Measuring radiation accompanying radon

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August 27, 2023

Acknowledgement

I thank Prof. Fred Sarazin, a colleague at the Colorado School of Mines, who reassured me about how common short half-life isotopes are in nature. Early on he fingered ^{212}Bi as one plausible candidate.

Contents

1 A mysterious radiation source

Only when I wrote up in August 2023 a document on precisely how radon gives rise to radiation risk did I think back to a test I made out of curiousity in early December 2017.

We had bought our furnace with an inline electrostatic precipitator to keep out pollen. It came with a better-than-HEPA MERV 15 air filter and it occurred to me that it would be interesting to check this filter for radioactivity. I yanked out the dirty filter and measured it over a fairly long count time (hours) using a data-logging Geiger-Müller counter placed very near but not in contact with the filter. I found to my consternation that there *was* a very clear excess count rate which decayed in time quite noticeably over a matter of a couple of hours. The half-life was about 47 minutes. I repeated a count during which I inserted a thin aluminum plate in front of the Geiger-Müller counter and the count rate plummeted (see the full-page graphic page). This indicates that it was detecting beta particles without many gamma rays (which it also would have detected). It's worth noting that in all cases reported (furnace filters or the 'balloon method' below) the methods used were to *concentrate* radon daughters in order to make it easy to count them; this is not to imply that their concentration in air is necessarily dangerous. It is in fact radon daughters which are detected by 'continuous' radon monitors (as opposed to one-shot alpha particle track detection kits).

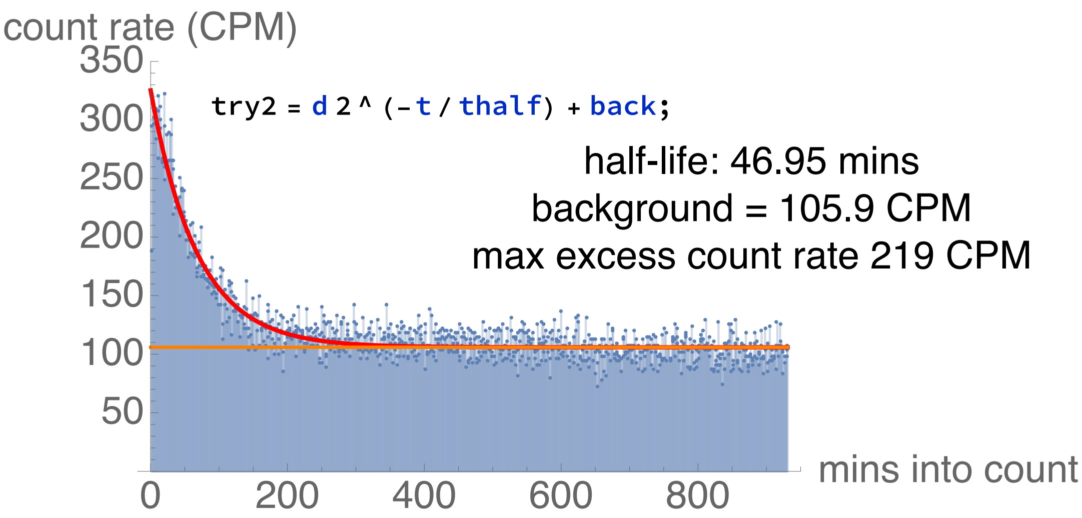
This was after our radon abatement system was installed but the power supply on the electrostatic precipitator was out at the time of these measurements I suspect.

