Liquid Scintillator Purification for SNO+

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on behalf of the SNO+ collaboration

Low Radioactivity Techniques Workshop
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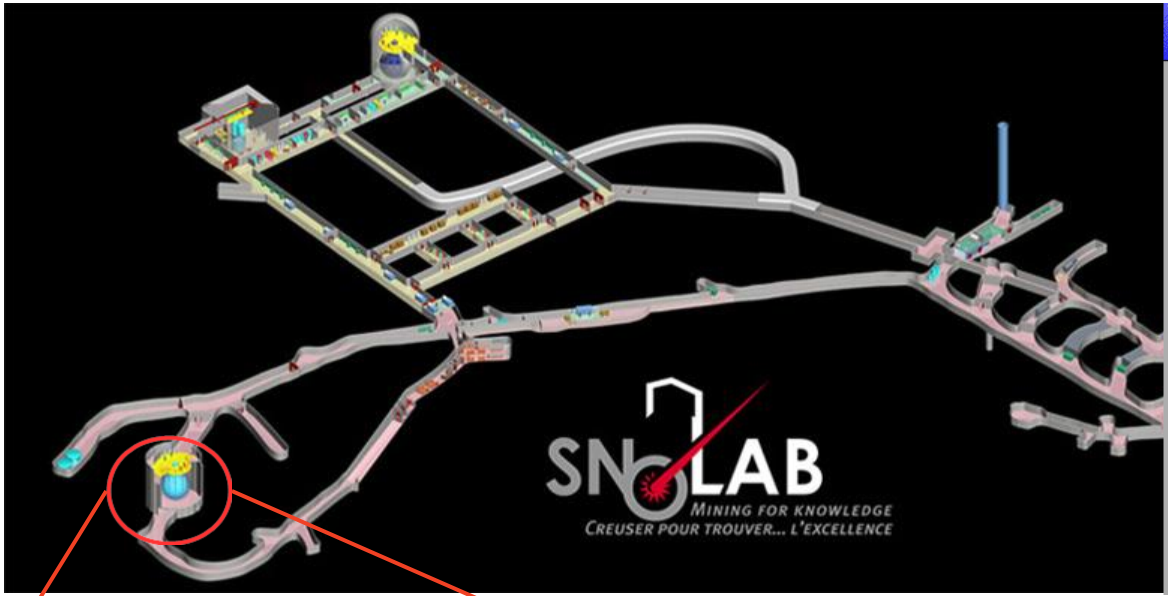
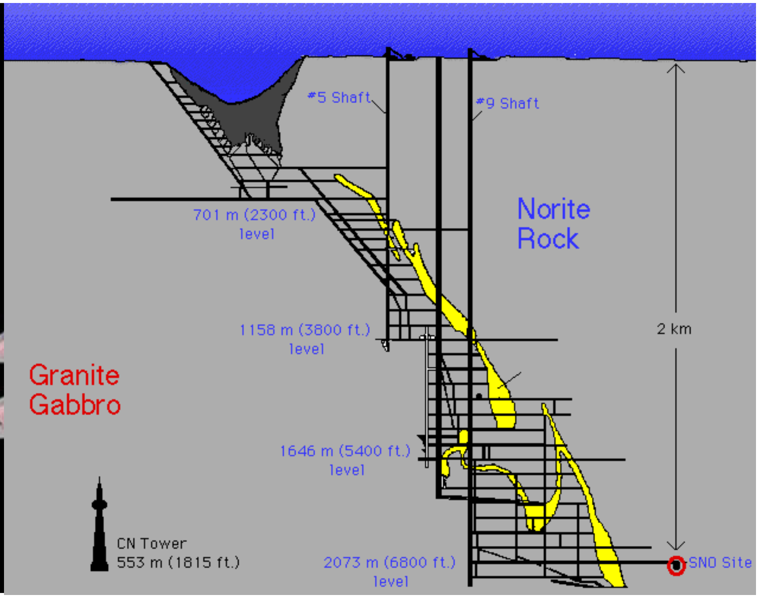
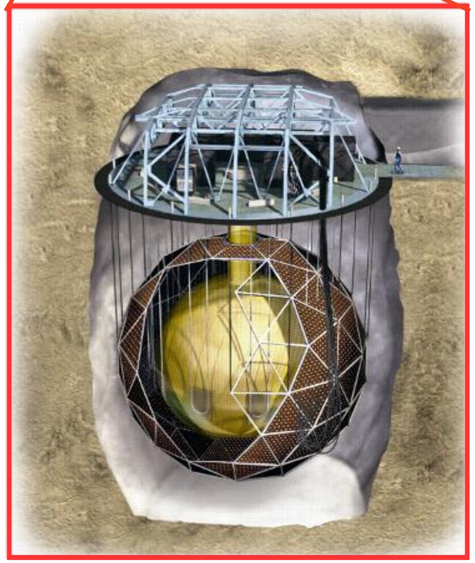
SNO+ @ SNOLAB



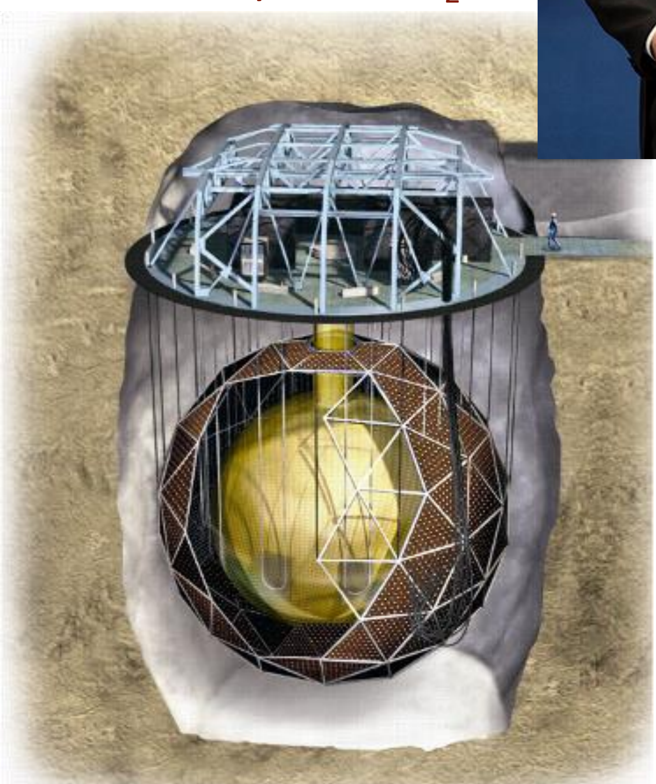




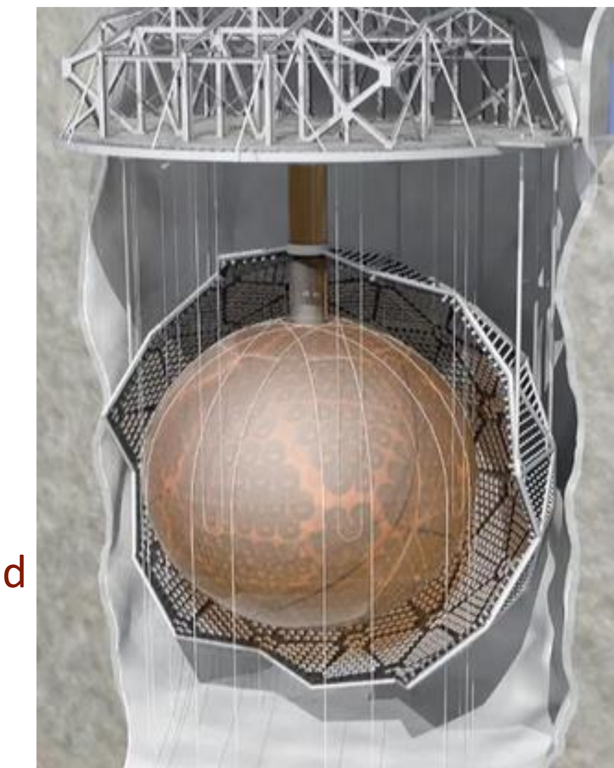
- SNOLAB – underground laboratory:
  - Creighton Mine, Sudbury, Canada
  - Deep: 2km, 6000 mwe
    - ~ 70 muons /day in SNO+
  - Clean : class 2000 clean room

