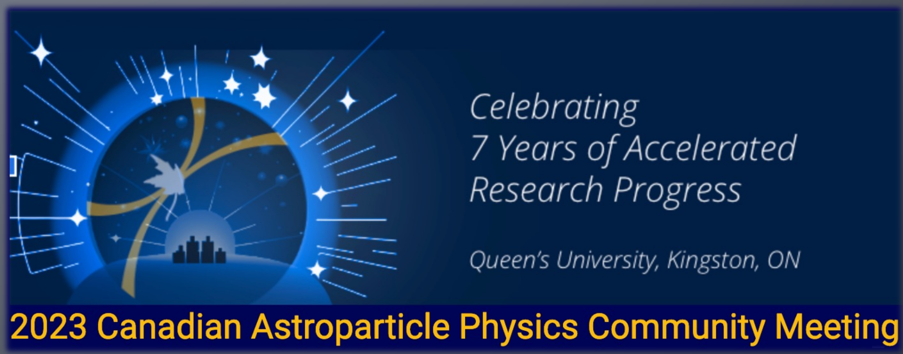
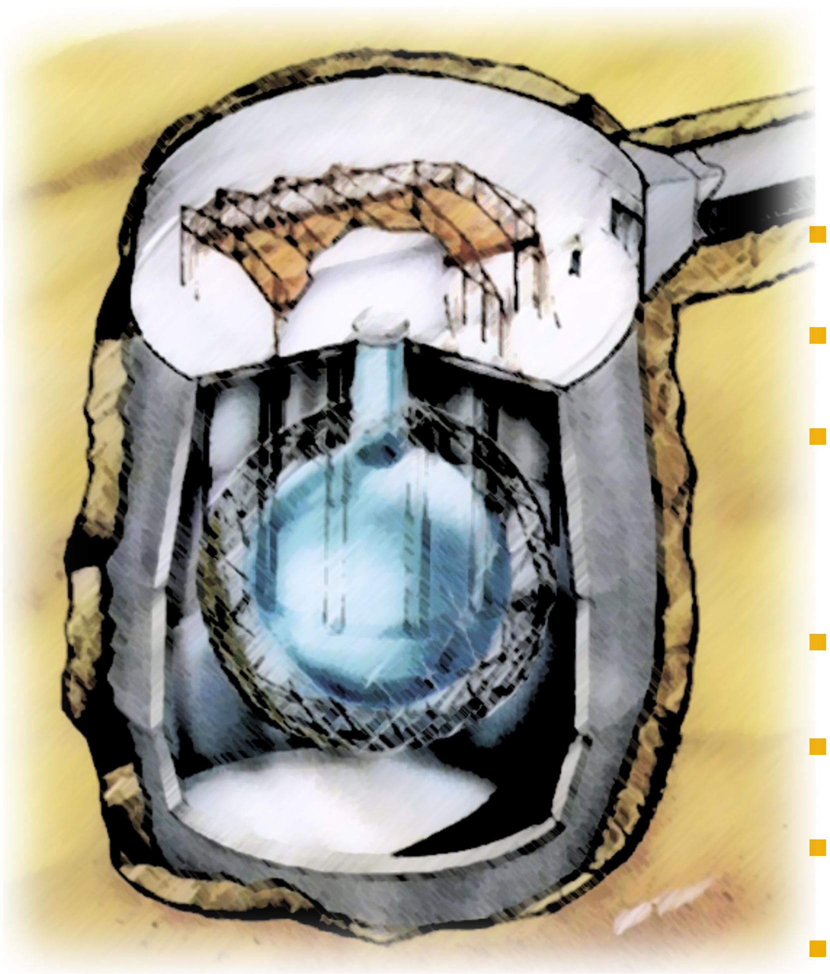
SNO+
Status and Outlook

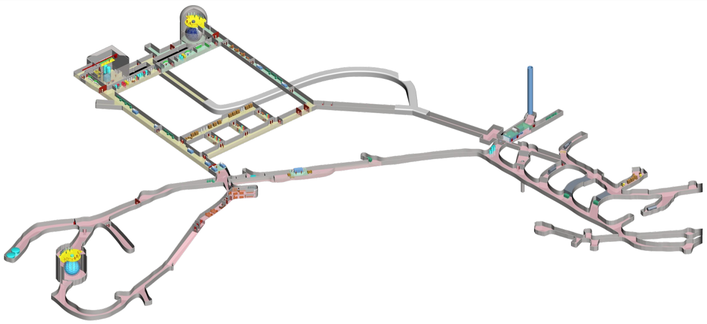
Szymon Manecki
August 9, 2023



SNO+ Detector

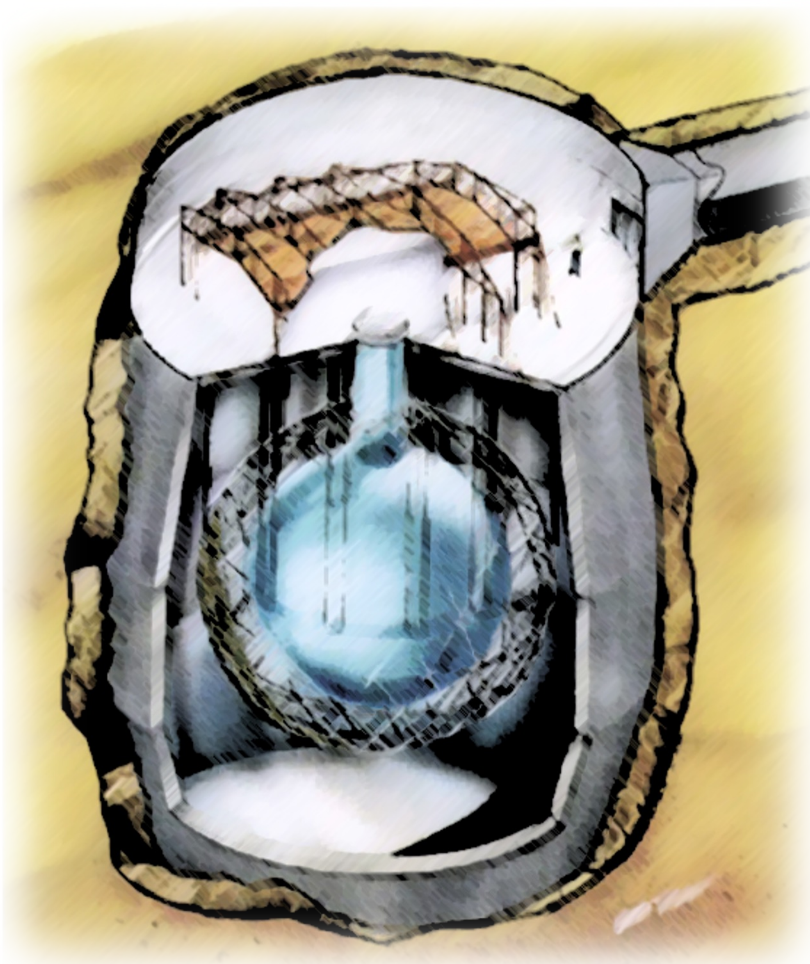


SNO detector (1999–2006)



- 6010 m water equivalent overburden
- 1000 cubic meters in volume
- Very low cosmic backgrounds (0.27 μ/m²/d)
- 9500 light sensors (PMTs)
- 12 m Diameter Acrylic Container (AV)
- Ultra-pure Water shield, H_2O
- Urylon Liner and Radon Seal

SNO+ Physics Goals

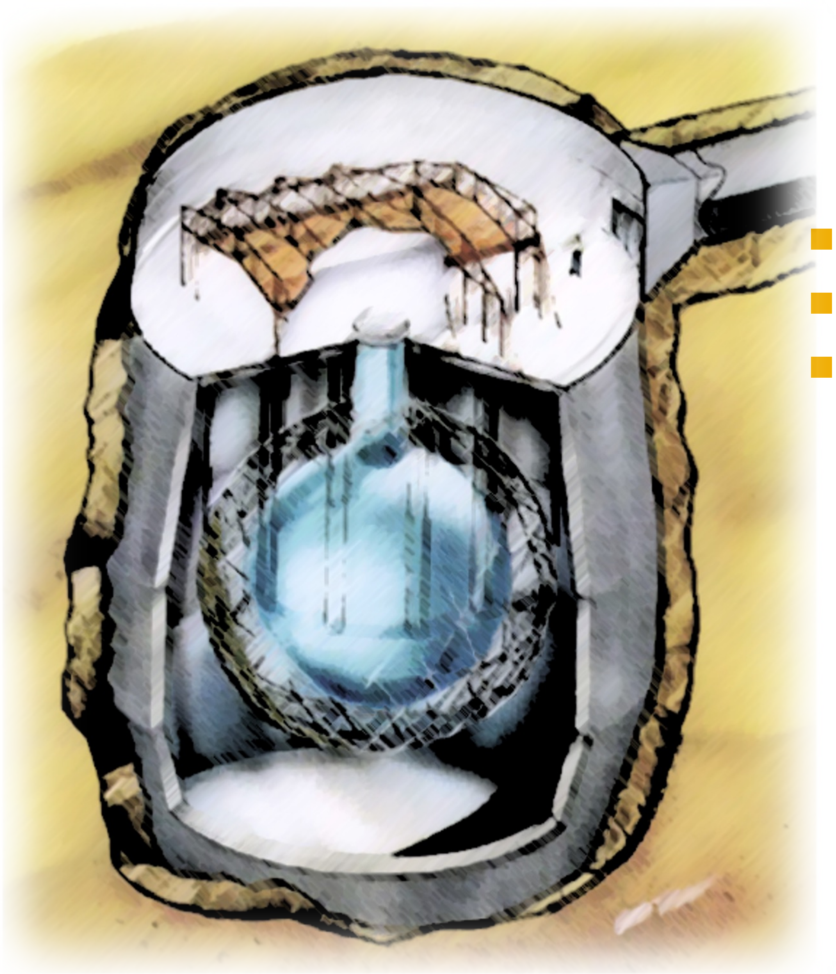


SNO detector (2007–2023+)

