SNO+ Liquid Scintillator Purification Plant

R.Svoboda, DESY THEIA Meeting, 23-25 March 2017

The SNO+ Scintillator Purification Plant and Projected Sensitivity to Solar Neutrinos in the Pure Scintillator Phase

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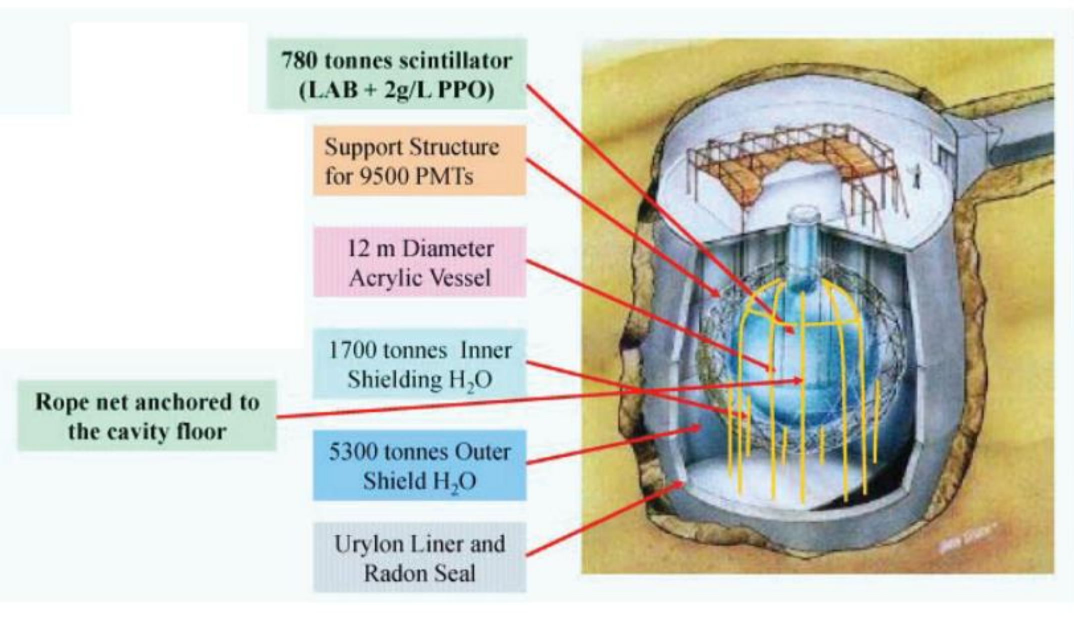
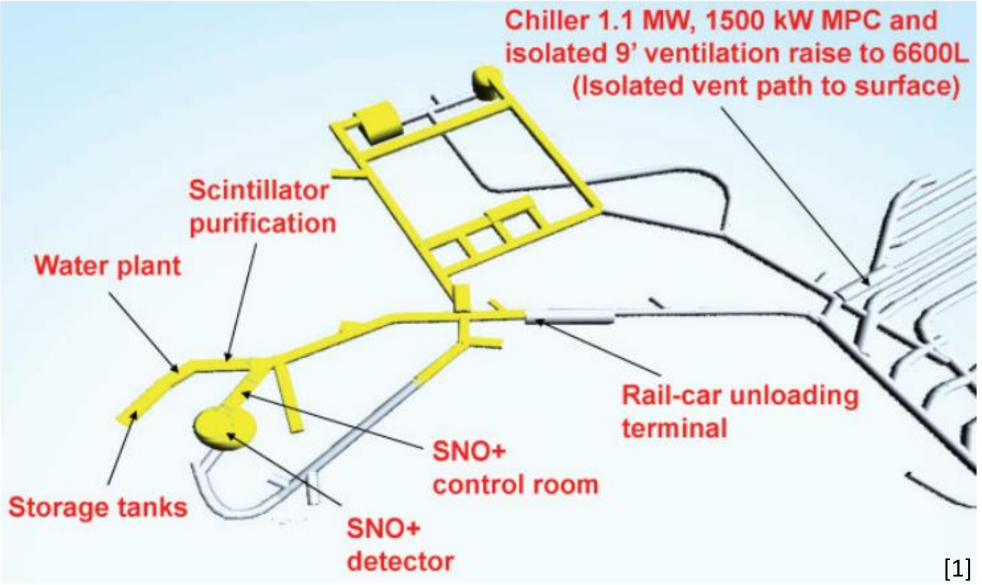
FOR THE SNO+ COLLABORATION
APS MEETING, APRIL 18TH, 2016

