# Emanation and Diffusion of Radon through Gaskets for SuperCDMS SNOLAB

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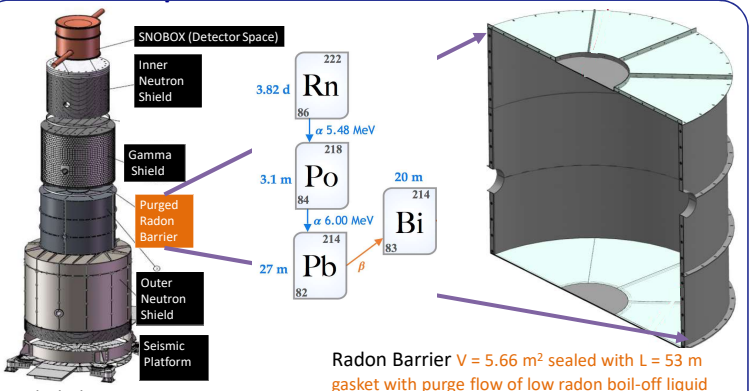
The SuperCDMS SNOLAB experiment, currently under construction, will attempt to directly detect dark matter particles. Shielding surrounding the experiment's detectors will reduce interactions of particles from radioactivity and cosmic rays. A gas purge will remove radon from gaps in the shielding to reduce backgrounds further. Gaskets used to seal this purge volume must allow sufficiently low radon diffusion through them while emanating little radon into the purge volume. Radon diffusion, solubility, and permeability were inferred by measuring the time-dependent radon concentration in a volume separated by gaskets made of EPDM, Zip-A-Way, and Silicone. Although the silicone tested has better radon properties, EPDM also is sufficient and is easier to use, and so EPDM will be used for the SuperCDMS radon barrier, with ZIP-A-Way used to reduce diffusion and patch leaks.

## SuperCDMS SNOLAB Shield




Exploded View of SuperCDMS shielding

Radon Barrier V = 5.66 m² sealed with L = 53 m gasket with purge flow of low radon boil-off liquid nitrogen to prevent backgrounds form high-energy gammas.

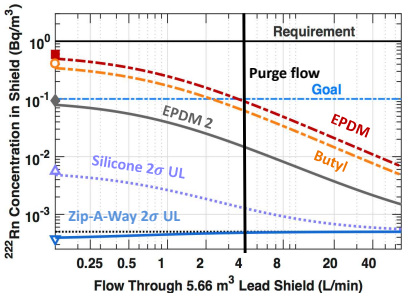
- The SNOLAB detector is 6800 ft below the surface to reduce backgrounds from cosmic rays and muons. Lead shielding reduces the flux from cavern gammas by $10^6\times$.
- Radon concentration in SNOLAB cavern is ~130 Bq/m³. Radon daughters produce high-energy gammas within shielding.
  - Without the purged radon barrier, the background from radon daughters would be the largest background source for the experiment.
- Goal is to make this background negligible (<1/50 of total background).
  - Met at 1 Bq/m³ inside shield.
  - Radon emanating from and diffusing through the gaskets needs to be small. Purge barrier consists of aluminum with negligible radon emanation.

$$\frac{dC}{dt} = \frac{F}{V}(C_{LN} - C) + \frac{1}{V}(A\varphi + \lambda E) - C\lambda \qquad C = \frac{FC_{LN} + (A\varphi + \lambda E)}{\lambda V + F}$$

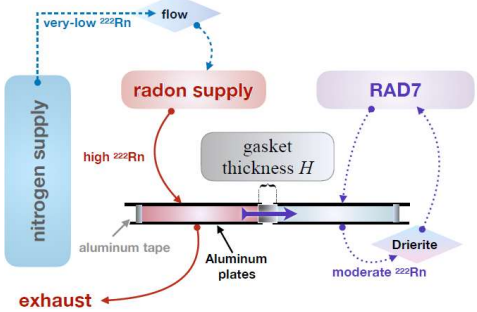
- V = 5.6 m³ (Shield Volume)
- F = 5 liter/min (Purge Flow)
- A = 0.27 m² (Gasket Surface area)
- λ= 1/5.52 days (Rn decay constant)
- C < 1 Bq/m³ (Rn concentration in shield)
- $C_{LN}$ = Rn concentration in purge gas [Bq/m³]
- φ = Rn diffusion through gasket [Bq / (m²s)]
- E = Rn emanation [mBq]

## Radon Emanation Within SuperCDMS Shielding

- Measured Emanation from several gaskets at SDSMT.
- All tested gaskets have acceptable based on emanation for planned purge flow (~5 L/min).
- $C = \frac{FC_{LN}+(A\varphi+\lambda E)}{\lambda V+F}$




