Radon-daughters Plate-out Measurements at SNOLAB

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Outline

Objectives of the measurements

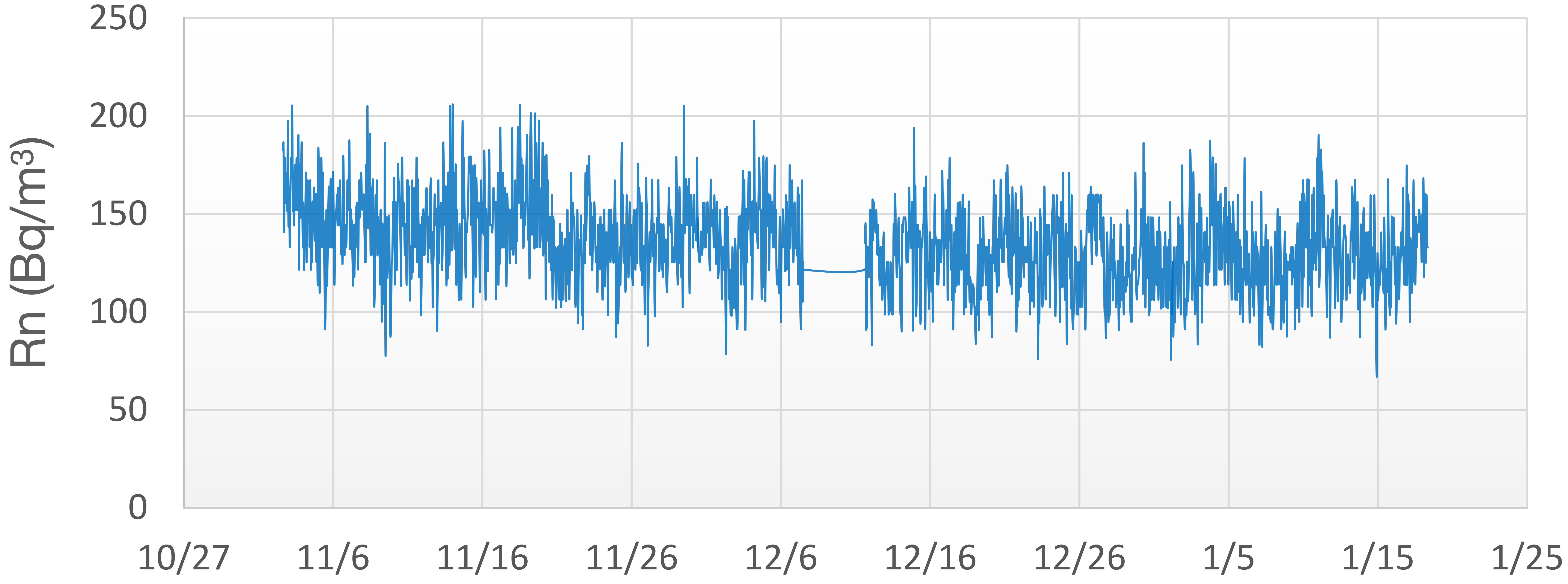
- To develop a ^{210}Pb plate-out model that can:
  - Predict alpha activity over time
  - Inform exposure limits for installation of experiment at SNOLAB
  - Be useful for other projects/experiments

To achieve this through measured samples of high density polyethylene (HDPE) and copper at SNOLAB

