Ex-situ measurement of radon emanation for ultra-low background experiments

Pushparaj Adhikari
Carleton University

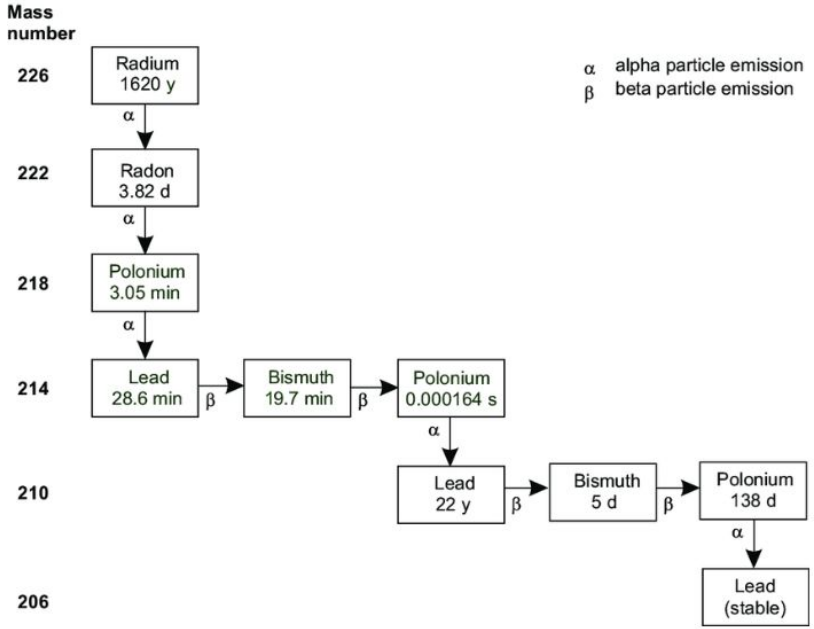
Carleton UNIVERSITY

Outlook

- Radon emanation into vacuum
- Radon measurement in gas
- Diffusion of radon daughter

Radon facts

- Half life of Rn-222 : 3.8 days
- Emanated from the breakdown of naturally-occurring radioactive elements (such as uranium and thorium) in soils and rocks (and detector materials).
- Radon and its daughters are diffuse from the material surface.
- Harmful to ultra low background detectors : Alpha decays from the subsequent Po-218, Po-214, and Po-210



Radon Emanation System

- It consists of an emanation chamber, two radon traps and a LUCAS cell for the sample collection.
- The system works on three steps,
- **Emanation:** The sample materials stay for several days in the emanation chamber.
- **Extraction:** Extract the Radon gas collected on the chamber to the LUCAS cell.
- **Measurement:** The alpha activity of the LUCAS cell in the counter slot.
- An optional adaptor for radon collection from gas is connected to the chamber

