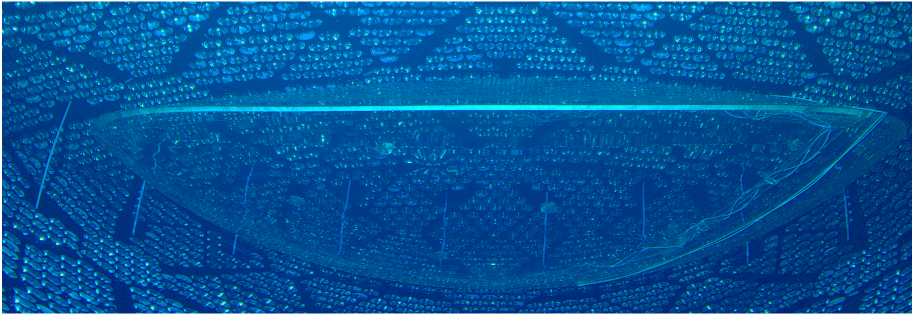

Rn-222 Assays for SNO+

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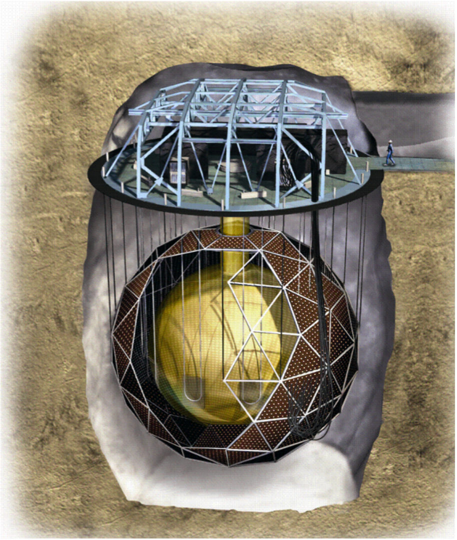
For the SNO+ Collaboration

2016 CAP Congress

The SNO+ Detector

- Reuses SNO detector
- Located at SNOLAB, Sudbury, ON
- Class-2000 clean room
- 2 km underground (6000 m.w.e)
  - 70 muons/day
- Urylon-lined rock cavern
- 5300 tons (outer) + 1700 tons (inner) ultrapure water shielding
- ~9500 PMTs, 54 % coverage
- 780 tons liquid scintillator
- 12 m dia. acrylic vessel



SNO+ will explore:

- Invisible nucleon decay
- Geo anti-neutrinos
- Reactor anti-neutrinos
- Low energy solar neutrinos
- Supernovae neutrinos
- Neutrinoless double beta decay ($0\nu\beta\beta$) in ^{130}Te
  - Lepton number violation, Majorana particles, neutrino mass

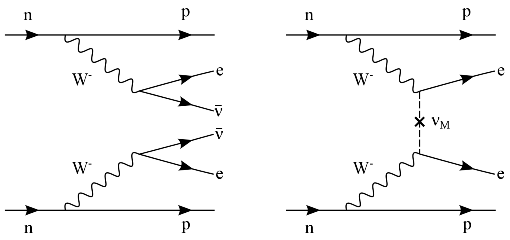


Figure 1: Left: $2\nu\beta\beta$, right: $0\nu\beta\beta$[1]

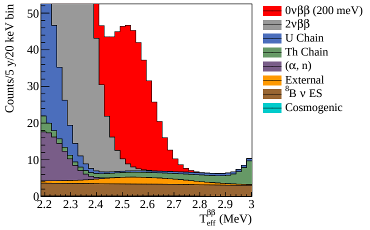


Figure 2: Simulated $0\nu\beta\beta$ signal in SNO+

[1] Image from `http://www.ecap.physik.uni-erlangen.de/nexo/research.shtml`

^{238}U Chain Background Mitigation

- Choose detector materials low in U-chain isotopes
- ^{222}Rn in SNOLAB $\sim$3.54 pCi/L due to naturally occurring U-rich norite rock[1]
- Use shielding (e.g. sealed AV N_2 cover gas, cavity UPW)
- Pre-purification and recirculation within scintillator and UPW purification plants
- *in-situ* monitoring: coincidence tagging (BiPo events)
- *ex-situ* monitoring: radioassays (Ra, ^{222}Rn)
- SNO+ targets[2]:

Phase/Medium	^{238}U [g/g]	^{222}Rn/L
Cavity UPW	3.5×10^{-13}	2
AV UPW	3.5×10^{-14}	0.2
AV Scintillator	1.6×10^{-17}	10^{-4}

[1] I. Lawson. Radon levels in the SNOLAB underground laboratory. SNOLAB, Sudbury, March 2015. SNOLAB internal document SNOLAB-STR-2014-001.

