# Low-background tracker development for SuperNEMO

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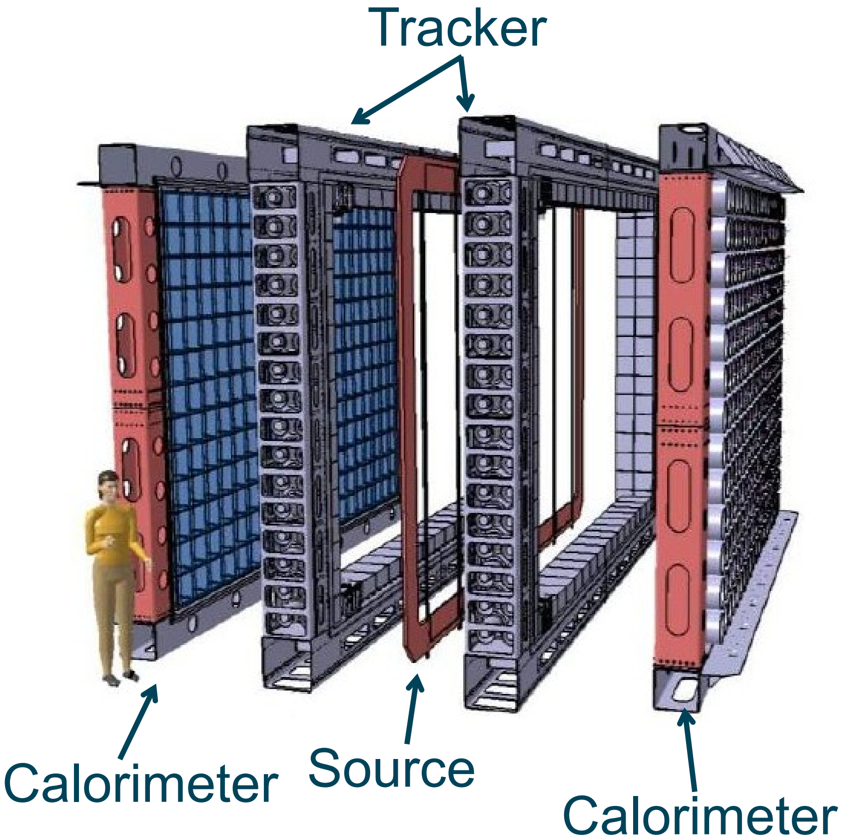
On behalf of the SuperNEMO Collaboration

LRT2013, 10th - 12th April 2013

INFN - Laboratori Nazionali del Gran Sasso

# The SuperNEMO Experiment

- SuperNEMO is a next-generation **0νββ** experiment.

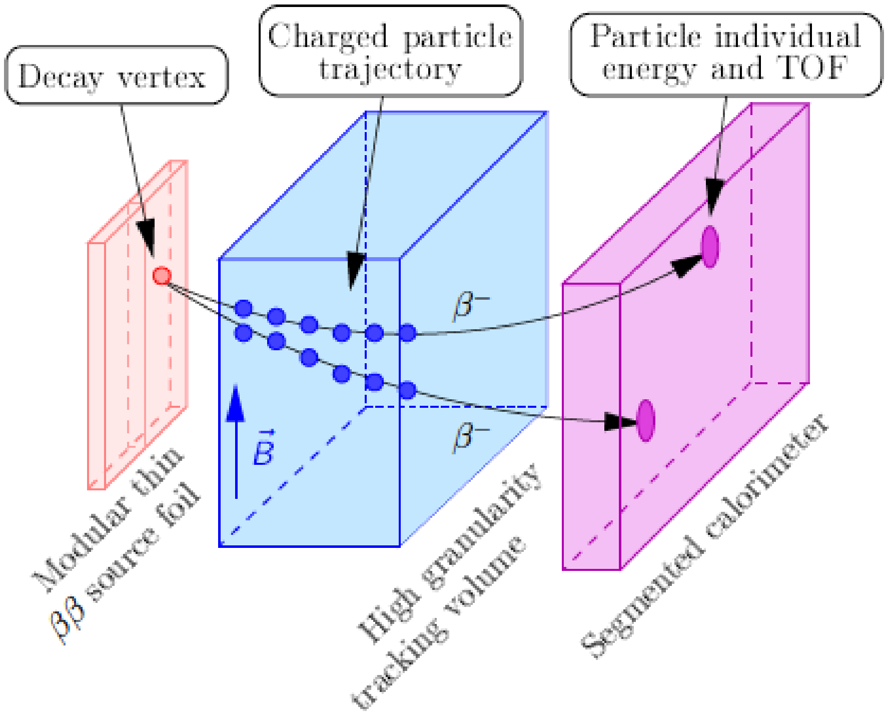



- **Source foil:**
  5-7 kg of $^{82}$Se (or $^{150}$Nd/$^{48}$Ca)
- **Tracker:**
  Drift chamber (2000 cells)
- **Calorimeter:**
  500 PMTs & plastic scintillator

- Phase 1: Demonstrator Module (7 kg of $^{82}$Se)
- Phase 2: Up to 20 identical modules (100 kg of source)

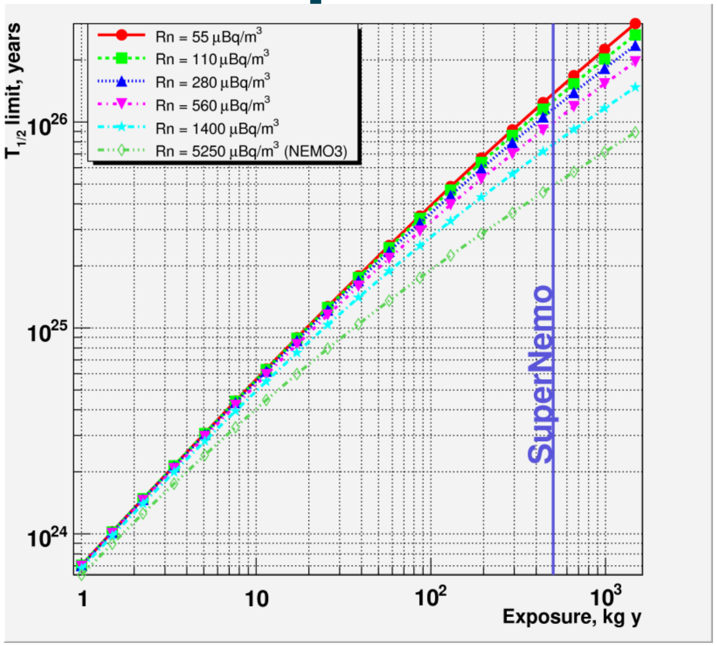
# The SuperNEMO Experiment

- Why include a tracker?
  - Strong background rejection
  - Particle ID ($e^-$, α, γ)
  - Mechanism behind 0νββ?




- Demonstrator module will be first **zero-background** 0νββ experiment.

# The SuperNEMO Tracker & Radon Sources

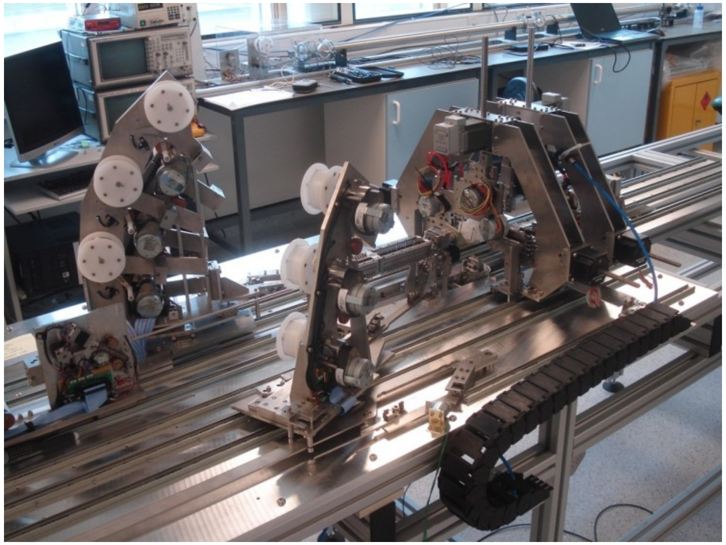



- $^{222}Rn$ requirement: **< 0.15 mBq/m³**
- Main sources of radon:
  - **Contamination** of tracker
  - **Emanation** from detector
  - **Diffusion** from outside detector

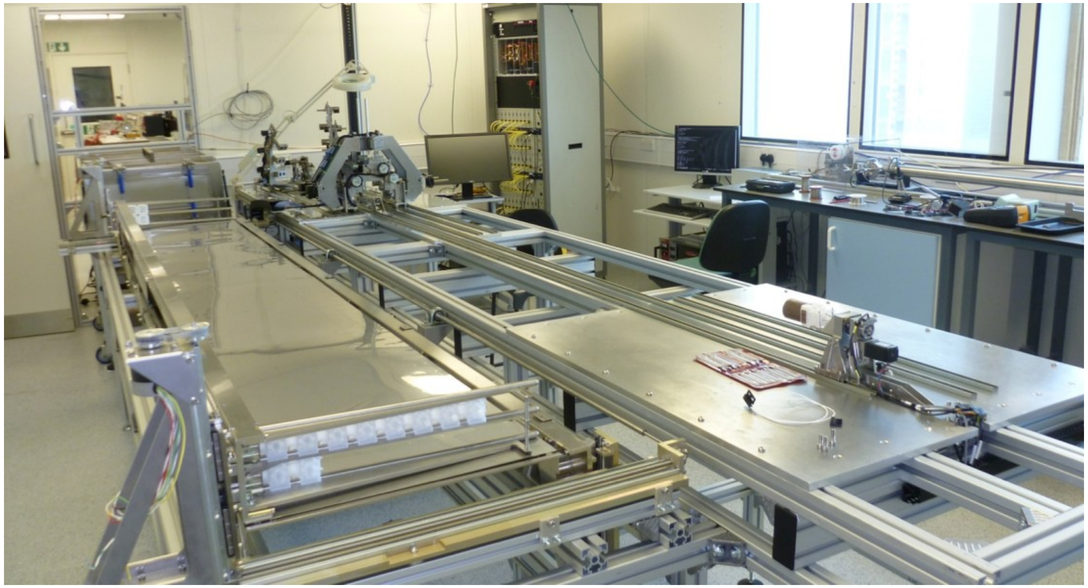
- Anti-radon measures shown here:
  1. A tracker-wiring robot
  2. Screening of detector materials
  3. Diffusion studies for a thin anti-radon film
  4. Large, radon-tight gas seals
  5. A radon concentration line to measure < 0.15 mBq/m³

# Tracker Construction: Wiring Robot

- Reduces **surface contamination**.
- 260,000 wires strung, crimped and terminated for full SuperNEMO.
- Makes cartridges of 18 cells for ease of handling and installation.



Wire spools and wire-feeding mechanism



Wiring robot, cartridge holder and test tank

- These are immediately transferred to a testing tank.
- Then transported to be used in the detector.