SNO+
Broad Physics Program

- <u>Neutrinoless Double Beta Decay</u>
- Invisible Nucleon Decay modes
- High Energy Solar Neutrinos
- Low Energy Solar Neutrinos
- Reactor Antineutrinos
- Geo-Neutrinos
- Supernova-ν

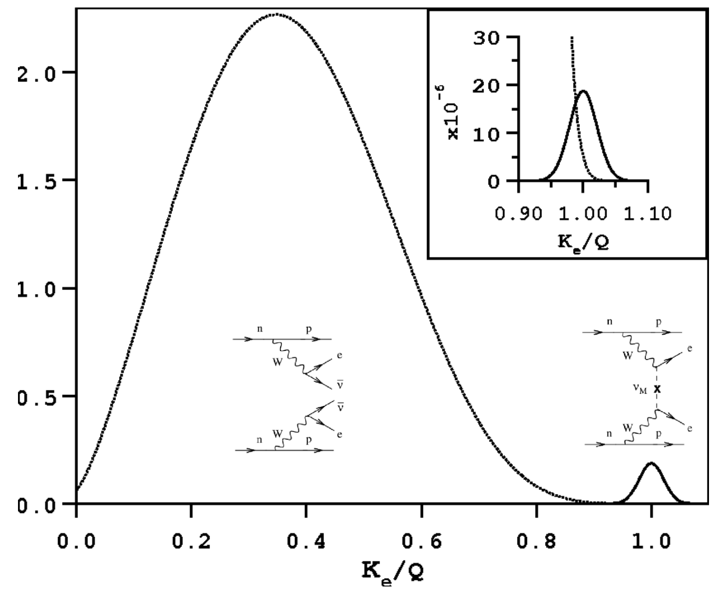
SNO+ Physics Goals



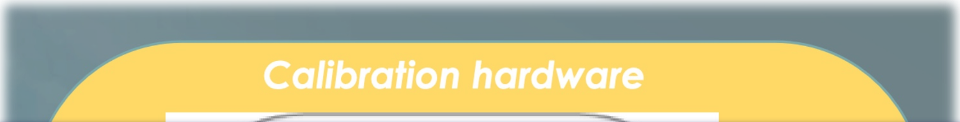
SNO detector (2007–2023+)

