Radon Background Mitigation for the SuperNEMO Experiment

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On behalf of the SuperNEMO collaboration

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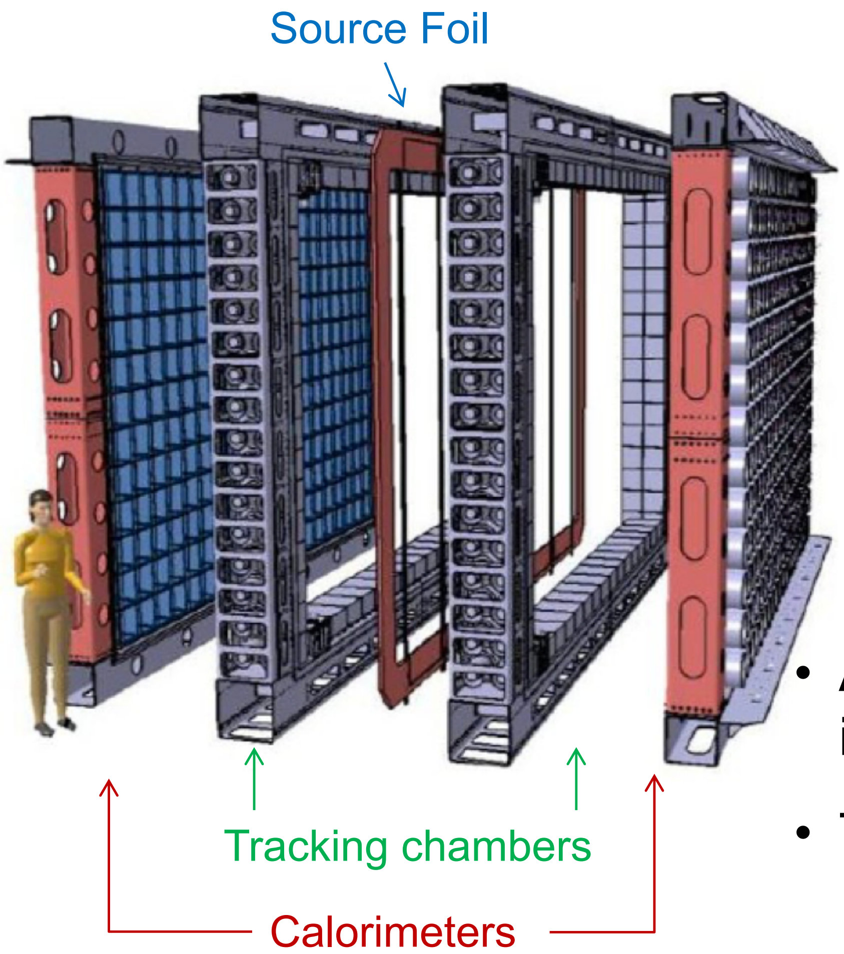
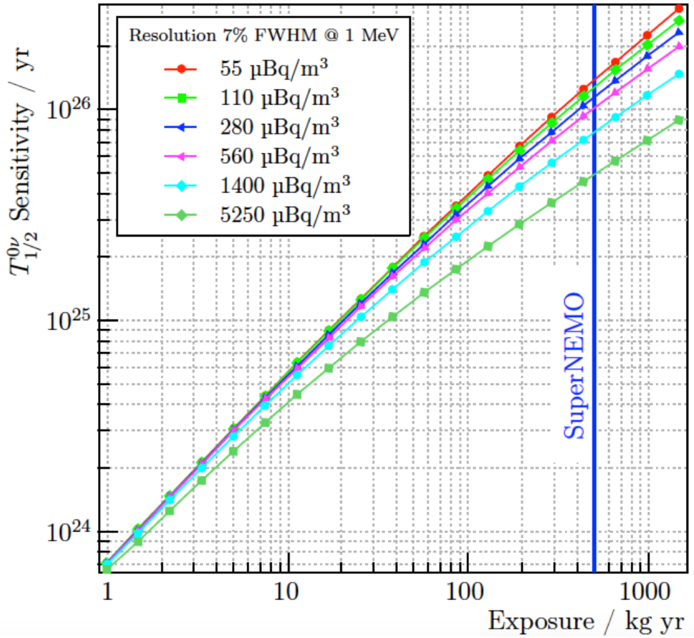
Overview

- Radio-purity Challenges
- Radon Detectors
- Emanation Measurement
- Radon Concentration Line
- Tracker Sub-module and Gas System Measurements

Radio-purity Challenges

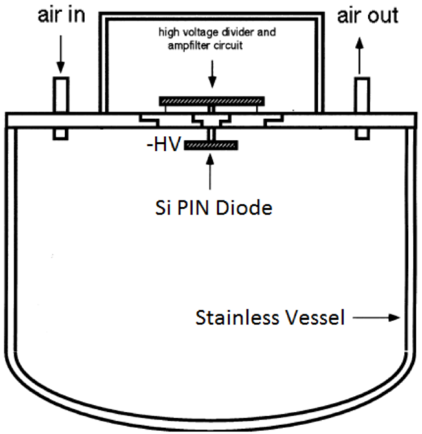


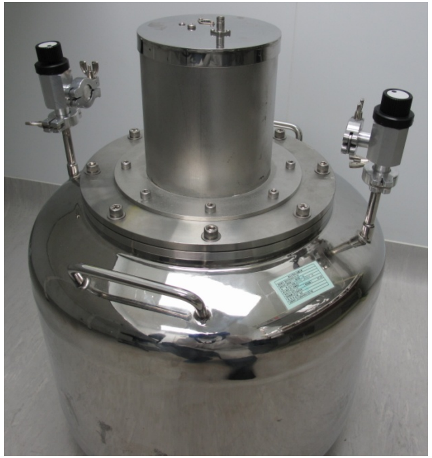


- Aim: zero background in the region of interest (2.8 – 3.2 MeV).
- Tracker gas requirement:

