# A Radon Daughter Deposition Model for Low Background Experiments

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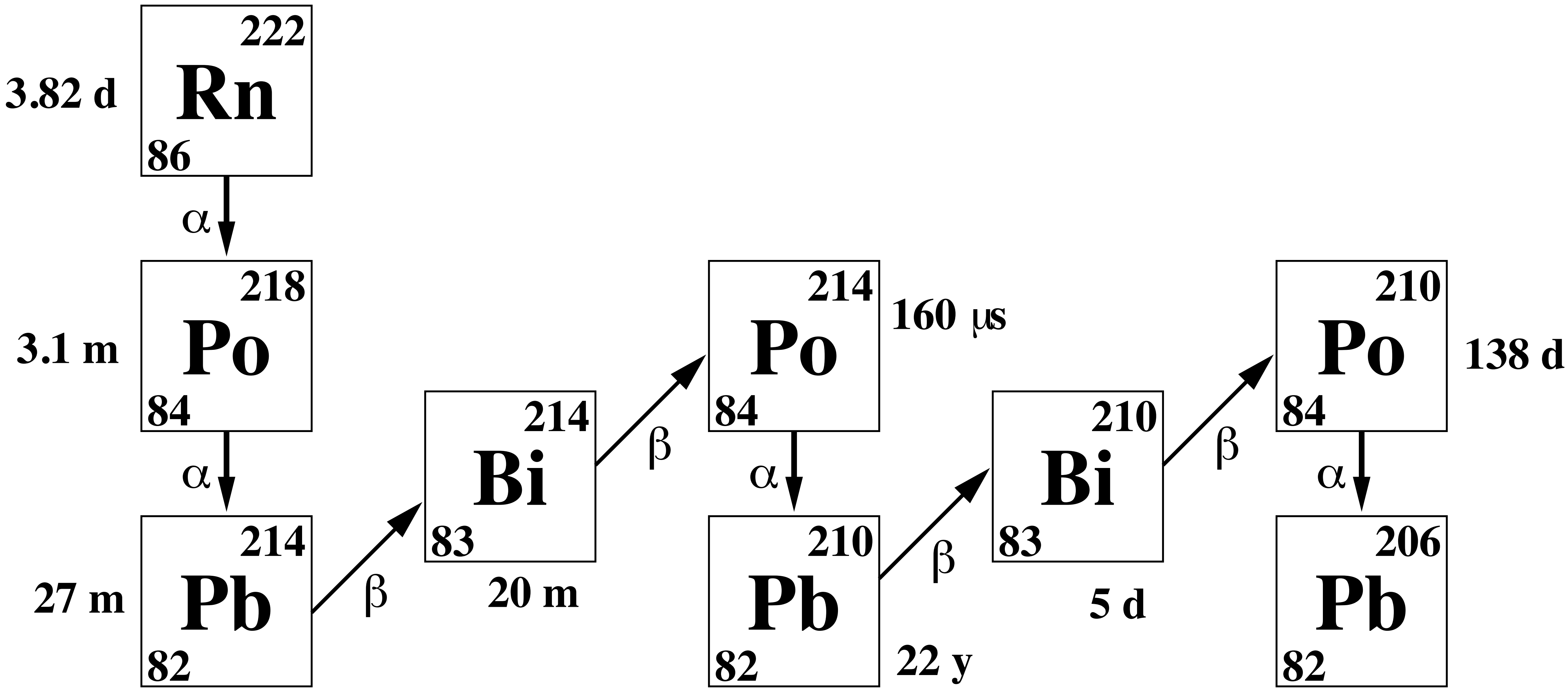
# Radon Generated Backgrounds

- Ultra-low background experiments aim for unprecedented levels of backgrounds
- Detector materials exposed to radon can potentially leave behind long-lived radioactive contaminants.