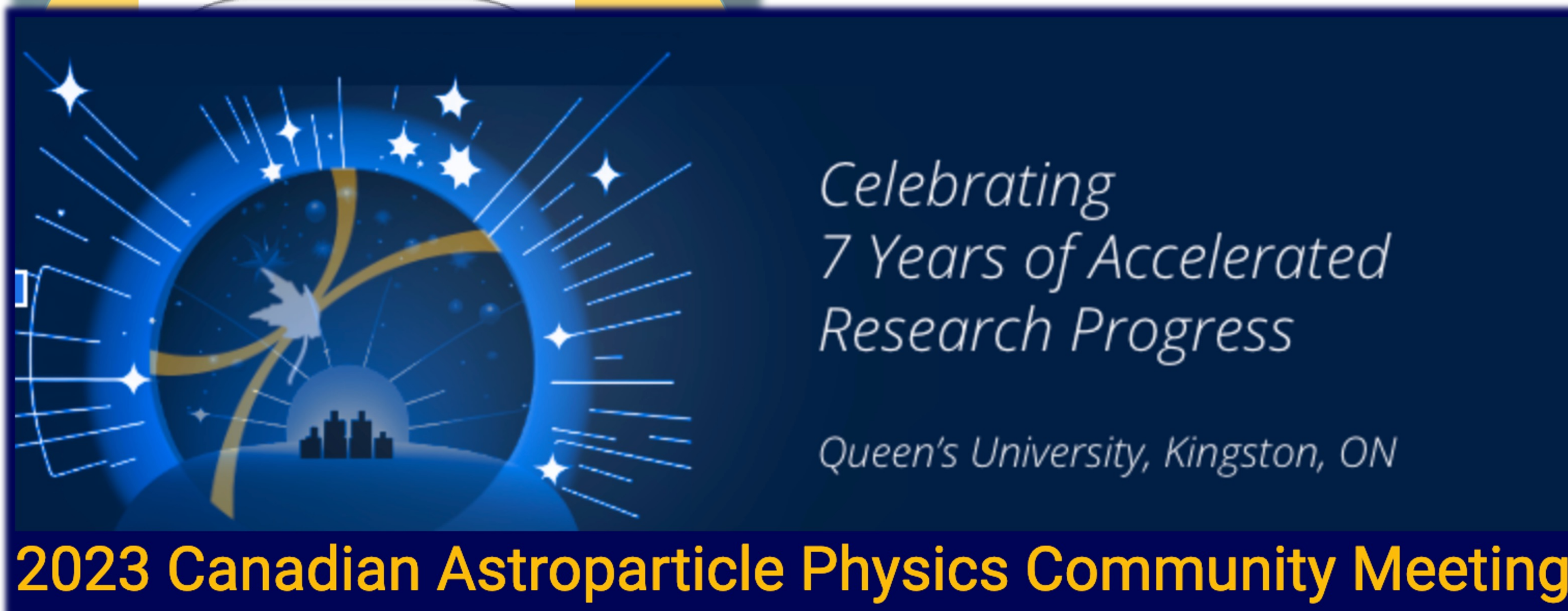
ονββ
Search Requirements

- Low backgrounds
- Good energy resolution
- Large amounts of isotope

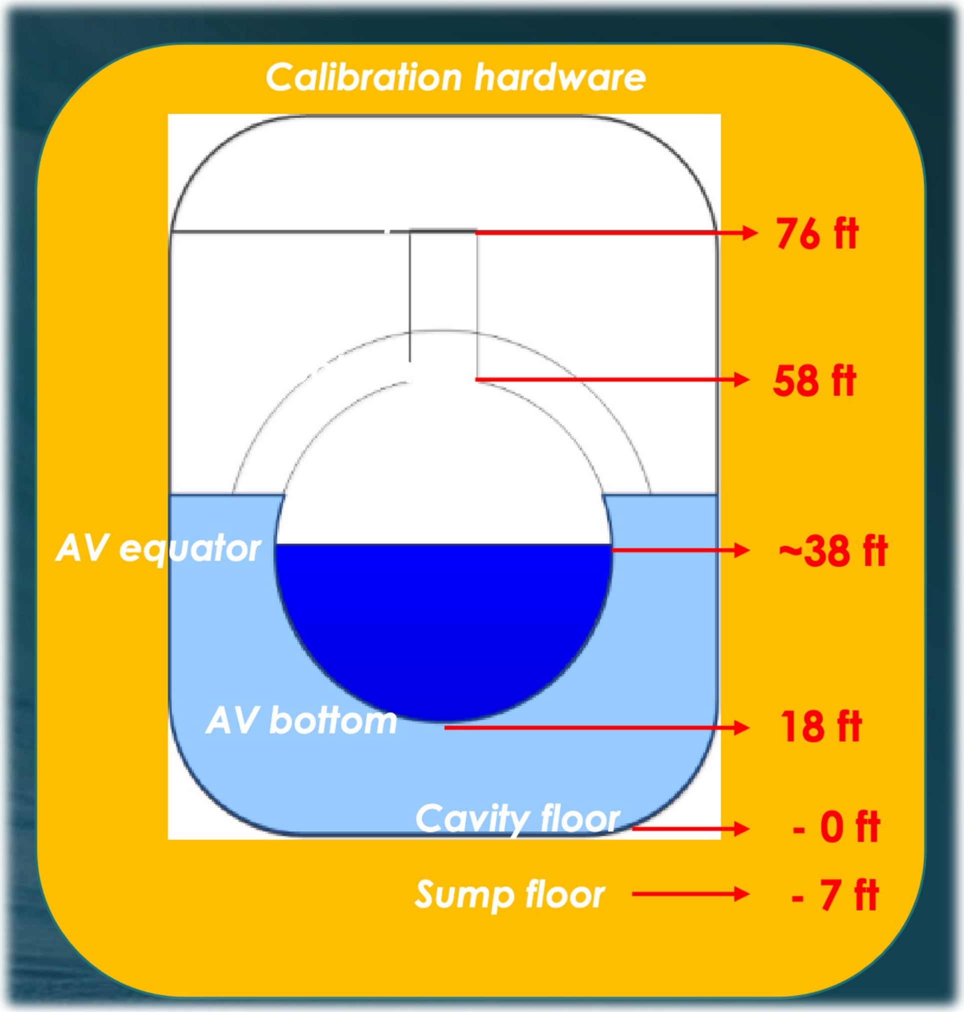


SNO+ 7 years ago



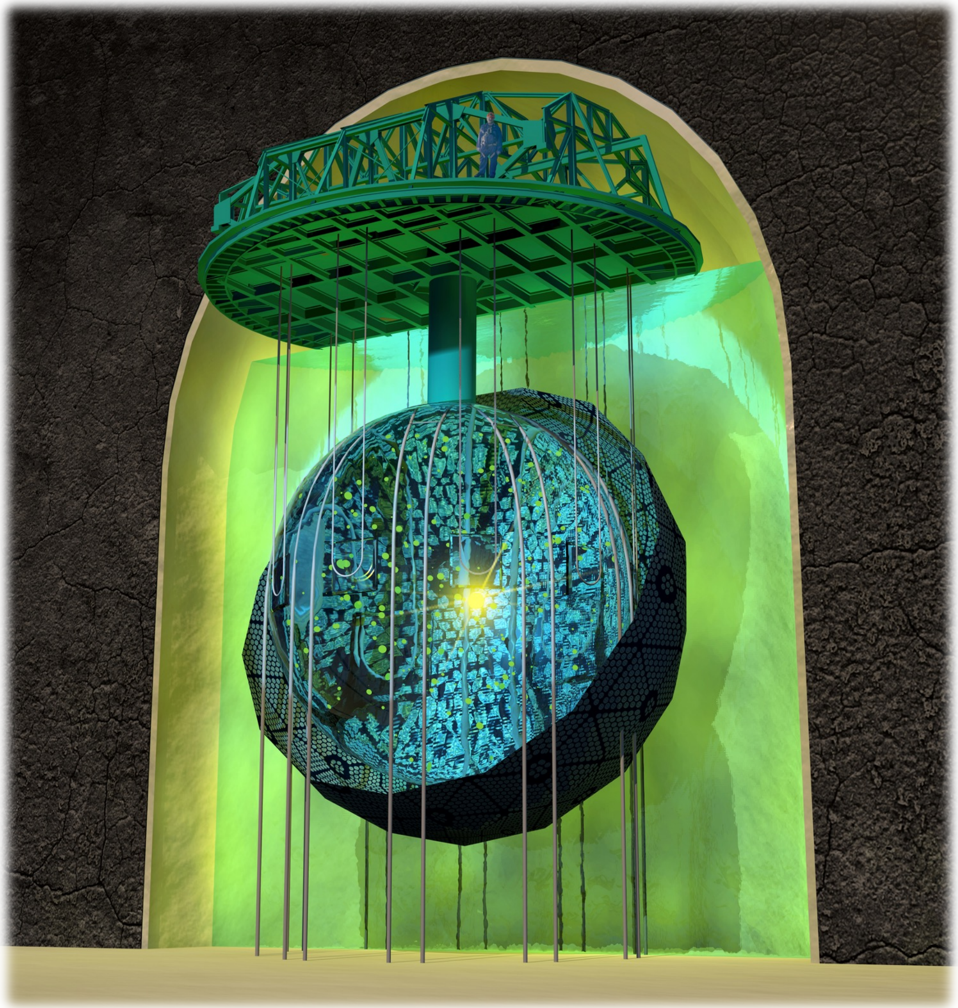


SNO+ 7 years ago



- Filling the detector with ultra-pure water
- Draining & searching for cavity leaks
- Refilling