SNO+ Detector

1984-2007
1 kt Heavy Water D_2O



2007-present
780 t Liquid Scintillator



- Target Materials:
  - Ultra-Pure Water
  - High-purity Liquid Scintillator
  - Tellurium-loaded Liquid Scintillator

SNO+ Program

Water Phase

May 2017-July 2019

- Solar Neutrinos
- Reactor Antineutrinos
- Supernova Neutrinos
- Nucleon Decay

Scintillator phase

April 2022 – Present

780 tonnes

- Solar Neutrinos
- Reactor Antineutrinos
- Supernova Neutrinos
- Geoneutrinos
- Exotic

Tellurium Phase

Deployment in 2025

- Neutrinoless Double Beta Decay with ^{130}Te
- Solar Neutrinos
- Reactor Antineutrinos
- Supernova Neutrinos
- Geoneutrinos
- Exotic

Szymon Manecki's Talk

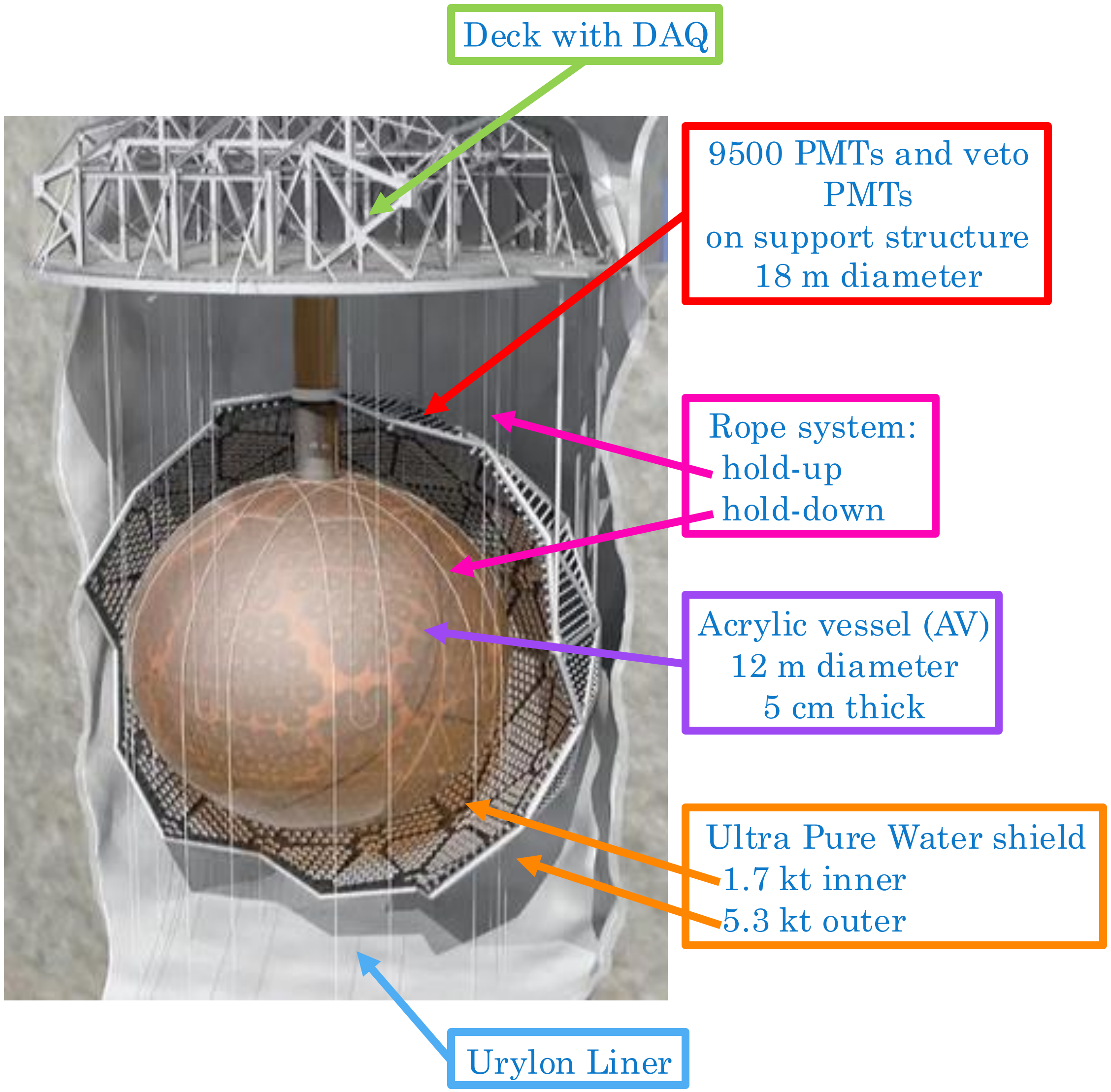
Partial Fill Phase

March - October 2020

365 tonnes of LAB + 0.6 g/L PPO

SNO+ Detector

- ✓ New hold-down net
- ✓ Replace hold-up ropes
- ✓ New Cover Gas
- ✓ New Purification Plants:
  - ✓ Scintillator, TeA, TeDiol
- ✓ Repair and re-install the PMTs
- ✓ Seal the liner in the cavity
- ✓ Upgrade the DAQ
- ✓ New calibration system Internal and External

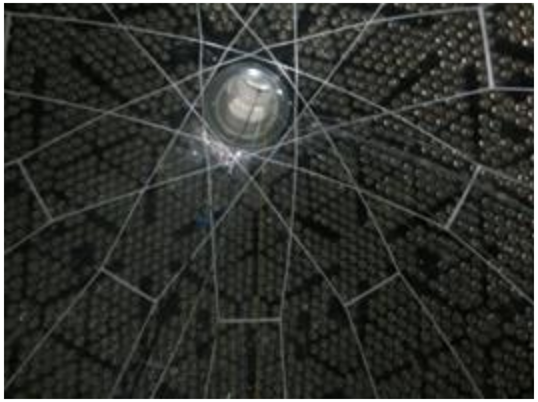


- ❑ 2021 JINST 16 P08059

SNO+ Detector: Rope System

- ✓ New hold-down net
- ✓ Replace hold-up ropes

	Cavity	AV	AV hold-up	AV hold-down
SNO	UPW 999.7 kg/m^3	D2O 1106 kg/m^3	10 loops	-
SNO+		LAB 854.7 kg/m^3		10 ropes



- ❑ Designed to counteract the buoyant force of 1.25 MN
- ❑ Ropes:
  - Tensylon (high-performance polyethylene fiber)
  - suitable mechanical properties
  - lower radioactivity than original SNO ropes

Material	^{40}K (ppm)	^{232}Th (ppb)	^{238}U (ppb)
Vectran:			
Lubricant #1[a] (JP)	73.42 ± 5.74	0.36 ± 0.16	0.12 ± 0.05
Lubricant #[b] (JP)	83.67 ± 6.53	0.60 ± 0.19	0.11 ± 0.05
F-F (USA)	40.76 ± 4.70	0.40 ± 0.90	7.94 ± 0.72
F-F: UPW (USA)	33.15 ± 4.99	3.44 ± 2.03	0.34 ± 0.43
Tensylon™	0.87 ± 0.20	0.23 ± 0.11	0.05 ± 0.03
Tensylon™: UC	0.53 ± 0.20	0.27 ± 0.12	0.74 ± 0.07