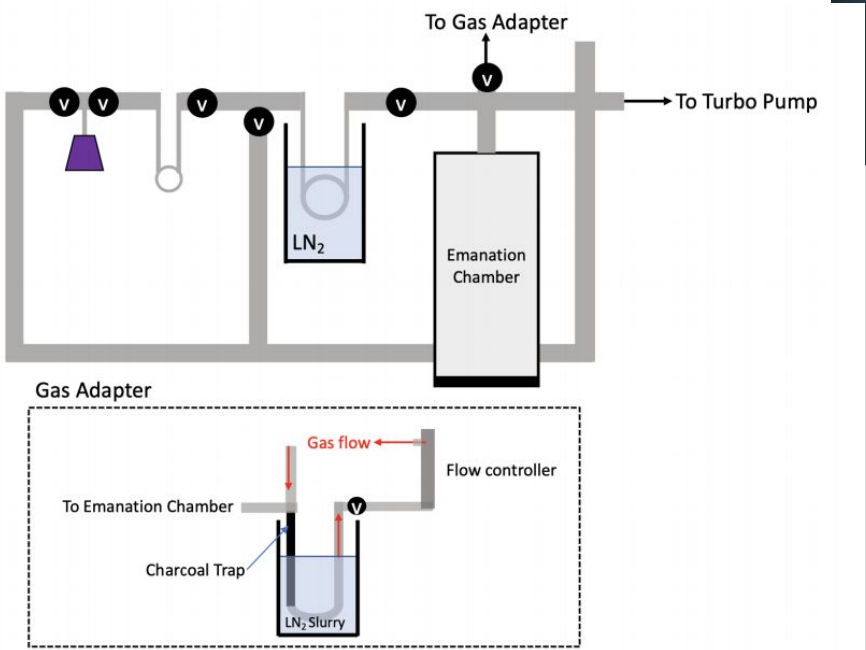


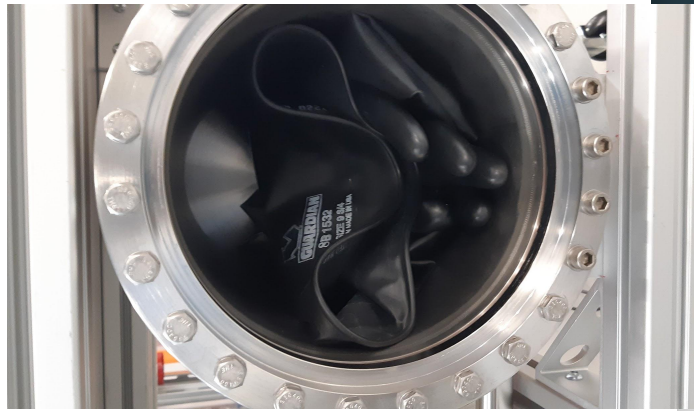
Figure 1: Radon Emanation chamber and gas handling system (top) and optional gas counting adapter (bottom).

Measurement

- Extraction and data collection is performed 4, 5 times in couple weeks until the steady rate is observed.
- The alpha counted in counter slot gives the radon emanation rate from the material

$$N = \frac{n_1}{(1 - e^{(\lambda/\tau)*t)}) * 3 * eff}$$

where, N= number of radon emanated from the sample.
n_1 = number of alpha events observed by the counter.
λ = decay constant.
τ = half life of radon.
eff = Efficiency of the radon emanation system/



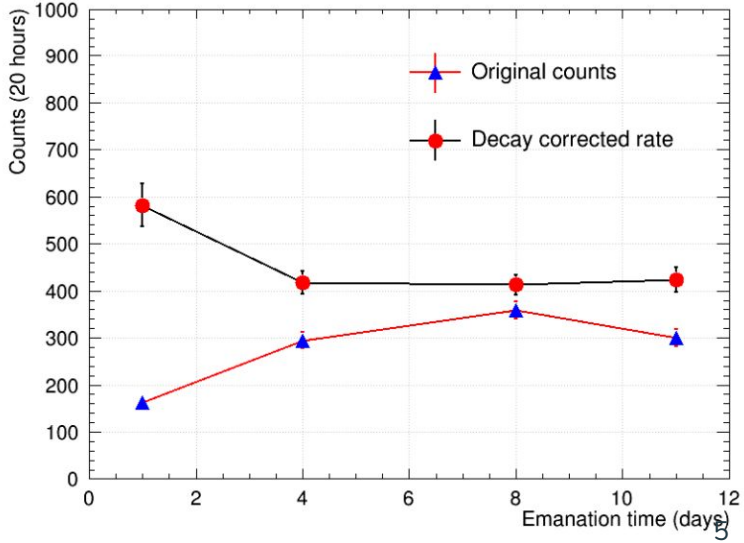


Figure 6: Radon rate for the two butyl gloves that has been using for the glove box.

Measurement summary

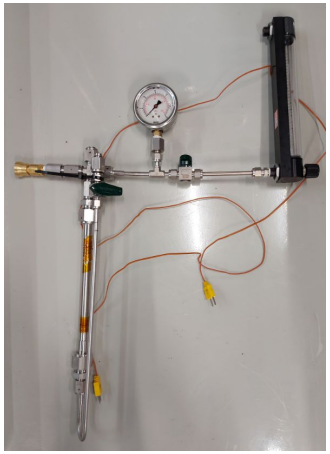
Table 1: Material Assay Results

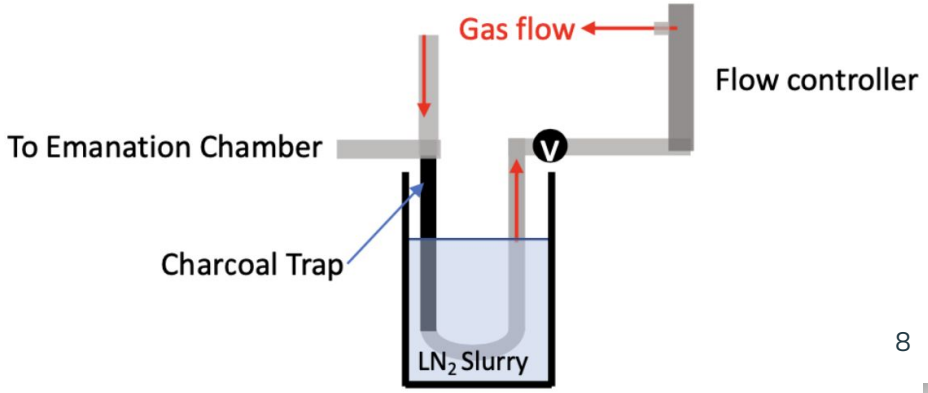
Material Name	**Sample Quantity**	**Emanation Rate (atoms/hr)**
Silicone gasket	1012.46 cm2	141.2±28 /m2
Butyl gasket	712.1 cm2	186.5±37 /m2
Buna gasket	712.1 cm2	31714.6±1400 /m2
Butyl glove	2	10±2 per glove
EPDM O-ring	588 cm	11±2 per m

Radon measurement in gas

Charcoal trap for the gas measurement

- Consists of the 20 cm long activated charcoal tower (0.5’’ diameter).
- Activated charcoal traps the radon atoms from the gases.
- Measure the radon concentration in the Nitrogen gas and also the radon emanation rate from the glove box.