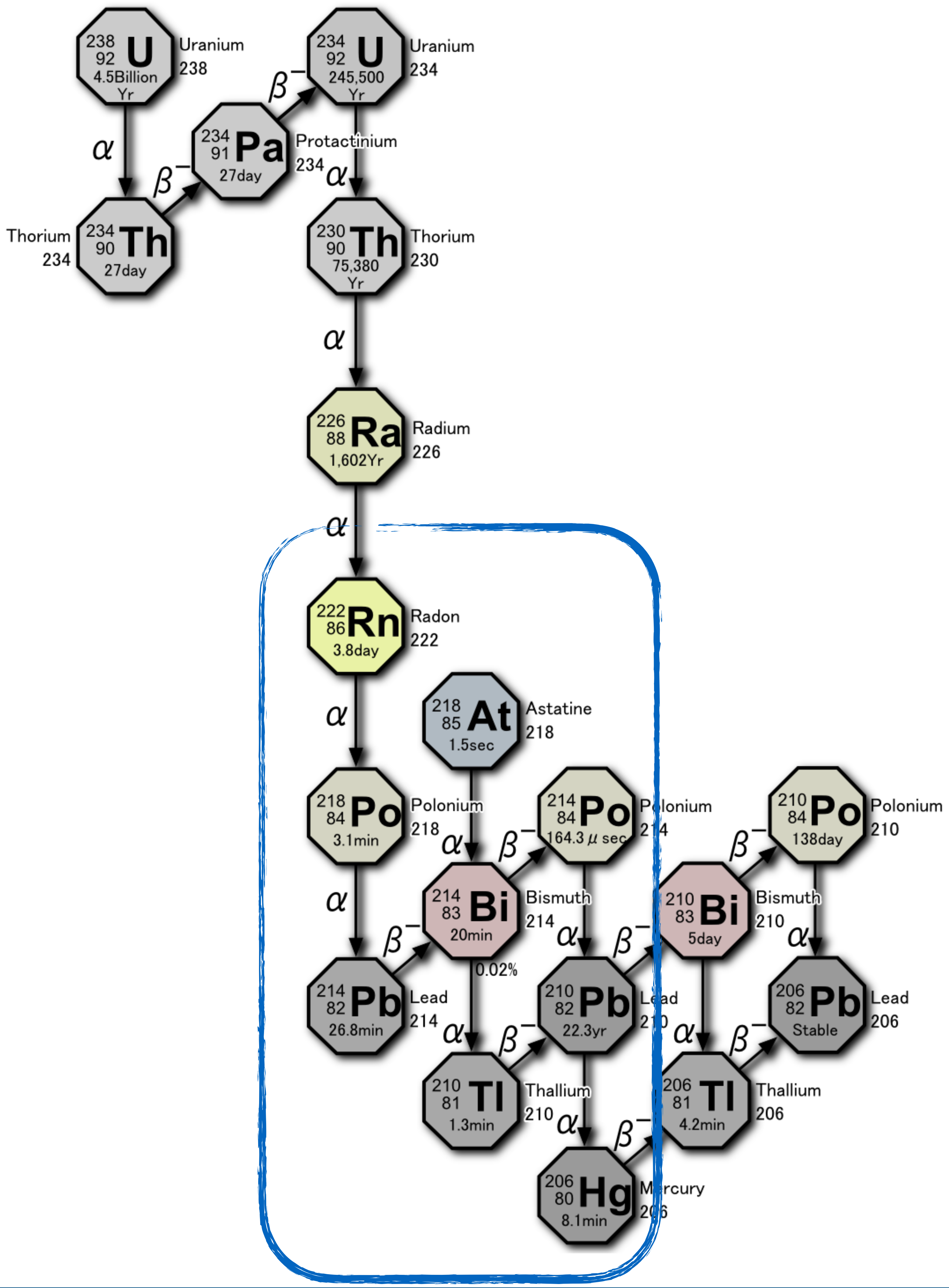
SNOLAB Environment

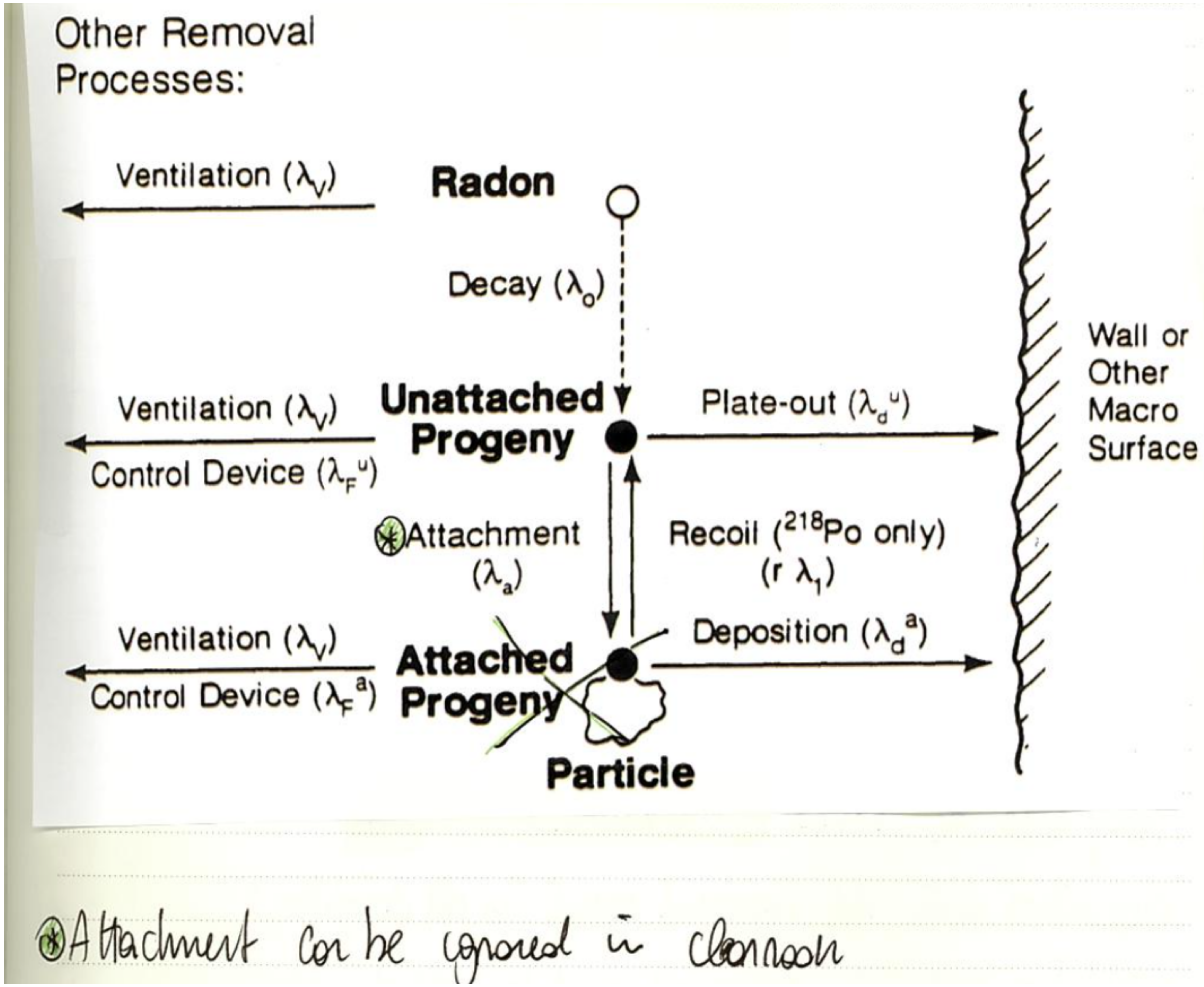
UG lab located at 6,800 ft level of operational Vale Creighton nickel mine (2,073 m overburden = 6,010 mwe)

- Average radon activity ≈ 135 Bq/m^3
- ^{210}Pb plate-out is a concern during installation

