Radiation Shielding

Alpha, beta, gamma, and X-rays can pass through matter, but can also be absorbed or scattered in varying degrees depending on the material and on the type and energy of the radiation. Medical X-ray images are possible because bones absorb X-rays more so than do soft tissues. Strongly radioactive sources are often stored in heavy lead boxes to shield the local environment from the radiation.

Some materials absorb beta rays. A sheet of common cardboard will absorb some of the betas, but will allow most to pass through. You can measure this absorption by fixing a beta source and a radiation monitor so their positions do not change, and then inserting layers of cardboard between them.

When an absorber is in the path of beta rays, it will allow a certain fraction f to pass through. The fraction f depends on the density and thickness of the absorber, but will be a constant for identical absorbers and fixed beta ray energy. If the number of counts detected in a count interval is N_0 when no absorber is in place, then the counts N with the absorber is $N = f N_0$. In the preliminary questions, you will develop a more general expression for additional layers of cardboard absorbers, and then test it against real data.

In this experiment you will use a small source of beta radiation. Beta rays are high-energy electrons. *Follow all local procedures for handling radioactive materials*.

OBJECTIVES

- Create a model for the absorption of radiation by matter.
- Use a radiation counter to study how the radiation emitted by a beta source is absorbed by cardboard.
- Test the model against experimental data to determine its validity.

MATERIALS

TI Graphing Calculator
LabPro or CBL 2
DataRad calculator program
Vernier Radiation Monitor
strontium-90 1 μC source taped to small support
ten 10 cm × 10 cm identical cardboard squares
adhesive tape

PRELIMINARY PROCEDURE AND QUESTIONS

1. Place your Sr-90 source on a table. Connect the Radiation Monitor to a DIG port on your interface and start the data-collection software if it doesn't start automatically. The LED on the Radiation Monitor flashes as the monitor detects radiation. The LED will flash more quickly when the monitor detects higher radiation level. By holding the monitor near the source, determine the most sensitive place on the detector.

2. Attach the source disc to a support using adhesive tape so that the source held at the same height as the Geiger tube in the radiation monitor. Do not cover the source with tape. Place the source so it is about eight centimeters from the most sensitive place on the monitor, so that there is room to place all ten layers of cardboard between the source and the monitor. It is essential that neither the source nor the monitor move during data collection.

   With only air between the source and the monitor, observe the flash rate for a short while. Now place five layers of cardboard between the source and the monitor, taking care not to move either one. Make observations again, and determine if the beep rate is larger, smaller, or unchanged. Now add five more layers of cardboard, again not moving the source or monitor. Observe and determine the change of the beep rate, if any. Does the cardboard seem to shield the monitor from the beta radiation?

3. Based on your observations, sketch a qualitative graph of the flash rate *vs*. number of layers of shielding.

4. In the introduction we used the expression $N = f N_0$ to describe the transmission of betas by one layer of cardboard. Assuming this model, how many counts would be detected if you added a second layer of cardboard, identical to the first, which also transmitted a fraction f? For example, if the first layer transmitted 90% of the radiation, then the second would transmit 90% of that transmitted by the first. The overall transmission would then be $0.90 \times 0.90 = 0.81 = 81\%$ of the no-shielding number of counts. In the data table, write a general expression for the number of counts N detected for any number x of identical layers, each of which transmits a fraction f of the incident radiation. Use N_0 as the counts detected when no shielding layers are used. You have just developed a model for the transmission of radiation through matter. Next you will test your model against experimental data.

5. Is your model consistent with your qualitative graph you sketched based on initial observations? Remember than f is a number less than one. Add the model function to your sketch without worrying about the vertical scale.

PROCEDURE

1. Connect the radiation monitor to a DIG port of LabPro or CBL 2 if it isn't already connected. Use the black link cable to connect the TI graphing calculator to the interface. Firmly press in the cable ends.

2. Turn on the calculator and start the DataRad program. Press CLEAR to reset the program.

3. Prepare the DataRad program for this experiment.
   a. Select SETUP from the main screen.
   b. Select SET INTERVAL from the SETUP MENU.
   c. Select SET INTERVAL from the INTERVAL SETTINGS screen.
   d. Enter **50** as the count time interval in seconds. Always complete entries with ENTER.
   e. Select OK from the INTERVAL SETTINGS screen.
   f. Select EVENTS WITH ENTRY from the SETUP MENU.
4. Confirm that the source and monitor are positioned so they will not move, and so that there is enough space between them for ten layers of cardboard. Remove all but one layer of cardboard from between the source and monitor.
5. Select START to prepare for data collection. Confirm that all is in position, and then press ENTER to start the first counting interval. The interface will begin counting the number of beta particles that strike the detector during a 50 second count interval.
6. After 50 seconds have elapsed, DataRad will prompt you for a value. In the entry field that appears, enter **1**, or the number of layers of cardboard.
7. Insert a second layer of cardboard between the source and detector. Be sure that the cardboard completely covers the source's "view" of the Geiger tube in the detector. Press ENTER to start the next count interval.
8. When the interval is complete, DataRad will again prompt for a value. Enter the new number of layers, or **2**.
9. In the same way as before, add a layer of cardboard without moving the source or monitor, and press ENTER to start counting. When counting is complete, enter the number of layers of cardboard. Repeat this process until you have completed data collection for ten layers.
10. Press STO▸ to end data collection and to display a graph.

DATA TABLE

Model equation	
Fitted equation with parameters	

ANALYSIS

1. Inspect your graph. Does the count rate appear to follow your model? How can you tell? After viewing your graph, press ENTER to return to the main screen.

2. Next you can fit an appropriate function to your data. To choose a function, select ANALYZE from the main screen. You will see a list of functions. Look for one that has the same mathematical form as your model. (**Hint**: which fit functions have an x, the horizontal axis variable, in the same special location as in your model equation?) Select an equation from the equation list. Record the parameters and the equation in your data table. Press ENTER to see a best-fit curve will be displayed on the graph. If your data follow the selected relationship, the curve should closely match the data.

3. Print or sketch your graph.

4. From the evidence presented in your graph, does the transmission of beta radiation through cardboard match that predicted by your model?

5. From the parameters of your fitted equation, determine the fraction f of beta rays transmitted, on average, by one layer of cardboard. Do not use your raw data to calculate the fraction, but instead use the information from your fitted equation. **Hint**: Remember that $A^{(Bx)} = (A^B)^x$.

EXTENSIONS

1. Use a longer counting interval so that you collect at least 2000 counts when no absorbing cardboard is in place. Is the agreement with the model any different? Try a much shorter count interval. How is the resulting graph different? Why?

2. Cosmic rays continue to strike the detector regardless of the absorbing cardboard. Measure the average background counts in one count interval, and correct your data for background radiation. Repeat the analysis.

3. Try other absorbers; for example, common household aluminum foil can be used in place of cardboard. You will need to experiment with the appropriate number of layers to use. You may want to add more than one (or five) layers at a time.