^{222}Rn reduction and evaluation gas system for rare search events experiments

Kirill Pushkin
on behalf of the LZ collaboration

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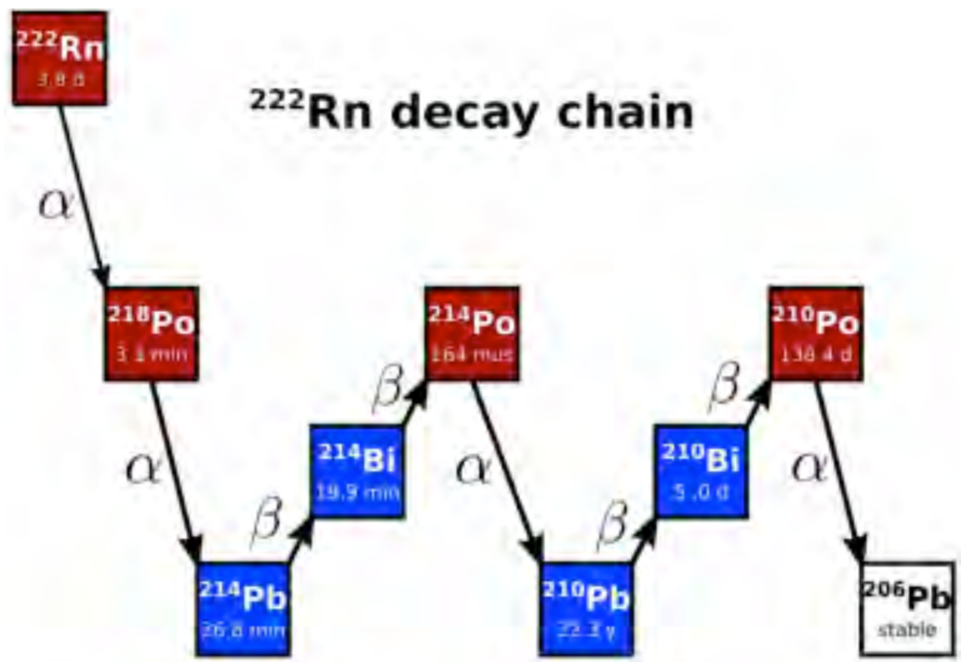
Contents

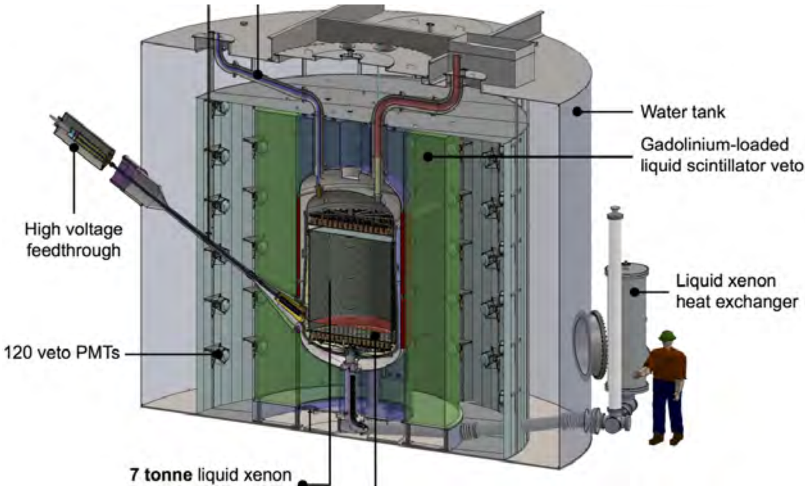
- Motivation
- Goals
- Prototype ^{222}Rn reduction and evaluation system
- Experimental results
- Summary and future plans

Motivation

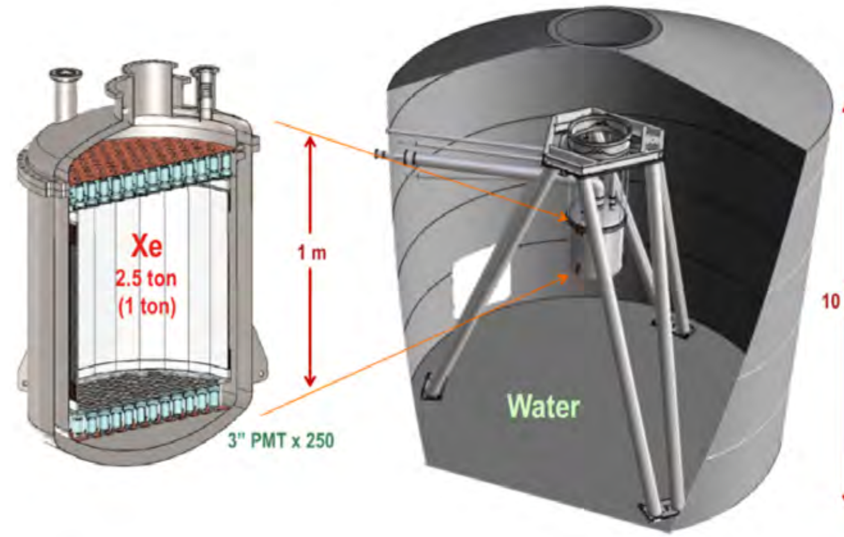
- ^{222}Rn is a colorless, odorless noble gas that cannot be removed from the Time Projection Chambers media targets by conventional methods such as hot gas purification getters.
- ^{222}Rn is resupplied continuously from ^{238}U nuclei from the detector components (e.g. cables, dust, etc.). It has high mobility to diffuse throughout the target volume of the TPCs, which undermines the power of fiducialization.
- ^{222}Rn reduction techniques are of essence for the current G2 DM, future G3, and Neutrinoless Double Beta Decay (NDBD) low background experiments.