# Tracker Construction: Materials Screening

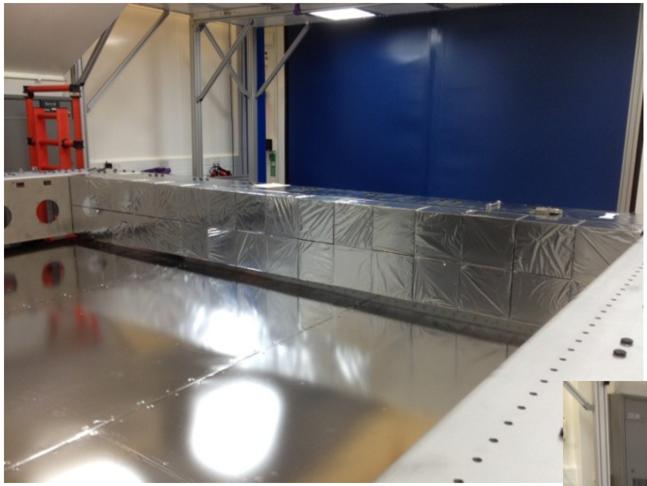
- Every component of detector is screened for radiopurity.
- Start with HPGe detectors, then tested for radon emanation.
- For big samples, **a large emanation tank** has been made.

- Volume = 0.7 $m^3$
- Sensitivity of 2.8 mBq (may be improved)
- Good for large surfaces
- e.g. 35 $m^2$ of Al Foil: A < 0.08 $mBq/m^2$

**Posters: HPGe – Frédéric Perrot. Emanation Tank – Benjamin Soulé**

# Tracker Construction: Current Status

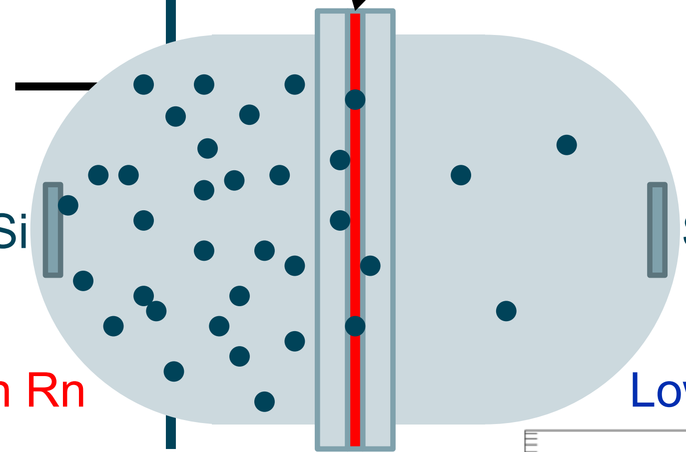
- Construction of the tracker is now well under way.
- So far, the 1st quarter of the tracker has been built (without cells) and is being prepared for a radon test.

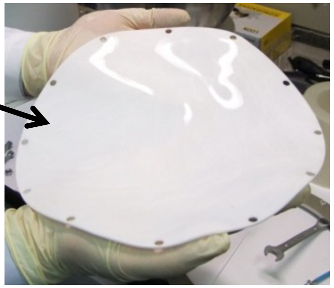


# Diffusion R&D: Setup for measurements

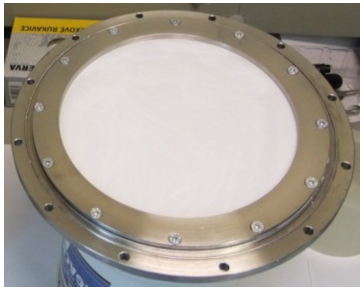
Pump (1 – 5 lpm)

$^{222}$Rn Source (107.5 kBq)



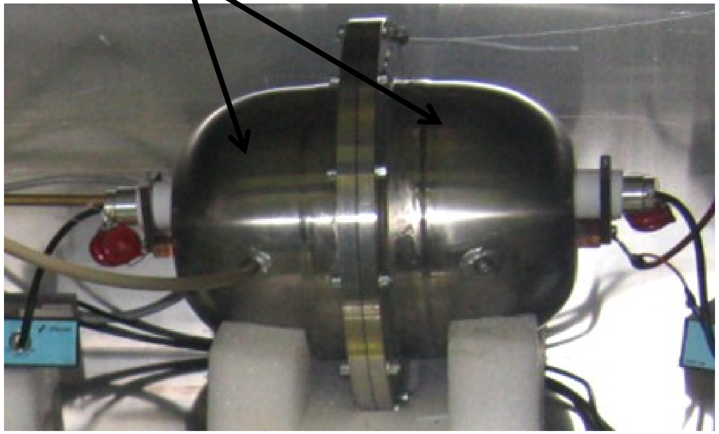



RTV 615 with 60% Stycast (1 mm)

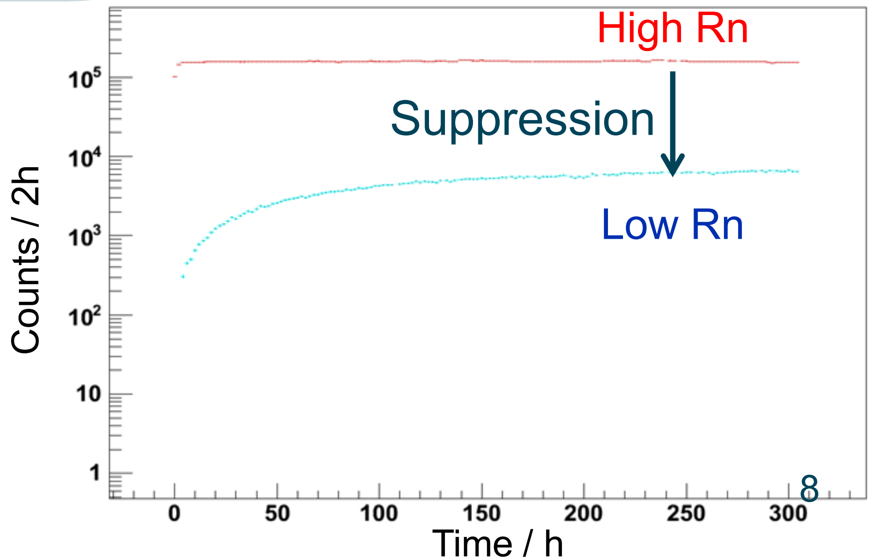


**See poster by Fadahat Mamedov**

2.8 L each side



Background ~ 7- 8 cpd

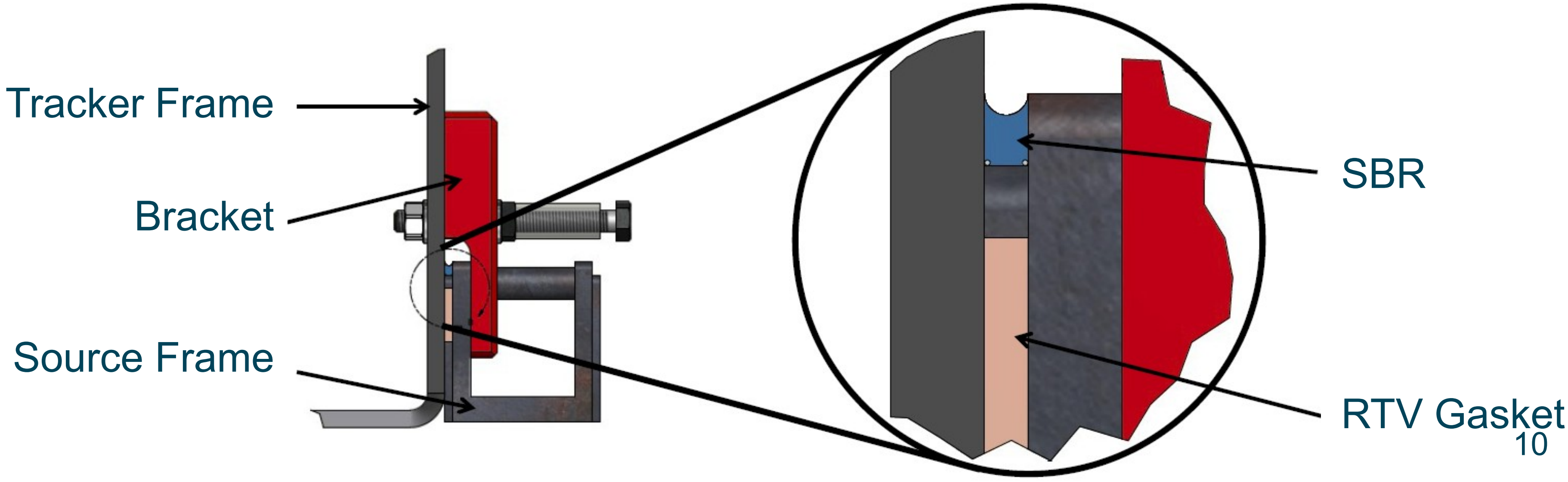


# Diffusion R&D: Selected results

| Material | Thickness (μm) | Diffusion Coefficient ($10^{-12}$ $m^2s^{-1}$) | Diffusion Length (μm) |
|---|---|---|---|
| **Foils** | | | |
| EVOH (2 layers) | 2×15 | < 0.00035 | < 13 |
| Mylar (2 layers) | 2×20 | < 0.0012 | < 24 |
| TROPAC III | 102 | < 0.0043 | < 46 |
| NYLON | 50 | 0.00047 | 15 |
| **Adhesives/Sealants** | | | |
| Silicone (RTV 615) | 2100 | 1080 | 22800 |
| Stycast 1264 | 2000 | <0.43 | <455 |
| SBR (Synthomer 47B40) + HDPE | 700 + 120 | 0.27 | 400 |
| PVA (Emultex 518) + HDPE | 6 + 11 | <0.00038 | <13 |
| HDPE (2 layers) | 2×144 | 19 | 3000 |

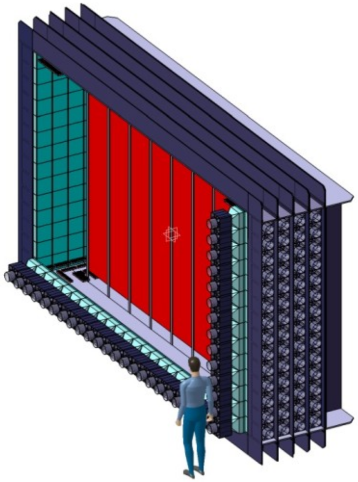
# Diffusion R&D: New detector seal design

- An anti-radon tent will surround the detector.
- We also want to make sure that the **seals stop diffusion**.
- Need large seals – not practical to use metallic seals, so we have used a combination of RTV & **SBR**.
- **SBR** is a flexible clear adhesive. It is favoured over PVA as it does not absorb moisture.