- ❑ NIM A, 827 (2016), 152-160

Status:
- ➢ Installed in 2012 and tested to its full capacity

SNO+ Detector: Cover Gas

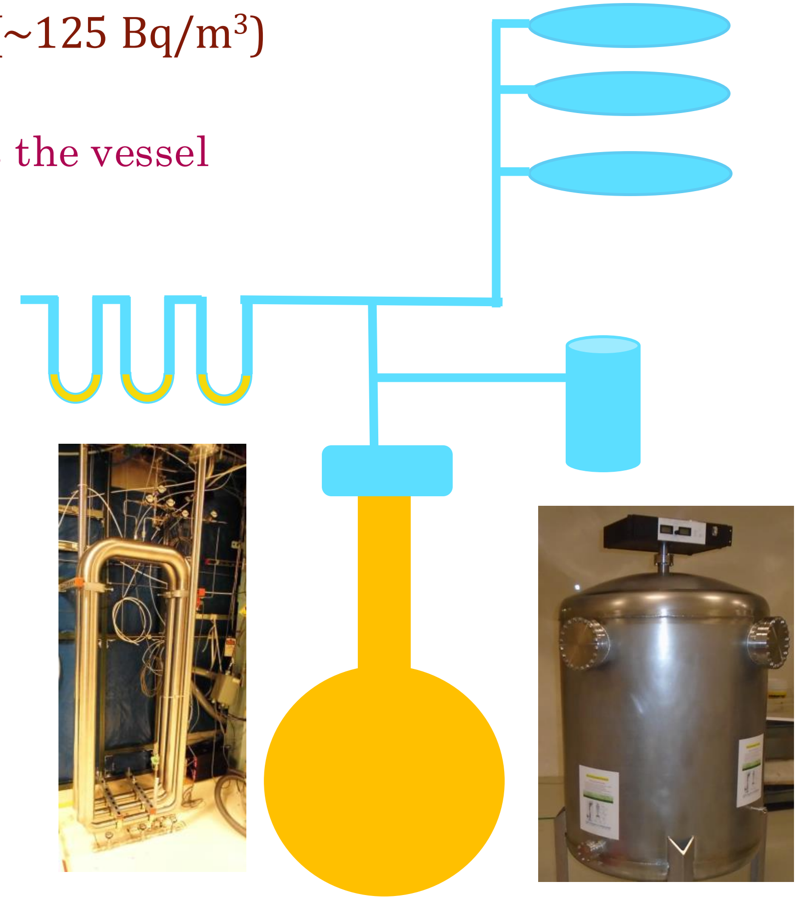
✓ New Cover Gas

Designed as a sealed system

- Reduce Rn gas level as compared to SNOLAB air (~125 Bq/m^3)
- Balance the pressure swings in the mine
  - ♦ mechanical constrains on the max dP across the vessel

- Buffer volumes (3 Bags)
  - for small external pressure changes
- Pressure relief system (3 U-traps)
  - for instant high-pressure changes

❑ 2021, JINST 16 P08059



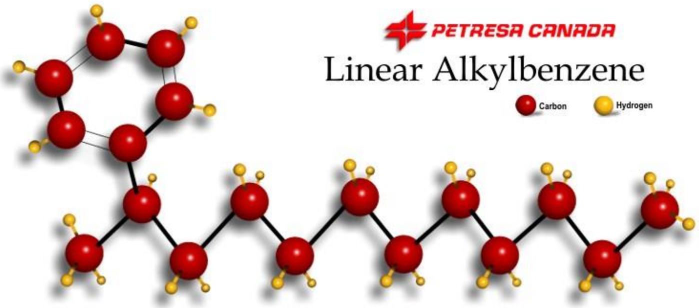
Status:
- ➢ Commissioned and operational since Sep 2018
- ➢ Reduction 1.9x10^4 in radon concentration
- ➢ Constant monitoring with radon monitor since Oct 2018

Search For a New Liquid Scintillator

Developed by SNO+

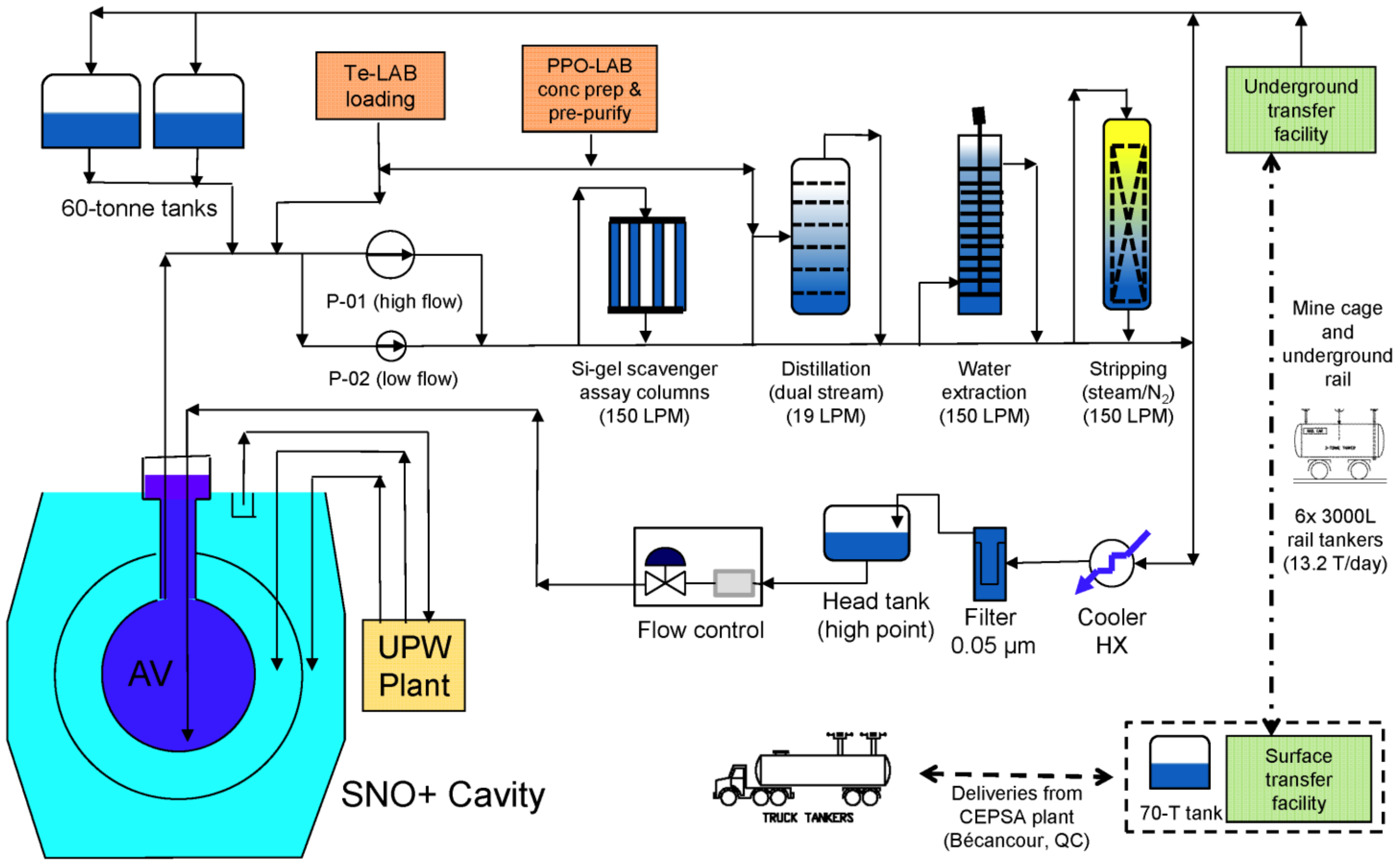
- Solvent: Linear alkylbenzene (LAB)
  - **Chemically compatible with acrylic**
  - Stable
  - High light yield
  - High purity
  - long attenuation and scattering length
  - Low cost
  - Safe (high flash point 140°C, low toxicity)
  - Low solubility in water
  - Density 0.86 g/cm3
- Primary Fluor: PPO (2.2g/L)
- Secondary Fluor: bisMSB (5.4 mg/L)
- Stabilizer: BHT (2.2 mg/L)
- 2021, JINST 16 P05009

Solvent	Density (g cm^{-3})	Flash point (°C)
Pseudocumene (PC)	0.889	44
Phenylcyclohexane (PCH)	0.950	98
Linear alkylbenzene (LAB)	0.856	143
Di-isopropylnaphthalene (DIN)	0.960	140
Phenyl-o-xylyletane (PXE)	0.985	167
1-Methylnaphthalene (1-MN)	1.020	82
Dodecylbenzene (DCB)	0.870	140