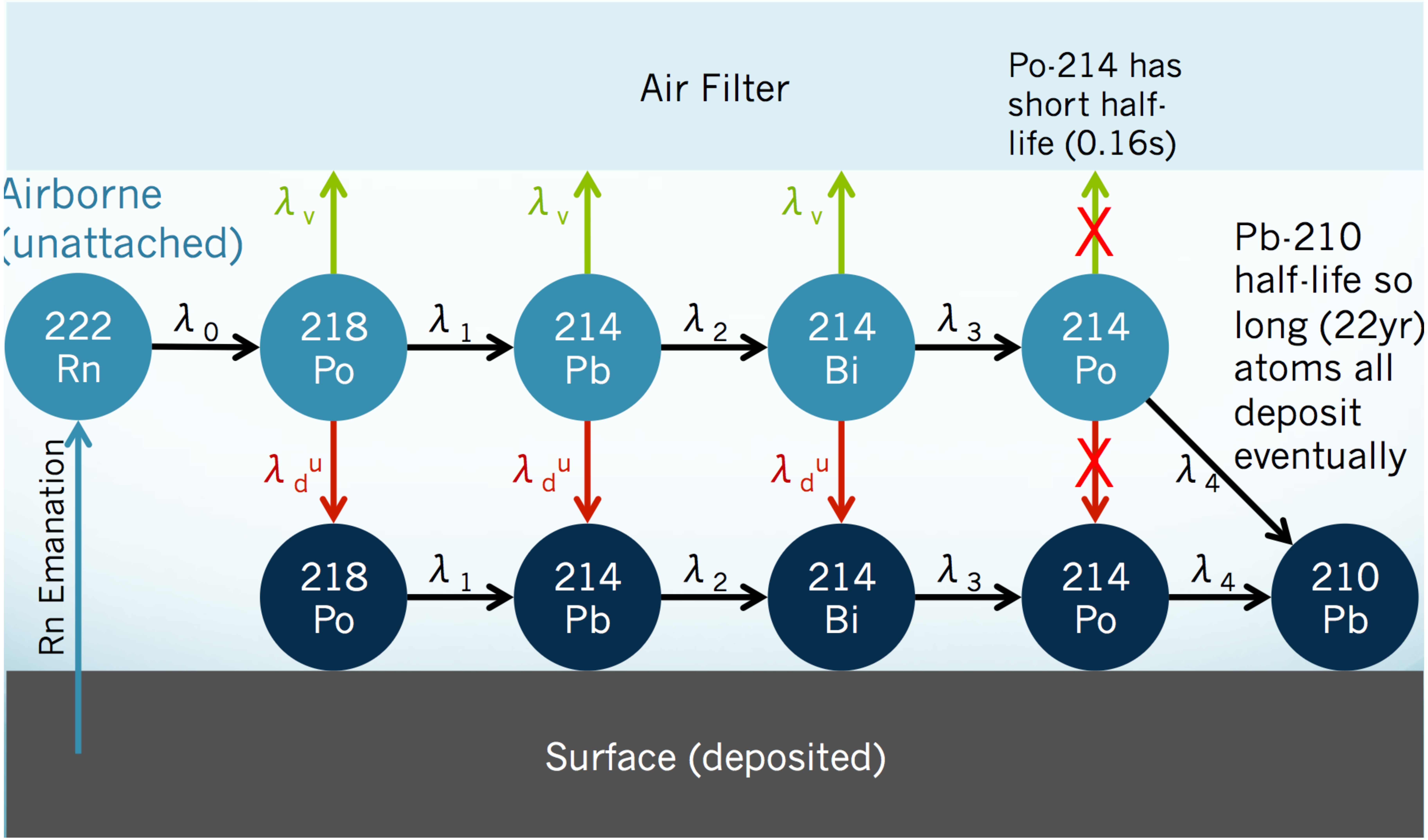


Radon Plate-out



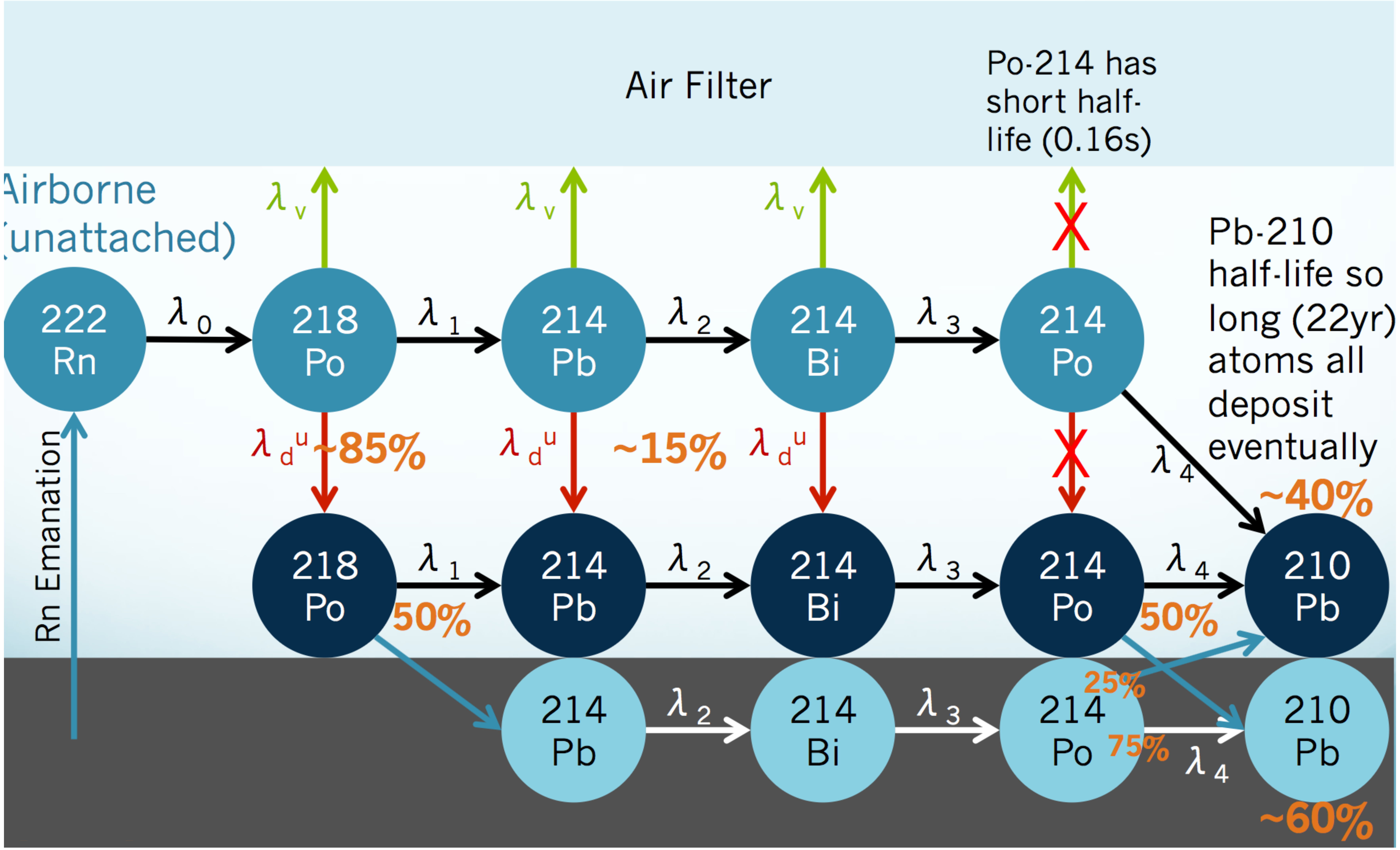


Radon Plate-out



D.Jardin

Radon Implantation



D.Jardin

GRENOBLE | MODANE

Experimental Setup

26 Oct 2016 - 18 Jan 2017 (83d)

Exposed 8 HDPE and 2 Cu samples in 4 locations underground