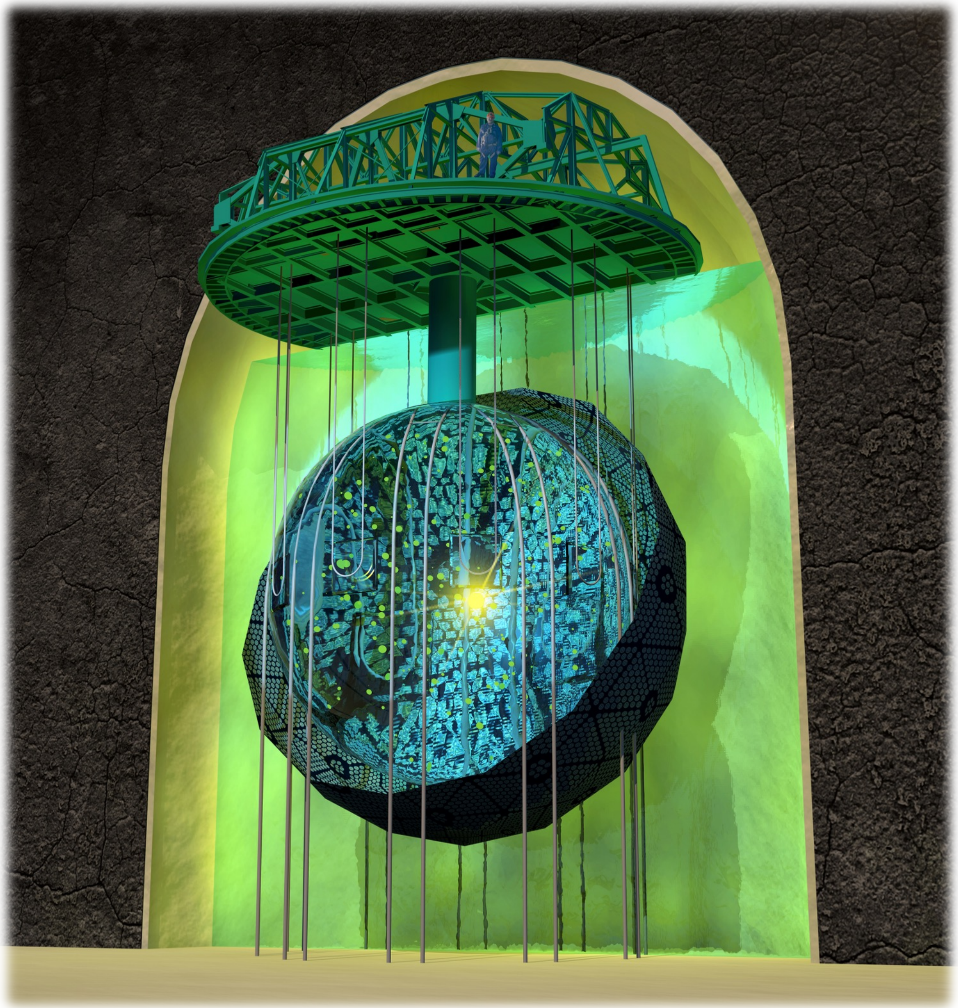
7 years into the future



Completed

- Water phase
- Scintillator phase
- Tellurium loading phase

7 years into the future



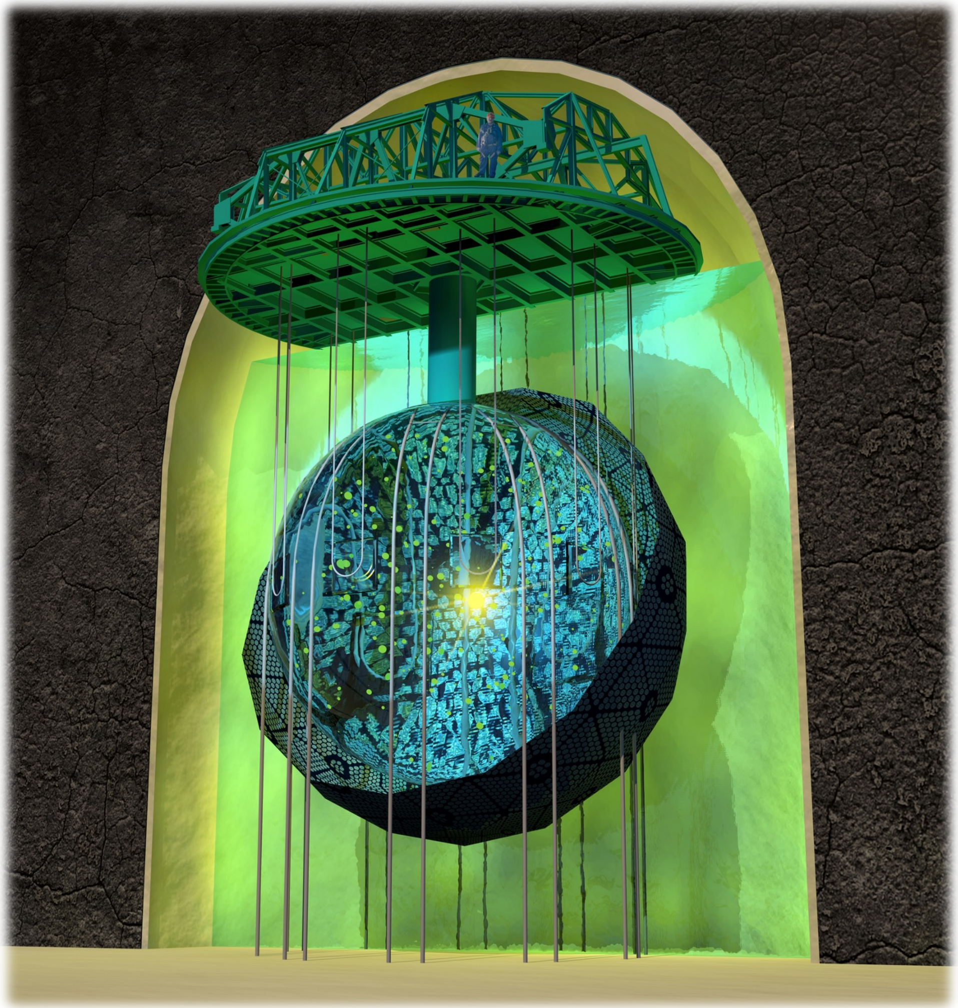
Completed

- Water phase

May 2017 - July 2019

- Scintillator phase
- Tellurium loading phase

7 years into the future



Completed

- Water phase

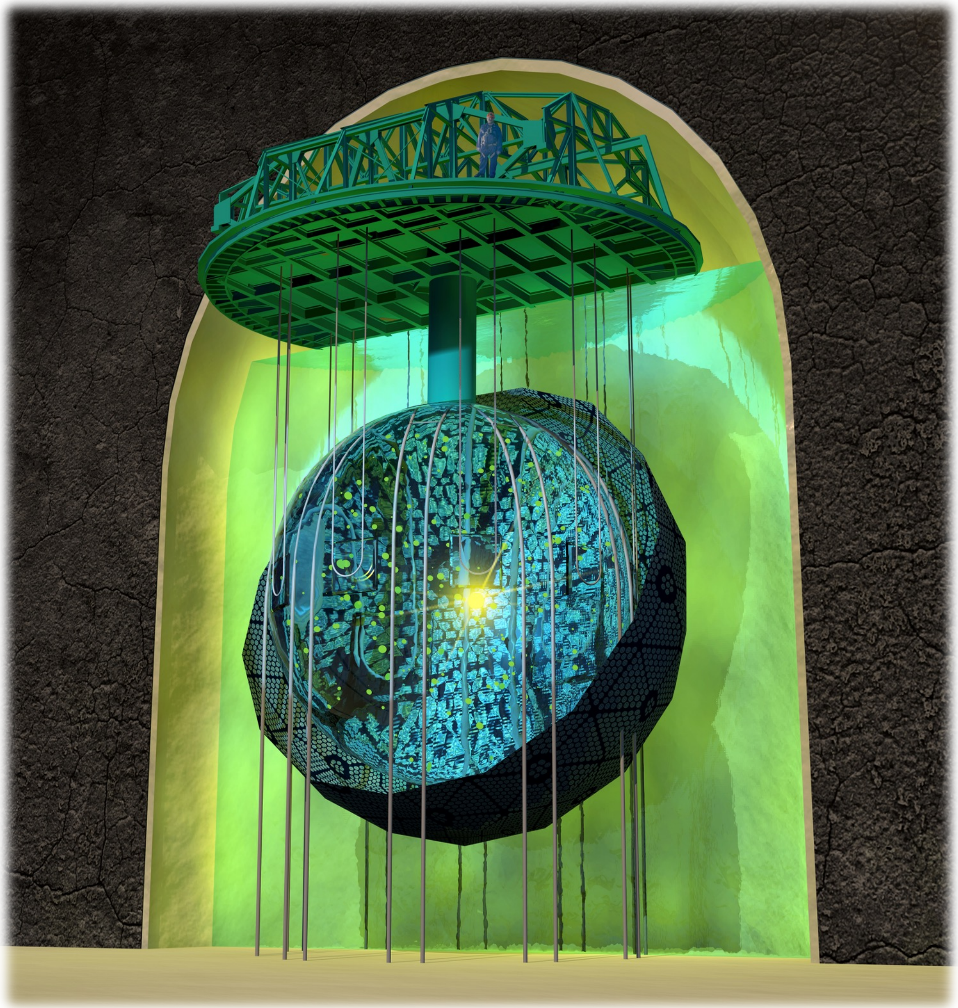
  May 2017 - July 2019

- Scintillator phase

  Started April 2022

- Tellurium loading phase

7 years into the future



Completed

- Water phase

  May 2017 - July 2019

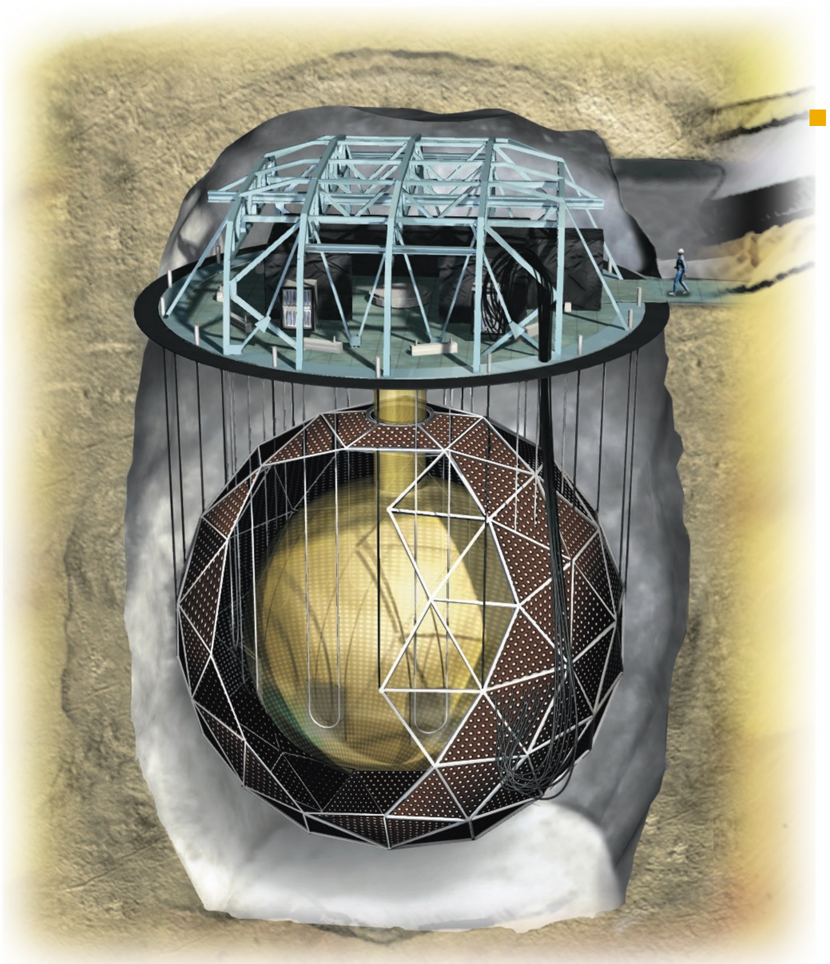
- Scintillator phase

  Started April 2022

- Tellurium loading phase

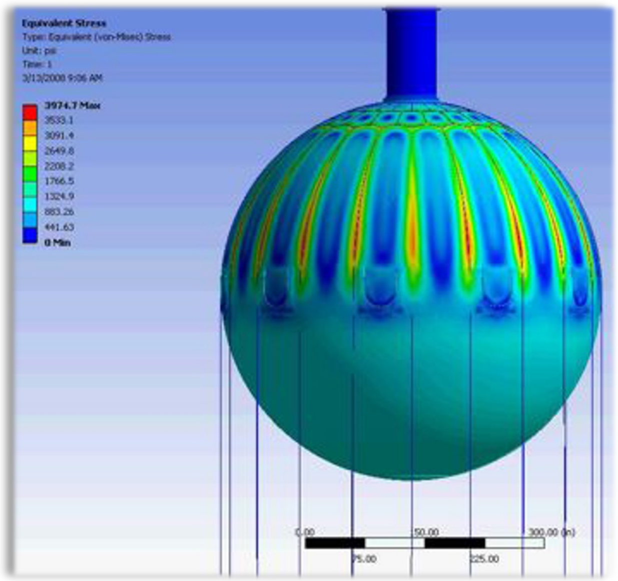
  Soon!

