Radon Screening for Low Background Experiments

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Motivations

- Radon is a large background in low background experiments.
    - Want to screen materials to only use low emanation materials.
- To make a competitive radon emanation system using commercial products.

Contents

1. Description of setup and method
2. Recent improvements to system
3. Emanation from Durridge RAD7 components
4. Outlook on how to improve sensitivity further

Setup in Sheffield

- We have 2 cylindrical vacuum vessels which the samples are placed in.

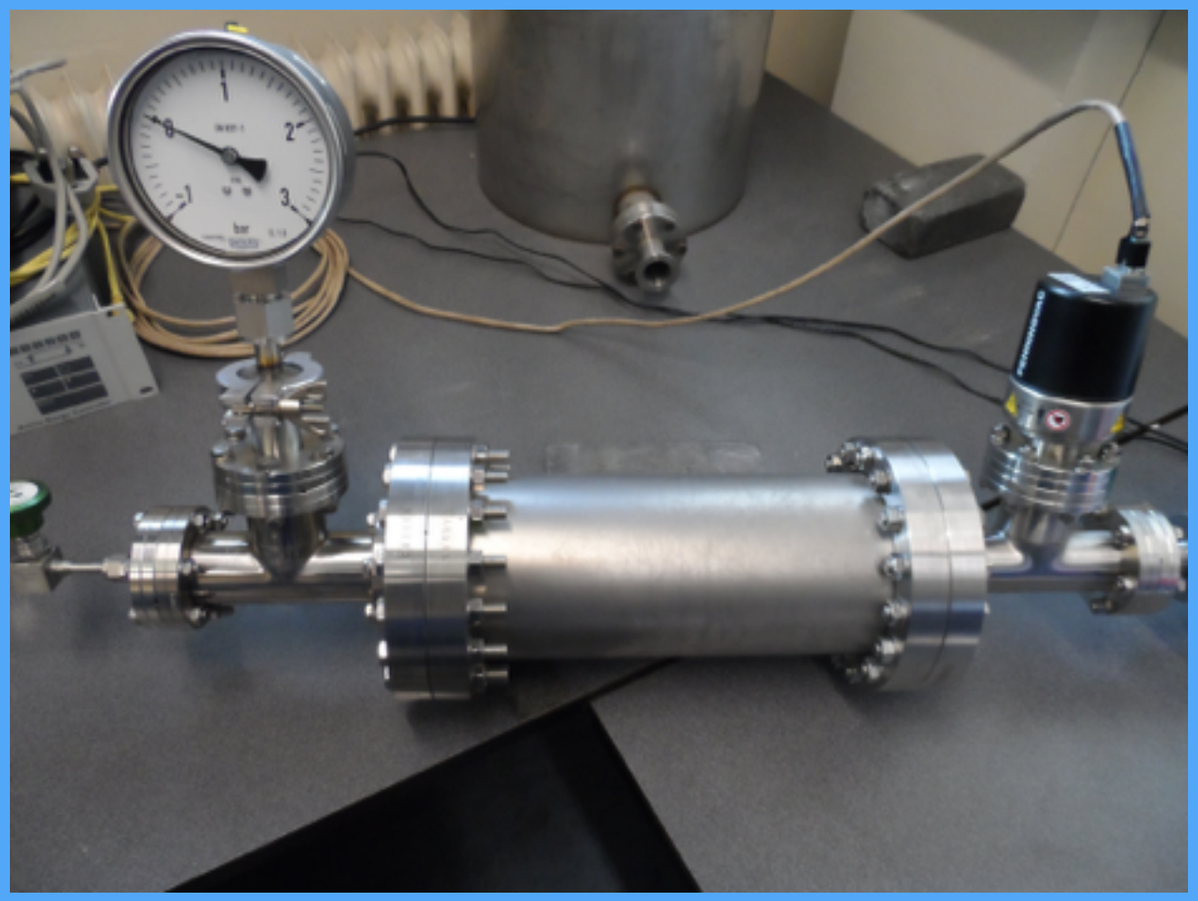


Fig. 1 - 2.7 litre vessel

Diameter = 10.2 cm
Length = 27.0 cm

Fig. 2 - 34.5 litre vessel

Diameter = 29.4 cm
Height = 50.2 cm

Method

- Place sample in vacuum chamber and pump down to vacuum. Leave to outgas for 2 days.
- Pump down to vacuum again, then leave sample to emanate for 7 days.
- Backfill sample with 1 atm pure N_2.
- The nitrogen flows through desiccant to remove moisture then a cooled charcoal trap to remove radon.
- Purge two Durridge RAD7 radon detectors for 20 minutes with dry nitrogen to remove any radon in the system.

