SBC-SNOLAB: Material Radiopurity Program

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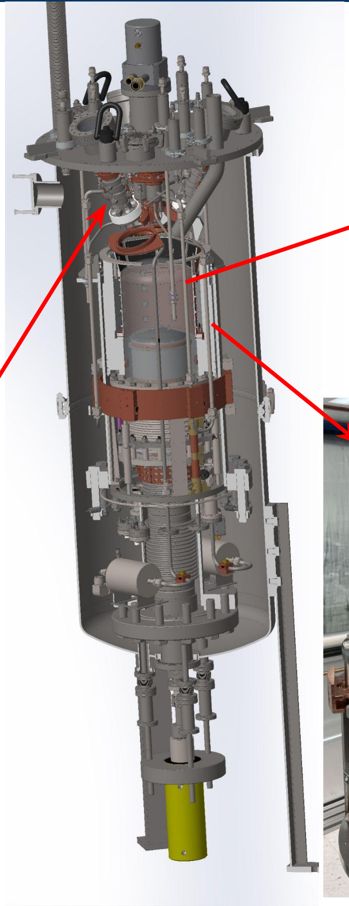
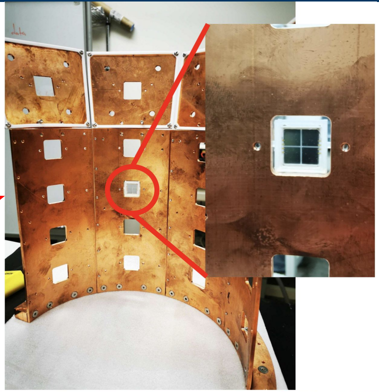
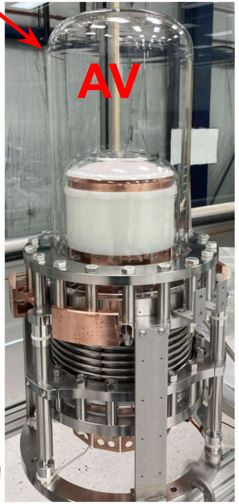
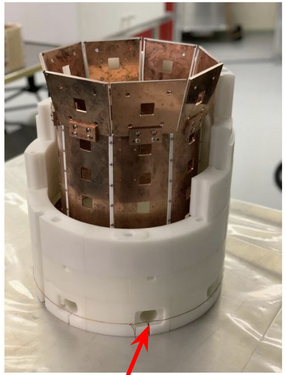
The Scintillating Bubble Chamber

- Liquid argon (LAr) target maintained at 130 K and 30 psi $\rightarrow$ 100 eV nucleation threshold (see Carter Garrah's talk).
- LAr doped with O(10-100) ppm of Xe: $\lambda = 128 \rightarrow 175$ nm $\Rightarrow$ high transmission.
- 32 LAr-facing FBK VUV-HD3 SiPMs to observe scintillation signals.
- 3 cameras to achieve mm-scale bubble position reconstruction.
- 8 PZT transducers to "listen" to the bubble signatures $\rightarrow$ α-rejection [arXiv:0807.1536]



