Radon Emanation Rate in the Detection Chamber

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The Total Radon Emanation Rate

\[ C_{total} = C_{sample} + C_{error} \]

- The total Radon Emanation Rate includes the sample and the error which we want to minimize as much as possible.

\[ C_{error} = C_{leakgas} + C_{residualgas} + C_{blank} \]

- And the error includes three parts: gas leakage, residual gas right after the pumping down process and the blank rate due the vessel walls etc. We deal with the three of them one by one.
Error 1: the Blank Rate

\[ C_{\text{blank}} = 2 \mu Bq \]

- I don’t know if this is constant. Does it change over time? Or should we replace it with:

\[ C_{\text{blank}} = 2 \mu Bq \cdot e^{\frac{-t}{\tau}} \]

\[ \tau = \frac{\text{halflifeofRadon}}{\ln 2} \approx 5.5 \text{day} \]
Error 2: Residual Gas

• Right after the pumping down process, there is some residual gas inside the detection chamber. Basically using PV=nRT, after some derivations, we can have

\[
C_{\text{residual gas}} = \frac{\sigma VP_m}{P_{\text{atm}}} \cdot e^{-\frac{t}{\tau}} \approx 9.4 \mu Bq \cdot e^{-\frac{t}{5.5 \text{day}}}
\]

• \(\sigma\) is the radon concentration of the air in the basement, 3.0 pCi/L = 0.111 Bq/L;
• \(V\) is the volume of the detection chamber, 1.9 L;
• \(P_m\) is the ultimate pressure we can get with the mechanical pump in high throughout mode, which is 34 mTorr;
• \(P_{\text{atm}}\) is one standard atmosphere pressure, 760 Torr.
Derivations for Error 2

• The radon concentration due to the residual air in the chamber should be the radon concentration in the normal air times the effective volume of the air in the chamber under one standard atmosphere. And according to state function of ideal gas, we have

\[ P_{\text{atm}} V_{\text{effective}} = VP_m \]

• V is the volume of the chamber and \( P_m \) is the ultimate pressure in the chamber. \( P_{\text{atm}} \) is one standard atmosphere.

\[ C_{\text{residual gas}} = \sigma V_{\text{effective}} \cdot e^{-\frac{t}{\tau}} = \frac{\sigma VP_m}{P_{\text{atm}}} \cdot e^{-\frac{t}{\tau}} \]
Error 3: Leak Gas

- After the mechanical is shut down, the pressure in the detection chamber decreases over time, 2.8 mTorr/day. The gas leaked into the chamber also decays over time. Based on this idea, after some derivations, we have

\[ C_{\text{leak gas}} = \nu \sigma \tau \cdot \left(1 - e^{-\frac{t}{\tau}}\right) \approx 3.9 \mu Bq \cdot \left(1 - e^{-\frac{t}{5.5\text{day}}}\right) \]

- \( \nu \) is the leak rate, 7.4x10^{-11} L/s, derived from 2.6 mTorr/day (See the graph in the next slide);
- \( \sigma \) is the radon concentration of the air in the basement, 3.0 pCi/L = 0.111 Bq/L;
- \( \tau \) is 1/ln2 of halflife of Radon, 5.5 day.
Rate of Pressure Rise in Rn Detection Chamber

Slope = 2.6 ± 0.2 mTorr/day
Derivations for Error 3

• Suppose there are $N$ Radons in the chamber due to the leakage. Then we know

$$N = N_0 \cdot e^{-\frac{t}{\tau}}$$

• Take its derivative, we have

$$-\frac{dN}{dt} = \frac{N}{\tau}$$

• So the number of Radon decays in the chamber over time interval $dt$ is

$$-\frac{N}{\tau} dt$$

• We know the Radon concentration in the room air is $\sigma=3.0\text{pCi/L}$. So the density of Radons in room air is

$$\sigma$$

• Since the leak rate is $\nu$. So over time interval $dt$, the number of Radons leaked into the chamber should be

$$\sigma \nu dt$$
• So over time interval $dt$, the increase of the number of Radons inside the chamber should be

$$dN = \sigma \nu \nu dt - \frac{N}{\tau} dt$$

$$\int_0^N \frac{1}{\sigma \nu \nu - \frac{N}{\tau}} dN = \int_0^t dt$$

$$N = \sigma \nu \tau^2 \cdot (1 - e^{-\frac{t}{\tau}})$$

• So the Radon Emanation Rate due to leak of the air into the chamber should be

$$C_{\text{leakage}} = \left| \frac{N}{\tau} \right| = \nu \sigma \tau \cdot (1 - e^{-\frac{t}{\tau}})$$
Summary

\[ C_{\text{total}} = C_{\text{sample}} + C_{\text{error}} \]

\[ C_{\text{error}} = C_{\text{leakgas}} + C_{\text{residualgas}} + C_{\text{blank}} \]

\[ = \nu \sigma \tau \cdot (1 - e^{-\frac{t}{\tau}}) + \frac{\sigma VP}{P_{\text{atm}}} \cdot e^{-\frac{t}{\tau}} + C_{\text{blank}} \]

\[ = 3.9\mu Bq \cdot (1 - e^{-\frac{t}{5.5\text{day}}}) + 9.4\mu Bq \cdot e^{-\frac{t}{5.5\text{day}}} + 2\mu Bq \]

\[ = 5.9\mu Bq + 5.5\mu Bq \cdot e^{-\frac{t}{5.5\text{day}}} \]
Methods to Improve the Results

\[
C_{error} = 3.9 \mu Bq \cdot (1 - e^{-\frac{t}{5.5 \text{day}}}) + 9.4 \mu Bq \cdot e^{-\frac{t}{5.5 \text{day}}} + 2 \mu Bq
\]

- Check the leakage. Reduce the leak rate.
- Improve the ultimate pressure in the high vacuum mode or flush repeatedly with dry N₂
- Blank Rate. Electropolish Stainless Steel.