Method

- Connect the two RAD7 detectors in series and to the emanation chamber.
- Take 12 measurements over 48 hours.
- RAD7s count alpha decays over the 4 hour cycles.
- The data is then taken from the Durridge software CAPTURE and the final analysis takes place.

Fig. 3 - Two Durridge RAD7s set up in series with the 2.7 l vessel

Method

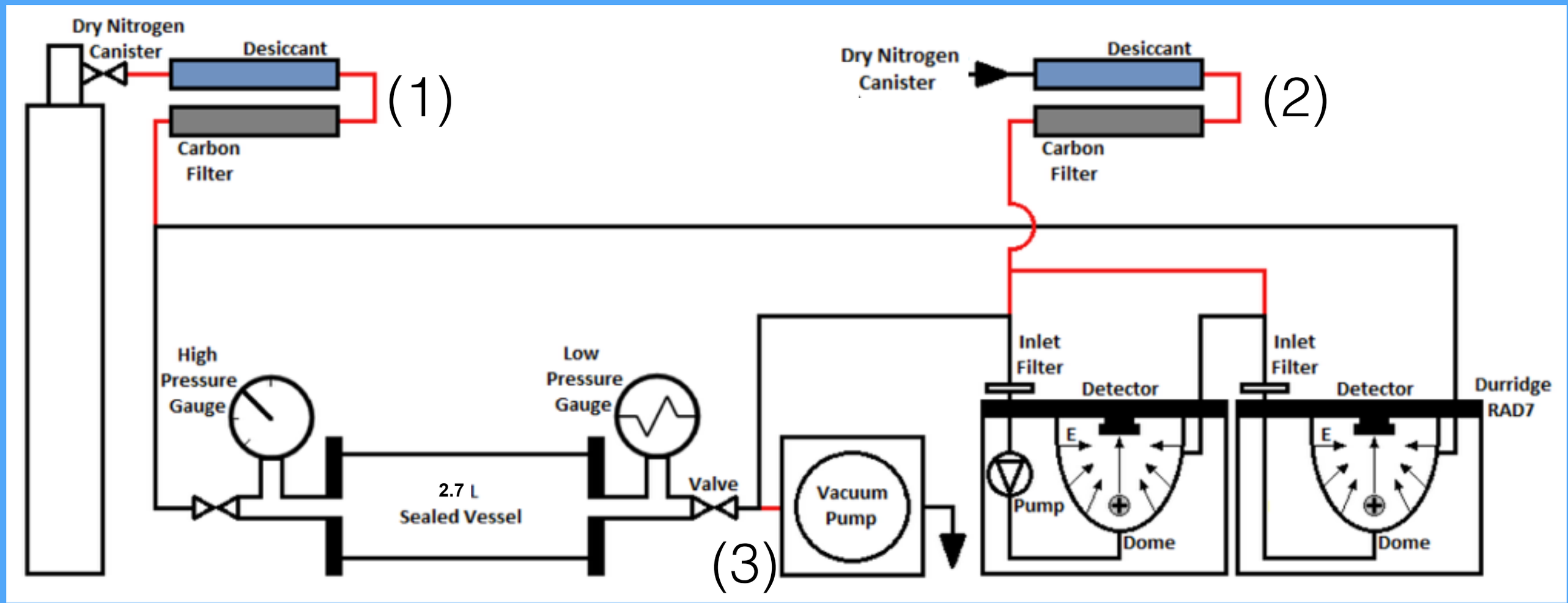


Fig. 4 - Diagram of set-up used. Red lines are only used for using dry nitrogen to fill the vessel (1) or purge the detectors (2) and for pumping out the vessel at the end of a test.

Diagram from T. Zorbas undergraduate project report, Dec 2015.

Durridge RAD7

- The RAD7 detection volume consists of a 0.954 litre alpha spectrometer.
- The inside of the dome is held at 2200 V and a silicon detector is held at 0 V.
- Charged radon daughters drift to the silicon detector.
- There is then a 50% chance of a subsequent alpha particle depositing energy in the detector.
- The detector captures the full alpha energy which is used to identify the decaying nucleus.
- The energy is measured to a precision of 50 keV in a 0-10 MeV window.
- The detector uses this to calculate a total equilibrium radon concentration per cycle in Bq m^{-3}.

