SNO+ Tellurium Purification for **0νββ**

Szymon Manecki, August 8th, 2024

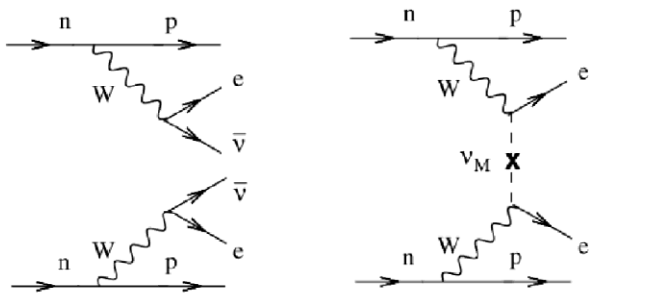
Double Beta Decay

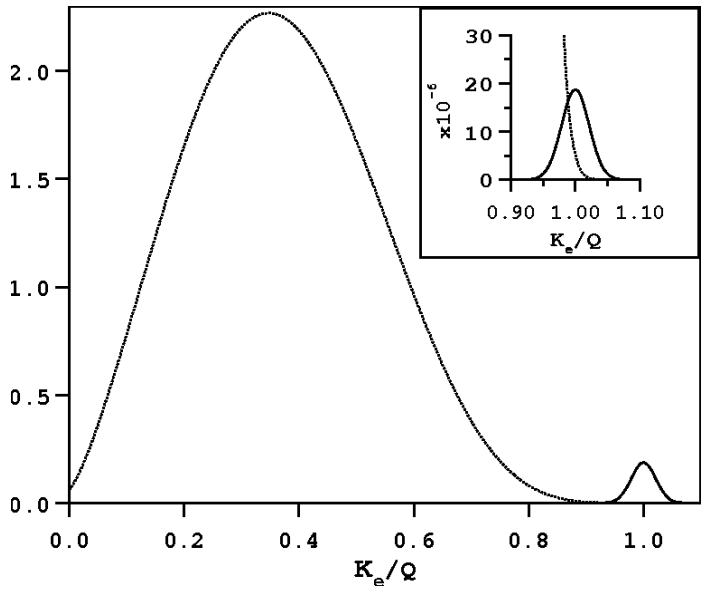
- Are neutrinos their own anti-particles?
- 2νββ (Dirac)
  $(A, Z) \rightarrow (A, Z + 2) + 2e^- + 2\nu_e$
  ~ 10^{18}-10^{21} years
- 0νββ (Majorana)
  $(A, Z) \rightarrow (A, Z + 2) + 2e^-$
  > 10^{25} years
- We measure:

$$\frac{1}{T_{1/2}} = G\, g_A^4\, \mathcal{M}^2 \left(\frac{m_{\beta\beta}}{m_e}\right)^2$$

