Mintek 75

Using Computing Power in Process Development

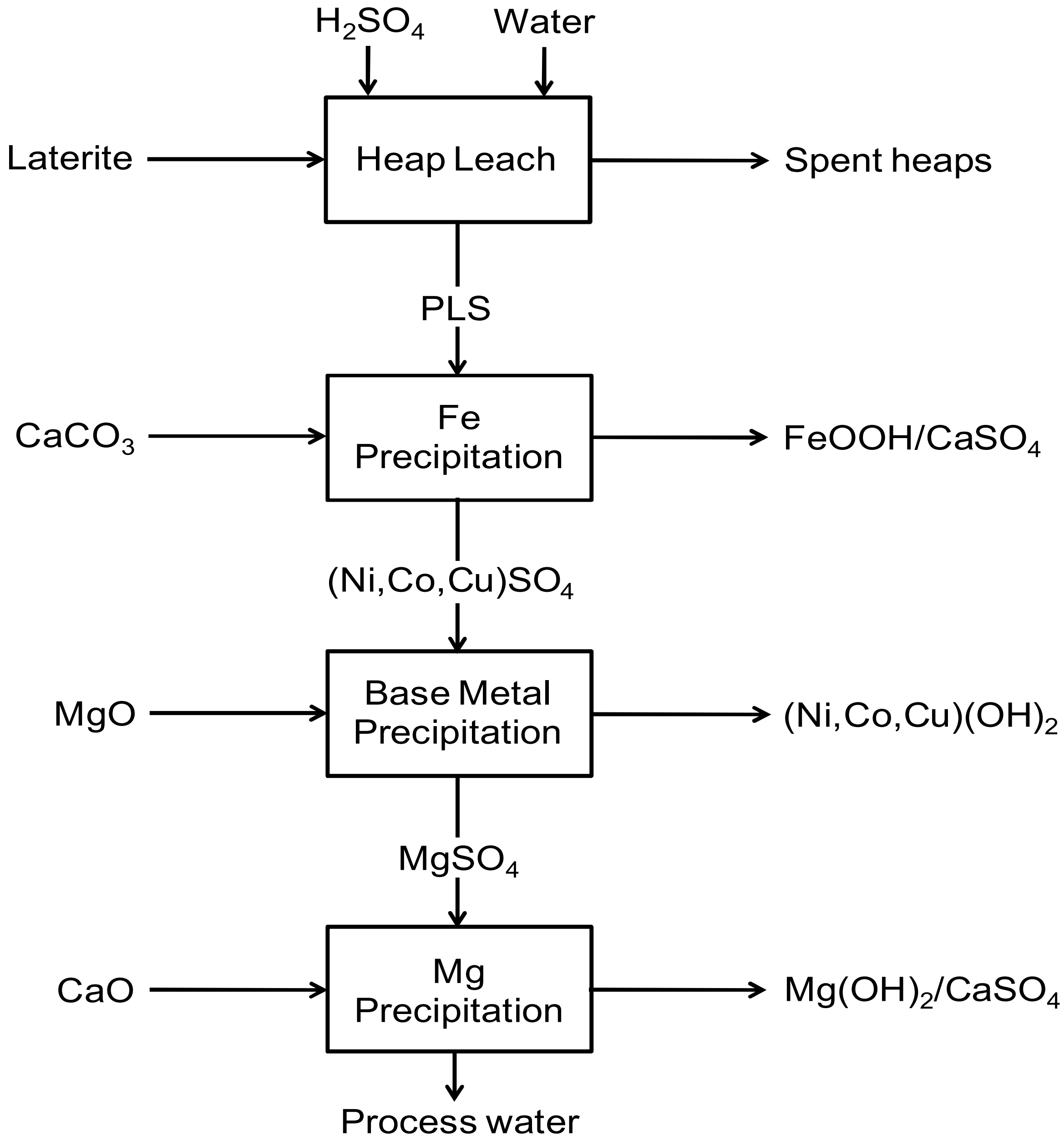
Mike Dry

Laterite
Uranium

Excel
AspenPlus

Nickel

Ni grade, mass %	1.1
Co grade, mass %	0.034
Cu grade, mass %	0.007
Fe grade, mass %	8.5
Mg grade, mass %	3.5
Extraction, %	92
H_2SO_4 demand, kg/t	210
Total ore reserve, Mt	31
Ni production, tpa	15000
Calculated life of mine, years	21



H2SO4
Water
Laterite
Heap Leach
Spent heaps
PLS
CaCO3
Fe Precipitation
FeOOH/CaSO4
(Ni,Co,Cu)SO4
MgO
Base Metal Precipitation
(Ni,Co,Cu)(OH)2
MgSO4
CaO
Mg Precipitation
Mg(OH)2/CaSO4
Process water

$$NiO + H_2SO_4 \rightarrow NiSO_4 + H_2O$$

$$CoO + H_2SO_4 \rightarrow CoSO_4 + H_2O$$

$$CuO + H_2SO_4 \rightarrow CuSO_4 + H_2O$$

$$MgO + H_2SO_4 \rightarrow MgSO_4 + H_2O$$

$$2FeOOH + 3H_2SO_4 \rightarrow Fe_2(SO_4)_3 + 4H_2O$$

Per 1000 kg ore:

- 0.187 kmol of NiO
- 0.006 kmol of CoO
- 0.001 kmol of CuO
- 1.440 kmol of MgO
- 1.522 kmol of Fe, as FeOOH and Fe_2O_3

