DETECTION OF RN-220 WHEN USING A RN-222 DETECTOR

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Abstract. Usual radon detection mechanisms rely on the assumption that radon-222 is the only radon isotope present in our basement air, without taking into account the radon-220 isotope. The presence of the latter makes the usual algorithm produce results that output negative concentration and hence make no sense. In this paper, we present a modification to the usual radon detection protocol which detects the presence of radon-220.

1. Introduction

Residential radon progeny exposure is the second leading cause of lung cancer in smokers and the leading cause of lung cancer in non-smokers. Radon can enter buildings through cracks in floors or walls, wires or pumps and its concentration is usually higher in basements than in other floor levels. The reader can refer to this article by Sung and Vogelsang [3] for more information.

Uranium and thorium in the soil decay into radon, which can then seep into basements and low-lying areas of the house. The two main radon isotopes are Rn-222, which is part of the U-238 decay chain, and Rn-220 (also called Thoron), which is part of the Th-232 decay chain. Thoron has been ignored in the past as it has a relatively short half-life and usually decays before reaching a house, however its decay products can reach living areas.

2. Problem statement

Environmental Instruments Canada Inc. manufactures a portable radon gas detector known as the *radon sniffer*. This tool can indicate the presence of a radon source in 15 seconds and can quantify the radon concentration in 5 minutes. It is an indispensable tool for any radon mitigation project. More information about a radon sniffer can be found on their website [1].

Since Radon gas is odourless and colourless, so far the only reliable way of detecting it is through the Radon Sniffer. The radon sniffer works by detecting alpha particles from the decay of these isotopes and their progeny. This detection is done by counting the number of alpha decays in any given time period, and a single measurement cannot distinguish between the different isotopes of radon that may be

[1] `https://radonsniffer.com/`

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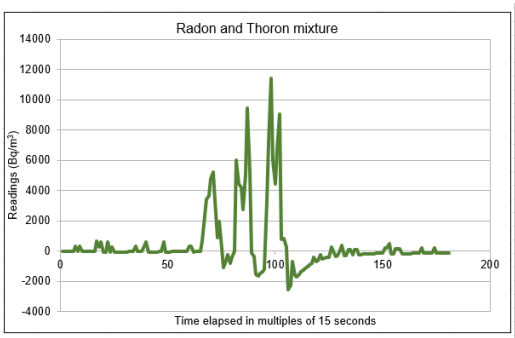
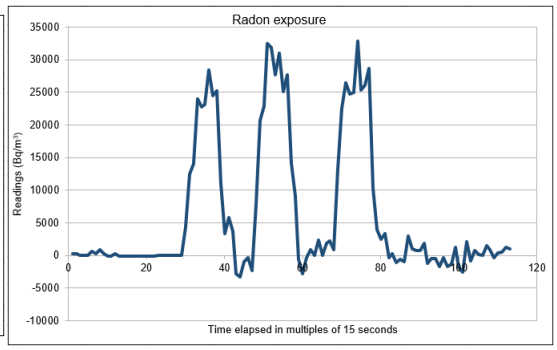
present.

The EIC team at the 2020 *M2PI* workshop, presented a method to approximate the relative amounts of radon-222 and radon-220 in a particular sampling sequence by performing a linear regression to the theoretical expected count rate from each of these isotopes [2].

The problem we were presented with was to, without changing the usual sampling scheme, modify the internal algorithm for it to be able to detect when a negative measurement is statistically significant and when it's just an artifact from the randomness of the decays.



(A) Radon-Thoron Mixture



(B) Pure Radon Concentration

3. Method

3.1. **Radioactive decay chains.** Unstable atoms can randomly and spontaneously decay. This decay consists of the expulsion of a particle from the atom, that is, either an $\alpha-$particle (helium nucleus) or a β particle (high energy electron or positron). The probability of an atom decaying is measured through the *half life* of the atom $t_{1/2}$, which measures the time over which a particle of the substant has a 50% probability of having decayed. Equivalently, it's the time by which 50% of the substance is expected to have decayed.

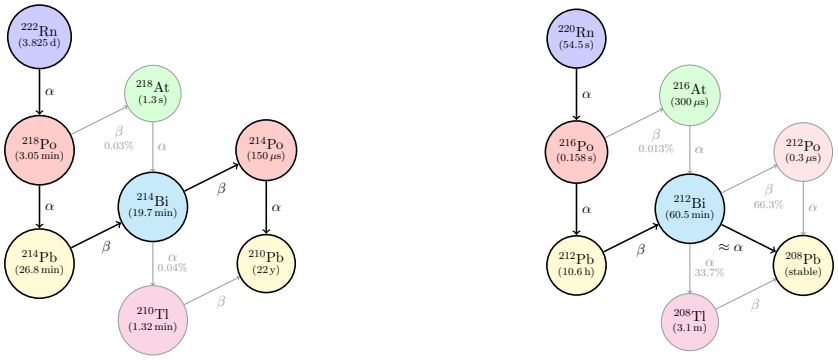
When an atom decays, the result might also be unstable. This leads to a *decay chain*, where atoms decay sequentially. When there's only one reasonable decay at each step, we say that the decay chain is linear These decay chains continue until a stable nuclide is reached. The probability of a decay occurring is memoryless, so it follows that the time it takes for a given atom to decay follows an exponential distribution, that is

$$N(t) = \lambda e^{-\lambda t},$$

[2] `https://m2pi.ca/2020/`

where $\lambda := \frac{\ln 2}{t_{1/2}}$ is called the decay constant of the atom.

In our particular case, we are concerned with the decay chains of Rn-220 and Rn-222 which are presented in figure 2 and can be ultimately modeled as linear decay chains. The extremely short life of Po-216 gives rise to overcounting alpha decays and thus renders the algorithm useless if nothing is done to correct that error.



