# Background Radiation Sources

1. See *Appendix A* for information about the word-processing files of the student experiments, as well as any other electronic resources available for this book.

2. Calculator users: If you are collecting data with TI graphing calculators, an application such as VST Apps or DataRad may need to be installed on the calculators. You can determine which app you need at www.vernier.com/til/2672

   The calculator instructions for this experiment are not intended for use with TI-Nspire handhelds or computer software. Radiation Monitors cannot be used with color-screen TI-84 Plus calculators (TI-84 Plus C Silver Edition and TI-84 Plus CE).

3. This experiment is based on ideas found in three papers: "Radioactiveball," by James Cowie, Jr., and Thomas A. Walkiewicz, The Physics Teacher 30, Jan, 1992, 16, and "The Hot Balloon (Not Air)," by Thomas A. Walkiewicz, The Physics Teacher 33, Sept., 1995, 344.

4. Since the radon decay products are produced as ions, we collect them electrostatically. The air must be dry for effective collection. If you cannot charge the balloon to the point that it will strongly attract hair and dust, it is too humid and you will collect little if any decay products. You may want to reserve this experiment for a dry winter day. If the count rate from the concentrated dust is not significantly different from background, then you have not collected a sufficient quantity of airborne radioactive dust. This could be due to high humidity, or it could be due to a low local radon concentration. It is possible that you will get little or no counts above background because radon is not spread evenly in any given region. You can see a map of potential for radon presence across the United States at http://energy.cr.usgs.gov/radon/usrnpot.gif

5. It is important to allow the balloon to remain undisturbed for 45 minutes. This time allows the decay products captured by the balloon to roughly reach secular equilibrium. You will need to allow time for this in class, in addition to the 200 minute data collection period. If you only have one class period available, have your students charge and place the balloon immediately, and then allow data collection to continue after the students have left. Analysis can then be performed at another time.

6. Some televisions and computer monitors acquire a static charge, and so they collect dust rapidly. If you have such a monitor you could use an alternative dust collection method. Clean the monitor thoroughly, and then let it operate undisturbed for 45 minutes. Using a clean piece of tissue or lens paper, wipe the screen clean with a small area of the paper. Use this dust sample for the same experiment as described in the student activity. Do not use the dust that has been on the screen for a long period, as it will represent a different equilibrium population of radon progeny with a longer half-life.

7. Students often confuse the decay constant parameter $\lambda$ with the half-life $t_{1/2}$. The decay constant $\lambda$ is larger for more rapidly decaying elements and has dimensions of time$^{-1}$, while


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the half-life has dimensions of time, and is smaller for more rapidly decaying elements. The decay constant λ is equal to the fit parameter C in the Natural Exponential fit of Logger *Pro* and LabQuest. The two parameters can be related in the following manner. After one half-life has elapsed, half of the radioactive nuclei have decayed, and so the activity is also cut in half. From the rate equation we can relate the decay constant to the half life.

$$R = R_0 e^{-\lambda t}; \text{ at } t = t_{1/2} \text{ we know that } R = \frac{1}{2} R_0$$

$$\frac{1}{2} R_0 = R_0 e^{-\lambda t_{1/2}}$$

$$\frac{1}{2} = e^{-\lambda t_{1/2}}. \text{ Taking the log of both sides,}$$

$$-\ln 2 = -\lambda t_{1/2}$$

$$t_{1/2} = \frac{\ln 2}{\lambda}$$

There is sufficient information in the student guide to perform this conversion, although some students with weak algebra skills may have difficulty with it. You may choose to work through this step with your students.

8. Since the dust sample collected by the balloon is not a single nuclear species decaying to a stable state, the resulting decay curve is not a single exponential, but a sum of several related exponential functions. The effective half-life measured here does not correspond to any one decay element. The value numerical value of the effective half-life will depend on several factors, including the length of time the balloon is allowed to collect dust and the time between deflating the balloon and beginning data collection. For a 45-minute data collection and a 3-minute delay before starting data collection, a typical half-life is about 40 minutes.

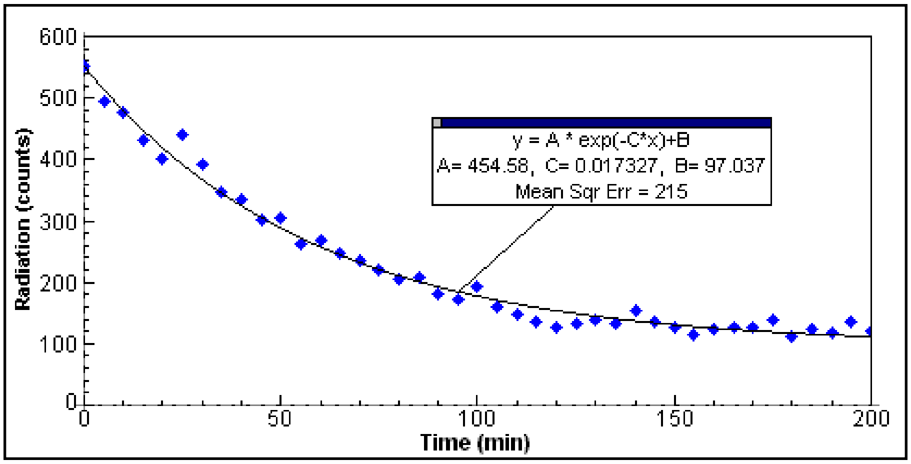
9. For counting measurements you can estimate the standard deviation of a set of measurements using the square root of the number of counts. For example, if you measured a rate of 100 counts in five minutes, the standard deviation would be 10 counts in five minutes. The standard deviation can be used as a measure of the uncertainty of a count rate measurement.