# Radon Concentration Line (RnCL): Concept

- Check that Rn conc. < 0.15 mBq/m$^3$ **during construction**.
- Our detectors are sensitive to ~1 mBq/m$^3$ so need a different technique:



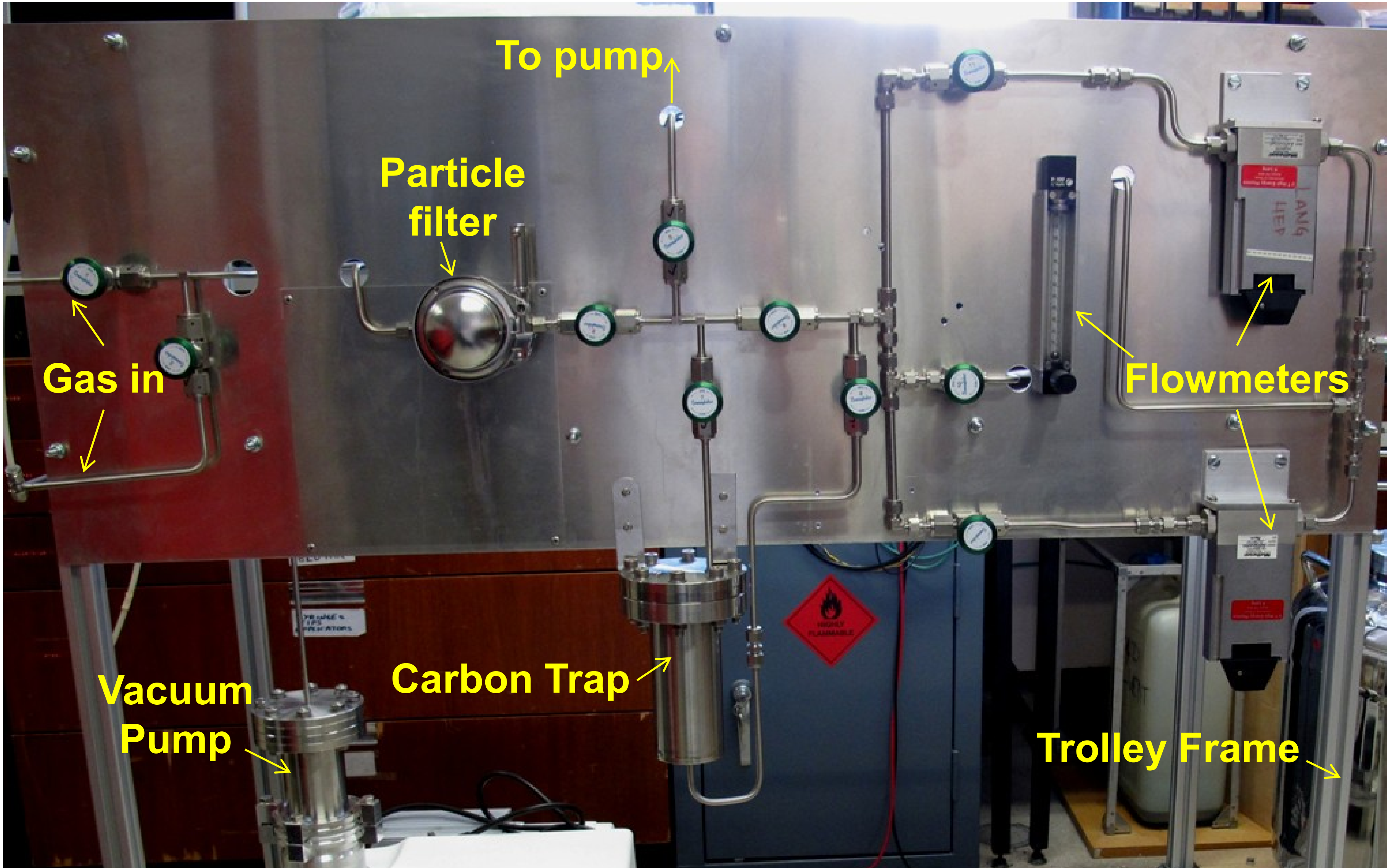
¼ SuperNEMO tracker (~ 3.8 m$^3$)

Radon concentration line (similar to MoReX in Heidelberg)

Electrostatic detector

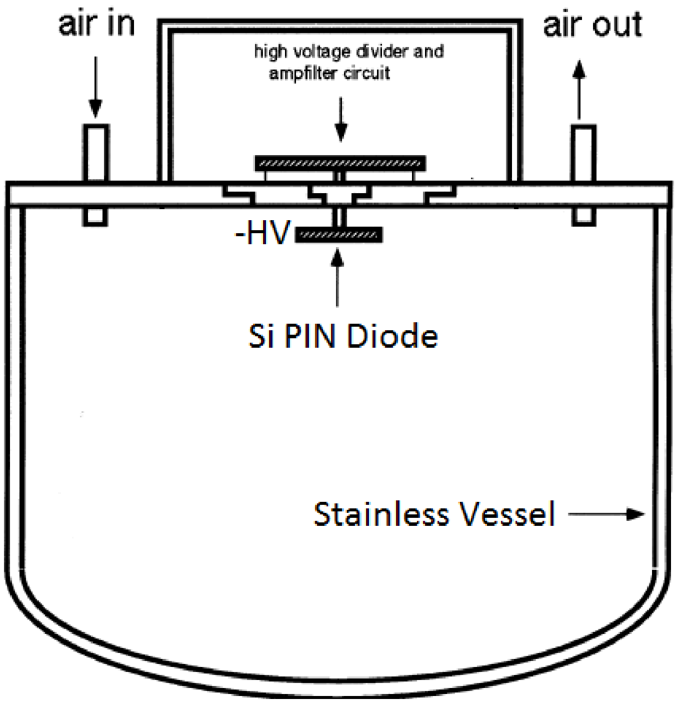
- Helium from the tracker is pumped through a **carbon trap** at **-30°C** and the $^{222}$Rn in the gas is adsorbed.
- The concentrated sample is then heated and transferred to an electrostatic detector via helium purge.

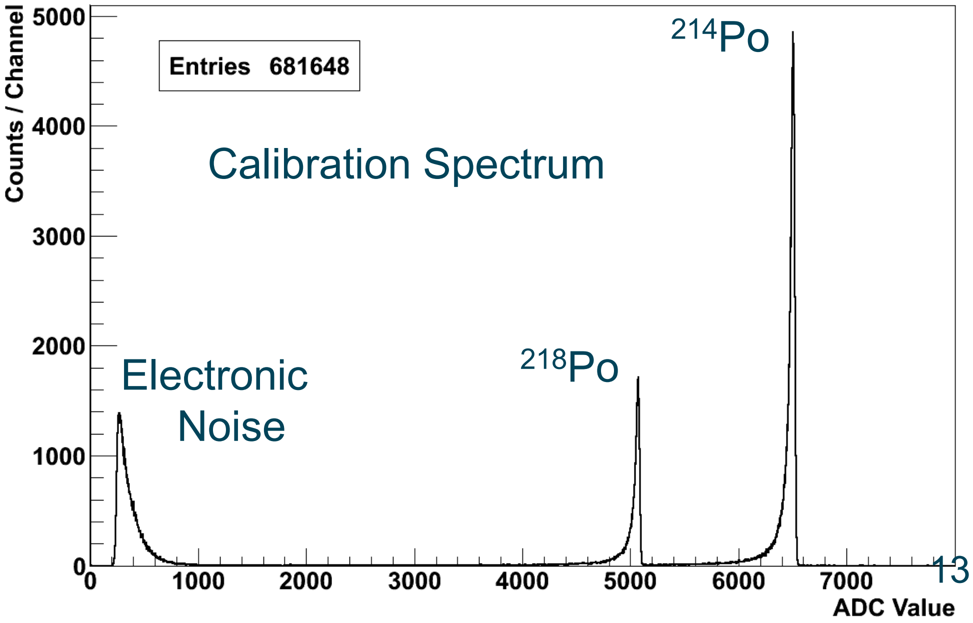
# RnCL: Real Life



# RnCL: Electrostatic Detector

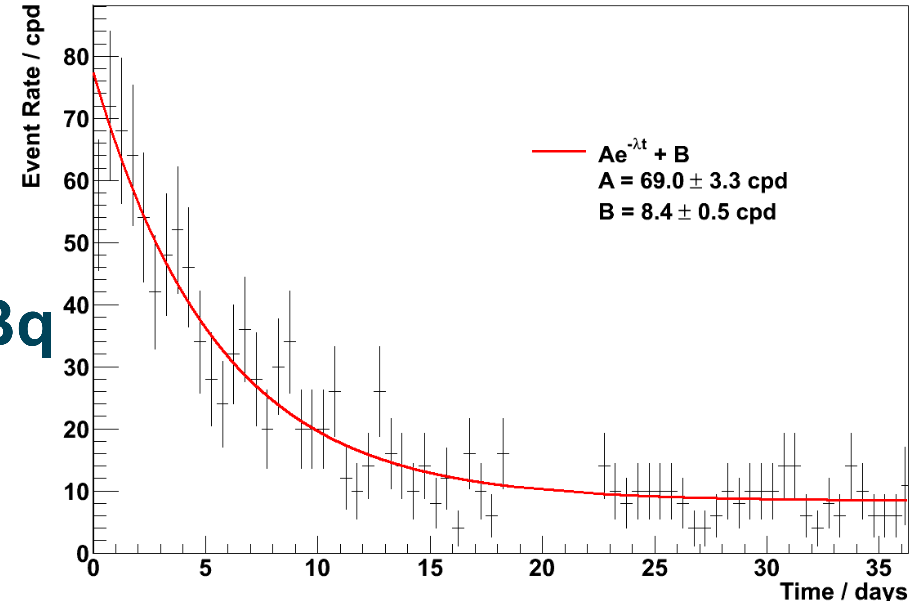
- Electro-polished stainless steel 70 L vessel
- Contains silicon PIN diode with -1500 V applied

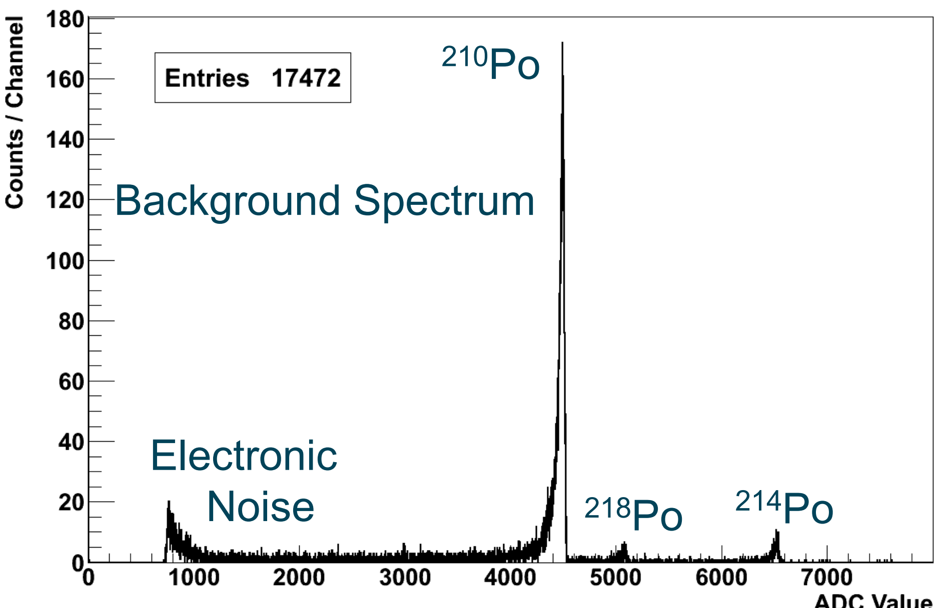


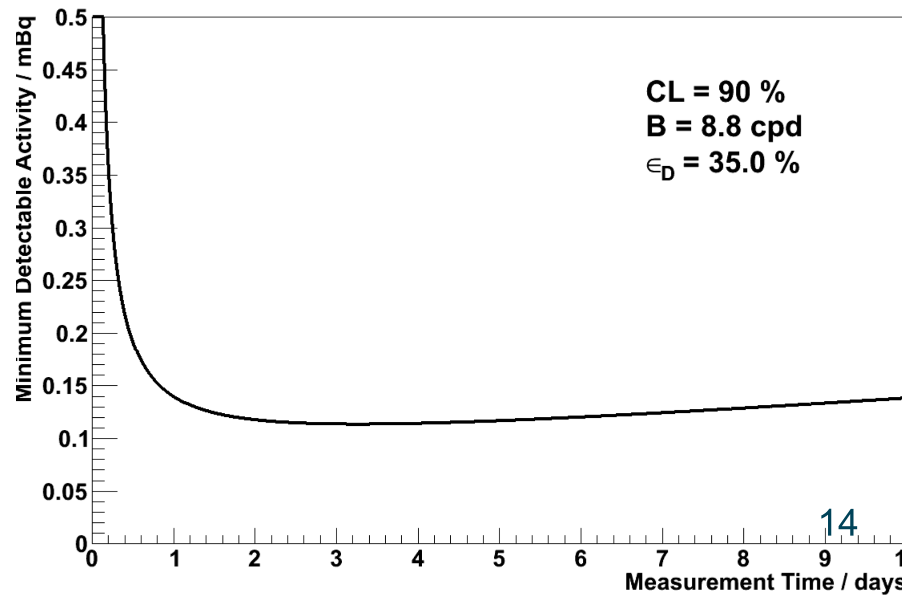



# RnCL: Detector Background

- Measurement of detector background shows **8 – 9 cpd**
- Gives sensitivity of ~ **0.12 mBq** (1.7 mBq/m$^3$) @ 90% CL