2.141 kmol H_2SO_4 is consumed in total

1.634 kmol consumed by Ni, Co, Co and Mg

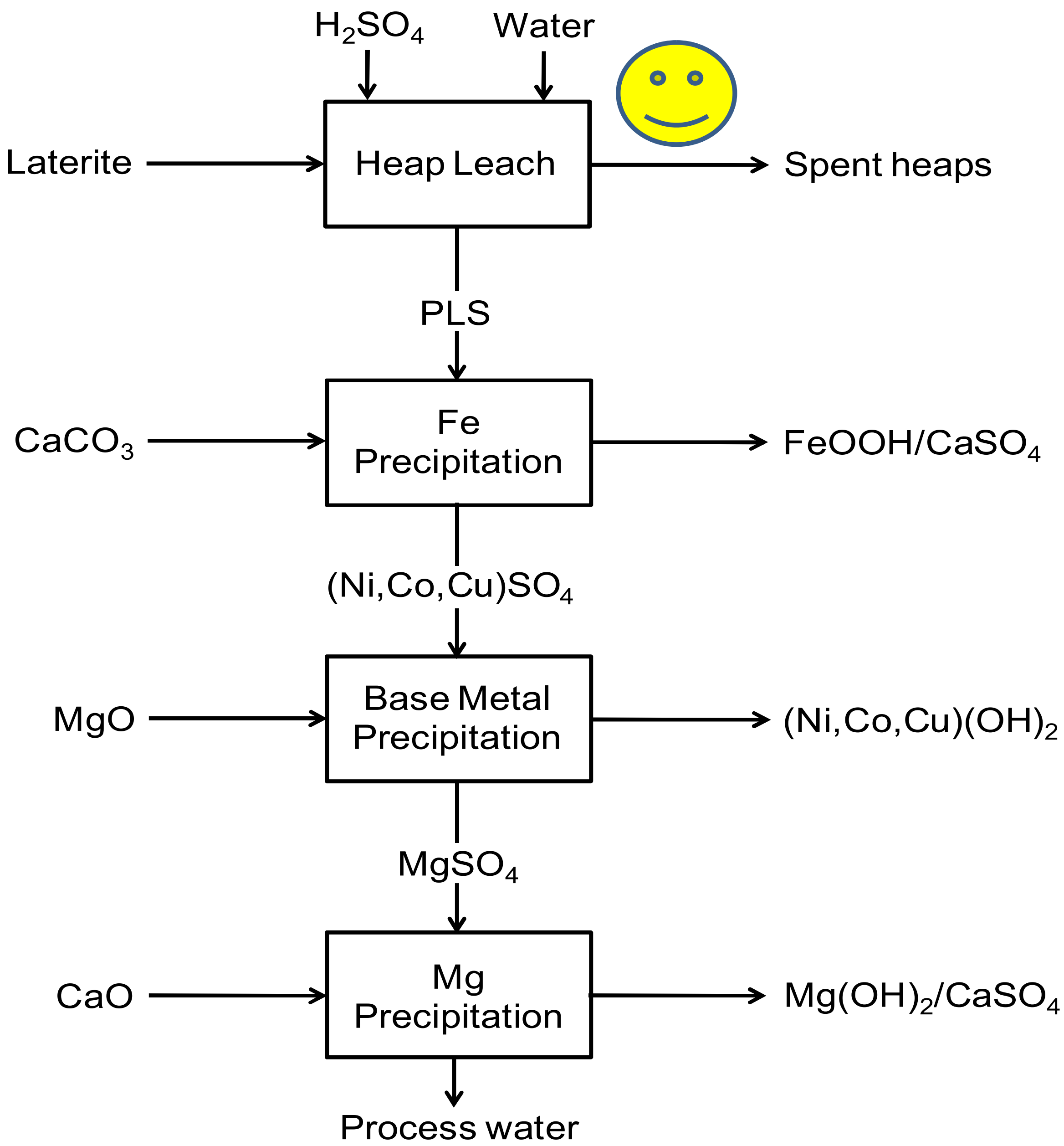
0.388 kmol of Fe is consumed

0.388 kmol FeOOH in the ore

1.522 kmol total Fe in ore

0.567 kmol Fe_2O_3 in the ore

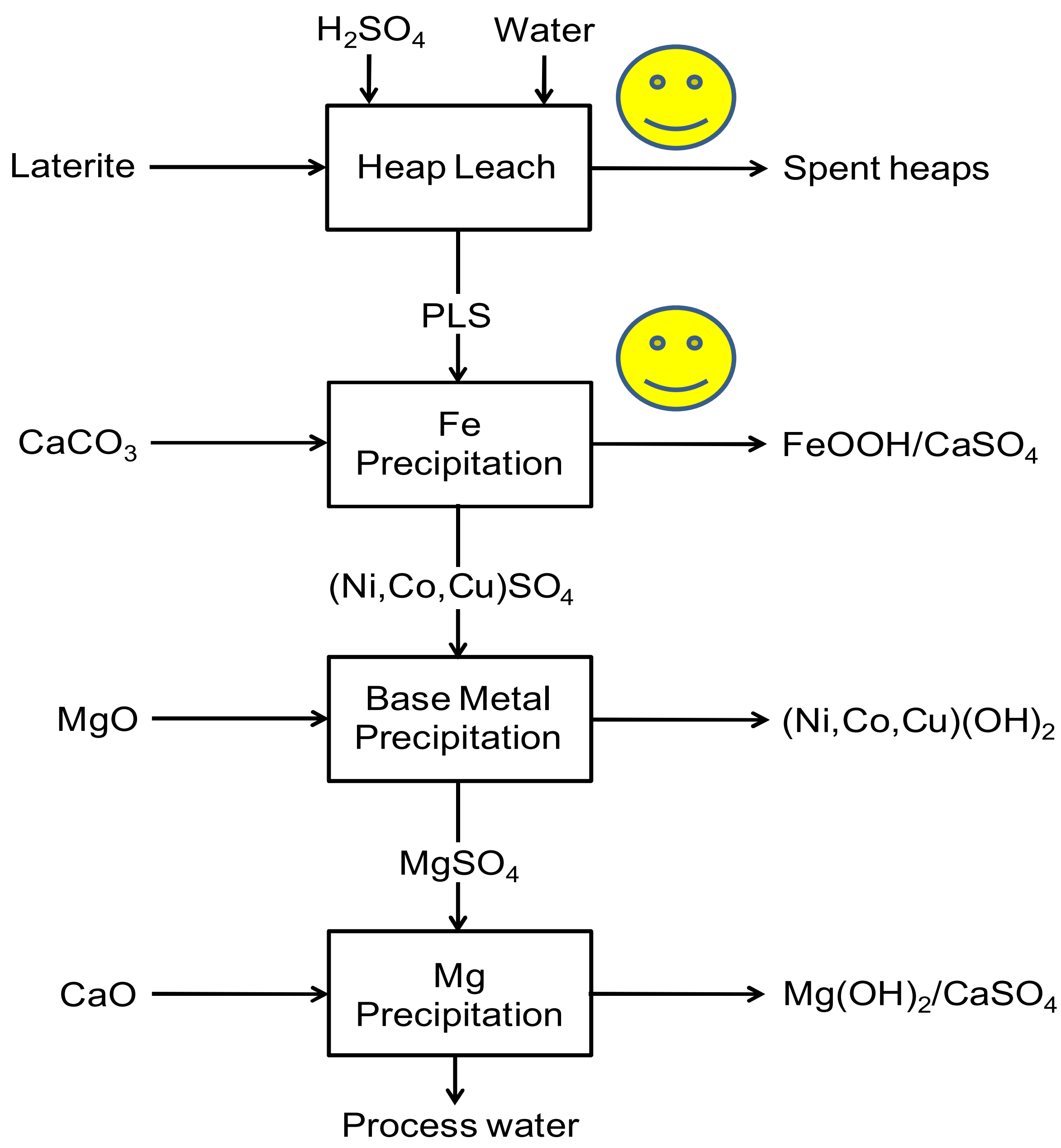
NiO	1.40%
CoO	0.04%
CuO	0.01%
MgO	5.80%
FeOOH	4.10%
Fe_2O_3	8.46%
SiO_2	80.2%



H_2SO_4
Water
Laterite
Heap Leach
Spent heaps
PLS
$CaCO_3$
Fe Precipitation
$FeOOH/CaSO_4$
$(Ni,Co,Cu)SO_4$
MgO
Base Metal Precipitation
$(Ni,Co,Cu)(OH)_2$
$MgSO_4$
CaO
Mg Precipitation
$Mg(OH)_2/CaSO_4$
Process water

$$H_2SO_4 + CaCO_3 \rightarrow CaSO_4 + H_2O + CO_2$$

$$Fe_2(SO_4)_3 + 3CaCO_3 + H_2O \rightarrow 3CaSO_4 + 2FeOOH + 3CO_2$$



H_2SO_4
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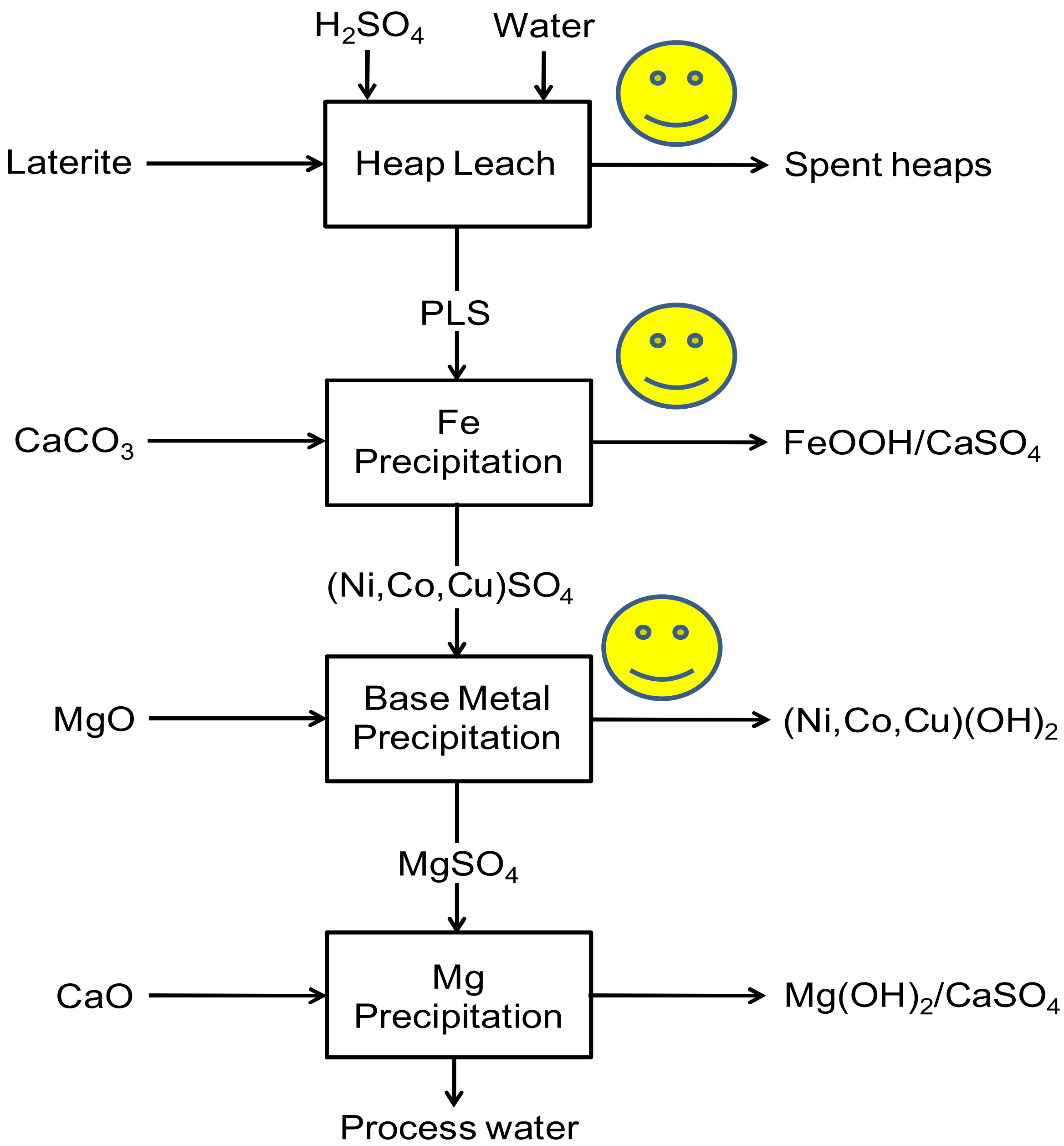
$(Ni,Co,Cu)SO_4$
MgO
Base Metal Precipitation
$(Ni,Co,Cu)(OH)_2$
$MgSO_4$
CaO
Mg Precipitation
$Mg(OH)_2/CaSO_4$
Process water

$$NiSO_4 + MgO + H_2O \rightarrow Ni(OH)_2 + MgSO_4$$

$$CoSO_4 + MgO + H_2O \rightarrow Co(OH)_2 + MgSO_4$$

$$CuSO_4 + MgO + H_2O \rightarrow Cu(OH)_2 + MgSO_4$$

Assumed Ni in MHP:	50 mass %
$Ni(OH)_2$ in MHP:	0.160 kg/ton ore
MHP produced:	0.202 kg/ton ore
$Co(OH)_2$ in MHP:	0.005 kg/ton ore
$Cu(OH)_2$ in MHP:	0.001 kg/ton ore
Therefore, MgO in MHP:	0.037 kg/ton ore