# Radon Generated Backgrounds

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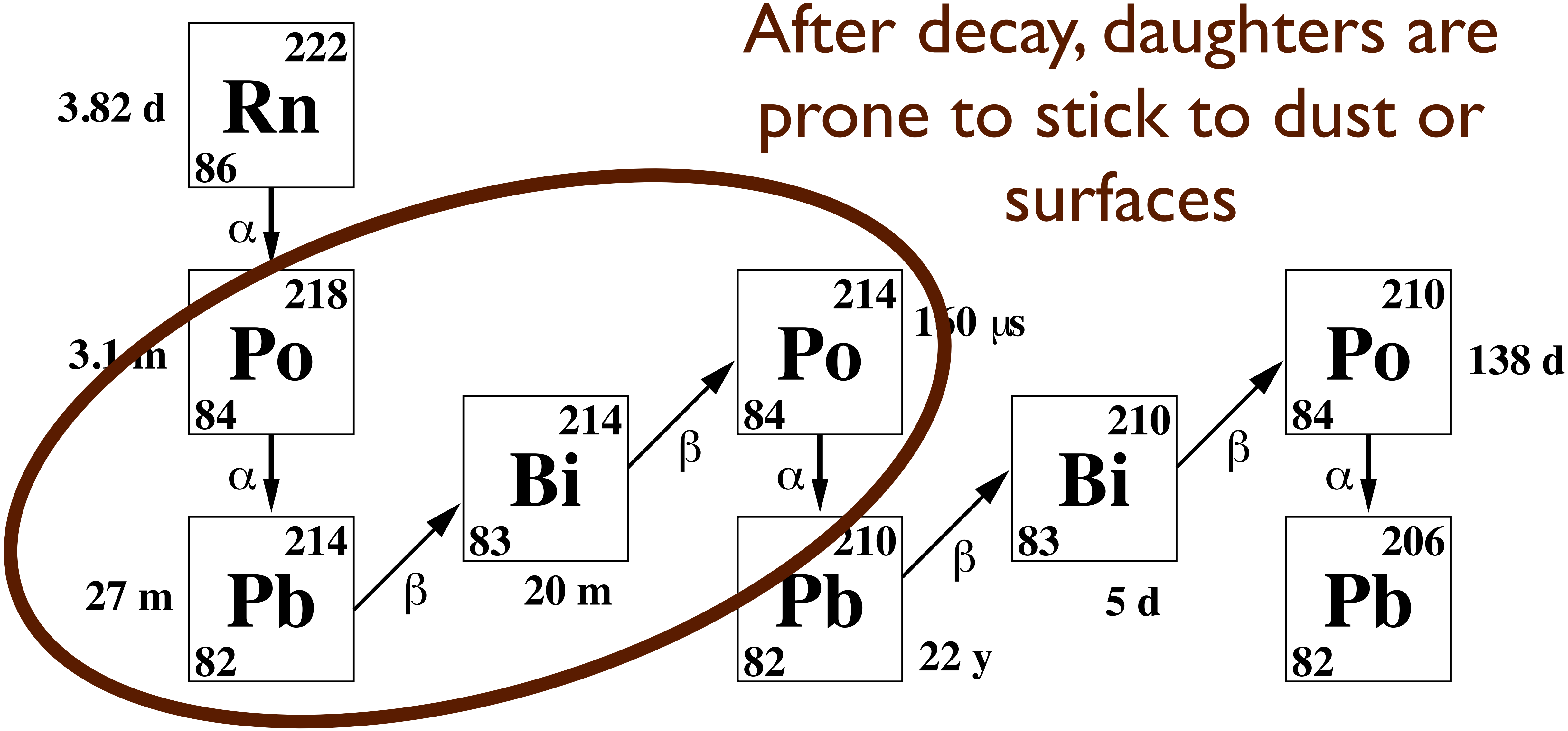
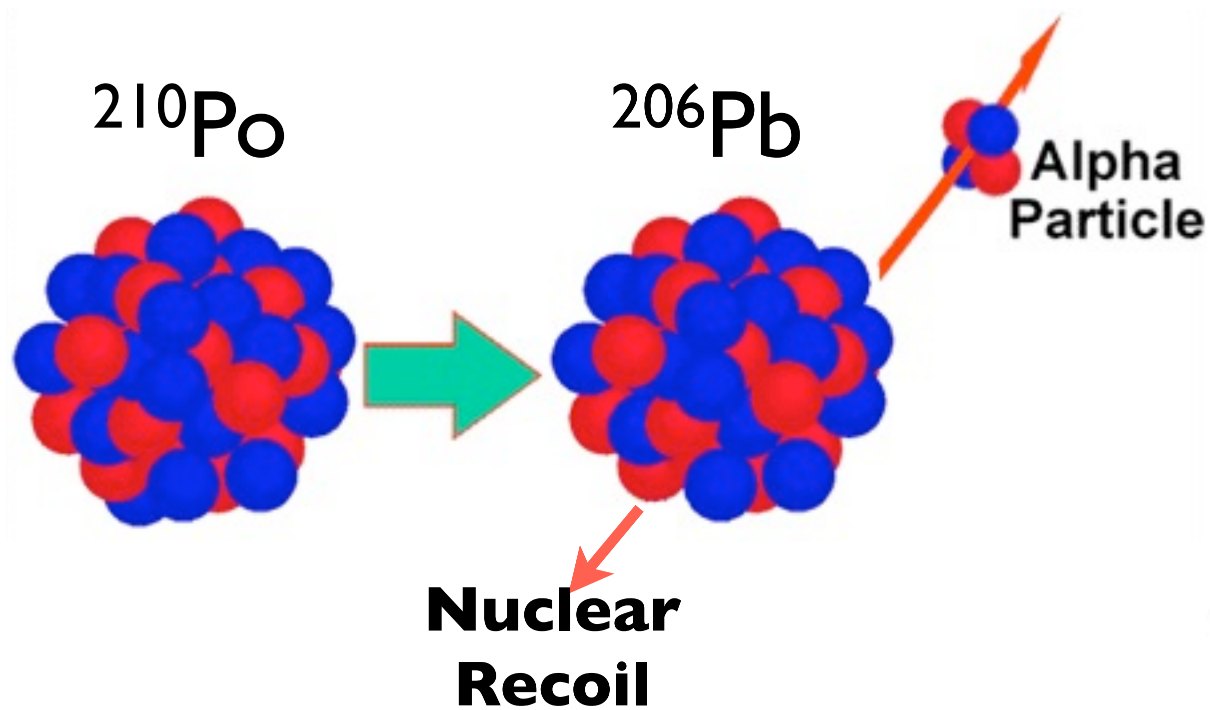
After decay, daughters are prone to stick to dust or surfaces

