Geiger Counter Experiment 4: ^{222}**Radon – the Balloon Experiment**

Reference: CNS publication "Uranium Decay Fact Sheet"

Objective:

In this experiment the students will observe that an electrostatically-charged surface – an inflated balloon will collect dust bearing radionuclides, and radionuclide ions derived from the decay of radon in the air. If the data collection is extended, the data will show the collective decay of a subset of the radionuclides present.

An option using plastic food wrap is also described. While the effect is smaller it does show the activity increasing as a function of time (for about 1 hour).

CAUTION:

This experiment uses electrostatic charge to collect radon progeny from the air. The results are dependent on:

- **avoiding high ventilation rates (e.g., classroom exhaust fan(s) off (windows closed), and ensure the balloon is not close to a fresh air supply); and**
- **maintaining the charge on the balloon or plastic film – this may not be possible if the relative humidity is high.**

Preparation:

The system should be configured as described in **Experiment 0**.

A counting interval (time base unit) of 60 seconds is recommended for this background / radon progeny measurement. (*To change the time base, see Experiment 0 Steps 5 & 7.*) In most locations the background level will produce an average of 30 to 50 counts per minute. Count rates with radon progeny radionuclides on a balloon should exceed 100 counts per minute.

If you have performed Experiment 1 with the same computer, you may skip steps: 4, 5, 6, and 8 below.

1. Click on the "Rad Collection" tab – click on the "Express Start …" command.

2. A window will open with the title "Select Aware Binary Rad Data File …" – click on "**Cancel**" unless you wish to use this function.

3. If the ASCII data file function is enabled, a window will open titled "Aware ASCII Output File …" If you do not wish to record data (to use in a spreadsheet or other program, click on "**Cancel**".
   OR
   If you do wish to record data, the default location for the file is in the "C:\Aware" directory. You may select another directory. Enter a file name such as "**balloon.txt**" (the ".txt" extension is not automatic). Click on the "**Save**" button.

The program will start and will launch the running average bar graph in a separate window.

4. Click on the Bar Graph window. Click on the "Options" tab. Here you may select either a "Points" average, or the "**Alarm Average**" value (default).

5. Click on the "Options" tab – click on the "Y value precision" function. A window will open. **Select 0** as no decimal points are needed for the counts unit.

6. Click on the "Options" tab – click on the "Manual Y axis min" function. Ensure the value is **zero**.

7. Click on the "Options" tab – click on the "Manual Y axis max" function. Ensure the value is **500** for radon progeny measurements.

   By now, there should be a few bars on the graph. The auto function can be used, but it scales the graph to the highest and lowest values detected within the graph window. This may result in the graph scale changing as one scrolls the window horizontally which can be confusing.

8. Click on the "Options" tab – ensure that the "**Place spaces around numbers**" function. This ensures the bars are spaced sufficiently widely that the count numbers are visible.

9. At this point you may click on the "Aw-Radw Exec #1" window and stop the data collection (Click on the "Rad Collection" tab – click on the "Stop Collection" function.) You may have to minimize the bar graph to find the control window.

   When you re-start data collection, your settings should be preserved. The program will ask you if you wish to record data files as in Steps 2 and 3 above. If you click on "Save" in step 3, the program will ask if you wish to over-write the data file you recorded previously. You may change the file name, or just click on "Yes".

Procedure:

1. Start the Aware data collection to obtain some background counts with the Geiger facing up.

2. Select a balloon, inflate it, use a document clamp to seal the stem (or tie a knot), secure a string to the clamp or stem (a magnet on the end of the string is useful)

3. Rub the balloon with a micro-fibre cloth or similar material to induce a static charge

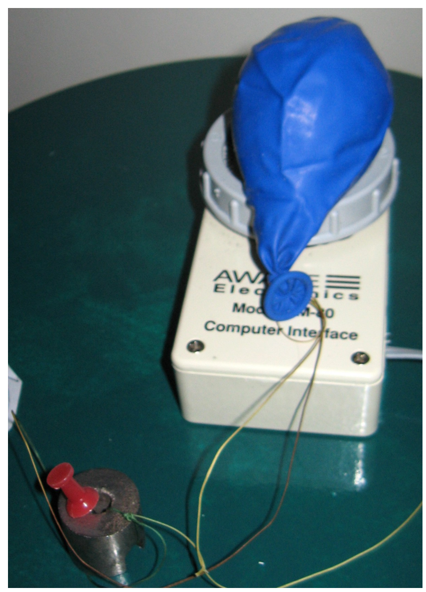
4. If you have a light source available have students observe the attraction of dust motes to the balloon