The SNO+ Detector

- SNO+: Located in SNOLAB in Sudbury, Canada
- Repurposing of the original SNO Detector
  - Replace heavy water with scintillator
- SNO+ is a 0νββ experiment, but solar physics can be performed before adding the 0νββ isotope (^{130}Te)





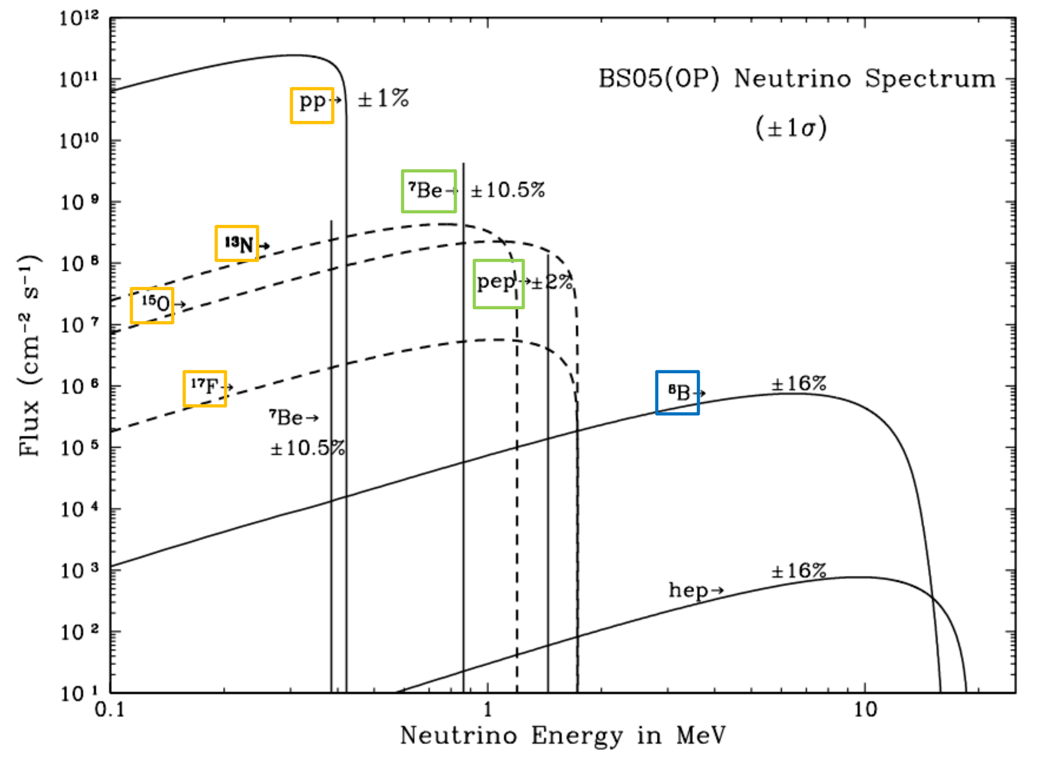
[1]

Solar Neutrinos in SNO+

- Main goal: direct measurement of solar neutrino fluxes
  - Measure ^8B spectrum for background characterization in $0\nu\beta\beta$ phase
  - Cross-check measurements made by other solar neutrino experiments (^7Be in KamLAND/BOREXINO, pep in BOREXINO)
  - Attempt to directly measure lower energy neutrino fluxes yet to be measured (CNO, pp)

- Measurements require extensive removal of radioactive backgrounds
  - **^{238}U, ^{232}Th chains** (detector components, mine dust, mine air)
  - **^{210}Pb, ^{210}Bi, and ^{210}Po** (piping in scintillator plant, AV surface)
  - **^{85}Kr, ^{39}Ar** (cosmogenic, gas entrained in LAB)
  - **^{40}K** (detector components, PPO)

- An underground scintillator purification plant is necessary to remove all types efficiently



[2]