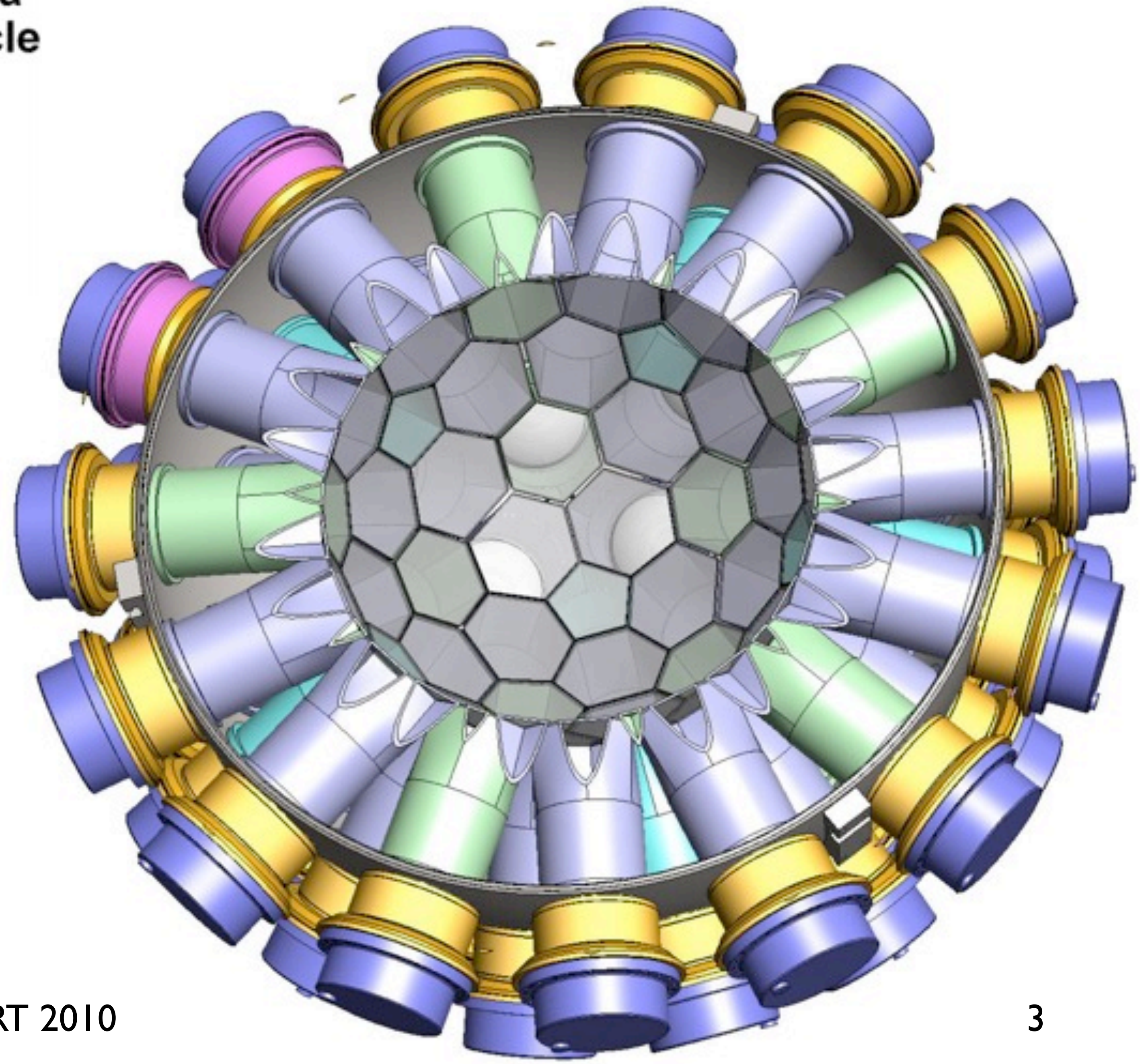


# A Background from Radon Daughters

Long-lived radon daughters on the surface of a target volume can cause a background signal




MiniCLEAN



If the $^{210}$Po is on the surface, the recoiling nucleus can enter the target volume

# Models of radon daughter deposition

- "Indoor Air Model" [Nazaroff & Nero 1988]
  - Rate of deposition is proportional to Rn concentration (C), surface area (S), and deposition "velocity" ($v_d$)
  - $R_d = v_d\ S\ C$
  - Deposition velocity is a function of particle concentration
    - More particles in the air ➔ More [closer] places for daughters to stick ➔ A lower deposition velocity (0.08 m/h)
    - Less particles in the air ➔ Greater deposition velocity (8 m/h)
    - Not that simple! Effect of of air circulation, HEPA filtering, clean room, materials?

- Borexino Model [ Leung, LRT 2004]
  - Surface deposition also proportional to deposition velocity
  - $\sigma\ (^{210}Pb) = C\ v_d\ t$
  - For a clean room, $v_d$ = 0.0001 m/h

# Development of a deposition model

- Test the known models or develop a new one
- Determine deposition rate as function of:
  - particle concentration
  - radon concentration
  - HEPA filtering and flow
  - materials
  - surface preparation
  - electrostatics
  - temperature, humidity, ?
- Expose materials to radon under controlled environmental conditions
- Directly count alpha-emitters on the material surface

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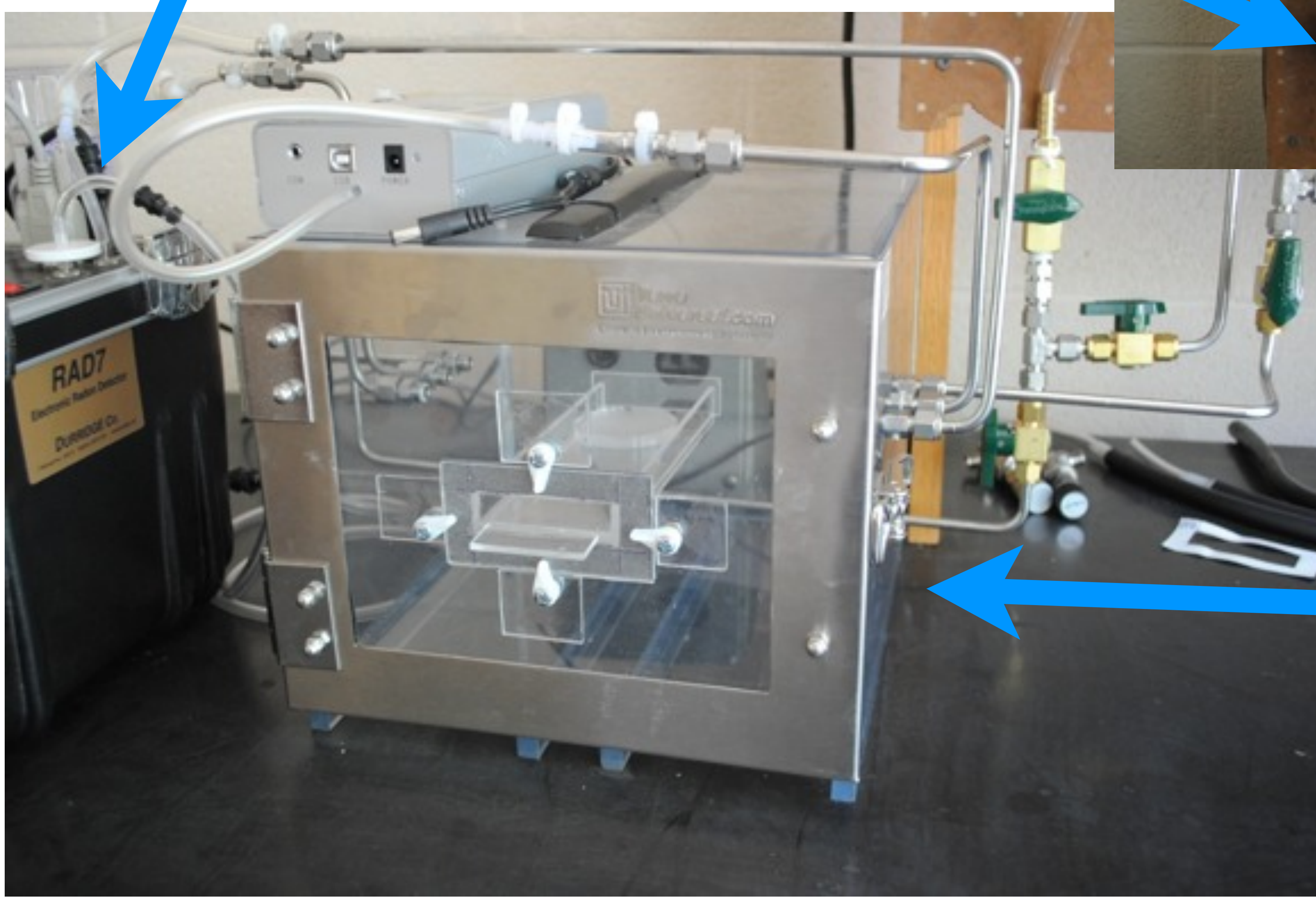
# Radon Daughter Deposition Setup