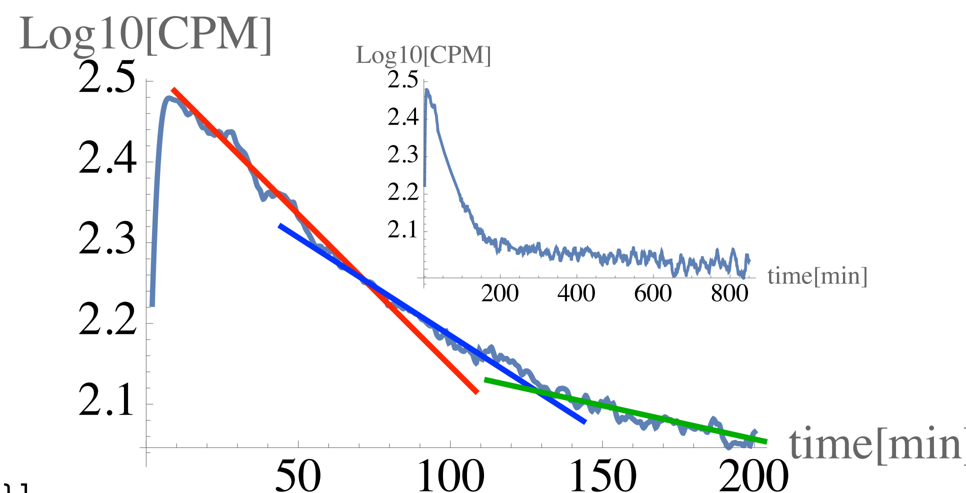
Gamma rays are very penetrating, beta particles can be stopped with a thin metal sheet, and alpha particles can be stopped by a sheet of paper.

After several preliminary counts and fits, I was informed that one often needed to count for at least 5 half-lives to get reliable statistics. I then made a long count whose results are shown on the graphics page attached. The furnace intake vent was about 4 feet above ground level in our side yard. I wondered whether what had been caught in the filter was from outside air and was not happy as a clam there appeared to be something radioactive in what was coming in. I deduced what I thought was *the* half-life of the radionuclide, then hunted around for radionucides known to have similar half-lives. (These are shown in the page of figures.) Because the uncertainty of the half-life value was fairly small, I placed more store in what I fit than was appropriate–see below.

Obviously this was *not* the case, as you will see.

I knew the species being measured were not alpha particles because the count rate appeared not to depend at all on the distance between the mica window on the detector and the surface of the filter paper.



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nlf[{"ParameterTable", "ParameterConfidenceIntervals", "RSquared"}]
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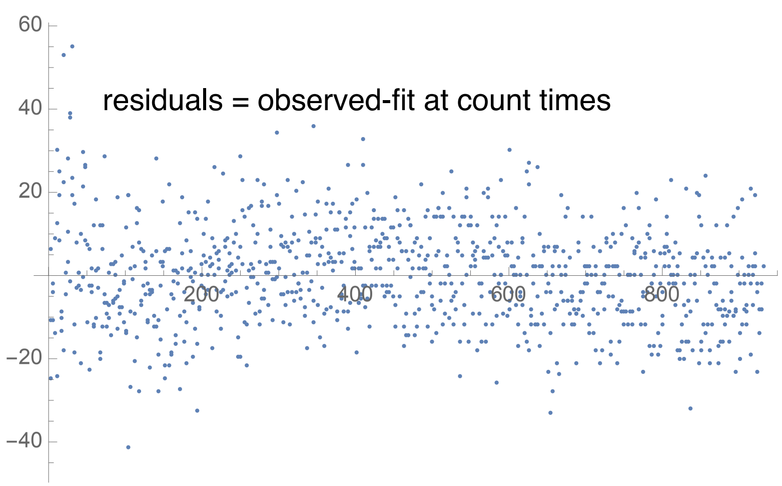
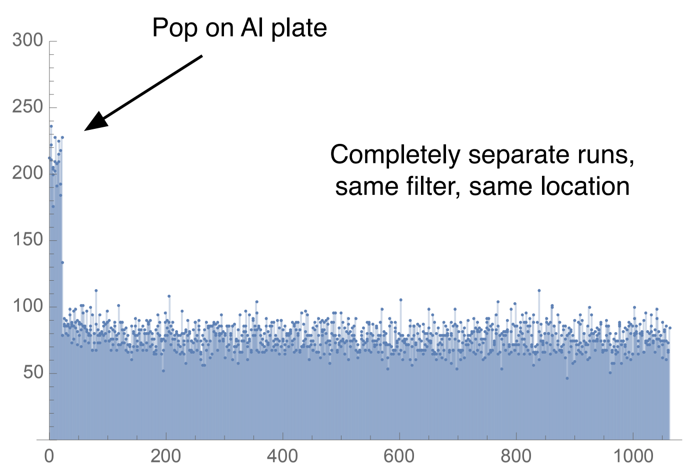
	Estimate	Standard Error	t-Statistic	P-Value
d	219.38	3.13944	69.8787	$6.08517898893 \times 10^{-372}$
thalf	46.946	1.03533	45.3439	1.34769×10^{-237}
back	105.897	0.495403	213.759	$1.389245805903 \times 10^{-791}$