## Diffusion Setup




- **Nitrogen gas flows through radon supply into high-radon zone.**
  - **R = 117 kBq**
  - **($C_H$ = 14.6 Bq/min /F)**
- **Radon diffuses through gasket of thickness H into low-radon zone.**
- **RAD7 takes time-series data in low-radon zone in a continuous loop with a drying column.**

## Mathematics of Radon Diffusion

Radon concentration in membrane (without) W(x,t) and (with) U(x,t) decay.

$$\frac{dW}{dt} = D\frac{d^2W}{dx^2} \qquad \frac{dU}{dt} = D\frac{d^2U}{dx^2} - \lambda U$$

Assume boundary conditions for U and W (H = Thickness C = Concentration).

$$W = 0,\ X = 0,\ t \geq 0$$
$$W = C,\ X = H,\ t \geq 0$$
$$W = 0,\ 0 < X < H,\ t = 0$$

Danckwerts [1] showed a relation between U and W.

$$U = \lambda \int_0^t W\exp(-\lambda t')dt' + W\exp(-\lambda t)$$

The radon activity y(t) in the low Rn zone obeys [2].

$$\frac{dy}{dt} = -\lambda y + AD\frac{dU}{dx}\Big|_{x=0}$$

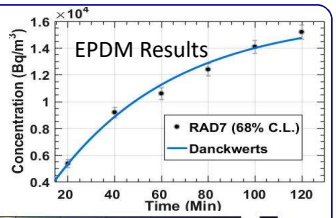
The analytic solution has been used by [2] :

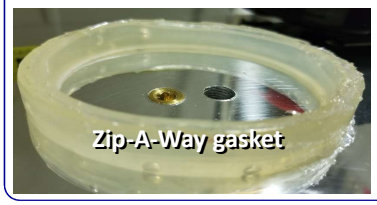
$$y(t) = \frac{ADCS}{H\lambda V}[1 - \exp(-\lambda t) + 2\sum_{n=1}^{\infty}(-1)^n\left(\frac{\lambda}{\beta}\right)(1 - \exp(-\beta t))]$$

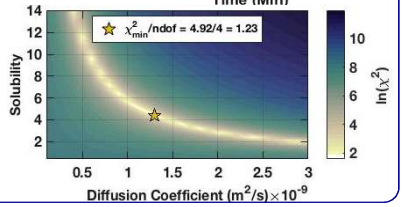
- A = Gasket surface area (inner low Rn)
- D = Diffusion coefficient
- H = Gasket thickness
- C = Concentration in high-Rn zone
- β = λ + (D(nπ)² / H²)
- t = Time
- S = Solubility
- λ = decay constant (1/5.52 days)

## Diffusion Results

- **EPDM 2:** P = D x S = (5.8 ± 0.1) x $10^{-9}$ m²/s
  - Diffusion Length = √(D/ λ) < 5 cm
  - **Literature:** √(D/ λ) = 1.1 cm [3]
- **Zip-A-Way:** P = (2.5 ± 0.1) x $10^{-10}$ m²/s
  - Diffusion length = √(D/ λ) ~ 11 mm
- **Silicone:** P = D x S = (2 ± 0.2) x $10^{-9}$ m²/s
  - Diffusion Length = √(D/ λ) ~ 2.6 mm



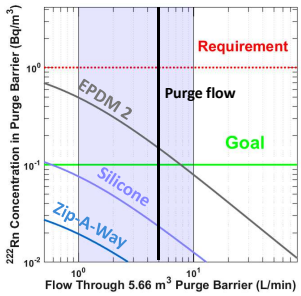




## Conclusions

**The results indicated that**

- Gaskets tested have low enough emanation.
- Radon diffusion through 1 cm EPDM 2 gasket is 10x higher than its emanation.
- Plot shows radon diffusion and emanation through H = 15 mm gasket
- EPDM 2 is a practical solution for radon shield gasket.
- Zip-A-Way can be used to patch or bolster areas in the gasket.




## References

[1] Danckwerts, P. V. "Absorption by Simultaneous Diffusion and Chemical Reaction into Particles of Various Shapes and into Falling Drops." *Transactions of the Faraday Society*, vol. 47, 17 Jan. 1951, pp. 1014–1023., doi:10.1039/tf9514701014

[2] Wójcik, M, et al. "Radon Diffusion through Polymer Membranes Used in the Solar Neutrino Experiment Borexino." NIM A, vol. 449, no. 1-2, 11 July 2000, pp. 158–171., doi:10.1016/s0168-9002(99)01450-3.

[3] Jiranek, Martin, and Jiri Hulka."Radon Diffusion Coefficient in Radon-Proof Membranes–Determination and Applicability for the Design of Radon Barriers." International Journal on Architectural Science 1.4 (2000): 149-155.

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