(A) Rn-222 Decay Chain

(B) Rn-220 Decay Chain

FIGURE 2. Decay series for Rn-222 and Rn-220, respectively. These are based on [2]*Chapter 15. The effective linear chains are indicated in bold.

3.2. **Modeling and Bateman's equations.** Assume we have a linear decay chain $(x_1, \ldots, x_n)$. Let us denote the activity of the isotope x_n by $I_{x_n}(t)$ at the time t and the decay constant of the isotope x_n by λ_{x_n}. We can use the Bateman's equations (see [1]) to model the activity of said isotope as follows:

$$\frac{dI_1}{dt} = -\lambda_1 I_1,$$
$$\frac{dI_m}{dt} = \lambda_m (I_{x_1} - I_m).$$

An analytical solution to these differential equations can be found without much trouble, but the frequency with which the alpha particle emissions are measured, allows us to use numerical methods for the sake of efficiency and estimate the change of each isotope in the chamber every 3 seconds,

$$\Delta I_n = \Delta t \lambda_n (I_{n-1} - I_n),$$
$$\Delta I_1 = \text{Counts} - \sum_{i=2}^{n} I_i.$$

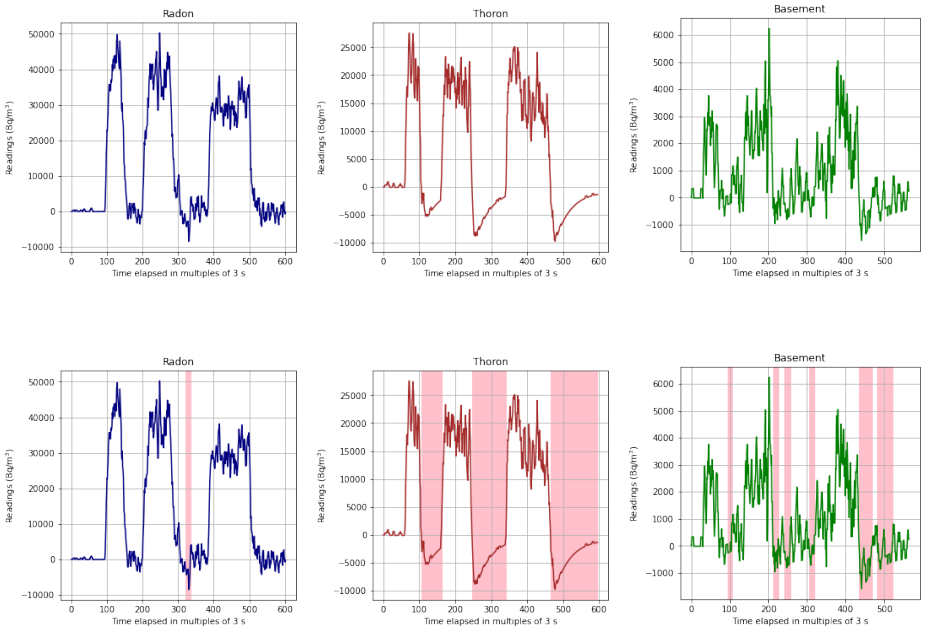
3.3. **Negativity test.** As stated before, the main issue with the current algorithm is that it yields negative estimations of radon density in the air, which is nonsensical. One possible explanation is that the probabilistic nature of the decays results in some inevitable negative values which are no issue, one can just set them to 0 without any problem. The second explanation suggests that the sniffer caught some thoron, and the high activity of Po-216 and Rn-220, makes the algorithm think there is more progeny than there actually is and that ends up being noise for future measures of radon-222.

Implementing the numerical solutions we can find an estimate of the extra progeny and thus get a *threshold* to compare the readings to and then perform a test to determine whether the value is significantly negative or not. The protocol we designed is as follows:

(1): Determine a sample size l.
(2): After having l measurements $x = (x_1, \ldots, x_l)$, if all of them are positive, continue as usual.
(3): If at least one is negative initiate the testing protocol.
(4): Using Bateman's equations, estimate the amount of extra progeny that should be in the chamber, and set μ_0 to be half of the average of that estimate in the sample.
(5): Compute the average $\overline{x}$ in the sample x.
(6): Perform a student T-test at a significance level of 90% comparing μ_0 and $\overline{x}$.
(7): If the test results on $\overline{x} < \mu_0$, then the timestamps in the sample are marked as *significantly negative*.
(8): When a new measurement z is done, make $x = (x_2, \ldots, x_l, z)$, if all entries of x are positive, continue, as usual, if not, return to step (3).

4. Results

Environmental Instruments Canada provided



3-second interval

5. Future work

A few improvements can be made in our current approach:

- For the student T-test to be reliable we assume the noise to be normally distributed. It is a reasonable assumption since when it fails it's usually because the data is biased towards the negatives, which in the worst-case scenario gives a false positive. Another approach with heuristic methods could be used to prevent that assumption.
- The sample size l is somewhat arbitrary in this context. it was chosen to be 5 since the algorithm is designed to be more effective for every 5 measurement.

6. Conclusion

We were able to determine when the measurement is negative enough to suggest that thoron is present in the air without modifying the sampling protocol. If this is persistent enough it is a good criterion to use that thoron estimation routine developed during the M2PI workshop 2020. Implementing this to the current algorithm used in the radon sniffer will increase the effectiveness of the estimation without necessarily relying on the user to follow the Thoron Detection protocol [3].

[3] `https://m2pi.ca/2020/`

The Python code used for this project is open sourced at GitHub repository[4].

7. Acknowledgements

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[4] `https://github.com/nehamainali/M2PI_2022_EIC_Project`

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