5. Secure the string to hang the balloon at a convenient location in the room (use the magnet to attach the string to a light fixture or a ceiling tile track)

6. After an arbitrary delay (10- 30 minutes?), remove the plastic wrap from the Geiger, recover the balloon and place over the Geiger window. It may be necessary to use wooden blocks or books to keep the balloon in place. Placing the magnet on the string atop the balloon may help keep it in position.

7. After 2 or 3 minutes of counting, remove the balloon. Holding it by the stem, deflate the balloon by removing the clamp (you may have to wiggle the end to unseal it), or use a push pin to pierce the balloon wall near the knot. You may have to stretch the opening with the pin to release the air. When the balloon is mostly deflated return it to the Geiger window. Place a plastic disk or piece of wood to flatten the balloon. The count rate should increase dramatically.

8. After a few minutes of counting, remove the balloon and place a paper disk that covers the Geiger window in the bezel. Replace the balloon. The count rate will show a decrease.



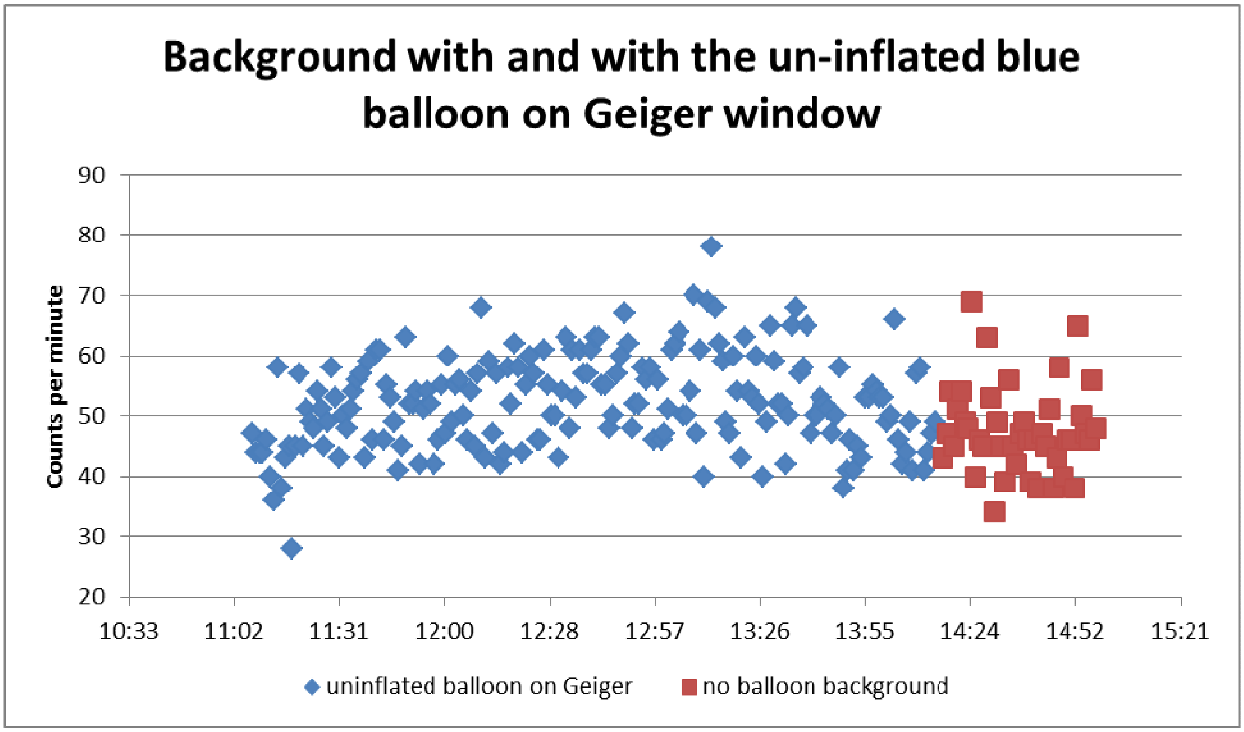
Background Inflated Balloon on Geiger Deflated Balloon on Geiger

Description of two sets of observations:

The balloon is an electrostatic precipitator collecting ions and dust particles from the air. The dust is radioactive due to the tendency for the radioactive decay progeny ions to attach to dust particles in the air.