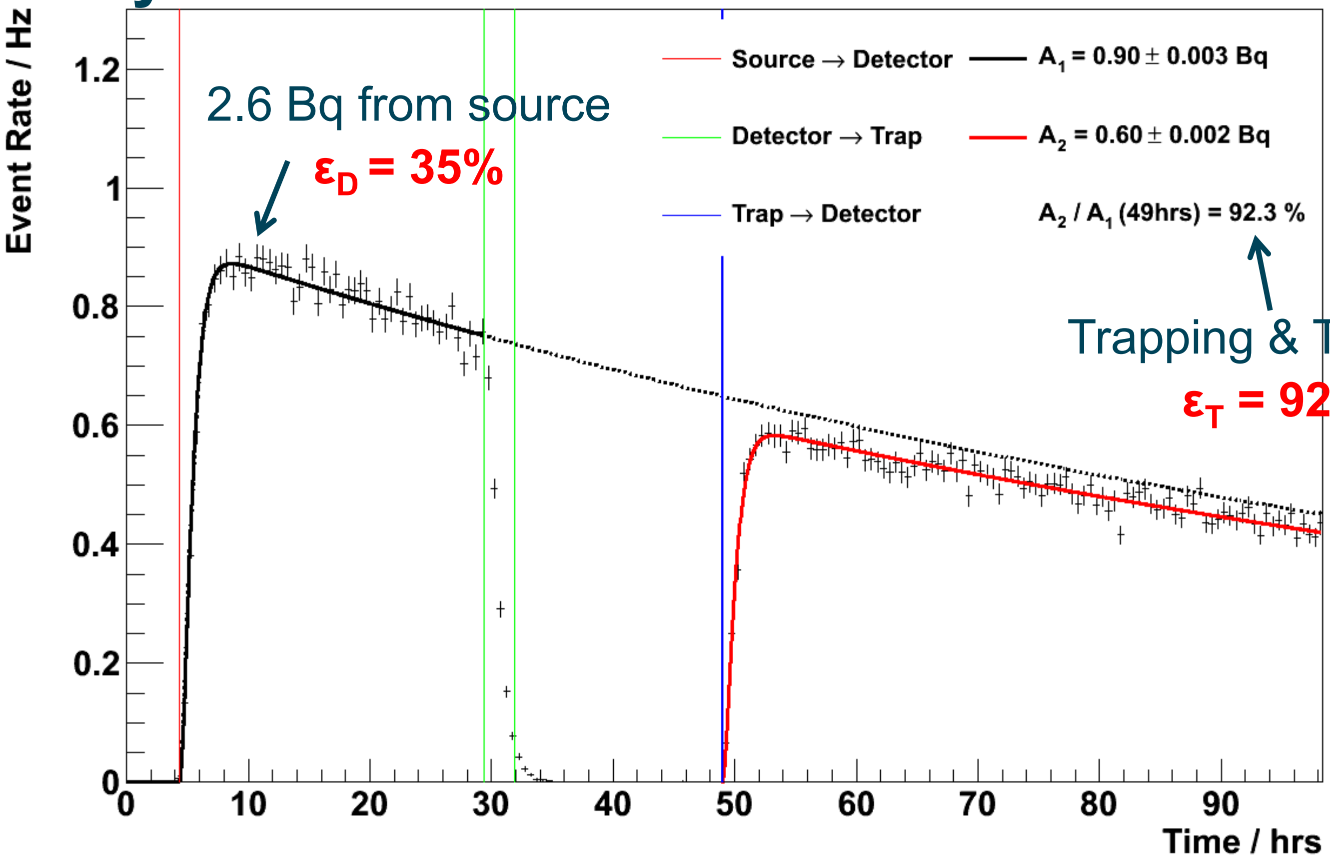


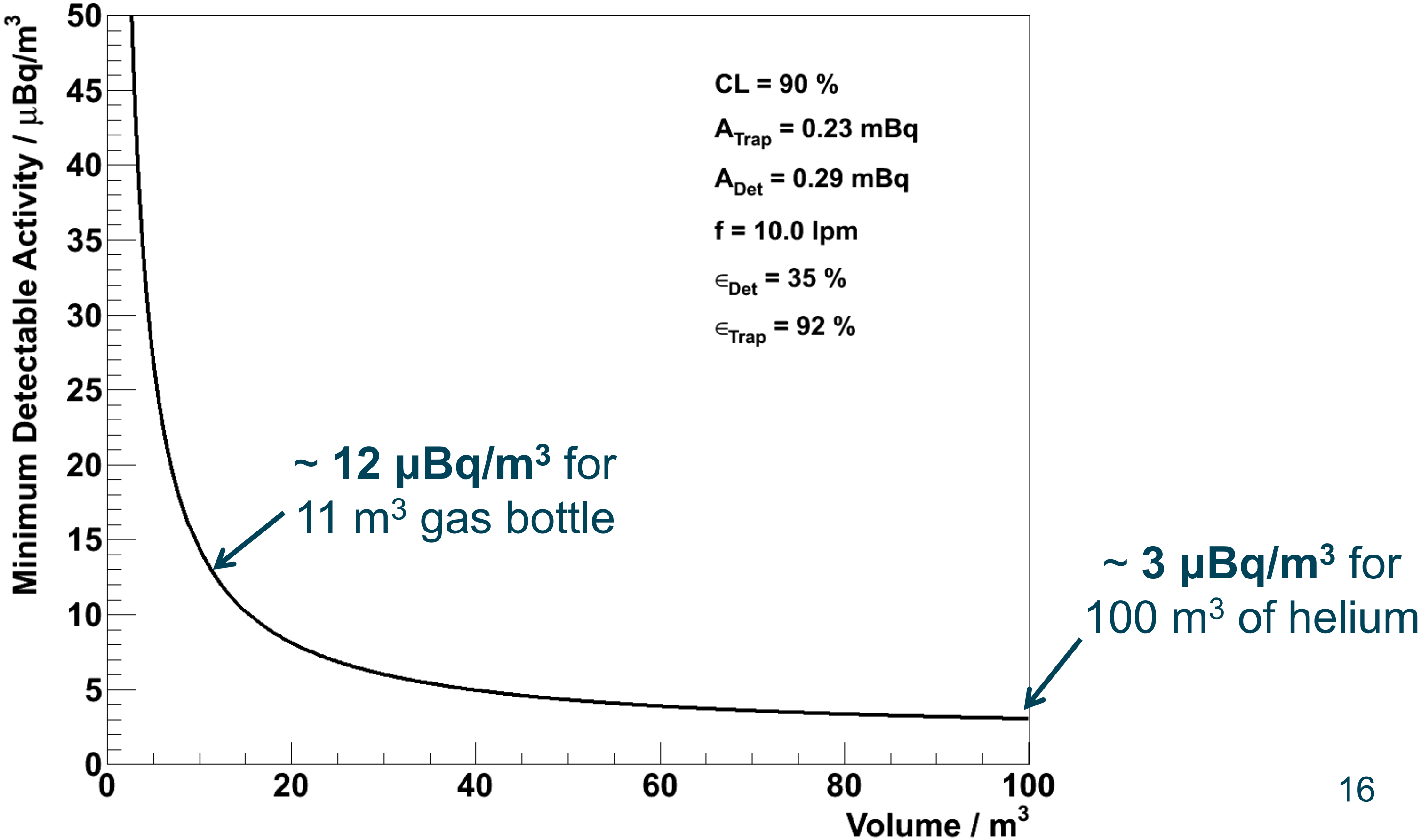
# RnCL: Detection, Trap & Transfer Efficiencies

- To measure **detection efficiency**, put a known amount of radon from a source in detector.
- Then transfer into trap and back to get **trapping & transfer efficiency**:



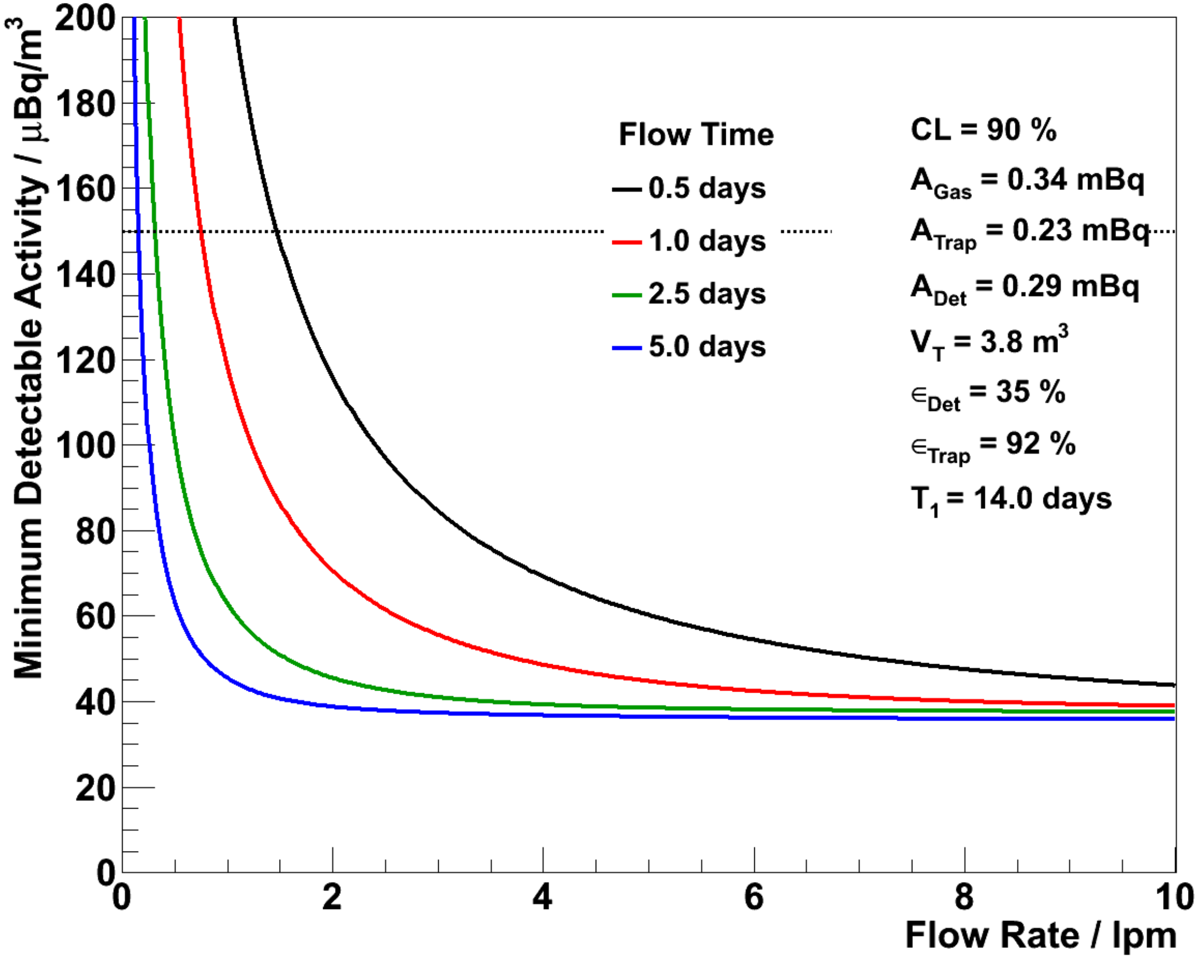
# RnCL: Sensitivity to “Unlimited” Gas Supply