Phase space factor

Nuclear matrix element





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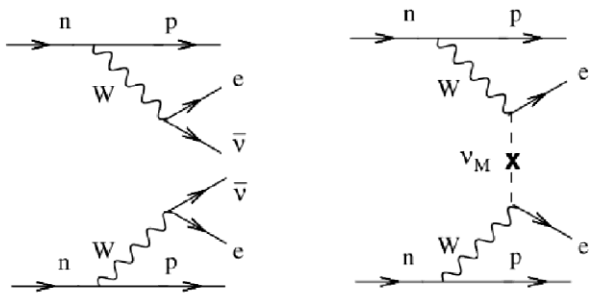
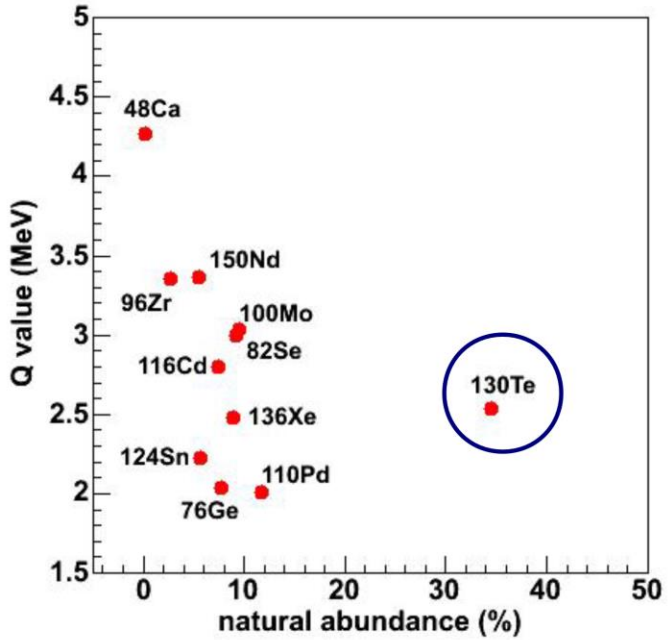
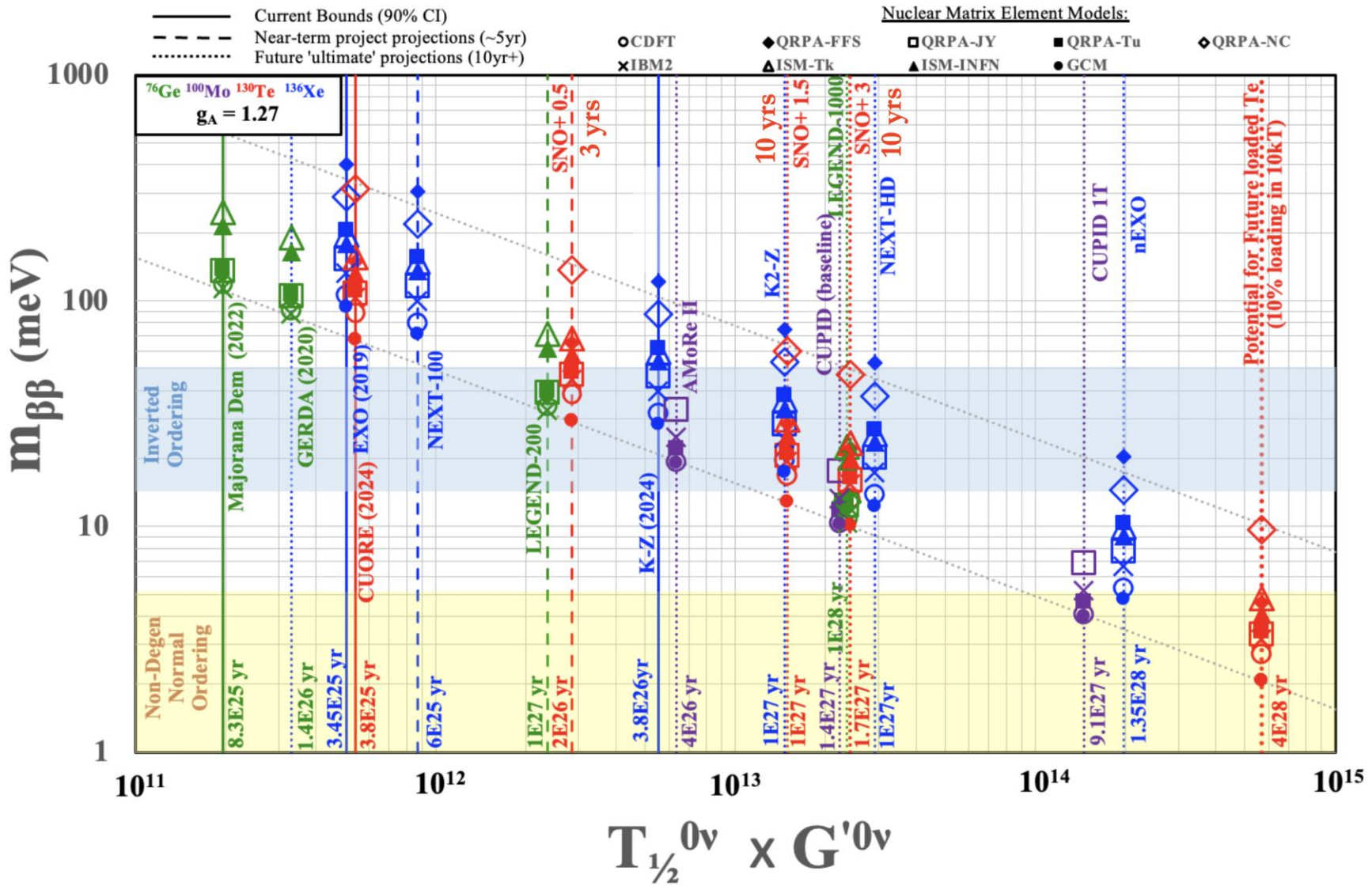




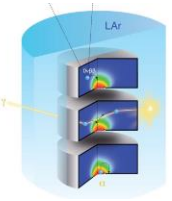
Neutrinoless Double Beta Decay



Neutrinoless Double Beta Decay

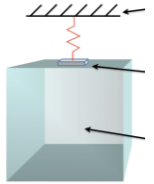
- LEGEND-200
  - 200 kg of ^{enr}Ge HPGe TPC's
    - $T^{0\nu}_{1/2}$ lower limits (90% frequentist C.L.)

Observed	Sensitivity
$> 1.9 \cdot 10^{26}$ yr	$2.8 \cdot 10^{26}$ yr



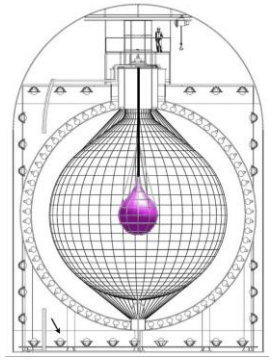
- CUORE
  - 750 kg TeO_2 cryogenic calorimeters

Half-life limit: $T^{0\nu}_{1/2} > 3.8 \times 10^{25}$ yr (90% C.I.)