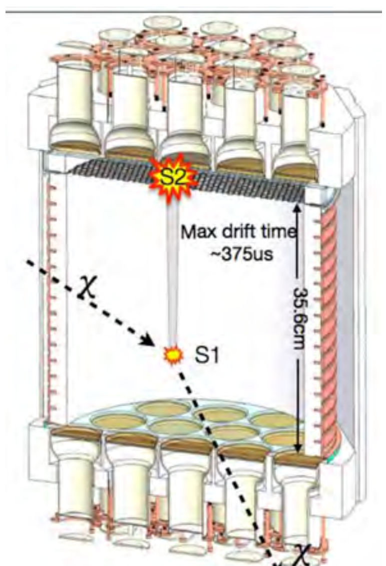
DM (G1&G2) and NDBD experiments



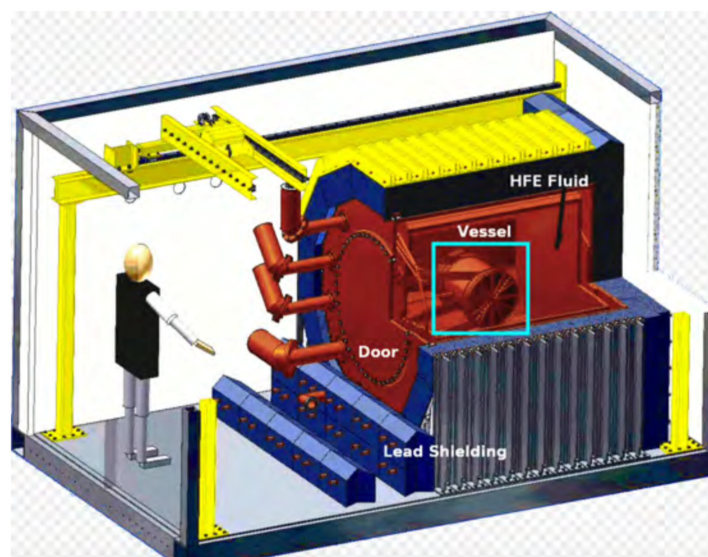
LZ (LUX-Zeplin), (G2, LXe)



Xenon-1T, (G2, LXe)

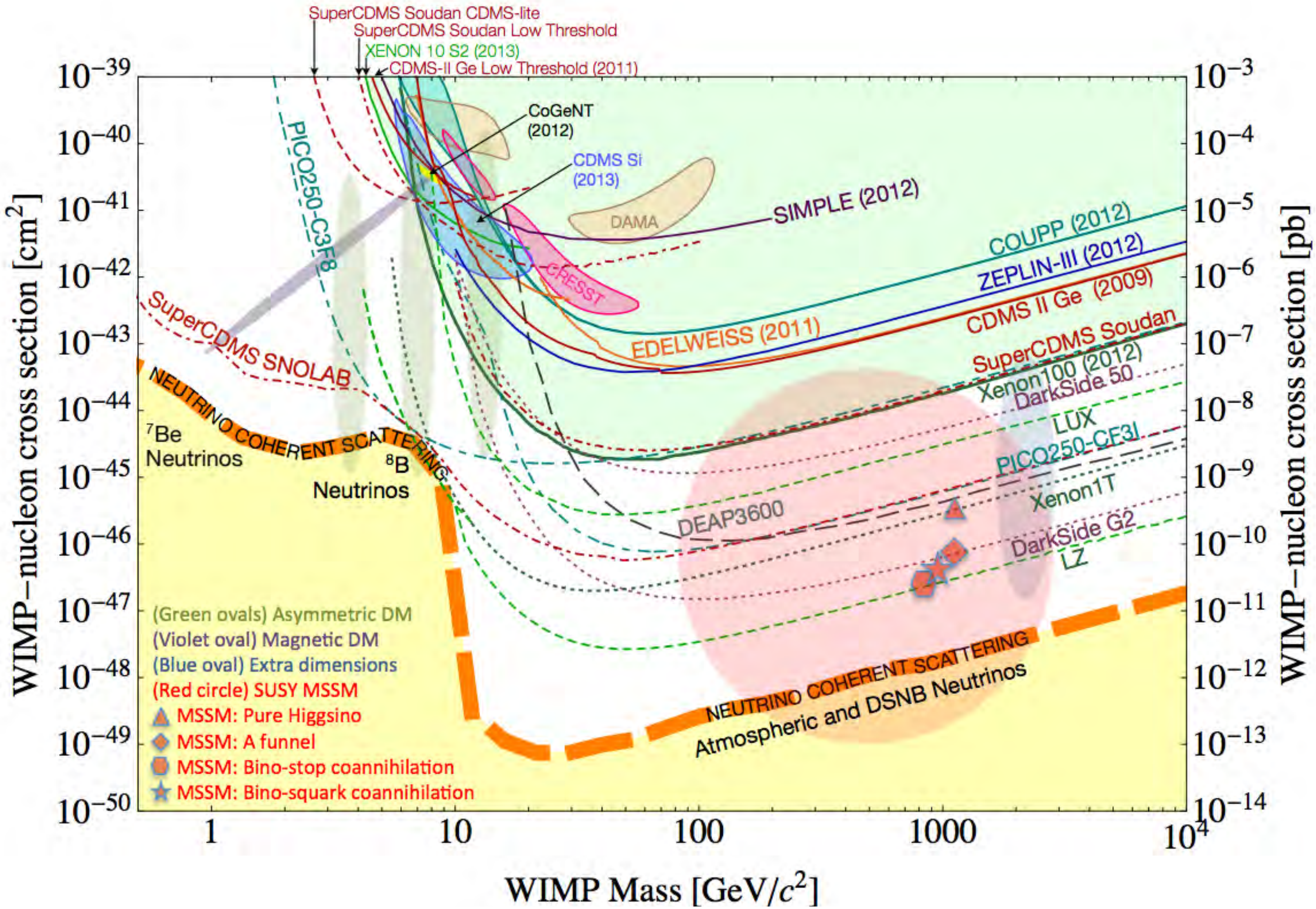


DarkSide-50, (G1, LAr)



EXO-200, (NDBD, LXe)

Compilation of WIMP-nucleon spin-independent cross-section limits and hints for WIMPs



G3 Dark Matter experiment

- Unless DM particles have been discovered in the G2 experiments, we might need the next generation of a DM detector or detectors with larger amounts of targets media (LXe/Lar).
- Stringent background limits (production and selection of materials).
- ^{222}Rn, in particular, must be significantly suppressed to focus on solar and atmospheric neutrinos backgrounds.

