ORTEC®

Equipment Required

• **905-3** (2-inch x 2-inch) NaI(Tl) Detector and PMT	• **807** Vacuum Chamber
• **266** Photomultiplier Base	• **ALPHA-PPS-115** (or -230) Portable Vacuum Pump Station
• **556** High-Voltage Power Supply	• **RSS8*** Source Kit (contains: 1 µCi each of ^{133}Ba, ^{109}Cd, ^{57}Co, ^{60}Co, ^{137}Cs, ^{54}Mn, ^{22}Na and a mixed source of 0.5 µCi ^{137}Cs plus 1 µCi of ^{65}Zn)
• **113** Scintillation Preamplifier	
• **575A** Amplifier	• **GF-137-M-25*** 25-µCi ^{137}Cs source.
• **4006** Minibin Power Supply	• **BF-204-A-0.1*** 0.1-µCi ^{204}Tl Beta Source.
• **GP35** End-Window Geiger Mueller Tube with Stand providing 6 counting levels	• **TDS3032C** 300 MHz, 2-Channel Digital Oscilloscope
	• Portable, Geiger-Mueller Health Physics Survey Meter (optional)
• **GPI** Pulse Inverter (to convert the negative GM tube signal to a positive pulse for the 996 input)	• 10 sheets of 10 x 10 x 0.16-cm lead plate
• **996** CCNIM™ Timer and Counter	• 8 sheets of 10 x 10 x 2.5-cm lead plate
• **BA-016-025-1500** Silicon Surface Barrier Detector	• 10 sheets of 10 x 10 x 0.16-cm cadmium plate
• **142A** Preamplifier	• 10 sheets of 10 x 10 x 0.3-cm steel plate
• **710** Quad 1-kV Bias Supply	• 10 sheets of 10 x 10 x 0.3-cm aluminum plate
• **480** Pulser	• 10 sheets of 10 x 10 x 2.5-cm polyethylene plate
• **EASY-MCA-8K** System including a USB cable, a suitable PC and MAESTRO software.	• 4 sheets of 2.5-cm x 2.5-cm x 2 mg/cm^2 aluminum foil
	• 4 sheets of 2.5-cm x 2.5-cm x 5 mg/cm^2 aluminum foil
• One **C-24-1/2** RG-62A/U 93-Ω coaxial cable with BNC plugs, 15-cm (1/2-ft) length	• 4 sheets of 2.5-cm x 2.5-cm x 10 mg/cm^2 aluminum foil
• Two **C-24-4** RG-62A/U 93-Ω coaxial cables with BNC plugs, 1.2-m (4-ft) length	• 4 sheets of 2.5-cm x 2.5-cm x 20 mg/cm^2 aluminum foil
	• 2 sheets of 2.5-cm x 2.5-cm x 50 mg/cm^2 aluminum foil
• Two **C-24-12** RG-62A/U 93-Ω coaxial cable with BNC plugs, 3.7-m (12-ft) length.	• Small, flat-blade screwdriver for tuning screwdriver-adjustable controls, or an equivalent potentiometer adjustment tool.
• **C-29** BNC Tee Connector	
• One **C-36-12** RG-59A/U 75-Ω Coaxial Cable with SHV Female Plugs, 3.7-m (12-ft) length	
*Sources are available direct from supplier. See the ORTEC website at www.ortec-online.com/Service-Support/Library/Experiments-Radioactive-Source-Suppliers.aspx	

Purpose

To study some of the basic concepts associated with radiation protection and good health physics practices.

The field of health physics is very broad, encompassing various facets of the nature of radiation effects in living animals. The primary concern is one of protection against exposure. This experiment is an attempt to inform the student of the merits of various types of shielding against common forms of radiation encountered in laboratory situations and does not exhaust the field of health physics. It is not meant to fully quality the student in the discipline of health physics. For additional information and applicable regulatory guidelines on this subject matter, consult the references for this experiment and the local pertinent authorities.