Radon load calculation in glovebox

- Glove Box is used to sanding and coating flow guides used for DEAP-3600 hardware upgrade. Sean Daugherty's talk (June 9)
- Expected radon emanation from each materials in glove box are measured/calculated.
- Expected radon emanation rate from the glovebox is agreed with the measurement from the nitrogen gas flow through glovebox.

Materials in glovebox	Expected emanation rate (atoms/hr)
Gloves *4	20
Lexan window	2
Stainless steel	1
Tygon tube	1
Silicone sealant	1
EPDM O-ring	20
EPDM gasket	170
Total	215

Table 3
Nitrogen gas assay results(charcoal trap)

Nitrogen Gas Flow	Flow Rate (LPM)	Time (hr)	Counts (20 hr)	Alpha Rate (μBq/m3) (Eff and bkg corrected)	Radon Emanation Rate in Glove Box (atoms/hr)
Dewar	2.4	7	61	1264±200	
Dewar	2.4	7	40	744±185	
Dewar and glove box	2.4	7	209	4960±760	178±27
Dewar and glove box	2.4	7	237	5630±844	203±30

Radon daughter’s diffusion

Motivation

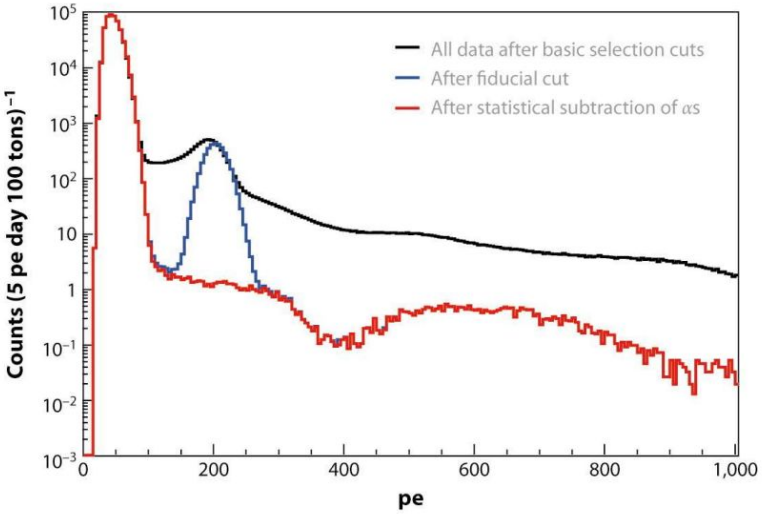
- Daughters of Rn-222 which is known to deposit on and diffuse into surfaces, leading to sustained backgrounds supported by the decay of long-lived 210Pb.

$$^{210}\mathrm{Pb} \xrightarrow[32.2\mathrm{y}]{\beta} {}^{210}\mathrm{Bi} \xrightarrow[7.23\mathrm{d}]{\beta} {}^{210}\mathrm{Po} \xrightarrow[199.63\mathrm{d}]{\alpha} {}^{206}\mathrm{Pb}.$$

- Surface background rates from Po-210 α-decays in Borexino, DEAP3600 and MiniCLEAN shows the significant disagreement between expected background rates and those observed.
- A model including the diffusion of polonium in detector materials can explain the experimental results.

Borexino : Expected surface alpha background <0.25 uBq/m2

Borexino data



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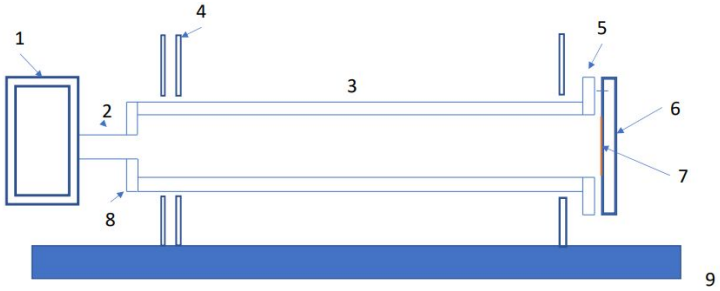
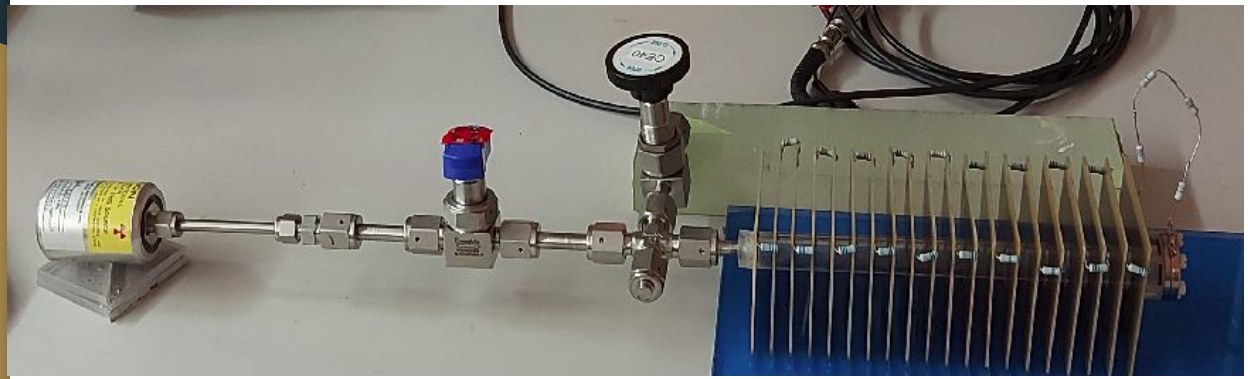
Experimental setup at Carleton