Pump

HEPA Filter

Rn Detector

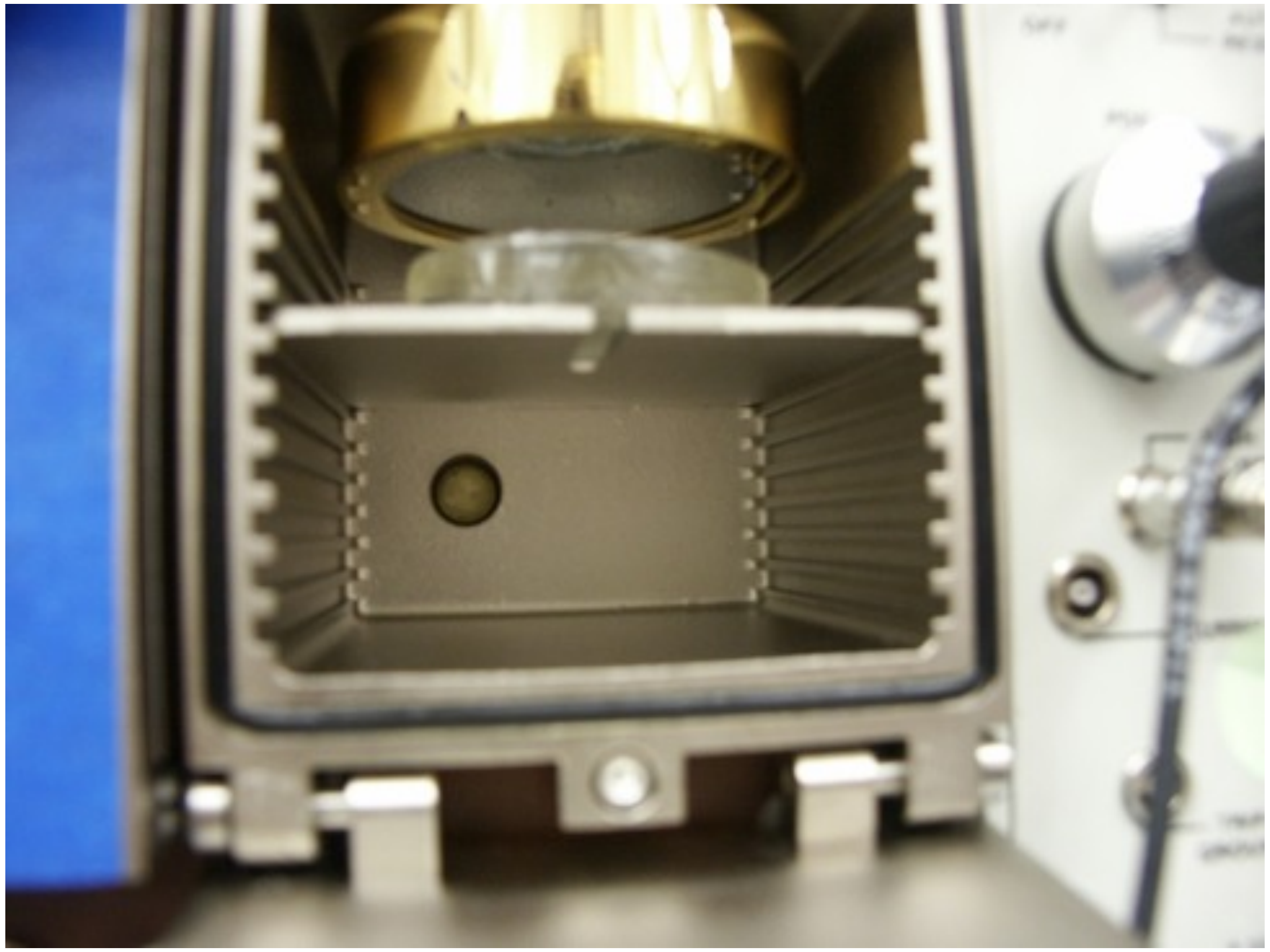



Rn Sources

Exposure Chamber

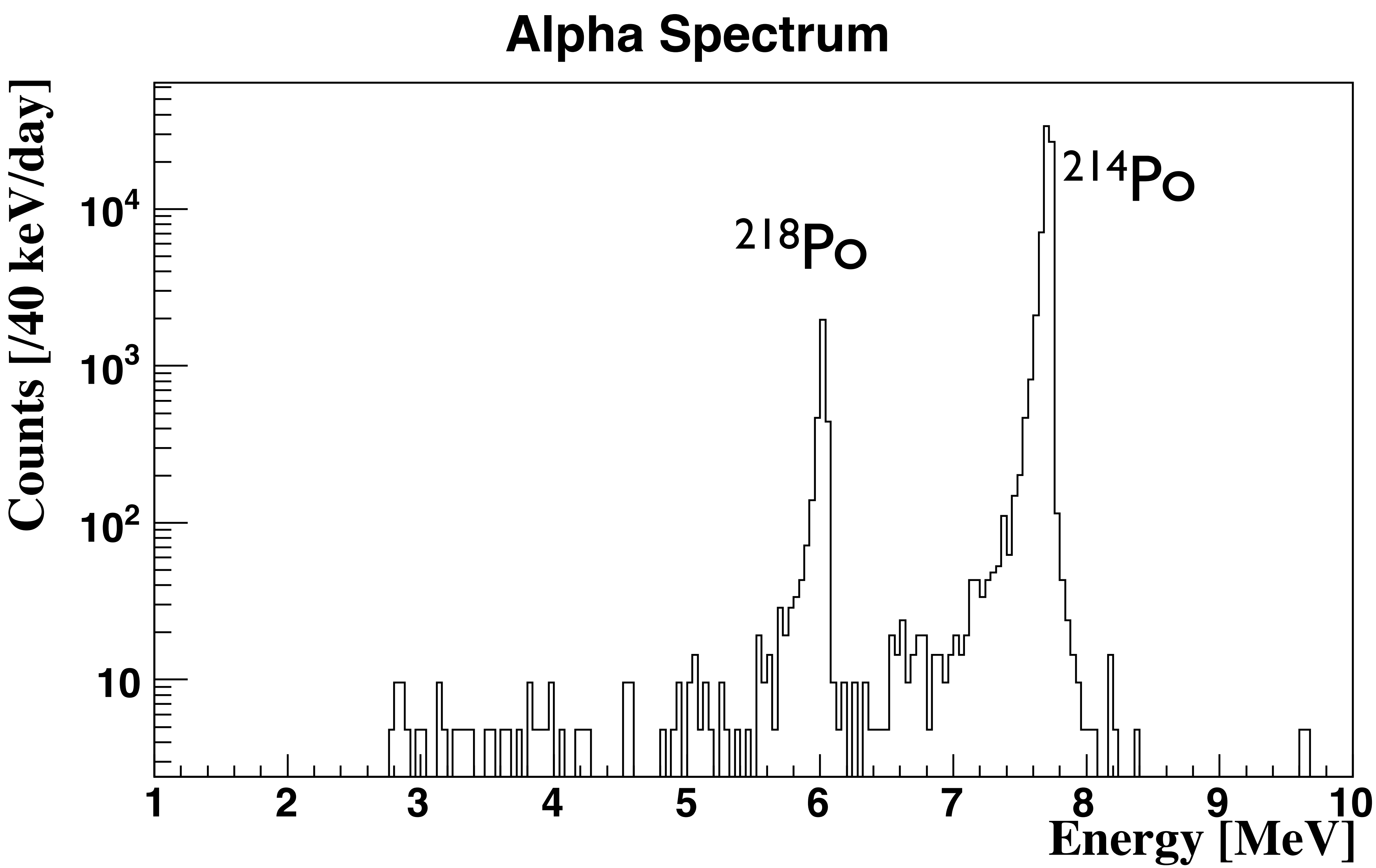
# Procedure

- Exposure to radon for a varying amount of radon concentrations - all other conditions fixed
  - acrylic and copper
- Material is exposed for fixed amount of time
  - Deposition of daughters occur