The data plotted below illustrate the start of one balloon experiment. As shown in the photographs above, no plastic disk was used to flatten the deflated balloon in this case.

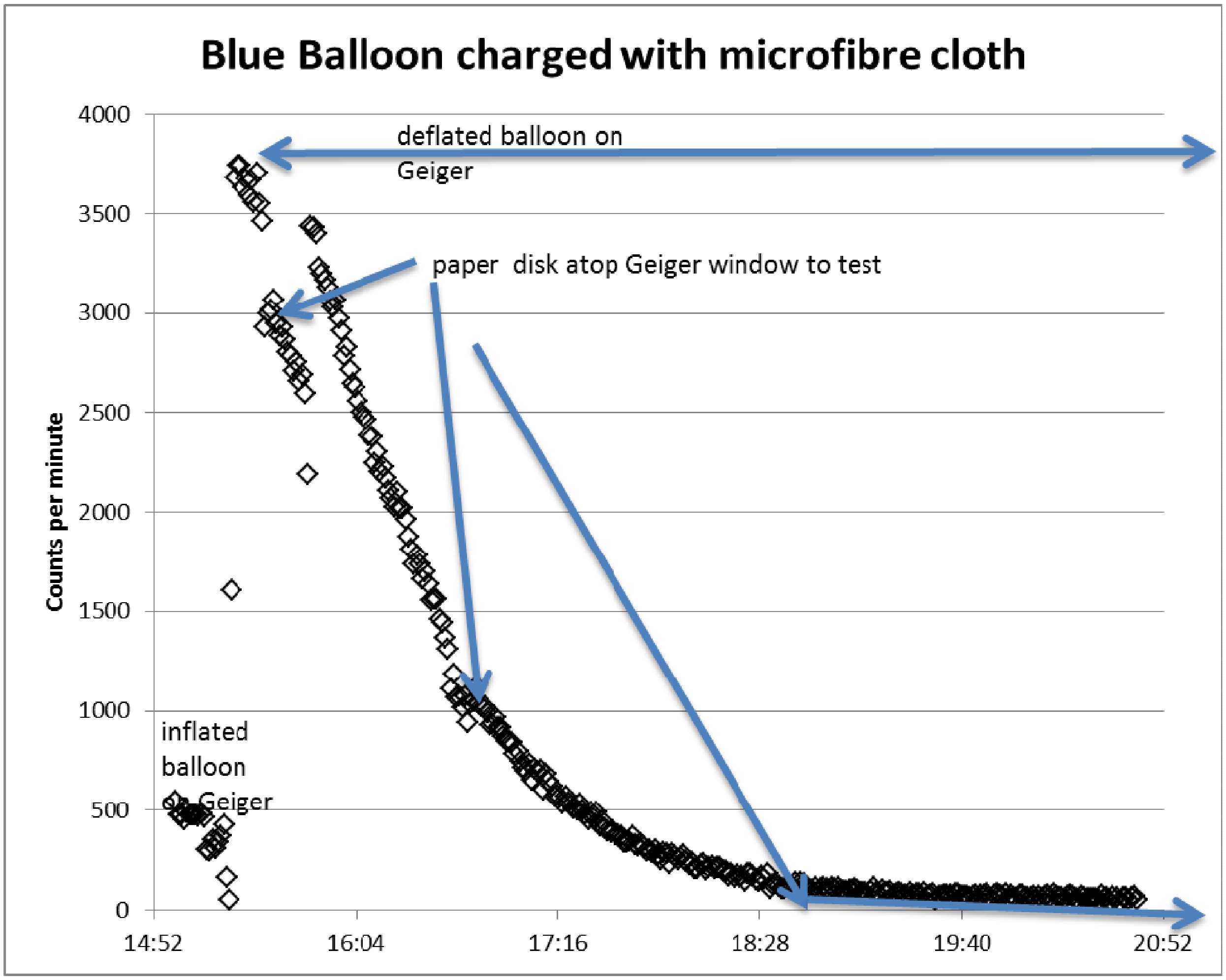
- The average background with the un-inflated balloon on the Geiger was 52 counts per minute.