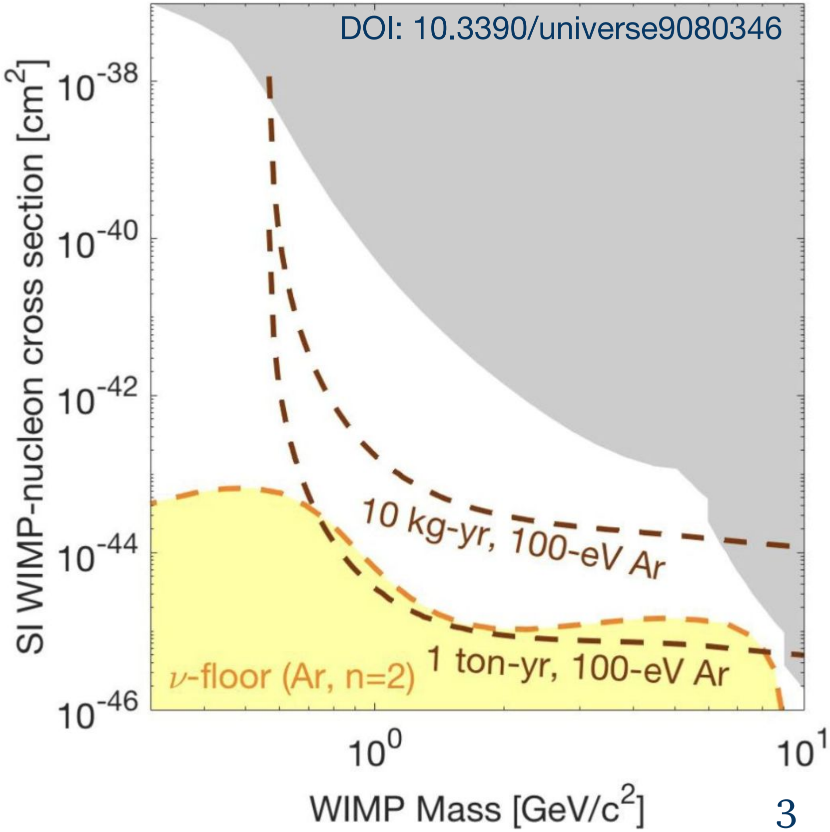






SBC-SNOLAB: Physics Reach

- Nuclear recoils (NRs) above 100 eV_{NR} are expected to nucleate a bubble.
- Scintillation veto for deposits > 50 keV_{NR}.
- Region of interest (ROI): 0.1 – 50 keV_{NR}.
- ROI corresponds to 1 – 10 GeV/c^2 WIMP mass.
- **Expected WIMP signal**: single bubble with minimal scintillation light.
- 10 kg-yr LAr target capable of 10^{-43} cm^2 at 1 GeV/c^2 (can use other targets for SI/SD).



Computing Background Rates with MC Simulations

- Monte Carlo (MC) simulations used to predict background event rates (R).
- Propagate N simulated particles through the detector and observe hits in the active volume → N_{Hits}.
- Event rates estimated by N_{Hits} and simulated livetime (t_{Live}).
- t_{Live} → time taken for a certain material or component to emit N events.
- Livetime dependent on material **activity** (α) and **production rates** (Γ/ε).

Bulk Livetimes

$$t_{Live} = \frac{N}{\Gamma \cdot M \cdot \alpha}$$

Surface Area Livetimes

$$t_{Live} = \frac{N}{\varepsilon \cdot A}$$

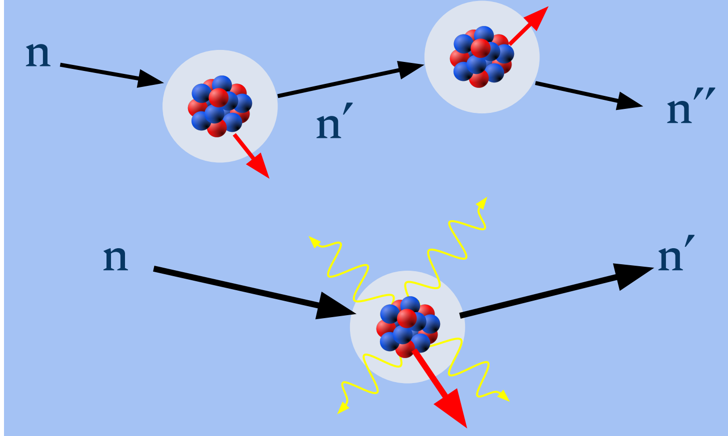
Event Rate Computation

$$R = \frac{N_{Hits}}{t_{live}}$$

Particle Backgrounds in Superheated LAr

Can be Vetoed:

- Multi-scatter events → WIMP xs too low.
- Deposits > 50 keV_{NR} → scintillation light.
- Alpha-scatters → scintillation + acoustics.