- Initital 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:



# RnCL: Sensitivity to SuperNEMO ¼ Tracker

- Measurement of emanation from quarter sub-section of SuperNEMO tracker:



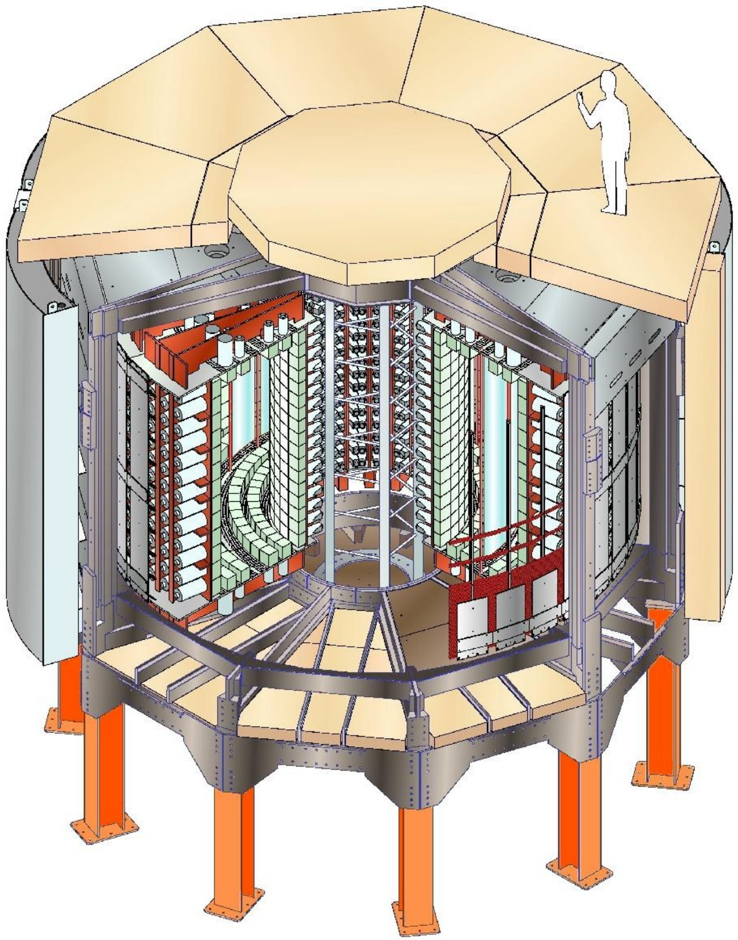
# Summary

- The required $^{222}Rn$ level for SuperNEMO is **< 0.15 mBq/m$^3$**
- This challenging level has resulted in a large program of radon R&D shared between many institutions, including:
  - A **wiring robot** to manufacture tracker cells.
  - Extensive **program of screening** of detector materials including a new large emanation tank.
  - A dedicated setup for diffusion studies of different materials to form **anti-radon barriers**.
  - New designs for **large-scale gas seals** that are mechanically viable and radon-tight.
  - Development of a **RnCL** capable of measuring a ¼ tracker at ~ 0.05 mBq/m$^3$ and large volumes of gas at ~ 3 μBq/m$^3$.

# Supplementary Slides

# The NEMO-3 Experiment

- NEMO-3 was the predecessor to SuperNEMO, which ran from Feb 2003 – Jan 2011.



- Cylindrical design with source foils of different ββ isotopes surrounded by a gas tracker and a calorimeter.
- Employed a ‘smoking-gun’ approach:
  - Particle ID, event topology reconstruction & strong background rejection
  - Compromise on energy resolution
- World’s best $T_{1/2}$ measurements of seven 2νββ isotopes (out of only 12 observed):

$^{100}$Mo, $^{82}$Se, $^{150}$Nd, $^{96}$Zr, $^{48}$Ca, $^{116}$Cd, $^{130}$Te

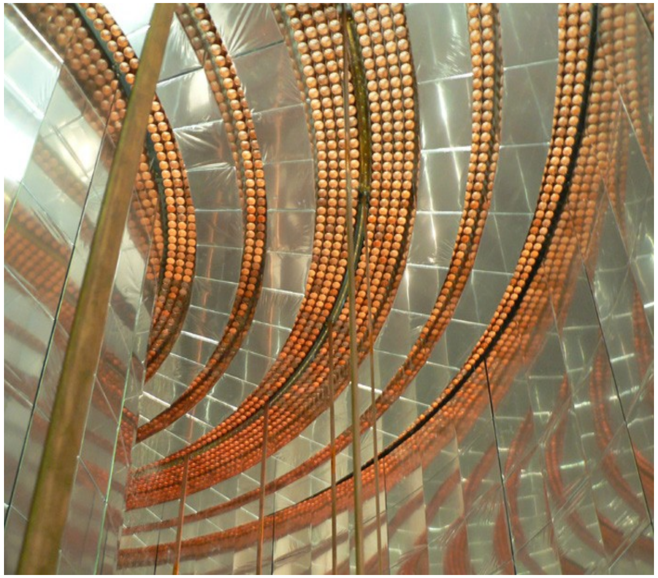
# The NEMO-3 Experiment

**Source foil:** 10kg of different ββ isotopes

**Tracker:** Drift chamber with 6180 vertical cells in He, Ar, alcohol & water.

**Calorimeter:** 1940 PMTs & plastic scintillator blocks

**Shielding:** Wood, iron & borated water to stop different external backgrounds



**Some important measurements:**

**$^{100}$Mo:** $T_{1/2}(2\nu) = [7.16 \pm 0.01(stat) \pm 0.54(sys)] \times 10^{18}$ y
$T_{1/2}(0\nu) > 1.0 \times 10^{24}$ y @ 90% CL

**$^{82}$Se:** $T_{1/2}(2\nu) = [9.6 \pm 0.1(stat) \pm 1.0(sys)] \times 10^{19}$ y
$T_{1/2}(0\nu) > 3.2 \times 10^{23}$ y @ 90% CL

# SuperNEMO Schedule

Construction and deployment of successive SuperNEMO modules

Sensitivity with 100 kg:

$T_{1/2}(0\nu\beta\beta) \sim 10^{26}$ yr $\rightarrow \langle m_\nu \rangle \sim$ 40—110 meV

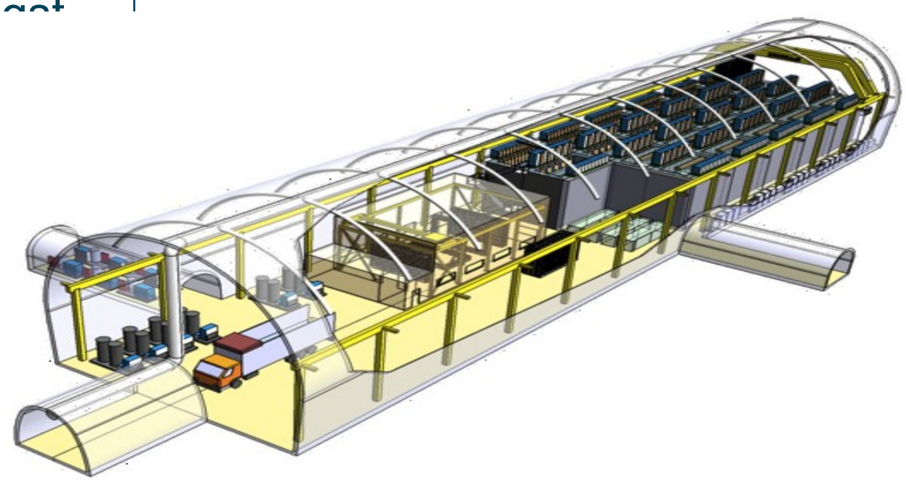
Demonstrator module construction and commissioning

| 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 |
|---|---|---|---|---|---|---|---|---|

Demonstrator module running

- Prove B ~ $10^{-4}$ cts/keV/kg/yr: amongst best of *any* experiment
- Limit on $T_{1/2} \sim 6.5\times10^{24}$ yr

LSM extension has been funded



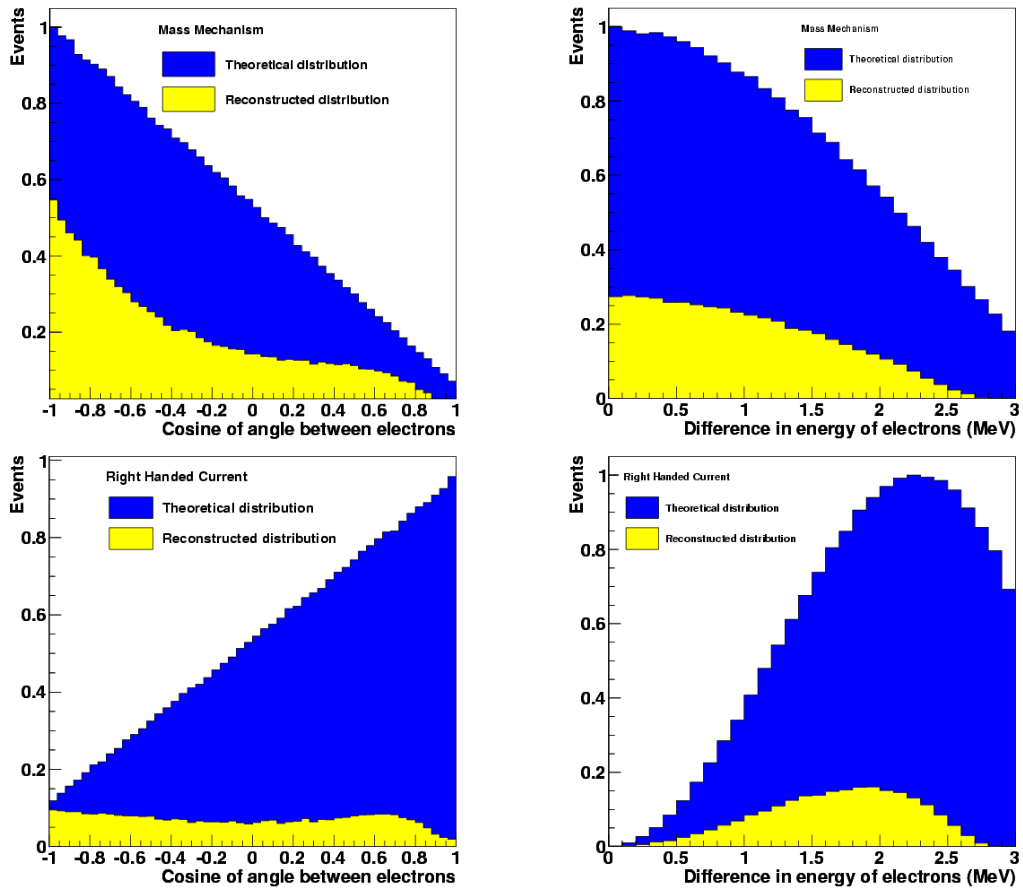
# 0νββ: Signatures for different mechanisms