H2SO4
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CaCO3
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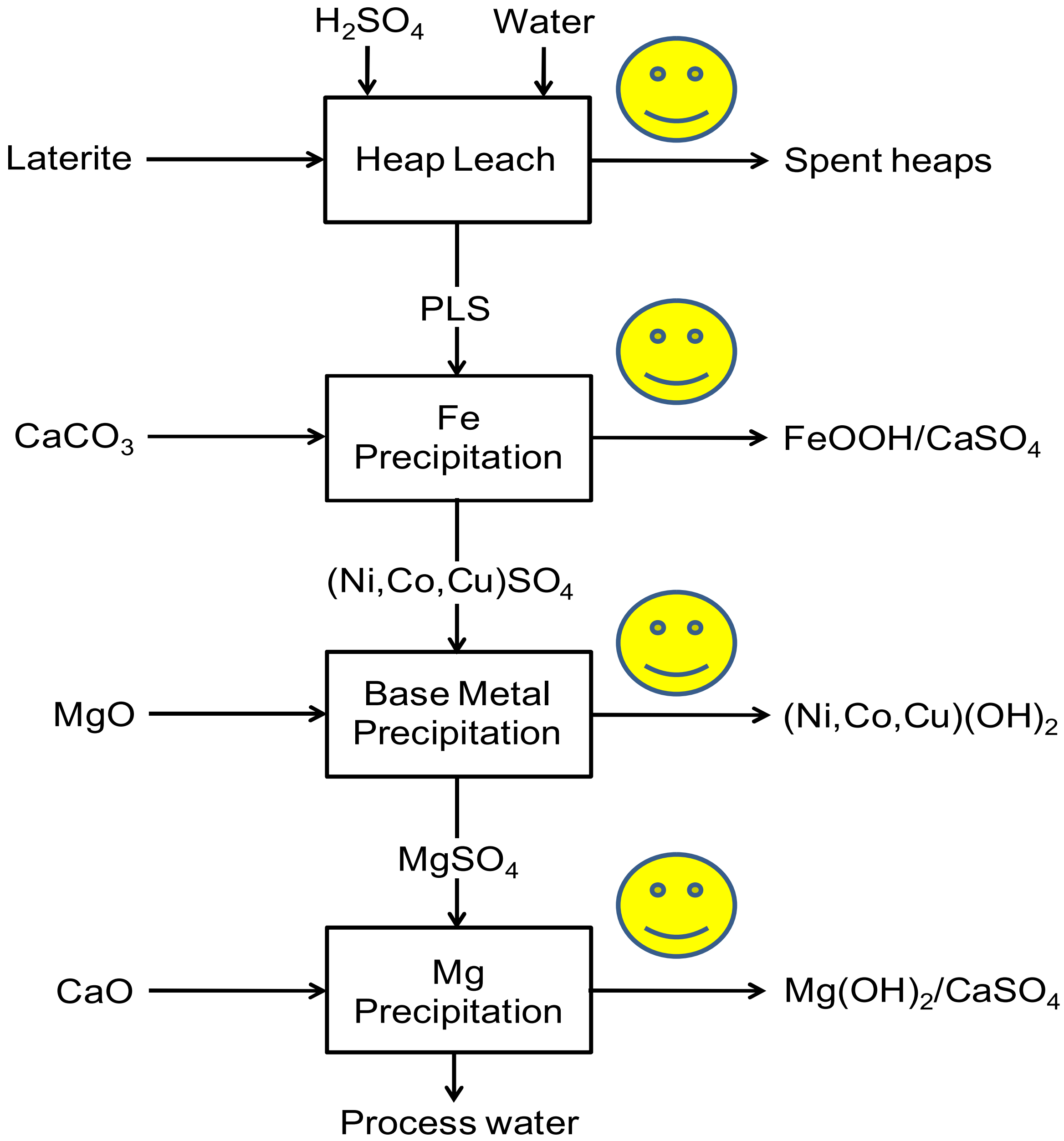
(Ni,Co,Cu)SO4
MgO
Base Metal Precipitation
(Ni,Co,Cu)(OH)2
MgSO4
CaO
Mg Precipitation
Mg(OH)2/CaSO4
Process water

$$MgSO_4 + CaO + H_2O \rightarrow Mg(OH)_2 + CaSO_4$$



H_2SO_4
Water
Laterite
Heap Leach
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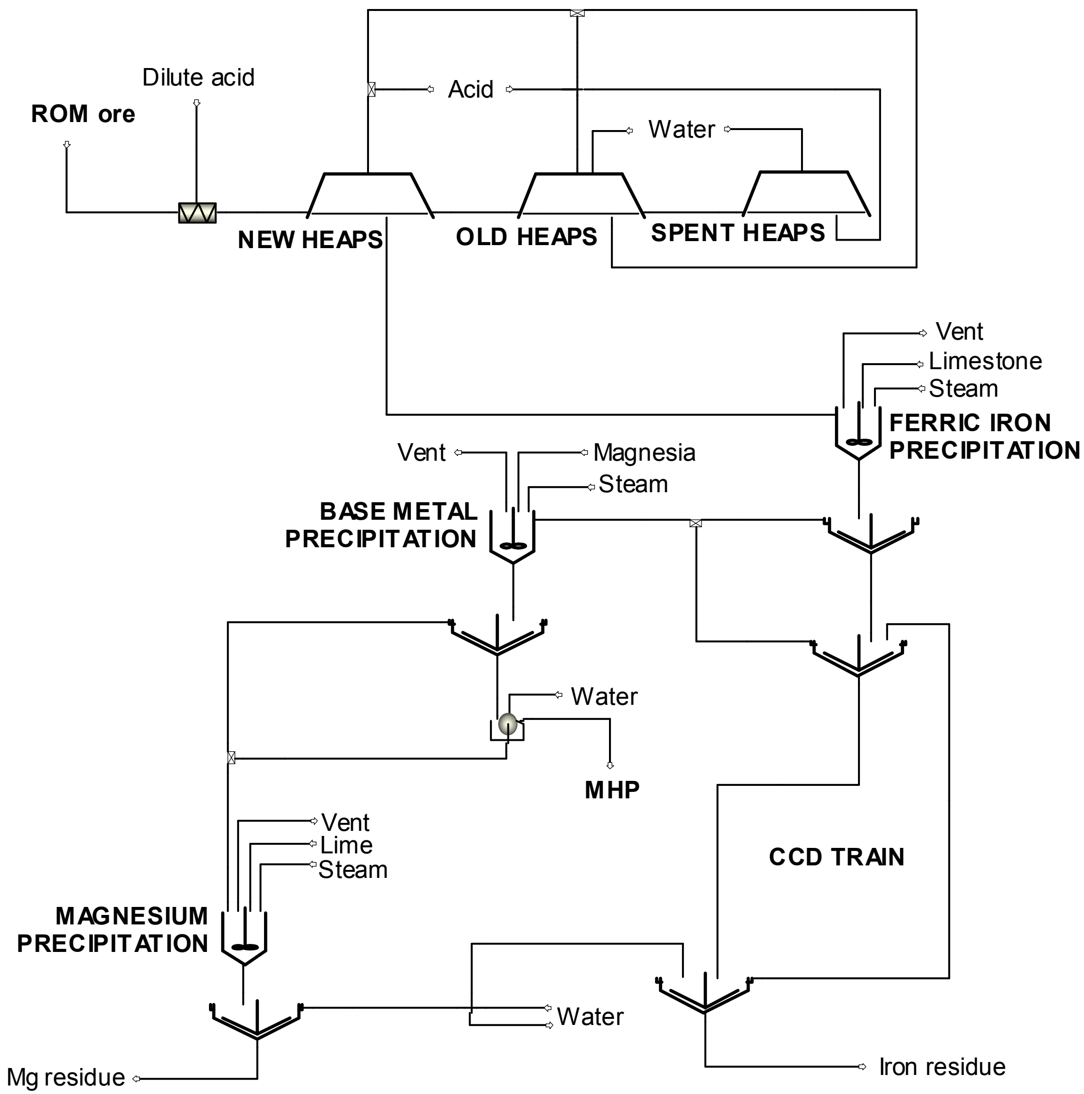
PLS
$CaCO_3$
Fe Precipitation
FeOOH/$CaSO_4$
(Ni,Co,Cu)SO_4
MgO
Base Metal Precipitation
(Ni,Co,Cu)$(OH)_2$
$MgSO_4$
CaO
Mg Precipitation
$Mg(OH)_2$/$CaSO_4$
Process water