[2] S. Andringa et al. Current status and future prospects of the SNO+ experiment. Submitted to *Advances in High Energy Physics*, 2015.

Radon Assays: Lucas Cell Design

- Custom designed at Queen's University for low levels ~cpd[1]
- Hemisphere cavity within acrylic cylinder
- Quick-connect for ingress/egress of gas
- 3.8 cm hemispherical diameter
- 15.5 cm^3 volume
- 20 cm^2 active area ZnS(Ag)
- ~3 cpd background
- 3×0.74 Rn detection efficiency

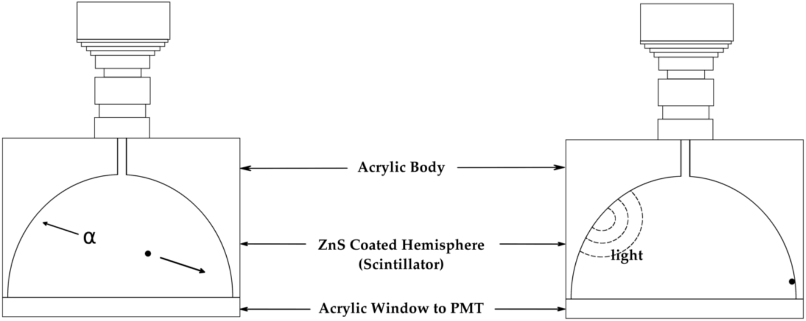


Figure 3: SNO+ Lucas cell diagram

[1] M. Liu. ^{222}Rn emanation into vacuum. Master's thesis, Queens University, 1991.

Lucas Cell Counting System

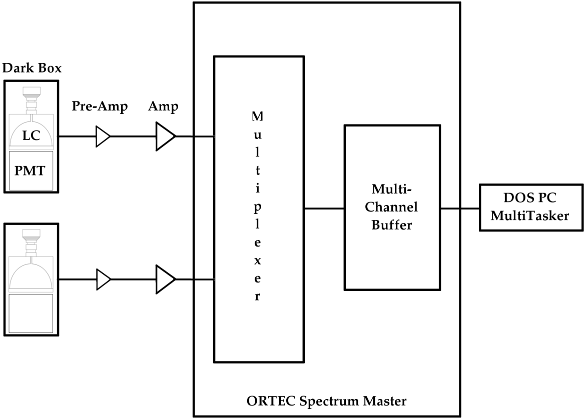


Figure 4: LC counting electronics flow diagram

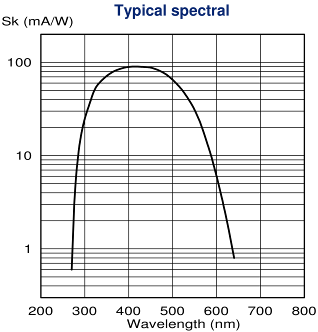
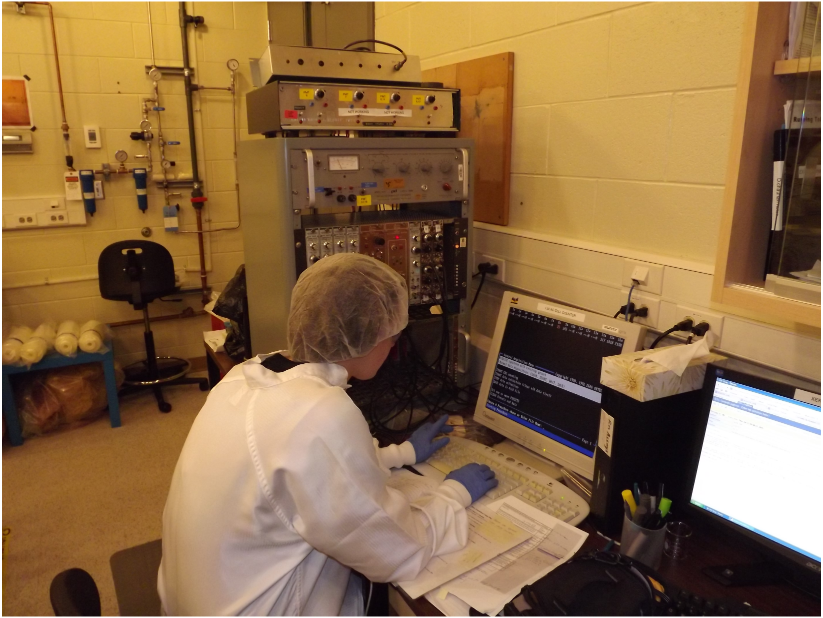