The SNO+ scintillator plant

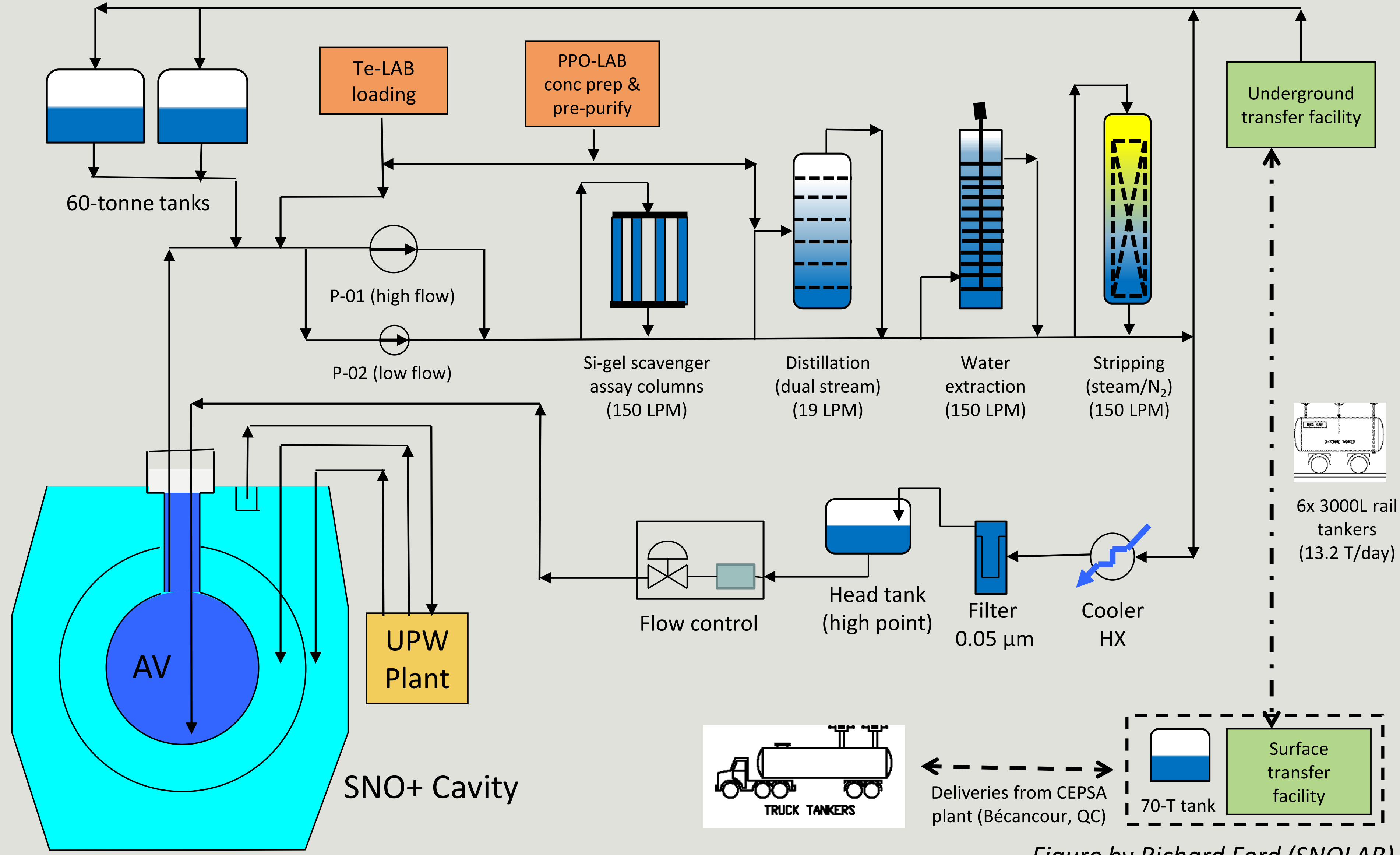
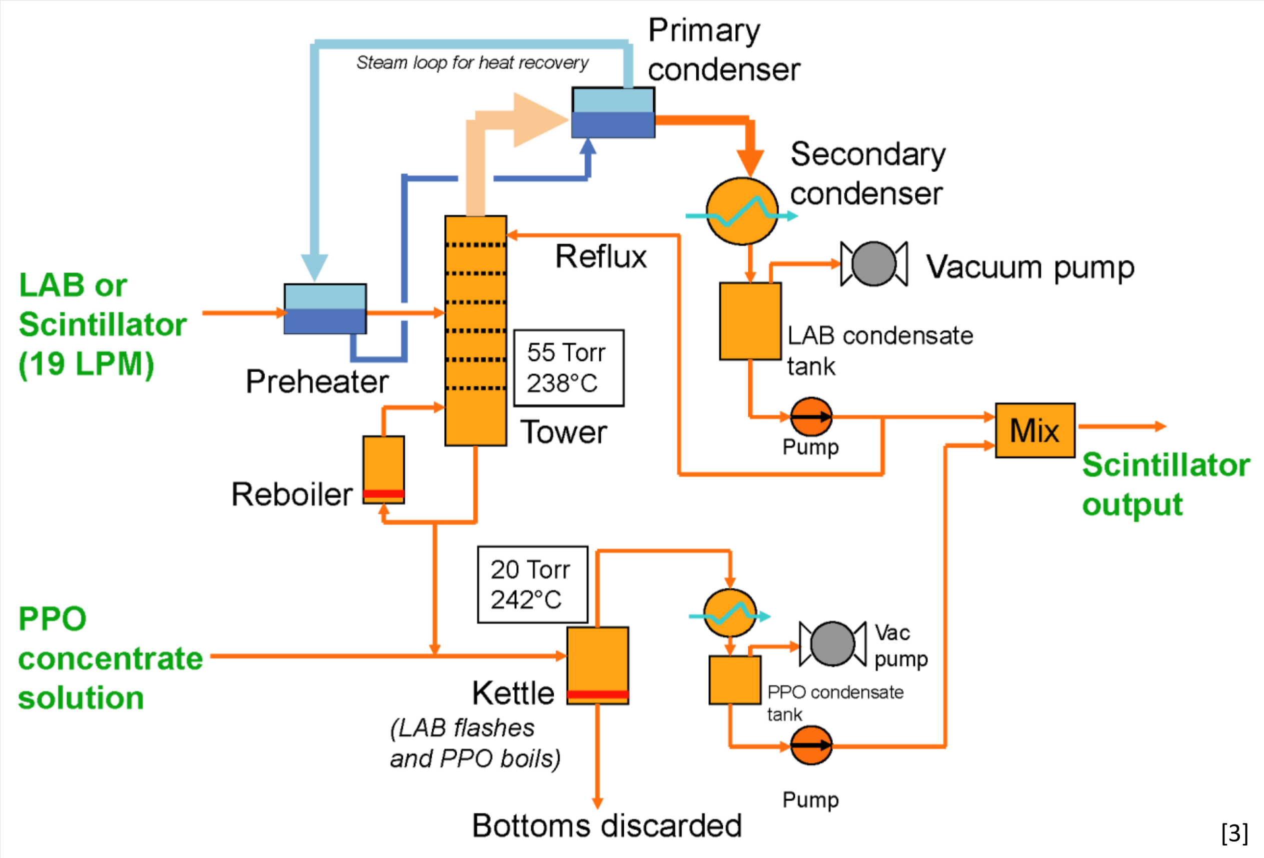