10. A longer version of this experiment can be found in Module 3, unit "Radioactivity and Radon," in the *Workshop Physics Activity Guide* by Priscilla W. Laws (John Wiley & Sons, 1996). A spreadsheet model of the radon decay product series can explain the observed half-life.

11. Note that the computer, LabQuest, and calculator versions of the activity use different notation for the fitted equation. The calculator versions use seconds as the x-axis time unit, so that the exponential fit parameter must be converted from $s^{-1}$ to $min^{-1}$ ($s^{-1} = 60\ min^{-1}$) to obtain a lifetime in $min^{-1}$.

12. If your radiation monitors have an audio mode (e.g., Digital Radiation Monitors), turning on the audio function during the Preliminary Activity will provide an auditory indication of counts in addition to the flash of the LED on the radiation monitor.

## SAMPLE RESULTS




## ANSWERS TO PRELIMINARY QUESTIONS

1. Yes, there is radiation in the laboratory since the LED on the radiation monitor flashes with no obvious source nearby. Since no source is apparent, there is no clear way as yet to determine the source of the radiation.

## DATA TABLE

| | |
|---|---|
| Average background count rate in 5 minutes | 103 |
| fit parameters for Y = A exp ( – C*X ) + B | |
| A | 454 |
| B | 97 |
| C | 0.0173 |
| $\lambda$ ($min^{-1}$) | 0.0173 |
| $t_{1/2}$ (min) | 40 |

## ANSWERS TO ANALYSIS QUESTIONS

1. Yes, the initial number of counts in a 5-minute interval is greater than the average background rate by a factor of (five), which is a significant difference in terms of the standard deviation of the count measurement. The count rate for the balloon-concentrated dust does decrease with time.

5. (number 4 for LabQuest and calculators) Since the fitted equation has an additive constant B, there is no need to correct for the cosmic-ray background. The coefficients of the exponential will reflect only the changing component of the count rates. The additive constant B from the curve fit is nearly the same as the average background count rate without the balloon.

6. (number 5 for LabQuest and calculators) The measured half-life (40 minutes) is significantly longer than any of the individual half-lives of the radon decay products. As a result we can conclude that we are observing a combination of decays from several products.

7. (number 6 for LabQuest and calculators) Given a 40-minute half-life, we have $2^{-5*60/40} = 0.055$, or about 6% of the initial activity remains after five hours. This does not include the constant-rate background counts from sources other than the balloon.

8. (number 7 for LabQuest and calculators) Since the count rate from the balloon-concentrated dust decreased in time, there must be some radioactive source in the environment other than the constant-rate cosmic rays. Radon is a likely source since, as a gas, it can easily spread from the soil.

9. (number 8 for LabQuest and calculators) If we assume that the radioactive dust collected by the balloon consisted of radon decay products, then there must be a continuous introduction of radon into the environment. If this were not the case, then the radon decay products would have long ago decayed and we would not detect their radiation.

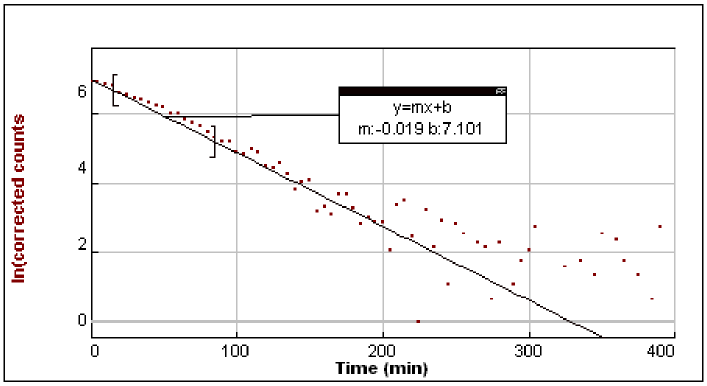
## ANSWERS TO EXTENSIONS

1. Answers will vary, but unless there is a location with very high radon concentration, students will generally find that the background count rate is independent of location within a single community. On the other hand, if radon concentrations vary or if the building acts as a significant cosmic ray shield, then the background will vary with location.

2. $^{222}$Rn (3.8 d) → $^{218}$Po (3.1 min) → $^{214}$Pb (27 min) → $^{214}$Bi (20 min) → $^{214}$Po (164 μs) →… Radon decays by alpha emission, followed by alpha, beta, and then beta emission.

3. The additive constant should be small in comparison to its original value before background subtraction.

4. A log plot of a single exponential function would be a straight line, with the slope equal to the decay constant. Since these data roughly follow a straight line we can assign an effective decay constant or half-life to the dust sample collected by the balloon. The points at longer times will show significant scatter.




5. Since the dust sample collected by the balloon is not a single nuclear species decaying to a stable state, the resulting decay curve is not a single exponential, but a sum of several related exponential functions. The effective half-life measured here does not correspond to any one decay element. The numerical value of the effective half-life will depend on several factors, including the length of time the balloon is allowed to collect dust and the time between deflating the balloon and beginning data collection.