Modeling radon daughter deposition rates for low background detectors

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The Problem

- Many next-generation detectors such as dark matter detectors and neutrinoless double-beta decay detectors require record low levels of background radiation
- Radon (most commonly ^{222}Rn) is a radioactive daughter of uranium found in the earth and is present in air
  - Daughters of ^{222}Rn are deposited on materials exposed to air
  - Long-lived daughters, particularly ^{210}Pb (with a half-life of 22 years) may present a long term source of background radiation above the acceptable threshold (for example, the threshold for miniCLEAN is $1\alpha/\text{m}^2/\text{day}$)

The Goal

- A better understanding of radon daughter deposition may allow for procedures to be developed that will minimize the amount of background radiation from this source
- The goal is to develop a model of radon daughter deposition so it can be understood as a function of several different environmental variables, including radon concentration, humidity, particle count, temperature, and so on

Deposition Setup

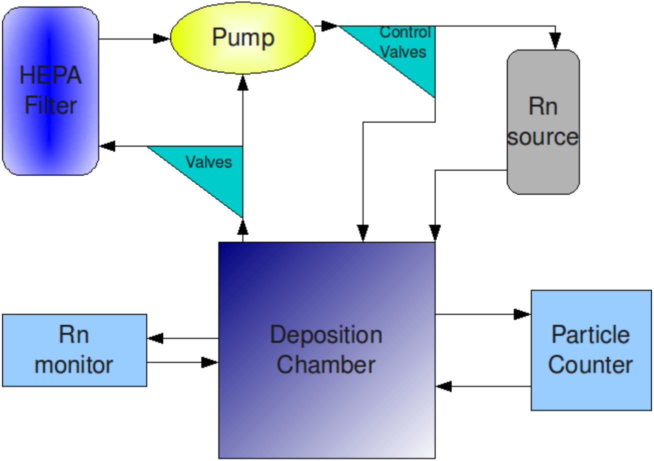

Figure: Diagram of deposition setup

Deposition Setup cont.

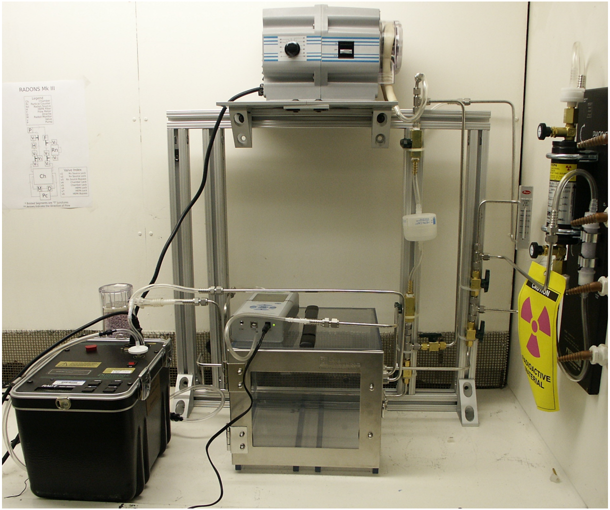

Figure: Deposition setup

Detector Setup

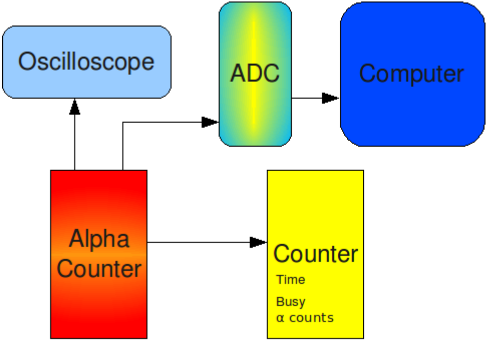

Figure: Diagram of detector and data acquisition

α Detector Geometric Efficiency

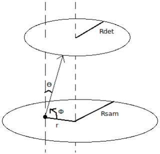

Figure: Model of α particles leaving sample and hitting detector

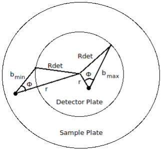

Figure: Top-down view

- What percentage of the α particles that leave the sample will hit the detector?
- Conditions for the α particle to hit the detector:
  - distance traveled by the particle parallel to the plates is

Distance Traveled

$$a = h \tan\theta \qquad (1)$$

Geometric Efficiency cont.