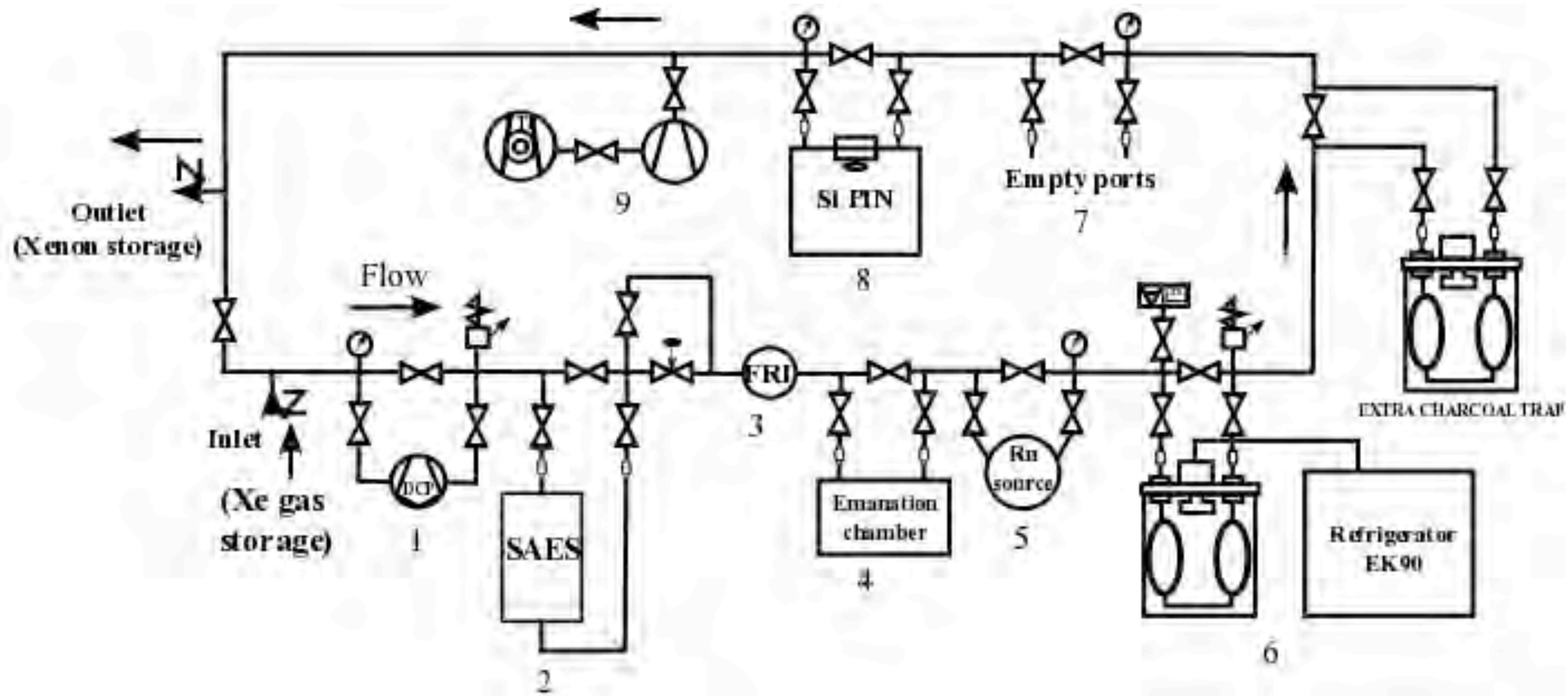
Goals for the prototype radon reduction system

- Study ^{222}Rn breakthrough times and other adsorption characteristics in N_2, Ar and Xe carrier gases through varied types of charcoals.
- Study ^{222}Rn adsorption properties at various mass flow rates of the carrier gases.
- Study adsorption properties at various low temperatures of the charcoal trap columns.
- Study ^{222}Rn recoil emanation from the investigated charcoals used as ^{222}Rn adsorbing elements.