Introduction

In any laboratory where radioactive sources are used, everyone should be aware of, and use, good health physics practices. Most of the radioactive sources that are used for these experiments are sealed and have low activity, so they do not present a real health physics problem. For the experiments that require higher activity sources, we have carefully explained the particular safety techniques that should be used in setting up and performing the experiment. The main goal of any health physics program is to reduce personal exposure, both external and internal, to a minimum.

Experiment 24
Measurements in Health Physics

Assume that a fairly "hot" source must be used in an experiment. There are three general ways to minimize exposure when using this source. These are:

1. Do not stay in the vicinity of the source any longer than necessary.

2. Remember the $1/R^2$ relationship that is valid for all isotropic radiation sources; stay as far away from the source as is practical during the experiment.

3. Where necessary, use shielding between the source and yourself. The amount of shielding and the type of shielding material depends on the type of radiation that the source is emitting.

Alpha particles lose energy rapidly in any medium because of their high specific ionization. Therefore, as was shown in Experiment 5, even a thin foil will stop most alphas. But there is another very important consideration; most alpha sources will decay not only to the ground state of the daughter nucleus, but also to excited states. The de-excitation of these levels can result in gammas, or x rays from internal conversion. The attenuation of gammas and x rays were studied briefly in Experiments 3 and 11. For low-energy gammas or x rays, the most pronounced attenuation mechanism is the photoelectric effect. Since the cross section for this process varies as Z^5, where Z is the atomic number of the absorber, the best shielding material for low-energy photons is something heavy like lead.

In Experiment 6 we were concerned with beta sources and internal conversion electron sources. The process by which betas lose energy in absorbers is similar to that of alphas. The beta particle is not as massive and, hence, its specific ionization is not as great as for alphas. In air, alphas travel only a few centimeters where betas will generally travel many feet. The thickness and choice of material for shielding betas depends on the end-point beta energy of the isotope and on the Bremsstrahlung radiation that is always present for a beta source. In general, the shielding thickness that is necessary to stop betas of a given end-point energy will decrease with increasing density of the shield. For example, 2.5 mm of aluminum will stop 1.5-MeV betas. For lead, 0.61 mm will do the same job. The Bremsstrahlung production in the shielding must also be considered. This production rate increases with the atomic number of the absorber. So, for this reason, aluminum or even glass might be the best and cheapest effective shield in the case of a pure beta emitting isotope. Like alphas, most beta-emitting isotopes also have gammas in their decay schemes and the shielding is done best with heavier atomic number materials such as lead.

Experiment 24.1. Gamma Intensity as a Function of Distance

Purpose

To study the $1/R^2$ (or R^{-2}) relationship of 0.662-MeV gammas from ^{137}Cs, typical for any gamma emitter.

Procedure

1. Set up the electronics as shown in Fig. 24.1. Adjust the voltage for the phototube to the recommended value.

Fig. 24.1. Electronic Block Diagram for Gamma-Ray Spectrometry System for $1/R^2$ Studies.

2. Use the 1-µCi ^{137}Cs source (Eg = 0.662 MeV). Place this at a distance of 2 cm from the face of the NaI(Tl) crystal detector. Adjust the gain of the amplifier so that the 0.662-MeV photopeak from the ^{137}Cs is stored in about channel 350. Check that the PZ ADJ is properly adjusted, per prior experiments.

3. Adjust the Region of Interest of the MCA at about the center of the Compton distribution range in the analyzer spectrum. Figure 24.2 shows the approximate Upper- and Lower-level settings.

