Purpose

The purpose of this experiment is to explore how distance, time and shielding affect radiation exposure.

Learning Objectives

Determine the effect of distance, time and shielding on radiation exposure using radioactive sources and a Geiger-Müeller counter.

Laboratory Skills

Use a Geiger-Müeller counter

Collect quantitative data

Equipment

- Geiger-Müeller counter (detection tube)
- Yardstick
- Sources of alpha- and beta-radiation
- Shielding materials (wood, plastic, water, etc.)

Chemicals

- None

Background

Isotopes and Types of Radioactive Decay

Isotopes are atoms with the same atomic number (the number of protons), but different mass numbers (the number of protons and neutrons). Some isotopes have unstable nuclei and emit particles of electromagnetic radiation, transforming the nuclei into more stable ones. This emission is called radiation and the isotope is said to have undergone radioactive decay. The most common types of radioactive decay are alpha, beta, and gamma radiation.

Alpha Radiation

Alpha particles are high energy helium nuclei that consist of two protons and two neutrons. They are represented by the symbol ${}^{4}_{2}\text{He}$ or ${}^{4}_{2}\alpha$ in a nuclear equation. When a nucleus undergoes alpha decay, emitting an alpha particle, the mass number will decrease by 4 and the atomic number will decrease by 2. This is shown in the Equation NU.1.

$${}^{238}_{92}\text{U} \longrightarrow {}^{4}_{2}\text{He} + {}^{234}_{90}\text{Th} \qquad \text{(Equation NU.1)}$$

Nuclear equations are balanced when the sum of the mass numbers and the sum of the atomic numbers are equal on both sides of the equation.

Beta Radiation

Beta particles are high energy electrons and are represented by the symbol ${}^{0}_{-1}\text{e}$ or ${}^{0}_{-1}\beta$ in a nuclear equation. These electrons have negligible mass, represented by the 0, and a negative charge, represented by the –1 in the symbol. Carbon-14 undergoes beta decay as shown in Equation NU.2.

$${}^{14}_{6}\text{C} \longrightarrow {}^{0}_{-1}\text{e} + {}^{14}_{7}\text{N} \qquad \text{(Equation NU.2)}$$

Beta particles are emitted from an unstable nucleus when a neutron (${}^{1}_{0}\text{n}$) decays to form *a* proton (${}^{1}_{1}\text{p}$) and a beta particle (Equation NU.3).

$${}^{1}_{0}\text{n} \longrightarrow {}^{0}_{-1}\text{e} + {}^{1}_{1}\text{p} \qquad \text{(Equation NU.3)}$$

Gamma Radiation

Gamma rays are very high energy electromagnetic radiation and are represented with the symbol γ or ${}^{0}_{0}\gamma$ in nuclear equations. Gamma decay occurs when an atom in an excited state (indicated by *) decays to its ground state. Gamma rays are pure energy and do not affect the mass number or atomic number as shown in Equation NU.4.

$${}^{235}_{92}\text{U}^{*} \longrightarrow {}^{0}_{0}\gamma + {}^{235}_{92}\text{U} \qquad \text{(Equation NU.4)}$$

Shielding from Radiation

Radiation can be very damaging to cells and is of particular interest in medicine, where it can be used in beneficial ways. Although radiation can be used for positive outcomes, caution must be exercised to minimize exposure. Precautions include shielding the body from the radiation, increasing the distance from the source of radiation, and limiting the amount of time exposed to the radiation. Most people experience these when having X-rays or other medical testing in the form of lead aprons. Increasing the distance from a radiation source also limits exposure. Doubling the distance will decrease the exposure by one-fourth. This is why the technician taking the X-ray moves away from the instrument when it is in use. Figure NU.1 illustrates different ways exposure to radiation can be limited.

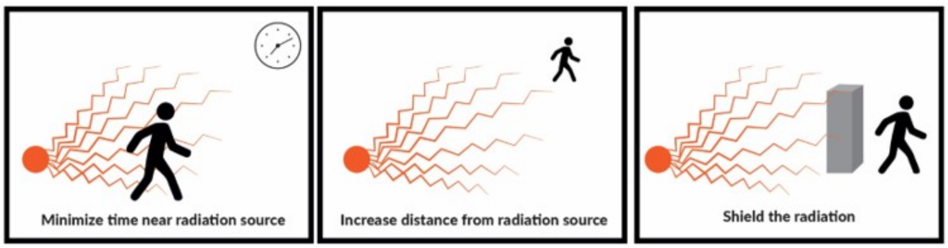

Figure NU.1: Effects of Time, Distance, and Shielding on Radiation Exposure

Sources of Background Radiation

Everyone is exposed daily to many low-level sources of radiation, including cosmic radiation from space and radiation from building materials. Fiestaware®, a popular brand of dishes first produced in the 1930s, used a red glaze that contained uranium, a source of gamma radiation. Other common sources of radiation are given in Table NU.1. Anyone can calculate their annual exposure to background radiation at Calculate Your Radiation Dose.

Table NU.1: Household Sources of Radioactivity

Item	Isotope	Type of radioactivity
Fiestaware®plate	Uranium-238	alpha, beta, gamma
Instant coffee	Potassium-40	beta
Salt substitute	Potassium-40	beta
Smoke alarm	Americium-241	alpha
Cream of tartar	Potassium-40	beta
Granite countertops	Radon-222	alpha

Detecting Radiation

Radiation can be detected using a Geiger-Müeller tube, or Geiger counter, similar to the one in Figure NU.2. This device works by producing ion pairs when radiation passes through the gas inside the tube. These ion pairs emit bursts of current that are converted to flashes of light and clicking sounds. The instructor will demonstrate how to use this device. Then, students will use it to detect background radiation, radiation from various sources, and finally to see how shielding, distance, and time affect the amount of radiation detected.