- The balloon was removed, inflated, and hung for about 40 minutes. During this interval the Geiger the average background count rate was 48 counts per minute.

The balloon was then recovered, and placed on the Geiger window as shown in the photograph (its prone to falling off). The data is plotted below.

- The average count rate with the inflated balloon was 480 counts per minute. The count rate over about 10 minutes was 480 counts per minute.
- The balloon was then removed and deflated using a push pin taking care to ensure it collapsed slowly. This took about 3 minutes.
- With the mostly-deflated balloon atop the Geiger, the count rate increased to 3700 counts per minute.
- After about 10 minutes the balloon was removed, a paper disk was inserted to cover the Geiger window, and the balloon was replaced. The count rate dropped by about 500 counts per minute.
- After a further 10 minutes, the balloon was removed, the paper disk removed, and the balloon replaced atop the Geiger. The count rate increased by about 1200 counts per minute.
- Later still, the paper disk was re-inserted dropping the count rate by about 200 counts per minute. When it was replaced, the count rate rose by 75 counts per minute.
- Hereafter the data is boring.

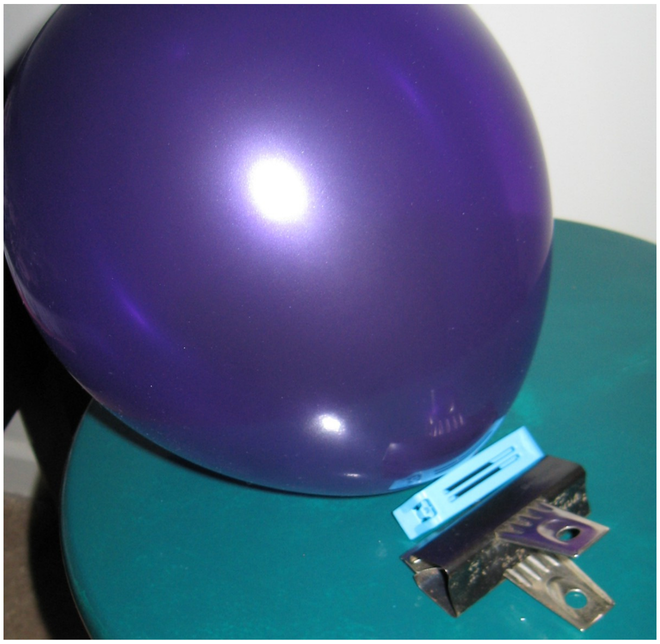


Two more tests were conducted with a purple (almost black) balloon collecting for about 20 minutes. These sets of data were taken on one evening and the following morning (when it started to rain – rain can affect the background count).

- The balloon was sealed with a document clamp as shown in the photograph below. The Ikea plastic clamp shown does not seal as well as the metal document clamp. Removing the clamp makes it easy to deflate the balloon quickly (you may have to wiggle the stem opening) – and it can be used again.

- A plastic disk (6 mm thick PMMA) was used to flatten the deflated balloon on the Geiger window. It also acts as a shield, reducing background count rate slightly.

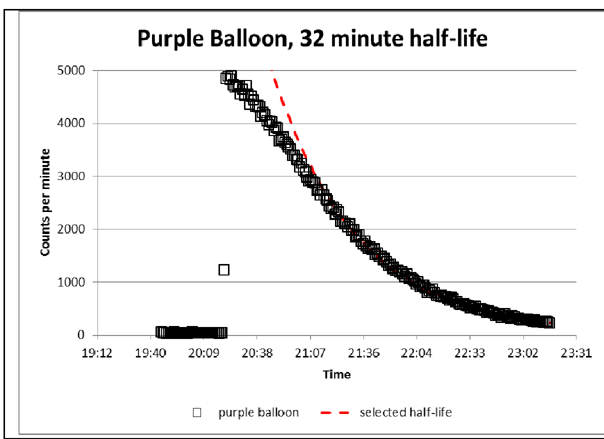
- In the second of these tests a paper disk was placed on the Geiger window underneath the balloon to attenuate the alpha radiation for the entire data set.