4. Remove the 1-µCi ^{137}Cs source and run a background spectrum for 400 s. Integrate the number of counts in the portion of the spectrum that is included in the ROI.
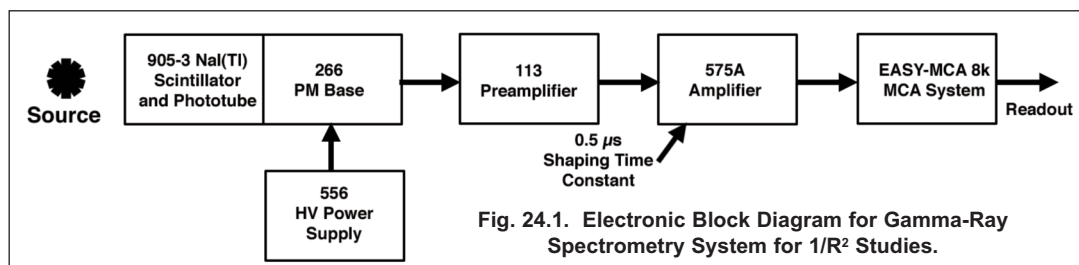
5. Handle the 25-µCi ^{137}Cs source carefully with tongs or forceps, and place it at a distance of 4 m from the detector. Accumulate a spectrum at this distance for 400 s and integrate the total number of counts in the MCA. Repeat for each of the other distances listed in the Table 24.1.

NOTE: In this experiment, support the source and detector so that external scattering from the surroundings is minimized, and be sure to remove all other sources from the area.

EXERCISES

a. Record the data in Table 24.1. Calculate the counting rate in cpm from the integrated count and the preset time (400 s). Subtract the background and record the true counting rate in column 4 of Table 24.1.

b. For an isotropic gamma source, the following relations are valid provided there is minimum external scattering.

$$I_1 = \frac{I_o}{R_1^2} \qquad (2)$$

$$I_2 = \frac{I_o}{R_2^2} \qquad (3)$$

Where I_1, is the gamma intensity at a distance R_1, and I_2 is the corresponding intensity at a distance R_2.

$$\frac{I_1}{I_2} = \frac{R_2^2}{R_1^2} \qquad (4)$$

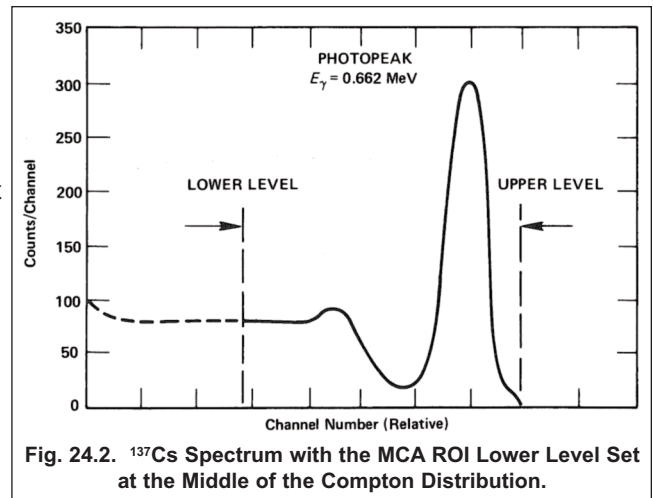$$I_1 = I_2 \frac{R_2^2}{R_1^2} \qquad (5)$$

Now, define I_2 to be the counting rate at 4 m as recorded in column 4 of Table 24.1. To get the rest of the theoretical values, simply multiply this 4-m rate by the ratio of the square of the corresponding distance for each value as in Eq. (5) above. Record these theoretical values in column 5 of Table 24.1.

c. Plot this theoretical intensity vs distance. On the same plot, record your experimental data points.

Fig. 24.2. ^{137}Cs Spectrum with the MCA ROI Lower Level Set at the Middle of the Compton Distribution.

Table 24.1. 1/R² Studies for ^{137}Cs Gammas.				
Distance (Meters)	Time (Minutes)	Integrated MCA Counts	Counting Rate Minus Background (cpm)	Theoretical Intensity
4				
3.5				
3.0				
2.5				
2.0				
1.5				
1.0				
0.5				
0.25				

Experiment 24.2 Gamma Intensity Measured with a Geiger Counter

Purpose

This experiment is similar to Experiment 24.1 except that a hand-held Geiger Mueller Counter is used instead of the more sensitive 2- by 2-in. NaI(Tl) detector.*

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*If a portable Geiger-Counter survey meter is not available, the GP35 or GP35HP GM Tube can be removed from its stand and substituted.