2 more HDPE control samples left at surface

Total of 83 days of exposure

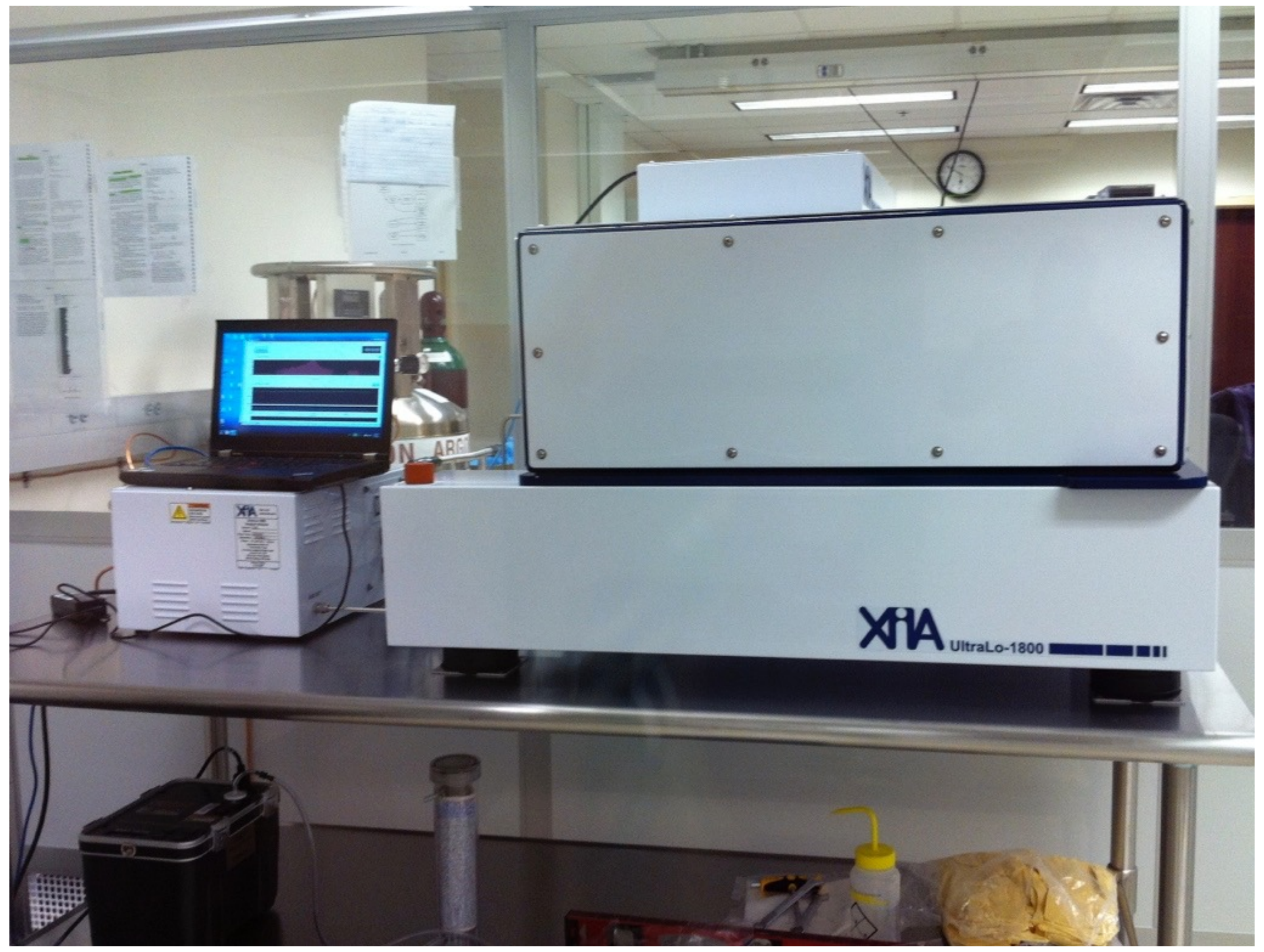
XIA LLC UltraLo-1800 measurement of ^{210}Po alphas (5.3 MeV) [ROI: 2-5.8MeV]

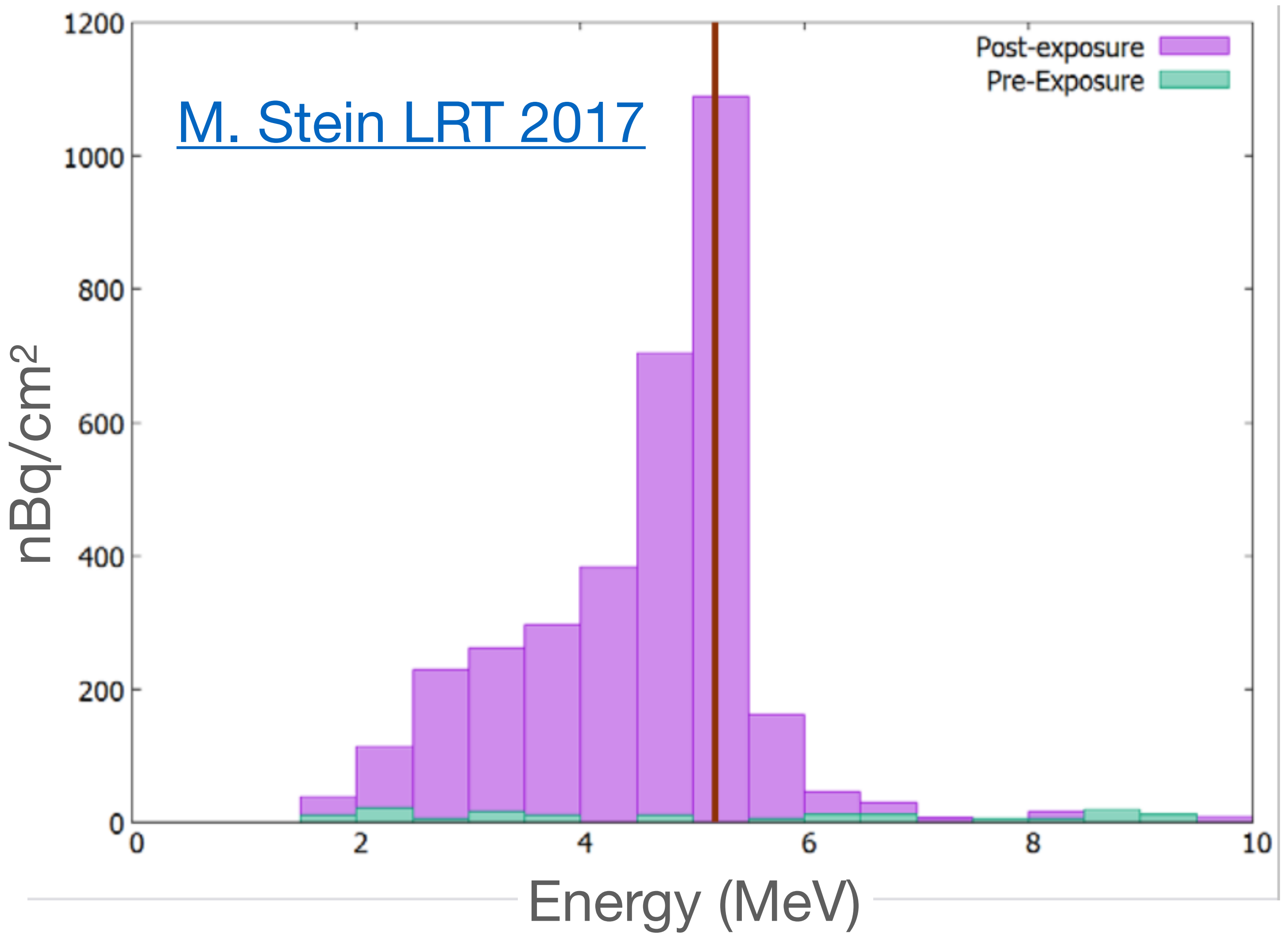
Pre-exposure assays performed
96 ± 18 nBq/cm^2 for HDPE
394 ± 62 nBq/cm^2 for Cu