- Material is removed
  - Counted on an alpha counter
  - Daughters decay



# Po Alpha Peaks

- Clear separation of two α emitters
  - $^{218}Po$ decay α particles at 6 MeV
  - $^{214}Po$ decay α particles at 7.8 MeV



# Model Radon Daughter Decay

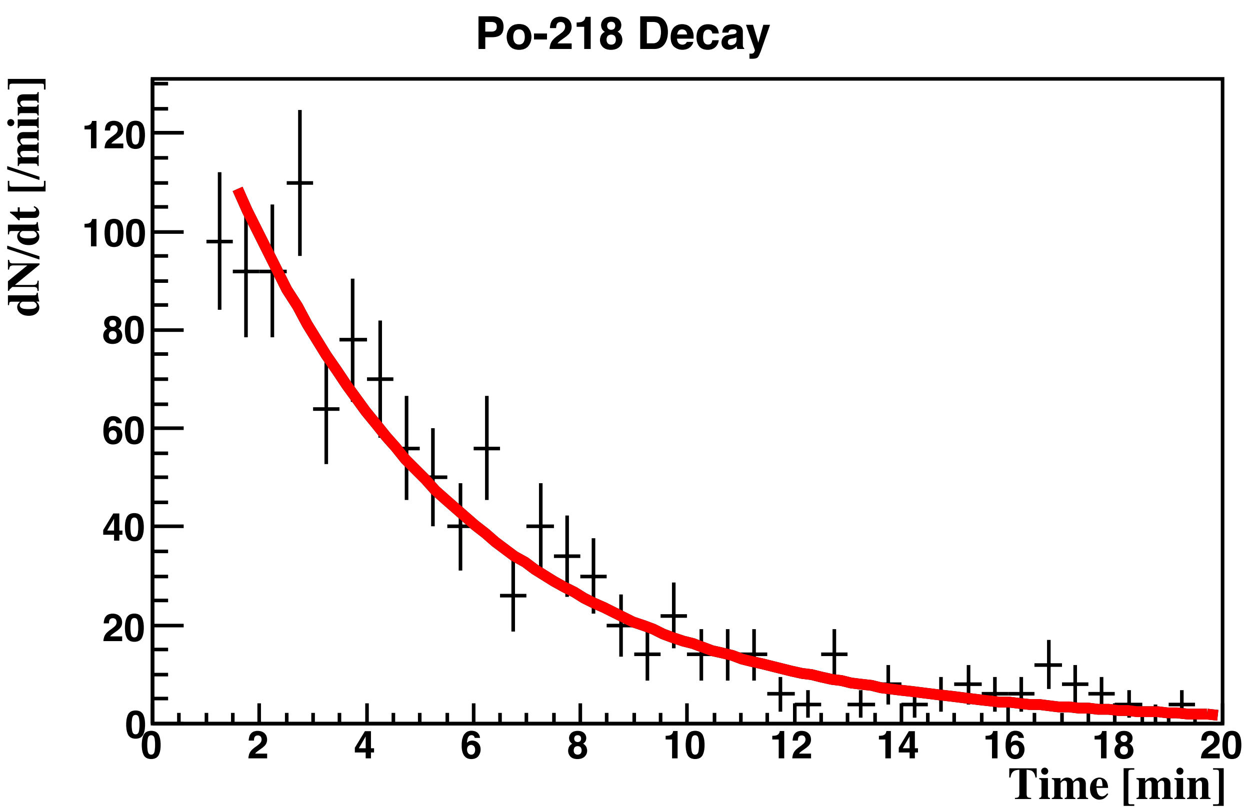
- The decay of the Rn daughters after deposition and while being counted is given by:

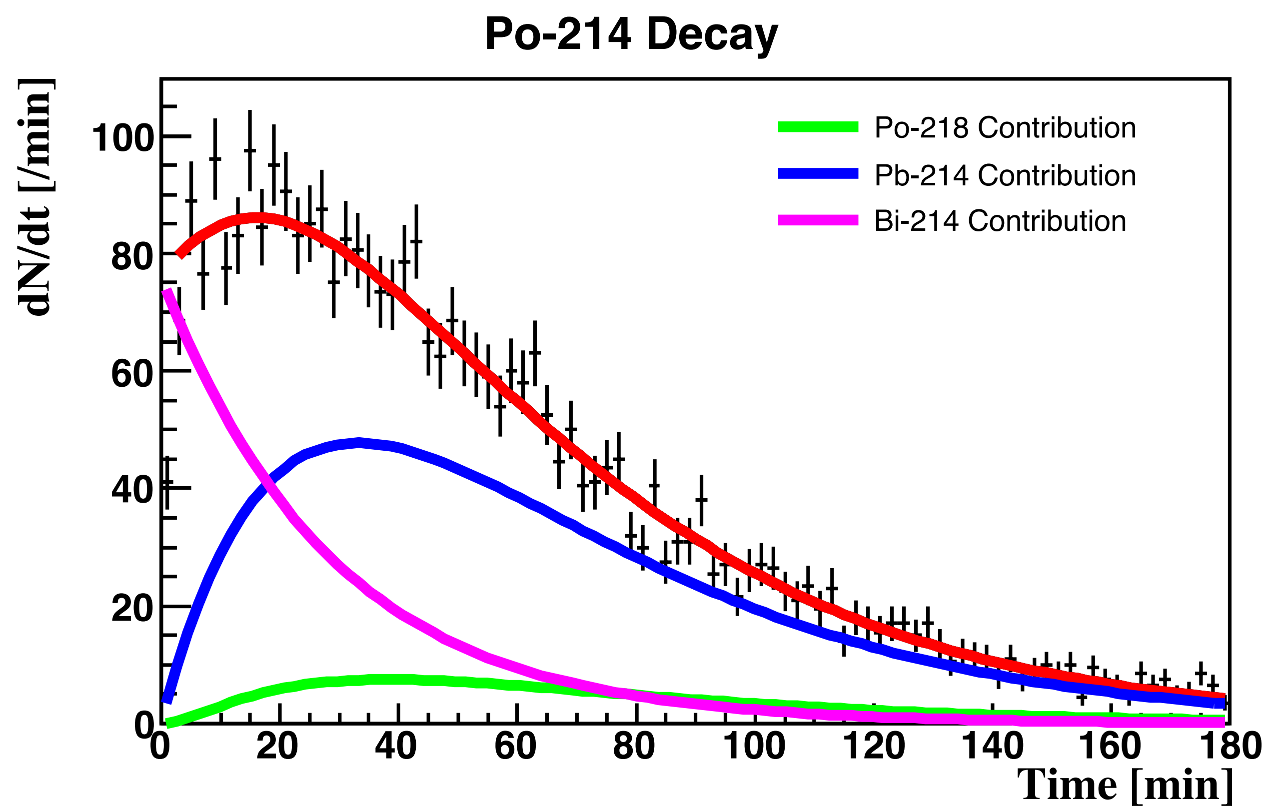
$N_1 \Rightarrow \#$ of $^{218}$Po atoms
$N_2 \Rightarrow \#$ of $^{214}$Pb atoms
$N_3 \Rightarrow \#$ of $^{214}$Bi atoms
$N_4 \Rightarrow \#$ of $^{214}$Po atoms

$$\frac{dN_1}{dt} = -\lambda_1 N_1$$
$$\frac{dN_2}{dt} = (1-r)\lambda_1 N_1 - \lambda_2 N_2$$
$$\frac{dN_3}{dt} = \lambda_2 N_2 - \lambda_3 N_3$$
$$\frac{dN_4}{dt} = \lambda_3 N_3 - \lambda_4 N_4$$

- Solve and fit to α-decay curves to get number of Rn daughters present at conclusion of deposition: t = 0

# Daughters Follow Expected Decay Curve




The fits provide the final number of $^{218}Po$, $^{214}Pb$, and $^{214}Bi$ atoms on the sample after exposure

# Radon Daughter Deposition Model

- Assume a linear deposition model, the number of Rn daughters on the sample during deposition is given by:

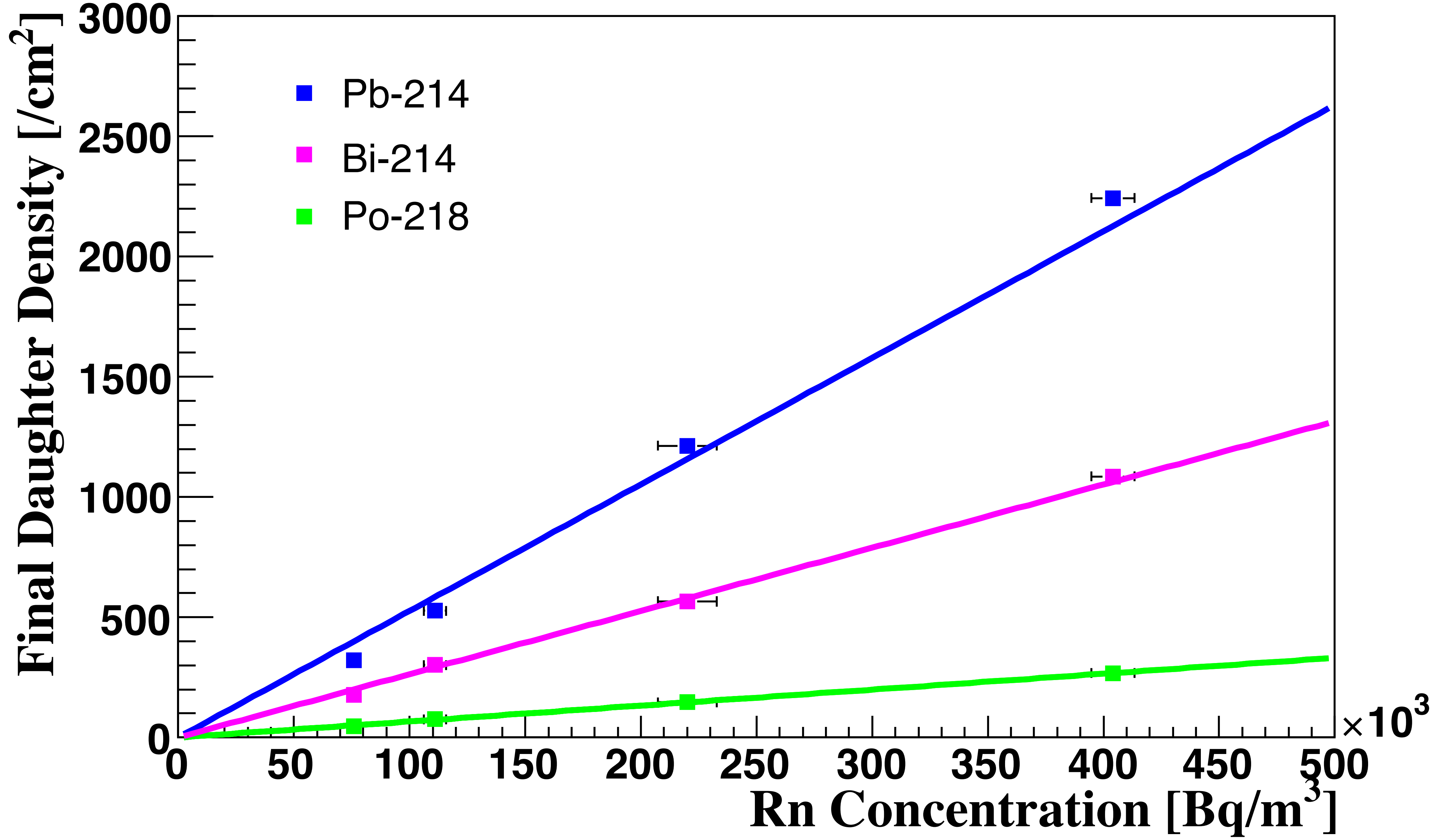
$R_1 \Rightarrow$ deposition rate of $^{218}$Po
$R_2 \Rightarrow$ deposition rate of $^{214}$Pb
$R_3 \Rightarrow$ deposition rate of $^{214}$Bi

$$\frac{dN_1}{dt} = R_1 - \lambda_1 N_1$$
$$\frac{dN_2}{dt} = R_2 + (1 - r)\lambda_1 N_1 - \lambda_2 N_2$$
$$\frac{dN_3}{dt} = R_3 + \lambda_2 N_2 - \lambda_3 N_3$$

- Solve and fit to a series of tests to get $R_i$
- Define R = d A C
  - d is atoms $m^2$ $min^{-1}$ $m^3$ $Bq^{-1}$
  - A is area
  - C is radon concentration