Experiment 24
Measurements in Health Physics

Procedure

NOTE: Observe health physics principles carefully when using a hand-held detector in this measurement; the source has a high enough activity level that prolonged exposure at close range can result in unnecessary exposure.

1. Remove all radioactive sources from the room. Take a background count and record the count rate from the GM counter.

2. Support the 25-μCi ^{137}Cs source in a position so that scattering in minimized. Starting at a distance of 4 m from the source, record the counting rate at all of the distances listed in Table 24.1.

EXERCISES

a. Subtract the background from the measured counting rates and record these in a table similar to Table 24.1 as counting rate minus background.

b. Normalize the theoretical intensity to the experimentally determined value at 2 m. Normalization at 2 m, rather than at 4 m, is recommended because the GM counter is not as sensitive as the NaI(Tl) detector and statistics are usually better at 2 m.

c. Calculate the rest of the theoretical values in Table 24.1 by multiplying the counting rate at 2 m by the ratio of the square of distances as in Experiment 24.1. Plot a curve of the theoretical counting rate as a function of distance. Plot the experimental points on the same curve.

d. From the definition of the Curie (3.7 x 10^{10} dps) and R^{-2} relationship, calculate the number of disintegrations/min/cm^2 that your source should produce at a distance of 2 m. Divide your observed counting rate by the approximate area of your detector window and compare the answer with the calculated intensity. What does this tell you about the efficiency of your GM counter for ^{137}Cs?

Experiment 24.3 Shielding Effectiveness of Different Materials for Gammas

Purpose

The purpose of this experiment is to investigate the shielding properties of various materials for 0.662-MeV gammas from ^{137}Cs.

Procedure

1. Set up the electronics the same as for Experiment 24.1 and set the MCA ROI at the center of the Compton region as in Fig 24.2.

2. Place the ^{137}Cs source from the source kit at a distance of 8 cm from the sensitive face of the detector. Count for 400 s and record the integrated count total from the analyzer.

3. Place the first 0.16-cm thick lead absorber at a distance of 4 cm from the detector and count for 400 s. Repeat for the other lead absorber thicknesses listed in Table 24.2.

Table 24.2. Shielding Properties of Different Absorbers for Gammas.				
Run No.	Absorber Thickness (cm)	Time (seconds)	Integrated MCA Counts	Counting Rate Minus Background (cpm)
1	0			
2	0.16			
3	0.32			
4	0.48			
5	0.64			
6	0.80			
7	0.96			
8	1.12			
9	1.28			

4. Remove the lead absorbers, (Z = 82), and replace them with the 0.16-cm thick cadmium absorbers. Make another table similar to Table 24.2 and record the measurements made with cadmium absorbers in this table.

5. Repeat the above procedure using iron or steel plate, (Z = 26), and then aluminum (Z = 13). Since these materials are supplied in 0.3-cm thicknesses, instead of the 0.16-cm thicknesses for lead and cadmium, it is only necessary to make half as many measurements for these two absorber types. Make tables similar to Table 24.2 and fill in the data for iron and aluminum.

6. Place four pieces of 2.5-cm thick polyethylene between the source and the detector and count for 400 s. Calculate the counting rate, (cpm), when using this 10-cm layer of polyethylene as an absorber.

7. Remove the source and all absorbers and determine a background counting rate for the room. Subtract the background counting rate from each of the uncorrected counting rates recorded in the tables. Record these corrected values in column 5 of each data table.