Two post-exposure measurements per sample (separated by 75d)

Control Samples, Post-Exposure:
91 ± 22 nBq/cm^2 for HDPE

LuminaLab @SMU (Dallas, TX)





Analytical Model

Bateman Equation

- Expected alphas come from short-lived daughter (Po210) of a long-lived parent (Pb210), a model for the number of Po210 atoms over time is built from the Bateman equation

- Short half-life of Bi210 we can neglect it in the equation

$$\lambda_i = \frac{Ln(2)}{t_{1/2,i}}$$

$$N_{Po}(t) = N_{Pb}(0)\frac{\lambda_{Pb}}{\lambda_{Po} - \lambda_{Pb}}(e^{-\lambda_{Pb}t} - e^{-\lambda_{Po}t})$$

$$N_{Po}(0) = 0$$

- Radon-daughter plate-out rate ~constant with time -> Pb210 atoms added at a constant rate R_{Pb}

$$^{210}Po\,Activity = A(t, R_{Pb}) = \lambda_{Po}\left[\sum_{i=1}^{t_{exp}/binSize} B(t, R_{Pb} \cdot binSize, i \cdot binSize)\right]$$

Analytical Model

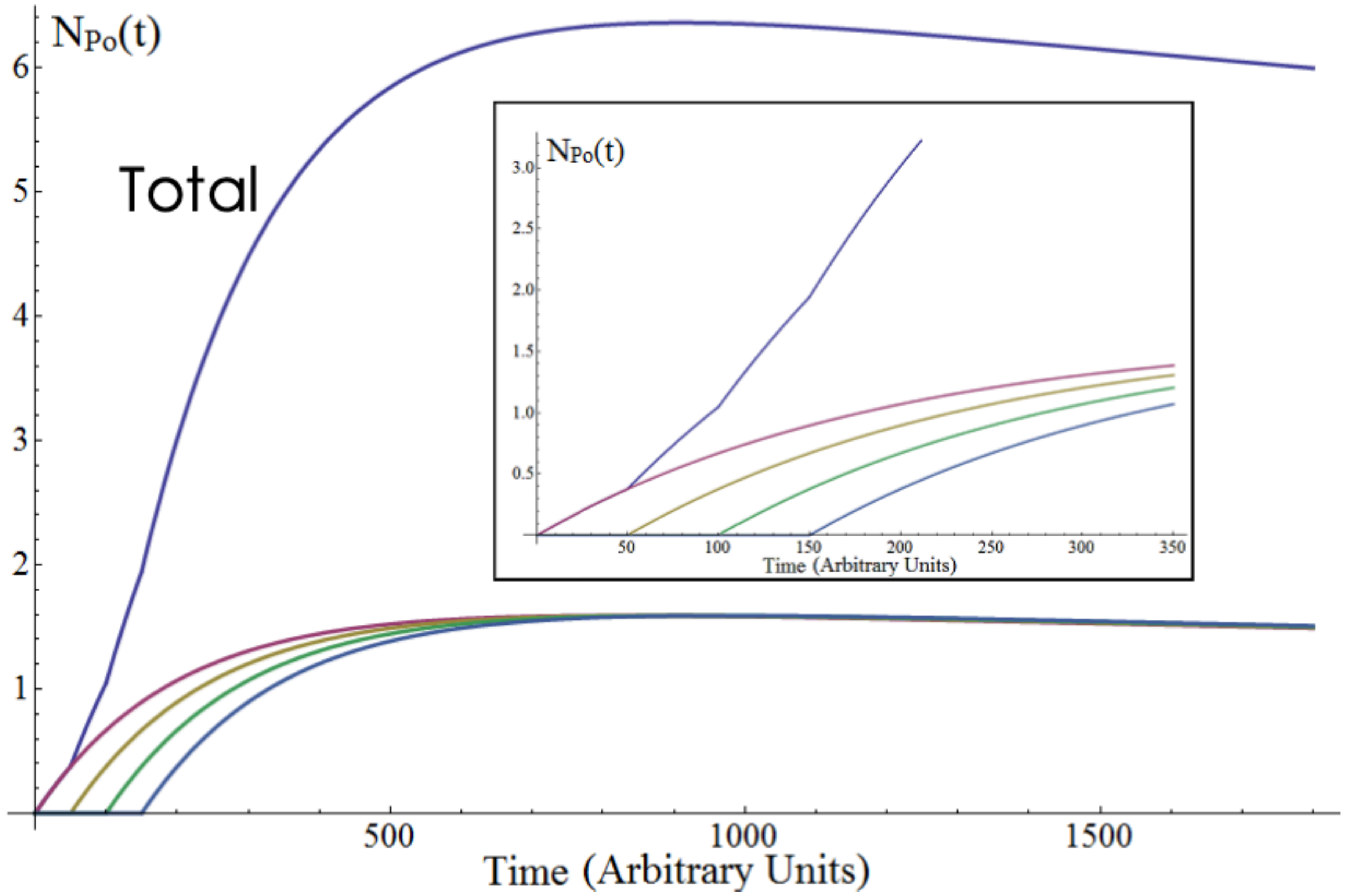
Po 210 Activity

Smaller is better (but slower)

$$^{210}P_o Activity = A(t, R_{Pb}) = \lambda_{Po} \left[\sum_{i=1}^{t_{exp}/binSize} B(t, R_{Pb} \cdot binSize, i \cdot binSize) \right]$$