Figure by Richard Ford (SNOLAB)

Multistage Distillation Column

- Purification based on difference in volatility of elements/molecules
- Highly effective for heavy metals
  - Ra, U, Th, Po, Pb, Bi, K, etc.
- Distillation operation speed: 19.3 LPM
  - Designed to keep pace with LAB rail car deliveries
- Reflux: condensed distillate returned to column
  - Fluid drips down column trays, improves distillate purification
- Also have a second PPO distillation kettle (dual-stream system)
  - PPO column combined with the Scintillator bottoms for space saving and thermal efficiency



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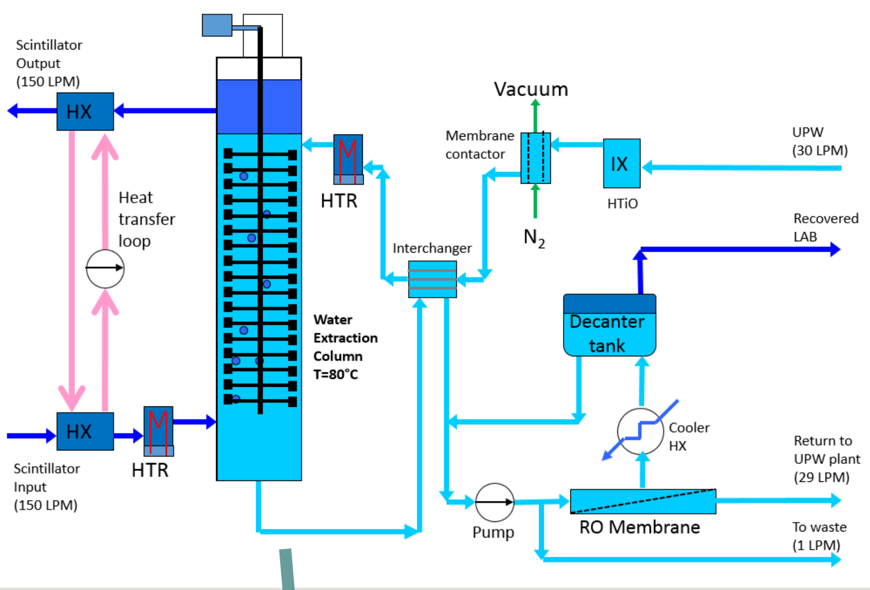
Water Extraction