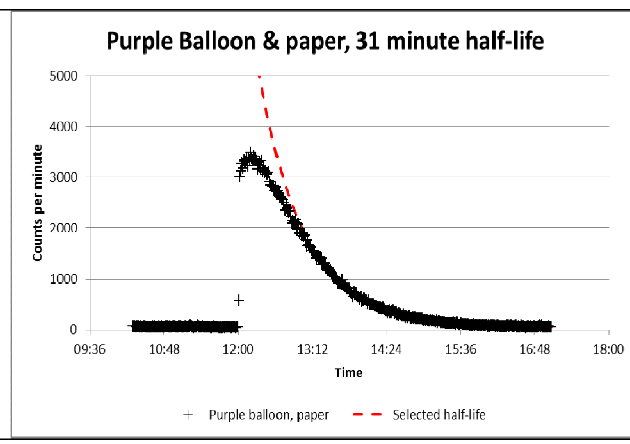


Balloon stem sealed with document clamp

Deflated balloon, plastic disk

The collection time was longer for the balloon & paper disk experiment shown on the right below. The two curves have different shapes over the first 30 minutes following the increase.





Discussion of the results

Handling of the balloon seems to produce an increase in the count rate in each case. Another experiment could be done where the balloon is simply removed and replaced to determine if this is reproducible. Moreover, a mark on the mostly-deflated balloon could be used to test the effect of rotating the balloon atop the Geiger.

The decrease in the blue balloon count rate when the paper disk was inserted is consistent with the paper absorbing alpha radiation (and possibly some very-low-energy beta radiation).

Radon is produced as part of the decay series for each of:

- $^{238}U \rightarrow$ ^{222}Rn that has a half-life of 3.82 days
- $^{235}U \rightarrow$ ^{219}Rn that has a half-life of 4 s, and
- $^{232}Th \rightarrow$ ^{220}Rn that has a half-life of 55.6 s.

In much of Canada uranium is more common in materials that make up the earth's surface than thorium. ^{238}U is the most abundant uranium nuclide at over 92%. Hence ^{222}Rn is the primary contributor to human exposure to radon. Radon is a noble gas and the long half-life of 3.82 days provides time for ^{222}Rn to emerge from the material where its progenitor radium nuclide ^{226}Ra – a metal, decayed.

The main decay series for ^{238}U is shown below.
(There are some low-probability side-branches that we've ignored.)

from	by	to	Half-life	100 Bq per m^3 corresponds to nuclides per m^3
U-238	α	Th-234	4.47 E9 year	
Th-234	β^-	Pa-234	24.1 day	
Pa-234	β^-	U-234	6.7 h	
U-234	α	Th-230	2.45 E5 year	
Th-230	α	Ra-226	7.5 E4 year	
Ra-226	α	Rn-222	1.6 E3 year	
Rn-222	**α**	**Po-218**	**3.82 day**	**4.76 x 10^7**
Po-218	**α**	**Pb-214**	**3.1 min**	**2.68 x 10^4**
Pb-214	**β^-**	**Bi-214**	**26.8 min**	**2.32 x 10^5**
Bi-214	**β^-**	**Po-214**	**19.9 min**	**1.72 x 10^5**
Po-214	**α**	**Pb-210**	**164 µs**	**~0**
Pb-210	β^-	Bi-210	22.2 year	
Bi-210	β^-	Po-210	5.012 day	
Po-210	α	Pb-206	138.4 day	

The short column at the right shows the number of nuclides corresponding to the half-life values for each of the **four nuclides** (bold font) considered to be important to these experiments. These are calculated for an equilibrium condition specified as 100 Bq per cubic metre for ^{222}Rn. The half-life for ^{214}Po is so short that it does not accumulate for this low activity level. The value of 100 Bq per m^3 is identified by Health Canada as the concentration of radon in air which, if sustained over long periods in the living area of a home may lead to health effects.

The number of radon atoms per cubic metre is less than 10^{-19} of a gram-mole (Avagadro's number ~ 6 x 10^{23}). This concentration is far below the detection limits of any chemical analytical methods.