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EXERCISES

a. On semilog graph paper, plot the corrected counting rate for lead as a function of absorber thickness. This technique was outlined in Experiment 3.7. Calculate the effective half value layer, (HVL), for lead as shown in Experiment 3.7.

b. From the data for cadmium, iron, and aluminum, determine the effective HVL values for these materials.

c. On semilog graph paper, plot the HVL for each material as a function of the atomic number of the material.

d. For the measurement made with 10-cm of polyethylene, calculate the percent of attenuation. Is polyethylene a very effective shield for gammas?
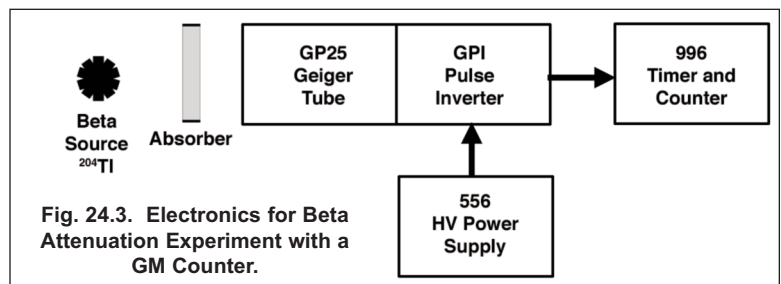
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Experiment 24.4 Attenuation of Betas in Aluminum by the Geiger Mueller Method

Purpose

To study the absorption of betas in order to determine the necessary parameters associated with beta shields.

Procedure

1. Set up the electronics as shown in Fig. 24.3. Without an absorber, adjust the voltage of the GM tube to its proper value. The techniques associated with Geiger tube counting were carefully outlined in Experiment 2.

2. Position the ^{204}Tl source ~3 cm from the window of the GM tube. Be sure that the absorbers can be inserted between the source and the detector without disturbing the geometry.

Fig. 24.3. Electronics for Beta Attenuation Experiment with a GM Counter.

3. Take a 400-s count without an absorber. Record the count in Table 24.3. Place the first aluminum absorber (2 mg/cm^2) in position between the source and the GM tube and count for 400 s. Continue for the other absorber thicknesses and times as listed in Table 24.3.

4. Remove the source and obtain a background count for 1000 s.

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EXERCISES

a. Subtract the background counting rate, (cps), from each of the measured counting rates and record the corrected values in column 5 of Table 24.3.

b. Make a plot on semilog graph paper of the corrected counting rate as a function of absorber thickness. Figure 24.4 shows some typical data that were obtained for this experiment. The experiment can be repeated with other beta sources if desired. Table 24.4 lists the approximate range of electrons of various energies in aluminum.

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Table 24.3. Beta Absorption in Aluminum.

Run No.	Thickness (mg/cm^2)	Time (seconds)	Counts	Counting Rate Minus Background (cps)
1	0.00	400		
2	2.00	400		
3	4.00	400		
4	6.00	400		
5	10.00	400		
6	20.00	400		
7	60.00	400		
8	80.00	800		
9	100.00	800		
10	120.00	1000		
11	140.00	1000		

Experiment 24.5 Attenuation of Betas in Aluminum by the Surface Barrier Detector Method

Purpose

To measure absorption of the true beta portion in aluminum by measuring the events with a surface barrier detector.
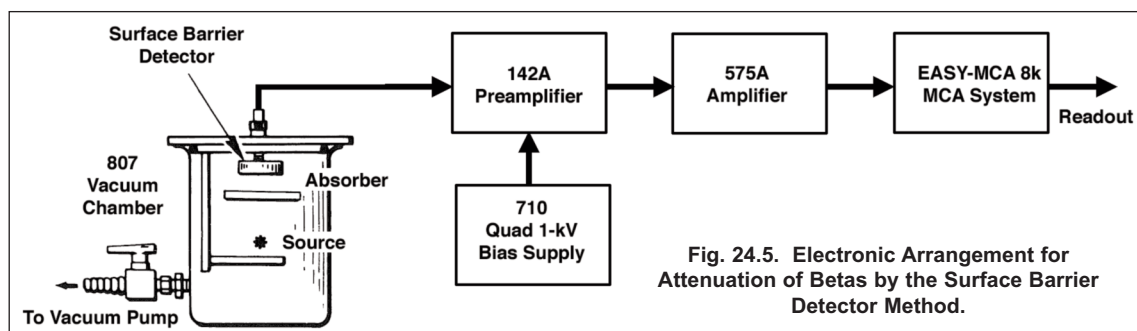
Discussion

