

Measurements in Health Physics

EQUIPMENT NEEDED FROM EG&G ORTEC

Bin and Power Supply
 905-3 2- by 2-in. NaI(Tl) Crystal and Phototube
 266 Photomultiplier Tube Base
 556 High Voltage Power Supply
 113 Scintillation Preamplifier
 575A Amplifier
 ACE-2K MCA System including suitable IBM PC (other EG&G ORTEC MCAs may be used)
 875 Counter
 719 Timer
 903 End-Window Geiger Tube
 906 GM Inverter
 Surface Barrier Detector A-015-025-1500
 142A Preamplifier

Oscilloscope
 807 Vacuum Chamber
 428 Detector Bias Supply
 905-5 Plastic Scintillator and Phototube
 Mechanical Vacuum Pump
 10 sheets each: PbPI-2, CdPI-1, SIPI-1, AIPI-1, PnPI-2
 4 each AIFI-1, AIFI-2, AIFI-3, AIFI-4
 2 each AIFI-5
 8 each PbPI-3
 Source Kit SK-1G
 25 μCi ^{137}Cs
 3 Ci Am-Be Neutron Source
 Portable Geiger-Mueller Health Physics Survey Instrument
 ORC-24 Cable Set

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 qualify 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 the experiments in this manual 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.

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 isotopic radiation sources; stay as far away from the source as is practical during the experiment.

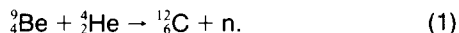
3. Where necessary, use shielding between the source and yourself. The amount of shielding and the type of shielding material depends on the type of radiation that the source is emitting.

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, 0.1 in. of aluminum will stop 1.5-MeV betas. For lead, 0.024 in. 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. As for 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.

A neutron source was used in Experiments 16, 17, 18, and 23, and will be used in this experiment. Shielding against these neutron sources presents a rather unique set of problems. Neutrons from these isotopic neutron sources are produced from the following reaction:



In some of these reactions the ${}^{12}_6\text{C}$ nucleus is left in an excited state. When the state de-excites, high-energy gammas are produced. Gammas are also produced by slow and fast neutron activation analysis in the source material as well as in the surroundings. Therefore these isotopic neutron sources also carry a rather heavy inventory of gammas. The gammas are attenuated quite effectively by lead, but this is not the case for neutrons. The most effective shielding material for neutrons is one that contains a large amount of hydrogen. The most practical common materials of this nature are paraffin and water. The reason that neutrons are effectively shielded by hydrogenous materials is that neutrons have a large scattering cross section with hydrogen. Fast neutrons therefore make a lot of billiard ball collisions with the protons in the shielding material. Each collision causes the neutron to lose some energy; on the average, about one-half its energy is lost per collision. Therefore, after ten collisions, the neutron is thermalized and can be captured by the large thermal cross section for hydrogen. So, in summary, a good shield for an isotopic neutron source is a combination of lead and a hydrogenous material such as paraffin.

In this series of experiments some of the properties of various shielding materials will be studied, accompanied by time, distance, and radiation protection parameters.

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 ${}^{137}\text{Cs}$, 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.
2. Obtain the ${}^{137}\text{Cs}$ source from the source kit ($E_\gamma = 0.662$ 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 ${}^{137}\text{Cs}$ is stored in about channel 350.
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.

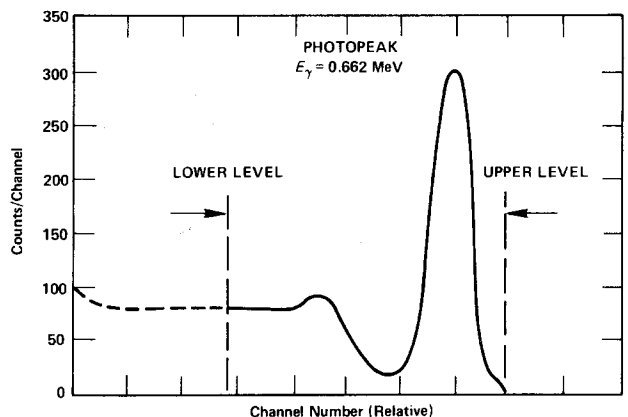


Fig. 24.2. ${}^{137}\text{Cs}$ Spectrum with the MCA ROI Lower Level Set at the Middle of the Compton Distribution.