Purification Methods

- Microfiltration
- Vacuum distillation
- N2/UPW Steam stripping
- Liquid-Liquid Extraction
- Metal scavengers



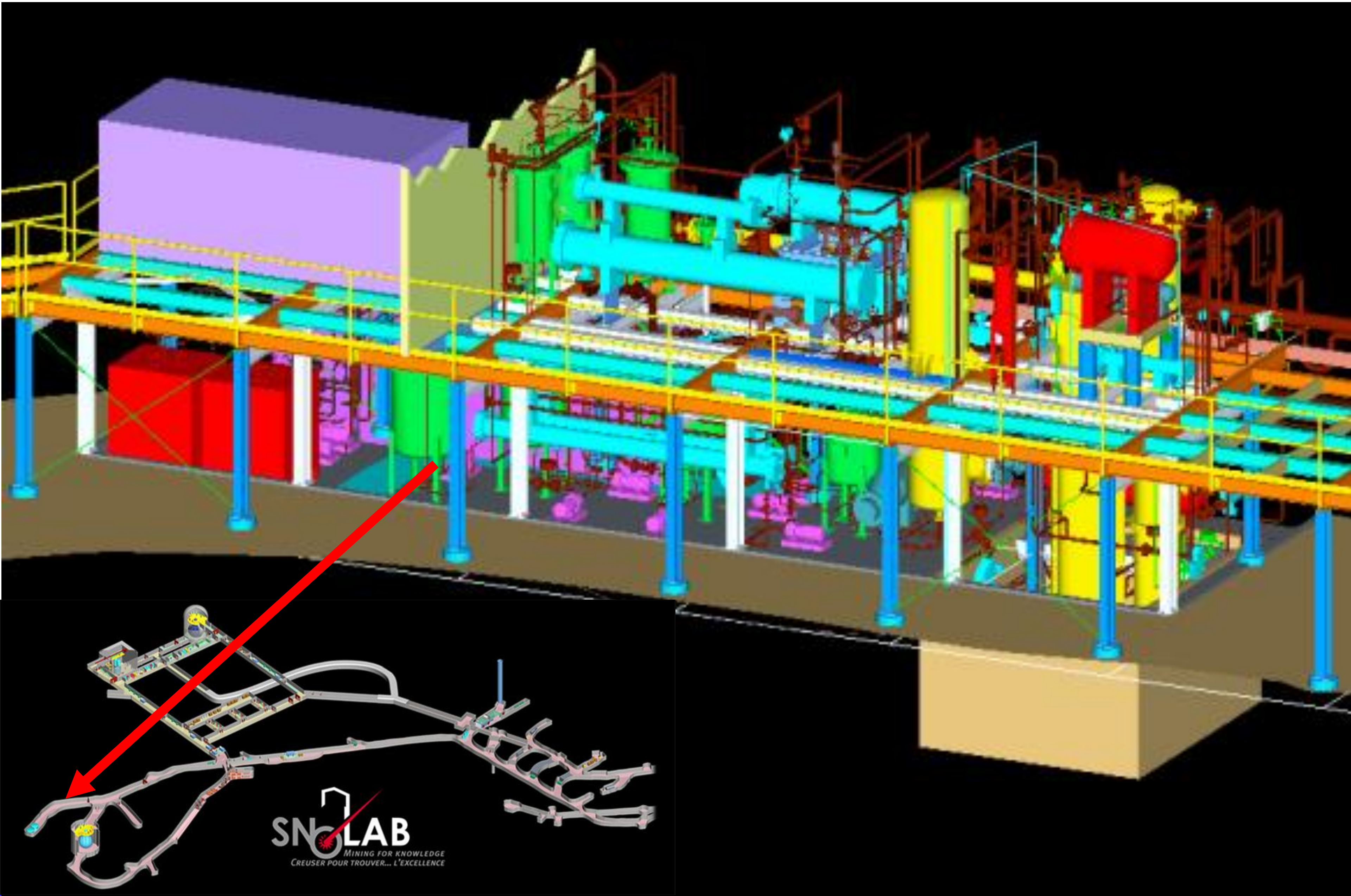
Process System Requirements

- **Materials:** SS316, Teflon, glass, acrylic
- **Pressure:** 150psi.
- **Temperature:**
  - 240°C (under boiling point, but above flash point)
- **Surface preparations and cleanliness:**
  - Electropolished, Passivated and Cleaned to Mil standard 1246 class 50 (LPC).
- **Leak tightness:**
  - 10^{-9} mbar*L/sec
- **Pumps, valves and fittings:**
  - SS electro-polished tubing, GTAW orbital weld
  - VCR fittings and Metal gaskets (Helicoflex)
  - O-rings Teflon Encapsulated Viton (TEV)
  - Diaphragm or bellows valves
  - Mag-drive pumps

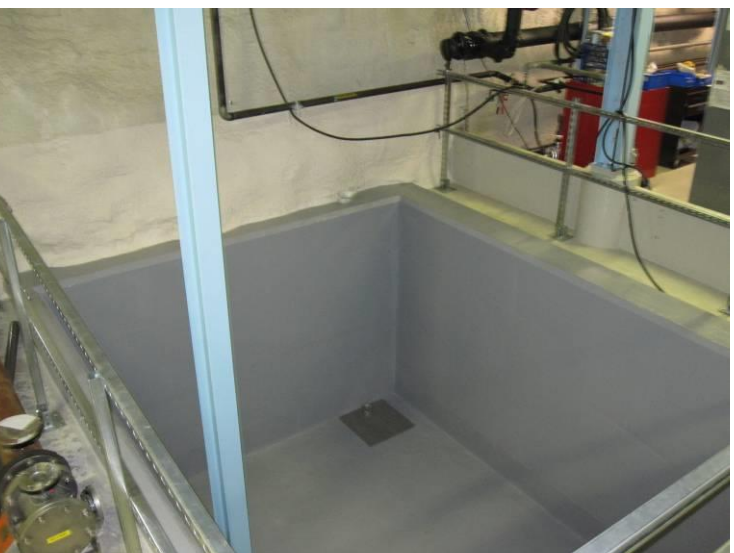
Process System Challenges

- ❑ Build a small refinery in the mine
- ❑ Constrained space in any direction
- ❑ Bring underground all the tall columns and vessels
- ❑ Construction to be done in a very strict cleanroom environment
- ❑ High purification efficiency
- ❑ High-vacuum tightness (Rn ingress)
- ❑ Only selected materials for purity and compatibility
- ❑ Constrains on the electrical power and cooling capacity
- ❑ Additional fire protection
- ❑ High LN2 demand