- SuperNEMO is unique among the next generation 0νββ experiments as it may allow us to disentangle the physics mechanism, for example:

**Cosine of electron opening angle** | **Electron energy difference**

Mass Mechanism

Right Handed Current




Theoretical Distribution

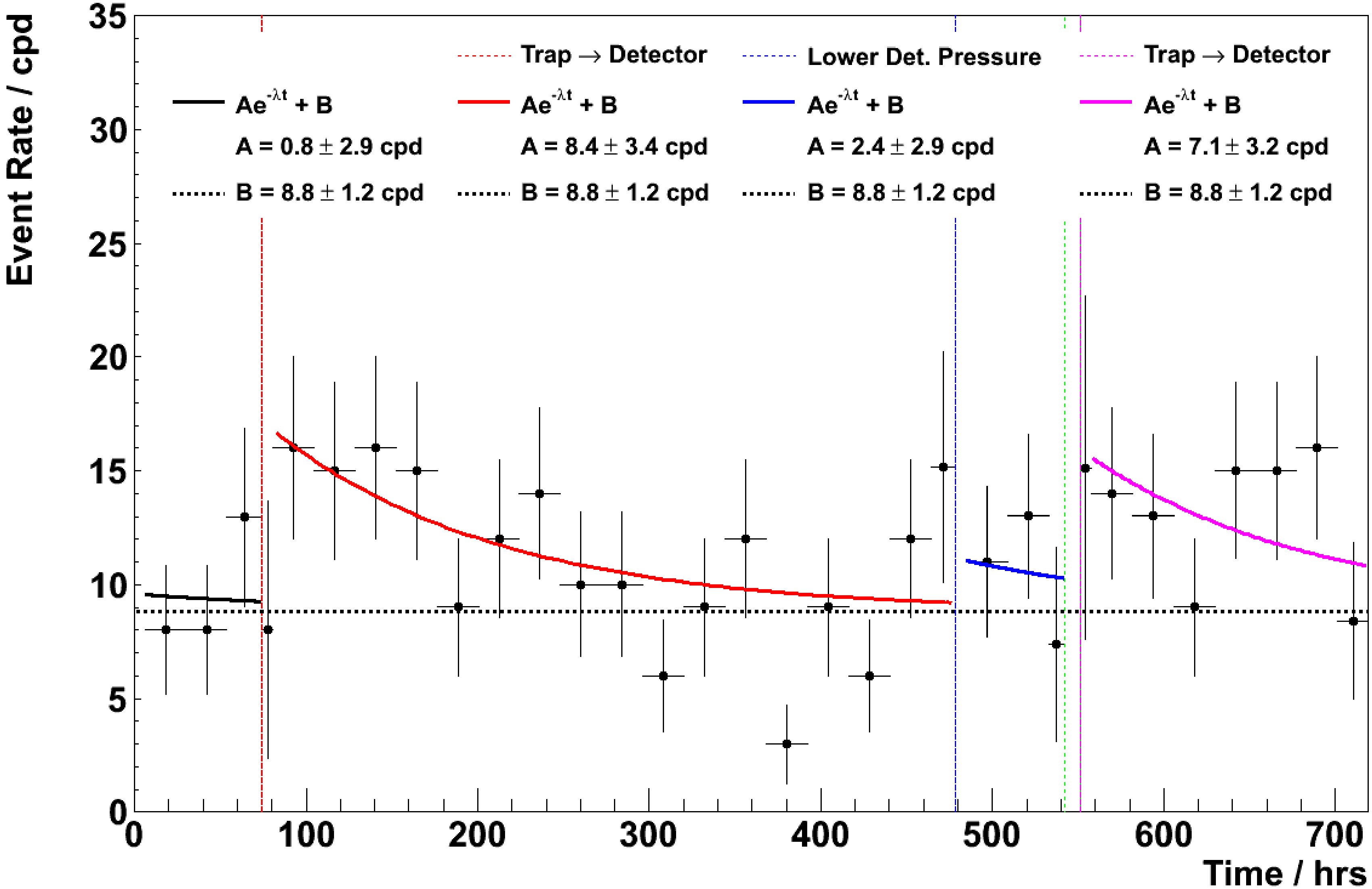
Reconstructed Distribution

# Diffusion R&D: Selected results

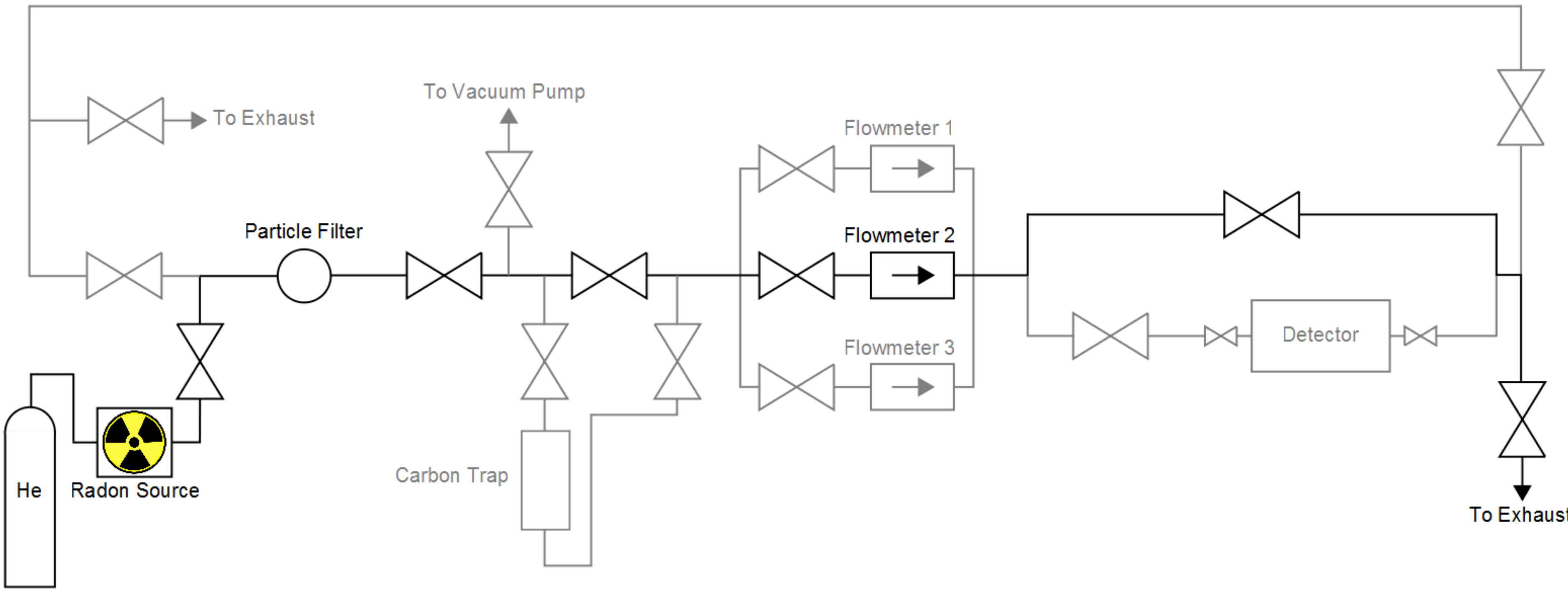
| Material | Thickness (μm) | Diffusion Coefficient ($10^{-12}$ $m^2s^{-1}$) | Diffusion Length (μm) |
|---|---|---|---|
| Silicon | 2 800 | 320 | 12 000 |
| RTV 116 (in the  metal) | 3.5 | 7201 | 58599 |
| RTV ECOO | 2 000 | 1 030 | 22 200 |
| RTV 615 with 60% resin Stycast | 1 000 | 521 | 15 765 |
| WB 50T | 50 | 0.74 | 593 |
| Butyl rubber | 1 000 | 1180 | 7 496 |
| Neoprene | 1000 | 12.4 | 2 430 |
| PVC 2mm | 2000 | 44 | 4 600 |
| PET | 1 000 | < 0.076 | < 190 |
| PLEXY | 1 000 | 0.29 | 371 |
| Delrin sheets | 1000 | 0.072 | 186 |
| EVOH + PE | 125 | 0.013 | 254 |