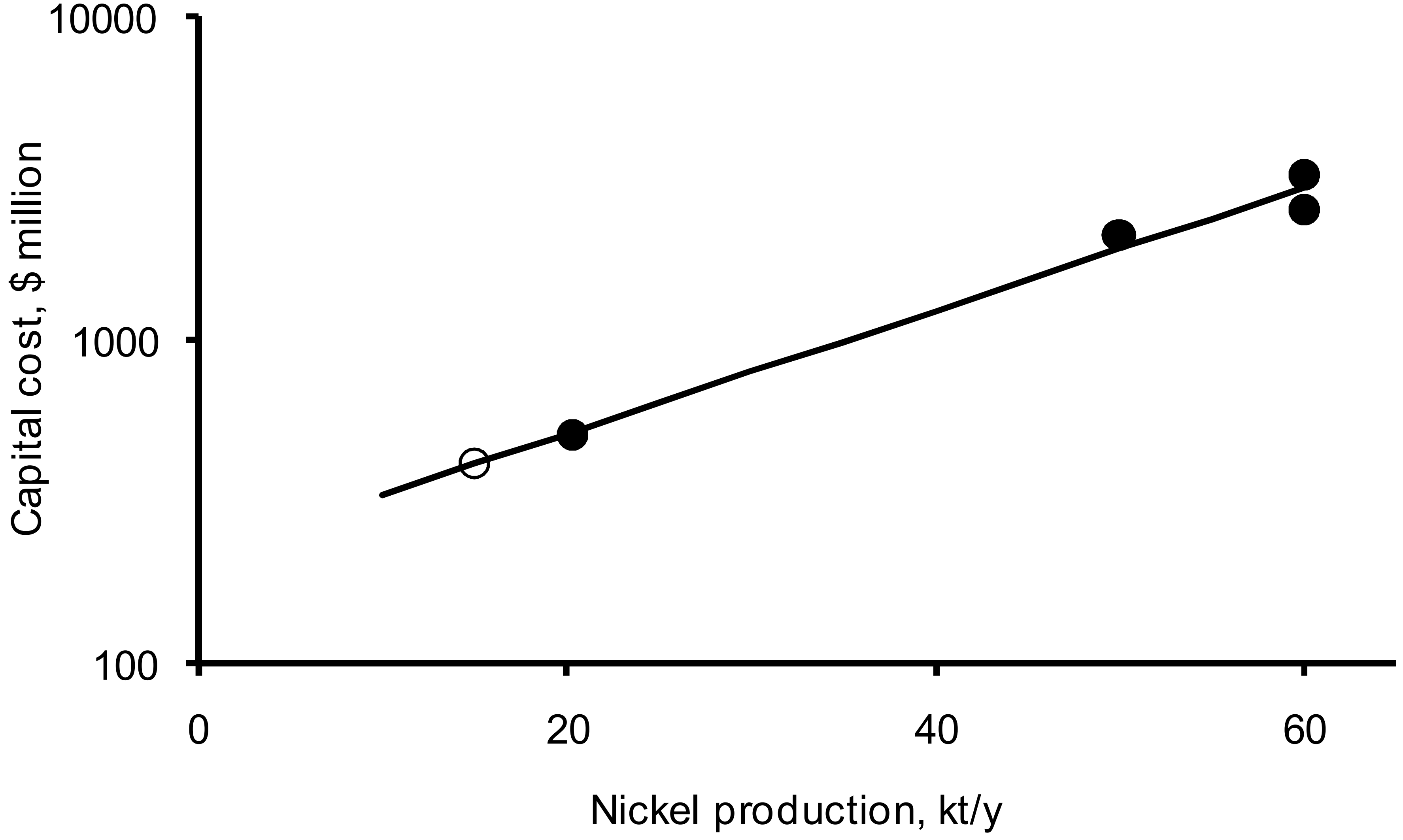
Dilute acid
ROM ore
Acid
Water
NEW HEAPS
OLD HEAPS
SPENT HEAPS
Vent
Limestone
Steam
FERRIC IRON PRECIPITATION
Vent
Magnesia
Steam
BASE METAL PRECIPITATION
Water
MHP
Vent
Lime
Steam
MAGNESIUM PRECIPITATION
CCD TRAIN
Water
Mg residue
Iron residue

Reagent	Calculation	Model
Limestone, as 100% $CaCO_3$	63.8	68.5
Magnesia, as 100% MgO	7.2	6.3
Lime, as 100% CaO	84.4	81.9

Reagent	$/t
H_2SO_4	100
$CaCO_3$	50
NaOH	1000
MgO	300
CaO	200

Metal	$/lb
Ni	5.00
Co	20.00
Cu	1.50

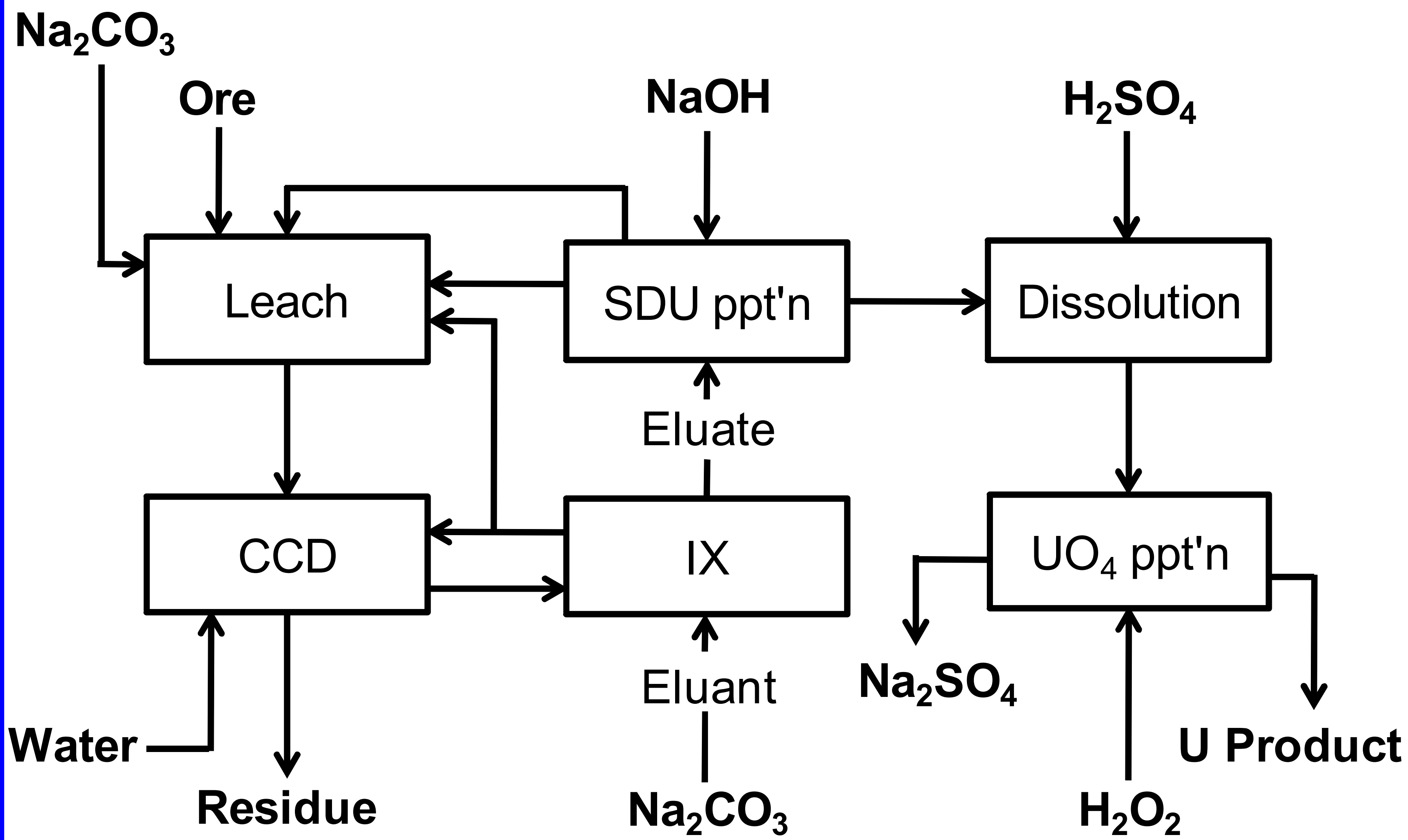
Company	Type	kt/y	Capex
Skye (2005)	Scoping	20	508
Ambatovy	Pre-feas.	60	2500
Goro	Bankable	60	3200
Ravensthorpe	Bankable	50	2100



10000
1000
100
0
20
40
60
Capital cost, $ million
Nickel production, kt/y

	Spreadsheet	AspenPlus
IRR	10.0	10.1

Uranium


Na2CO3
Ore
NaOH
H2SO4
Leach
SDU ppt'n
Dissolution
Eluate
CCD
IX
UO4 ppt'n
Eluant
Na2SO4
Water
Residue
Na2CO3
U Product
H2O2

U_3O_8 grade, mass %	0.06
Total ore reserve, Mt	51
Assumed leach extraction, %	99
Assumed life of mine, years	20
Calculated U_3O_8 dissolution, tpa	1515