SNO Upgrades

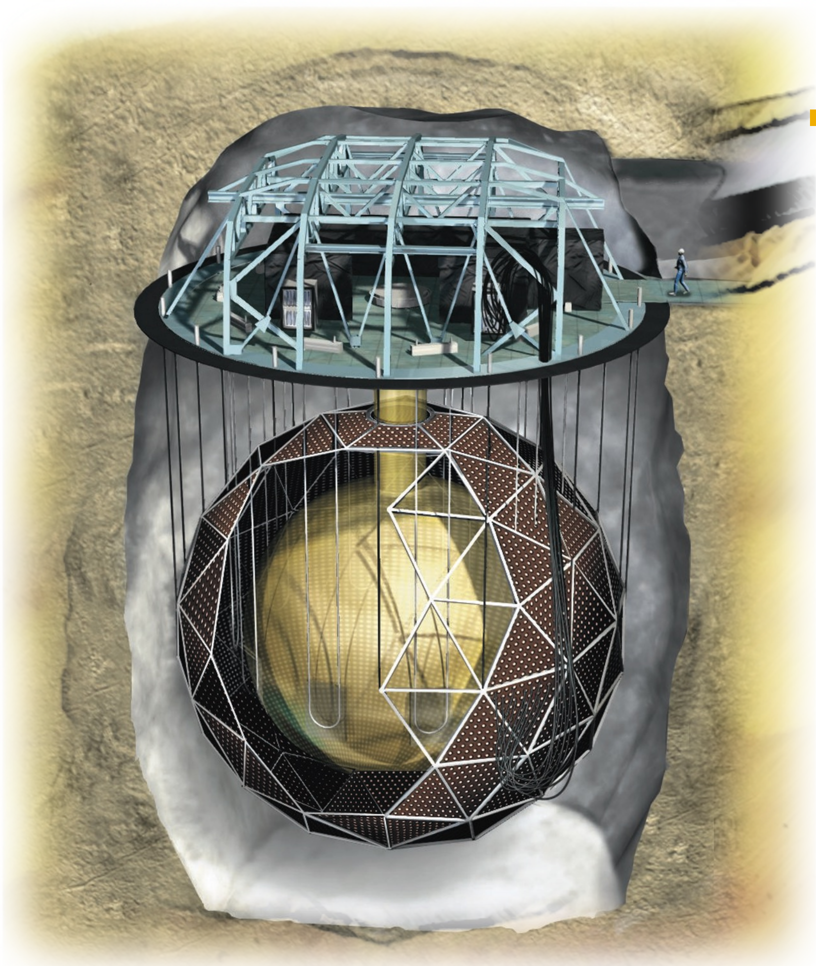


SNO+ detector (2007-2023+)

- Added new hold-down ropes
  - LAB surrounded by water causes about 1.25 MN of buoyancy
  - Tensylon^{TM} material was selected due to low radioactivity
  - Max AV stress 600 psi

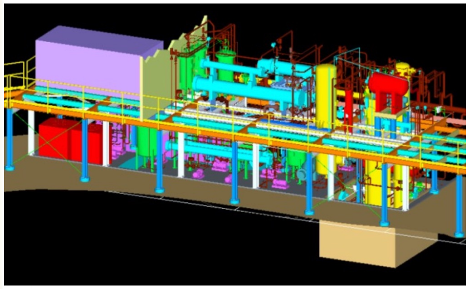


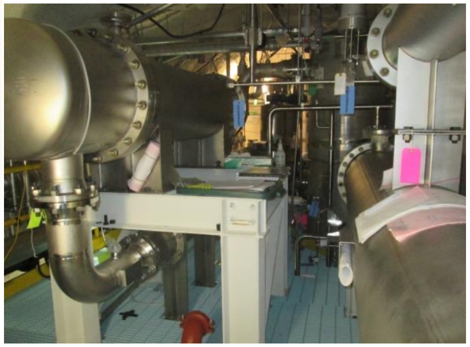
SNO Upgrades



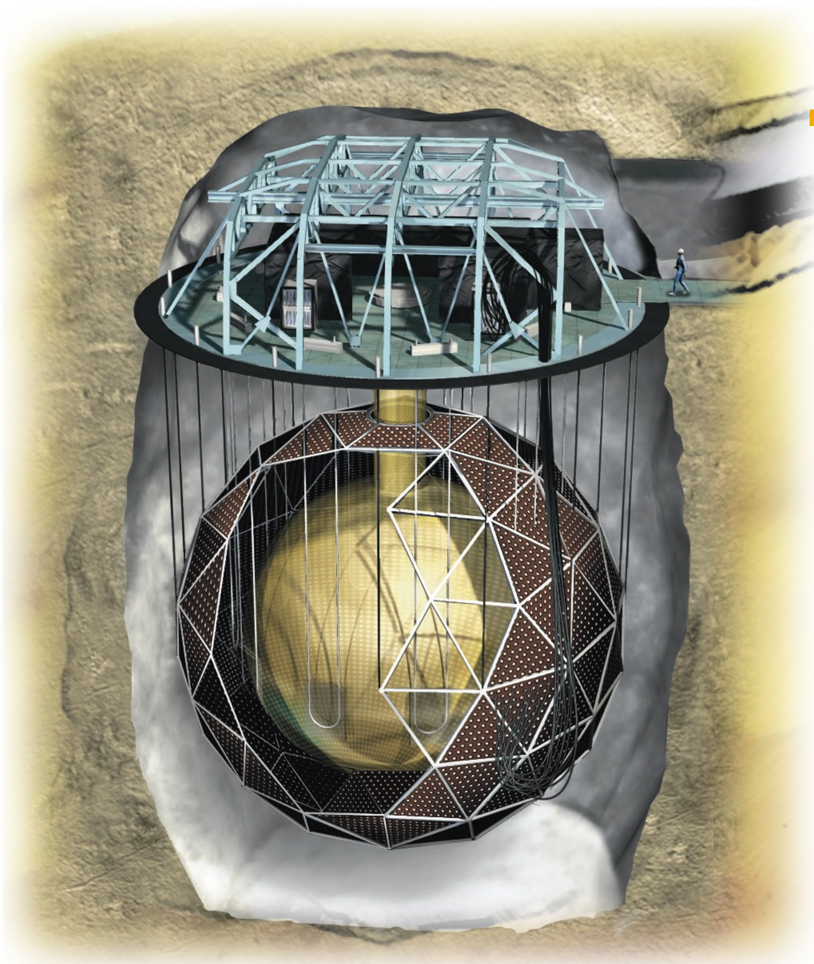
SNO+ detector (2007-2023+)

- New scintillator purification plant
  - Primary distillation of LAB
  - Secondary distillation
  - Water extraction
  - Nitrogen and steam stripping
  - Scavenger columns





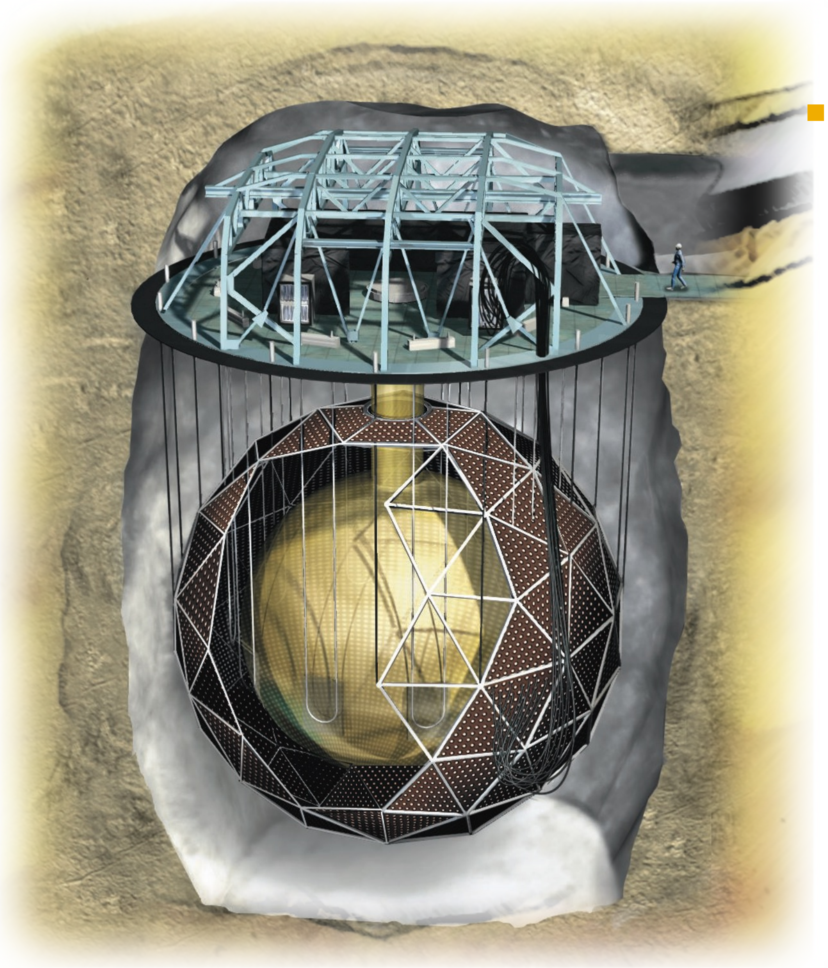
SNO Upgrades



SNO+ detector (2007-2023+)