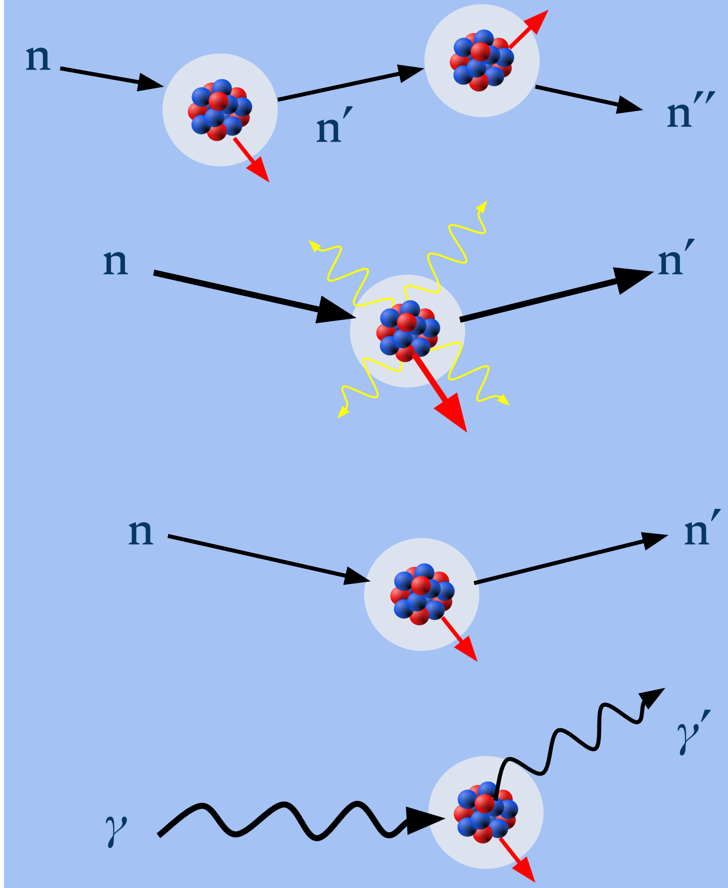
Particle Interactions in Superheated LAr

Can be Vetoed:

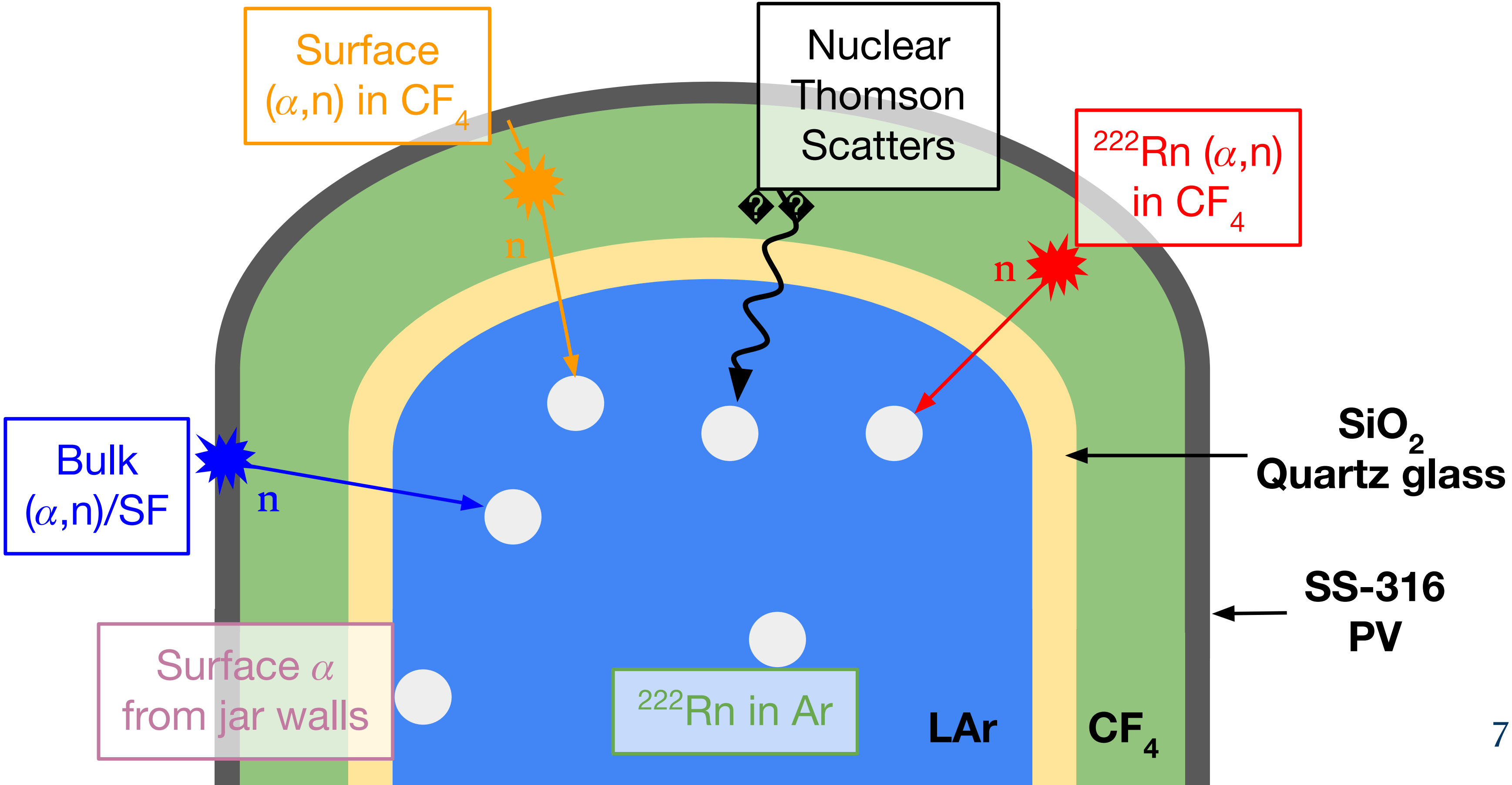
- Multi-scatter events → WIMP xs too low.
- Deposits > 50 keV_{NR} → scintillation light.
- Alpha-scatters → scintillation + acoustics.