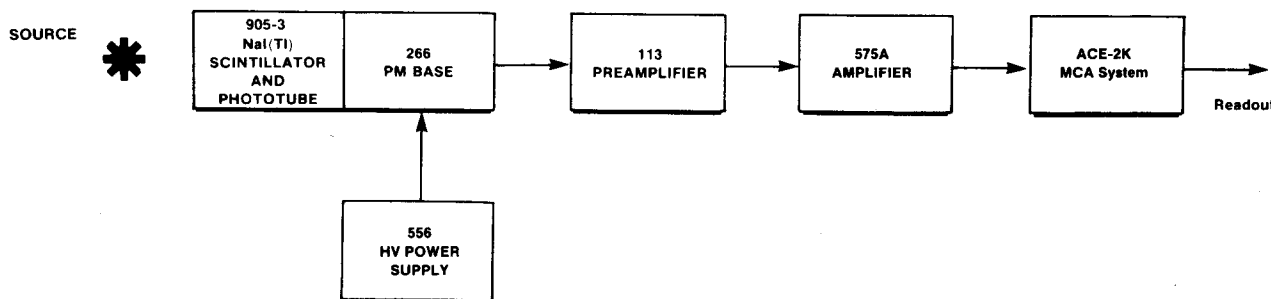


Fig. 24.1. Electronic Block Diagram for Gamma-Ray Spectrometry System with a Linear Gate for $1/R^2$ Studies.

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 Table 24.1.

Table 24.1. $1/R^2$ 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				

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 isotopic gamma source, the following relations are valid provided there is minimum external scattering.

$$I_1 = \frac{I_0}{R_1^2}, \tag{2}$$

$$I_2 = \frac{I_0}{R_2^2}, \tag{3}$$

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

$$\frac{I_1}{I_2} = \frac{R_2^2}{R_1^2}, \tag{4}$$

$$I_1 = I_2 \frac{R_2^2}{R_1^2}. \tag{5}$$

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.

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.

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 is 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 (3.7×10^{10} dps) and R^{-2} relationship, calculate the number of disintegrations/min/cm² 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 ¹³⁷Cs?

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 ¹³⁷Cs.

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 ¹³⁷Cs source from the source kit at a distance of 8 cm from the face of the crystal. Count for 400 s and record the integrated count total from the analyzer.
3. Place the first PbPI-2 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.
4. Remove the lead absorbers, ($Z = 82$), and replace them with the CdPI-1 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, ($Z = 26$), and then aluminum, ($Z = 13$). Since these materials are supplied in 1/8-in. thicknesses, instead of the 1/16-in. thicknesses for PbPI-2 and CdPI-1, 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 PnPI-2 (1-in. thick paraffin) between the source and the detector and count for 400 s. Calculate the counting rate, (cpm), when using this 4-in. layer of paraffin 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.

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 4 in. of paraffin, calculate the percent of attenuation. Is paraffin a very effective shield for gammas?

Table 24.2. Shielding Properties of Different Absorbers for Gammas.

Run No.	Absorber Thickness (1/16 in.)	Time (Seconds)	Integrated MCA Counts	Counting Rate Minus Background (cpm)
1	Zero	200		
2	1.0	200		
3	2.0	200		
4	3.0	400		
5	4.0	400		
6	5.0	400		
7	6.0	400		
8	7.0	400		
9	8.0	400		

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 ²⁰⁴Tl source from the source kit ~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.
3. Take a 400-s count without an absorber. Record the count in Table 24.3. Place the first aluminum absorber (2 mg/

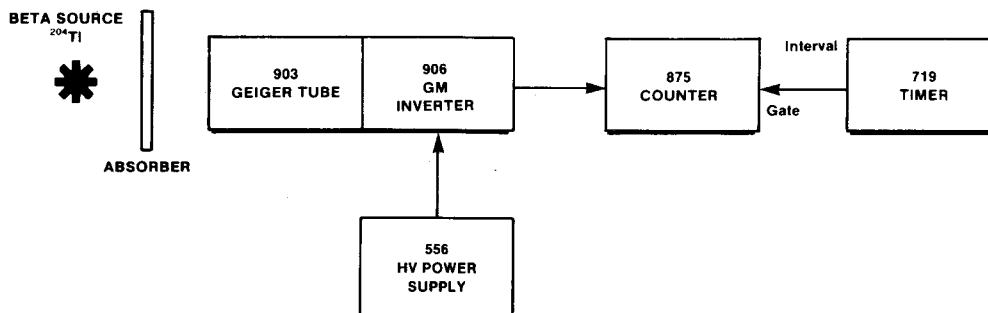


Fig. 24.3. Electronics for Beta Attenuation Experiment with a GM Counter.

cm²) 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.