$K_2(UO_2)_2(VO_4)_2 \cdot 3H_2O$	0.10
$NaCa_2Mg_4Al_3Si_6O_{22}(OH)_2$	2
$KAl_3Si_3O_{10}Cl_2$	3
$CaSO_4$	0.5
$CaCO_3$	10
SiO_2	84.4

$$K_2(UO_2)_2(VO_4)_2 \cdot 3H_2O + 6CO_3^{2-} \rightarrow 2K^+ + 2UO_2(CO_3)_3^{4-} + 2VO_3^- + 4OH^- + H_2O$$

$$NaCa_2Mg_4Al_3Si_6O_{22}(OH)_2 + 8CO_3^{2-} + 12H_2O \rightarrow Na^+ + 2CaCO_3 + 4MgCO_3 + 3Al(OH)_3 + 6H_2SiO_4^{2-} + 2HCO_3^-$$

$$KAl_3Si_3O_{10}Cl_2 + 7CO_3^{2-} + 11H_2O \rightarrow K^+ + 3Al(OH)_3 + 3H_2SiO_4^{2-} + 2Cl^- + 7HCO_3^-$$

$$CaSO_4 + CO_3^{2-} \rightarrow CaCO_3 + SO_4^{2-}$$

$$HCO_3^- + OH^- \rightarrow CO_3^{2-} + H_2O$$

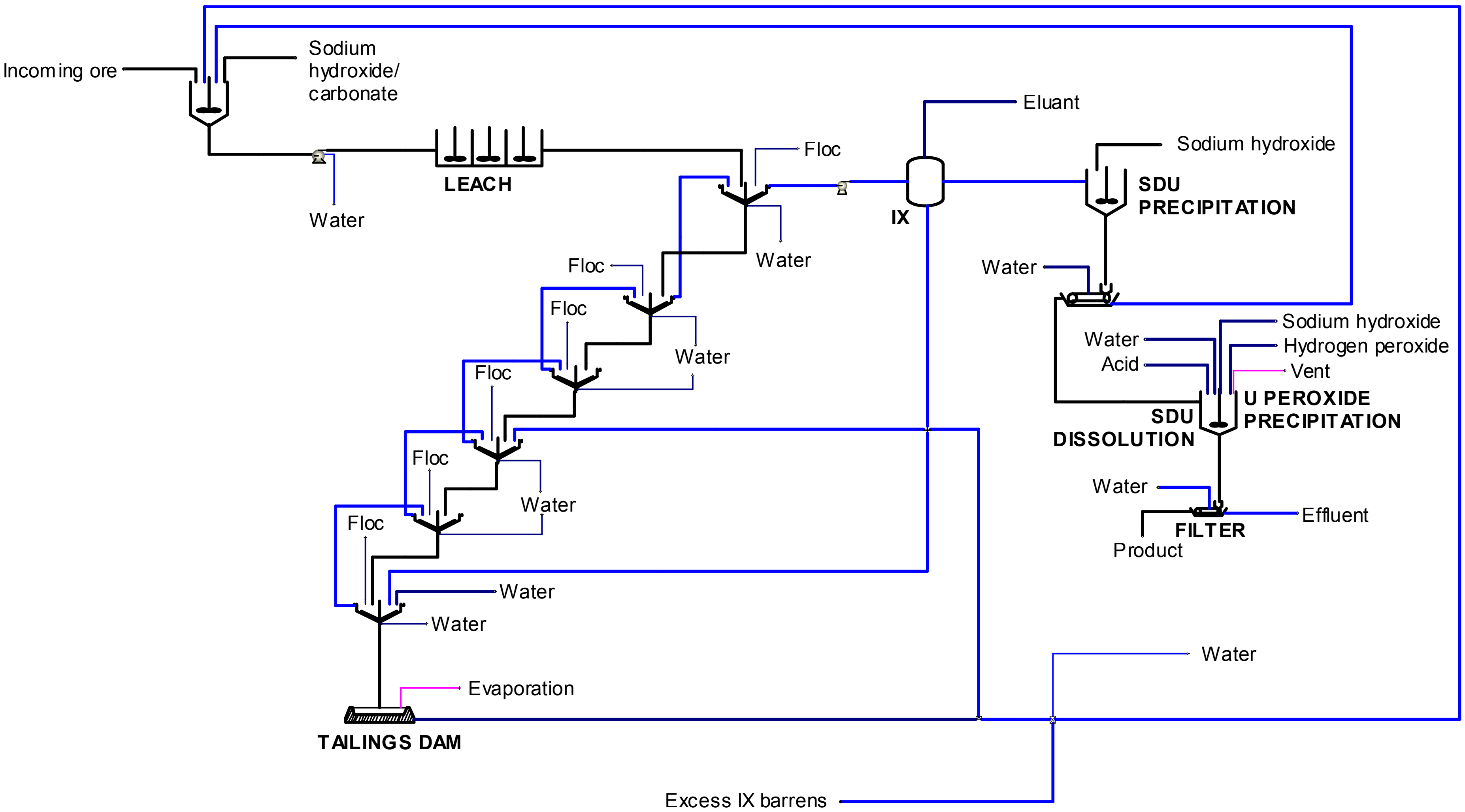
$$2(R_4N)_2 \cdot CO_3 + UO_2(CO_3)_3^{4-} \rightarrow (R_4N)_4 \cdot UO_2(CO_3)_3 + 2CO_3^{2-}$$

$$(R_4N)_4 \cdot UO_2(CO_3)_3 + 2CO_3^{2-} \rightarrow 2(R_4N)_2 \cdot CO_3 + UO_2(CO_3)_3^{4-}$$

$$2UO_2(CO_3)_3^{4-} + 6OH^- + 2Na^+ \rightarrow \mathbf{Na_2U_2O_7} + 6CO_3^{2-} + 3H_2O$$

$$\mathbf{Na_2U_2O_7} + 3H_2SO_4 \rightarrow 2Na^+ + 2UO_2^{2+} + 3SO_4^{2-} + 3H_2O$$

$$xH_2O + UO_2^{2+} + H_2O_2 \rightarrow \mathbf{UO_4 \bullet xH_2O} + 2H^+$$



Incoming ore
Sodium hydroxide/ carbonate
Water
LEACH
Floc
Water
Eluant
IX
Sodium hydroxide
SDU PRECIPITATION
Floc
Water
Floc
Water
Water
Floc
Water
Sodium hydroxide
Acid
Hydrogen peroxide
Vent
U PEROXIDE PRECIPITATION
SDU DISSOLUTION
Floc
Water
Water
FILTER
Effluent
Product
Floc
Water
Water
Water
Evaporation
TAILINGS DAM
Excess IX barrens

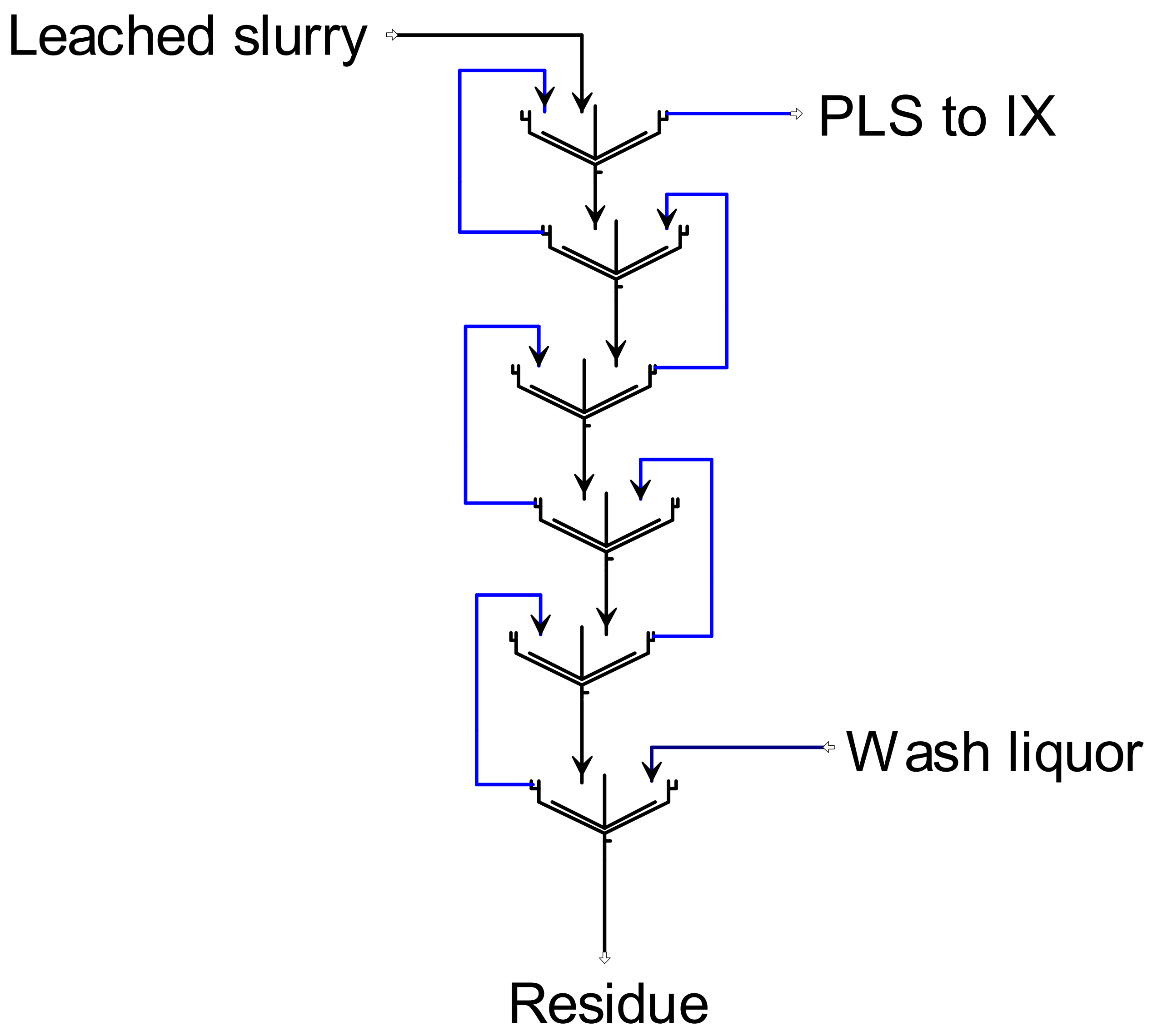
Operating days per year	350
Moisture in incoming ore, mass %	5
Na_2CO_3 consumption in leach, kg/t	20
S/L ratio to leach, kg/m^3	300
Residual Na_2CO_3 ex leach, g/L	20
IX barrens wash ratio to CCD 4	1.00
S/L ratio ex CCD, kg/m^3	815
S/L ratio of final tailings, kg/m^3	1236
Evaporation on tailings dam, %	5
Uranium recovery in IX, etc., %	100
Na_2CO_3 in IX eluant, M	1.0
U_3O_8 in IX eluate, g/L	10
NaOH ex SDU precipitation, g/L	10.0
Times stoichiometric H_2SO_4 to SDU	1.1
Times stoichiometric H_2O_2 to UO_4	1.5