WIMP-like Events:

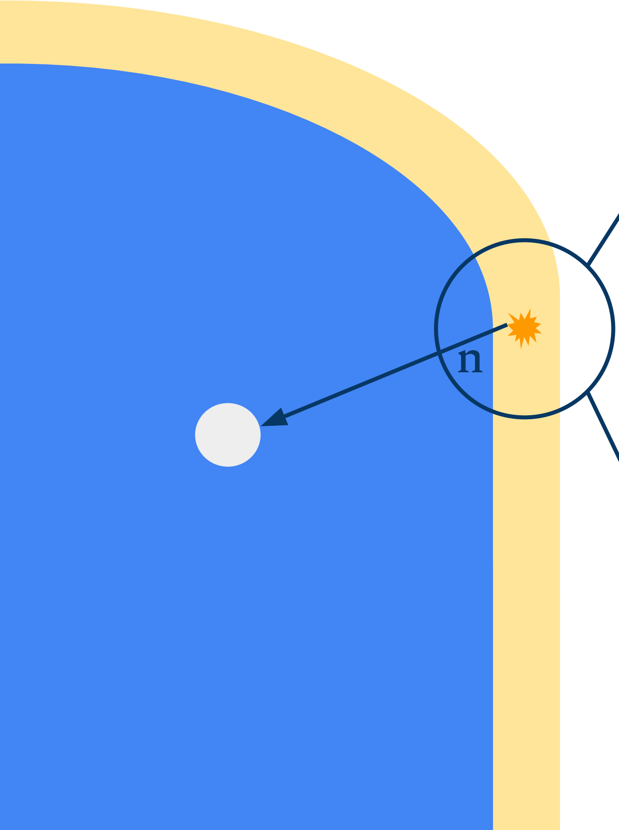
- Single-site NRs in the ROI: neutron capture recoils and inelastic scatters.
- Nuclear Thomson scatters → single site NRs from MeV-scale γs.



Internal Radiogenic Backgrounds



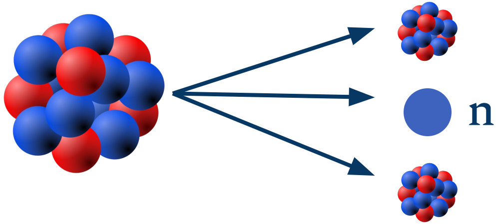
Internal Backgrounds – Bulk Neutrons



- $(\alpha$,n) → Most dominant.

$$\alpha + {}^{A}_{Z}X \rightarrow {}^{A+4}_{Z+2}X \rightarrow {}^{A+3}_{Z+2}X + n$$