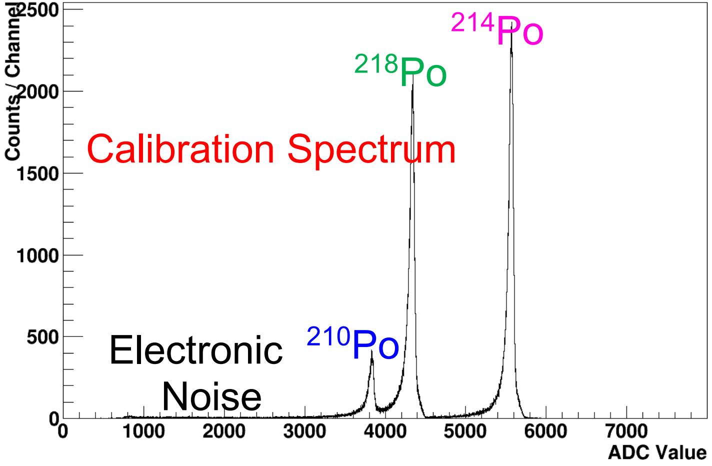
  A(^{222}Rn) < 0.15 mBq/m^3

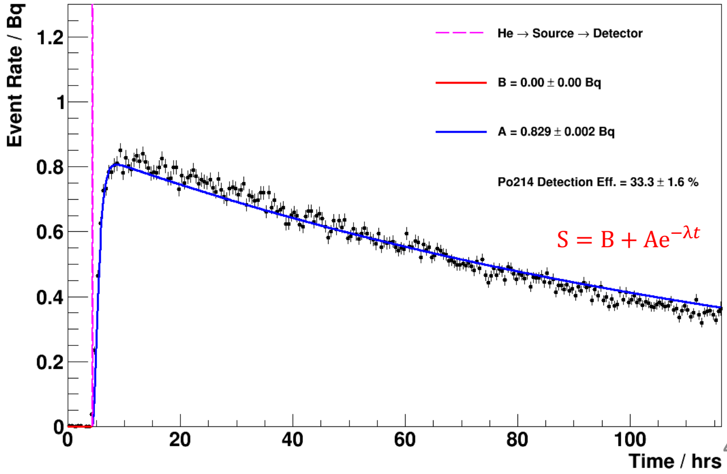
Electrostatic Detector





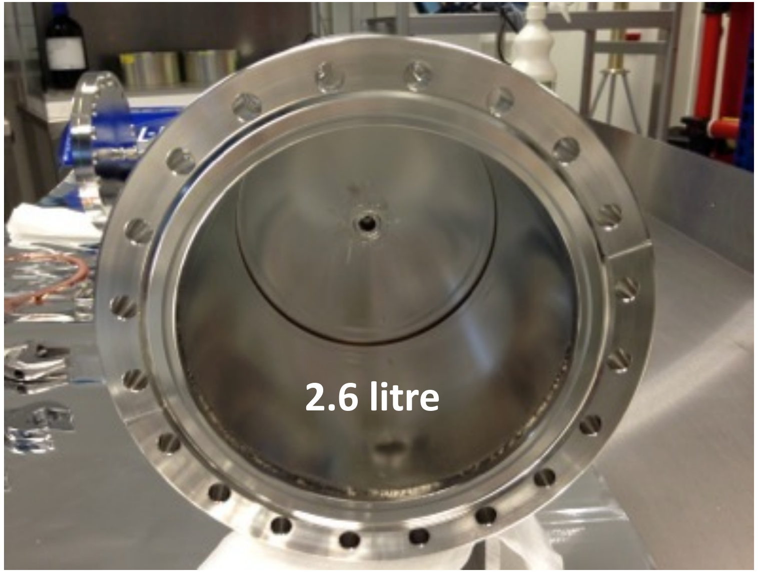
- Electro-polished stainless steel 70 litres vessel.
- -1500 V applied on the silicon PIN diode.
- Sensitive to ~0.09 mBq.



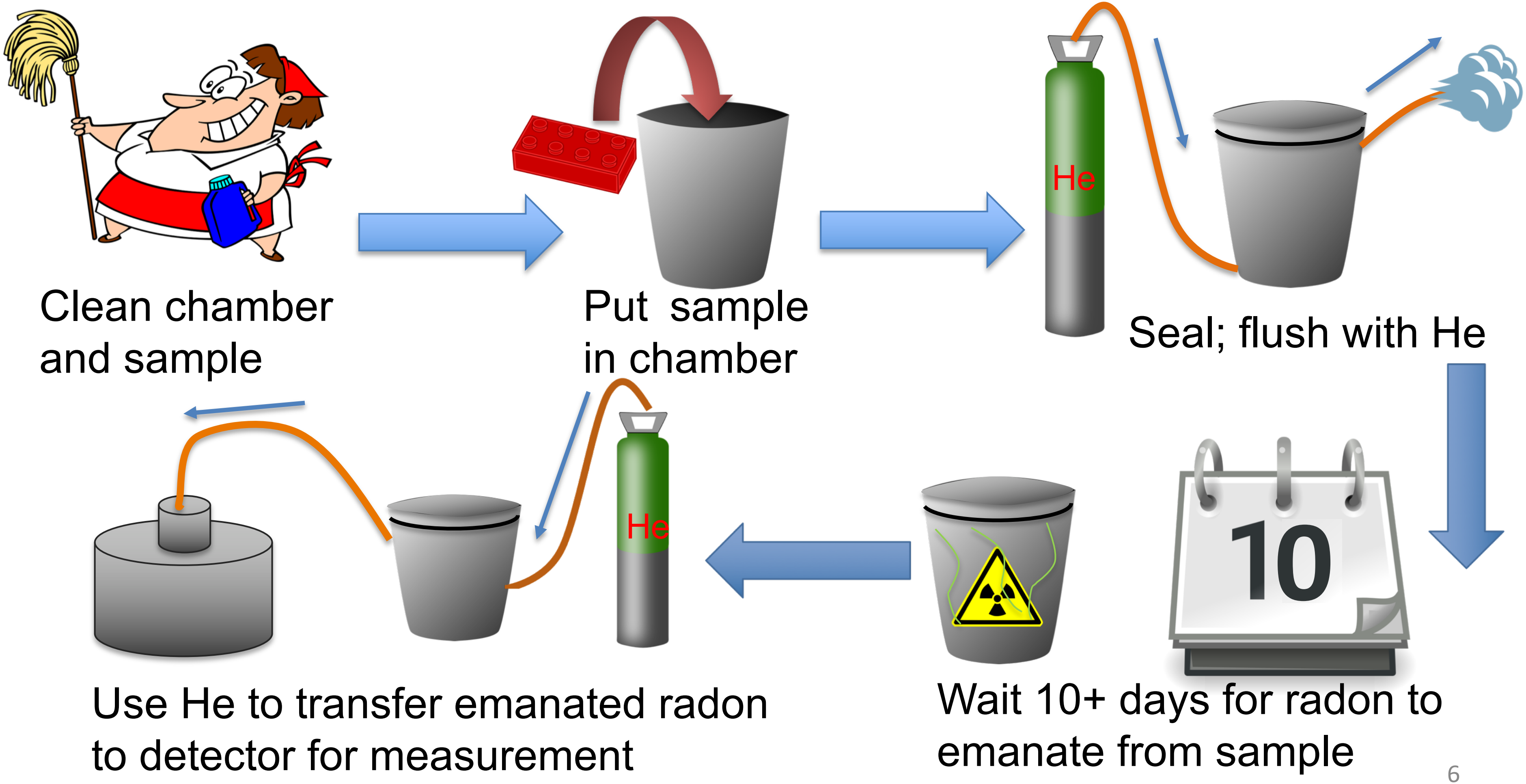


Emanation Chamber

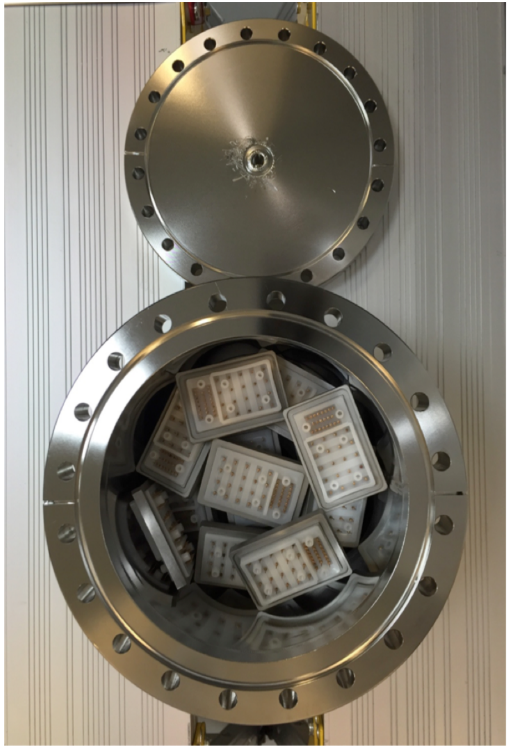
- All detector components and construction materials are tested for their radon emanation levels.
- For small samples with large surfaces.
- Sensitivity (@90% CL): ^{214}Po < 0.09 mBq per sample