- New isotope plants
  - Telluric Acid purification plant
  - Tellurium Diol synthesis plant

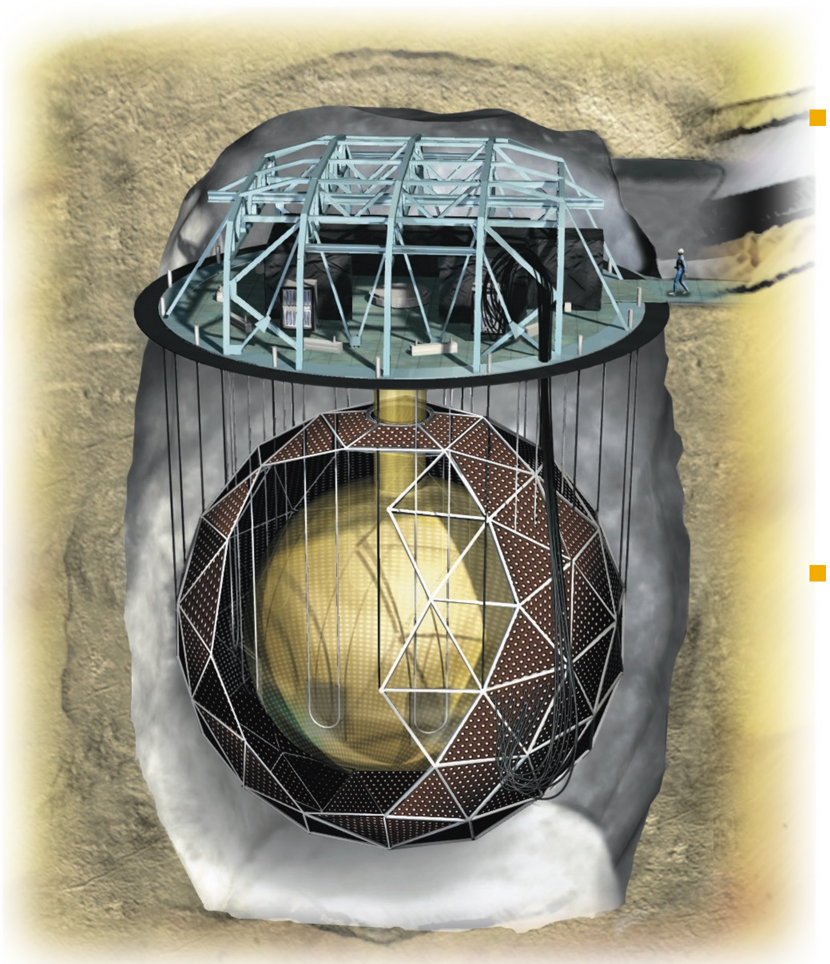
SNO Upgrades



SNO+ detector (2007-2023+)

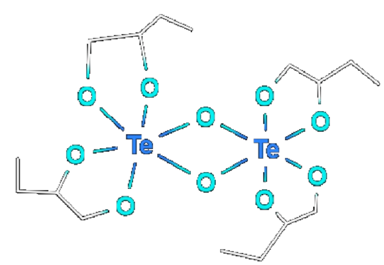
- And more
  - New DAQ
  - Upgraded electronics
  - Calibration sources and hardware, including in-situ LED and laser
  - New cover-gas system
  - CCD cameras

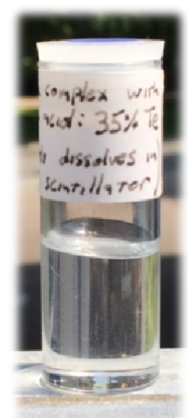
SNO Upgrades



SNO+ detector (2007-2023+)

- And more
  - New DAQ
  - Upgraded electronics
  - Calibration sources and hardware, including in-situ LED and laser
  - New cover-gas system
  - CCD cameras
- Continued R&D
  - Scintillator properties
  - Metal-loading in LAB





Three Phases

- Water phase
- Scintillator phase
- Tellurium I and II phases

Water Phase

- Best limits on invisible modes of nucleon decay

  PRD 99, 032008 (2019); PRD 105 112012 (2022)

- Measurement of the 8B solar neutrino flux in SNO+ with very low backgrounds *PRD 99, 012012 (2019)*

- Highest efficiency (~50%) for neutron detection in a water Cherenkov detector *PRC 102, 014002 (2020)*

- Detection of antineutrinos from distant reactors using only pure water *PRL 130, 091801 (2023)*

Water Phase

- Best limits on invisible modes of nucleon decay

PRD 99, 032008 (2019); PRD 105 112012 (2022)

Decay Mode	Partial Lifetime Limit	Existing Limits
n	9.0×10^{29} y	5.8×10^{29} y [5]
p	9.6×10^{29} y	3.6×10^{29} y [6]
pp	1.1×10^{29} y	4.7×10^{28} y [6]
np	6.0×10^{28} y	2.6×10^{28} y [6]
nn	1.5×10^{28} y	1.4×10^{30} y [5]

- Measu … flux in SNO+ …

…2012 (2019)

- Highes … etection in a wa…

…4002 (2020)

- Detection of antineutrinos from distant reactors using only pure water

PRL 130, 091801 (2023)

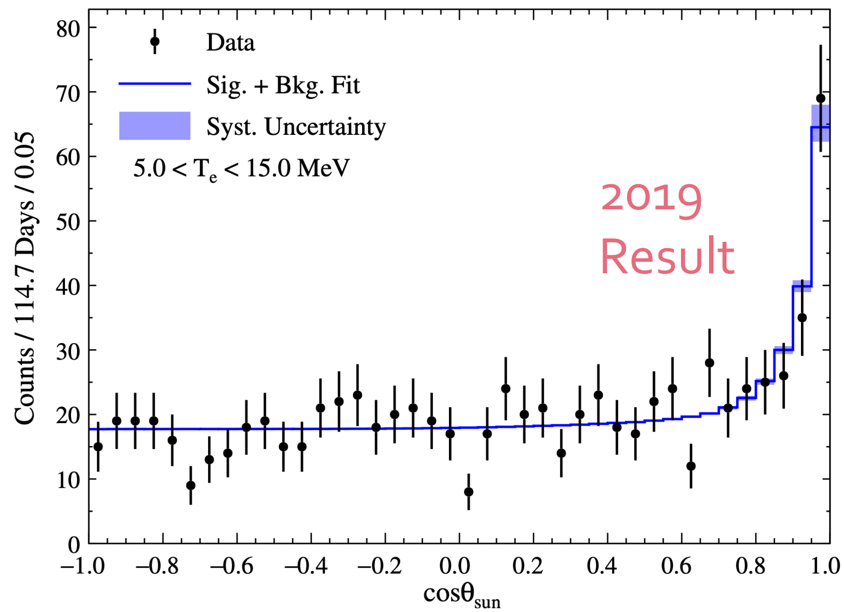
Water Phase

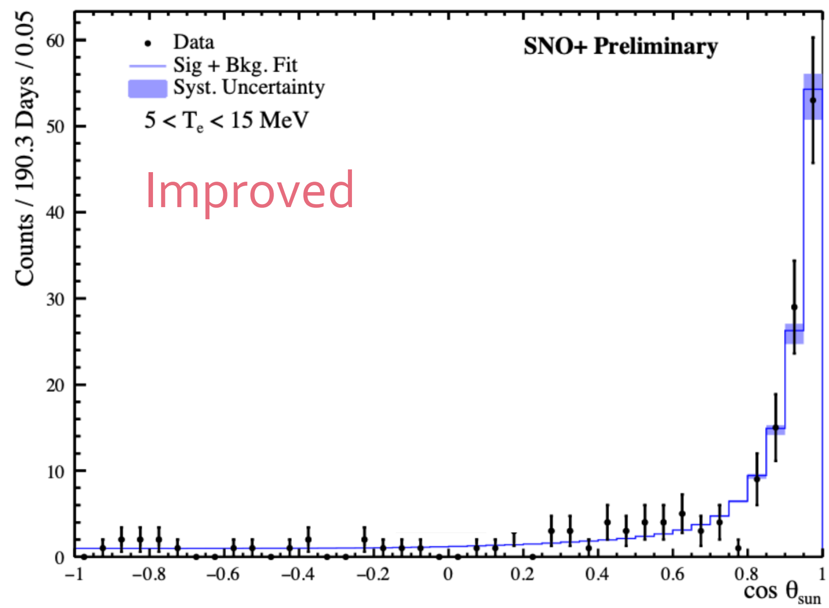
- Best limits on invisible modes of nucleon decay