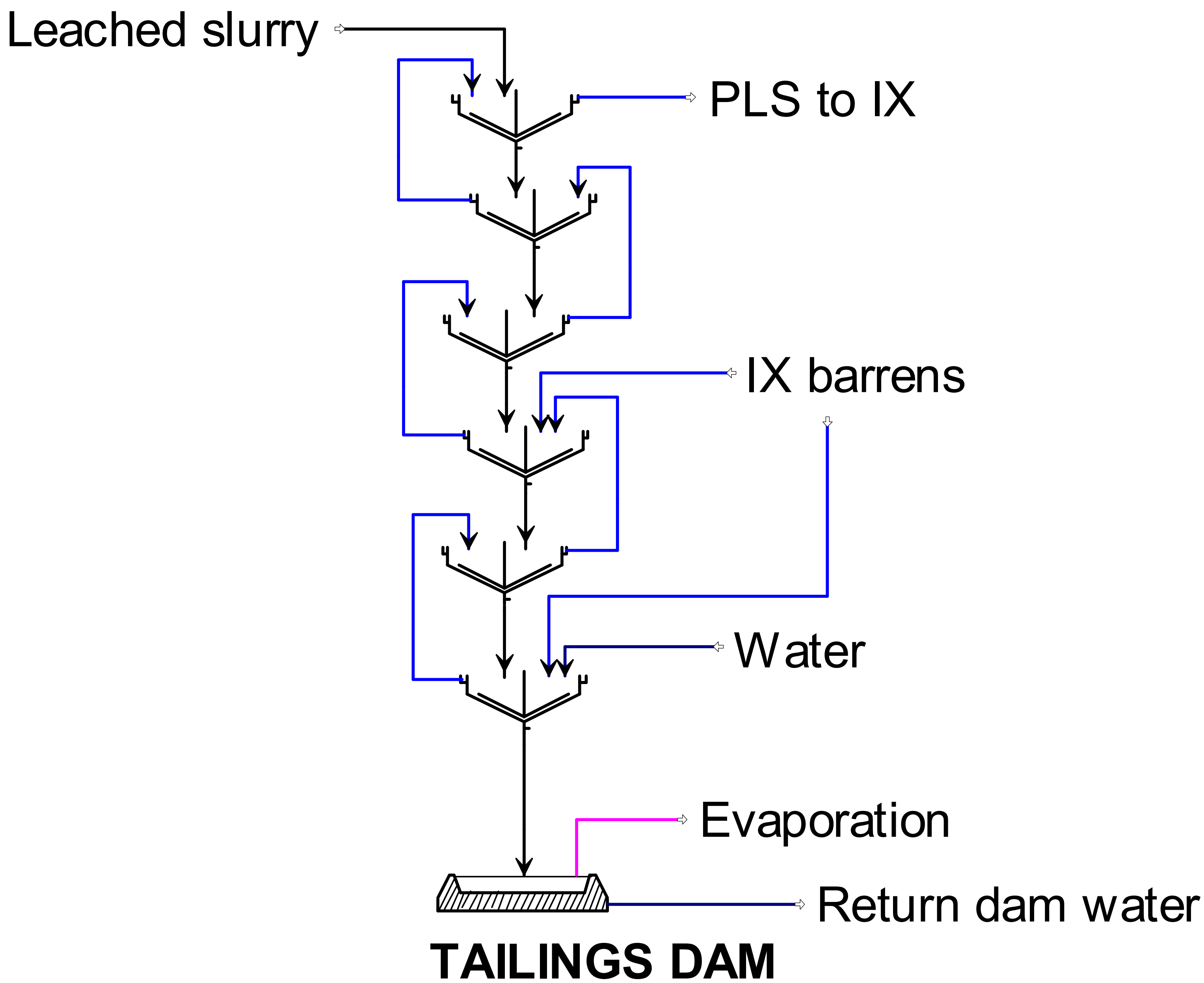
Item	Calculation	Model
Solids to leach, t/h	304	304
Water in incoming ore, m^3/h	16	16
Total solution to leach, m^3/h	1012	1012
Gangue dissolution in leach, %	23	28
Solids ex leach, t/h	299	302
Solution ex leach, m^3/h	1012	1020
U_3O_8 in solution ex leach, g/L	0.18	0.18
V in solution ex leach, g/L	0.14	0.26
SO_4^{2-} in solution ex leach, g/L	4.38	8.33
Cl^- in solution ex leach, g/L	1.42	3.26
Na_2CO_3 in solution ex leach, g/L	20	20
$NaHCO_3$ in solution ex leach, g/L	3	3

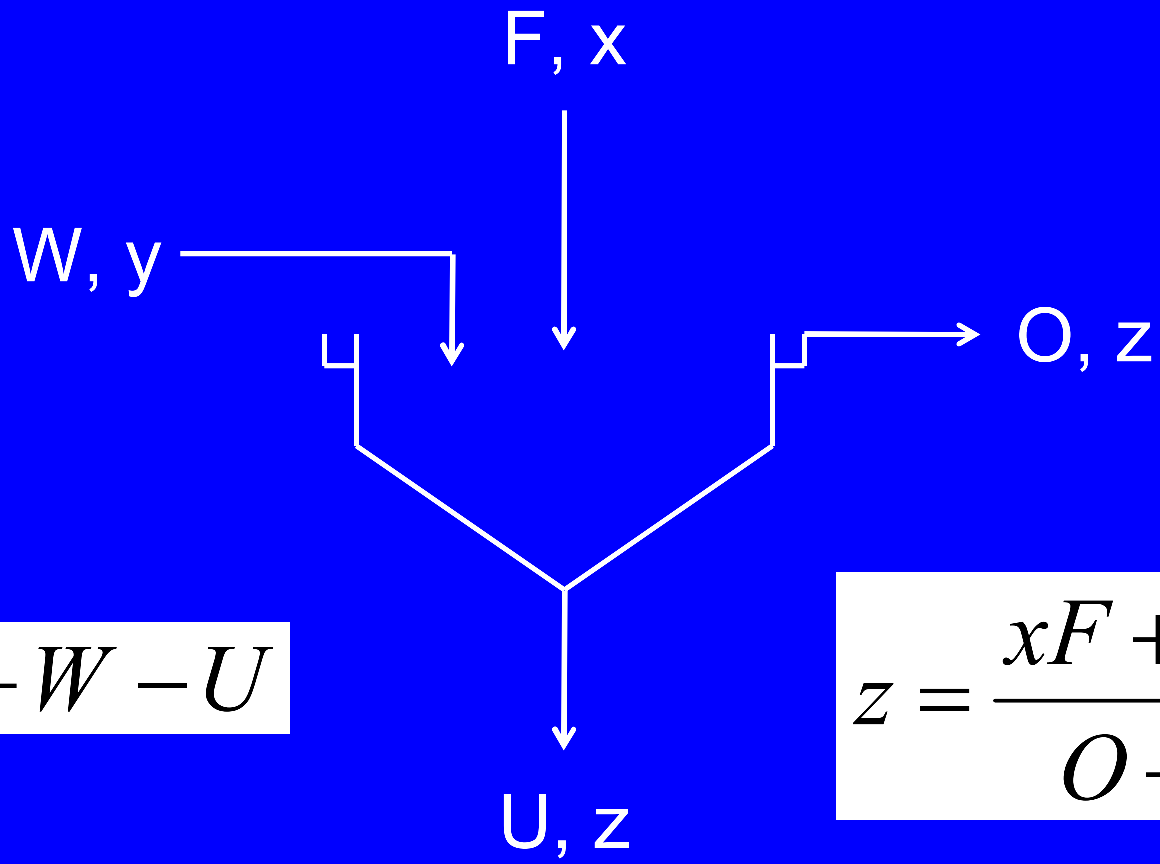
Carbonate Losses:

- Leach – gangue reactions
  - Ca/Mg carbonate
  - Bicarbonate

- CCD underflow → tailings

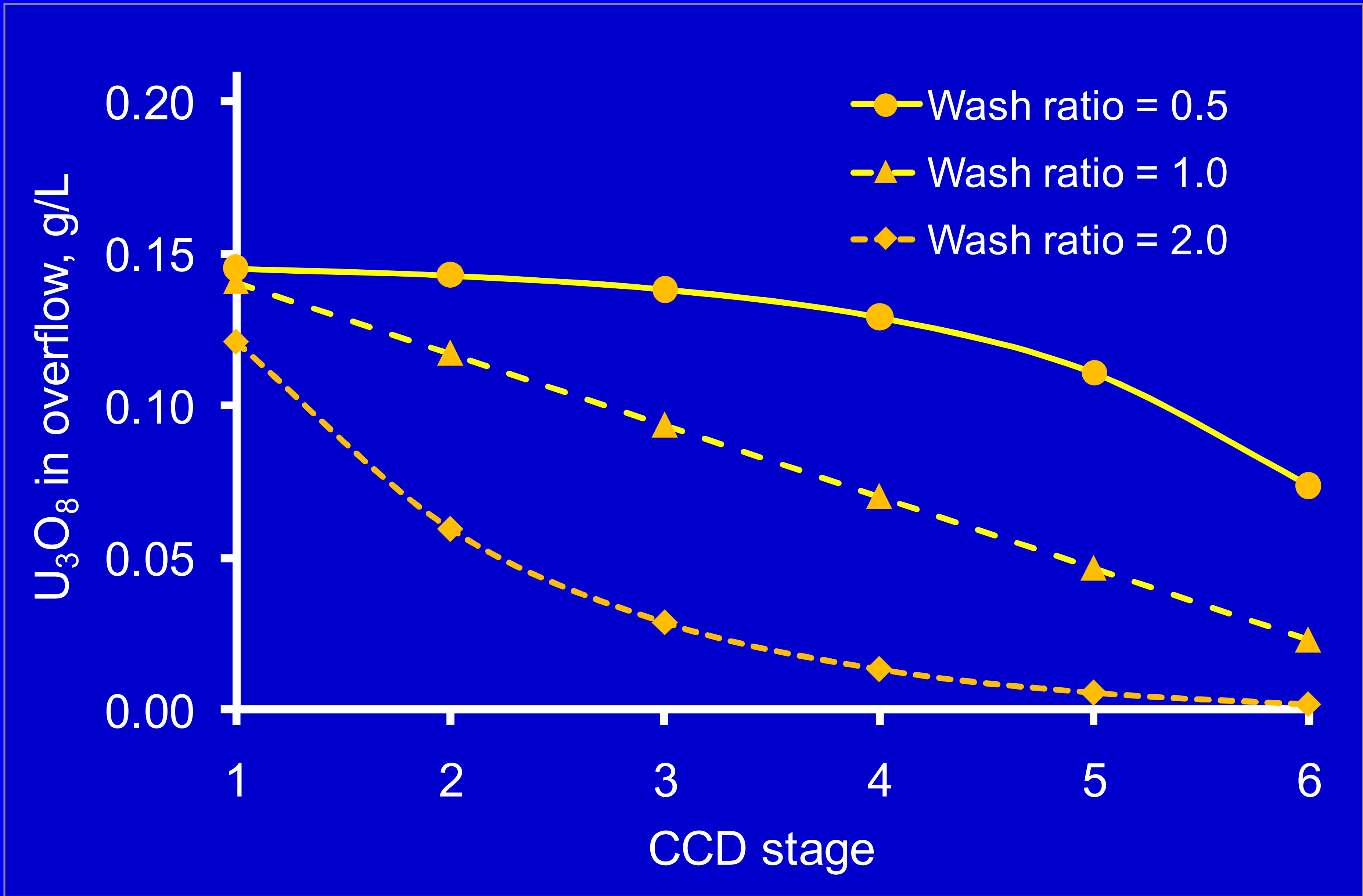

Leached slurry
PLS to IX
Wash liquor
Residue


Leached slurry
PLS to IX
IX barrens
Water
Evaporation
Return dam water
TAILINGS DAM