{{213.219, 225.541}, {44.9141, 48.9778}, {104.925, 106.869}}, 0.990187}

95% confidence intervals

parent	daughter	half-life (min)	decay mode
^{222}Rn (radon)	^{218}Po	3.1	α
^{222}Rn (radon)	^{214}Pb	26.8	β
^{222}Rn (radon)	^{214}Bi	19.7	β
^{220}Rn (thoron)	^{212}Bi	60.5	α





candidate	half-life (mins)
^{226}Th	30.57
^{84}Br	31.80
^{138}Cs	32.2
^{211}Pb	36.1
^{236}Th	37.5
^{134}Te	41.8
^{213}Bi	45.65
^{134}I	52.6
^{133m}Te	55.4
^{103}Rh	56.12
^{259}No	58
^{212}Bi	60.55
^{240}Np	65
^{68}Ga	68
^{129}Te	69.6
^{97}Nb	72.1

For several years I left his measurement aside, since I was not sure precisely which nuclide was responsible since the half-life I measured did not agree very well with candidate half-lives.

2 *The explanation*

Only when reading more about radon did I understand that danger of inhalation comes *not* from radon *per se*, but from its decay daughters, almost definitely stuck to tiny dust particles or other unknown species. I stumbled on a well-described modern physics demonstration available at Harvard which used a charged balloon (rubbed with cat fur) to attract charged radioactive particles produced by radon decay daughters. They found what I found in terms of behavior, but they had explicitly attributed the excess counts to radon daughters. Each of these has distinct half lives, ranging from microseconds to less than an hour or so.

The authors noted, "The count rate dropped to half its original value after about 3000 seconds, or 50 minutes. Clearly the measured decay is not exponential in character in the first 1.5 hours, so complicated things are going on."

In other words: even though the decay details are complicated, there is an overall half-life of about 50 minutes. When you compare this with what I found by direct fit (about 47 minutes), it seems very likely that what I observed was exactly what they observed– a complicated decay of radon daughters with a variety of half-lives (see the red, blue, and green lines in the logarithmic count rate in the upper right of the page of figures.

2.1 *Complications*

- We do not know the proportions of radon and thoron in basement air
- Even in the absence of thoron, different amounts of the decay daughters may bind to the aerosols in the air (and then to the balloon surface).
- The pancake Geiger-Müller counter is [1] about 20% efficient at detecting β particles (high-energy electrons), about 15% efficient for α particles within range, but is fairly inefficient (about 2%) at detecting γ rays.
- As the authors explain, the count rate can *rise* once β particles start to be produced appreciably. (See below.)
- Interpretation is made more complicated by the different response of the Geiger-Müller counter to α particles (provided they are not absorbed, they can be detected within a few cm of the source), β (fairly efficient detection since they carry a charge and ionize molecules in the Geiger-Müller tube), and γ rays (a few percent detection efficiency).

They proceeded to put the balloon in a NaI scintillation spectrometer. They detected a 239 keV gamma ray from ^{214}Pb decay and a 609

Long after I measured the filter with a Geiger-Müller I set up a NaI scintillation spectrometer in my basement, but with the radon mitigation system in place I have been completely unable to detect any further radiation from radon daughters in the filters.

v 2.0

keV gamma from ^{214}Bi decay. They found three other strong gamma peaks from *thoron* daughters.