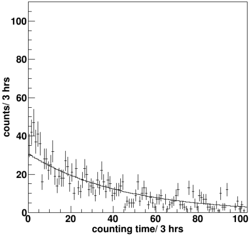
Figure 5: PMT XP2262B absorption spectra[1]

[1] PHOTONIS, 18 Avenue Pythagore, 33700 Mérignac, France. Photomultiplier XP2262, 2006.

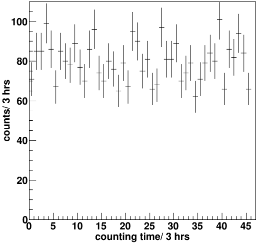


Lucas Cell Backgrounds & Leaks

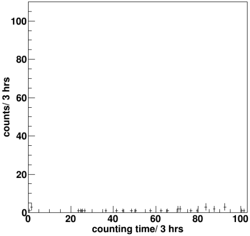
- Flush with N_2 & evacuate $\times$ 3
- Leave cells underground for $\sim$6 hours
- Return to surface, commence counting



(a) Leaking cell



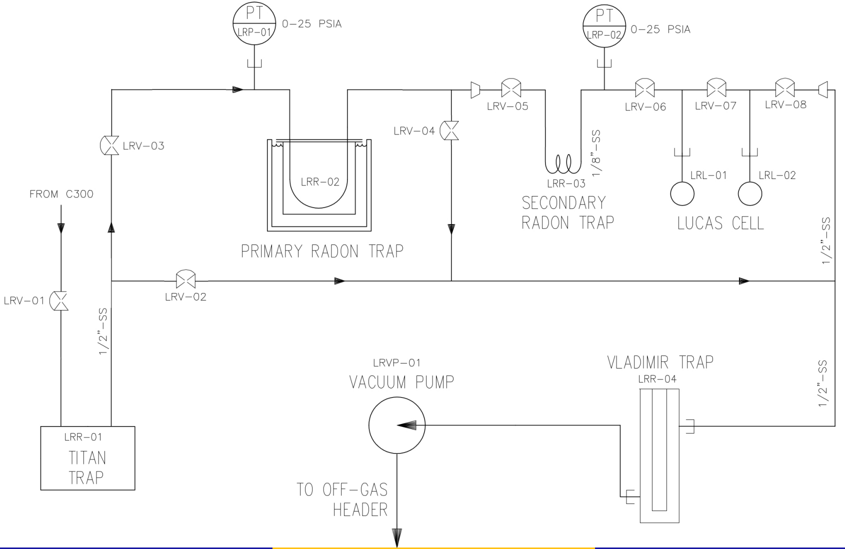
(b) High background cell



(c) Acceptable cell

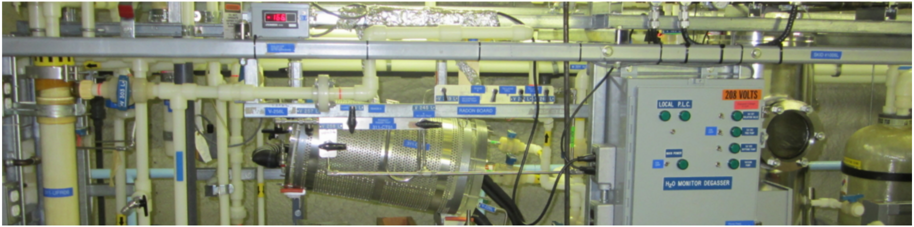
^{222}Rn Assays with Cryo-cooling Techniques