Goals for the final radon reduction system

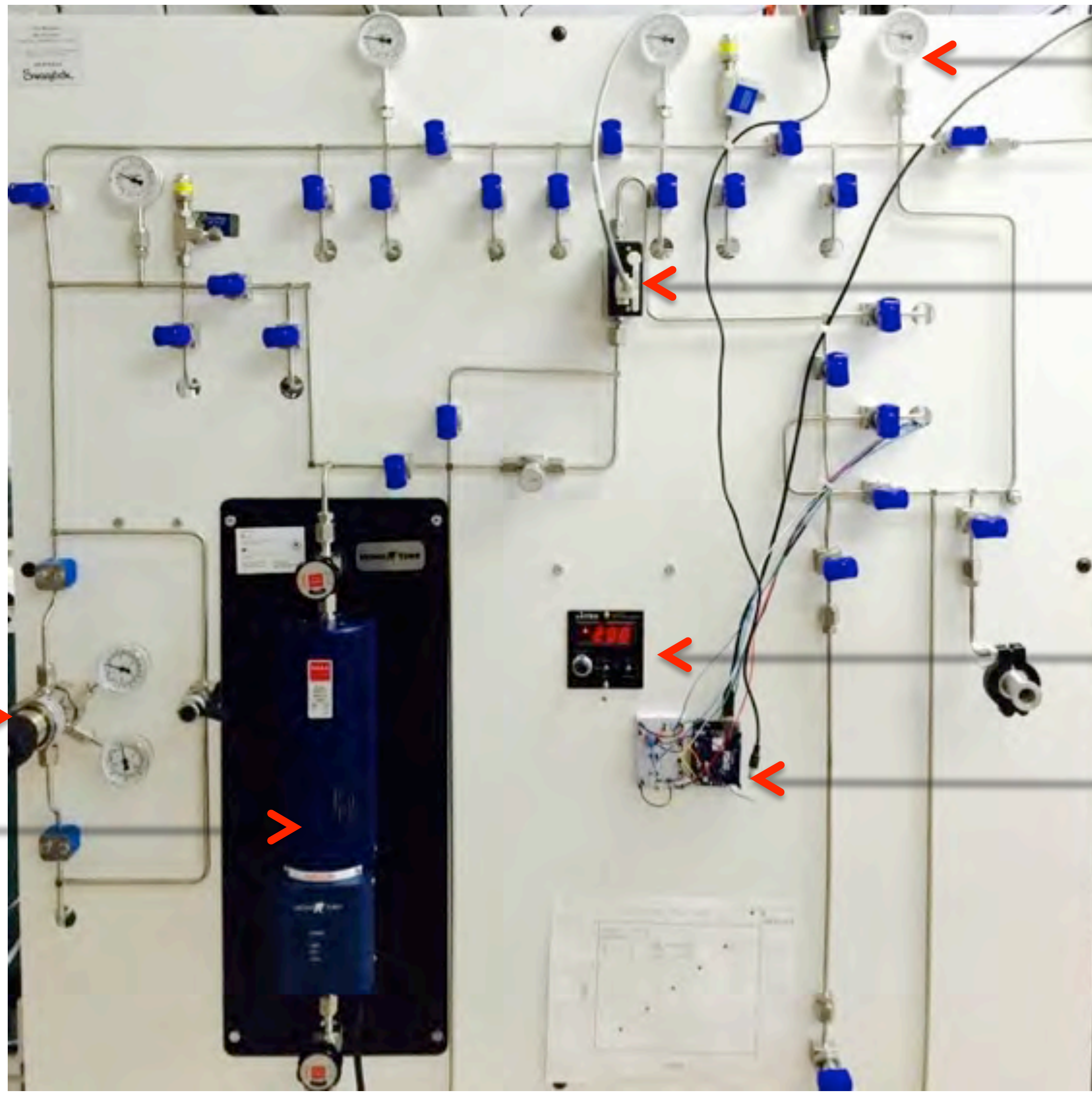
- Build a clean radon reduction system.
- Based on the R&D results, evaluate a charcoal trap column to reduce radon by desired amounts for the present G2 and future G3 DM and NDBD experiments.

Prototype radon removal system



1: Diaphragm (circulation) pump
2: SAES high temperature gas purification getter
3: Gas mass flow meter
4: Emanation chamber with ^{238}U ores
5: Radon source (Pylon source, 103.6 kBq)
6: Cryo-dewar with charcoal trap
7: RAD7 radon detector
8: In-house radon detector
9: Vacuum pumping station

Prototype radon removal system



Pressure gauge(s)

