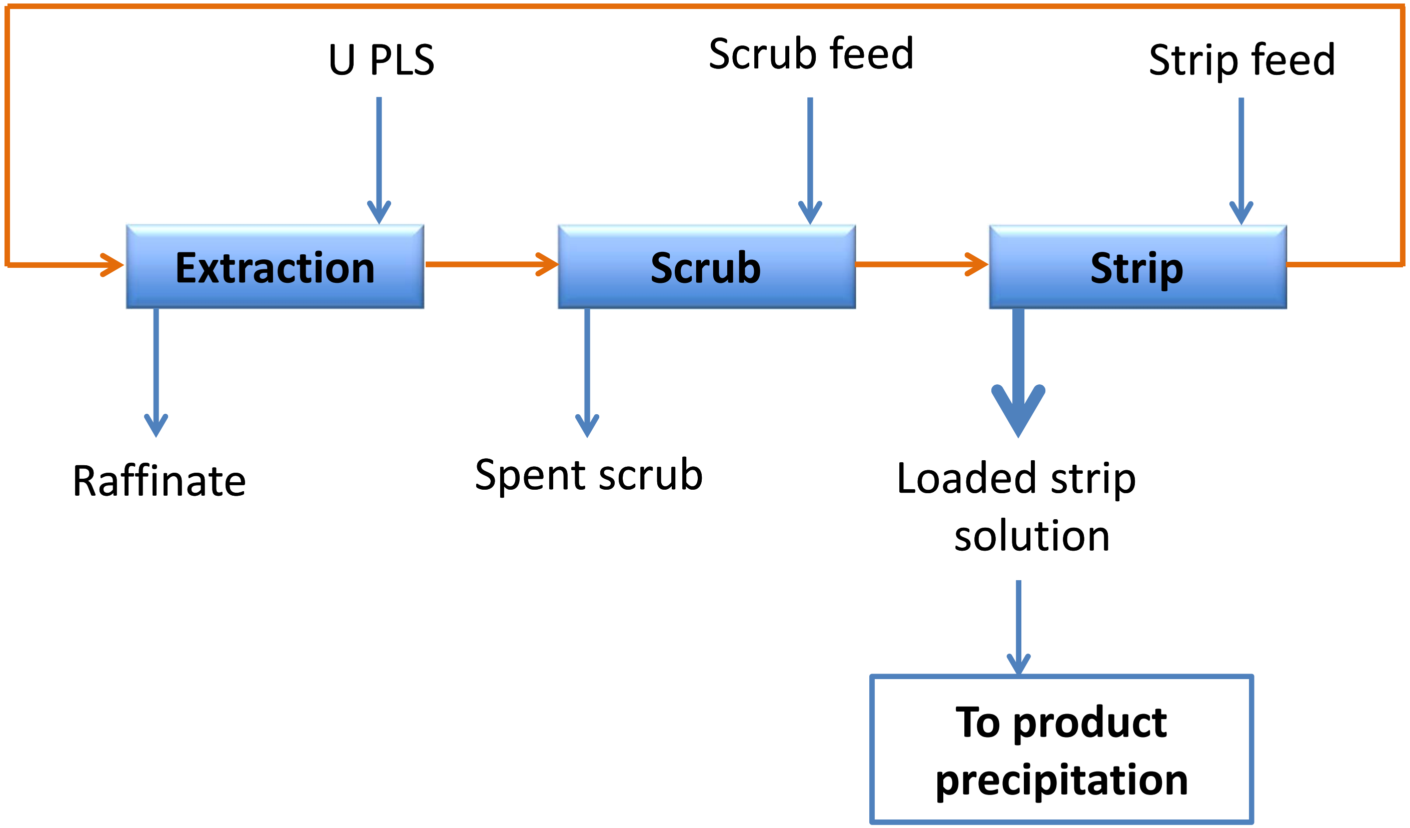
Solvent Extraction Testwork Objectives

To carry out equilibrium batch testwork and to operate solvent extraction mini-pilot plant:

- To compare the performance of the ammonia and acid options for uranium stripping;
- To further define the solvent extraction process unit operation for the Kintyre Uranium Project to obtain engineering design data for a DFS.
- Confirm/optimise operating conditions;
- Identify potential operational issues;
- To trace the deportment of impurities.