Purification Plant @ SNOLAB

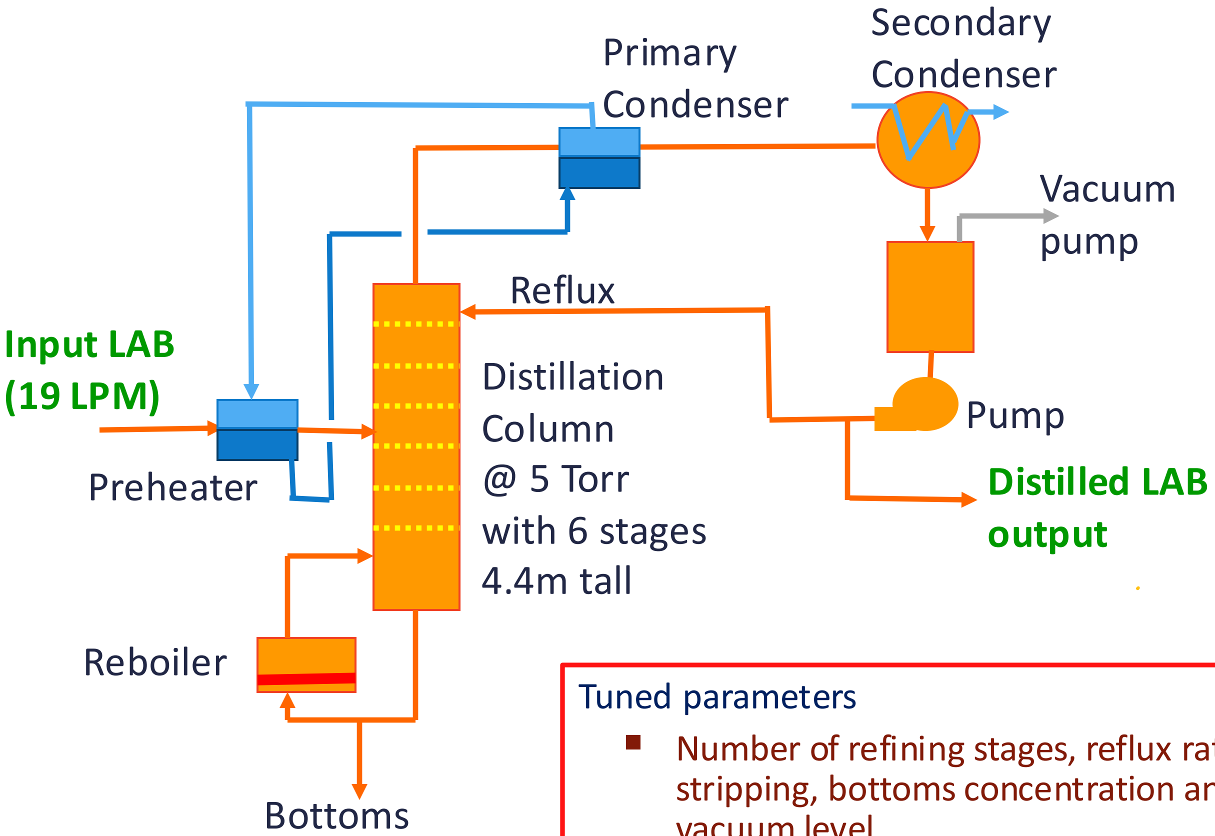


Process System Challenges: Construction



LAB Distillation

- Continuous multistage vacuum distillation
  - Initial purification of LAB
  - Remove radioactive heavy metals (Bi, Pb, Po, K, Ra, Th)
  - Improve UV optical transparency



Tuned parameters
- Number of refining stages, reflux rate, stripping, bottoms concentration and vacuum level
- >99.85% efficiency

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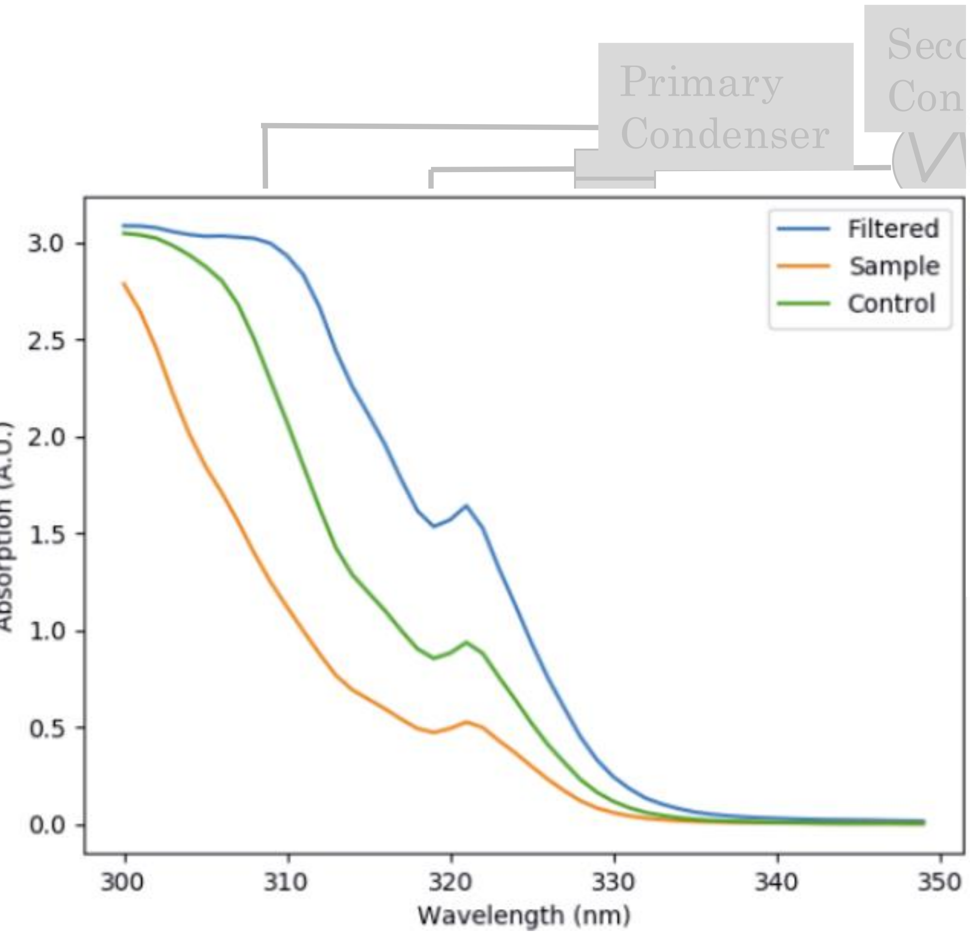