MKS flow meter

MKS flow controller

Gas regulator

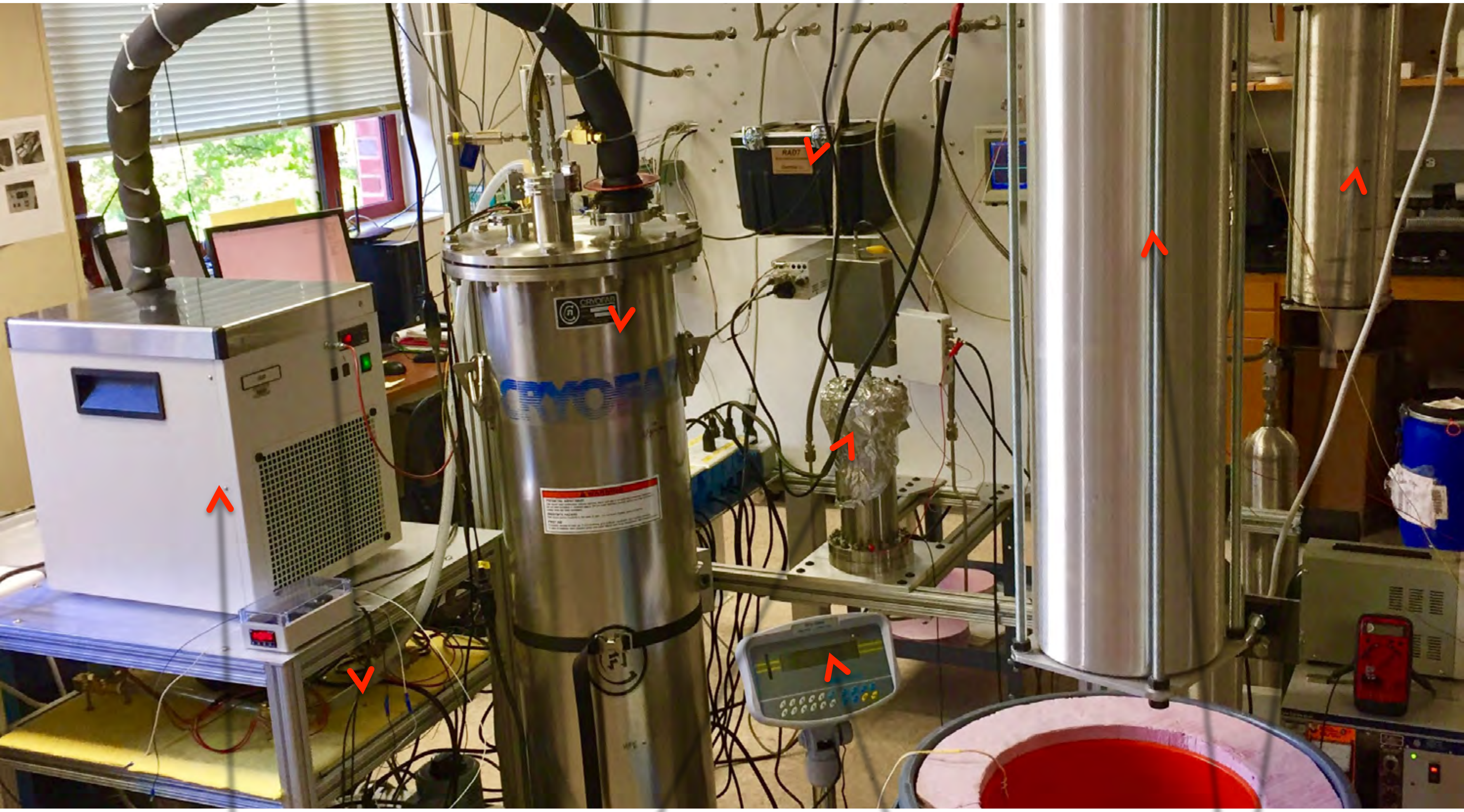
SAES getter

SC boards

Novec7100 fluid electric pump

Cryostat (Charcoal trap inside)

RAD7 (^{222}Rn in N_2 and Ar)



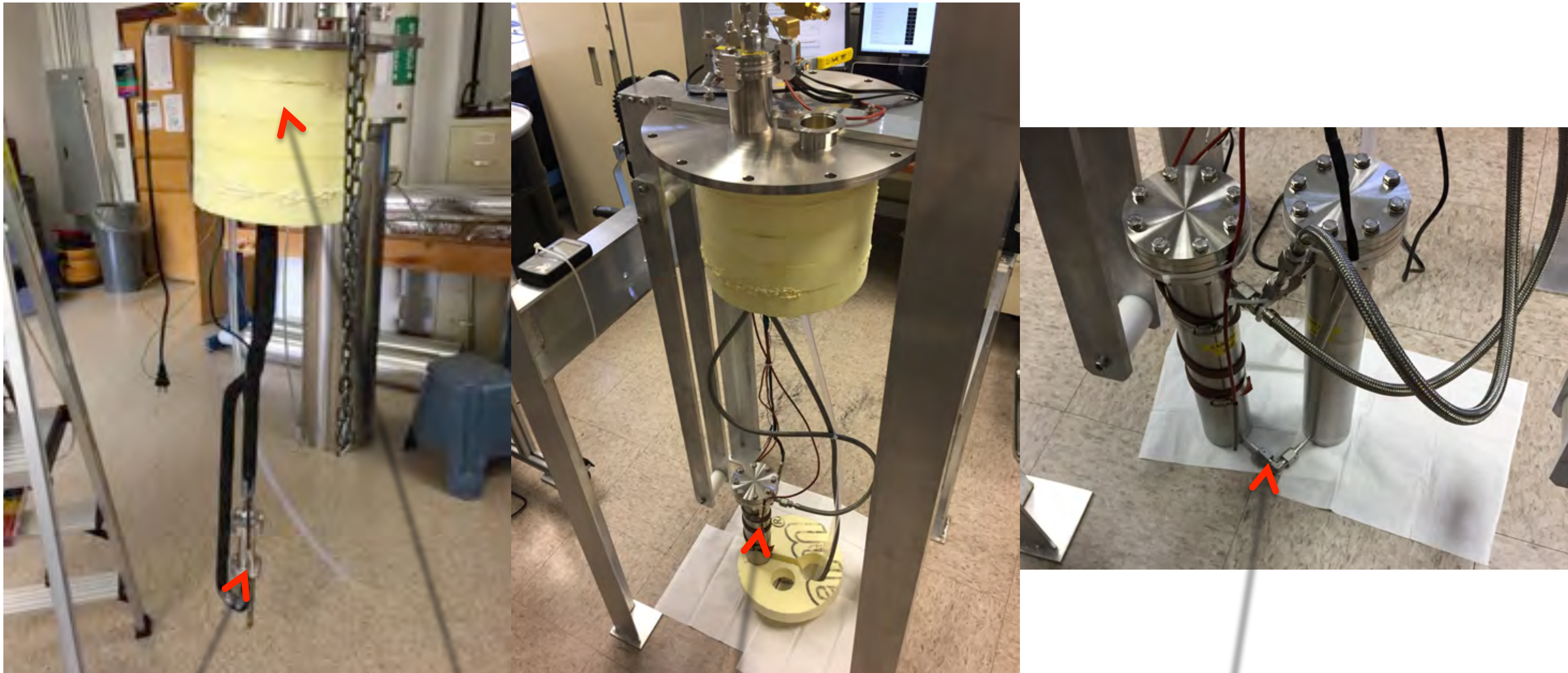
EK-90 cooler (Novec7100 fluid)

UHV in-house detector (^{222}Rn in Xe)

Scales

Xe gas storage bottles

^{222}Rn trap columns



Polystyrene

Charcoal trap column (0.11 L)

Charcoal trap column (1.1 L)

Charcoal trap column (2.2 L)

Investigated ^{222}Rn adsorbers

Carbon	Bulk Density (g/cm^3)	Surface Area (m^2/g)	Size (mm)	Shape
OVC (4x8), Calgon	0.45	1100	3.0 - 8.0	Flake
Shirasagi, G2x4/6-1	0.40 - 0.47	1237	3.0 - 5.0	Cylinder
Saratech, Blucher	0.6	1342	0.5	Sphere
Carboact	0.28	800 - 1200	0.4 - 2.0	Fragmented

^{222}Rn recoil emanation from the used charcoals

PRELIMINARY!