- KamLAND-Zen
  - 800 kg ^{enr}Xe scintillator based detector

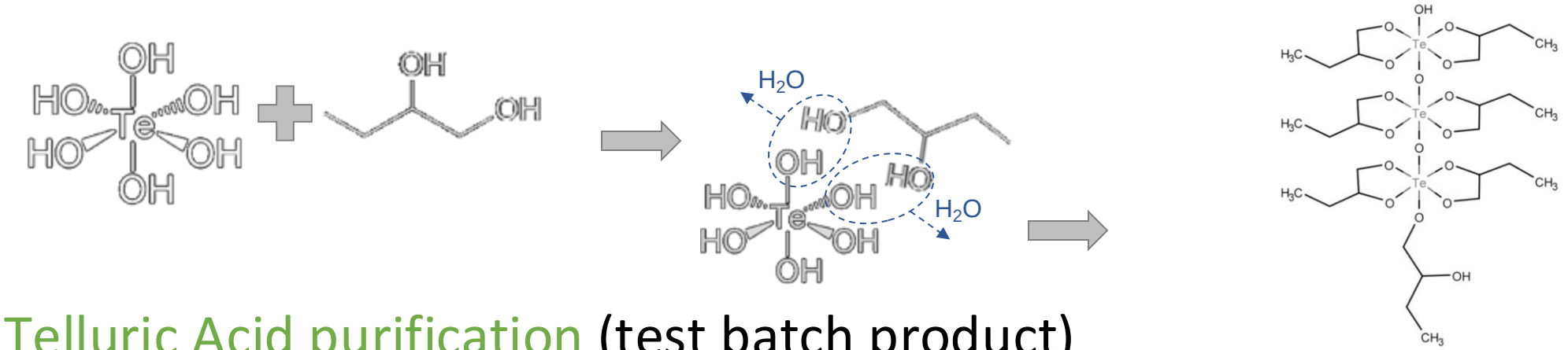
Combined $T^{0\nu}_{1/2} > 3.8 \times 10^{26}$ yr



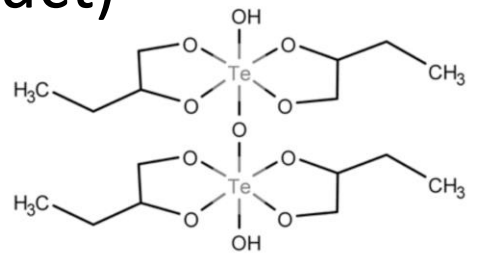
Milan '24 0νββ:
https://agenda.infn.it/event/37867/sessions/29923/#20240618

SNO+ Tellurium-Diol Synthesis

- LAB-soluble TeDiol complexes are formed in condensation and further oligomerization reactions of Telluric Acid with 1,2-Butanediol

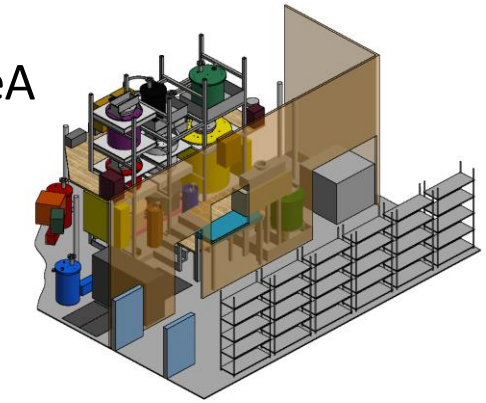


- Telluric Acid purification (test batch product)
- 1,2-Butanediol *distillation*
- DDA *distillation*