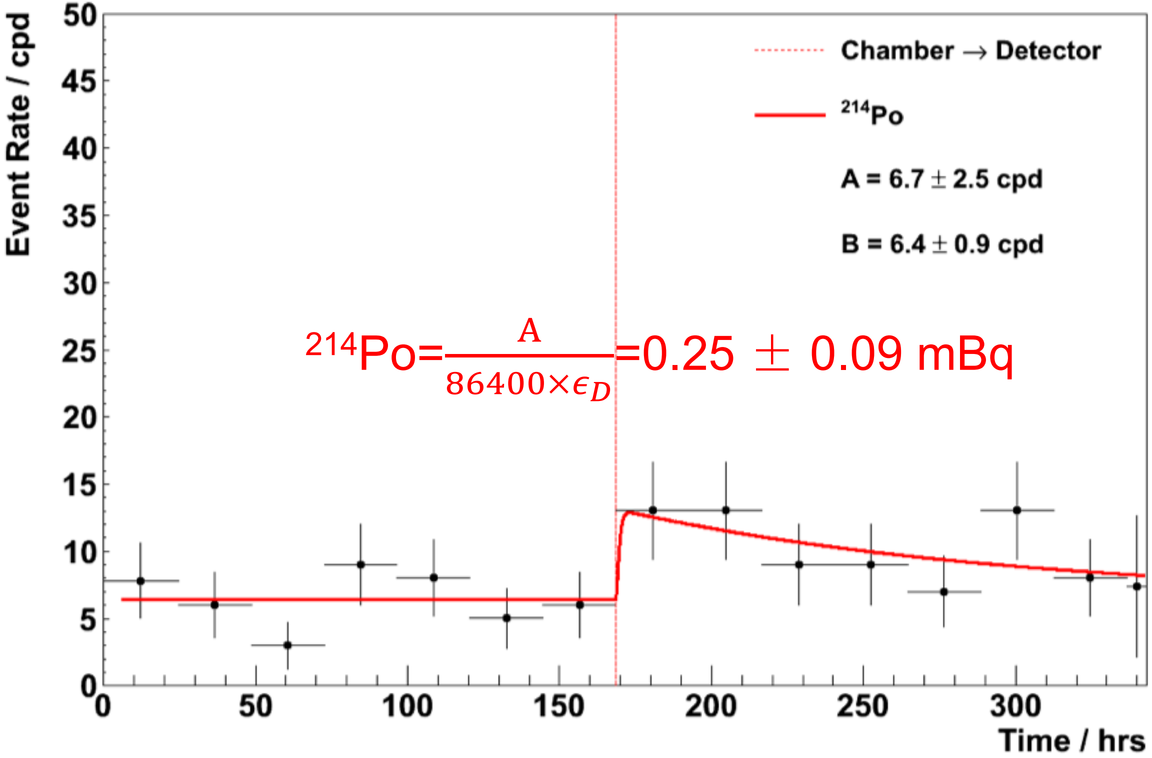


Emanation Measurement - Spike Method



Feedthrough Emanation Measurement

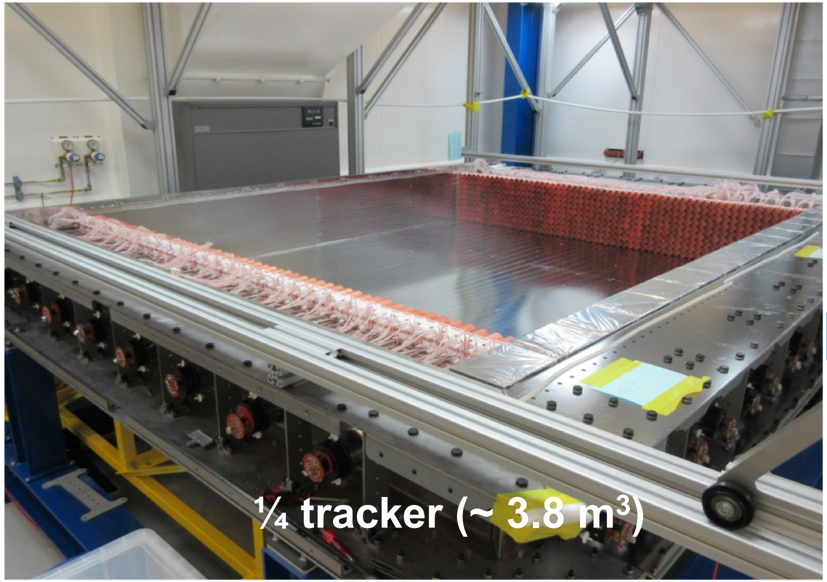


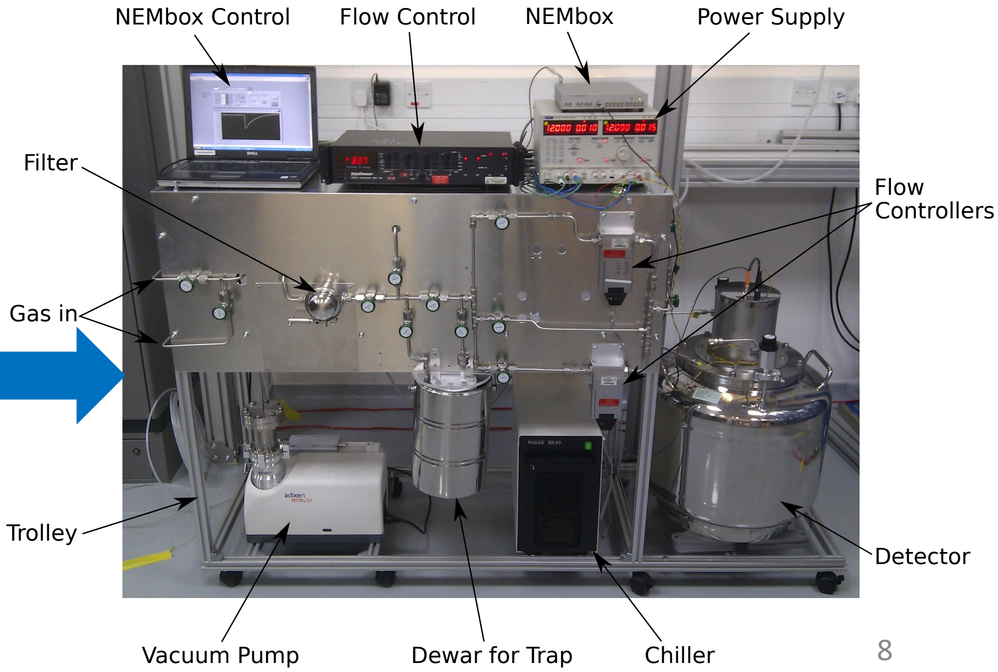


$$^{214}\text{Po} = \frac{A}{86400 \times \epsilon_D} = 0.25 \pm 0.09 \text{ mBq}$$

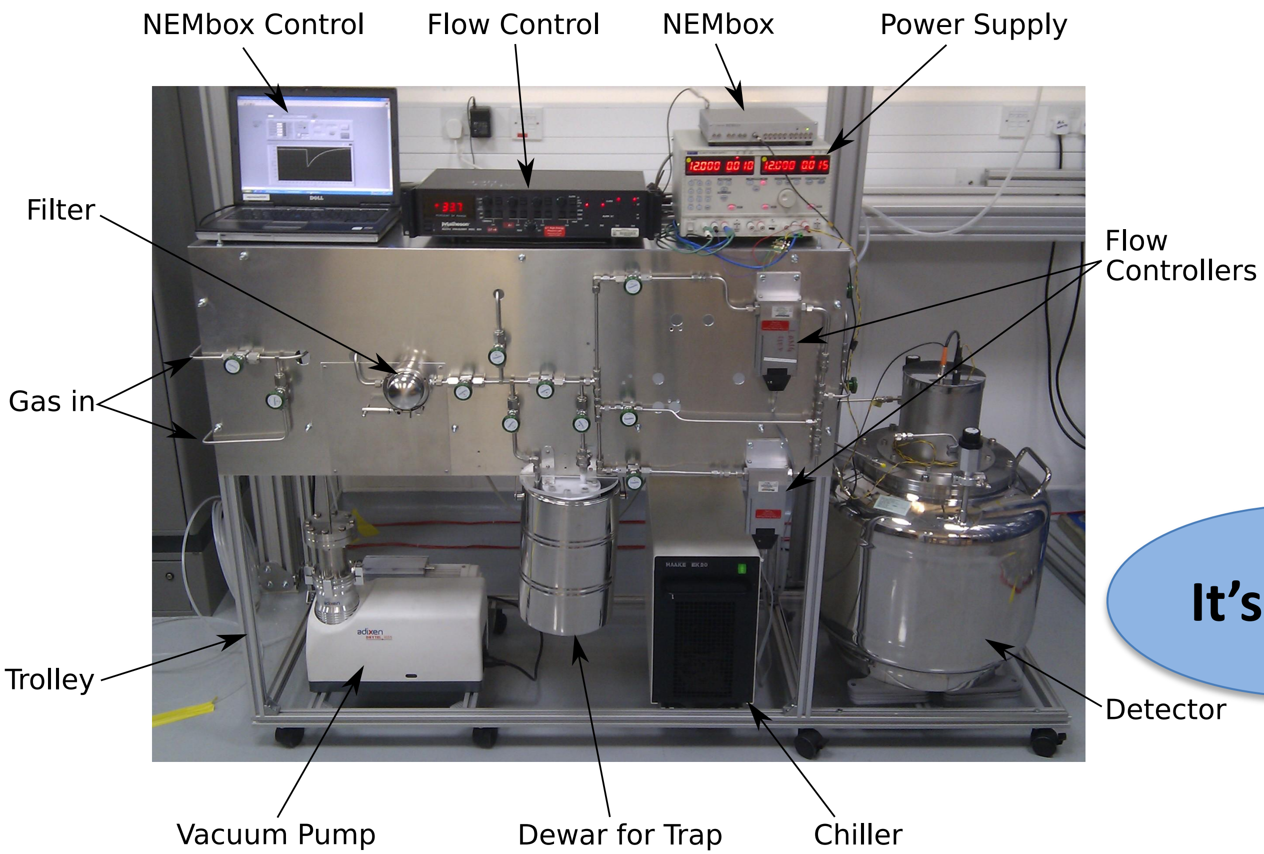
Radon Concentration Line (RnCL) Motivation