PRD 99, 032008 (2019); PRD 105 112012 (2022)

- Measurement of the 8B solar neutrino flux in SNO+ with very low backgrounds

PRD 99, 012012 (2019)



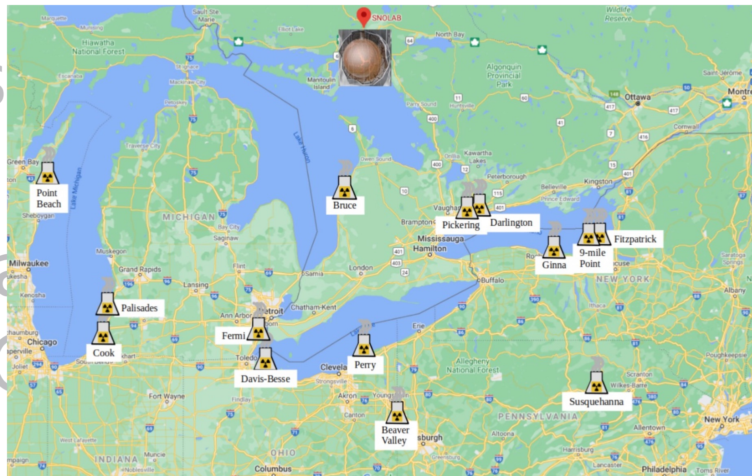


Water Phase

- Bes... odes of nucleon decay

PRD 99, 032008 (2019); PRD 105 112012 (2022)

- Mea... s... SNO... kgrounds



$$\overline{\nu}_e + p \rightarrow e^+ + n$$

PRD 99, 012012 (2019)

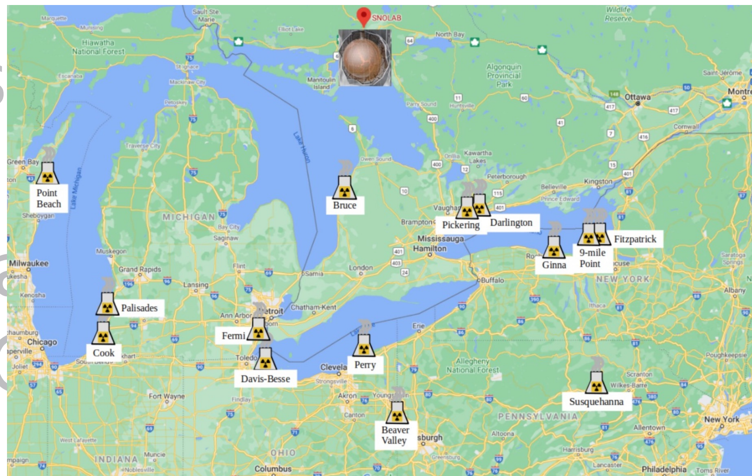
- Highest efficiency (~50%) for neutron detection in a water Cherenkov detector

PRC 102, 014002 (2020)

- Detection of antineutrinos from distant reactors using only pure water

PRL 130, 091801 (2023)

Water Phase



- Bes… odes of nucleon decay

  PRD 99, 032008 (2019); PRD 105 112012 (2022)

- Mea… SNO… grounds

  $$\overline{\nu}_e + p \rightarrow e^+ + n$$

  PRD 99, 012012 (2019)

- Highest efficiency (~50%) for neutron detection in a water Cherenkov detector

  PRC 102, 014002 (2020)

- Detection of antineutrinos from distant reactors using only pure water

  PRL 130, 091801 (2023)

PHYS.ORG physicsworld Physics CTV NEWS NORTHERN ONTARIO

"The unexpected finding of antineutrinos in pure water is exciting researchers at the possibility of being able to monitor nuclear power plants around the world."

Scintillator Phase

- During filling (paused "partial-fill") demonstrated purification goals of ~0.5×10^{-17} g/g for U and Th
- Full-phase started in April 2019 with 780 tonnes of LAB and 2.2 g/L of PPO (wavelength shifter)

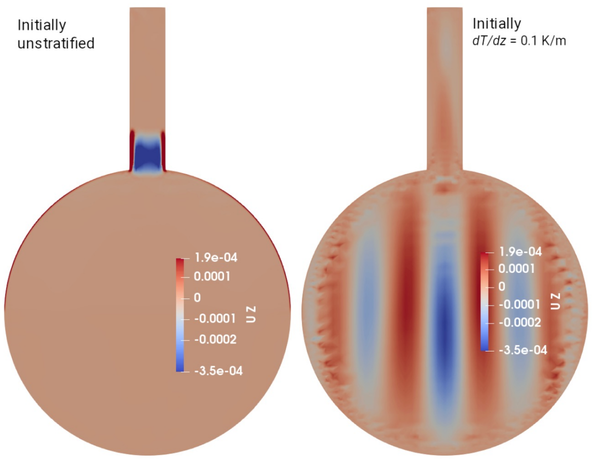
PRD 99, 012012 (2019)

- Currently in the process of adding:
  - BHT – stabilizer (target of ~4 kg already added)
  - Bis-MSB – light yield booster (target of ~5 kg with 0.5 kg already added) – expected to double the output

Scintillator Phase

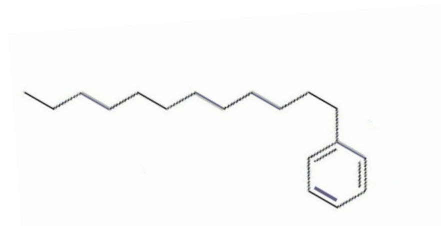
- Stay tuned for upcoming physics results
  - Reactor and geo-neutrinos
  - Solar neutrinos (including directionality)
  - Exotic physics
  - Supernova monitoring
- Spin-off analysis of the thermal gradient effect
  - "Thermally-driven scintillator flow in the SNO+ neutrino detector"

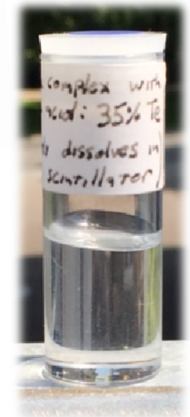
J.D. Wilson for the SNO+ Collaboration



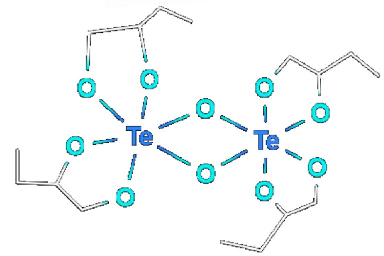
Tellurium Phase

- 780 T Linear Alkylbenzene (LAB)
  + 2.2 g/L PPO (Primary Fluor)
  + 5 mg/L bisMSB (WS)

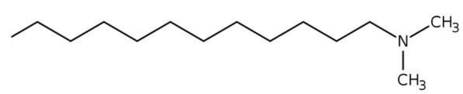


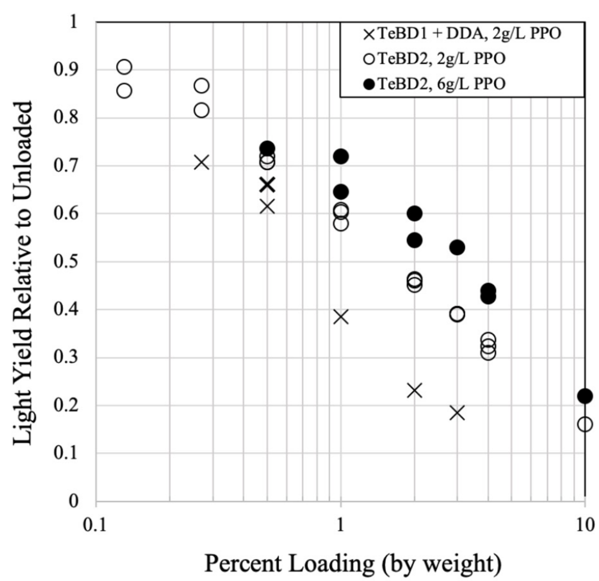


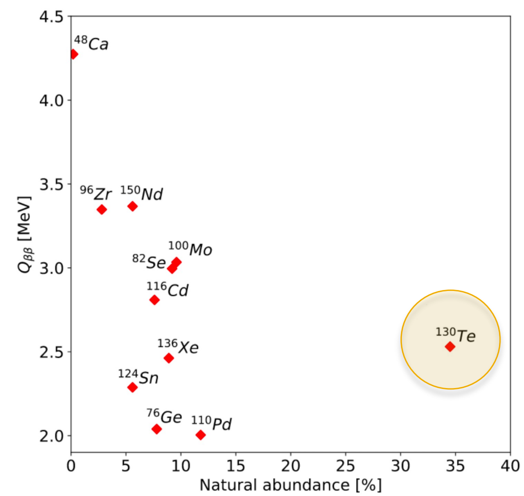
- Tellurium Butanediol (TeDiol)
  0.5% Te in LAB