Surface barrier detectors are rather insensitive to gammas. So, if an isotope has gammas in its decay scheme, the true beta portion of the absorption can be measured with these detectors. Most isotopes that decay by beta emission will, in fact, decay to excited levels in the residual nucleus which, in turn, gamma-decay to the ground state of the daughter nucleus.

Procedure

1. Set up the electronics as shown in Fig. 24.5. Place the ^{204}Tl source in the vacuum chamber so that all of the absorbers that will be used can be placed between the source and the detectors (Table 24.3). Evacuate the chamber and set the detector bias voltage to its recommended value. These techniques were outlined in Experiment 6.

2. Adjust the gain of the amplifier so that the end point of the ^{204}Tl spectrum falls in about channel 350. The spectrum will be similar to Fig. 6.1. Check that the PZ ADJ is properly adjusted per experiment 6.

3. Count for 200 s, or a time period long enough to obtain ~5000 counts in the entire spectrum. Since the background should be essentially zero, the counting rate can be calculated directly and entered into column 5 of a table similar to Table 24.3.

4. Repeat for each value of aluminum absorber shown in Table 24.3.

Fig. 24.4. Attenuation of the 0.766-MeV Betas from ^{204}Tl by Aluminum Absorbers.
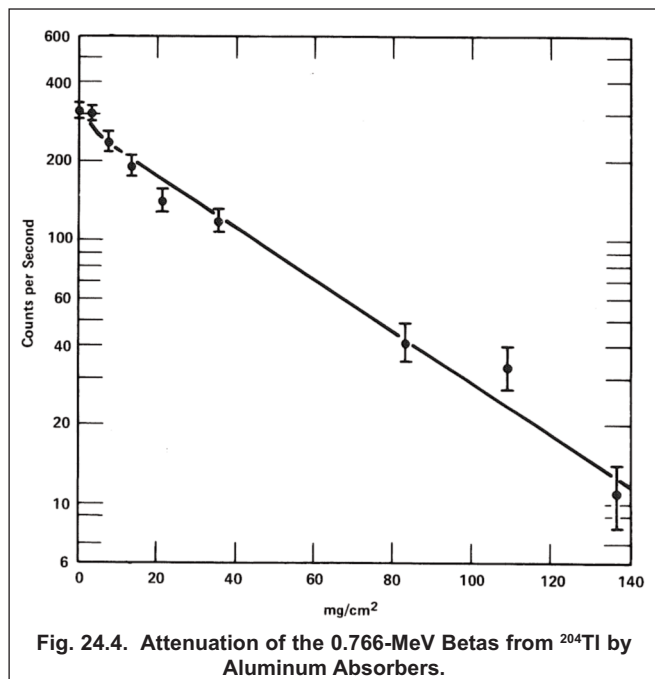
Table 24.4. Approximate Range of Electrons of Various Energies in Aluminum.	
Energy (MeV)	Range (mg/cm^2)
0.010	0.20
0.020	0.75
0.030	1.40
0.040	2.60
0.050	4.00
0.080	9.00
0.100	12.00
0.200	40.00
0.300	80.00
0.400	120.00
0.500	160.00
1.000	500.00
2.000	900.00

Fig. 24.5. Electronic Arrangement for Attenuation of Betas by the Surface Barrier Detector Method.

EXERCISE

Plot the data and compare with the values obtained in Experiment 24.4. Explain any differences.

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