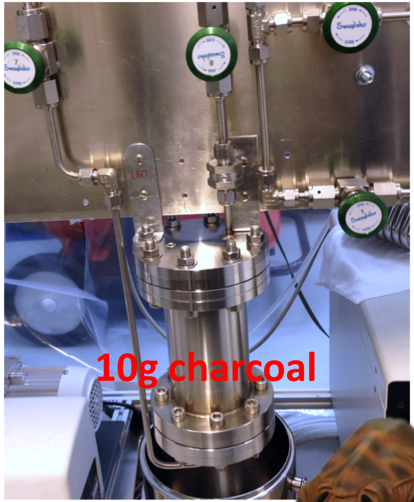
- Radiopurity target requires the detector sensitivity: ~0.01 mBq.
- Detector sensitivity: ~0.09 mBq.
- A "Radon Concentration Line" (RnCL) was developed at UCL.



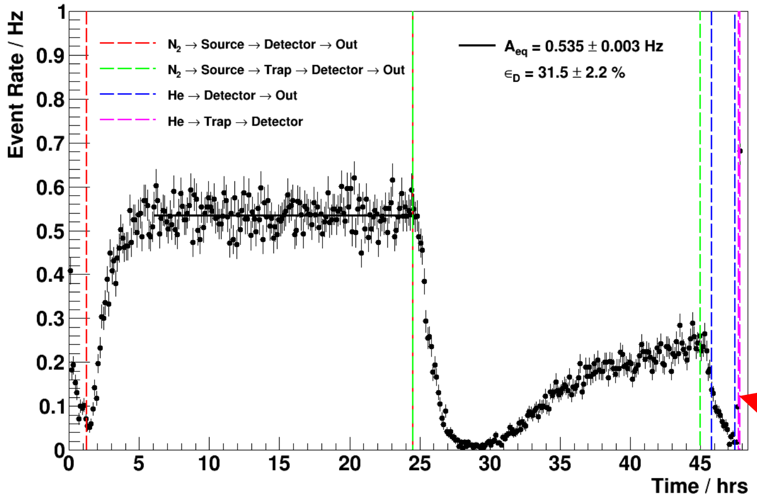


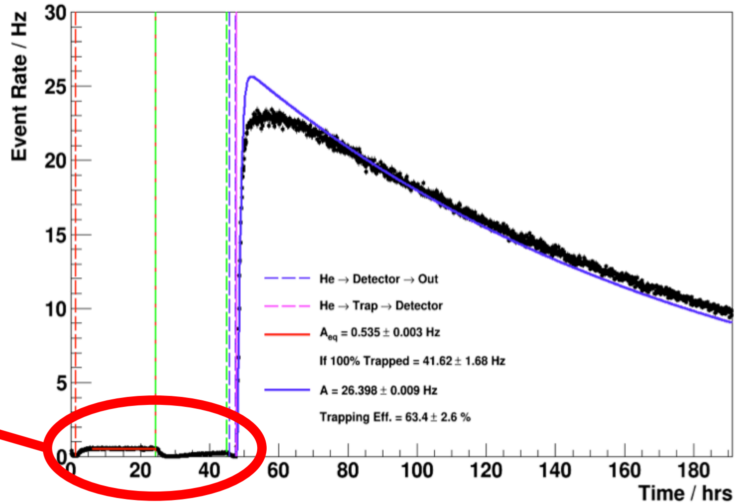
Radon Concentration Line





RnCL Calibration





Measure the source **activity at equilibrium**

Detection Efficiency

Cool trap to absorb radon 20h

Trapping Efficiency

Heat trap to release radon

Transfer radon into detector

Trapping & Transfer Efficiency

C-section Measurement

- The ¼ tracker (C-section) was kept in a anti-radon tent.
- A standard RnCL method measurement was carried out.
- Flush with N_2 through the RnCL trap, sampling 8.4 m^3 of gas in total.
- Measurements of the first two C-Sections produced results;

C0: 11.37 ± 1.44 mBq

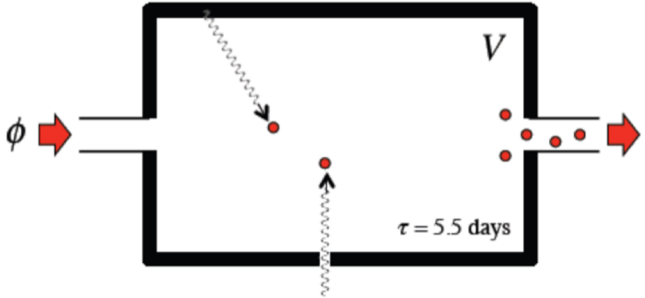
C1: $15.26\ ^{+2.5}_{-4.0}$ mBq

- A tracker component showed positive radon contribution, and was replaced during C2 and C3 construction.

C-section Measurement

- The C2 activity was measured as **4.36 ± 1.31 mBq**
- Tracker activity (with C3 activity estimated as the average value for C0-C2);

A_T = 41.3 ± 4.7 mBq (equivalent to 2.72 ± 0.31 mBq/m^3)



Radon Suppression Factor :

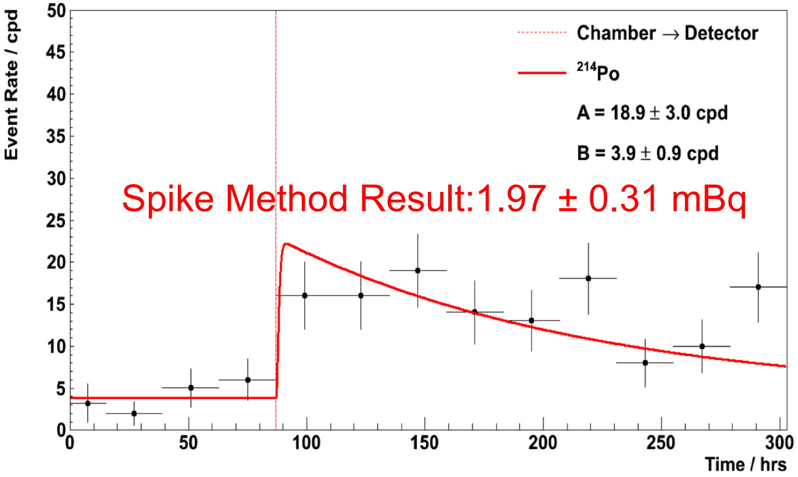
$$S = \frac{1}{(\phi\tau/V)+1}$$

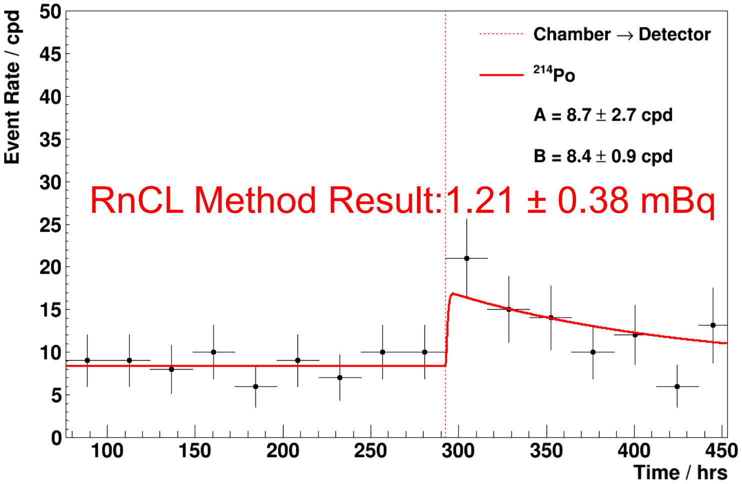
Input Flow m^3/hr	Suppression Factor $(1 + \phi\tau/V)$	a_T with tent (mBq/m^3)
0.5	5.35	0.51 ± 0.06
1.0	9.71	0.28 ± 0.03
2.0	18.42	0.15 ± 0.02

Demonstrator target reached!