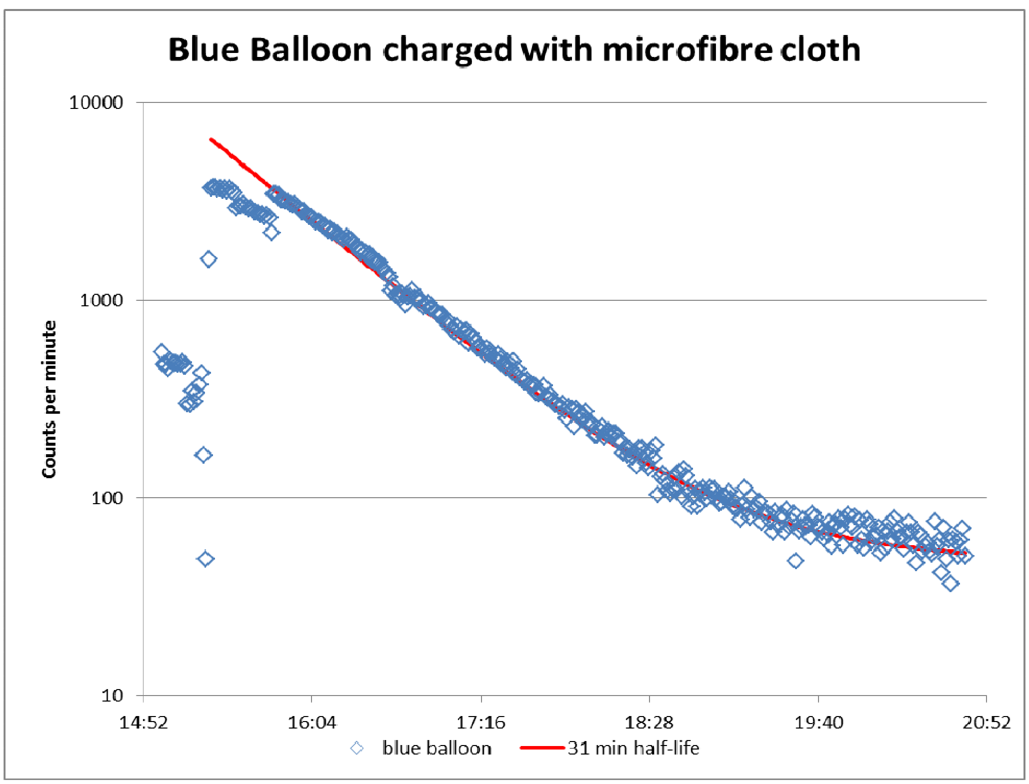
The equilibrium condition is related to "secular equilibrium" – see Appendix B for a related discussion. This is a convenient assumption to make for the first 4 decay progeny of ^{222}Rn. Since their half-lives are relatively short, they have sufficient time to accumulate and approach the equilibrium condition for indoor air without high ventilation rates.

Data Analysis:

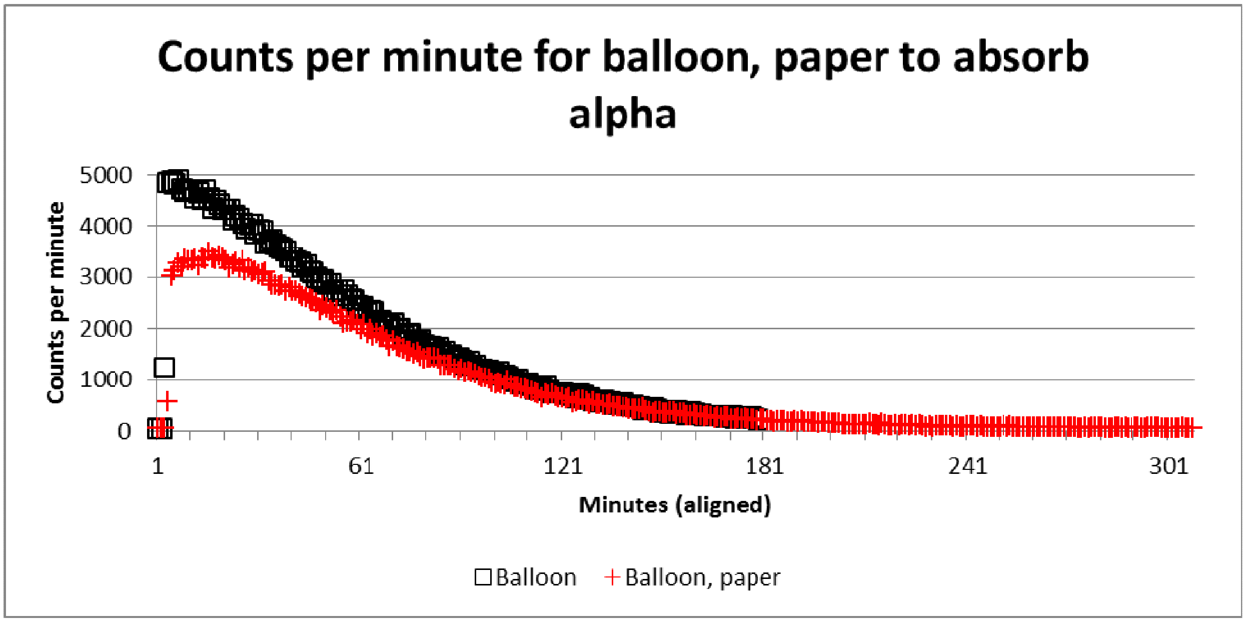
To examine the nature of the decay curves, it is helpful to plot the data using a logarithmic scale for the vertical axis. With the logarithmic scale the exponential decay corresponds to a straight line. It is helpful to monitor the background count level prior to the experiment and treat the decay as providing "excess counts" relative to background.