- Preparing the Pb-210 source on the thin Nylon/acrylic/metal film.
- Pb-210 will be deposited on the thin film from a radon source in an electric field excitation.
- Diffusion of deposited Pb-210 sample is monitored in an ORTEC alpha counter.



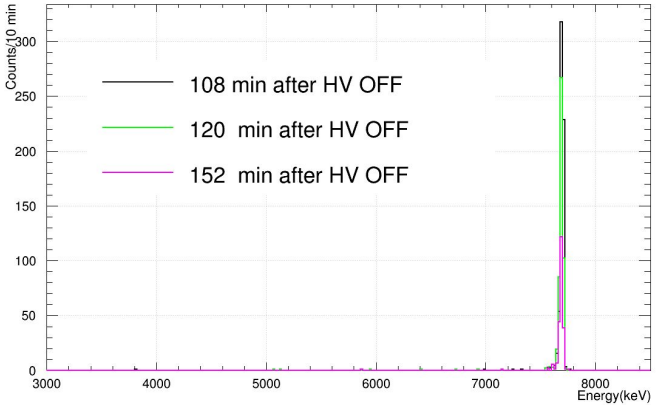


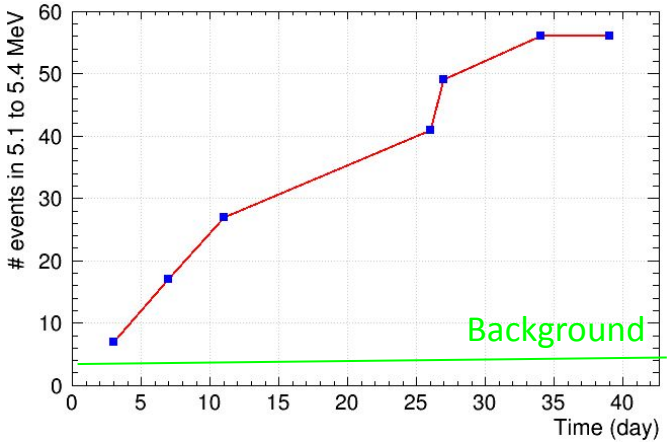
1. Radon source
2. ¼” metal tube
3. acrylic tube ~1 cm diameter about 20 cm long
4. Electrodes and support made of PCB with hole to match tube OD, mount in 9. Total about 20 with 1 cm spacing
5. Acrylic flange bonded on
6. Backing plate bolts to 5, details of foil support to be determined
7. Catcher foil, nylon etc, mounted on thin ring
8. Acrylic adaptor bonded on, bonded to ¼” tube
9. Support – insulator, could be wood, slots cut to hold PCBs.

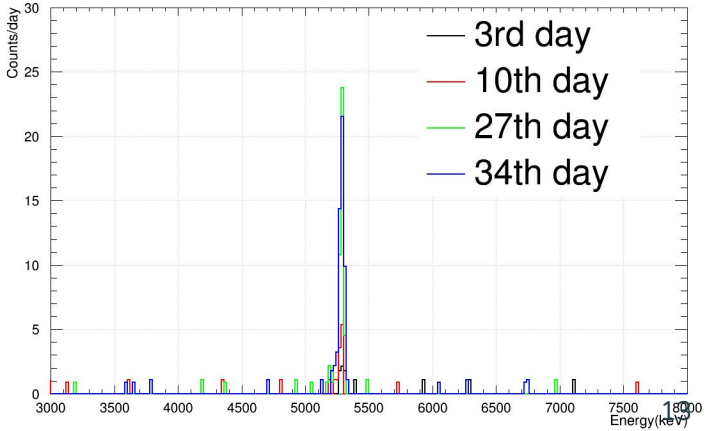
Source deposited on stainless steel

- A 9mm diameter steel sample of 2mm thickness exposed to 10 days.
- There is a prominent peak of Po-214, that decays in a day and only remain Pb-210 on the surface of the source disc.
- The alpha from Po-210 will grow with a characteristic time of τPo = 200 days until an equilibrium is reached.