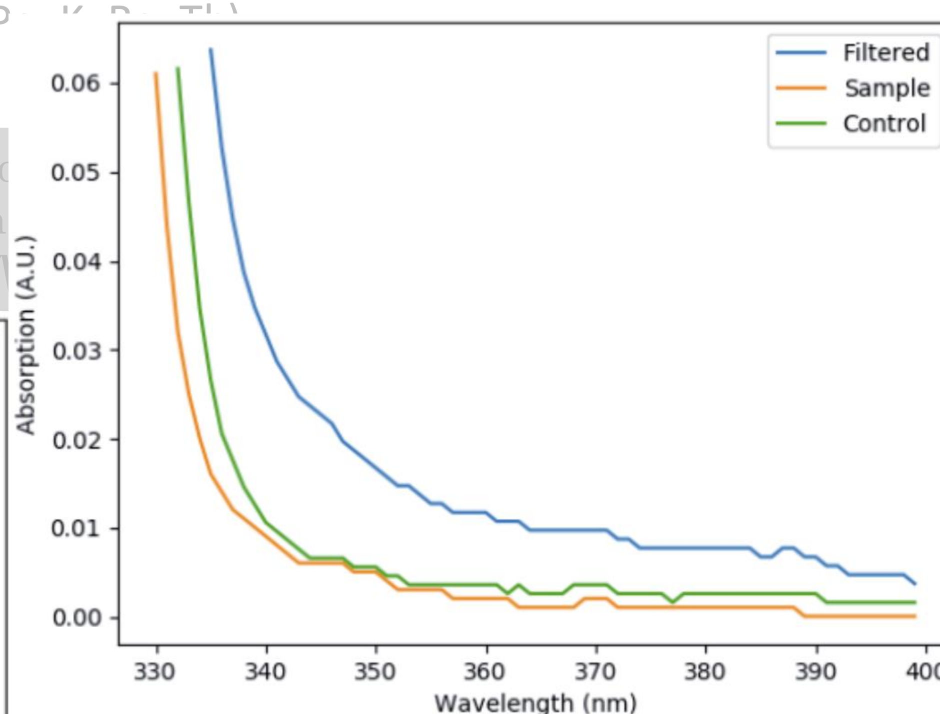

Tuned parameters

- Number of refining stages, reflux rate, stripping, bottoms concentration and vacuum level
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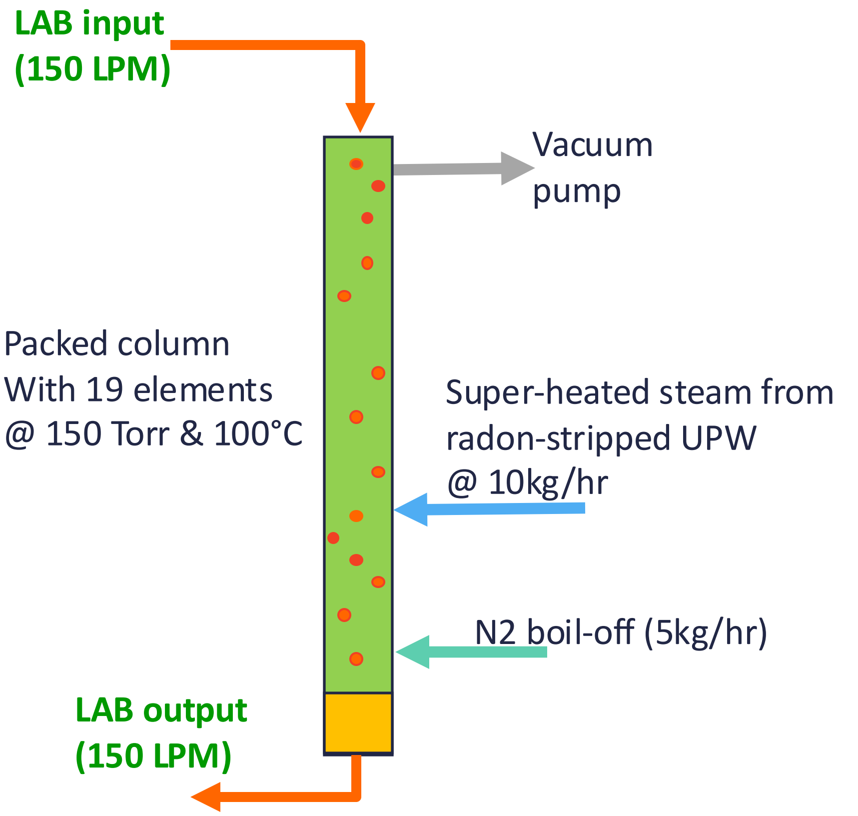
Gas Stripping

- N2/UPW Steam stripping
  - Remove noble gases Rn, Kr, Ar and O_2
  - Removes residual water
- Well understood process:
  - Nitrogen as a continues phase with upward flow
  - LAB as dispersed phase introduced from top

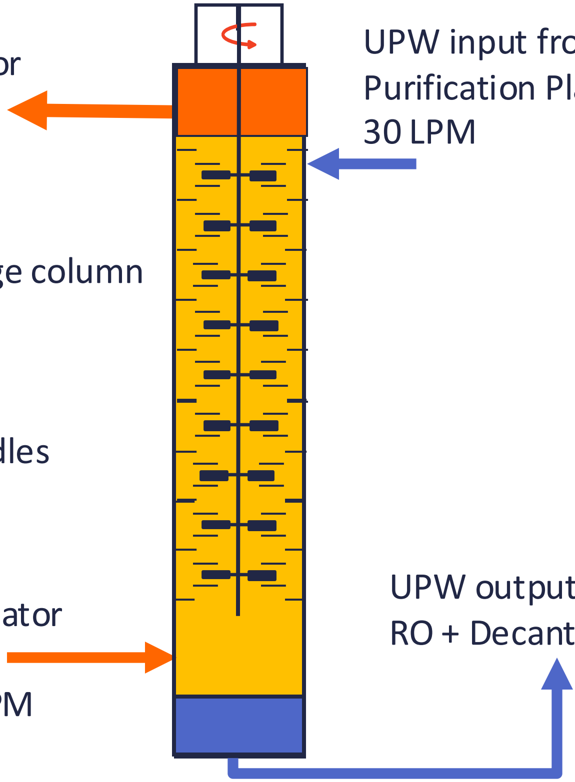
Efficiency:
- 95% Rn removal
- 99% O2 removal
- < 5ppm of water



Liquid-Liquid Extraction

- Process with immiscible phases: Water and LAB:
  - LAB continuous phase flowing upward
  - UPW dispersed phase flowing downward
- Based on differences in solubility for chemical impurities
  - Remove ionic radioactive metals U, Th, Ra, K, Pb
- Not effective in removing optical impurities

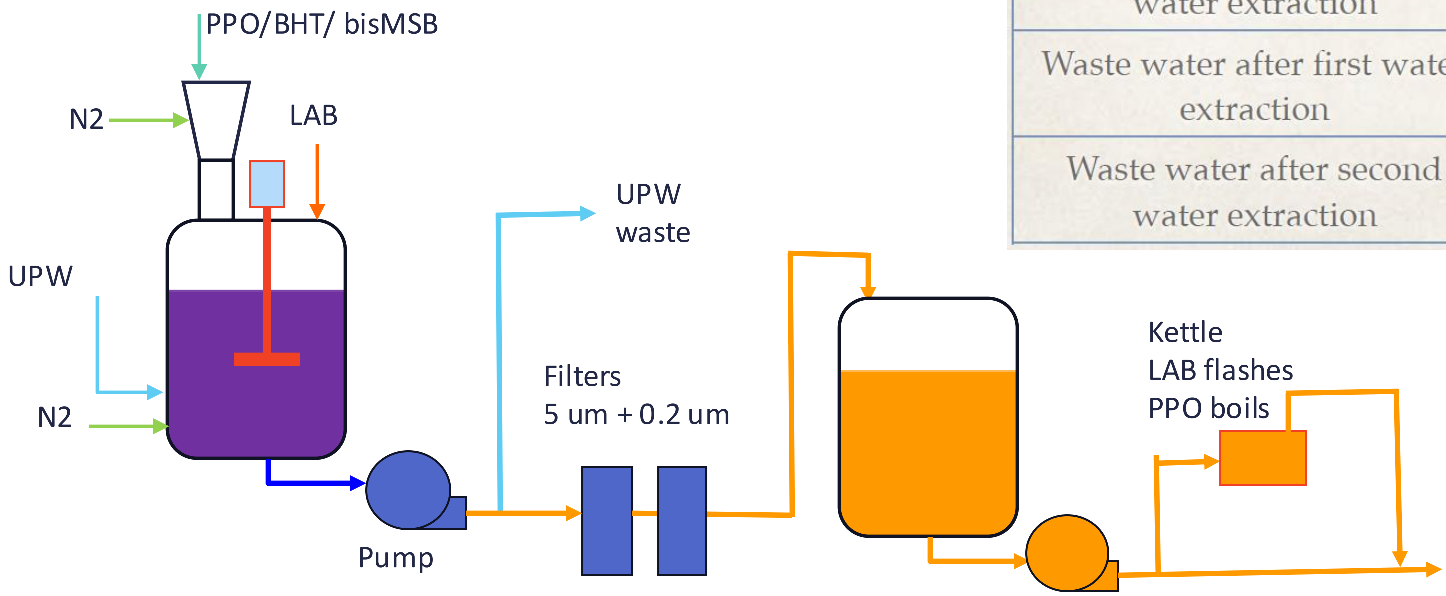
Efficiency:
- 87% removal 212Pb
- 98% removal 224Ra



Purification Of The Other Components

- PPO:
  - dissolved in LAB in concentrated solution at 120 g/L
  - PPO solution:
    - N2 sparged to reduce radon
    - 2x water extraction to reduce potassium contamination
    - Filtered and distilled in a flash kettle
    - Added to recirculated LAB and N2 stripped
- BHT and bisMSB
  - Same as PPO, but no distillation

Sample	K content (ppb)
Master solution after first water extraction	137.45
Master solution after second water extraction	< 40
Waste water after first water extraction	89.25
Waste water after second water extraction	< 40



LAB Delivery Sequence

CEPSA plant (Bécancour, QC)
High quality LAB transported in 20T tanker trucks

SNOLAB: Surface Transfer Facility (STF)
(70-tonne storage tank)