- DDA (stabilizing amine)
  0.2% in LAB





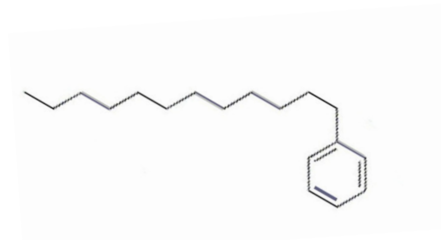


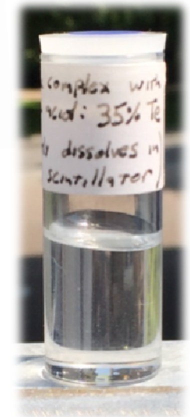
NIM.A. 1051:168204

Very high natural abundance

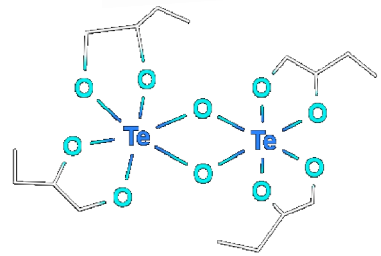
Tellurium Phase

- 780 T Linear Alkylbenzene (LAB)
  + 2.2 g/L PPO (Primary Fluor)
  + 5 mg/L bisMSB (WS)

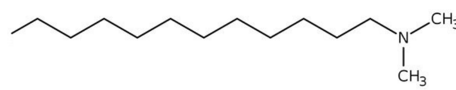


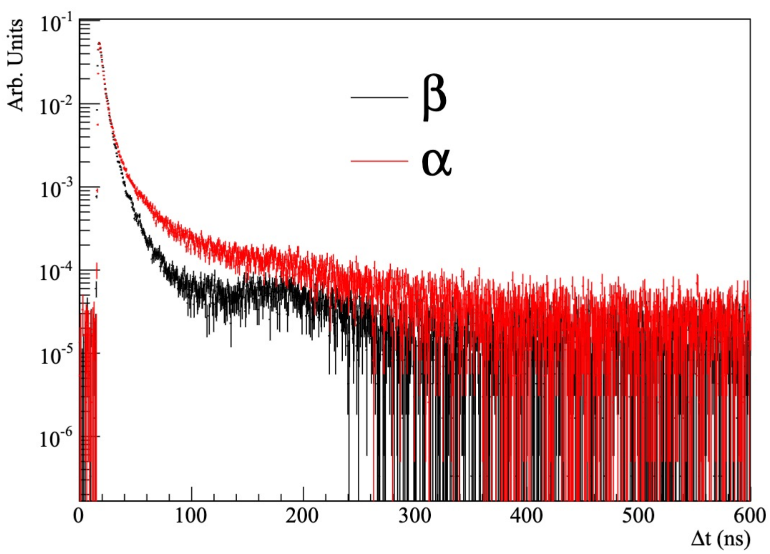


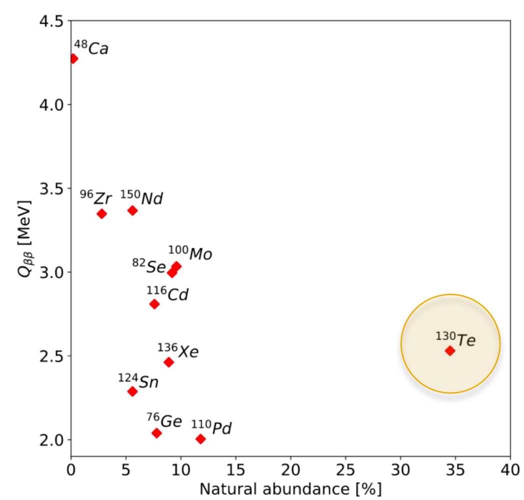
- Tellurium Butanediol (TeDiol)
  0.5% Te in LAB



- DDA (stabilizing amine)
  0.2% in LAB



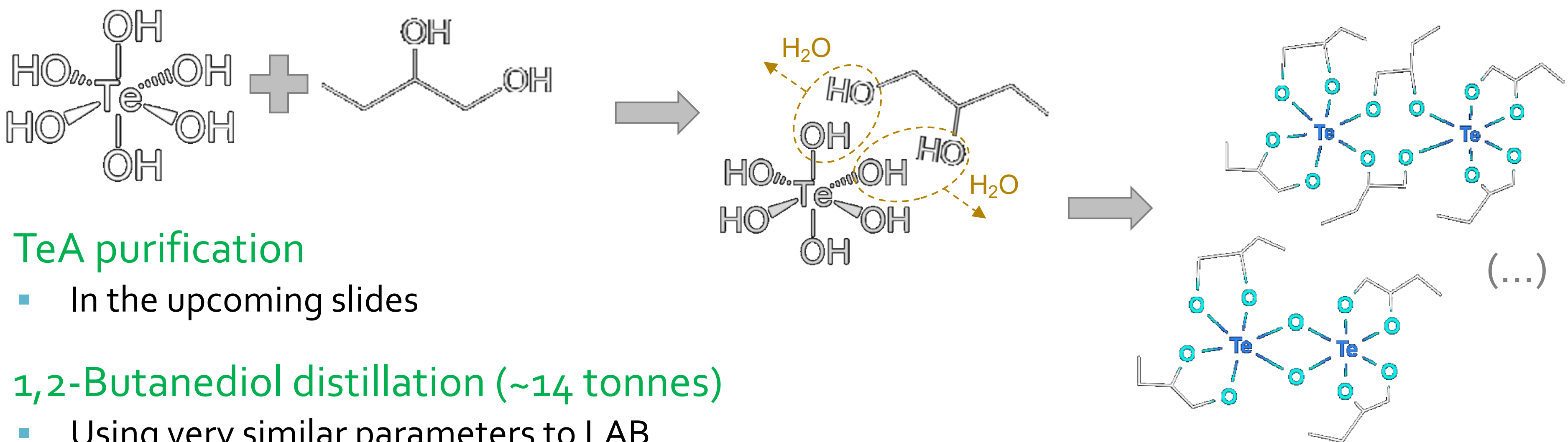




Very high natural abundance

Te Scintillator

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



- TeA purification
  - In the upcoming slides
- 1,2-Butanediol distillation (~14 tonnes)
  - Using very similar parameters to LAB
- DDA distillation (~3 tonnes)
  - U/Th target at ~10^{-15}g/g (expected reduction factor of 1000 from the assayed level has been easily reached with spiked distillation)
  - Expected reduction factors for Co/Na have been achieved, but clean handling post-distillation is going to be important

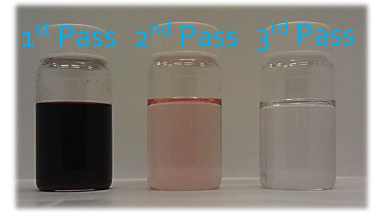
TeA Purification

- The purification technique relies on solubility of TeA in water based on pH
  - $Te(OH)_6 \leftrightarrow Te(OH)_5O^- + H^+$

    in-soluble   soluble
- Insoluble contamination
  - Dissolve in water, and filter
- Soluble contamination
  - Force TeA to recrystallize then drain the "dirty" liquid

Isotope	t_{exp}=1 yr
^{22}Na	15309
^{26}Al	0.048
^{42}K	565
^{44}Sc	102
^{46}Sc	43568
^{56}Co	2629
^{58}Co	25194
^{60}Co	6906
^{68}Ga	37343
^{82}Rb	18047
^{84}Rb	11850
^{88}Y	390620
^{90}Y	823
^{102}Rh	276189
^{102m}Rh	133848
^{106}Rh	1534
^{110m}Ag	69643
^{110}Ag	939
^{124}Sb	3101138
^{126m}Sb	240
^{126}Sb	358996

10kg pilot-scale



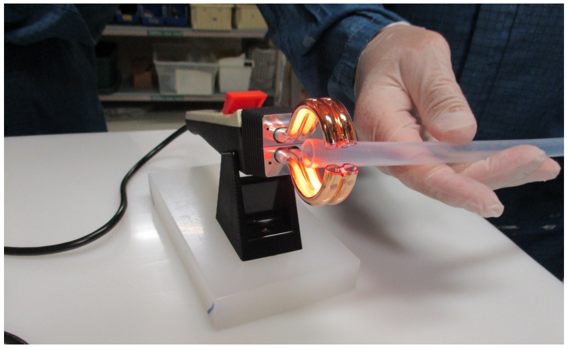
Target (r.f. 10^3):
^{238}U: 1.3×10^{-15} g/g
^{232}Th: 5×10^{-16} g/g

Needed reduction for cosmogenics by: 10^5-10^6

Target 8 tonnes of TeA "cooling" UG

Te Commissioning

- Almost all systems ready, currently entering the phase of final commissioning
- Most vessel pre-cleaned and verified to meet the target (of below 0.1 ppt U and <0.05ppt Th)
- Target-out approach allows us to measure most backgrounds before the isotope finally enters the detector
- First test-batch (no deployment) of TeA purification scheduled later this year



Thank You

Backup