UPW and Scintillator



^{222}Rn Levels within UPW

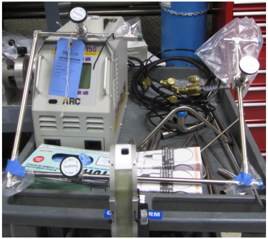
- Monitor Degasser Unit (MDG)
- Formerly used in SNO[1] for levels $\mathcal{O}(10^{-13}$ gU/g) (2 Rn/L)
  - $\epsilon_{degas} = 58\pm10\%$, $\epsilon_{transfer}$ $64\pm2\%$
  - R_{back} ~460 Rn atoms/day (degasser+collection system)
- Recomissioning:
  - Summer 2015: Vacuum commissioned, $R_{back} = 453 \pm 158$ Rn/day
    - ★ Sensitive for internal water assays
  - Summer 2016: Water commissioning

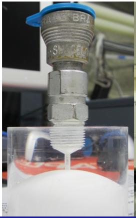


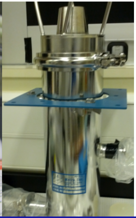
[1] Quoted values from I. Blevis et al. Nucl. Instrum. Meth. A 517 (2004) 139153

Scintillator ^{222}Rn Assay System

- $\mathcal{O}(10^{-4})$ Rn/L scintillator vs. $\sim$2 Rn/L UPW
- Improved efficiencies, lower background, colder condensing trap (-100 °C vs. -60°C)
- ϵ_{degas} >95% via steam/N_2 stripping gases
- $\epsilon_{transfer}$ >85%
- Will possess no leak greater than 10^{-9} mbar·L/sec
- All process lines 316L SS, all permanent connections undergoing welding
- All pieces in possession, assembly nearing completion
- Commissioning anticipated Fall 2016







Conclusions

- SNO+ will investigate $0\nu\beta\beta$, various neutrino physics topics
- Background mitigation through a variety of different techniques
- *Ex-situ* monitoring via ^{222}Rn assays:
  - Lucas cell tests ongoing
  - MDG vacuum recommissioned (2015), $R_{\text{back}} = 435 \pm 158$ Rn/day, recommissioning with H_2O
  - Scintillator system under construction, commissioning Fall 2016

Thank you!

Backup

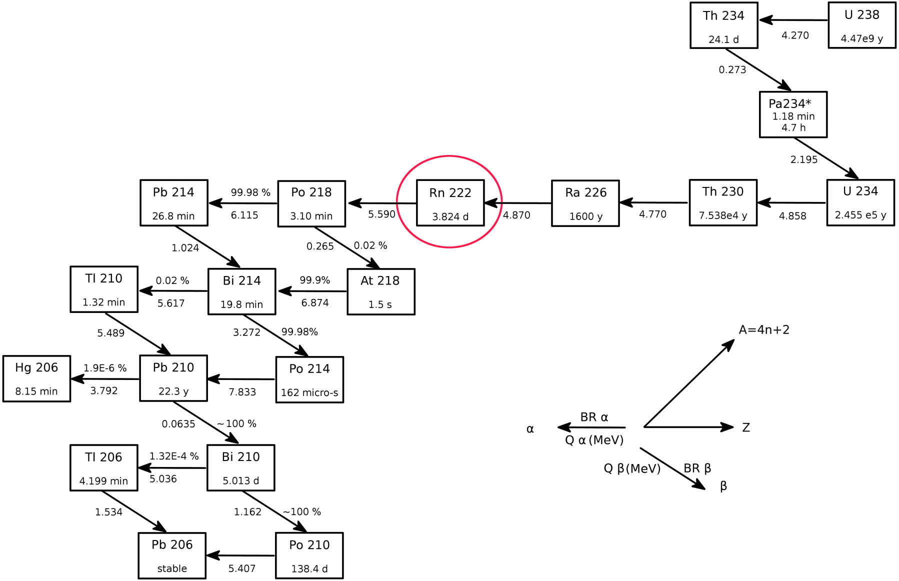


Figure 8: Radioactive decay chain of ^{238}U with Q values and major branching ratios