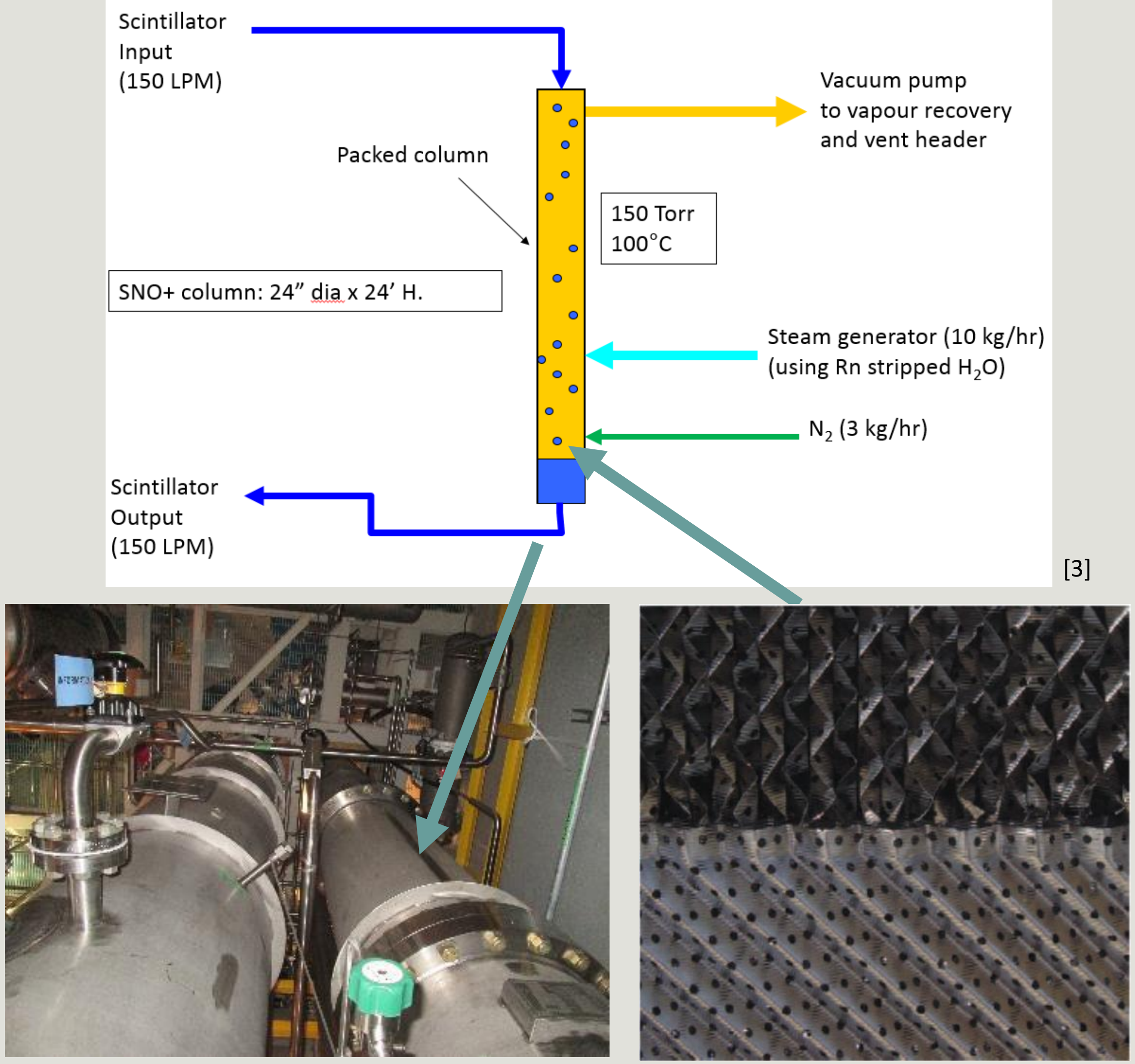
- Removal of impurities using differences in solubility of elements in different solvents
  - Particularly effective: Ra, U, Th, K, Pb, Bi
- Operation flow: 150 LPM
  - Allows for ~4 day turnover of detector (Purify whole detector volume before ~1 half-life of radium passes)
- Benchtop test with KARR column showed 96.5% removal of Radium in one pass
- 82% of ^{212}Pb removed in first pass, but none in following passes
  - ^{210}Pb daughter from ^{214}Po α-decay can form organo-metallic molecules within scintillator; not effectively removed