Gas System Measurement

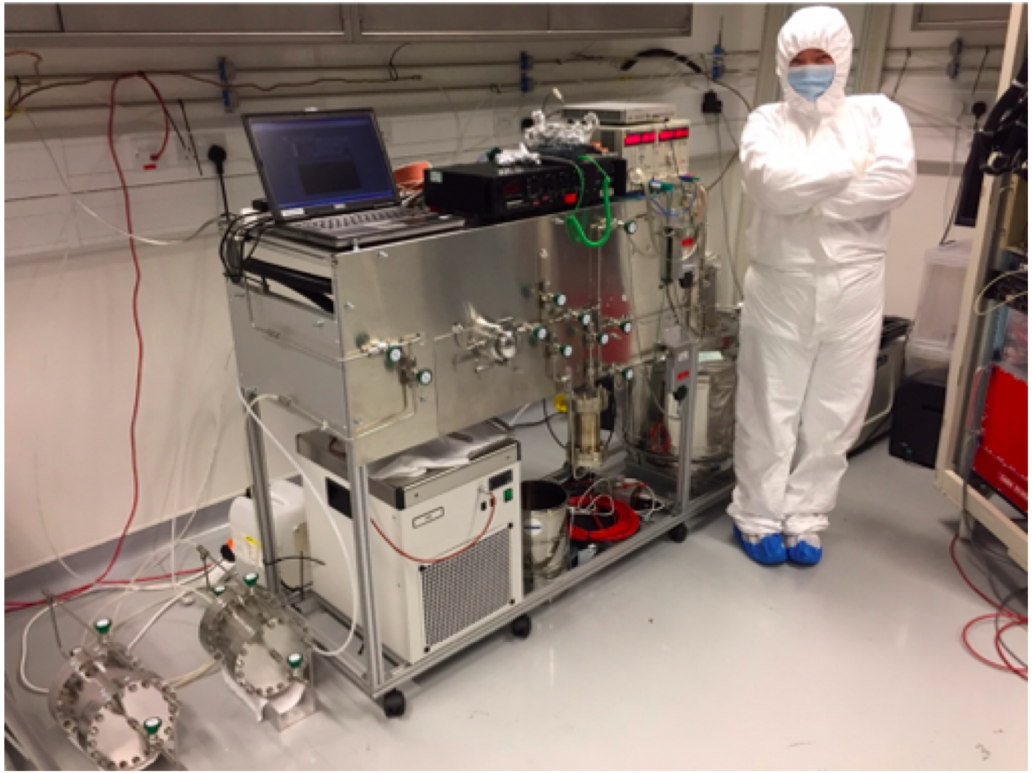
- Drained of ethanol.
- Measured via Spike and RnCL methods.
- Consistent results: equivalent to ~10% of the tracker radon budget.





Summary

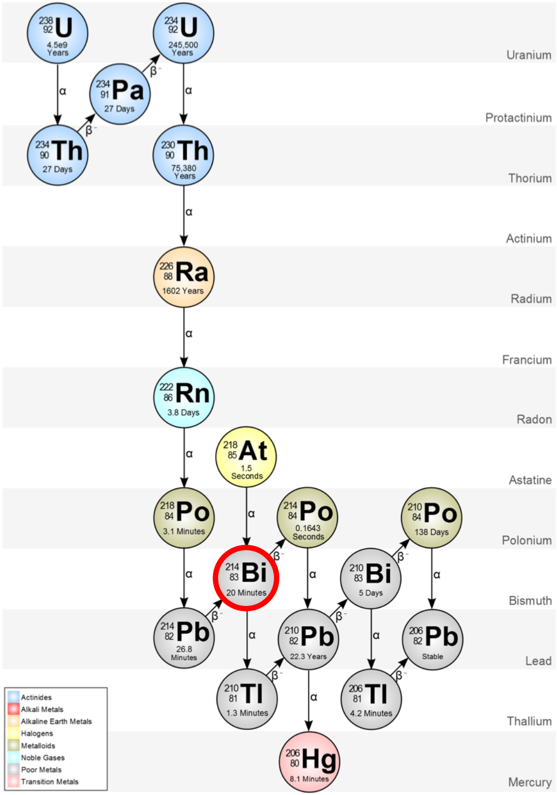
- Tracker radon radiopurity target: < 0.15 mBq/m^3.
- To measure such low activities, we developed:
  - A Radon concentration line **~5 μBq/m^3** with large gas volume.
  - Two high sensitivity emanation chambers **~0.09 mBq**
- **Target achieved!**

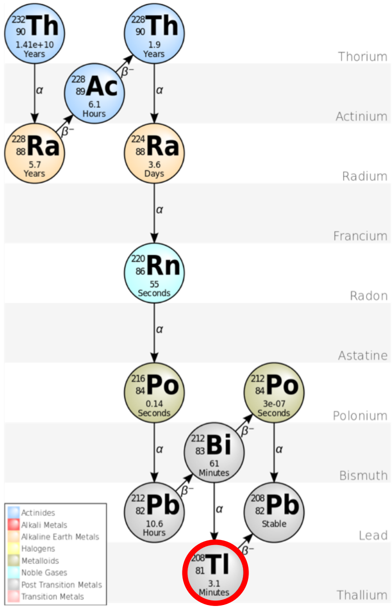


- Next: tune SuperNEMO simulation to use latest activity measurements.

Backups

Radon: Decay Chain

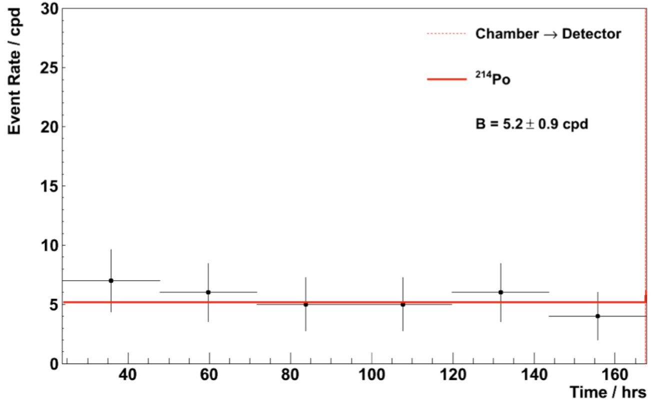


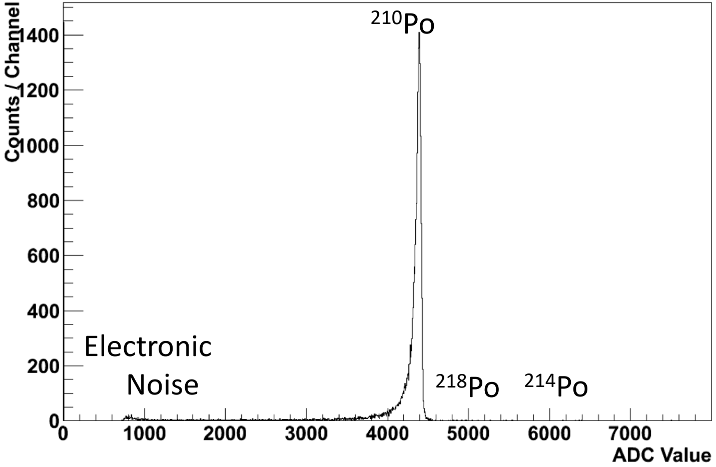


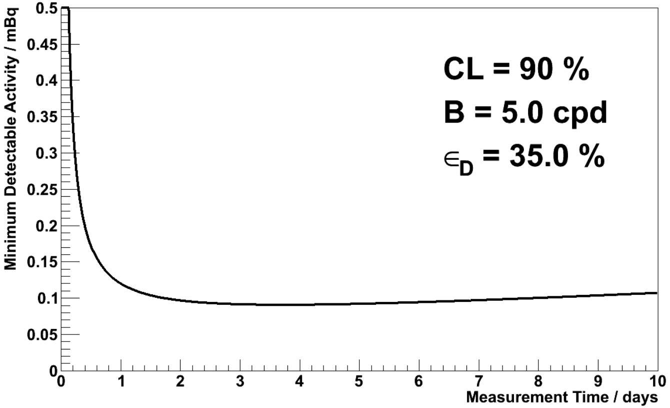
^{214}Bi (Q_{β}= 3.27 MeV) and ^{208}Tl (Q_{β}= 4.99 MeV) can mimic double beta decay.