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		

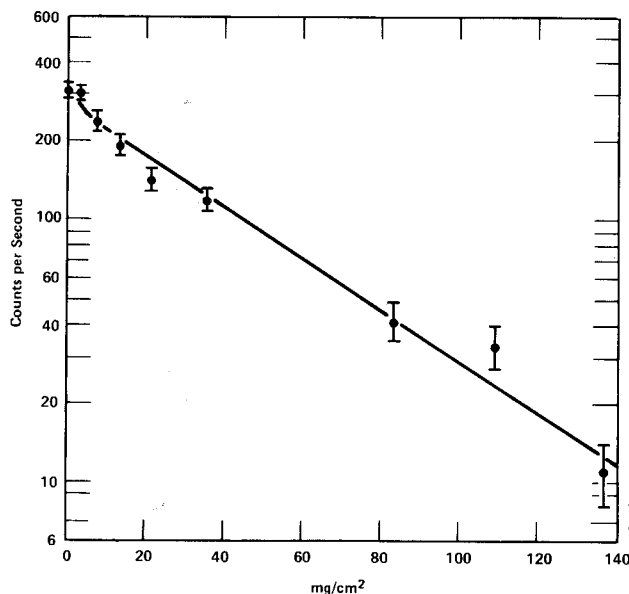


Fig. 24.4. Attenuation of the 0.766-MeV Betas from ²⁰⁴Tl by Aluminum Absorbers.

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

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.

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 from the source kit in the vacuum chamber so that all of the absorbers that will be used can be placed between the source and the detector (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.
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.

EXERCISE

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

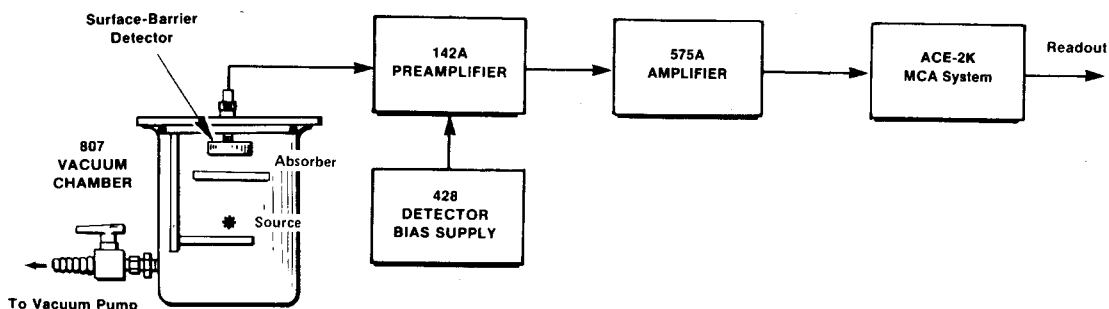


Fig. 24.5. Electronic Arrangement for Attenuation of Betas by the Surface Barrier Detector Method.

EXPERIMENT 24.6

A Study of Paraffin as a Neutron Shielding Material

Purpose

To study the properties of paraffin and lead as shielding materials for the fast neutrons that are produced from an isotopic neutron source (Am-Be).

Procedure

1. Set up the experimental arrangement shown in Fig. 24.6. Adjust the amplifier gain so that the end-point of the neutron spectrum is in about channel 550 (Fig. 24.7).
2. Remove the Am-Be source and place the $1\text{-}\mu\text{Ci } ^{60}\text{Co}$ source (from the source kit) at a distance of 1 cm from the 905-5 Plastic Scintillation Detector. Adjust the Lower Level of the MCA to cut out the steep slope in the lower portion of the spectrum as shown in Fig. 24.7.
3. Remove the ^{60}Co source and return the 1-Ci Am-Be source 100 cm from the detector as shown in Fig. 24.6.
4. Place the ten sheets of PbPI-2 (1/16-in. thick lead) at a position 10 cm from the Am-Be source. This lead helps shield the gammas from the plastic scintillator. The total lead thickness is 0.625 in., but the experiment will prove that this does little to attenuate the neutrons from the source.
5. Accumulate a neutron spectrum in the MCA for a time period long enough to have ~ 50 counts in each channel in the flat portion of the curve in Fig. 24.7.
6. Integrate the counts in the MCA spectrum and operate for a period of time long enough to record ~ 5000 total counts. Record the time and the number of counts. Place the first PnPI-2 paraffin absorber in its proper position and count for the same time used for the measurement without the absorber.
7. Continue making measurements while adding 1-in. increments of paraffin up to 10 in. It is probably wise to increase the time for the thicker absorbers so that the number of counts recorded stays above 3000. The live time for each accumulation is recorded in channel zero in the MCA.