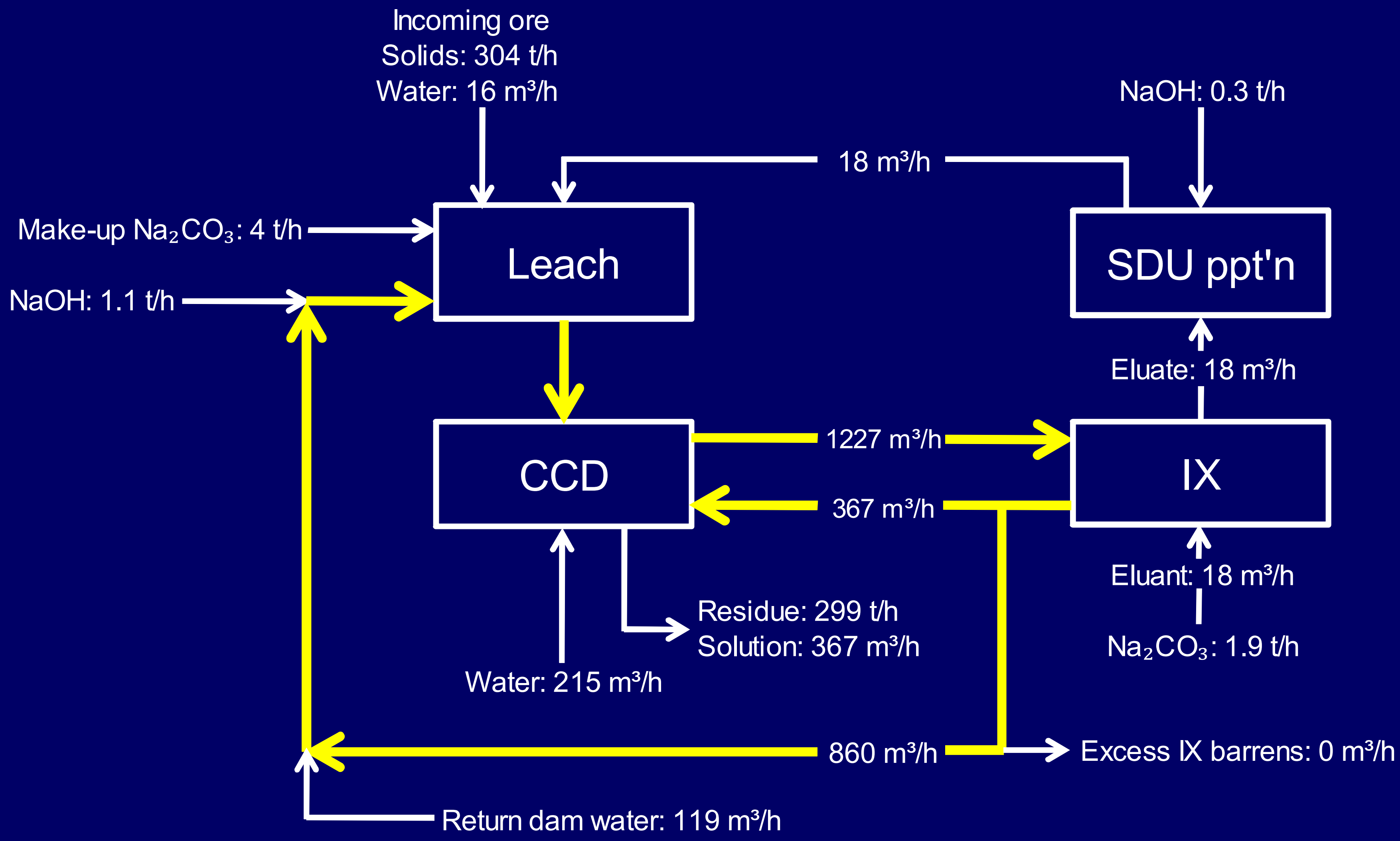


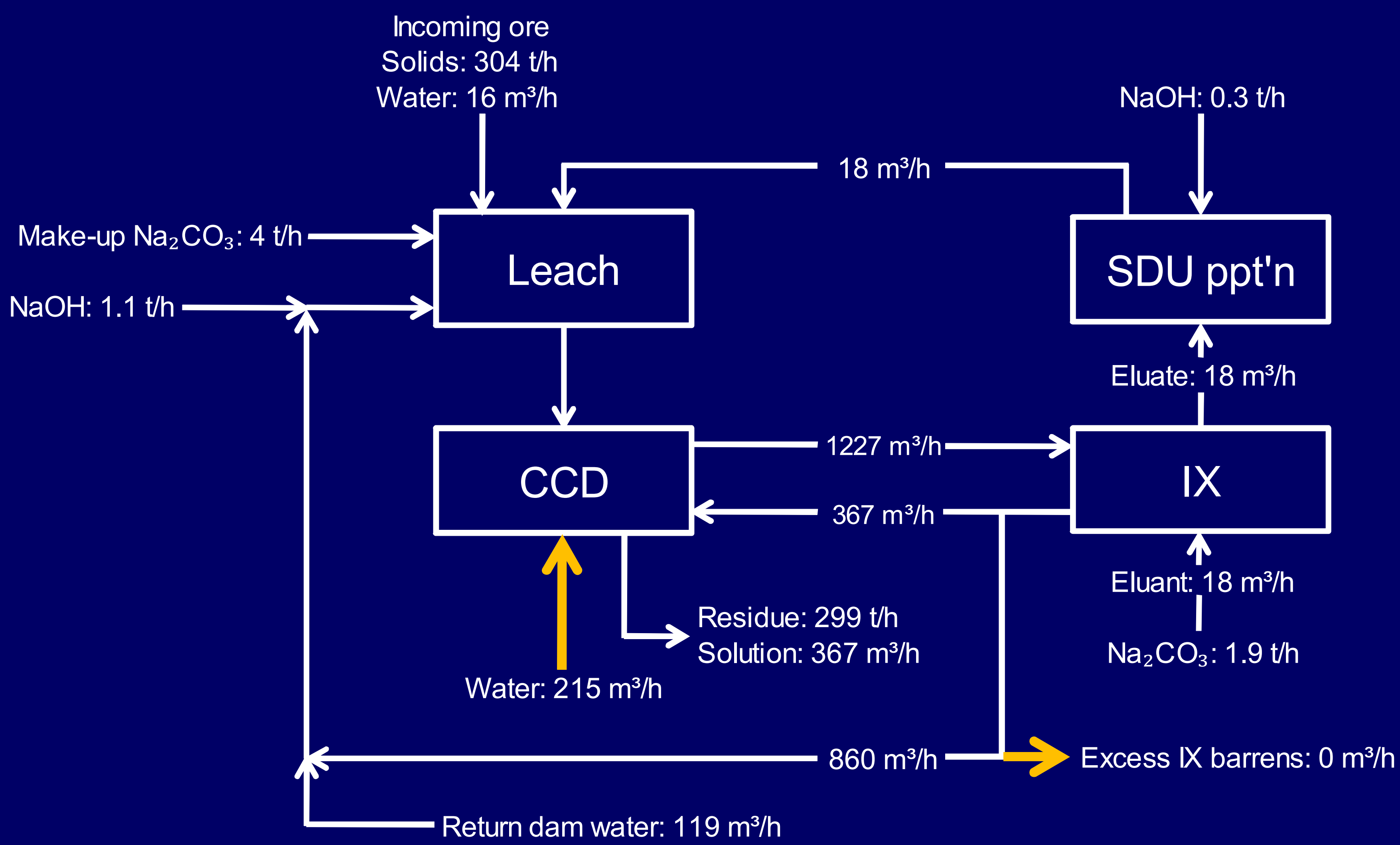
$$O = F + W - U$$

$$z = \frac{xF + yW}{O + U}$$



Wash ratio = 0.5
Wash ratio = 1.0
Wash ratio = 2.0
0.20
0.15
0.10
0.05
0.00
U_3O_8 in overflow, g/L
1
2
3
4
5
6
CCD stage


Incoming ore
Solids: 304 t/h
Water: 16 m³/h
NaOH: 0.3 t/h
18 m³/h
Make-up Na₂CO₃: 4 t/h
Leach
SDU ppt'n
NaOH: 1.1 t/h
Eluate: 18 m³/h
CCD
1227 m³/h
IX
367 m³/h
Eluant: 18 m³/h
Residue: 299 t/h
Solution: 367 m³/h
Na₂CO₃: 1.9 t/h
Water: 215 m³/h
860 m³/h
Excess IX barrens: 0 m³/h
Return dam water: 119 m³/h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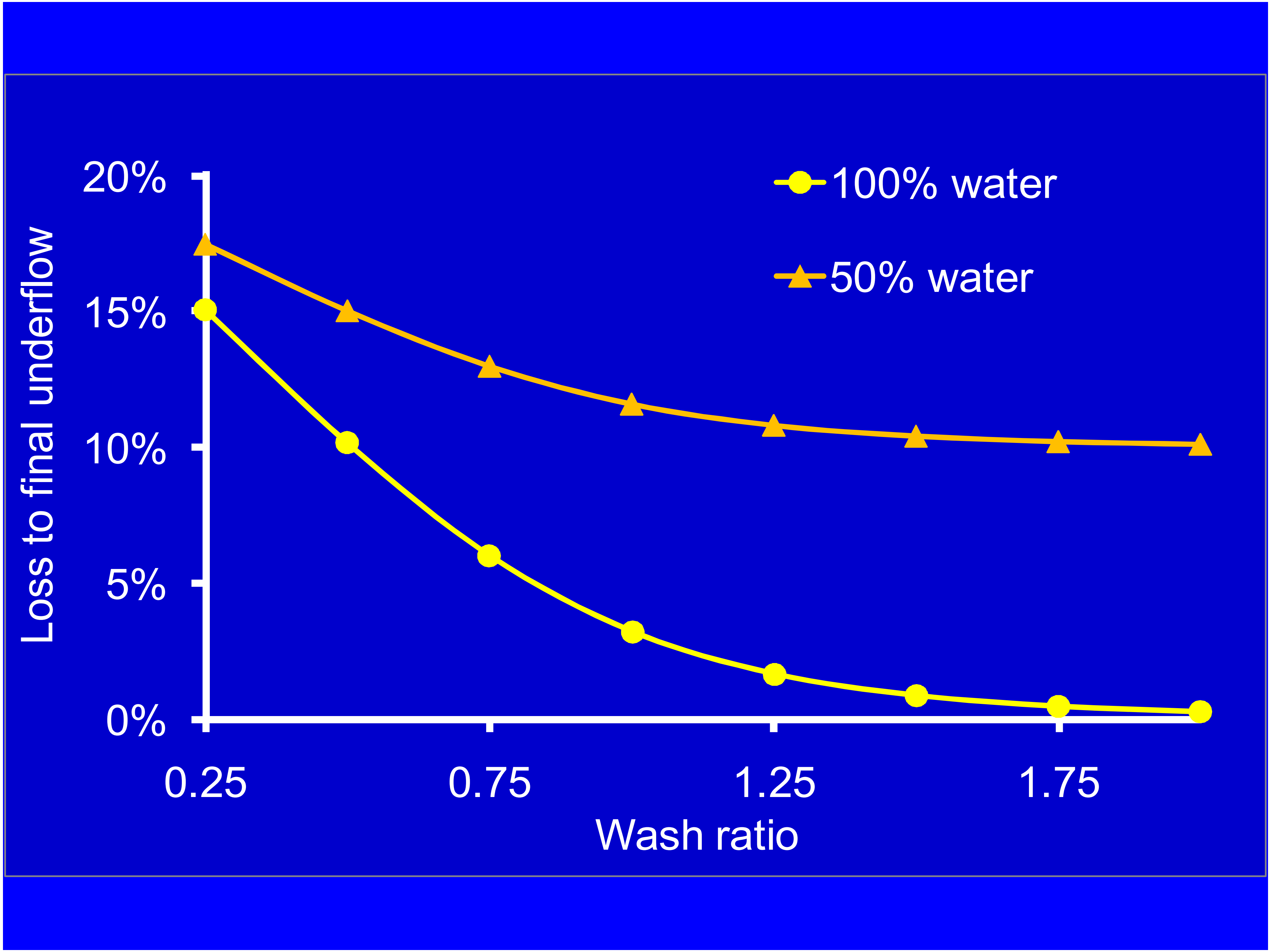
100% water
50% water
Loss to final underflow
20%
15%
10%
5%
0%
0.25
0.75
1.25
1.75
Wash ratio

Item	Calculation	Model
U_3O_8 recovery over CCD, %	97.1	98.4
U_3O_8 lost to residue, %	1.9	1.1
Carbonate recovery over CCD, %	80.1	86.5
Carbonate lost to residue, %	13.1	8.9

$$\text{Selectivity} = \frac{[U]_R/[U]_S}{[X]_R/[X]_S}$$

$$\text{Selectivity} = \frac{(U\ \text{flow})_R/(U\ \text{flow})_S}{(X\ \text{flow})_R/(X\ \text{flow})_S}$$

$$\frac{(X\ \text{flow})_R}{(X\ \text{flow})_S} = \frac{(U\ \text{flow})_R/(U\ \text{flow})_S}{\text{Selectivity}}$$

$$\text{Extraction of X} = \frac{\text{Extraction of U}}{\text{Selectivity}}$$

Item	Calculation	Model
Pregnant liquor to IX, m^3/h	1119	1236
U_3O_8 in PLS to IX, g/L	0.15	0.14
V in PLS to IX, g/L	0.13	0.2
SO_4^{2-} in PLS to IX, g/L	4.30	7.9
Cl^- in PLS to IX, g/L	1.40	3.1
Na_2CO_3 in PLS to IX, g/L	19.6	18.4
$NaHCO_3$ in PLS to IX, g/L	3.0	2.7
IX eluant/eluate, m^3/h	17	18
U_3O_8 in IX eluate, g/L	10	10
V in IX eluate, g/L	0.1	0.4
SO_4^{2-} in IX eluate, g/L	1.4	2.7
Cl^- in IX eluate, g/L	0.2	0.4
CO_3^{2-} in IX eluate, g/L	52	52

Item	Calculation	Model
NaOH to SDU precipitation, t/h	0.25	0.25
$Na_2U_2O_7$ ex SDU precipitation, t/h	0.20	0.20
H_2SO_4 to SDU re-dissolution, t/h	0.10	0.10
H_2O_2 to UO_4 precipitation, t/h	0.03	0.03
NaOH to UO_4 precipitation, t/h	0.06	0.07
Na_2SO_4 ex UO_4 precipitation, t/h	0.13	0.15

Reagent	\$/t	kg per kg U_3O_8	Cost distribution
Na_2CO_3	300	22	62%
NaOH	500	7	33%
H_2SO_4	300	0.6	2%
H_2O_2	3000	0.2	5%

Reagent	\$/t	kg per kg U_3O_8	Cost distribution
Na_2CO_3	300	21	58%
NaOH	500	8	36%
H_2SO_4	300	0.6	2%
H_2O_2	3000	0.2	5%

Labour costs, $ million/y Maintenance, $million/y	10 2

Capital cost, $ million	107
Assumed tax rate, %	30

Internal rate of return : 37%	NPV at 10% discount rate : $315 million

Internal rate of return : 39%	NPV at 10% discount rate : $344 million

Message

- Evaluation enhances process development
  - Do need leach tests early on
  - S/L separation also needs testing early
- Spreadsheet calculations are useful

Use the potential economics as an input to rational decision making.