[3]

Gas Stripping

- Removal of radioactive gases
  - Rn removal eff.: 95%
- Removal of oxygen gas; oxygen quenches light output in the scintillator
  - O_2 removal eff.: 99%
- Combination of steam and nitrogen gas
  - Limited access to N_2 underground
- Packing – minimizes pressure drop in column while maximizing fluid/vapor crossflow
- Always performed before returning scintillator to AV
- Operation flow rate: 150 LPM



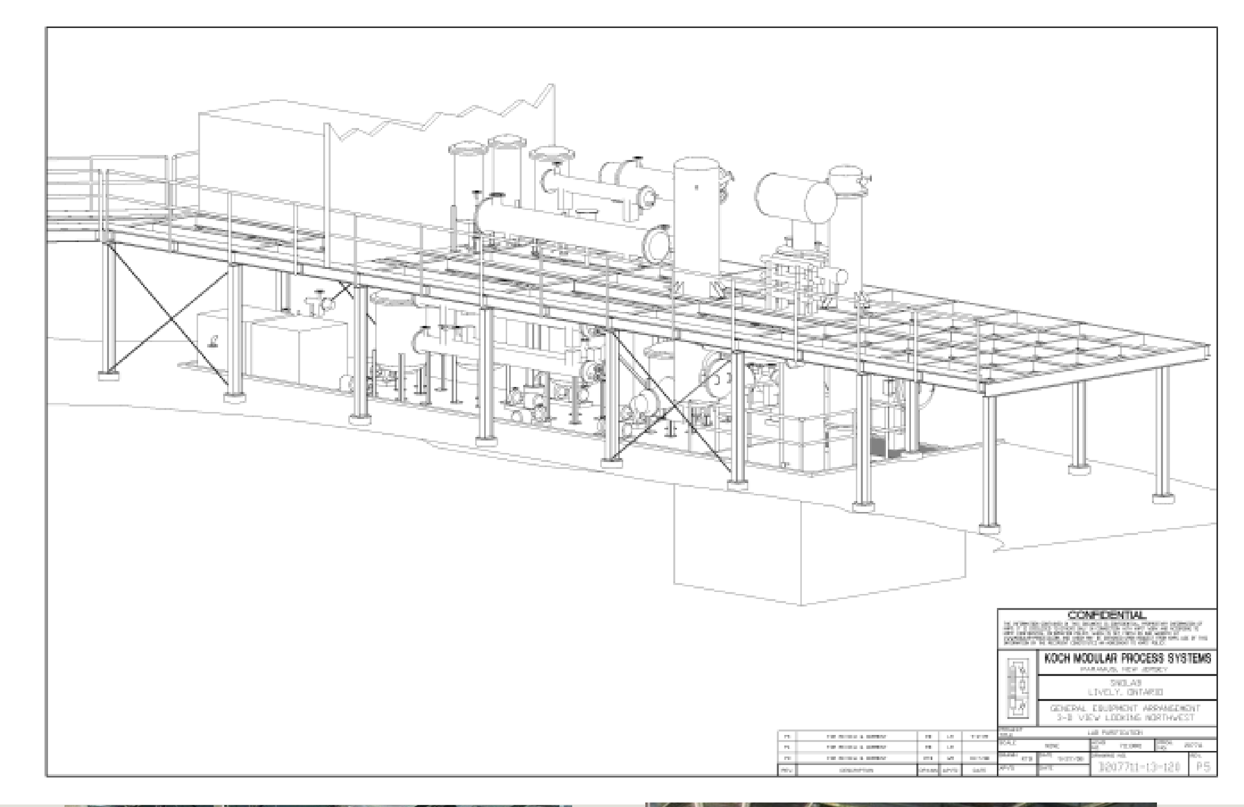
[3]