Detector Background and Sensitivity

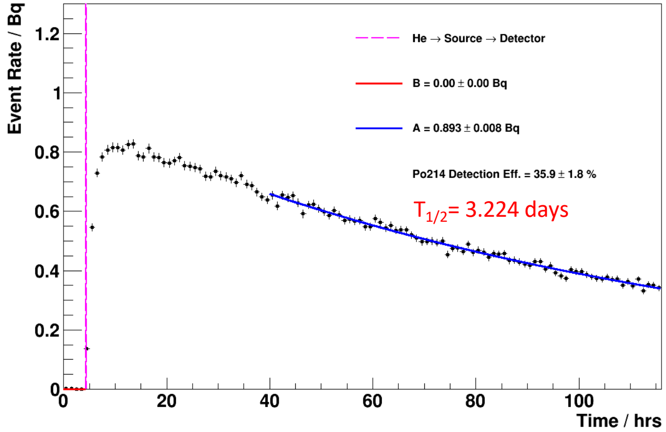
- Measurement of detector background shows **~ 5 cpd**
- Gives sensitivity of ~ **0.09 mBq** (1.3 mBq/m^3) @ 90% CL

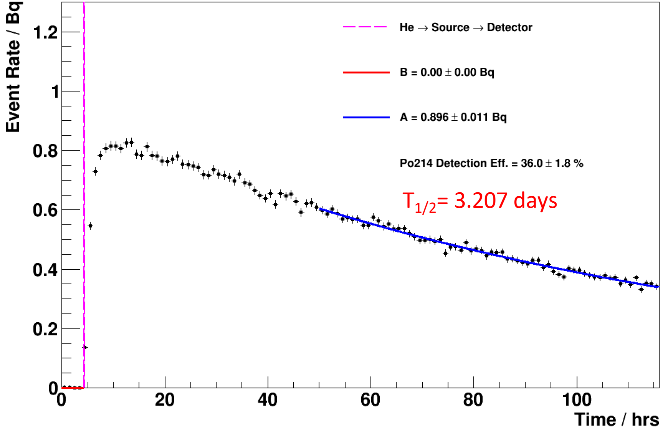


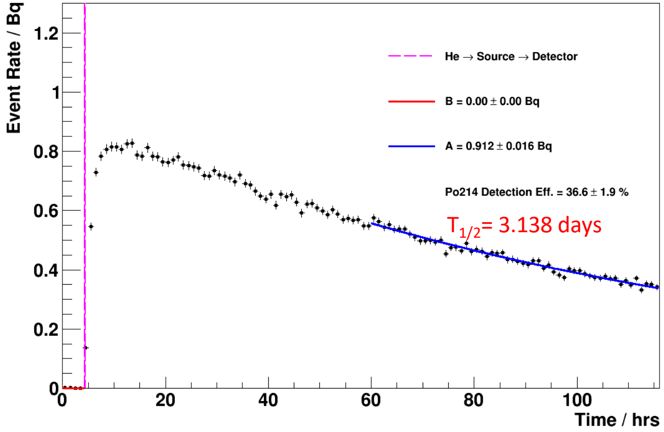


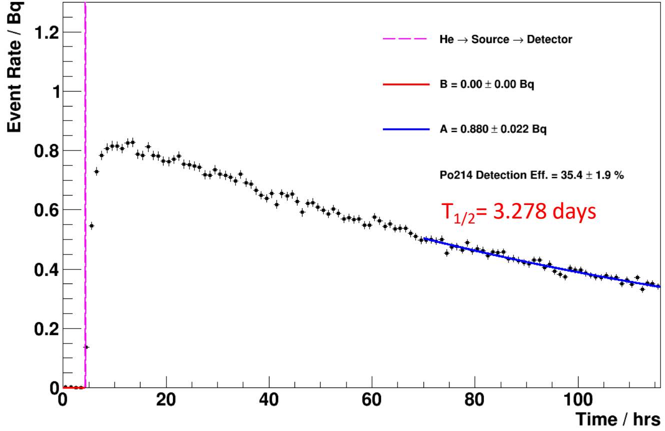


Detector Calibration Different Fittings



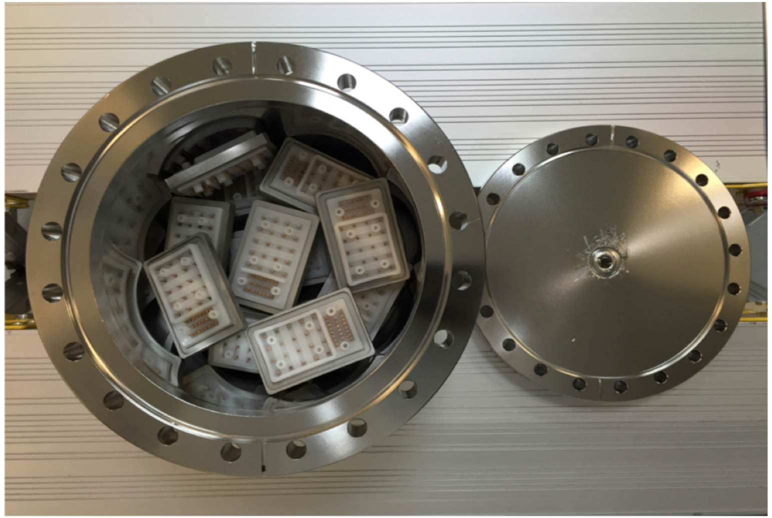


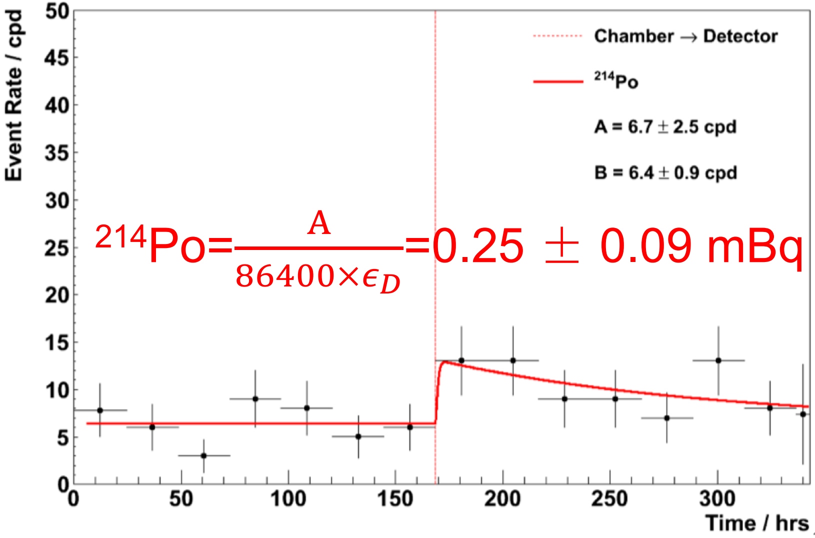




Emanation Measurement - Spike Method

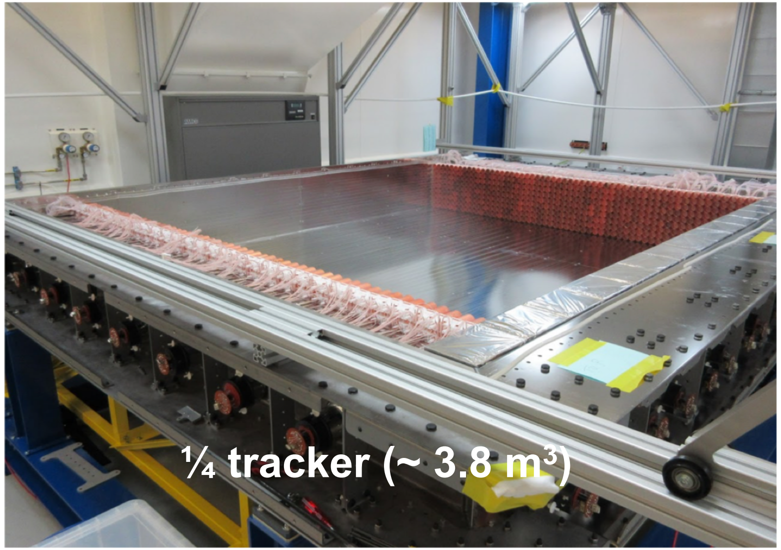
- Clean chamber and sample before insertion.
- Seal the chamber and flush with Helium for 100 volumes.
- 10+ days for emanation.
- Transfer radon carried by 25 litres of Helium into detector.