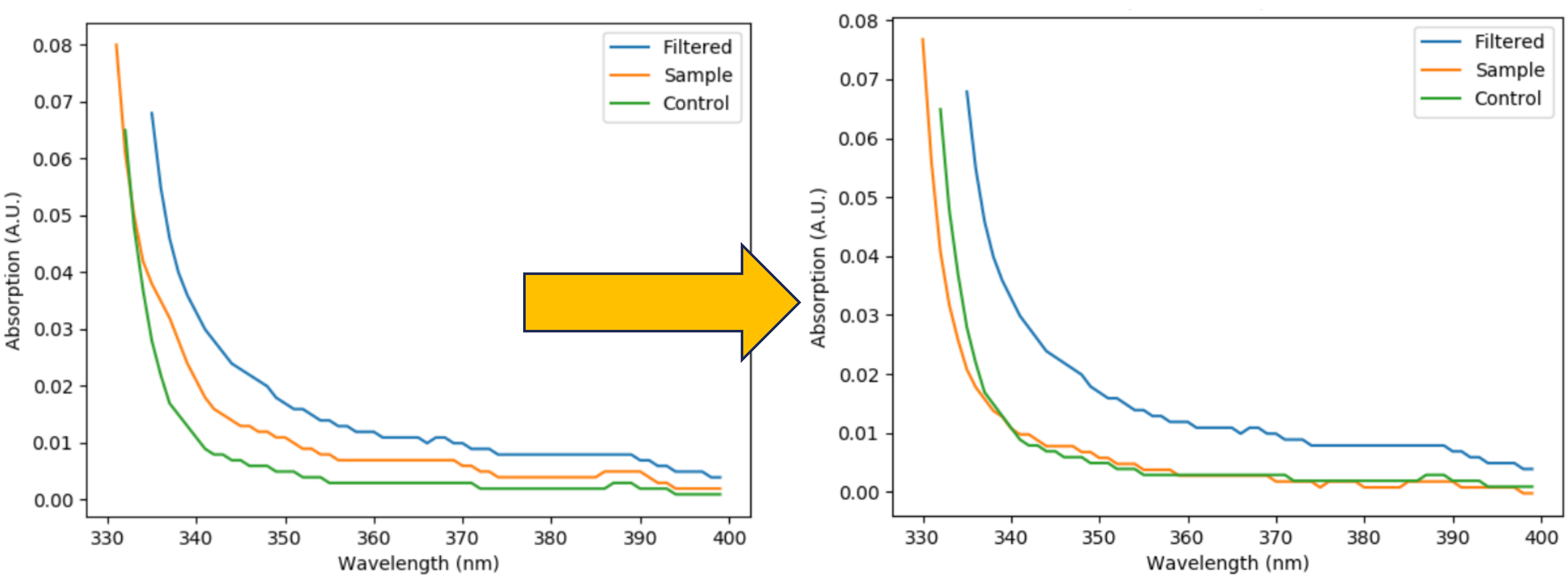
SNOLAB STF:
Transferred to 6 x 2.2T steel rail cars with N2 cover Gas

SNOLAB Underground Transfer Facility (UTF):
Transferred to 2x 60T storage tanks

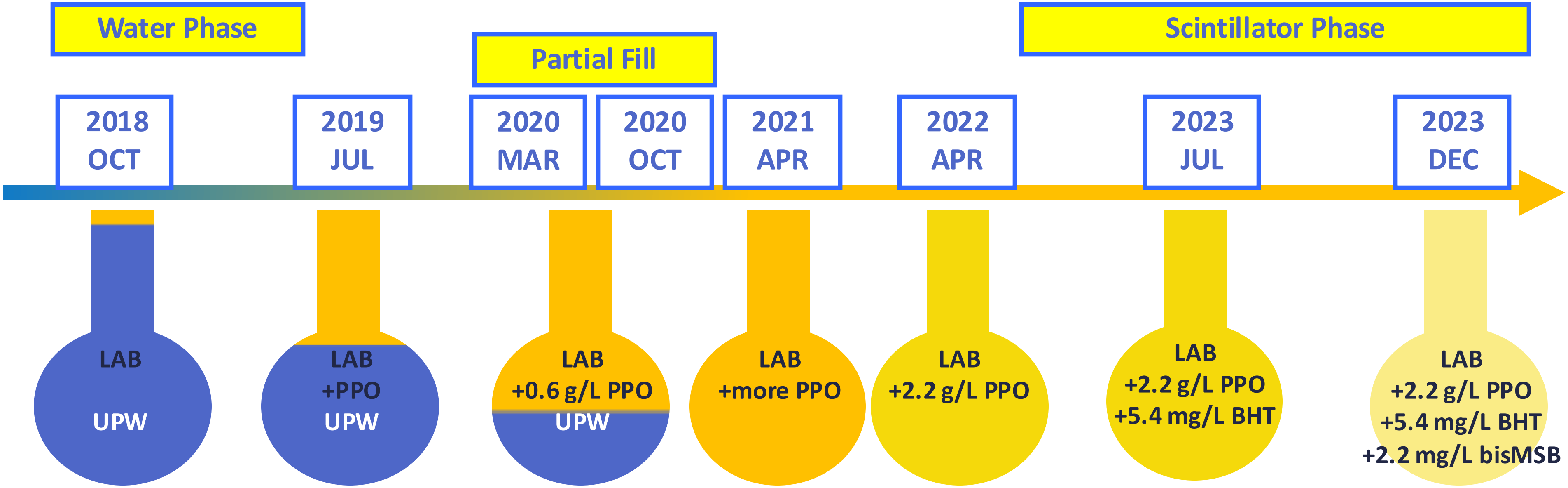
Scintillator Purification Plant (SPP):
Distillation @ 19 LPM and N2 stripping

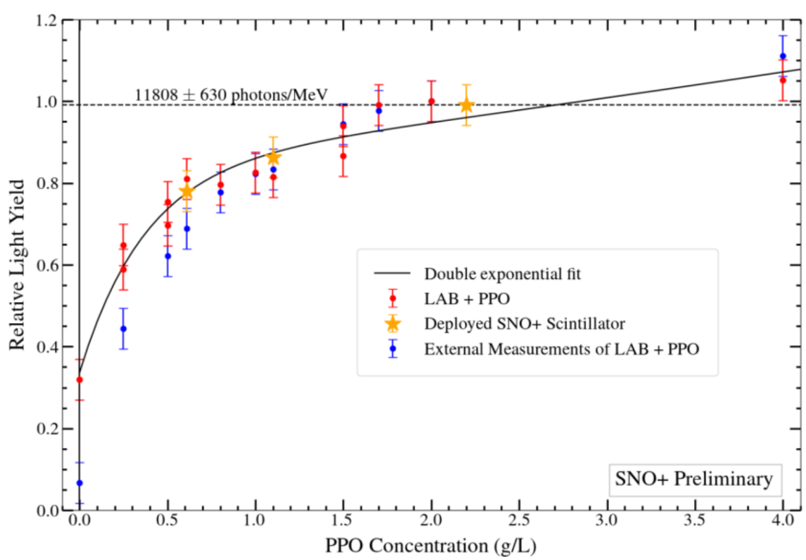
QA/QC Requirements

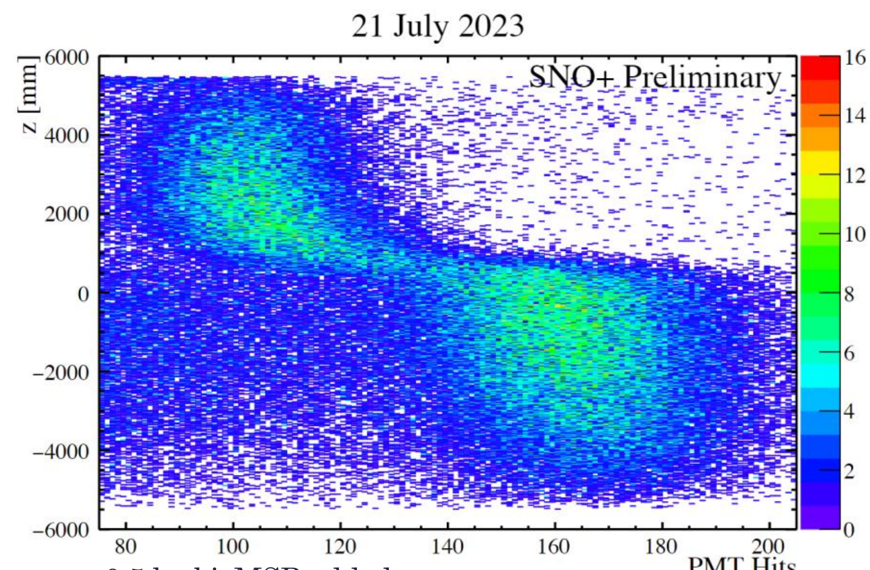
- ❑ Physical properties
  - Density, turbidity, temperature, humidity
- ❑ Optical properties
  - UV-Vis spectra, UV-Vis transparency
  - Light Yield
- ❑ Very strict approval procedures for filling the detector
- ❑ Constant monitoring of the UV-Vis spectra
  - hourly analysis during operations