- distance to edge of detector plate is

Maximum Distance

$$b_{max} = r\cos\phi + \sqrt{R_{det}^2 - r^2\sin^2\phi} \quad (2)$$

- distance to reach the detector plate

Minimum Distance

$$b_{min} = r\cos\phi - \sqrt{R_{det}^2 - r^2\sin^2\phi} \quad (3)$$

- So in order for the particle to hit the detector, a must be less than b_{max}, non-negative, and greater than b_{min}
- Running a Monte Carlo simulation with randomized values for ϕ,θ, and r yields a geometric efficiency of 0.246944

α Detector Sampling Frequency

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- Is the detector likely to miss a significant number of α particles if the radon daughters decay too quickly?

α Detector Sampling Frequency

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- Is the detector likely to miss a significant number of α particles if the radon daughters decay too quickly?
- Found that the detector does not start missing pulses until they are coming in at a frequency of approximately 40 kHz

α Detector Sampling Frequency cont.

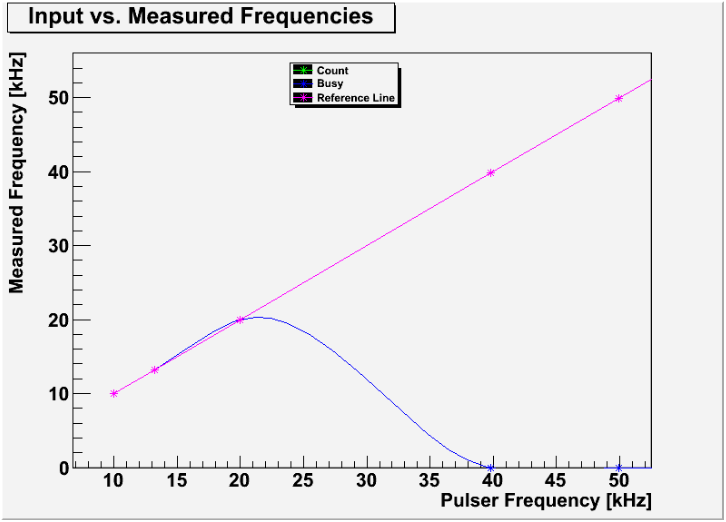


Figure: Pulse Generator vs. Detected Frequencies

ADC Sampling Frequency

- What is the maximum rate at which the ADC can collect data from the α detector?
- Is data likely to be lost due to restrictions on the ADC?

ADC Sampling Frequency

- What is the maximum rate at which the ADC can collect data from the α detector?
- Is data likely to be lost due to restrictions on the ADC?
- Used a random generator to send pulses to ADC and compared the measured frequencies to the input frequencies

ADC Sampling Frequency cont.

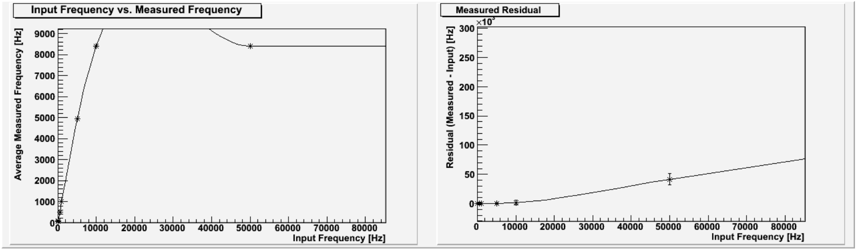
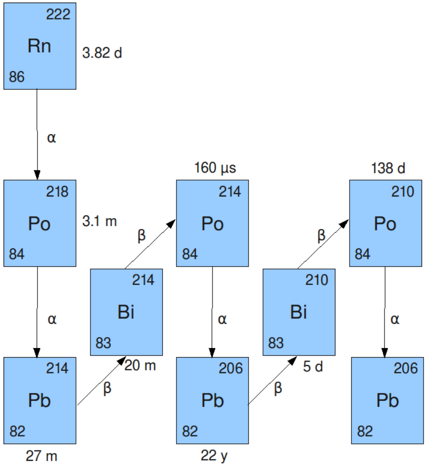