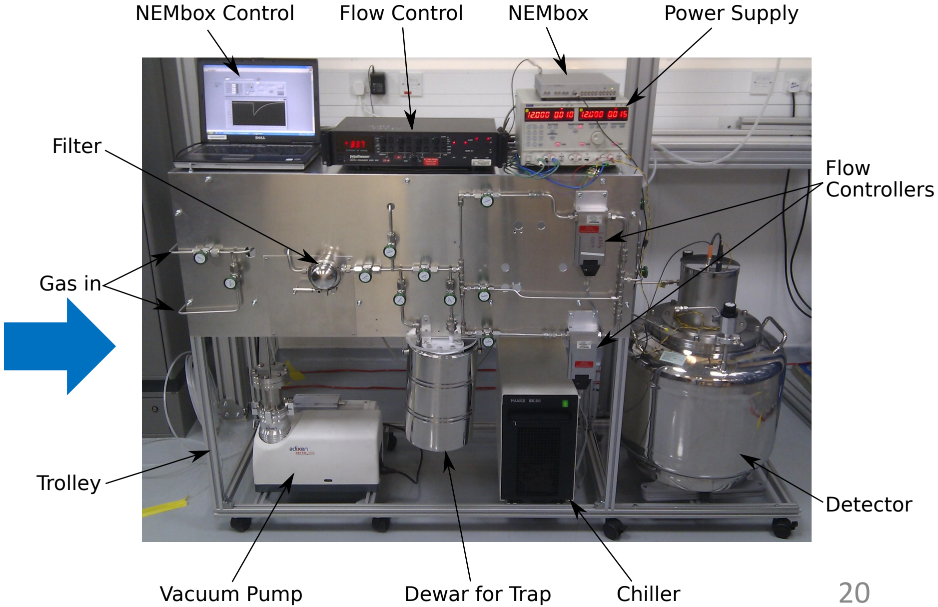




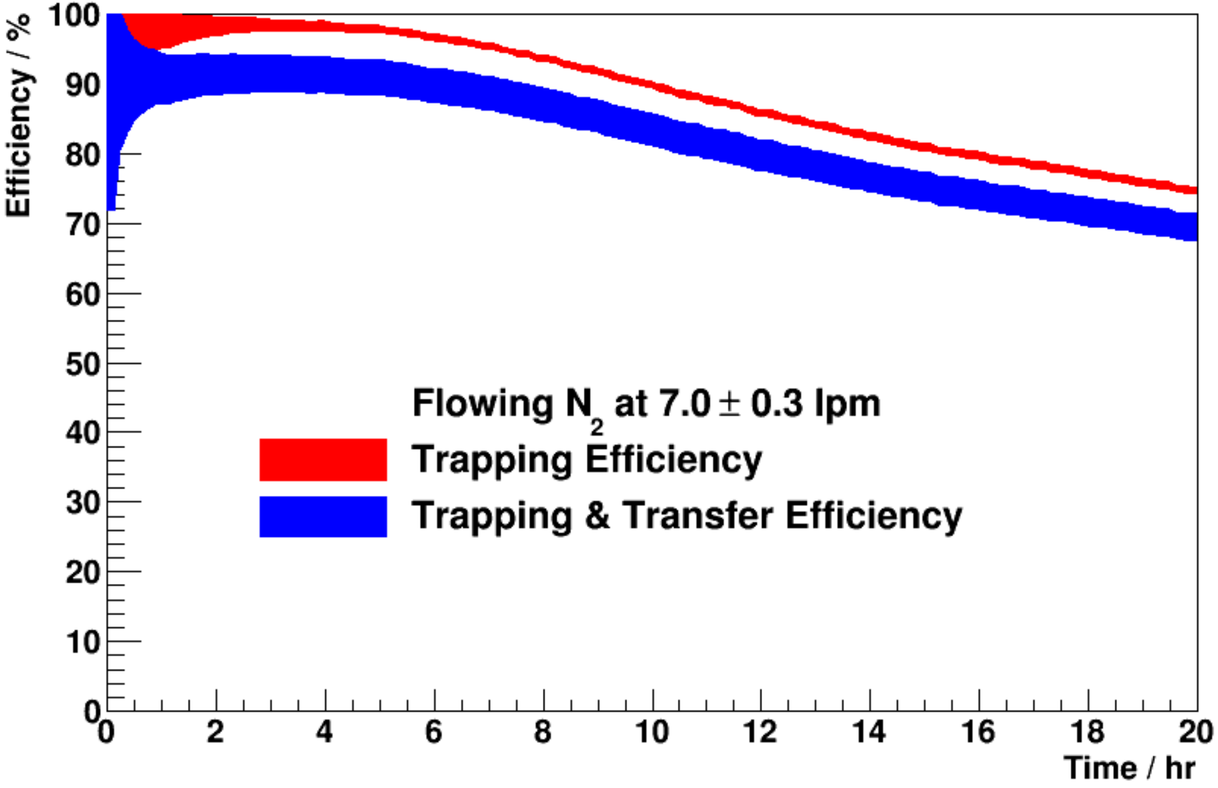
Radon Concentration Line (RnCL)

- Radiopurity target requires the detector sensitivity: ~0.01 mBq.
- Detector sensitivity: ~0.09 mBq.
- A "Radon Concentration Line" (RnCL) was developed at UCL. It use a cold carbon trap to concentrate radon.