For the blue balloon data a decay curve was selected using a 31 minute half-life.

The plot shows that as the count rate is much lower than the decay curve selected at the beginning of the decay data. The half-life was selected to provide a reasonable match to the data without the benefit of wisdom. (Using a spreadsheet to generate an arbitrary reference curve is not too difficult.)



The data sets collected with the purple balloon shown earlier include similar reference curves. The plot below shows the two data sets aligned to the start of the counts when the deflated balloon was placed on the Geiger in each case. This arrangement emphasizes the difference in the curve shapes.



Exploration of the Physics:

While these data sets show that it is simple to detect demonstrable radioactivity collected from the air in a room, the detailed explanations for the observations are not simple. This effect was first observed in 1901 by Elster and Geiteel and studied further by Rutherford and Allen in 1902 (they didn't use balloons). Publications on this subject continue into the 21st Century.

The balloon experiment was first reported by T. Walkiewicz and his colleagues in 1992. The following publication was obtained by inter-library loan:

Walkiewicz, Thomas A., "The Hot Balloon (Not Air)", The Physics Teacher, 33, 344-345 (1995)

The two publications below are readily available on the internet:

Austen, D. and Brower, W., "Radioactive balloons: experiments on radon concentration in schools or homes", Institute of Physics, Phys. Educ. **32**, 97-100, 1997, http://www.iopscience.org

Bacon, M.E., "A comparison of electrostatic and filtered air collection of radon progeny", Institute of Physics, Eur. J. Phys. **25**, 239-248 (2004), http://www.df.uba.ar/users/sgil/physics_paper_doc/papers_phys/modern/radon2k4.pdf

Among the phenomena that may contribute to this experiment are:

• Radon series contributing nuclides	Uranium or thorium series or both?
• Electrostatic charge on the balloon	Polarity, potential, potential decay
• Ionisation state of the nuclide following decay	α ➔ -2; β ➔+1 ??
• Relative numbers of each nuclide collected	Many hypotheses available
• Nuclides repelled by charge on balloon	Following decay?
• Nuclides in dust vs. as free ions	Which ones collect?

- Detector relative efficiencies for α, β, γ Energy dependence?

Using a neon glow lamp as described at http://amasci.com/emotor/polarity.html, a balloon was shown to have a negative charge.

It was not possible to determine the charge polarity on the plastic film in the same manner. However the charged balloon was repelled by one side of the plastic wrap showing that it also has a negative charge. (This isn't easy to do – the balloon is attracted to the experimenter's hands. A large piece of plastic wrap is needed.)

If one proposes that only the positively charged ions resulting from decay are collected by the balloon, only ^{214}Bi would be collected (^{214}Po decays before it goes very far).

If one considers that the ions have a short life in air (about one minute) and that each alpha particle ionises several hundred thousand atoms, it is follows that some of the radionuclides are re-ionised with a positive potential and then may be collected by the balloon. The collection in this manner depends on the number density of nuclides – which is inversely proportional to their respective half-lives.