ansto Minerals

Uranium Solvent Extraction – General Process



Mini-Plant Continuous Operation

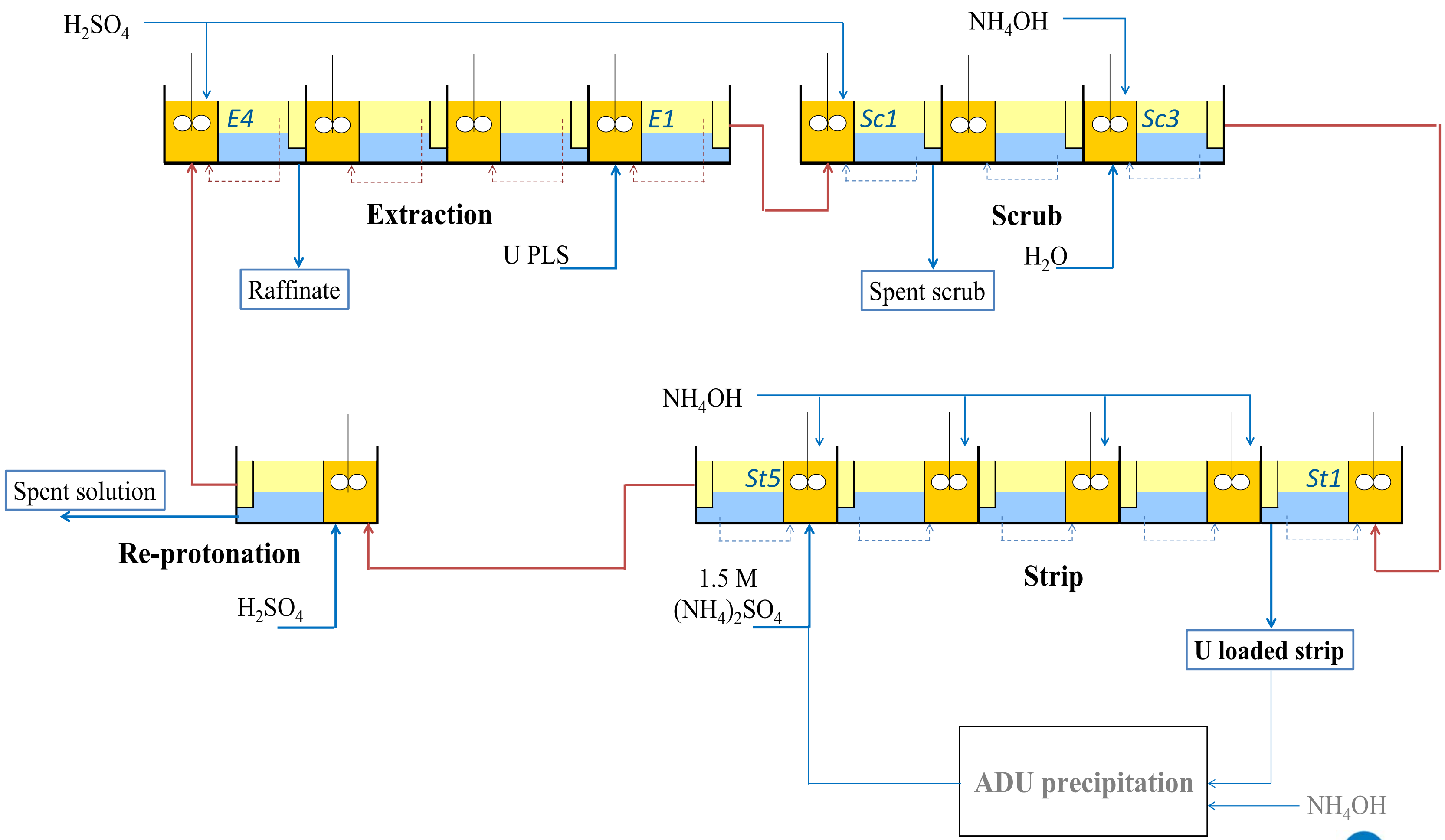
- Two separate continuous solvent extraction mini – plant trials operated for a total of 6 days;
- Total of ~1000 L of PLS was treated
- Alamine 336 (5 vol. %) + 2.5% iso-decanol in Shellsol 2046
- Stripping methods:
  - ✓ Ammonia stripping process ($NH_4OH/(NH_4)_2SO_4$),
  - ✓ Acid stripping process (H_2SO_4)