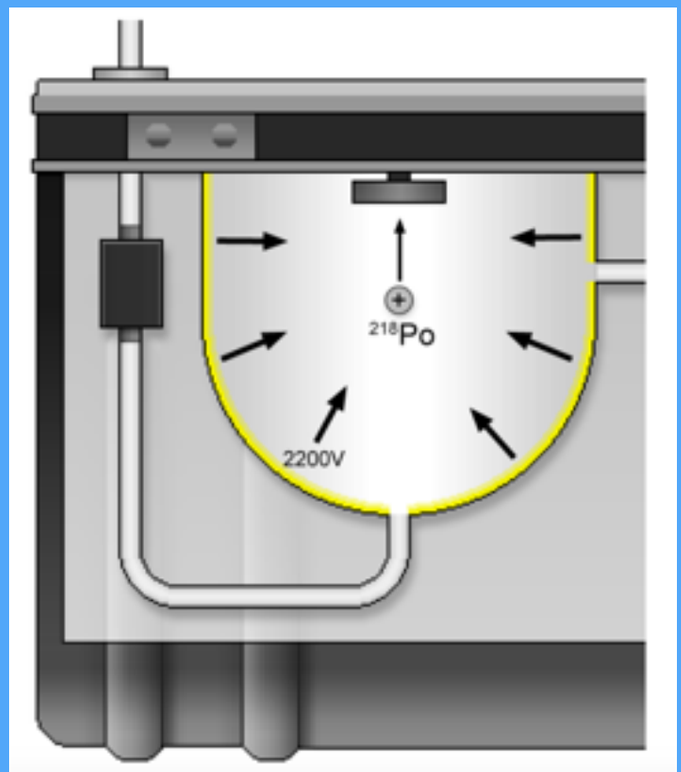


Fig. 5 - Durridge RAD7 (Image credit: Durridge)

Analysis

- Three corrections need to be made to the data.

- Volume - To convert the Bq m^{-3} output from CAPTURE into Bq.

$$\mathrm{Bq} = \mathrm{Bq\ m^{-3}} \times (V_{chamber} + V_{RAD7s} - V_{sample})$$

- Humidity - RH > 15% lowers the efficiency of the RAD7 so is accounted for.

$$A_{\mathrm{after}} = A_{\mathrm{before}} \times \frac{100}{116.67 - 1.1 \times RH}$$

Where A represents radon activity & RH stands for relative humidity.

- Emanation time - This accounts for the fact that the sample has not reached equilibrium.

$$R_{\mathrm{em}} = A_{\mathrm{meas}} \times \frac{1}{1 - \exp\left(\frac{-t}{t_e}\right)}$$

Where t is the emanation time and t_e is the time taken for a sample of radon to decay by at factor of 1/e (5.52 days).

Recent Improvements

- The current set-up has been improved from that used from those results to attempt to lower the background levels.

- The first improvement was to use two RAD7s in series to improve the sensitivity of the system.

- The next step was to try and lower the background of the system. This was done in 2 ways:

    1. Flow the dry nitrogen through a LN_2 cooled charcoal filter to remove any radon in the gas.

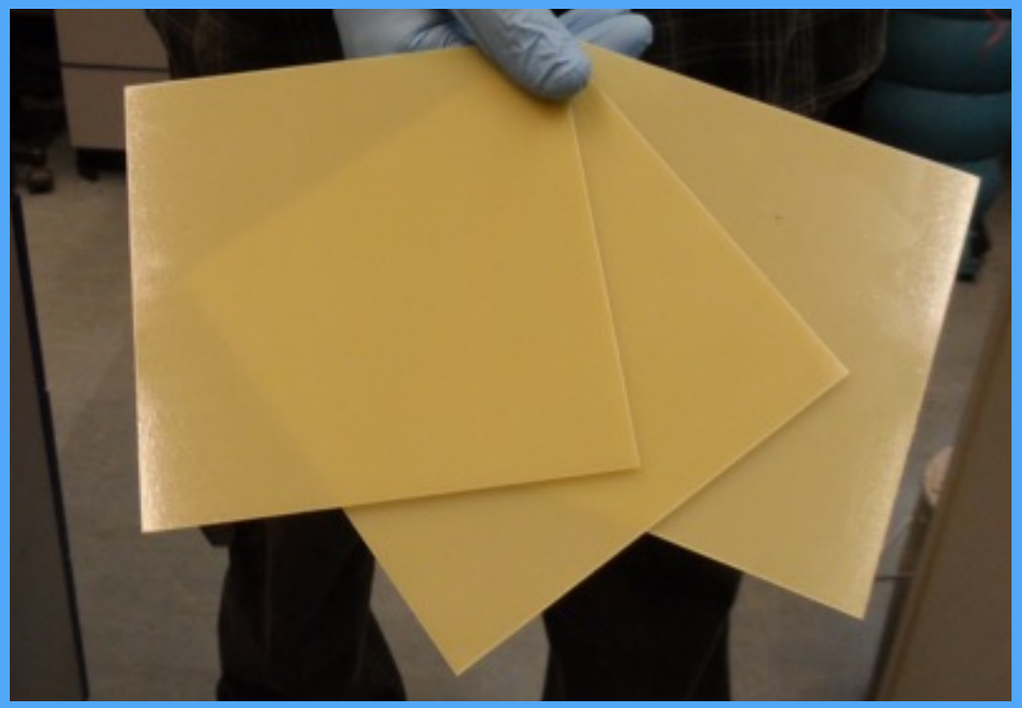
    2. Change the vacuum fittings on the chamber to remove known radon emitters, e.g. rubber o-rings.