# RnCL: Real Life – in situ

# RnCL: Trap BG Measurement

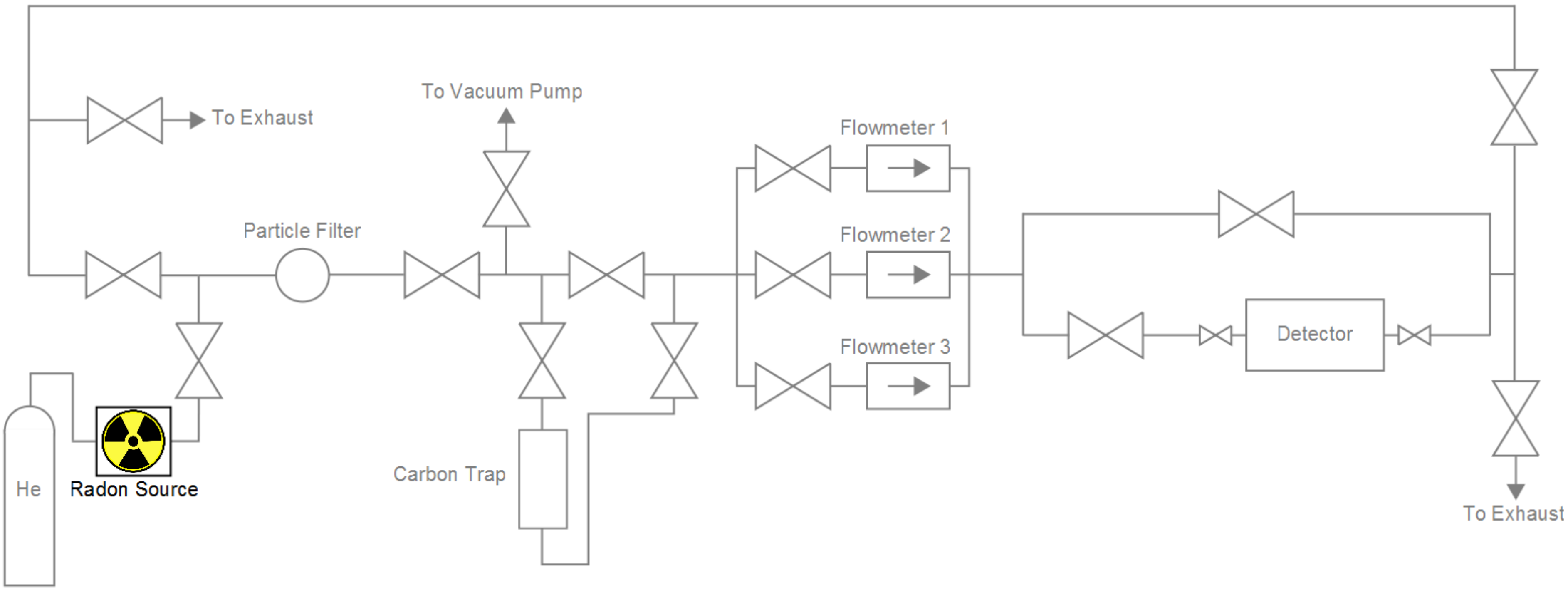


# Measurement Process: Stage 1



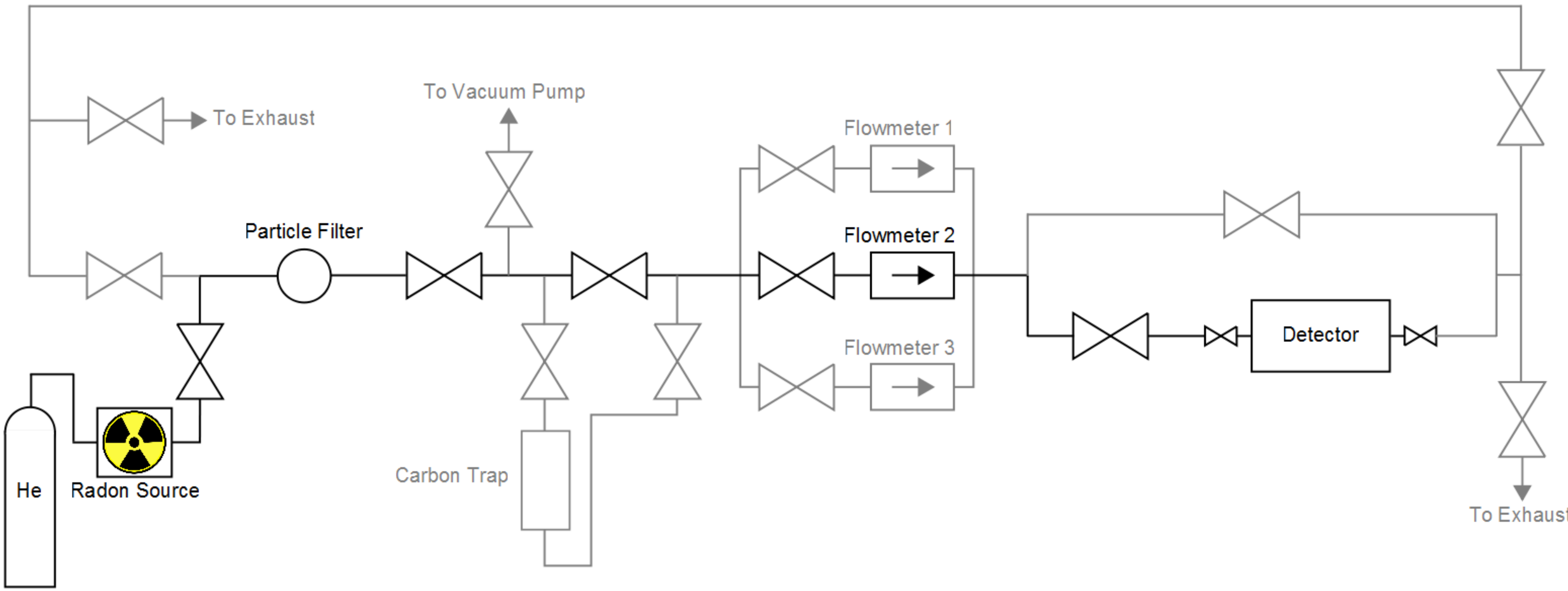

- Start measurement by flushing radon source out to atmosphere.
- This removes the radon that has built up in there.

# Measurement Process: Stage 2



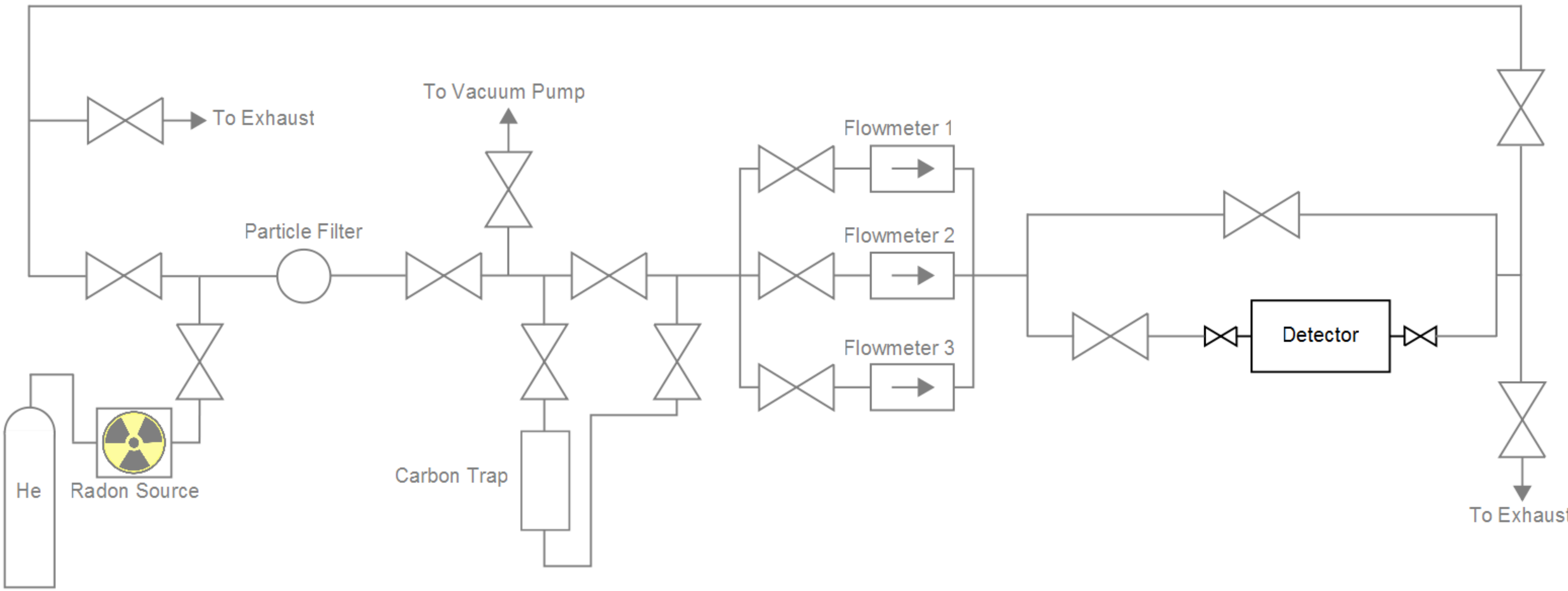

- Then seal source and wait for 15 mins to allow radon to build-up in source.
- Can calculate that this corresponds to 2.5 Bq

# Measurement Process: Stage 3



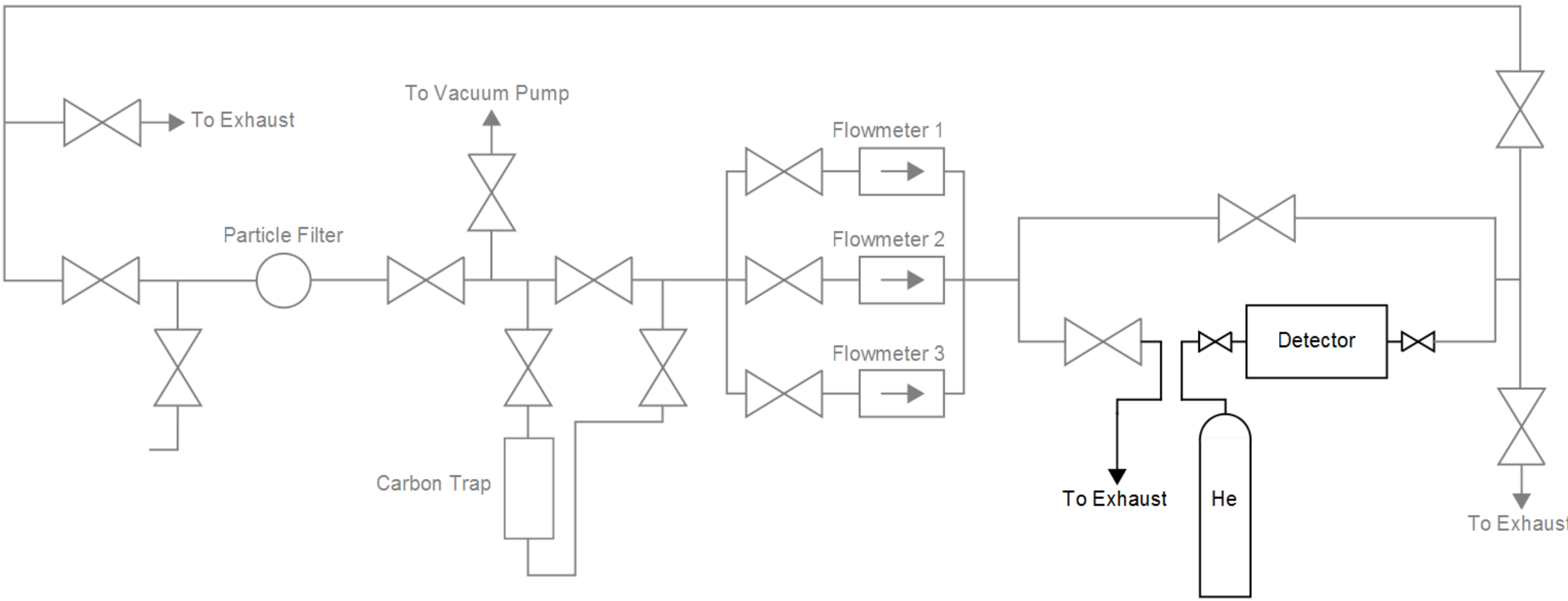

- Now flush through the radon source into the detector, always keeping track of times

# Measurement Process: Stage 4



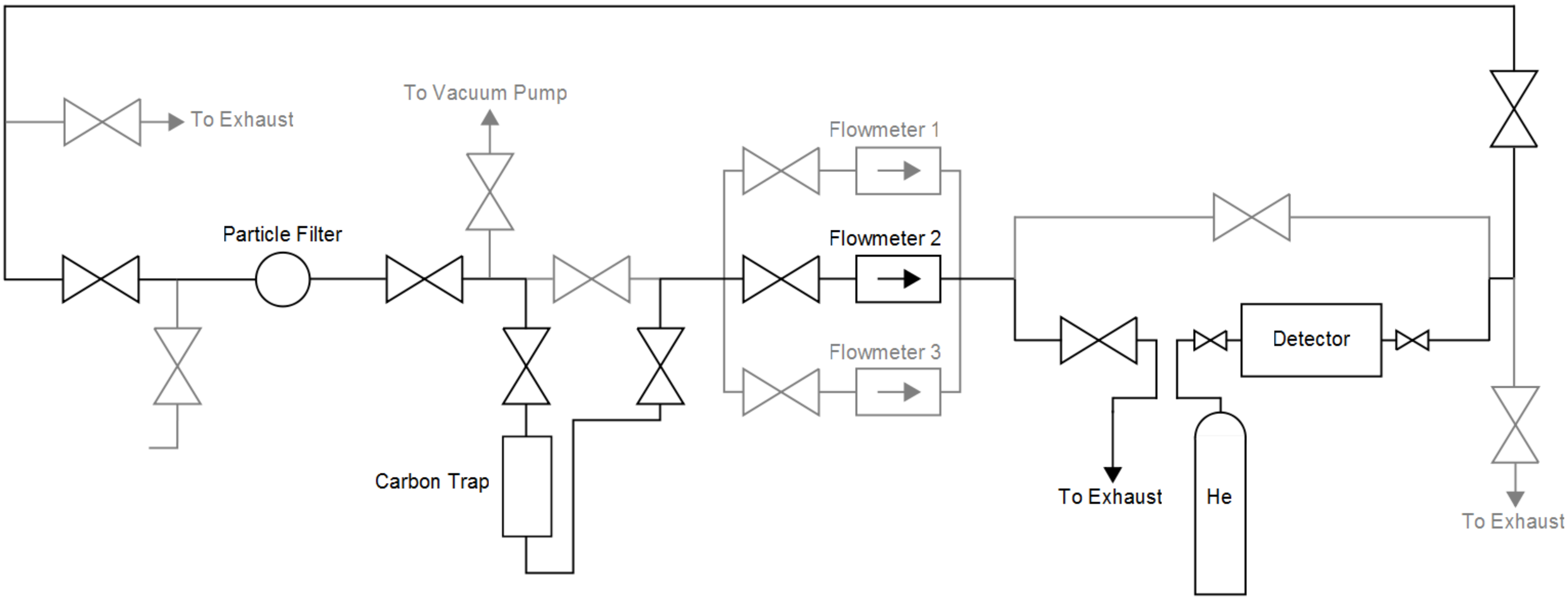

- Seal detector and leave for 24 hours to measure the amount of radon in there.