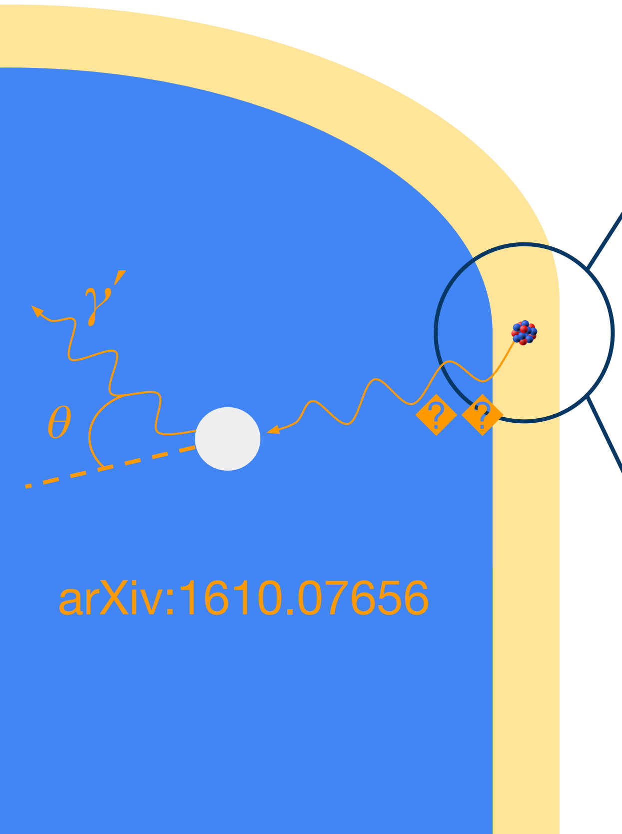
- Spont. Fission → Upper Th/U chains.



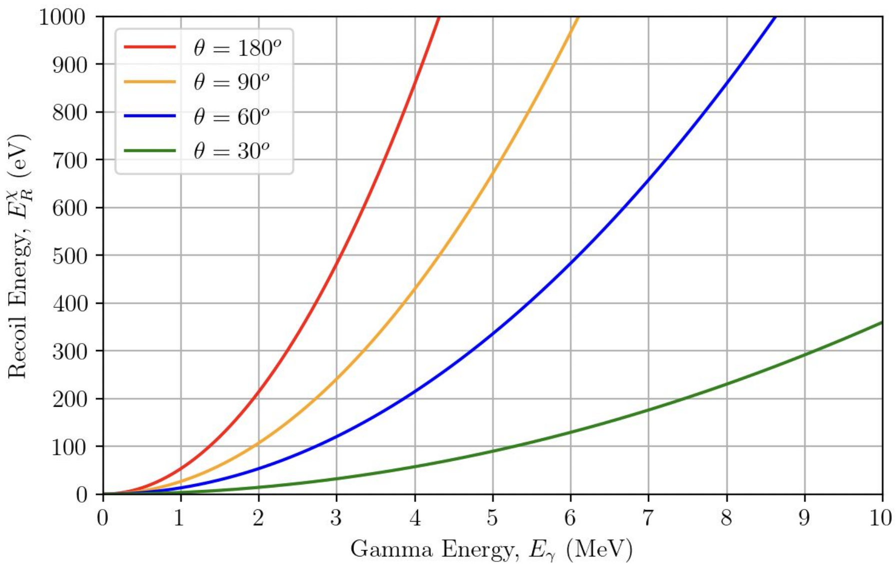
- Estimate neutron energy spectra and production rates using SOURCES-4C[1].

- Compute event rates with MC simulations and bulk activity measurements.