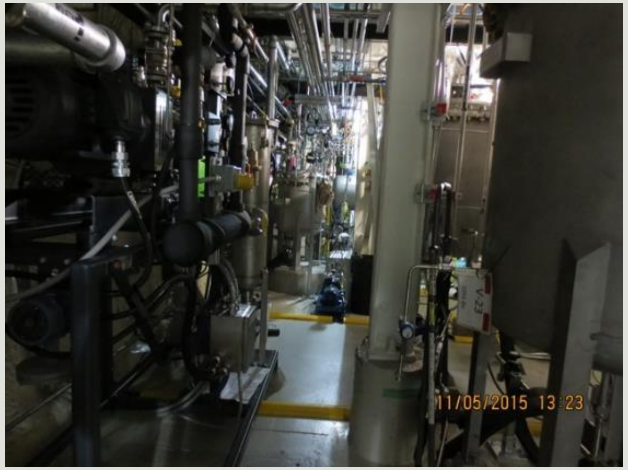
Scavenger Columns

- Columns packed with Quadrasil-AP™
  - Silica beads with functional groups found to be efficient at removal of metals
- Small-column testing yielded over 90% efficiency for Pb & Ra removal
  - Higher than one pass of water extraction for Pb; organo-metallic forms are effectively removed
- Columns are "re-chargeable" for extensive purification use
- Also offer an ex-situ assay method
  - Strip the impurities off columns with HCl acid, count sample with alpha-beta coincidence counting
- Flow rate: 150 LPM achievable

Conclusions

- A scintillator plant has been constructed in SNOLAB to meet the background limits required for SNO+
- Plant construction is now completed and water commissioning is underway
- Given enough measuring time, SNO+ can attempt to directly measure several sub-MeV solar neutrino fluxes





References

Talk & Figures

[1] Ford, R. “A scintillator purification plant and fluid handling system for SNO+”, *AIP Conf. Proc.* **1672**, 080003 (2015); doi: 10.1063/1.4927998

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[4] S. Andringa,[1] E. Arushanova, et al. “Current Status and Future Prospects of the SNO+ Experiment”, *Advances in High Energy Physics*, **Volume 2016**, Article ID 6194250 (2016)

Liquid Scintillator & Purification

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F. Suekane, T. Iwamoto, H. Ogawa, et al. for the KamLAND RCNS Group, “An Overview of the KamLAND 1-kiloton Liquid Scintillator”, arXiv:physics/0404071 **[physics.ins-det]**

J. Benziger, L. Cadonati, F. Calaprice, M. Chen, et al. for the Borexino Collaboration, “The Scintillator Purification System for the Borexino Solar Neutrino Detector”,*Nucl. Instrum. Meth***. A587** 277-291 (2008)

Solar Neutrino Measurements

Borexino Collaboration (Smirnov, O. *et al.*), “Solar neutrino with Borexino: results and perspectives”, *Phys. Part. Nucl.* **46** (2015) no.2, 166-173

KamLAND Collaboration (Gando, A. *et al.*), “7Be Solar Neutrino Measurement with KamLAND”, *Phys. Rev.* **C92** no.5, 055808 (2015)

KamLAND Collaboration (S. Abe *et al.*), “Measurement of the 8B solar neutrino flux with the KamLAND liquid scintillator detector”, *Phys. Rev.* **C84,** 035804 (2011)

Back-up Slides

Requirements on LAB/PPO purity

Gas leak rates into nitrogen cover gas

- $<1 \times 10^{-6}$ atm cc/sec for the entire plant (RICHARD'S FINAL)
- Confirmed through helium leak-checking all scintillator plant lines

Uranium/Thorium (equilibrium components): at or lower than Phase-I Borexino

- Purification plant components similar in design & from same company
- U chain: 1.6×10^{-17} g/g_{scint}, ~13 decays/day
- Th chain: 6.8×10^{-18} g/g_{scint}, ~2 decays/day

Required fines purity

- Military Std 1246C
- No particles larger than 5 µm found in a 1 L sample
- Limits on how many <5 µm particles can be present

The SNO+ scintillator plant overview

LAB brought in by rail cars through Creighton mine, stored in SNOLAB until purification starts

Purification is performed in four parts:

- Distillation
- Solvent-Solvent Extraction
- Gas stripping
- Scavenger columns

- Initial purification: distillation, then stripping
- On-line purification: water extraction or scavengers, then stripping

All materials made of SS316L, PTFE, or glass

Process pressure maximums in plant: 150 PSI

All equipment rated for full vacuum

Process temps.: LAB distillation 238°C @ 55 Torr, PPO distillation 242°C @ 20 Torr, water extraction 80°C, steam stripping 100°C.