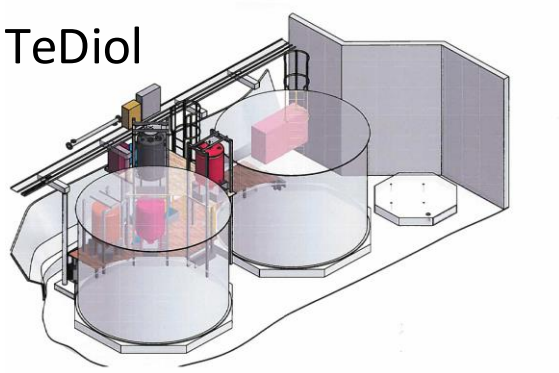


SNO+ Tellurium Systems

TeA



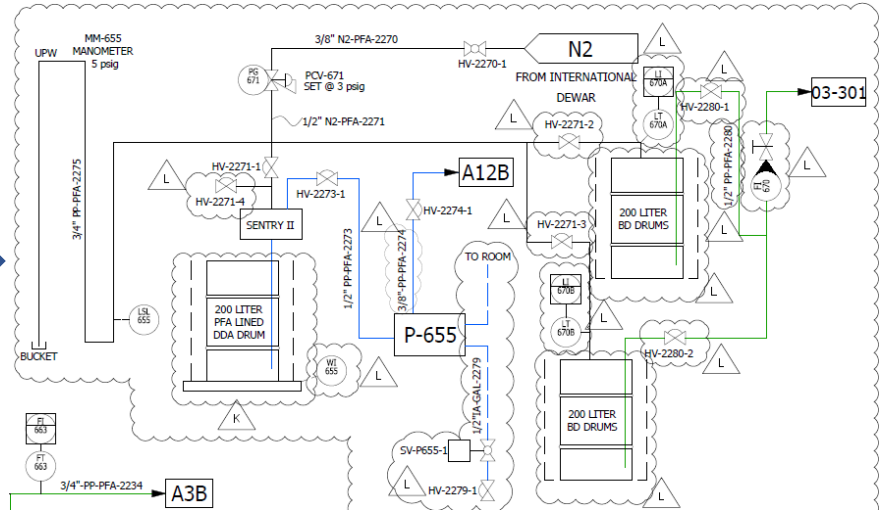
TeDiol



AV

DDA Distillation

DDA & BD UG Transfer



TeA Purification

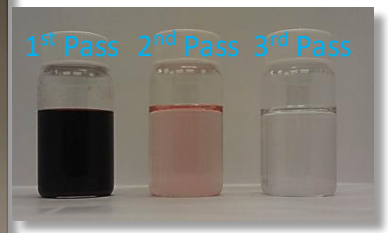
- The purification technique relies on solubility of TeA in water based on pH
  - $Te(OH)_6$ ⇔ $Te(OH)_5O^- + H^+$
    in-soluble soluble
- Insoluble contamination
  - Dissolve in water, and filter
- Soluble contamination
  - Force TeA to recrystallize by adding Nitric Acid, let it precipitate out, and drain the “dirty” liquid

Nucl. Inst. Meth. A. 795:132-139 (2015)

Cosmogenic isotope	Counts in Year 1 (no purification)
^{22}Na	7.04×10^{3}
^{26}Al	9.67×10^{-2}
^{42}K	6.55×10^{2}
^{44}Sc	8.41×10^{1}
^{46}Sc	5.21×10^{-2}
^{56}Co	1.02×10^{-3}
^{58}Co	2.50×10^{-3}
^{60}Co	6.62×10^{3}
^{68}Ga	6.20×10^{2}
^{82}Rb	5.15×10^{-16}
^{84}Rb	8.88×10^{-12}
^{88}Y	2.23×10^{1}
^{90}Y	5.05×10^{2}
^{102}Rh	1.33×10^{3}
^{102m}Rh	9.54×10^{4}
^{106}Rh	8.59×10^{1}
^{110m}Ag	7.96×10^{2}
^{110}Ag	1.07×10^{1}
^{124}Sb	1.77×10^{-2}
^{126m}Sb	3.06
^{126}Sb	2.92×10^{-35}