Internal Backgrounds – MeV Scale Gammas



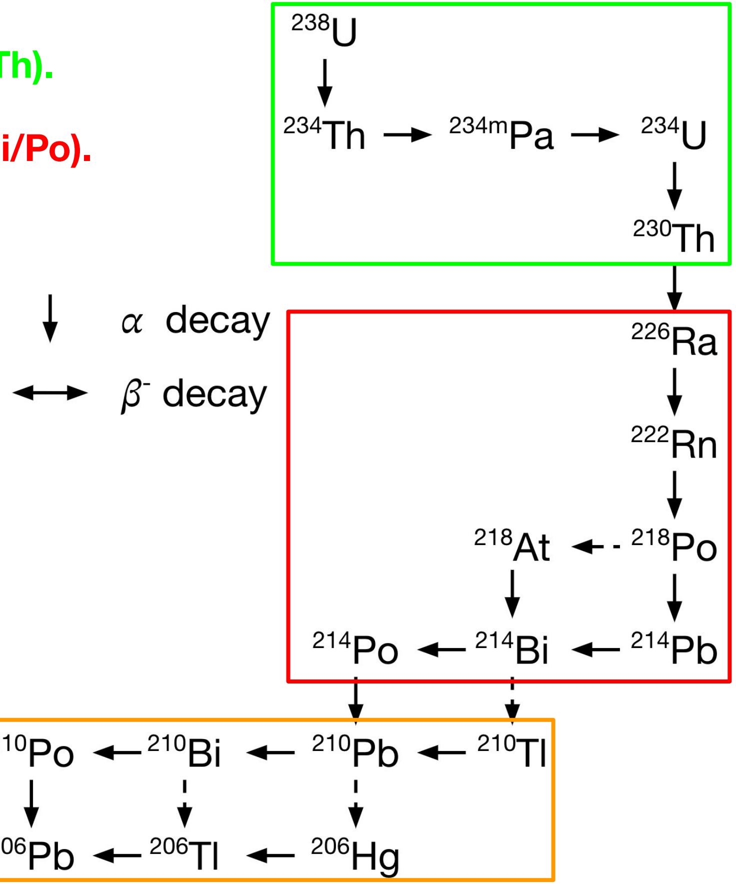
- Small chance MeV-scale gammas can elastically scatter off nuclei .



- Compute event rates with MC sims and bulk material activity.

Internal Backgrounds – Bulk Activity

- Mass spectroscopy: ICP-MS/GDMS → **upper chains (U/Th).**
- Rn-emanation: Rn-traps + Lucas cells → **mid chain (Rn/Bi/Po).**
- Surface alpha counting: XIA → **lower chain (Pb/Po).**
- Gamma counting: HPGe → **full chain.**
  - ^{232}Th:
    - ^{228}Ac: 911 keV
    - ^{212}Pb: 239 and 300 keV
    - ^{208}Tl: 583 and 2614 keV
  - ^{238}U upper chain (^{238}U → ^{226}Ra):
    - ^{226}Ra: 186 keV
  - ^{238}U lower chain (^{222}Rn → ^{206}Pb):
    - ^{214}Pb: 295 and 352 keV
    - ^{214}Bi: 609, 1120, 1764 and 2204 keV
  - ^{235}U:
    - ^{235}U: 144, 163 and 205 keV