Carbon	**Shape**	**Specific Activity** (mBq/kg)
Calgon OVC 4x8	Flake	53.6 ± 1.3
Shirasagi G2x4/6-1	Cylinder	51.7 ± 3.9
Saratech	Sphere	1.87 ± 0.25
Carboact	Fractured	0.33 ± 0.26

Elution curve measurements

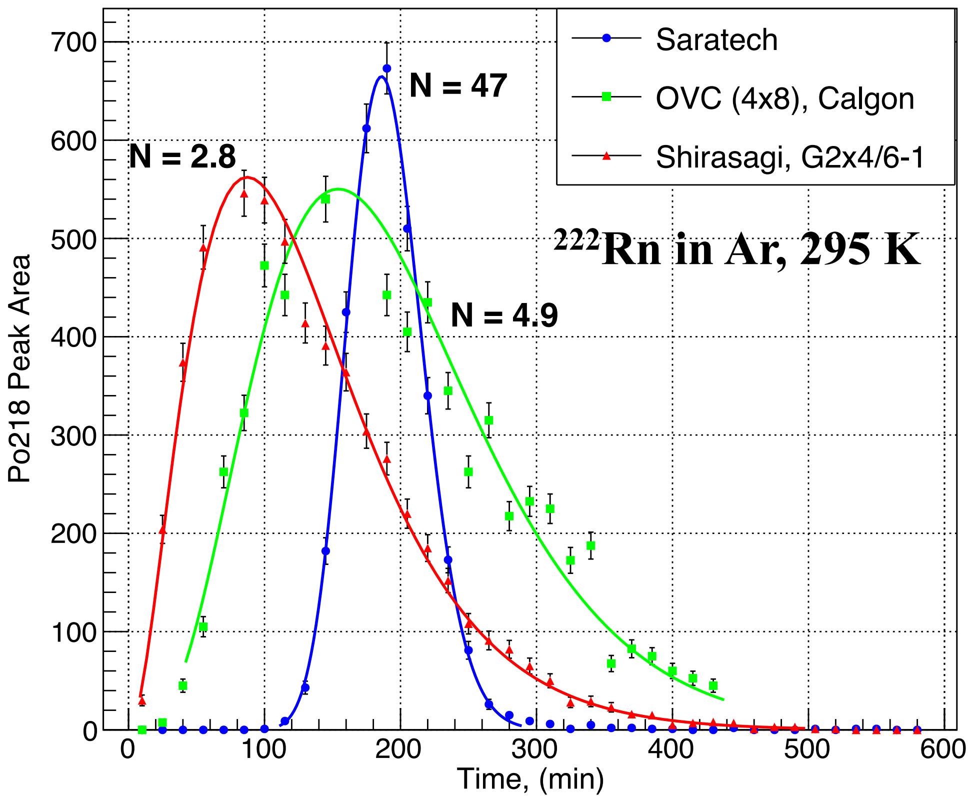
Elution curves were fitted with function based on the chromotographic plate model for radon "spike" input:

$$y\left(\frac{t}{\tau}\right) = \frac{\alpha N^N}{(N-1)!}\left(\frac{t}{\tau}\right)^{N-1} \exp\left(-\frac{Nt}{\tau}\right)$$

where τ (p2) – breakthrough time in minutes, α (p0) – the amplitude of input δ - function and N (p1) – the number of theoretical stages. The maximum of the elution curve is at:

$$t_{\max} = \frac{N-1}{N}\tau$$

$$\sigma_\tau = \frac{\tau}{\sqrt{N}}$$ **- experimental error for radon breakthrough time, τ**