ansto Minerals

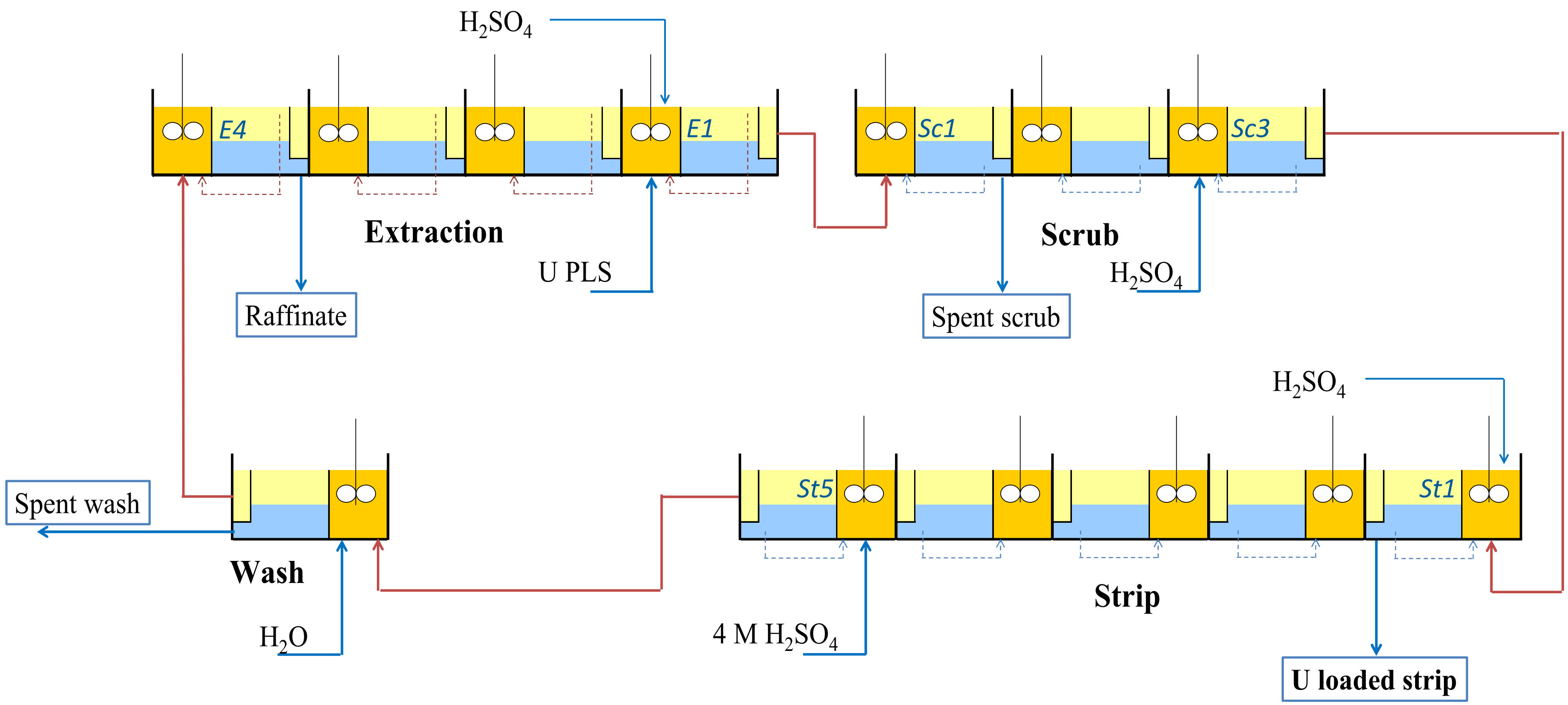
SX Mini-Plant Setup

ansto
Minerals

Uranium Solvent Extraction - Ammonia Strip Process



Uranium Solvent Extraction - Acid Strip Process



Feed Liquor

	g/L
U	2.7
S	53

pH	1.8
ORP (mV)	420

Elements	g/L
As	0.002
Mo	<0.001
Si	0.3
Zr	0.01
V	<0.001

Fe	1.5

Elements	g/L
Al	1.6
Ca	0.57
Cu	0.02
Mg	25
Mn	16
Na	1
Ni	0.02
Zn	0.03

ansto Minerals

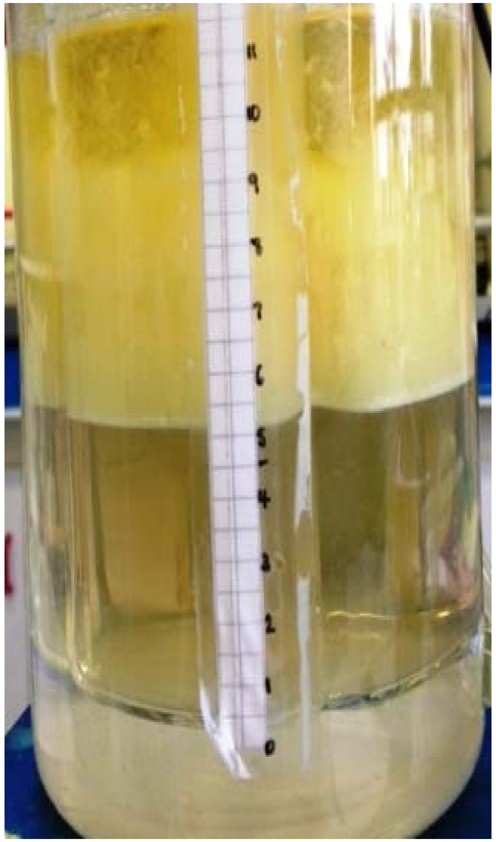
Extraction

- **Operating Conditions:**
  - pH 1.9-2.1 in E1 (loaded organic)
  - 1.6-1.8 in E4 (raffinate)
  - Temperature = 35-45°C
  - O/A = 0.65

- **Performance:**
  - U extraction = 99.7-99.96 %
  - $[U]_{raffinate}$ = 1-9 mg/L
  - $[U]_{loaded\ solvent}$ = 4.2-4.3 g/L

ansto Minerals

Phase Disengagement – Extraction

Organic Continuous	Aqueous Continuous
	

Scrub

Operating Conditions:

	pH	
Stage	Sc1 (spent scrub)	Sc3 (scrubbed organic)
Ammonia strip process	1.5	2.5
Acid strip process	1.7	1.6

Temperature 30-40°C   O/A ~10

Performance:

- ≥ 50 % of entrained Mg and Mn removal;
- Negligible scrubbing of As, Ca, Cu, Si and Zr;
- U scrubbing = 0.1-0.3 %

Operating Conditions

Ammonia Strip:

- $[(NH_4)_2SO_4]$ = 1.5 M
- pH gradient:

  pH 3 in St1 (product stream)

  pH 5 in St5 (stripped organic)
- Temperature = 30-40°C
- O/A = 5

Strong Acid Strip:

- H_2SO_4 Concentration:

  390 g/L in St1 (product stream)

  400 g/L in St5 (stripped organic).
- Temperature = 30-40°C
- O/A = 10

ansto Minerals

Mini-Plant Performance - Comparison

Ammonia Strip:

	$[M]_{product\ stream}$	$[M]_{stripped\ solvent}$	Strip
Element	**g/L**	**mg/L**	**%**
U	18	30	**99.3**
S	54	-	

Strong Acid Strip:

	$[M]_{product\ stream}$	$[M]_{stripped\ solvent}$	Strip
Element	**g/L**	**mg/L**	**%**
U	41	15	**99.6-99.8**
S	126	3,700	

ansto Minerals