Free purification factor due to underground cooldown

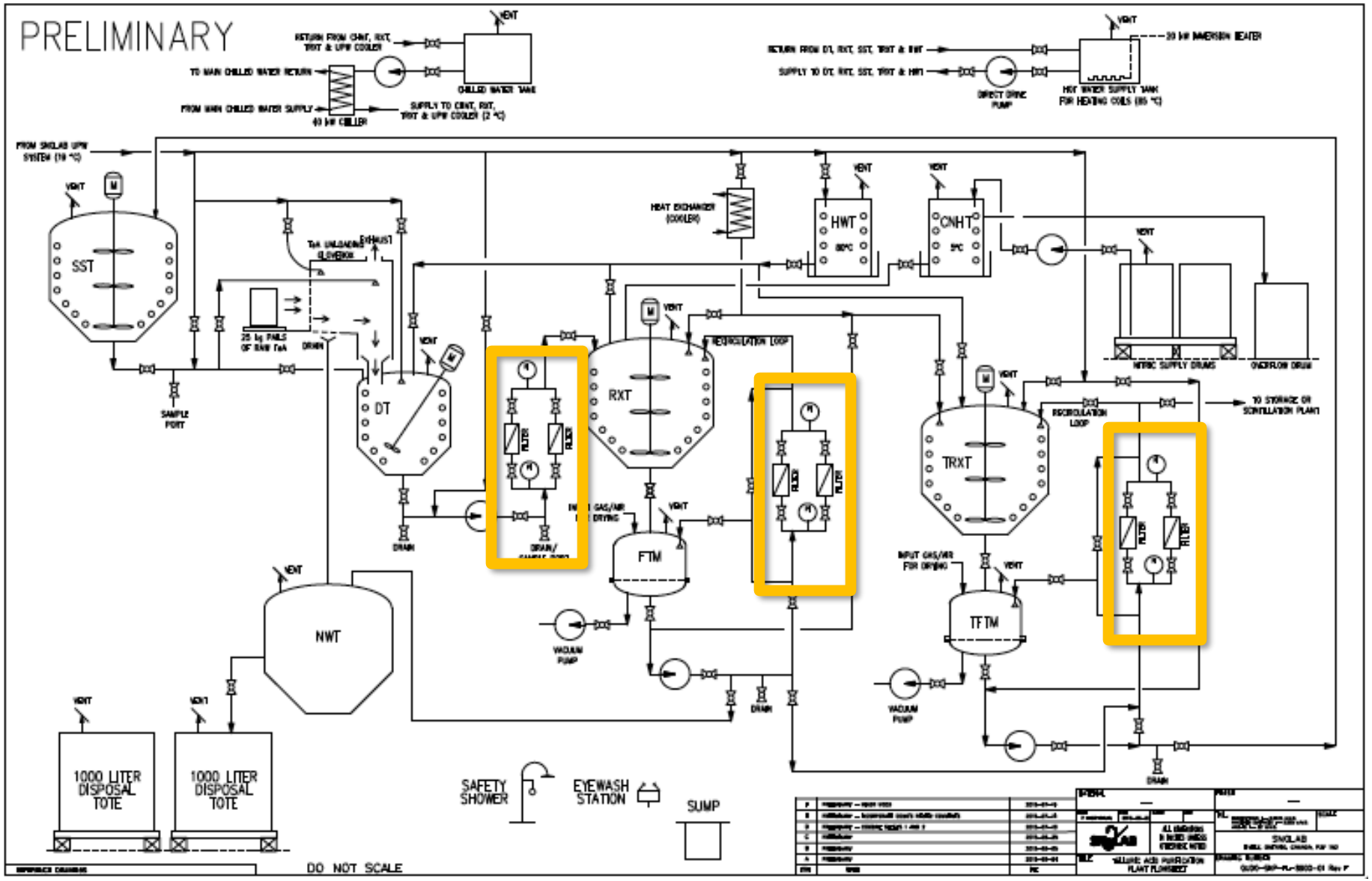
10kg pilot-scale



AV Target (r.f. 10^3):
^{238}U: 1.3×10^{-15} g/g
^{232}Th: 5×10^{-16}g/g

Expected r.f. for cosmogenics: 10^5-10^6

Flow Diagram For TeA Plant



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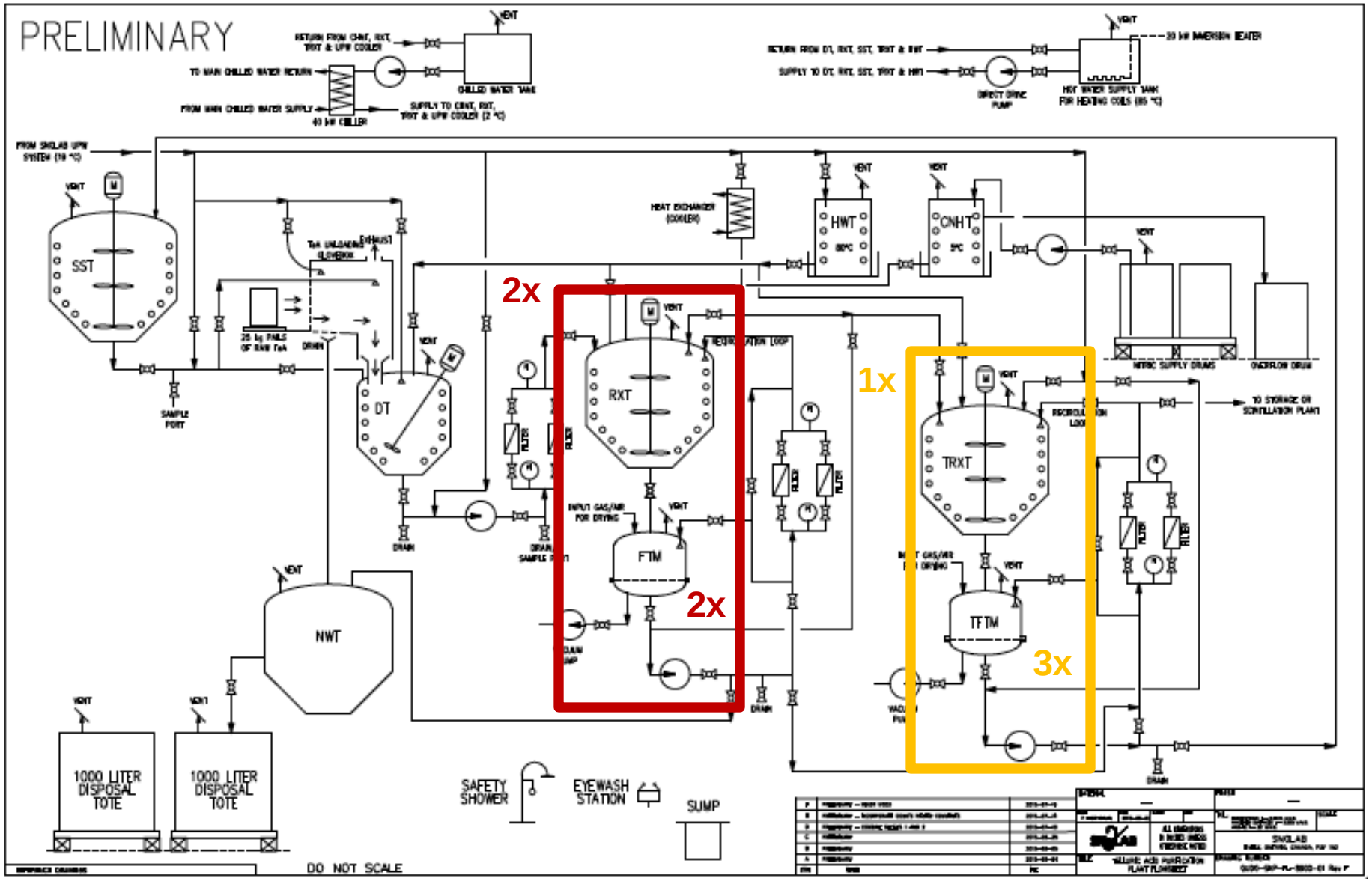