3 Future plans

Since the radon abatement system apparently works very well, it may now be difficult to find radon daughters in the basement. On the other hand, the garage sits on a concrete slab with some cracks and seams and radon levels could be much higher than in the basement, despite the fact that the garage is better ventilated. Because I now have a gamma ray spectrometer, the intent is to use the balloon method [2] to prepare a radioactive sample. The spectrometer software logs count rates over time and I intend to dump the (now time-dependent) gamma spectrum at various points during the count to watch the evolution of gamma peaks expected for the daughter isotopes. Stay tuned. Also using InterSpec, one can predict the time

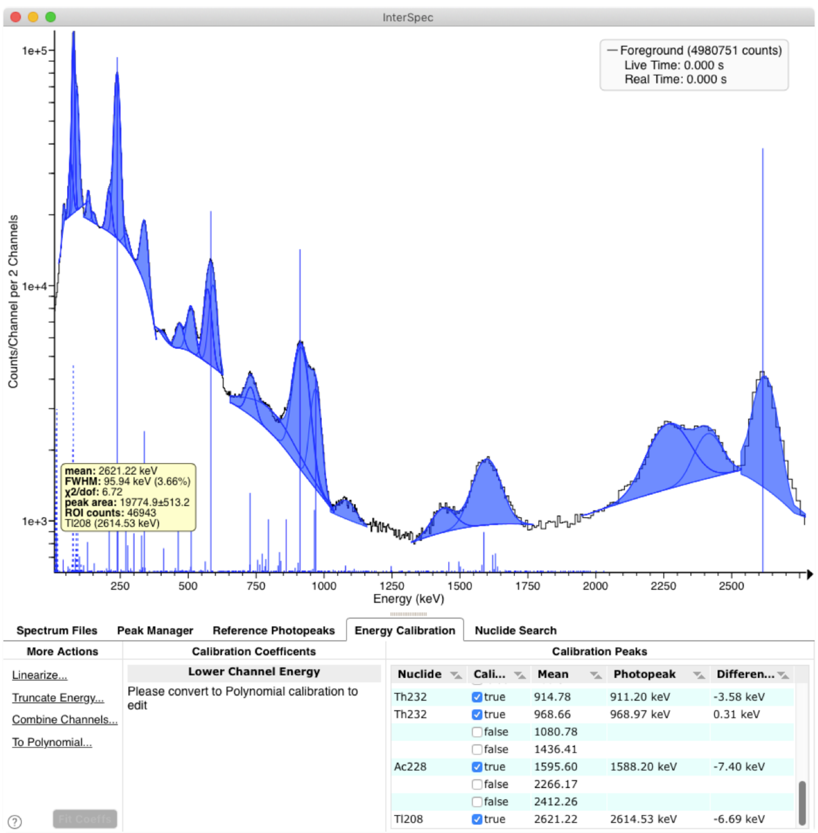


Figure 1: A peak-fit spectrum of a 1980s-era unused Coleman thorium salt based lantern mantle, acquired on a 2"× 2" NaI:Tl scintillator/PMT gamma ray spectrometer. Vertical blue lines are peaks known and catalogued for ^{232}Th decay products; their height reflect the branching ratio of the particular gamma line. Fits performed with the excellent free gamma spectroscopy tool InterSpec, maintained by William Johnson of Sandia National Labs and available here.

evolution (of beta particles of specific energy or of specific gamma ray lines) from pure ^{222}Rn or ^{220}Rn at time t=0. These figures were generated assuming equal starting decays per second for each, very