$$R_\alpha(t) \approx A(1 - e^{-(t-t_0)/\tau_{\mathrm{Po}}}), \qquad (1)$$

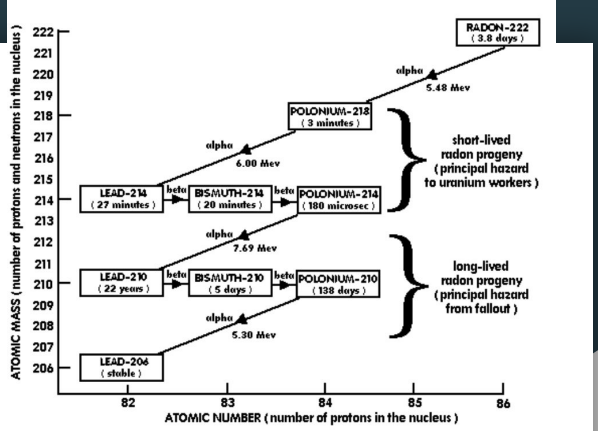


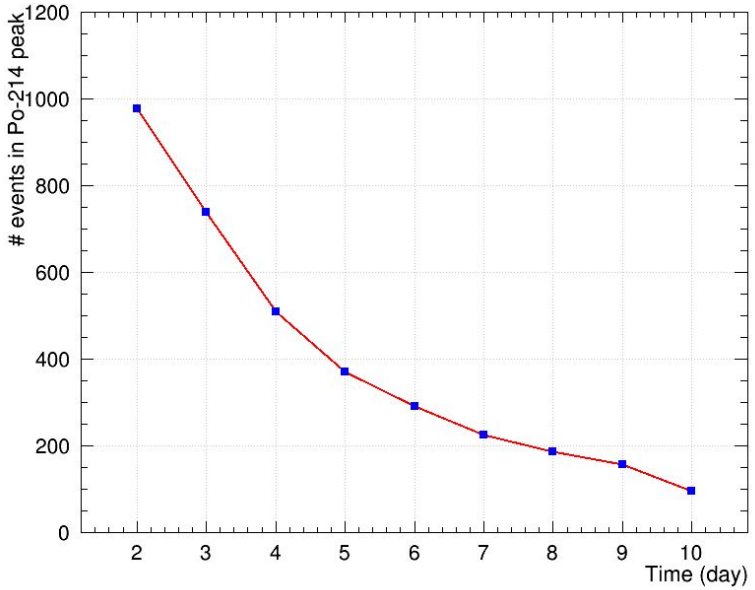


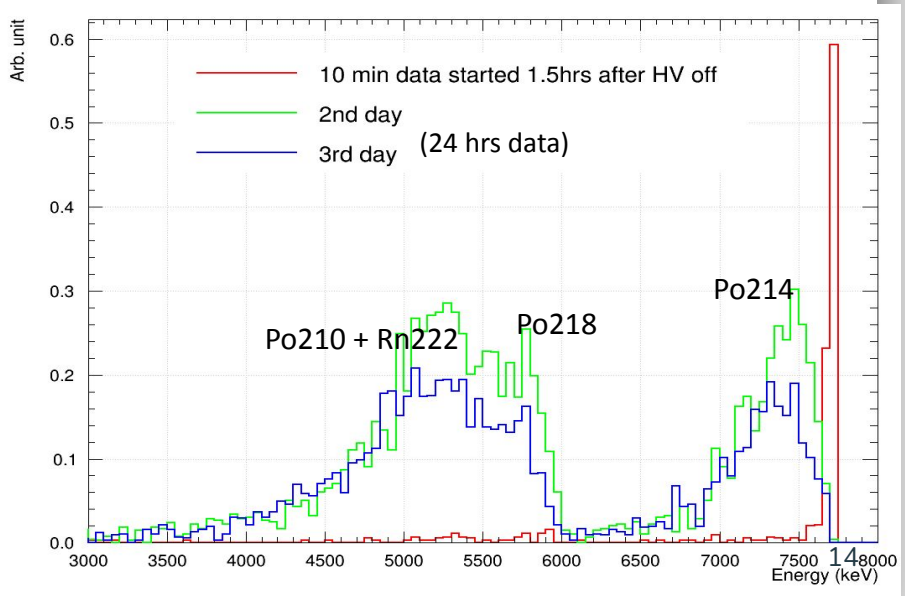


Source deposited on acrylic disc

- Rn-222 daughter peaks are observed in the sample for long time.
- Radon is highly soluble in acrylic so it is absorbed into the sample.
- It took a month to decay radon fully from the sample.