TeA Purification

TeA Test Batch

- Safety (Process Checklist and Monitoring)
  - Transport and handling of nitric acid and telluric acid
  - Sampling
- Process (Plant and Performance QA)
  - Mechanical, Hydraulic, Electrical, Instrumentation, DeltaV
  - Yields and efficiencies
- Physics (Process Purification QA)
  - Purifications factor and ICP-MS analysis

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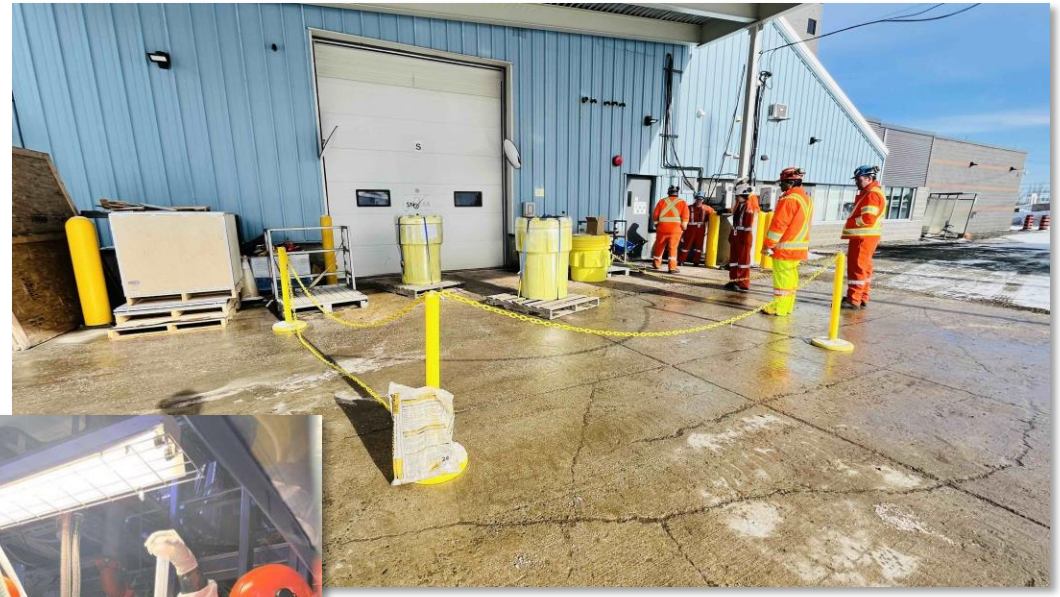
Safe Reagent Handling Underground

- Nitric acid shipping and logistics
- TeA loading into the plant
- Nitric and telluric acid sampling
- Process systems



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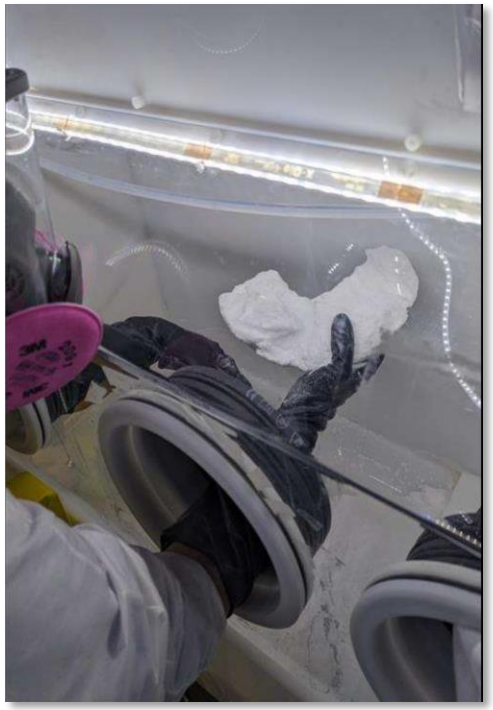