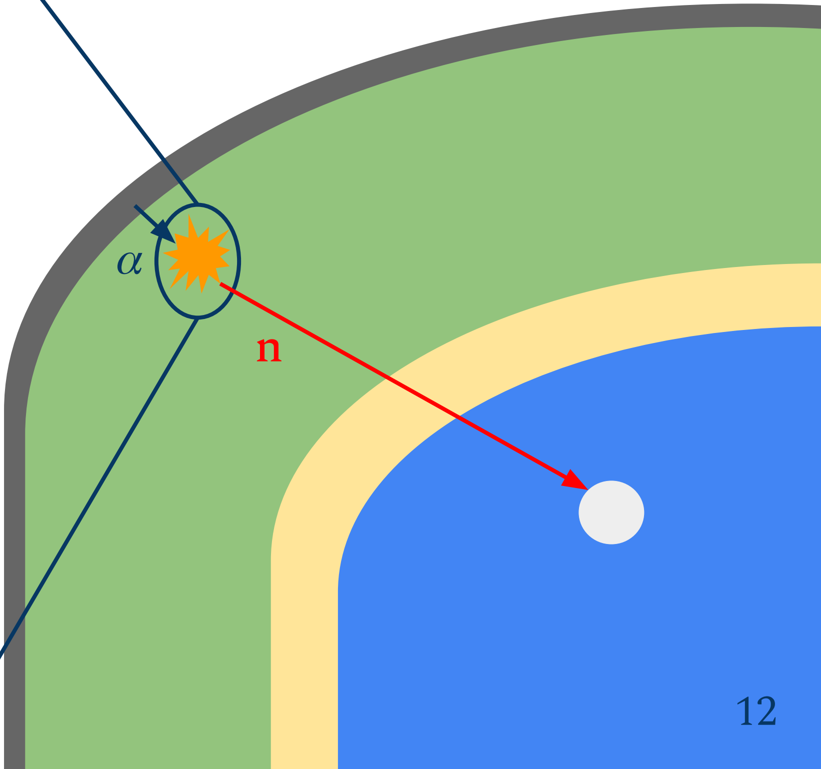
(Some) Material Bulk Activities

Component	Mass Counted [kg]	^{232}Th [mBq/kg]	$^{238}U_{Up}$ [mBq/kg]	$^{238}U_{Low}$ [mBq/kg]	^{235}U [mBq/kg]	^{210}Pb [mBq/kg]
OFHC Copper	1.5117	< 1.03	30.31 ± 15.16	< 0.15	< 0.22	5732.1 ± 3936
SS-316	1.6952	15.84 ± 1.97	< 42.9	4.94 ± 0.86	< 0.57	< 36428
SS Bolts	0.7449	3.42 ± 1.10	< 63.11	< 1.40	< 0.79	< 38239
HDPE	0.6866	2.85 ± 0.66	< 25.16	15.63 ± 0.94	< 0.26	< 860.70
Cirlex PCBs	0.0107	< 42.74	< 339.20	< 7.47	< 11.52	< 19240
FBK SiPMs	0.0135	< 6.48	< 15.80	< 2.03	< 1.24	< 263.40
Fused Silica	0.0321	13.90 ± 5.16	58.72 ± 31.83	< 0.45	< 0.92	< 1175

Components counted by the SNOLAB Low Background group using HPGe detectors.

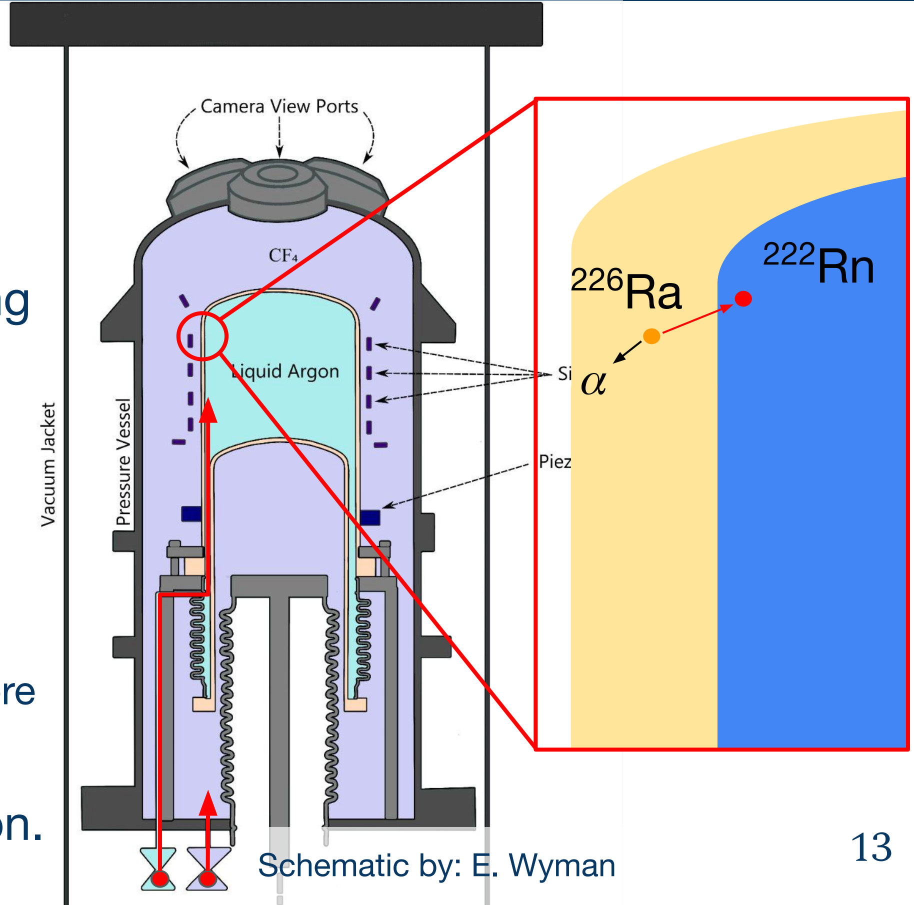
Internal Backgrounds – (α,n) in CF_4

- Large (α,n) cross-sections on ^{19}F & ^{13}C are problematic.
- α-decay from surfaces adjacent to CF_4 can result in neutron production.
- Estimate the α-emissivity by counting material samples with XIA at SNOLAB.
- Emissivity measured as a function of surface area [$\alpha \cdot s^{-1} \cdot cm^{-2}$].
- Neutron production rate and energy spectra estimated using NEUCBOT[2].