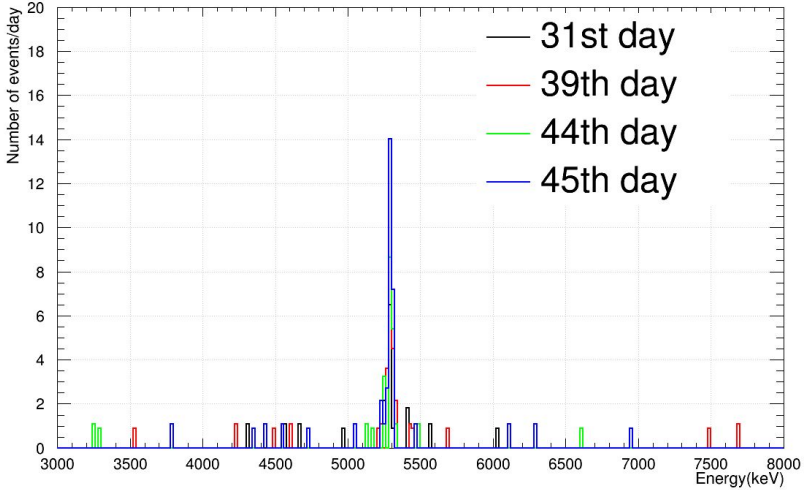


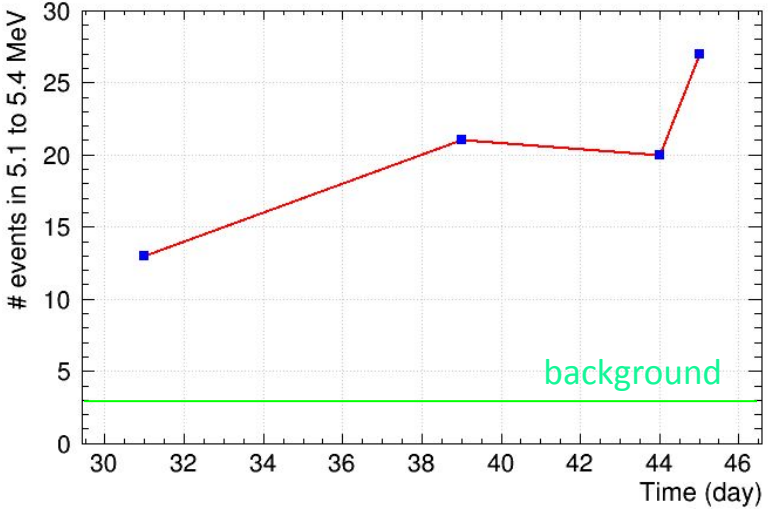




Source deposited on acrylic disc

- The Po-210 peak is increases slowly and it may take couple years to reach equilibrium.
- The peak will be monitored regularly.
- Efficiency of the radon deposition from the source to sample is low (5% of the total source), we are working to improve it.





Summary

- The radon emanation system is working well and ready to measure more samples.
- Radon daughter diffusion test is ongoing. The Pb-210 deposition on the sample's surface is successful.
- The radon diffusion on the surface of acrylic is higher, need to wait for a month to completely decay the radon peaks and see the Po-210 events.
- The collection efficiency of the radon diffusion chamber is 5%, work need to be done to improve it.

Backup

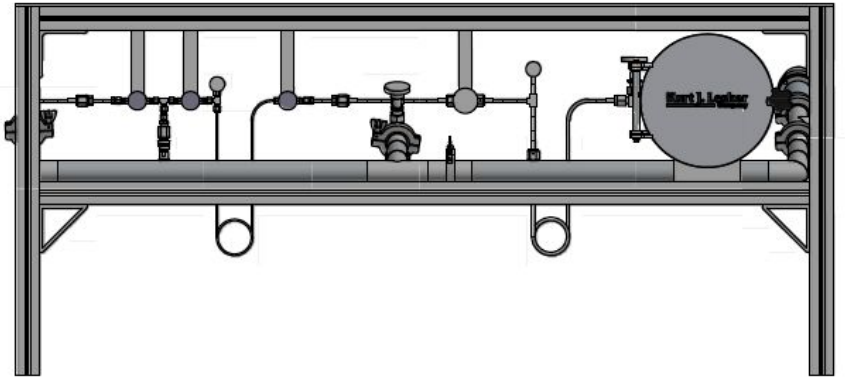
Extraction

Extraction of radon from chamber to the LUCAS cell is completed by two radon traps.

Collect the Radon in primary trap (Radon trapped in liquid nitrogen temperature).

Transfer Radon gas to secondary trap.

Collect it to the LUCAS cell.