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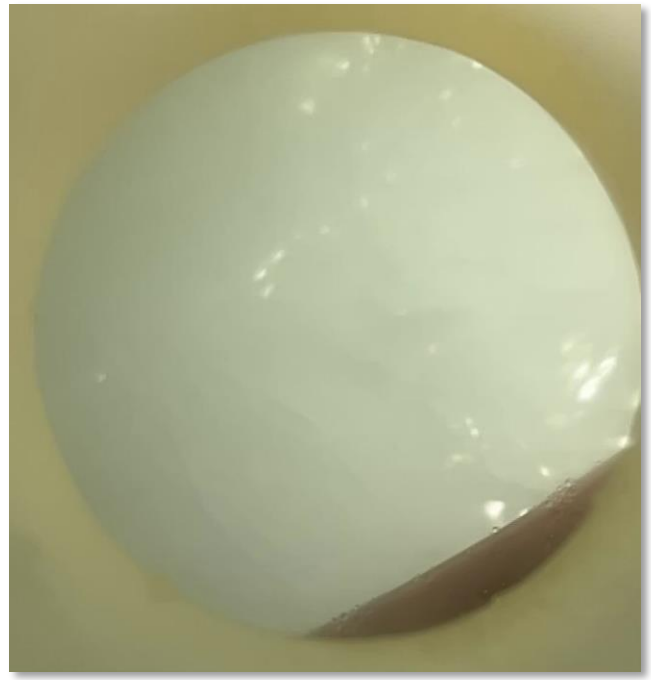
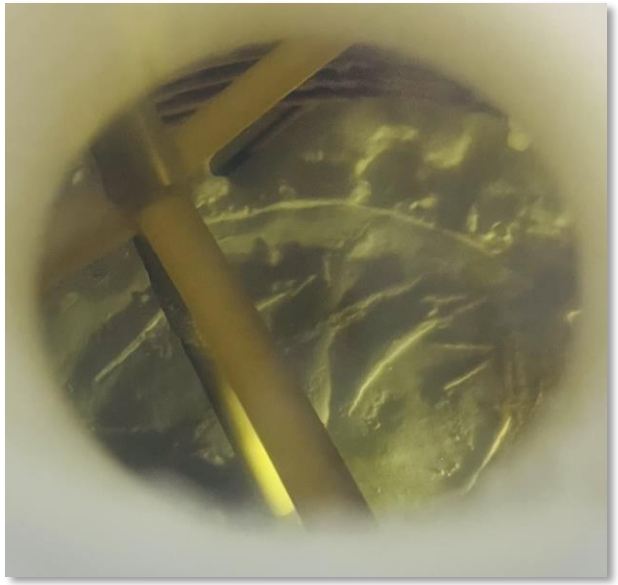
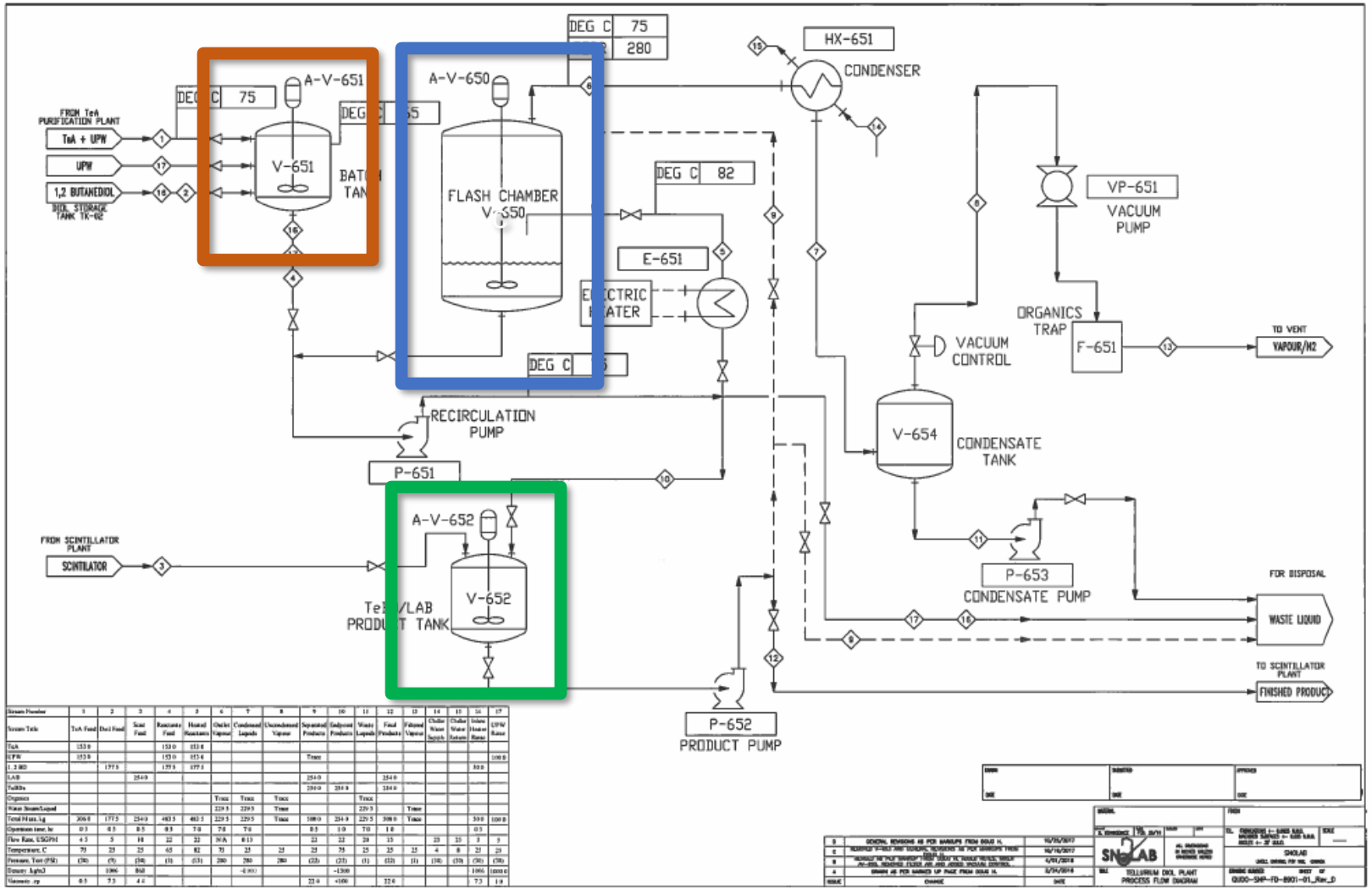