Radon Control

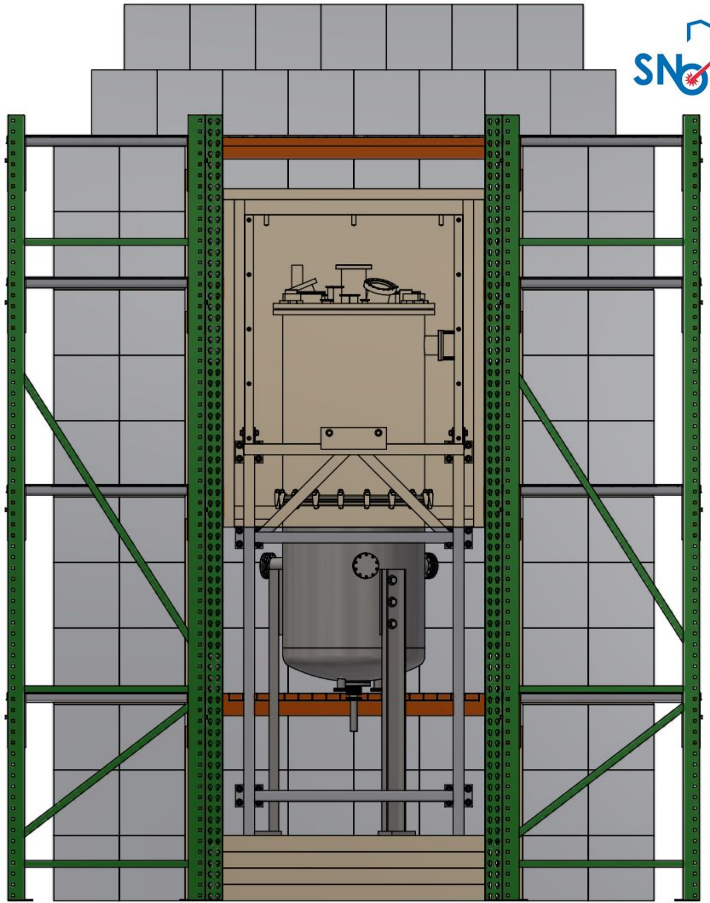
- Radon diffusion is suppressed from cryogenic temperatures.
- Emanation is still possible from O(um) deep emissions (Ra-decay) in surrounding materials.
  - Materials in contact with CF_4 and argon to be measured for Rn emanation.
- Radon can also seep in through warm areas → gas handling systems (GHS).
  - GHS fit with Rn-traps to remove radon before entering active areas.
- Activity limits currently under investigation.



Schematic by: E. Wyman

Summary and Outlook

- Material selection is essential for rare event searches → minimize internal backgrounds.
- SBC has a very mature radiopurity program with majority of materials gamma counted and alpha counted.
- External shield design well underway with hopes to begin construction and operation in 2026.
- Exciting time for both SBC-LAr10 and SBC-SNOLAB!



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Université de Montréal

Pacific Northwest National Laboratory

UC Riverside

Thank you!

Merci!

References

[1]W. Wilson et al., *Sources: A code for calculating (alpha, n), spontaneous fission, and delayed neutron sources and spectra*, Progress in Nuclear Energy 51, 608 (2009).

[2]S. Westerdale and P. Meyers, *Radiogenic neutron yield calculations for low-background experiments*, Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment 875, 57–64 (2017).

Purpose and Effects of Xenon Doping

- Argon scintillation light is really hard to transmit through fused silica → doping with xenon shifts peak from 128 nm to 175 nm.
- FBK VUV-HD3 SiPMs have high sensitivity at 175 nm.
- Also expected to slightly improve the scintillation light yield
- SBC is aiming for a doping level of 10-100 ppm of xenon → optimize xenon emissions.
- Potential for PSD capabilities to add another method of veto (ER vs NR).

arXiv.2112.07427