Solar Metallicity Problem

- A high metallicity (GS98) and low metallicity (AGS09) model result in a solar sound speed discrepancy between SSM measurements and helioseismology measurements

- The two models have a considerable difference in measurable CNO neutrino fluxes (17F, 15O, 13N); an accurate measurement could break this degeneracy
  - GS98 predicted CNO flux: $10.71 \pm 0.46 \times 10^{8}\ cm^{-2}\ s^{-1}$
  - AGS09 predicted CNO flux: $7.13 \pm 0.45 \times 10^{8}\ cm^{-2}\ s^{-1}$

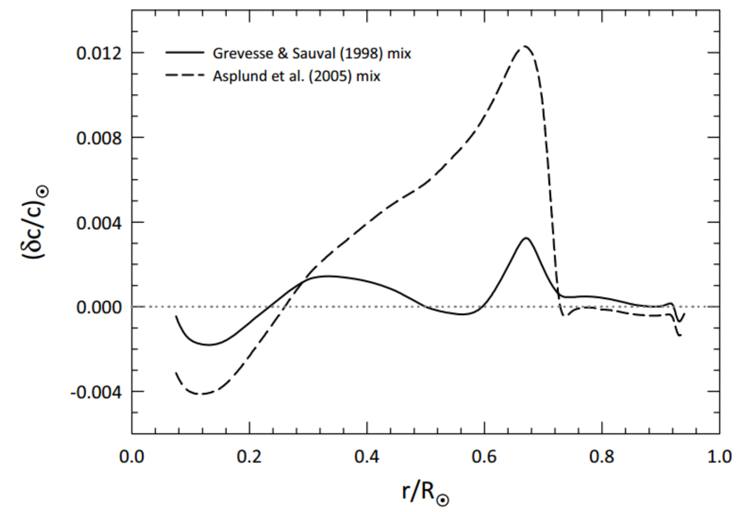

Figure 3. Illustration of the "solar abundance problem" circa 2005. The relative difference $(\delta c)/c$ between the sound speed as inferred from helioseismology and that predicted by the "standard solar model" is shown for two different choices of the solar heavy element mix: Grevesse & Sauval [42, *solid line*] and Asplund et al. [5, *dashed line*].

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Fluxes: Borexino Collaboration (Smirnov, O. *et al.*), "Solar neutrino with Borexino: results and perspectives", *Phys. Part. Nucl.* **46** (2015) no.2, 166-173

Table of Uncertainties of ν-flux Measurements

ν source	SNO+ Simulated Unc. (6 months live-time)	SNO+ Simulated Unc. (one year live-time)	Borexino Published Uncertainties	KamLAND Published Uncertainties
pep	13%	8.9%	21.6% [1]	N/A
CNO	N/A	~15%?	<7.4 x 10^8 cm^{-2} s^{-1} [2]	N/A
^8B	10%	7.1%	17.1% [3]	14.9% [4]
^7Be	5.1%	3.3%	4.9% [2]	17.5% [5]

[1] G. Bellini, et al., First evidence of pep solar neutrinos by direct detection in Borexino, Phys. Rev. Lett. 108 (2012) 051302
[2] Borexino Collaboration (Smirnov, O. *et al.*), "Solar neutrino with Borexino: results and perspectives", *Phys. Part. Nucl.* **46** (2015) no.2, 166-173
[3] G. Bellini, et al., "Measurement of the solar 8B neutrino rate with a liquid scintillator target and 3 MeV energy threshold in the Borexino detector",Phys. Rev. D 82 (2010) 033006
[4] KamLAND Collaboration (S. Abe *et al.*), "Measurement of the 8B solar neutrino flux with the KamLAND liquid scintillator detector", *Phys. Rev.* **C84,** 035804 (2011)
[5] KamLAND Collaboration (Gando, A. *et al.*), "7Be Solar Neutrino Measurement with KamLAND", *Phys. Rev.* **C92** no.5, 055808 (2015)