Figure: Pulse Generator vs. Measured Frequencies

Decay Chain


222
Rn
86
3.82 d
α
218
Po
84
3.1 m
α
214
Pb
82
27 m
β
214
Bi
83
20 m
β
160 μs
214
Po
84
α
206
Pb
82
22 y
β
210
Bi
83
5 d
β
138 d
210
Po
84
α
206
Pb
82

The Model

$N_1 = ^{218}\text{Po}$, $N_2 = ^{214}\text{Pb}$, $N_3 = ^{214}\text{Bi}$, $N_4 = ^{214}\text{Po}$

Deposition

$$\frac{dN_1}{dt} = C_1 D_1 - \lambda_1 N_1 \tag{4}$$

$$\frac{dN_2}{dt} = C_2 D_2 - \lambda_2 N_2 + \lambda 1 N_1 \tag{5}$$

$$\frac{dN_3}{dt} = C_3 D_3 - \lambda_3 N_3 + \lambda 2 N_2 \tag{6}$$

$$\frac{dN_4}{dt} = C_4 D_4 - \lambda_4 N_4 + \lambda 3 N_3 \tag{7}$$

Decay

$$\frac{dN_1}{dt} = -\lambda_1 N_1 \tag{8}$$

$$\frac{dN_2}{dt} = -\lambda_2 N_2 + \lambda 1 N_1 \tag{9}$$

$$\frac{dN_3}{dt} = -\lambda_3 N_3 + \lambda 2 N_2 \tag{10}$$

$$\frac{dN_4}{dt} = -\lambda_4 N_4 + \lambda 3 N_3 \tag{11}$$

Energy Spectra

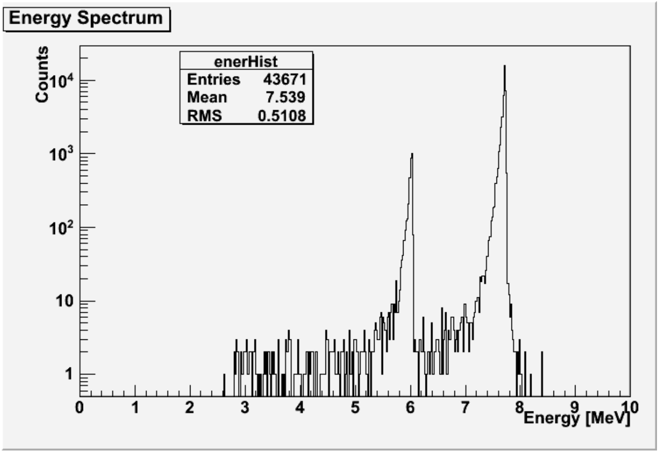


Figure: ^{218}Po around 6 MeV, ^{214}Po around 7.8 Mev

Decay Spectrum

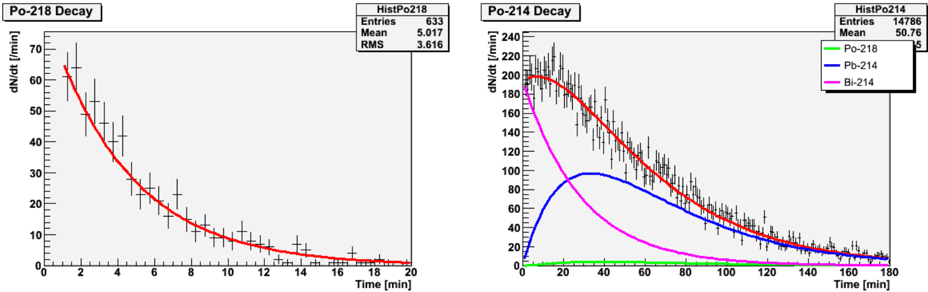
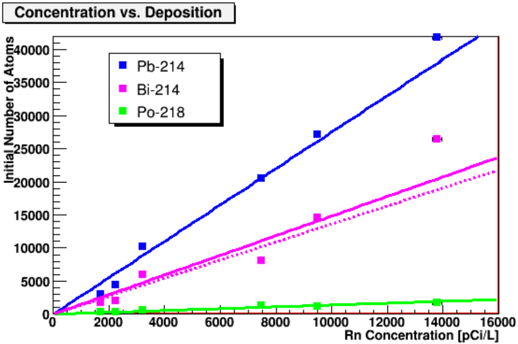