Scintillator Cocktail

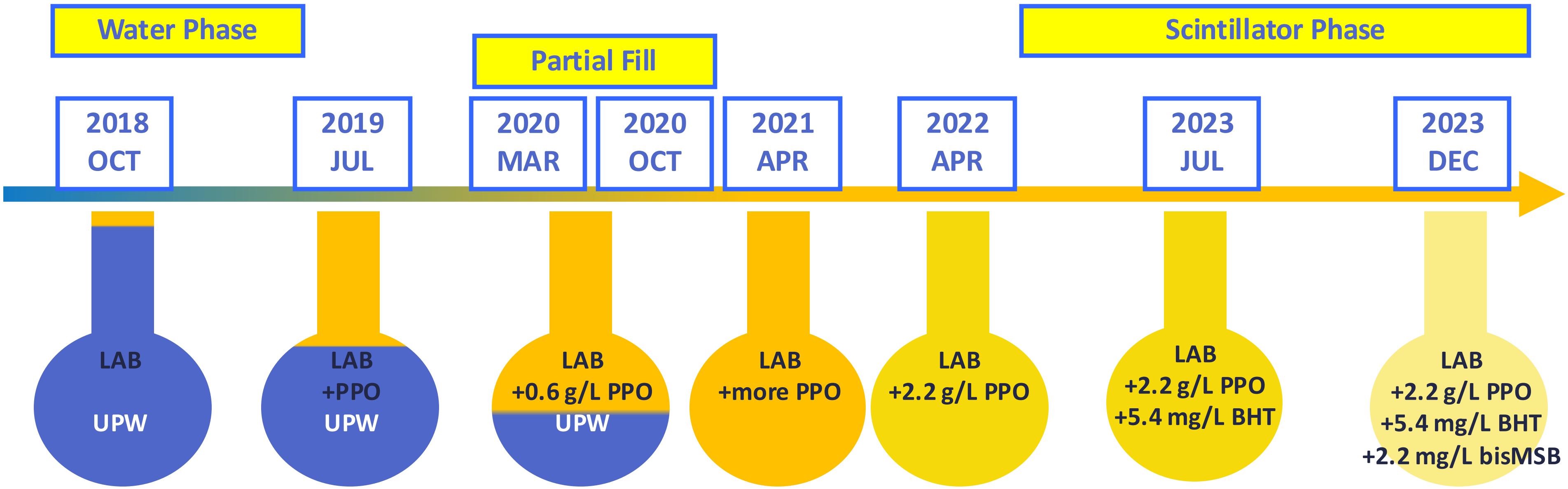




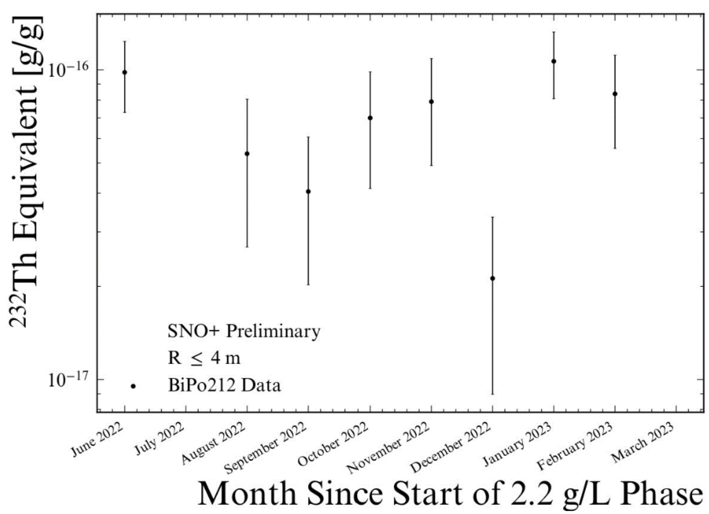


0.5 kg bisMSB added
~1.5 x increase in light output

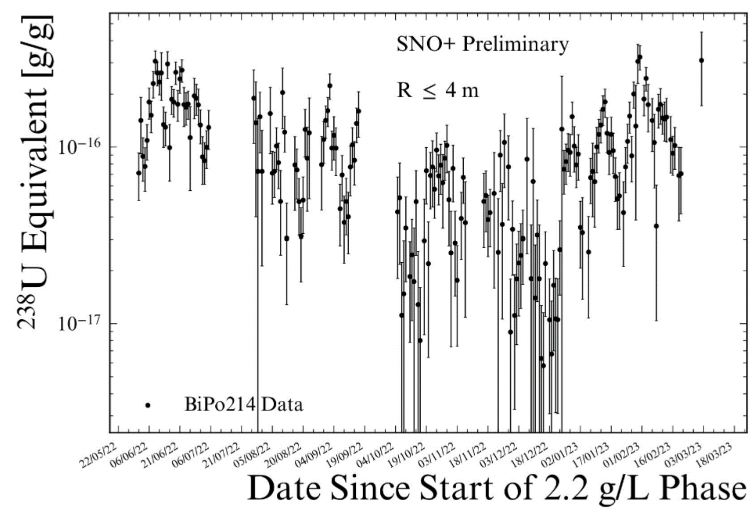
Scintillator Cocktail



^{232}Th = (5.29±0.762)10^{-17} g/g (^{212}BiPo)

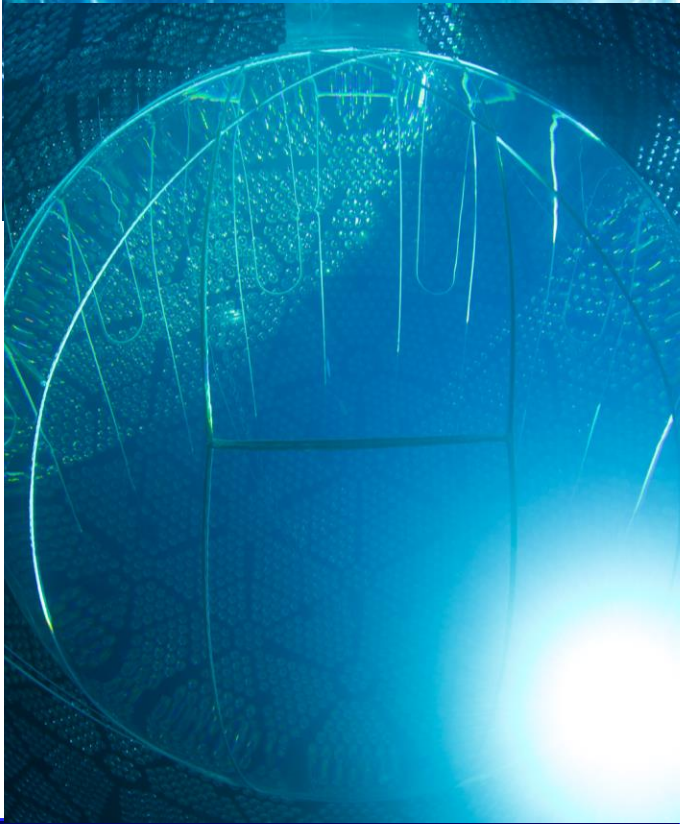


^{238}U = (4.32±0.136)10^{-17} g/g (^{214}BiPo)



Summary

- SNO+ has successfully filled the detector with Scintillator
  - LAB +2.2 g/L PPO +5.4 mg/L BHT +2.2 mg/L bisMSB
- Process Plant delivers ultra-pure product
  - We reached 10^{-17} g/g in both U and Th
    - Which is our requirements for the scintillator phase
    - It is well below the minimum requirement for the tellurium phase
- SNO+ is taking a very good quality data while preparing for the Tellurium phase



Thank you Dziękuję