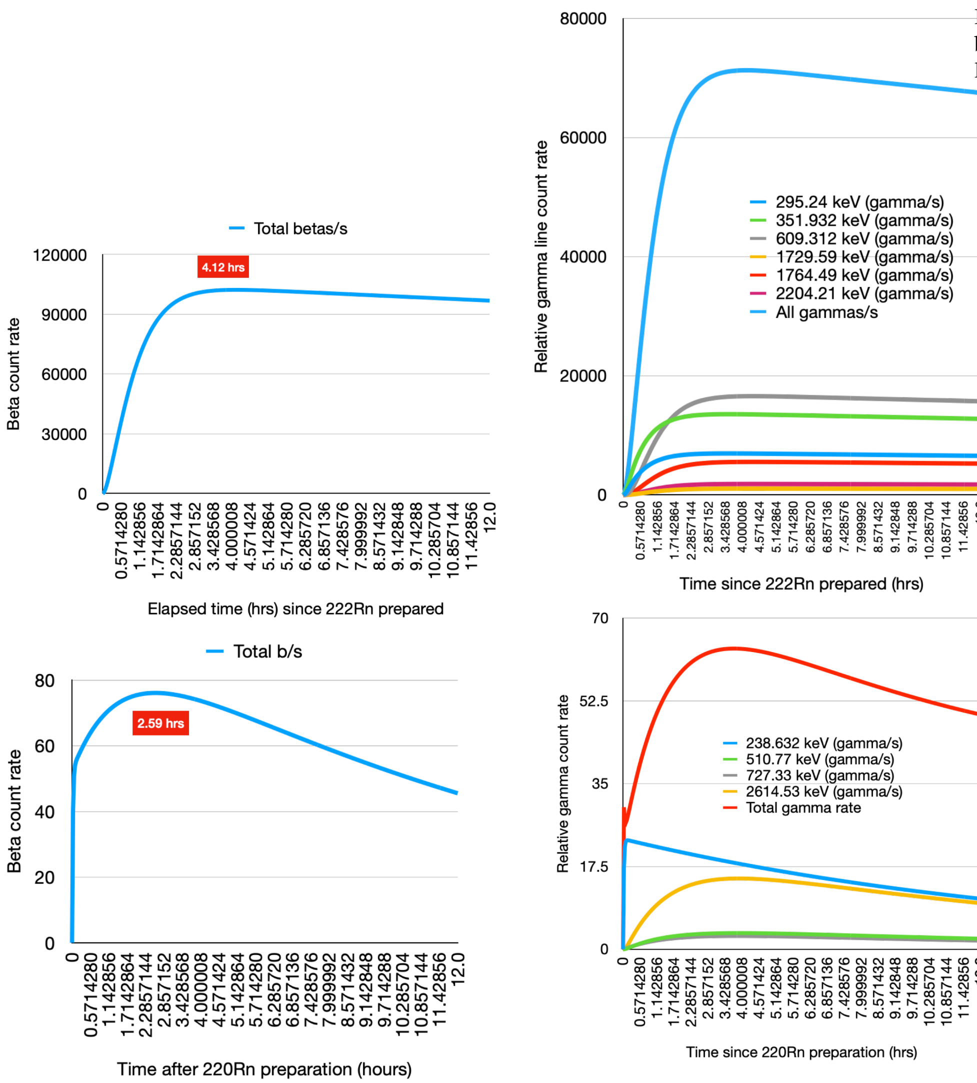


Figure 2: InterSpec-predicted relative beta count rates and relative gamma lines as a function of time in hours.

unlikely since we expect more radon than thoron. Evidently we expect very few β particle counts from thoron and also relatively few thoron gamma rays. The strongest gamma lines expected is 351.9 keV

The Harvard demonstration write-up indicates that 5 strong gamma peaks were observed: only two, 353 keV from ^{214}Pb and 609 keV from ^{214}Bi were from radon. They note that a ^{212}Bi gamma line at 727 keV was *not* observed.

The predictions in Fig. 2 show that the two lines they observed for ^{222}Rn are the two strongest we predict. In comparison the gamma lines from ^{220}Rn are all very weak, so it is not surprising they were not observed. The 727 keV line in fact is *not very strong*: the most plausible gamma to detect from thoron is 238.6 keV.

Reminder: green links below are clickable.

References

[1] Paul R Steinmeyer. "G-M Pancake Detectors: Everything You've Wanted to Know (But Were Afraid to Ask)". In: *RSO Magazine* (2005). URL: https://ehs.berkeley.edu/sites/default/files/lines-of-services/radiation-safety/G-M_pancake_detectors.pdf.

[2] Thomas A. Walkiewicz. "The hot balloon (not air)". In: *The Physics Teacher* 33.6 (1995), pp. 344–345. ISSN: 0031-921X. DOI: 10.1119/1.2344235.