Recent Improvements

- The improvement in the large, 34.5 l, vessel is a factor > 5.
    - Previous background (1.56 ± 0.30) atoms/min.
    - Current background: (0.29 ± 0.11) atoms/min.
- Reduction in the background in the small, 2.7 l vessel is a factor > 6.
    - Previous background: (0.63 ± 0.08) atoms/min.
    - Current background: (0.09 ± 0.03) atoms/min.

Example of Sensitivity

- Sample measured for the ProtoDUNE collaboration.
- G10 sample proposed as a cathode material.
- Sample initially measured in large vessel
  - No emanation above background so upper limit set
- Sample then cut to fit small vessel.
- Again no emanation above background so improved upper limit set.

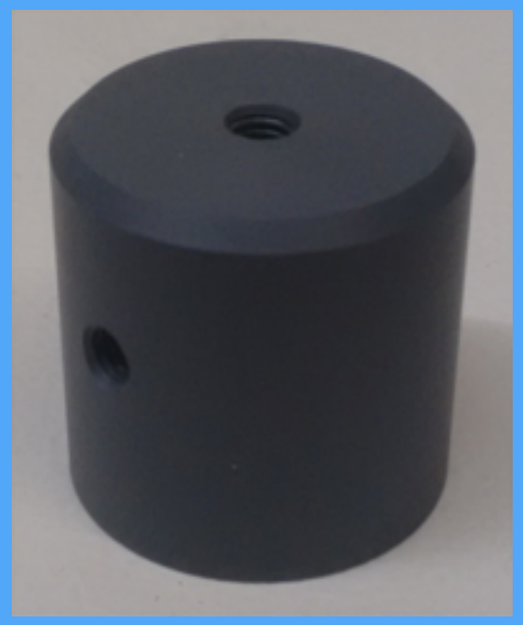


Example of Sensitivity

Material	Emanation Result (Atoms/min)	Sample Emanation - 90% CL (mBq/m^2)	Sensitivity (mBq)
BG - Large	0.28 ± 0.11	-	3.3
G10	0.22 ± 0.09	< 14.4	3.0
BG - Small	0.09 ± 0.03	-	0.77
G10	0.10 ± 0.02	< 6.5	0.94

RAD7 Component Emanation Tests

- The highest contributor to the remaining background is believed to be the RAD7 detector itself.
- Started testing the inner materials of the RAD7 detector.
- Low emanation replacements will be sourced for any large emitters if possible.



RAD7 Component Emanation Tests

- Pump appears to be worst emitter.
- Sum of individual components slightly below detector as a whole.
- Still to test some materials - e.g. tubing & dome.

Material	Rn Concentration per RAD7 (Atoms/min)
Sensor Pod	0.006 ± 0.002
Pod Gasket	0.0031 ± 0.0003
Dome Gasket	> 0.0009 ± 0.0003
Pump	0.032 ± 0.008
Sum of components	> 0.042 ± 0.008
Whole detector	0.060 ± 0.011
Whole - sum of components	**0.018 ± 0.014**

RAD7 Component Replacement

- A FEP-teflon encapsulated o-ring was sourced to test as a replacement for the dome gasket.
- RAD7 background compared before and after the swap.
- No significant difference seen.

Material	Rn Concentration per RAD7 (Atoms/min)
RAD7 background - old gasket	0.060 ± 0.011
RAD7 background - new o-ring	0.050 ± 0.018
Difference	0.010 ± 0.021
Dome Gasket	0.0009 ± 0.0003

Summary

- A large improvement has been made to the sensitivity of our radon screening facility in the last few months.
- Current sensitivity of the system (90% CL):
    - 0.77 mBq (2.7 litre vessel)
    - 3.0 mBq (34.5 litre vessel)
- The inner materials of the RAD7 have started to be tested.
- Plan to test inner parts of RAD7 further and attempt to lower the intrinsic background to further increase our sensitivity.