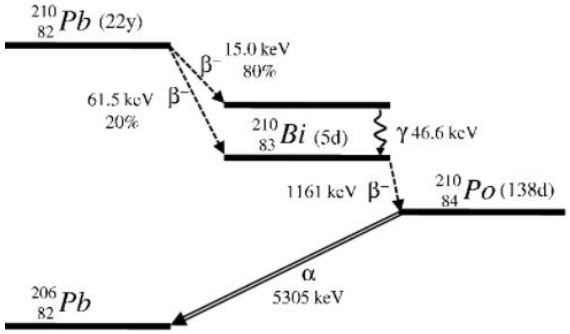


Alpha rate from Po210

If the 210Po contamination is zero at the time when 222Rn exposure occurs, it will grow with a characteristic time of τPo = 200 days until an equilibrium is reached.

https://arxiv.org/pdf/1510.04519.pdf

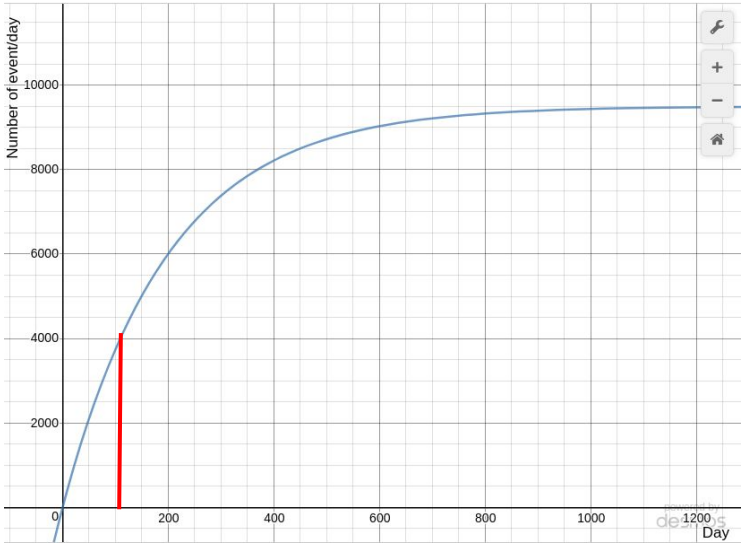
$$R_\alpha(t) \approx A(1 - e^{-(t-t_0)/\tau_{\mathrm{Po}}}),$$



If the Pb210 rate is 9500 events/day

~4000 events/day after 3 months $y = 9500\left(1 - \exp\left(-\frac{(x-0)}{200}\right)\right)$

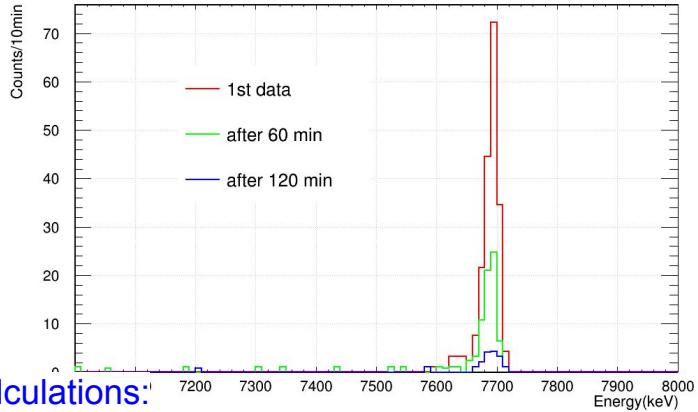
(4000*0.018 = 72 events/day can be seen in alpha counter)
If alpha counter efficiency increases to (~15%) it can be seen 600 events/day



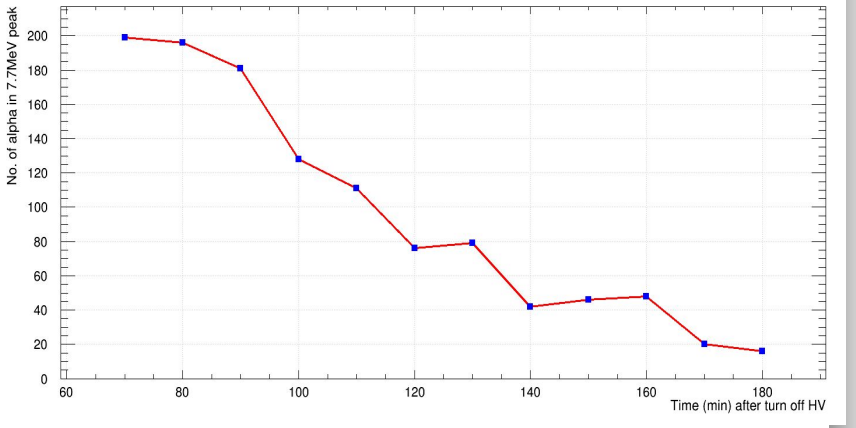
Data are stored in every 10 min

Number of events in 7.7 MeV Po 214 peak

Data is taken from the base of the counter (42mm far from the detector)