Figure: RH= 2%, Temp= 27.1 °C, Concentration= 15500 ± 108 pCi/L

[^{218}Po]= 1496.46 ± 62.22 atoms, [^{214}Pb]= 35770.7 ± 469.65 atoms, [^{214}Bi]=22599.5 ± 442.39 atoms

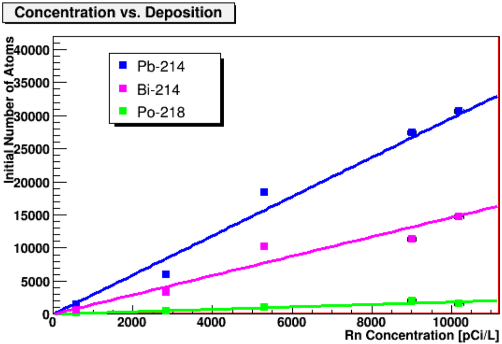
Results

Deposition Rates for Acrylic



$$D_1 = 3.12 \times 10^{-2} \pm 7.78 \times 10^{-4} \text{ L/pCi/min/cm}^2$$
$$D_2 = 6.01 \times 10^{-2} \pm 8.85 \times 10^{-4} \text{ L/pCi/min/cm}^2$$
$$D_3 = 0 \pm 8.75 \times 10^{-4} \text{ L/pCi/min/cm}^2$$

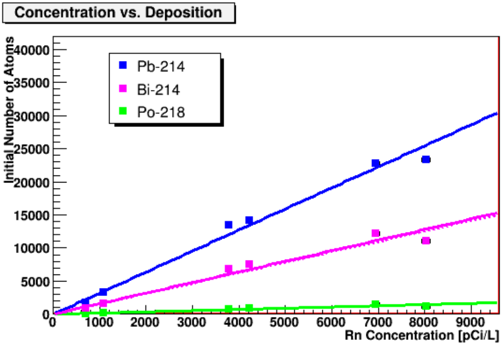
Deposition Rates for SUVT Acrylic



$$D_1 = 4.12 \times 10^{-2} \pm 1.10 \times 10^{-3} \mathrm{L/pCi/min/cm^2}$$
$$D_2 = 5.74 \times 10^{-2} \pm 1.12 \times 10^{-3} \mathrm{L/pCi/min/cm^2}$$
$$D_3 = 0 \pm 2.92 \times 10^{-4} \mathrm{L/pCi/min/cm^2}$$

Results

Deposition Rates for Copper



$$D_1 = 4.08 \times 10^{-2} \pm 1.18 \times 10^{-3} \mathrm{L/pCi/min/cm^2}$$
$$D_2 = 6.51 \times 10^{-2} \pm 1.23 \times 10^{-3} \mathrm{L/pCi/min/cm^2}$$
$$D_3 = 0 \pm 1.21 \times 10^{-3} \mathrm{L/pCi/min/cm^2}$$

Summary

	D_1 (L/pCi/min/cm^2)	D_2 (L/pCi/min/cm^2)	D_3 (L/pCi/min/cm^2)
Acrylic	$3.12 \times 10^{-2} \pm 7.78 \times 10^{-4}$	$6.01 \times 10^{-2} \pm 8.85 \times 10^{-4}$	$0 \pm 8.75 \times 10^{-4}$
SUVT Acrylic	$4.12 \times 10^{-2} \pm 1.10 \times 10^{-3}$	$5.74 \times 10^{-2} \pm 1.12 \times 10^{-3}$	$0 \pm 2.92 \times 10^{-4}$
Copper	$4.08 \times 10^{-2} \pm 1.18 \times 10^{-3}$	$6.51 \times 10^{-2} \pm 1.23 \times 10^{-3}$	$0 \pm 1.21 \times 10^{-3}$

- The deposition rates per concentration per unit area are as shown above
- Deposition rate varies linearly with radon concentration
- Sample material has little to no effect on deposition rate
- Deposition rate is insensitive to small fluctuations in temperature and particle count in deposition chamber

Continuing

- Repeat experiment at several varying
  - Temperatures
  - Humidity levels
  - Particle count
  - etc.
- Compare results using acrylic samples to those using copper samples

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