# Measurement Process: Stage 5



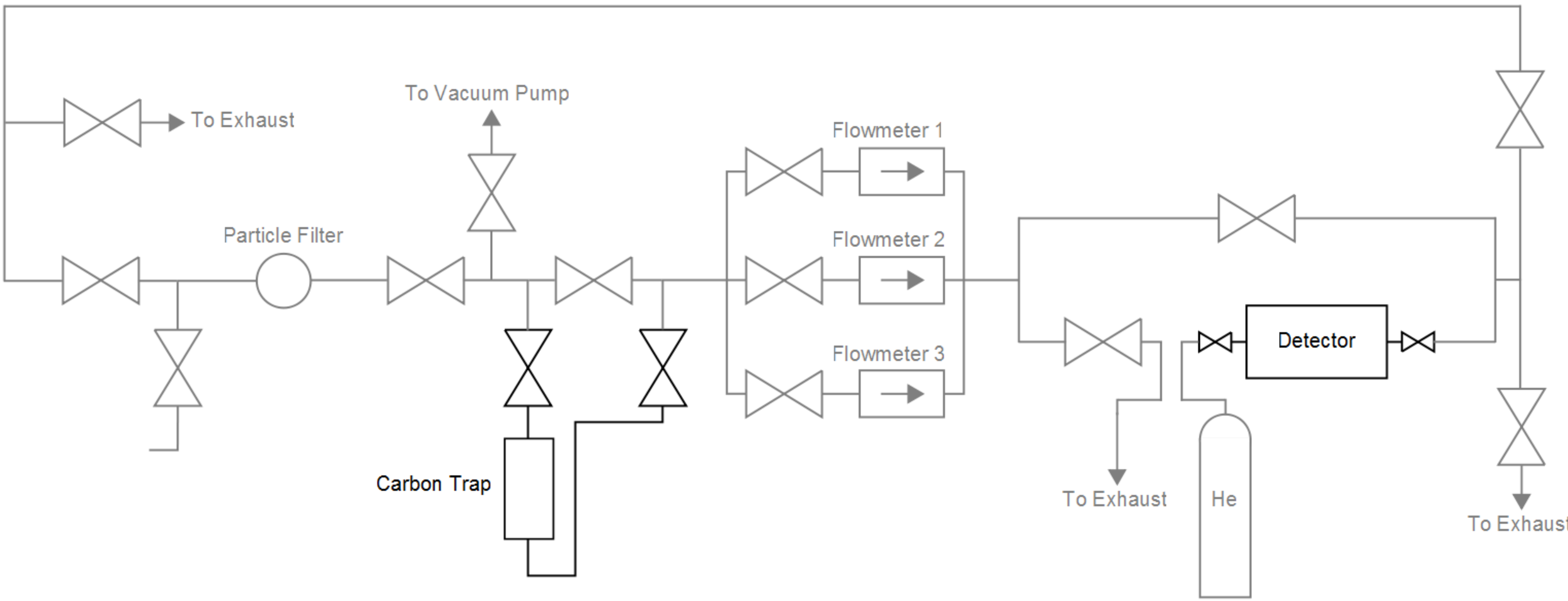

- Re-work RnCL.
- Move He cylinder next to detector and add additional exhaust.

# Measurement Process: Stage 6



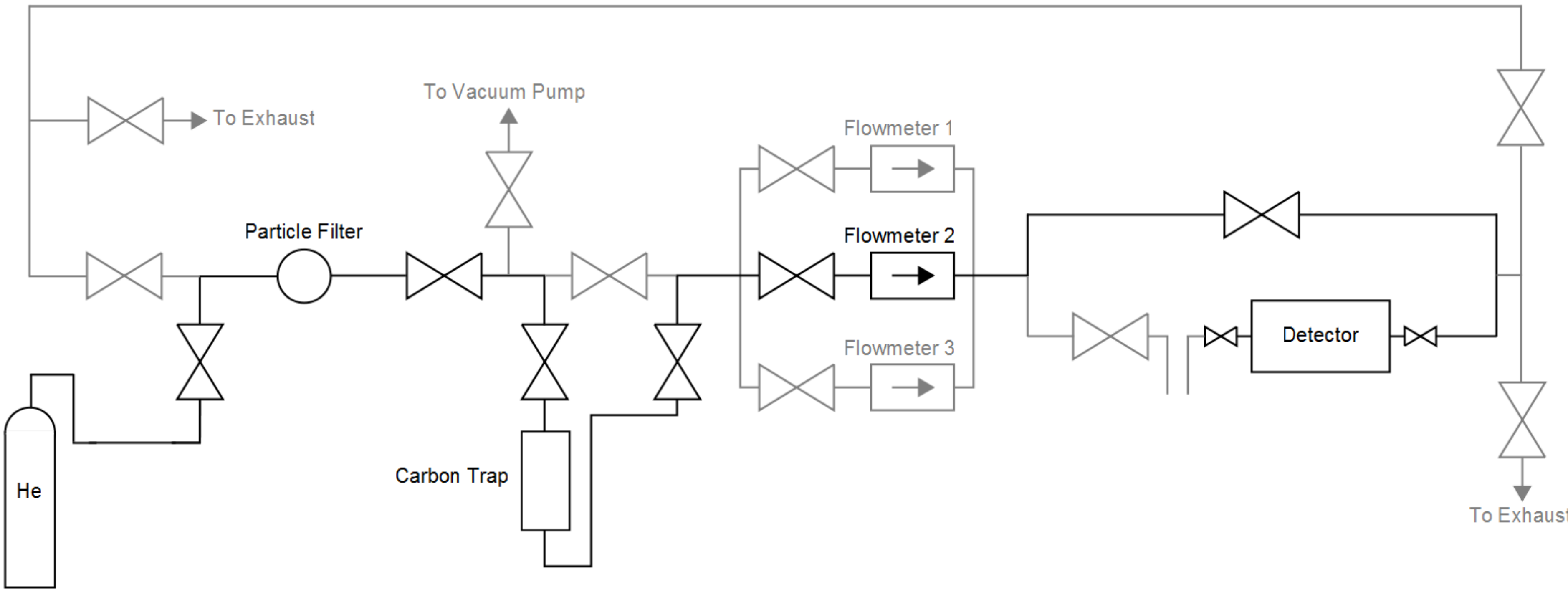

- Cool down trap to -30°C.
- Flush detector gas through circulating line to get to input line for trap and then out via a flowmeter.

# Measurement Process: Stage 7



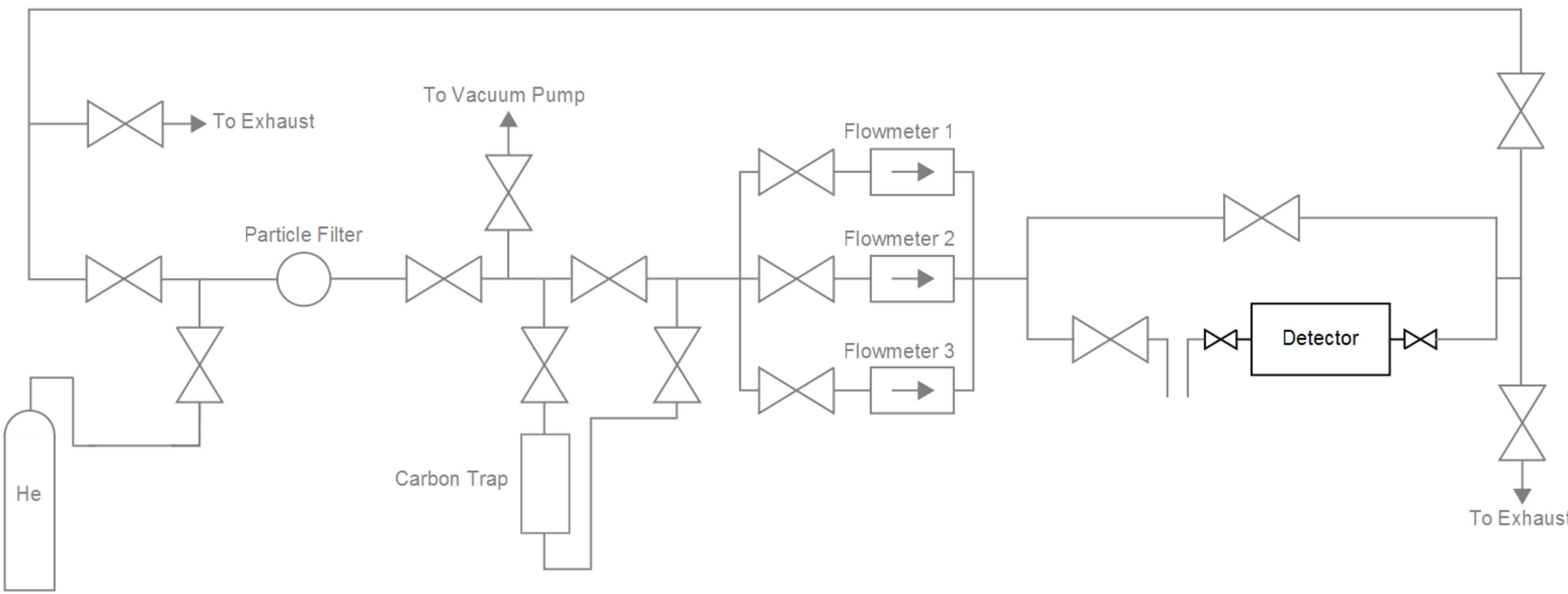

- Seal up detector and trap and leave for a few hours to allow $^{214}$Po still in detector to decay.

# Measurement Process: Stage 8




- Heat-up trap to 200 °C and flush contents into detector.

# Measurement Process: Stage 9




- Finally seal detector again and re-measure contents.

# SuperNEMO Tracker: Rn Reduction vs Flow