TeA Purification

- Redissolved TeA sample after first stages of nitric acid recrystallization will be analyzed with ICP-MS soon
- We've determined that our TeA is much cleaner than what we've been assuming so far (U and Th at the level of a few ppt from two different batches/drums)
- Alternative nitric acid supply also demonstrated to be better than expected: ~5×10^{-15} gU/g and ~6×10^{-16} gTh/g
- Ultimately the purification factor is determined by the amount of residual nitric acid in the TeA crystal - which we just demonstrated to be satisfactory

TeDiol Plant Flow Diagram



TeDiol Test Batch

- 8g synthesis R&D
- 160g synthesis system
- Pilot Plant (1.5 kg batch size)
- Full Scale plant (~250kg/batch)

TeDiol Test Batch

- Full Scale plant (~250kg/batch)
  - Already demonstrated water removal
  - Final commissioning tasks TBC
  - Distilled Butanediol needed

Surface Distillation

- DDA Installation
  - Completed as of last week (piping, mechanical and electrical)
    - Minor adjustments remaining (labelling, etc.)
- DDA Still commissioning
  - Planned shortly
  - Further ‘full commissioning’ will be done this Fall including distillation runs of LAB, BD and DDA

Picture from January 2024

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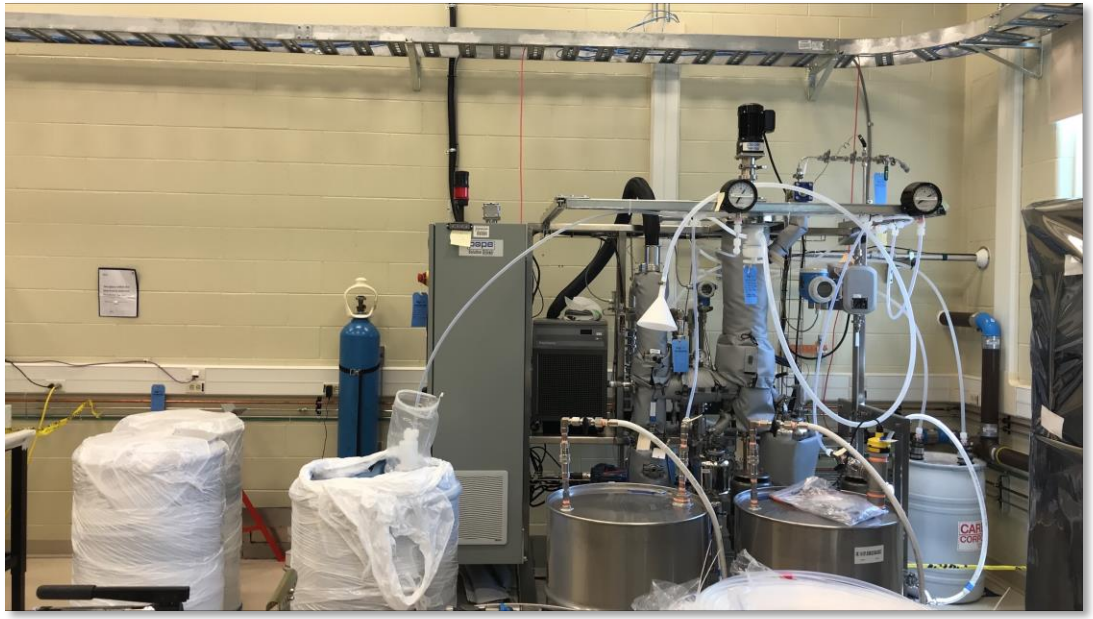

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Summary

- TeA Test Batch was a success
- TeDiol Synthesis test run is the next major milestone
- In parallel we are building reagent transfer stations and commissioning the surface distillation plant

Backup