Mini-Plant Performance - Comparison

	U Normalised Recovery (%)			
	To Raffinate	To Spent Scrub	To Loaded Strip	
Ammonia Strip	0.3	0.1	**99.6**	
Strong Acid Strip	0.04-0.35	0.1-0.3		**99.6-99.8**

Ansto Minerals

Impurities in the Product Stream

	Ammonia strip	Acid strip	*Max. U Concentrate Limit***
	% of U		
As	0.03	0.02	*0.10*
Ca	0.16	0.29	*1.0*
Fe	0.04	0.01	*1.0*
Mg	0.07	< 0.002	*0.50*
Mo	< 0.03	< 0.01	*0.30*
Si	< 0.03	< 0.01	
V	< 0.03	< 0.01	*0.30*
Zr	0.06	**0.15***	*0.10*

* Zr rejected by H_2O_2 precipitation

** Without rejection (ASTM C967-13 Standard Specification for Uranium Ore Concentrate)

Acid vs. Ammonia Stripping Methods

- Both methods are equally effective, achieving > 99 % stripping of U;
- The acid circuit is easier to control;
- Higher U concentration in the loaded acid strip solution;
- Acid route – more options for uranium final product;
- Environmental issues associated with ammonia;
- Use of corrosive reagent.

ansto Minerals

Conclusions

- Acid leaching has been identified as a robust process for Kintyre ores

- Testwork showed that optimum leach conditions for Kintyre are:
  - pH 2.2
  - ORP 450 mV
  - P_{80} 500 μm
  - 18 h Residence time

- Average Uranium Extraction of 95.5% for Variability Samples

ansto Minerals

Conclusions

- Two fully integrated U SX mini-pilot plants were successfully operated for 6 days testing ammonium strip and acid strip processes;
- High U recoveries from feed to product stream were achieved:
  - [U]raffinate < 10 mg/L;
  - acid strip process: 99.8 %;
  - ammonia strip process: 99.6 %.
- Comparable stripping efficiency:
  - ammonia strip process: 99.3 %;
  - acid strip process: 99.6-99.8 %.
- Potential operational issue with ammonia strip – stable emulsion formation (extraction) and crud.