Number of 210Po atoms at t

Number of ^{210}Pb atoms plated out per unit time



Analytical Model

Dust Activity

$^{210}Pb \rightarrow {}^{210}Po$ ($t_{1/2}$138d)

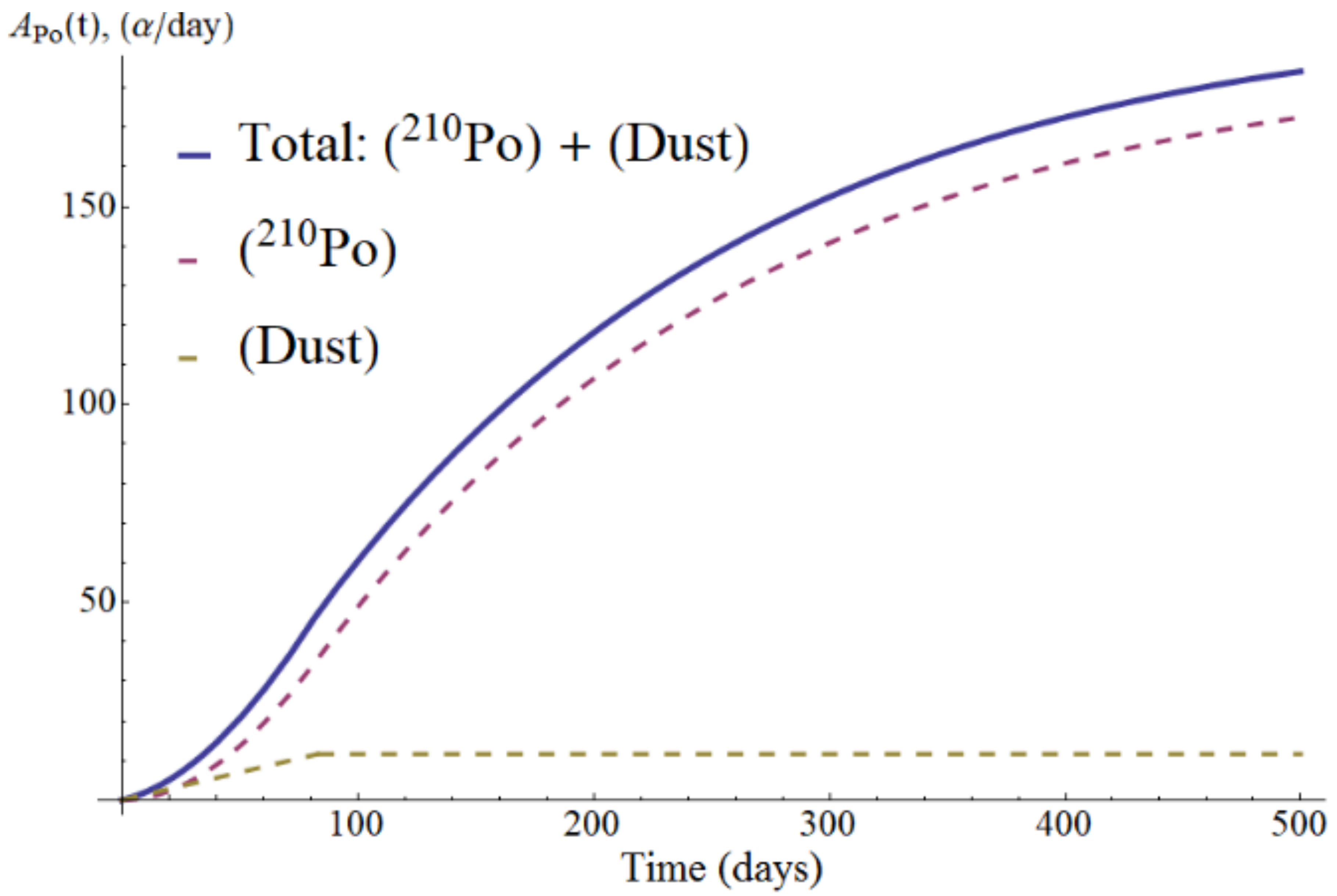
^{210}Po activity **increases** with time, after exposure

U and Th chains activity, **constant** in time

$$TotalActivity = (^{210}PoActivity) + (DustActivity)$$

$$A_{dust}(t, t_{exp}) = (S_{dust}t)\Theta(t_{exp} - t) + (t_{exp}S_{dust})\Theta(t - t_{exp})$$