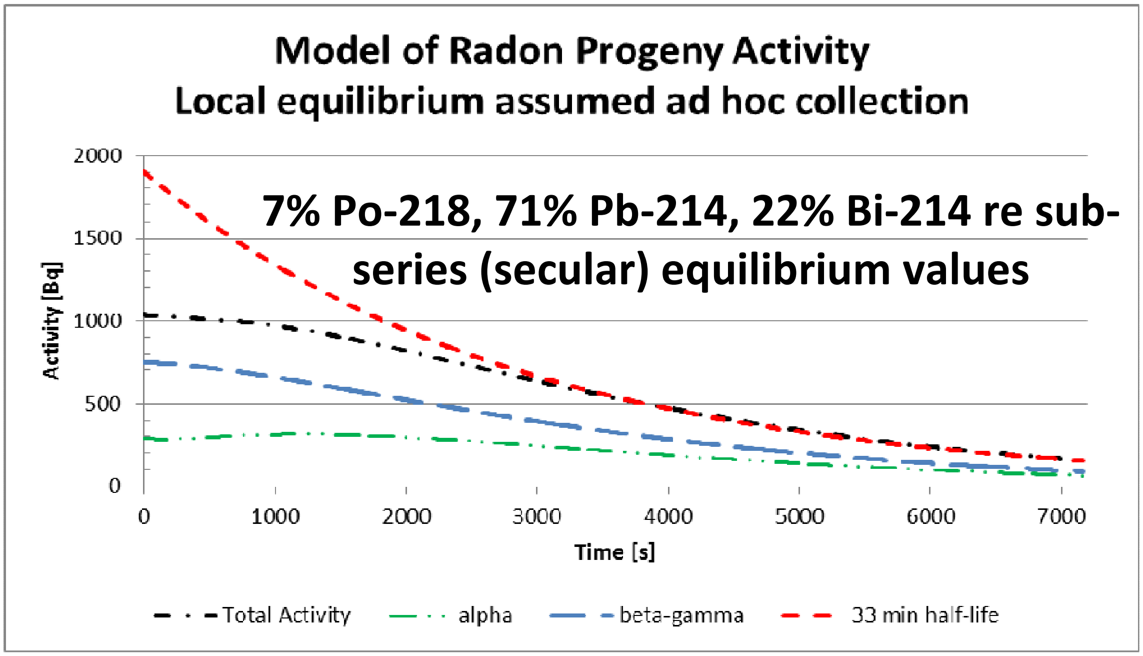
A simple a spreadsheet model was developed to compare the predicted decay curves corresponding to various hypotheses for the collection of the nuclides by the balloon. It was assumed that α, β, and γ are sensed with equal efficiency (they're not). The hypotheses included are summarized in the table below:

Description of nuclide collection	Reference	Comparison with balloon data
Proportional to secular equilibrium	Bacon	poor
Bi-214 only (+ve ion, negative balloon)	None	Poor
Pb-214 only	Austen & Wytze	Poor
Po-218 only	Bacon	Poor
Ad hoc 7% Po-218; 71% Pb-214; 22% Bi-214	None*	Tail fits 33 min half-life

*Bacon's paper includes discussion of mixtures of ions.

As shown below, the ad hoc collection was adjusted until it resembles the purple balloon data. Correcting for the sensitivity of the Geiger to the radiation as a function of type and energy would be expected to modify the curve shape. The relative number densities of the collected nuclides would have to be changed to match the curve.

Alas, while this ad hoc model may be tuned to resemble the one set of data, using it to predict the results with the paper absorber is a dismal failure. We will have to keep working on this experiment!



OPTIONAL Experiment: The plastic food wrap caper

A variation of the experiment using plastic food wrap produced the data plotted below. In this case the plastic was unrolled, and cut. The piece of plastic film was inverted so that the side that came off the roll faced up when it was placed over the Geiger bezel. It was stretched flat and secured with a rubber band. In this case the radionuclides are collected from the air above the plastic film. After about one hour the activity stops increasing and then decreases with a decay curve. The maximum count rate obtained was 160 counts per minute (increase of ~110 relative to background). The data shown is from the "best" of several attempts. Flipping the film didn't seem to make a difference.