Average number of event in 10 min run

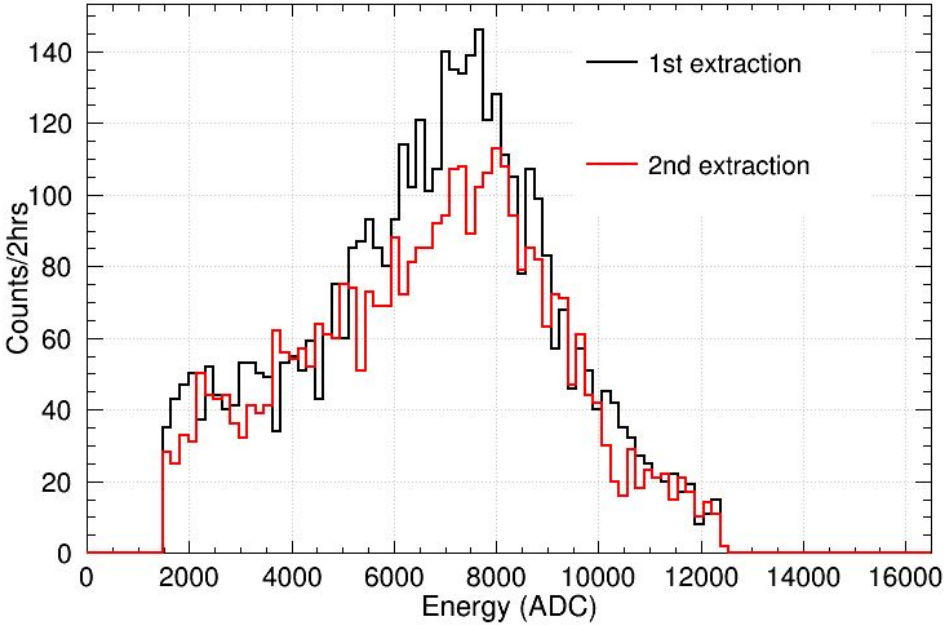


Calculations:

The early measurements of the rate for the 7.7 MeV peak are about 200 count in 10 minutes.
The alpha counting efficiency is about 0.018 so the decay rate in the sample is 200 / .018 / 600 Hz or about 18.5 Hz.
The 70 minutes delay in the initial count is ~ 3 half-lives so the **initial activity would have been about 185 Hz**.
The Rn source is about 4000 Hz so we are collecting about 185/4000 or about **5%** of the daughters.

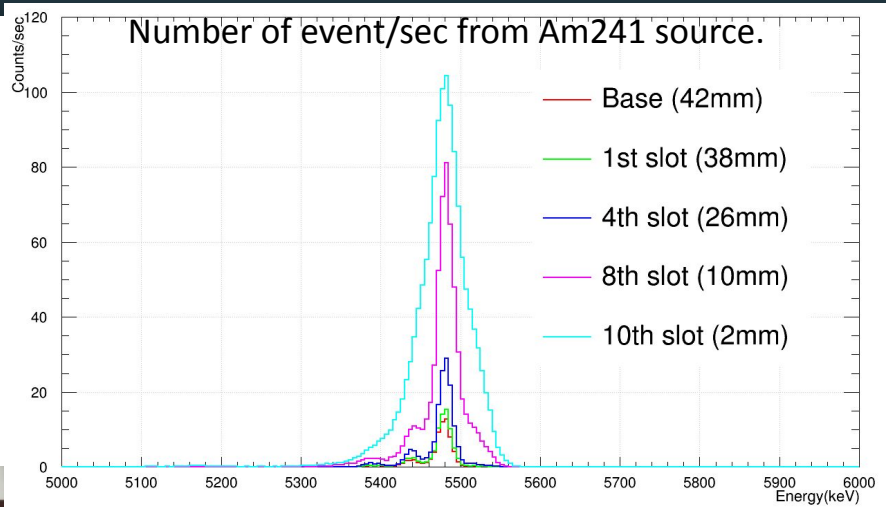
Background and efficiency

- Background of the system is ~10 events/day.
- Efficiency is estimated by the double extraction and collection of the same sample from the system.
- Radon emanated from the buna rubber is used for the source.
- Number of events in 1st extraction = 4210 in 2 hrs.
- Return the extracted radon from the lucas cell to chamber and re-extract the radon from the chamber .
- Number of events in second extraction = 3703 in 2 hrs
- Efficiency = Ratio of 2nd to 1st extraction = 87.9%



Alpha counter

- Diffusion of deposited Pb-210 sample is monitored in an ORTEC alpha counter.
- Am-241 source of similar size as sample is used to estimate the efficiency of counter.



Distance from detector (mm)	Event rate (Hz) (5-6MeV)	Efficiency (%)
2 (10th slot)	1319.6	33.95
10 (8th slot)	569.7	14.66
26 (4th slot)	150.0	3.86
38 (1st slot)	76.0	1.95
42 (base)	68.5	1.76