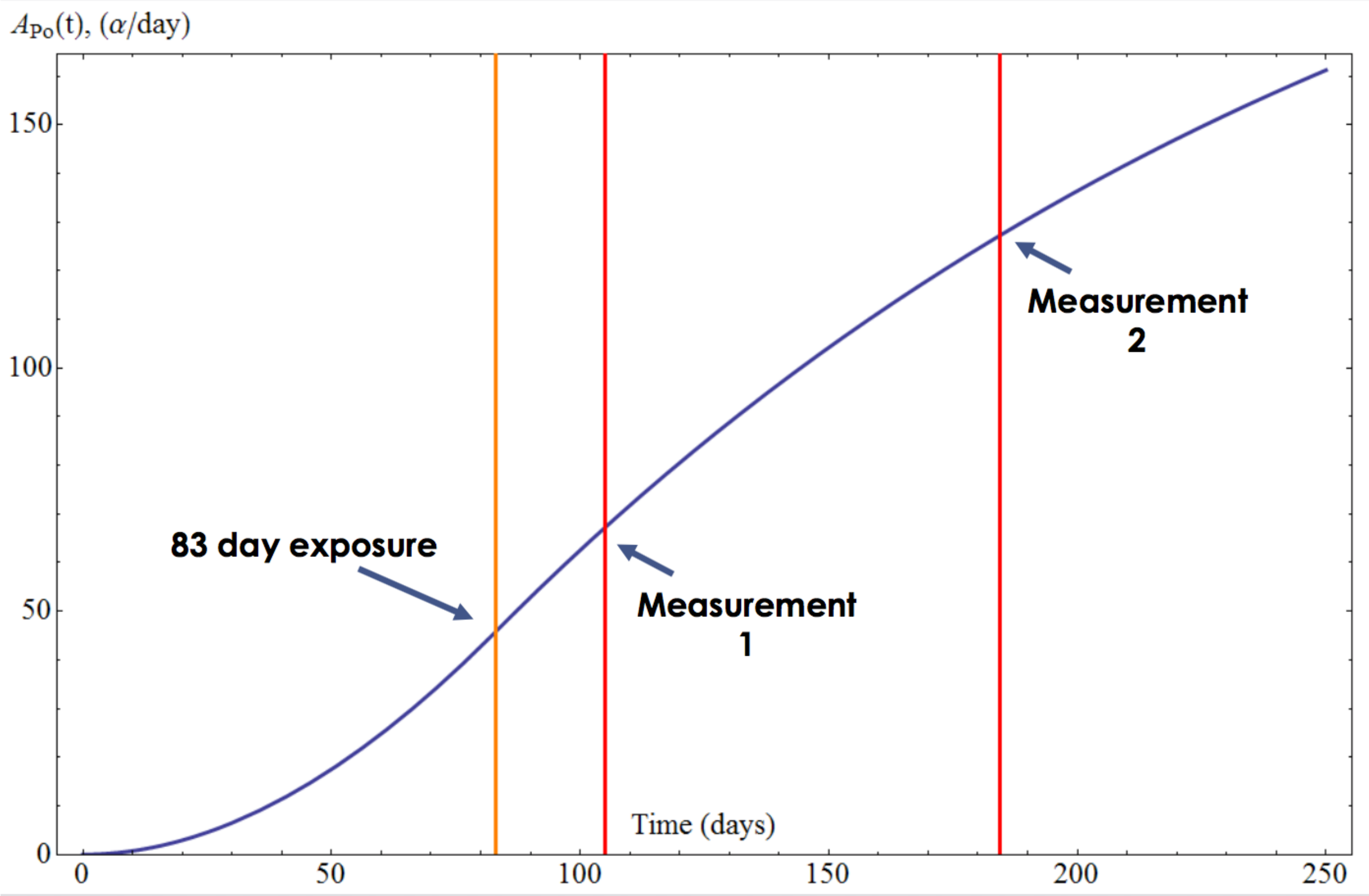
Rate of activity accumulated per unit time from dust (i.e. Bq/d/cm²)



Analytical Model

Total Activity

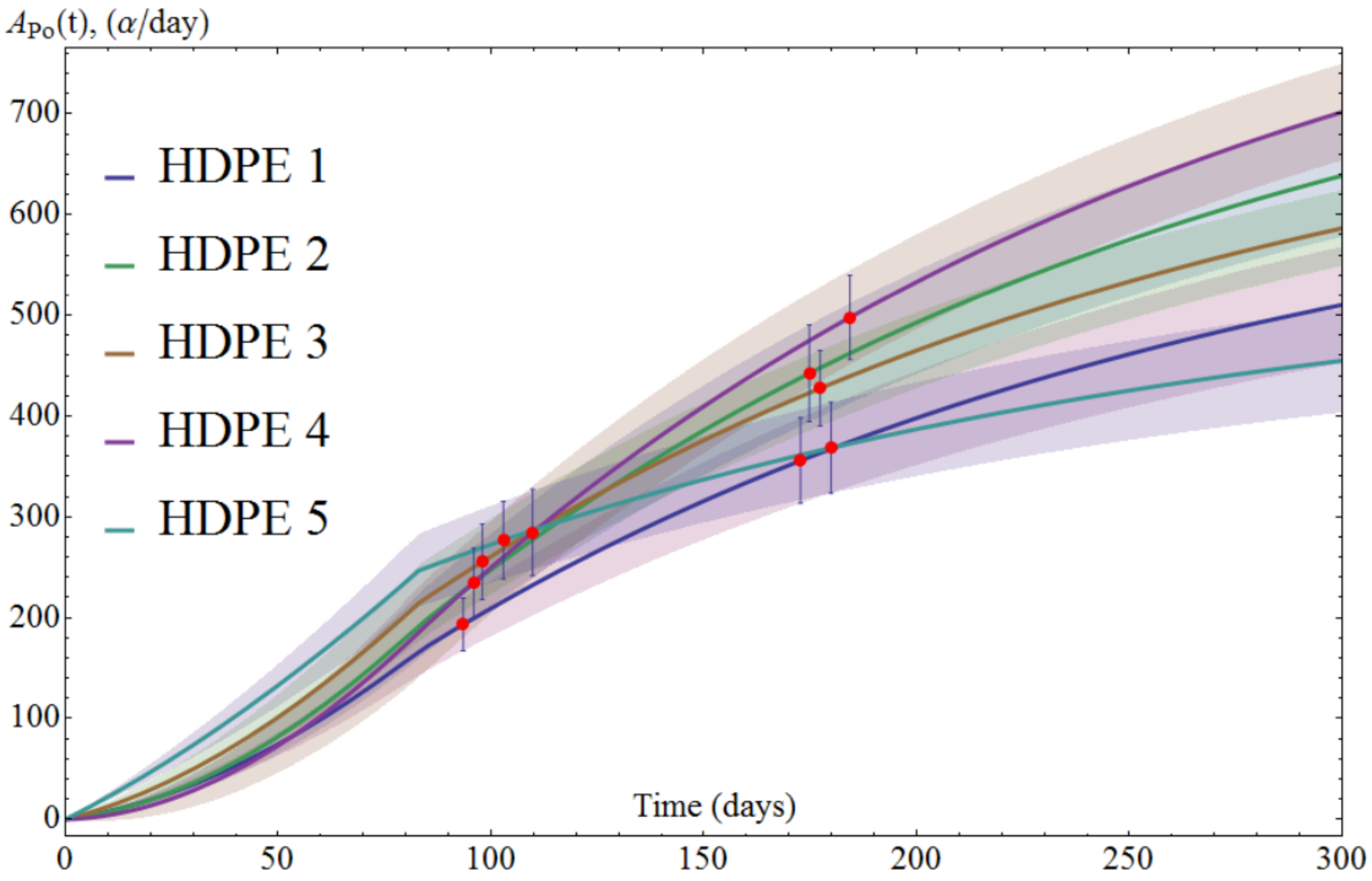
$$Total\ Activity = R_{Pb}K_{Pb} + S_{dust}K_{dust}$$