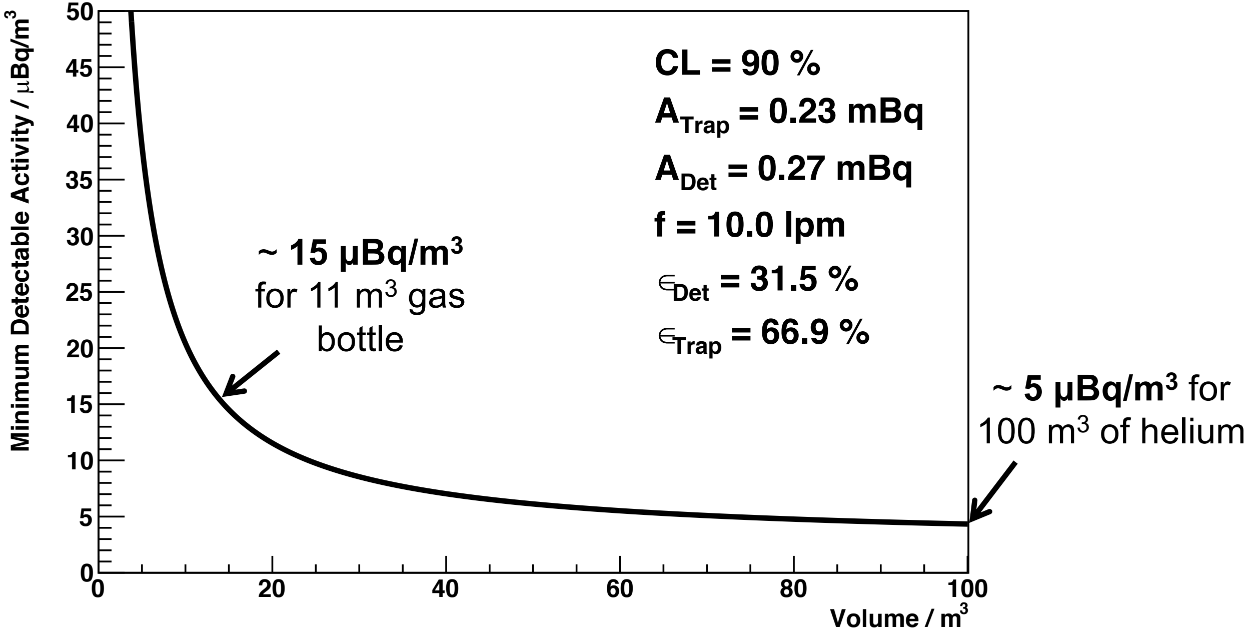


RnCL Flow-through Calibration



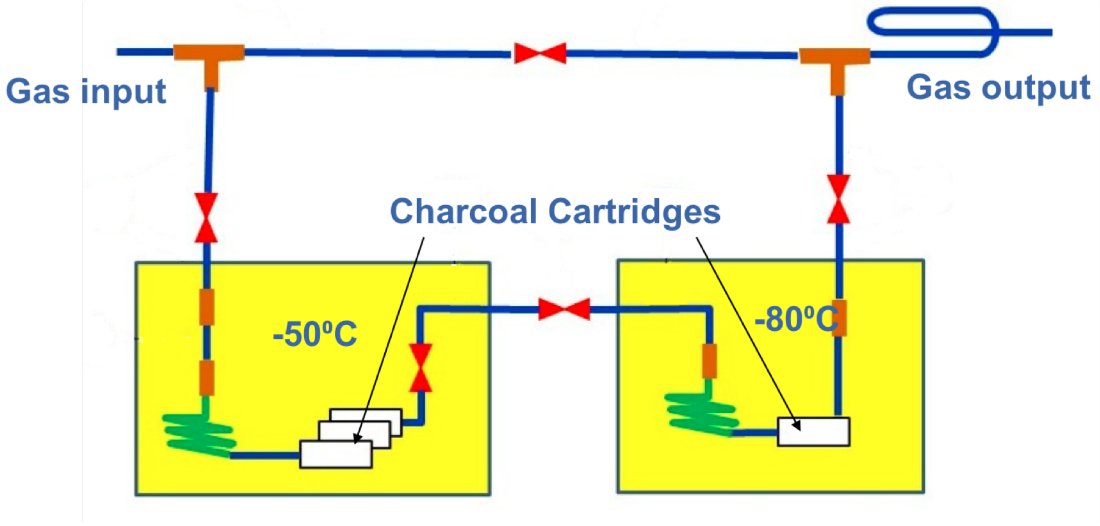
RnCL: Sensitivity Estimates

- Initial measurements of carbon trap activity are ~0.23 mBq.
- Assuming a supply of gas of constant activity leads to the following sensitivity for a given volume of gas:



Radon Trap System (J-trap)

- A **Radon Trap** was designed and built at CPPM to minimise the source of systematics from radon contamination of carrier gas.
- Two freezers with charcoal cartridges were installed right after gas cylinder and prior to the RnCL for carrier gas pre-purification.



Suppression factor:

Helium: 5E+10

Nitrogen: ~10

C-section Measurement

- The C-section was kept in a anti-radon tent under a constant overpressure for at least 18 days for any radon harboured within detector material to decay away.
- Then the C-section volume needs to be flushed at a faster rate, required for flowthrough measurements, for at least 50 hours before it reaches equilibrium...
- Then a standard RnCL measurement was carried out. Flush with nitrogen through the RnCL trap at 7 lpm over 20 hours, sampling a total volume of 8.4 m^3 of gas.

C-section Measurement

- The activity inside the C-section is given by;

$$\frac{dN_T}{dt} = A_T + A_G - \lambda N_T - \frac{f_{in} N_T}{V_T} + \frac{f_{in} a_G}{\lambda}$$

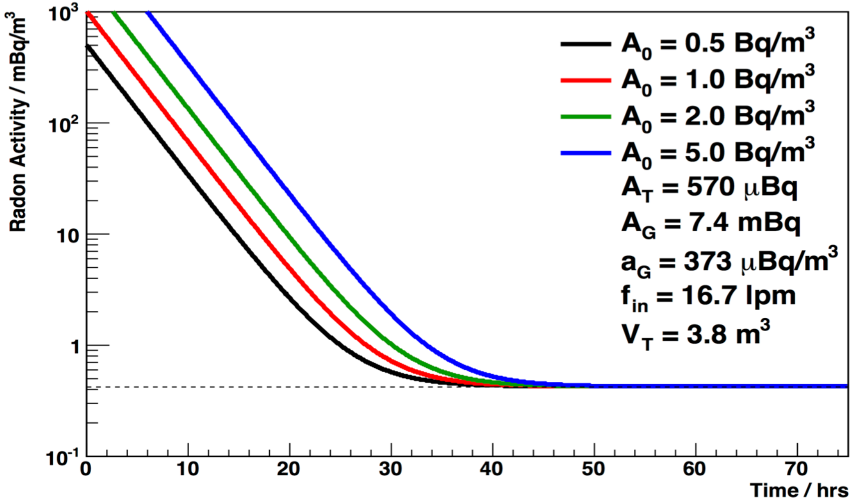
where N_T is number of ^{222}Rn atoms in tracker
A_T is intrinsic tracker activity
A_G is activity of gas supply line (1.8 mBq factor 4 reduction)
λ is radon decay constant
f_{in} is input flow rate
a_G is activity of gas from J-trap gas (20±13 μBq/m^3)
V_T is tracker volume

- In equilibrium, the activity in the C-section is given by;

$$a_T^{eq} = \frac{A_T + A_G + f_{in} a_G / \lambda}{V_T + f_{in} / \lambda}$$

C-section Measurement – Starting Point

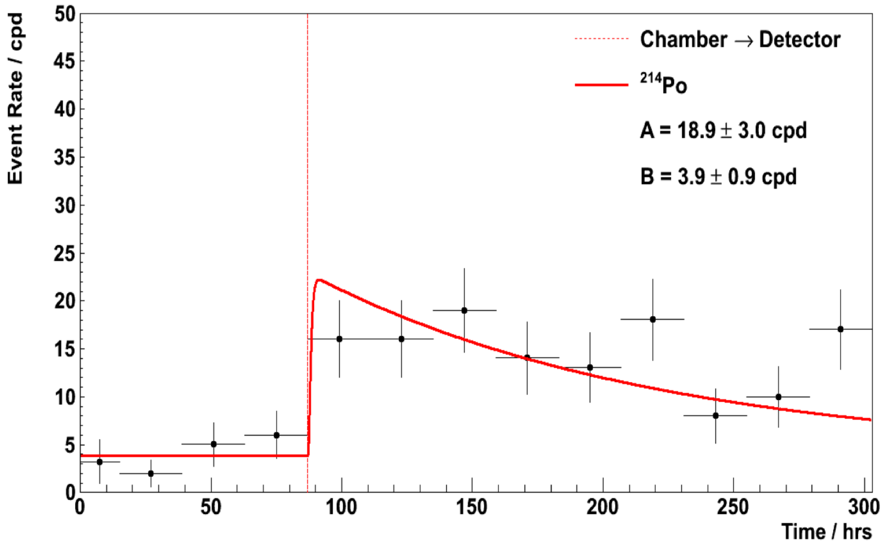
- The C-section is kept under a constant overpressure with continuous gas flow for at least 18 days for any radon harboured within detector material to decay away.



- Then the C-section volume needs to be flushed at a faster rate, required for flowthrough measurements, for at least 50 hours before it reaches equilibrium...

- Finally the standard flowthrough measurement requires ~26 hours, so in total a measurement requires ~ 3 weeks.

GS Spike Measurement



- The gas system was sealed for radon build-up over 17 days.
- 214Po Activity;

  0.69 ± 0.11 mBq

- There are some uncertainty regarding the transfer efficiency. Conservative estimate is at 35%, presuming 50% of gas is transferred from the GS with a efficiency of 70%. results in an activity of 1.97 ± 0.31 mBq.

GS RnCL Measurement

- The radon activity introduced into detector is;

$$A_D = \epsilon_{tr} A_C \left(1 - e^{-\lambda T_C}\right) + \frac{\epsilon_{tr}\epsilon_T (T_f) f a_{GS}^{eq}}{\lambda}\left(1 - e^{-\lambda T_f}\right) e^{-\lambda T_{trans}}$$

where

λ is the decay constant of ^{222}Rn;
ϵ_{tr} is the transfer efficiency;
ϵ_T is the trapping efficiency;
T_C is the time between clearing the trap and detector transfer (1705 min);
T_f is the time that the line is in contact with the trap (1200 min);
T_{trans} is the time between stopping trapping collection and detector transfer (240 min);
A_D is the radon activity in the electrostatic detector;
A_C is the radon activity of the carbon trap;

- In equilibrium, the activity in the Gas System is given by;

$$a_{GS}^{eq} = \frac{A_{GS} + f_{in} a_G / \lambda}{V_{GS} + f_{in}/\lambda}$$

where

f_{in} is the input flowrate of gas;
A_{GS} is the radon activity of the gas system;
V_{GS} is the volume of the gas system.