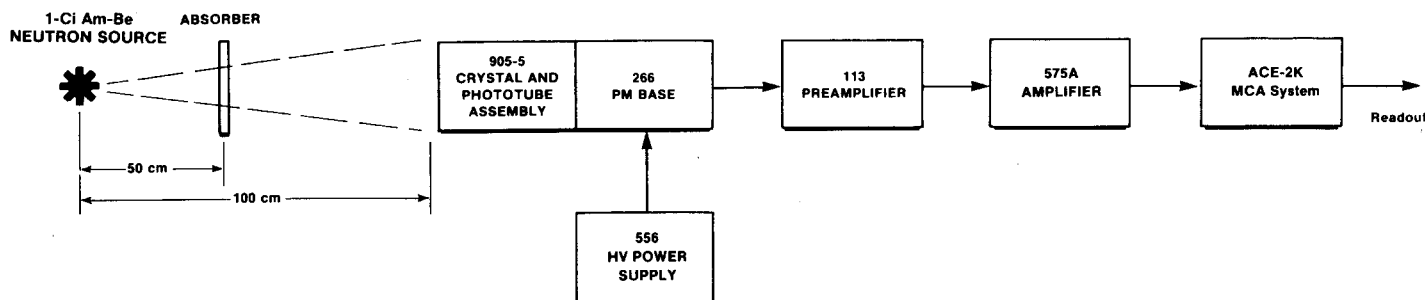


Fig. 24.6. Experimental Arrangement for Neutron Shielding Materials Study.

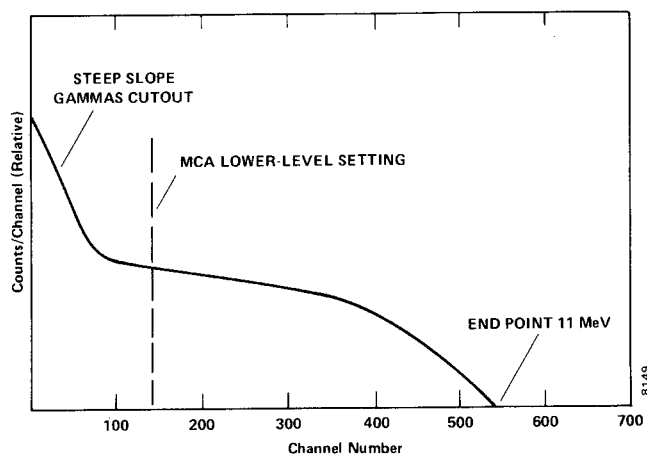


Fig. 24.7. Neutron Spectrum from Plastic Scintillator for Shielding Studies.

8. Remove the Am-Be source and take a background count for 400 s.

EXERCISES

- a. Calculate the counting rates for each measurement made. Determine the background counting rate and subtract it from each of the other measurements.
- b. Plot the corrected counting rate on semilog graph paper as a function of the paraffin absorber thickness. Calculate the effective half value layer, (HVL), for paraffin.

EXPERIMENT 24.7

A Study of Lead as a Neutron Shielding Material

Purpose

To study the absorption properties of lead for neutrons.

Procedure

1. Use the experimental arrangement and format of Experiment 24.6 for this experiment. Follow steps 1 through 5 in Experiment 24.6.

2. Place the first PbPI-3 (1-in. thick lead) absorber in position and count for a long enough period of time to accumulate ~5000 integrated counts in the analyzer spectrum.
3. Add one 1-in. thickness of lead and count for the same time period. Add each of the remaining lead shields, one at a time, and repeat this procedure.
4. Measure the background as in Experiment 24.6 and subtract it from each of the counting rates found above.

EXERCISES

- a. Plot the corrected counting rate on semilog graph paper as a function of lead thickness.
- b. From the projected straight line extrapolation on the curve, calculate the HVL of lead for neutrons from the Am-Be source. From the HVL of paraffin established in Experiment 24.6, calculate the ratio of the HVL values for paraffin and lead.

References

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