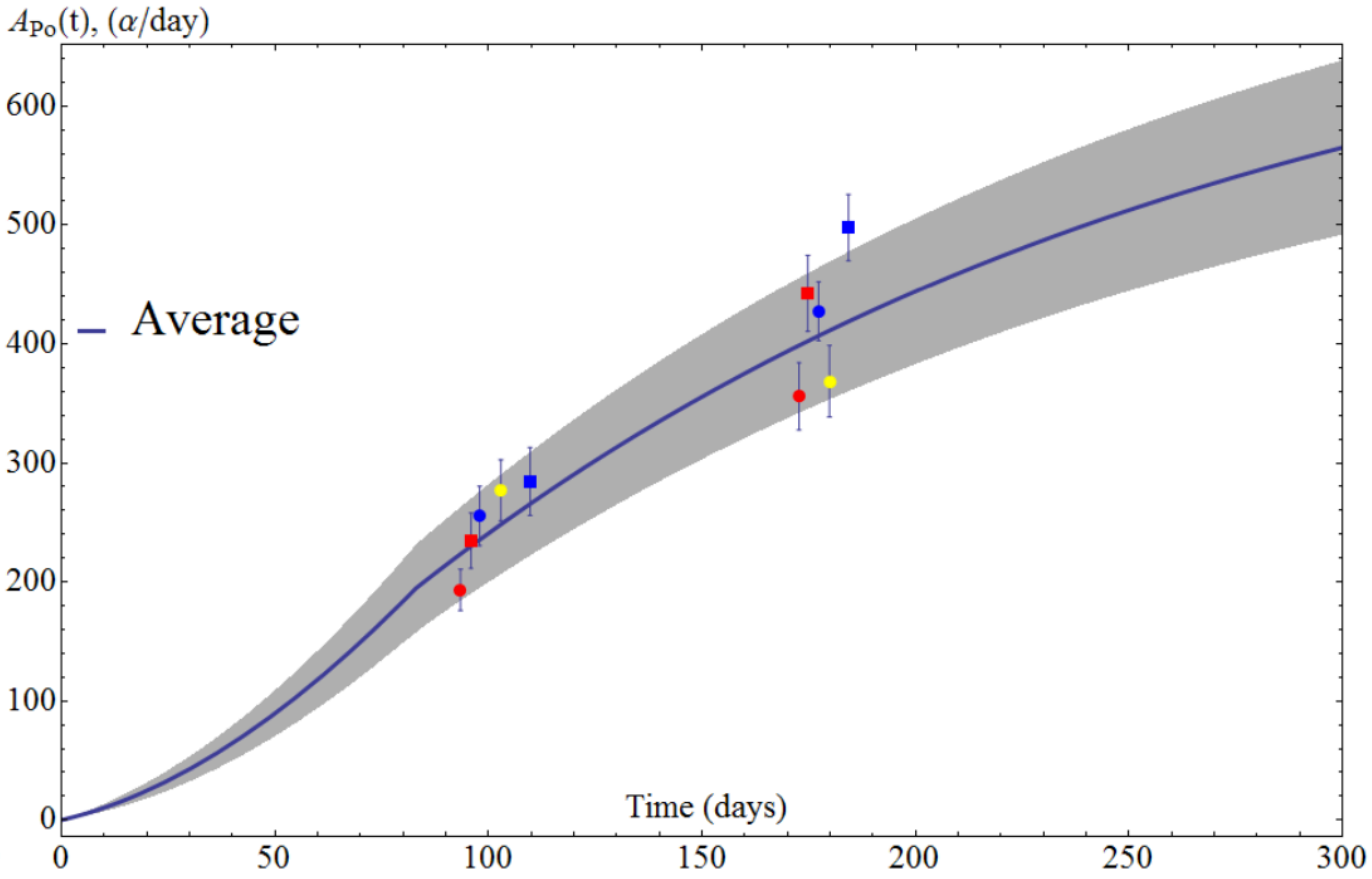


- Two measurements of activity:
  - two unknown variables
  - ingrowth of ^{210}Po

Analytical Model

Total Activity





Analytical Model

Total Activity

$$Total\ Activity = R_{Pb} K_{Pb} + S_{dust} K_{dust}$$

Plate-out rate: ~278(423) ^{210}Pb atoms/day/cm^2 for HDPE(Cu)

Dust activity increases ~27(5) nBq/day/cm^2 for HDPE(Cu)

Compatible with SNOLAB TR:

- Dust fallout of 1-7 ng/cm2/hour(SNO-STR-95-050)
- Activity of ~150 Bq/kg (238U + 232Th chains) (SNOLAB-STR-2007-003

➡ Yields expected value of (3.6– 28.8) nBq/day/cm2

Conclusions

- Developed activity prediction model that accounts for ^{210}Pb and dust:

$$TotalActivity = \lambda_{Po} \sum_{i=1}^{t_{exp}/binSize} B(t, R_{Pb} \cdot binSize, i \cdot binSize) + (S_{dust} t)\Theta(t_{exp} - t) + (t_{exp} S_{dust})\Theta(t - t_{exp}))$$

- Determined:
  - Plate-out rate: ~278(423) ^{210}Pb atoms per day per cm^2 for HDPE(Cu)
  - Dust activity increases ~27(5) nBq per day per cm^2 for HDPE(Cu)
- Constraint for installation of shielding for a targeted 10 $\mu Bq/cm^2$
  - ~39 days to limit the ^{210}Pb
  - ~60 days to limit dust activity

XIA at LPSC-LSM

Alpha spectrometer for large surface screening: specialized ionization counter comprising an active volume filled with boiled-off argon, a lower grounded electrode that is a conductive tray (holds sample), and an upper pair of positively charged electrodes

- Empty tray monitoring (*in-fieri*)
- Detector characterization via electroformed Cu tray (courtesy of SNOLAB) (*in-fieri*)
- First sample: Rn implanted copper lids of Ge semiconductor detectors to study the background discrimination power.
- Commissioning of gas recycling system (developed by CPPM - Marseille)
- Relocation underground at LSM (summer/fall 2025)

Thank you