Background Radiation Sources

When a Geiger counter is operated it will usually record an event every few seconds, even if no obvious radioactive source is placed nearby. Where do these counts come from?

Two significant sources are cosmic rays and radon decay products. Cosmic rays, as the name suggests, are fast-moving particles from space that enter the Earth's atmosphere, along with their decay products. Since the atmosphere absorbs some of these particles, the rate of detection of cosmic rays increases with increasing altitude. If you were to take a Geiger counter on a cross-country jet flight, you would observe a marked increase in count rate while at high altitude.

Another radiation source comes not from above us, but from below. The Earth's crust contains, among other radioactive elements, uranium-238 (^{238}U). ^{238}U has a long half-life, but its decay products do not. One of these products is radon gas, or ^{222}Rn. As a result of the long uranium half-life, there is a nearly steady production of radon, which itself decays with a short half-life of 3.8 days. Since radon is a gas, it diffuses out of the soil into the air, and can collect in low enclosed areas such as basements. Radon decays to a series of species including polonium, lead, and bismuth. These decay products precipitate out of the air onto dust particles since they are solids, unlike gaseous radon.

The decay products are also electrically charged, so that it is relatively easy to collect them on a charged surface for analysis. One simple way to create a charged surface is to rub a balloon with fur or hair—you have probably done this to stick balloons to the wall using their static charge. If you allow the balloon to sit undisturbed for 45 minutes or so, it will collect a fresh set of decay products. The beta and gamma ray emissions as these products themselves decay can be detected using a Geiger counter.

The ^{238}U decay sequence relevant to this experiment is ^{222}Rn (3.8 d) $\rightarrow$ ^{218}Po (3.1 min) $\rightarrow$ ^{214}Pb (27 min) $\rightarrow$ ^{214}Bi (20 min) $\rightarrow$ ^{214}Po (164 µs) $\rightarrow$… The times in parenthesis are the half-lives of each species. Since your Geiger counter is unable to distinguish between the emissions from each of these decays, you would only be able to measure a composite effect of some of the components. Nevertheless, if you observe a time-dependent count rate from your balloon, you will have evidence that there must be a continuous re-supply of the parent radon to the environment.

OBJECTIVES

- Concentrate naturally occurring radioactive substances using a charged balloon.
- Use a radiation counter to detect emissions from naturally occurring radioactive substances.
- Determine the effective lifetime of the collection of radon decay products.

MATERIALS

computer	Radiation Monitor
Vernier computer interface	toy balloon, hair, or fur for charging
Logger *Pro*	string, 2 m

PRELIMINARY QUESTION

1. Turn on the radiation monitor to the audio mode, so that it beeps when radiation is detected. Can you detect any radiation in your laboratory? Do you have any way to determine what the radiation is coming from?

PROCEDURE

1. Blow up your balloon so that it is firm. Tie the string to the balloon so you can suspend it in mid-air. Rub the entire surface of the balloon vigorously on the fur for about a minute to give it a static charge. Test the charge by picking up small bits of paper with the balloon by bringing it near the paper. The paper should jump to the balloon's surface and stick there.

2. Suspend the charged balloon away from other objects and where it will not be disturbed. An enclosed basement room is best. Be sure the balloon is at least 2 meters from the radiation monitor. Let the balloon remain in position for 45 minutes.

3. Connect the radiation monitor to DIG/SONIC 1 of the computer interface. Switch the monitor to the on (not audio) mode.

4. Prepare the computer for data collection by opening "05 Background" from the *Nuclear Radiation w Vernier* experiment files of Logger *Pro*. One graph is displayed: counts *vs*. time. The vertical axis is scaled from 0 to 1000 counts/interval. The horizontal axis is distance scaled from 0 to 200 minutes.

5. While you are waiting for the balloon to collect its radioactive dust, determine the average background count rate from cosmic rays and unconcentrated dust. To do this, click the ▶ Collect button and allow the computer to count events. Every five minutes a new point will be added to the graph.

6. When the balloon still has five minutes remaining in its dust collection time, click the ■ Stop button of Logger *Pro*. To determine the average background count rate, click once on the graph, and then click the statistics button. Record the average number of counts for each 5-minute interval in your data table.

7. Once the balloon has been in position for 45 minutes, take it down and deflate it. Taking care not to rub the collected dust from the surface, roll it into a small cylinder. Place the roll as close as possible to the window of the radiation monitor.

8. Click the ▶ Collect button to begin data collection. Logger *Pro* may ask you what you want to do; click Erase and Continue to start data collection. Wait 200 minutes for Logger *Pro* to complete data collection.

DATA TABLE

Average background count rate in 5 minutes	
fit parameters for Y = A exp (– C*X) + B	
A	
B	
C	
λ (min^{-1})	
$t_{1/2}$ (min)	

ANALYSIS

1. Inspect your graph. Is the count rate from the balloon-concentrated dust greater than the average background rate you observed? Is the difference significant? Does the count rate decrease with time? (If the initial count rate is not higher than background, the balloon may not have collected sufficient radioactive dust for the following analysis to be meaningful.)

2. Fit an exponential function to your data. To do this, click the Curve Fit button, 📈. Select Natural Exponent from the equation list, and then click [Try Fit]. A best-fit curve will be displayed on the graph. If your data follow the exponential relationship, the curve should closely match the data. When you are satisfied with the fit, click [OK].

3. Print or sketch your graph.

4. Record the fit parameters A, B, and C in your data table.

5. From the fit parameters, determine the decay constant λ and the half-life $t_{1/2}$. Is it necessary to correct for background counts from cosmic rays? Note that there is an additive constant in the fitted equation Y = A exp (– C*X) + B. How does the additive constant compare to the background count rate you measured?

6. Is your value of $t_{1/2}$ consistent with any one half-life of the radon decay products?

7. What fraction of the initial activity of your sample would remain after five hours, if you were to continue the experiment for that length of time?

8. Cosmic rays arrive at the Earth's surface at a roughly constant rate. Do you have evidence of the presence of a non-cosmic ray source of radiation in your laboratory? Explain.

9. If radon gas is the source of any time-dependent count rates you observed, must there be a continuous source of fresh radon gas to the environment?

EXTENSIONS

1. Is there a variation in the background radiation count rate in different places in your school? List several reasons why the rate might vary, or why it might be the same.

2. From the decay sequence given in the introduction, determine the type of nuclear decay (alpha, beta, or gamma) in each step.

3. Rather than allowing Logger *Pro* to determine the background count rate with the additive term of the exponential curve fit, correct the experimental count rates by subtracting the average background count rate you measured earlier in the experiment. Plot a new graph of corrected count rate *vs.* time, and fit a new exponential function to the data. Now that you have corrected for background counts, what should happen to the fitted value of the additive constant B in $Y = A \exp(-C*X) + B$?

4. Using the background-corrected data created in the previous extension, create a plot of the natural log of the corrected count rates *vs.* time. What is the significance of the slope of a line fitted to the data?

5. Why would you expect a graph of count rate *vs.* time, such as collected for this experiment, to *not* be a simple exponential function?