# Daughter density vs. Rn Concentration

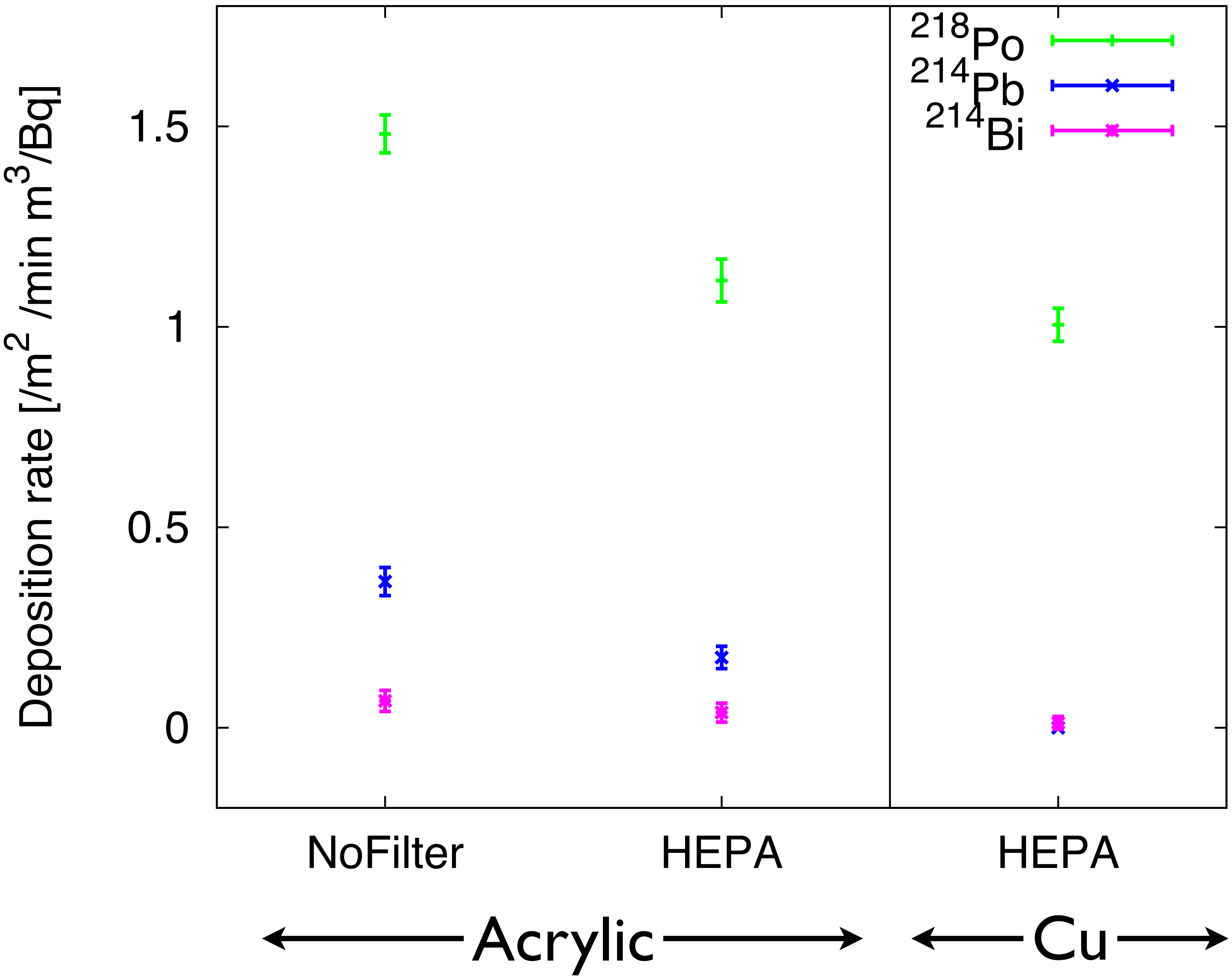
From fits to decay curves




The fit provides the deposition rate of three daughters

This case is for acrylic in unfiltered chamber with a flow rate of 2.5 L/min

# Effect of Filtration and Material

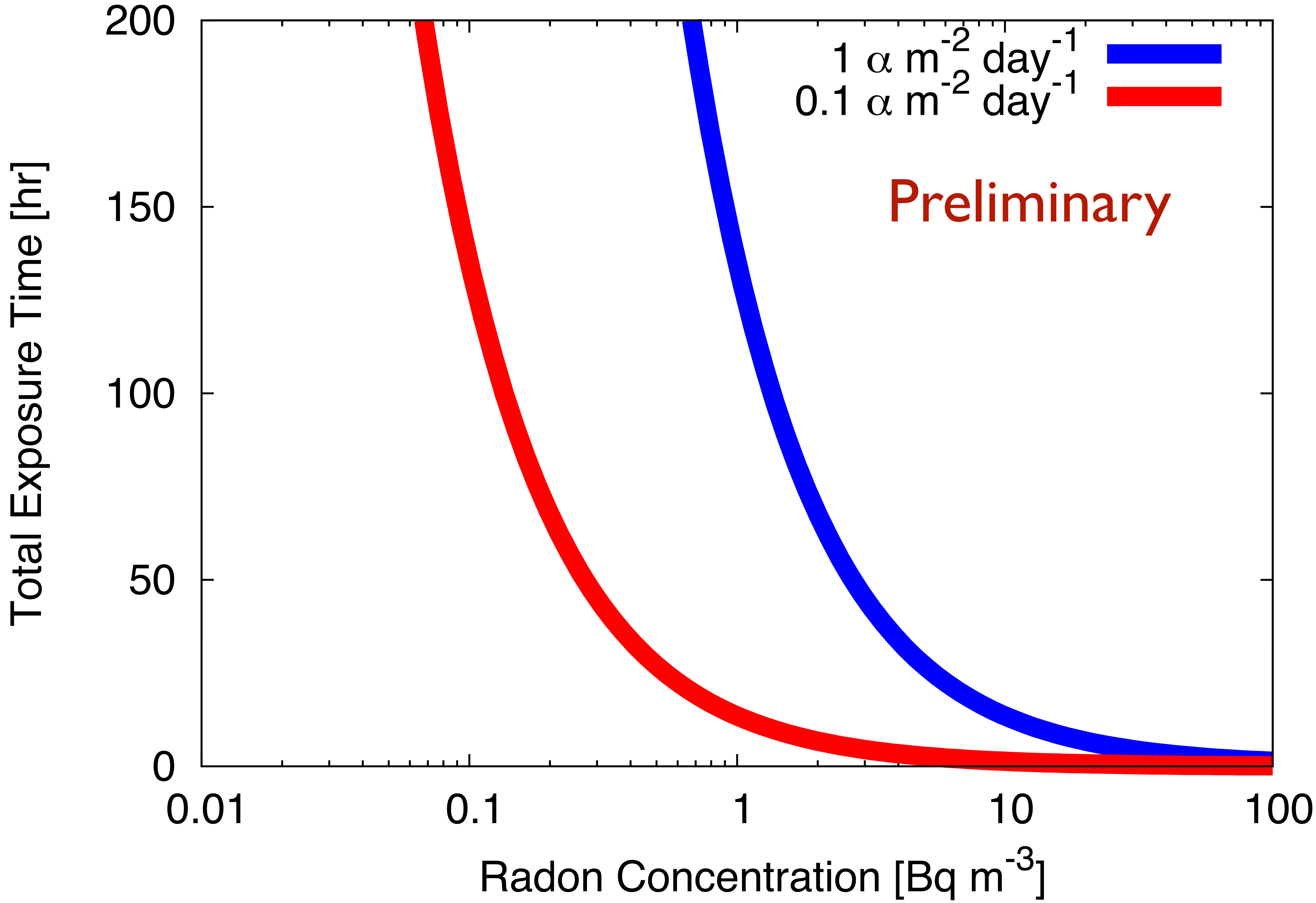



Not a large difference between acrylic and Cu

Filtration suppresses late daughters

# Model Sets Exposure Requirements

- Based on the previous fits, radon exposure limits can be placed to achieve a desired surface activity.



# Summary

- Detector materials exposed to radon at any stage of construction can leave behind long-lived backgrounds.
- In order to set manufacturing and construction requirements for radon control, the deposition of radon daughters onto surfaces must be understood.
- By exposing materials to radon under controlled conditions enables a measurement of the daughters present and the development of a surface deposition model.
- HEPA filtration and flow rates affect radon daughter deposition rates onto surfaces

# Radon Daughter Deposition Setup

1. Rn source
2. Continuous Rn monitor
3. Exposure chamber
4. Particle counter
5. HEPA filter
6. Pump
7. Flowmeter