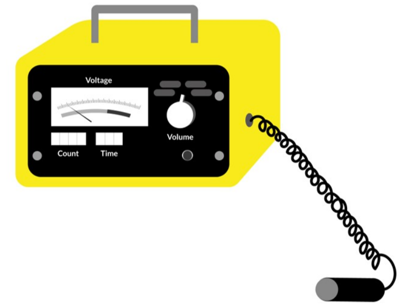

Figure NU.2: Depiction of Geiger-Müeller Tube

Procedure

Background Radiation Count

1. Set the counter to the proper voltage for operation and let it warm up for at least 5 minutes. Make sure that no sources of radiation are near the counter.

2. Once the device is warmed up, count the radiation in the room for 1 minute and record.

3. Repeat step 2 twice more (three times total), recording the counts each time.

Radiation from Sources

4. Retrieve one of the radioactive sources available in the lab and make note of it in your notebook.

5. Place the source ~15 cm from the detection tube.

6. Count the radiation for 1 minute and record. Be sure to subtract the background radiation from your measurement.

7. Repeat the process to measure a total of five sources of radiation, making sure that all the sources are the same distance from the counter during the measurements.

Effects of Shielding, Time, and Distance on Radiation Count

Time

8. Obtain a radiation source and place it the same distance from the counter as in the previous steps.

9. Count the radiation for 1 minute and record. Be sure to subtract the background radiation count.

10. Repeat the process two more times, counting the radiation for 2 minutes and then 5 minutes. Remember

to subtract the two minutes and five minutes worth of background counts. That is, subtract twice the background count for one minute from the two-minute radiation count. Subtract five times the background count for one minute from the five-minute radiation count.

Shielding

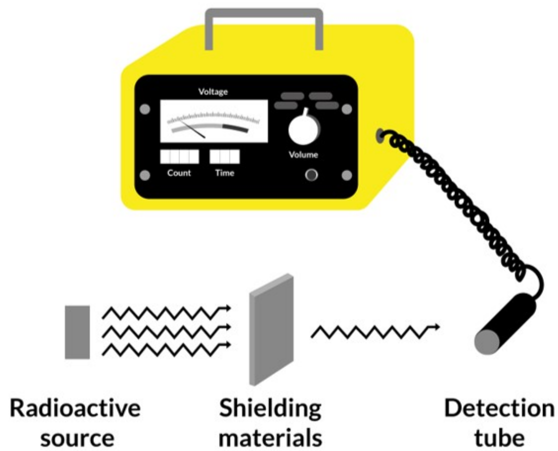

Figure NU.3: Setup For Measuring Shielding

11. Obtain a radiation source and place it the same distance from the counter as in the previous steps.

12. Choose a shielding material and place it between the source and the counter as shown in Figure NU.3. Record the type of shielding material used.

13. Place the shielding material between the source and the detector (counter).

14. Count the radiation for 1 minute and record. Subtract the background radiation count.

15. Repeat these steps to measure the shielding effects of a total of three different types of shielding materials.

Distance

16. Remove the shielding material from between the source and counter.

17. Move the radiation source so it is 10 cm from the counter.

18. Count the radiation for 1 minute and record. Don't forget to subtract the background radiation.

19. Repeat the previous two for distances of 30 cm, 60 cm, 90 cm, and 120 cm and record the counts per minute. Subtract the appropriate background radiation from all measurements.

Data Analysis

20. Using the counts per minute measured in **Time**, calculate the counts per minute at 20 minutes and 60 minutes.

21. Using the counts per minute measured in **Distance**, calculate the ratio of counts per minute at 30 cm and 60 cm. This ratio is equal to the increase in radiation when the distance is halved.

22. Graph the counts per minute versus the distance from the source.

23. Predict the counts per minute at two distances that were not directly measured (25 cm and 50 cm, for example).

Background Radiation

Report Table NU.1: Background Radiation Data

Time	**Counts**
First minute	________
Second minute	________
Third minute	________
Total Counts	________
Average Counts, counts/minute (cpm)	________

Radiation from Sources

Report Table NU.2: Radiation from Sources Data

	Item Used	**Counts**	**Type of radiation**
Source 1	________	________	________
Source 2	________	________	________
________	________	________	________
________			
Source 3	________	________	________
Source 4	________	________	________
Source 5	________	________	________

Effects of Distance, Time, and Shielding on Radiation Count

Time

Report Table NU.3: Time Data

Time	Counts per minute (cpm)	Background cpm × number of minutes	Source cpm
1 minute	______	______	______
2 minutes	______	______	______
5 minutes	______	______	______
20 minutes (calculated)	N/A	N/A	______
60 minutes (calculated)	N/A	N/A	______

Shielding

Report Table NU.4: Shielding Data

Shielding Type	Counts per minute (cpm)	Background cpm	Source cpm
No shielding	______	______	______
______	______	______	______
______	______	______	______
______	______	______	______

Distance

Report Table NU.5: Distance Data

Distance	Counts per minute (cpm)	Background cpm	Source cpm
10 cm	______	______	______
30 cm	______	______	______
60 cm	______	______	______
90 cm	______	______	______
120 cm	______	______	______
25 cm	N/A	N/A	______
50 cm	N/A	N/A	______

Ratio: 30 cm/60 cm = ____________________

Include your graph with counts per minute versus the distance from the source.