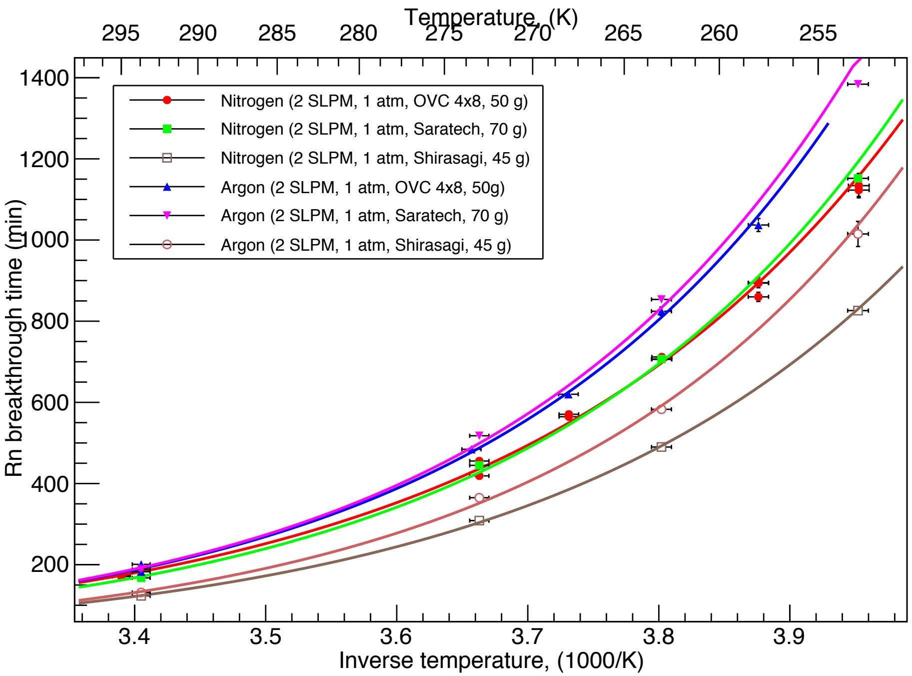


^{222}Rn breakthrough times vs inverse temperature

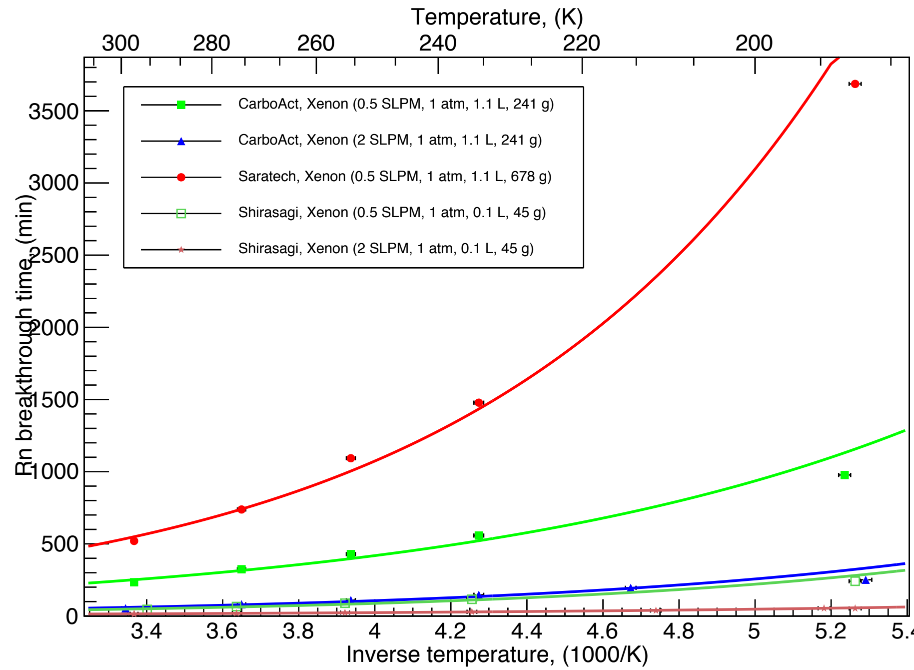
$$k = A\exp\left(-\frac{E_k}{k_b T}\right) - \text{Arrhenius equation},$$

k-rate constant, E_k-activation energy (J),

k_b-Boltzman constant (J/K), T-temperature (K)



^{222}Rn in Ar and N_2



^{222}Rn in Xe

^{222}Rn in Ar and N_2: Follows the Arrhenius relationship well.

^{222}Rn in Xe: Follows the Arrhenius relationship up to 4.25 1000/T. **Hypothesis**: Due to charcoal saturation effects.

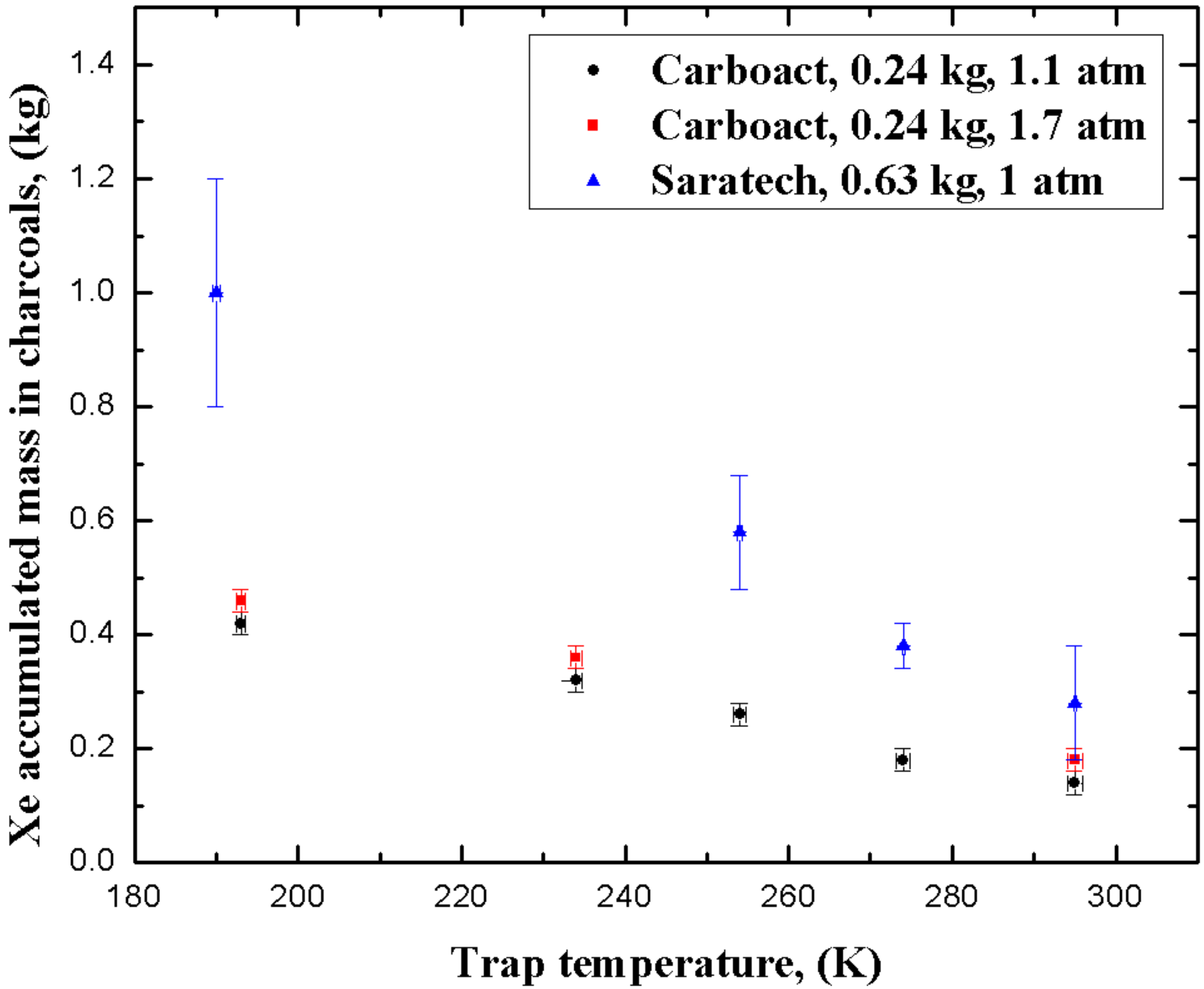
^{222}Rn adsorption coefficients on various charcoals measured in Xe carrier gas

PRELIMINARY!