C-300: Gas Stripping Column

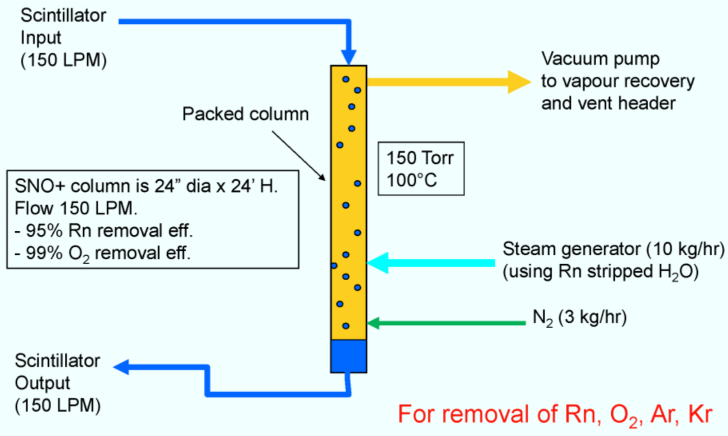


Figure 9: Simplified gas stripping process of the SNO+ scintillator plant[1]

[1] R. Ford. A scintillator purification plant and fluid handling system for SNO+. Submitted to *Low Radioactivity Techniques Conf. Proc.*, 2015.

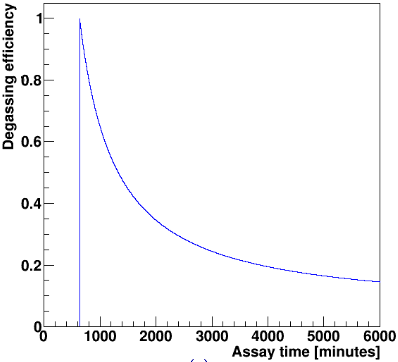
Values for SRAS: What is required for a signal?

$$C = \frac{1}{F\epsilon_{\text{degasser}}}\left[\frac{(S - Bt_{\text{count}})\lambda}{\epsilon_{\text{count}}\epsilon_{\text{transfer}}\epsilon_{\text{trap}}(1-e^{-\lambda t_{\text{count}}})(e^{-\lambda t_{\text{delay}}})(1-e^{-\lambda t_{\text{assay}}})} - R_{\text{back}}\right]$$

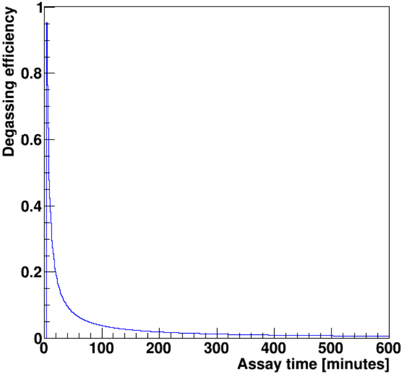
Variable	Value	Description
λ	0.182 days^{-1}	^{222}Rn decay constant
ϵ_{count}	3×0.74	Typical counting efficiency
$\epsilon_{\text{transfer}}$	0.85	Minimum SRAS trans. eff.
ϵ_{trap}	1.00	Expect perfect trapping eff.
ϵ_{degas}	< 1.00	Unknown degassing eff.
S	$> 1.5Bt_{\text{count}}$	Total LC counts
B	2 cpd	Lowest achievable LC bkg
t_{count}	12 days	Typical LC counting time
t_{delay}	3 hours	Typical delay time
t_{assay}	0 to 100 hours	Possible time range for assays
R_{back}	0 Rn/day	No system bkg
F	150 LPM	Standard flow through C-300
C [LAB+PPO]	8.1×10^{-5} Rn atoms/L	[Rn] in LAB+PPO
C [Te+LS]	1.3×10^{-2} Rn atoms/L	[Rn] in Te+LS

Table 1: Hypothetical parameters for theoretical calculations with the SRAS

Values required for a LC signal



(a)



(b)

Figure 10: Limit curves depicting minimal possible values of assay time and degassing efficiency to see a signal with LC counting. For a signal, the chosen values for ϵ_{degas} and t_{assay} must be above the curve for (a) pure LAB+PPO, and (b) Te-LS assays

(a)

$\epsilon_{\text{degas}} = 100\% \Rightarrow t_{\text{assay}} = 11$ hours

$t_{\text{assay}} = 100$ hours $\Rightarrow \epsilon_{\text{degas}} = 15$ %

N_2 purge to increase ϵ_{degas}

(b)

$\epsilon_{\text{degas}} = 100\% \Rightarrow t_{\text{assay}} = 4$ min.

$\epsilon_{\text{degas}} = 13$ % $\Rightarrow t_{\text{assay}} = 30$ min.