Carrier Gas	Charcoal Type	k_a(L/g)				
		295 K	273 K	253 K	233 K	190 K
Xenon (0.5 SLPM)	CarboAct	0.49±0.02	0.67±0.03	0.89±0.04	1.15±0.06	2.03±0.10
	Saratech	0.41±0.02	0.58±0.03	0.86±0.04	1.17±0.06	2.93±0.15
	Shirasagi	0.51±0.03	0.73±0.04	0.99±0.05	1.3±0.06	2.30±0.12
Xenon (2 SLPM)	Shirasagi	0.64±0.03	0.87±0.04	1.06±0.05	1.30±0.07	2.34±0.12

Where k_a is the adsorption coefficient

Mass accumulation of Xe in the charcoal trap columns



Charcoal trap parameters

- Chromatographic plate model:

$$\tau_b = \frac{k_a m}{F},$$

k_a-adsorption coefficient, m-carbon mass (g),

$\tau_b - \textit{breakthrough time}$ (min), F-flow rate (SL/min)

^{222}Rn activity from detector

^{222}Rn activity from charcoal

$$N_{total} = N_{in} e^{-\frac{k_a m}{F\tau}} + S_0 F \frac{\tau}{k_a}(1 - e^{-\frac{k_a m}{F\tau}})$$

N_{in}-initial background activity in mBq, τ-average ^{222}Rn half-life,

S_0- ^{222}Rn recoil emanation per kg

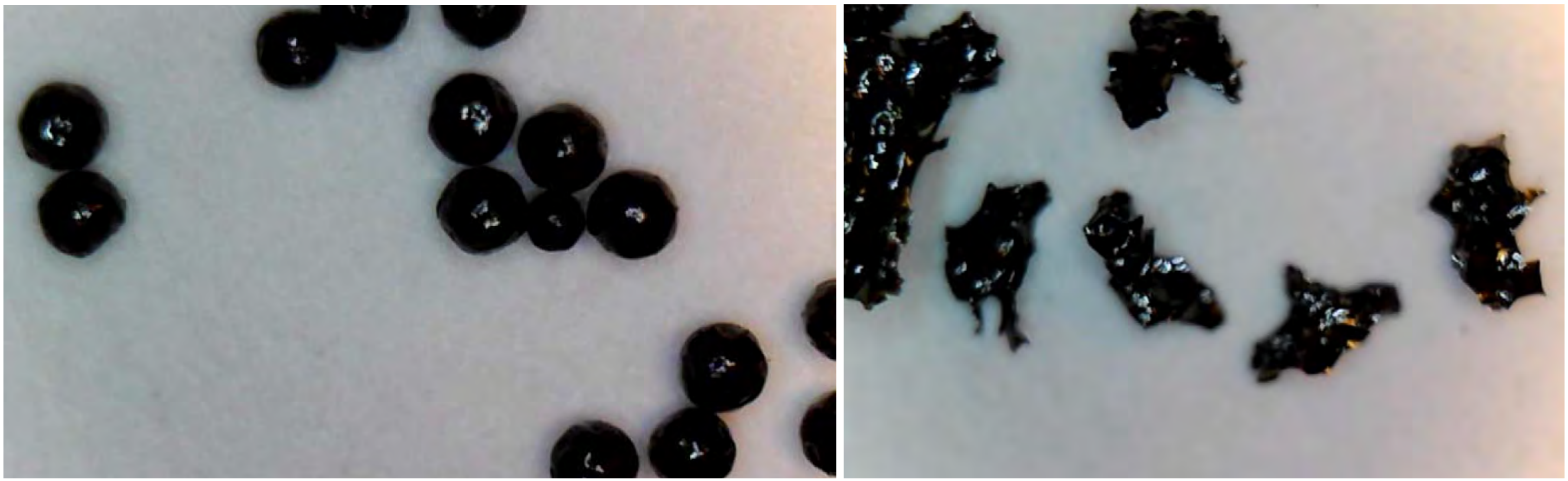
- Based on the measurements and the relationships posted above, it would require ~2.1 kg of Saratech charcoal to remove ^{222}Rn from N_2 gas or 1.45 kg to remove ^{222}Rn from Ar gas by at least 90% at a temperature of the trap of 253 K (F=2 slpm). On the other hand, if the temperature of the trap were to be lowered down to -85°C with the mass of Saratech, 70 g, ^{222}Rn would completely decay away in N_2 or Ar carrier gases.

- It would require ~7.2 kg of Carboact at a temperature of the trap of 190 K (F=0.5 slpm) to remove ^{222}Rn from Xe by 90%.

Summary

- We have measured ^{222}Rn breakthrough times in N_2, Ar, and Xe carrier gases through various charcoals in the range of 295-190K.
- ^{222}Rn breakthrough times in N_2 and Ar gases are longer even in moderately sized charcoal columns measured at 253 K.
- On the contrary, ^{222}Rn breakthrough times in Xe gases are faster relative to N_2 and Ar due to strong attraction of Xe atoms resulting in the occupation of most of the surface area of the adsorbing elements inside the trap column.
- Based on these measurements, it was shown that the shape of the charcoal granules has a large impact on the shape of the experimental elution curves (τ vs 1000/T) as ^{222}Rn breaks through the trap column, i.e. the more uniform the granules of the adsorbing element are the larger its surface area to the volume of the column would be (no air pockets) which can result in smaller uncertainty for the average radon breakthrough times (τ_b).
- Since the shapes of the elution curves for different charcoals brands vary, these factors can be mitigated by employing a hybrid trap system consisting of different charcoals (Carboact + Saratech) which would meet the sensitivity limits of the experiments and make the trap system cost effective.
- Other chemical purification methods are being investigated to allow reducing the natural radioactivity of relatively cheap adsorbing elements (e.g Saratech).
- The current concept of ^{222}Rn mitigation is very promising for the current and future G3 DM and NDBD low background experiments. However, further serious investigations are required.

Backup slides



(a) (b)

Microscopic images of Saratech (a) and Carboact (b) charcoals