Attenuation of Radiation

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Objectives

The objectives of this experiment are: (1) to study the interaction of radiation with matter, (2) to study how charged particles interact with materials, (3) to study the 3 primary ways that gamma rays interact with matter, (4) to learn how materials are effective in shielding radiation, (5) to learn some radiation terms and parameters that affect the stopping power of radiation, and (6) to measure radiation attenuation coefficients for beta particles and gamma rays.

Theory

There are two primary types of radiation that originate from the nucleus of the atom, and these are charged particles and gamma rays. Charged particles from radioactive sources consist primarily of alpha particles and beta particles. Alpha particles are doubly charged helium nuclei, and beta particles are negatively charged electrons. Alpha particles are emitted with a specific kinetic energy, but beta particles have a distribution of energies. The energy available for the creation of a beta particle is shared between the beta particle and a neutrino particle created simultaneously. Neutrinos are massless particles that interact with matter with a very low probability. Alpha and beta particles interact with matter by their charges interacting with the outer electrons of atoms making up the material. Kinetic energy of the particle is transferred to the material by the particle exciting the electrons to higher lying excited states and/or by the particles ionizing the atoms and molecules, i.e. removing the electrons from the outer shells. This is easily understood by considering the electrical interaction that charges have with each other. Alpha particles are much heavier than beta particles, more than 7,000 times heavier, and at the same energy, move much slower than beta particles. Hence, they have longer times to interact and to transfer their energy to the outer shell electrons. Also, they have twice the charge and the electrical interactions are therefore greater. As a result then, alpha particles have greater interactions and give up their kinetic energy much more quickly than do beta particles. Therefore, alpha particles have very short pathlengths in the material. The range of charged particles at a given energy is defined as the average distance they travel before they come to rest. The range of a 4 MeV alpha particle in air is about 3 cm, and they can be stopped by a thin piece of paper or a thin sheet of some other solid or liquid material. 4 MeV beta particles have a maximum range of about 1,700 cm in air whereas they have a maximum range of about 2.0 cm in water and about 0.26 cm in lead. Figure 1 shows the maximum range of beta particles as a function of their energy for some selected materials of interest for this experiment.

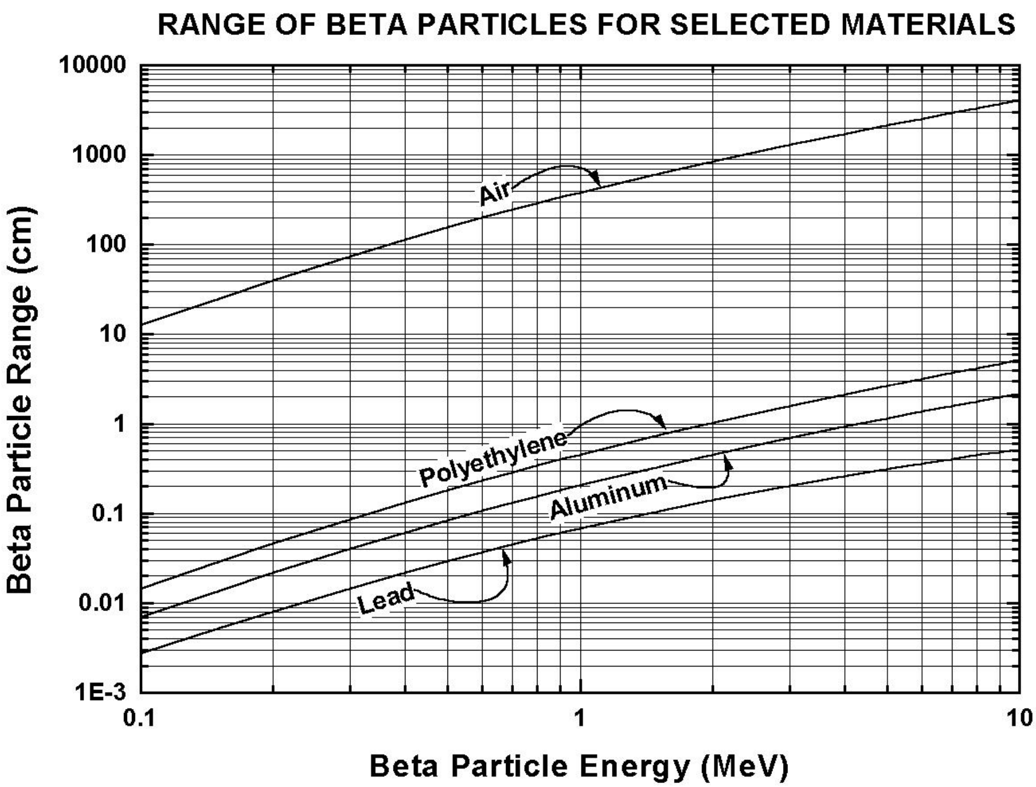


Figure 1. The maximum range of beta particles as a function of their energy for polyethylene.

The penetrating power of gamma rays is much greater than that of charged particles. They interact with matter in three primary ways: (1) by the photoelectric effect, (2) by the Compton effect, and (3) by pair production. Of these three, the photoelectric effect is the most effective. In the photoelectric effect, a gamma ray photon ejects an electron from an atom, transferring almost all of its energy to the electron by giving it kinetic energy. The energy of the gamma ray $E\gamma$ supplies the energy E_b to free the electron from its bound state and to give it kinetic energy,

$$E_\gamma = E_b + e^-_{\text{Kinetic Energy}} \,. \tag{1}$$

The binding energy is a few electron volts and is negligible compared to the energies of the gamma rays that may be on the order of a few million electron volts. The kinetic energy given the electron by the gamma ray then gives up its energy to the material in which it is located by interacting with the outer electrons of the atoms of the material. As with alpha particles and beta particles, the energetic electron excites and ionizes the atoms along its path until it loses all of its kinetic energy.

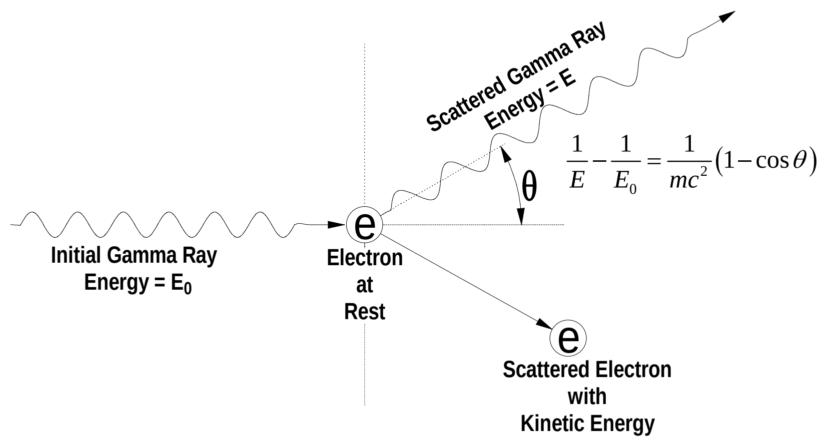


Figure 2. Schematic diagram illustrating Compton scattering.

In the Compton effect, a gamma ray is scattered by an electron, and in the process, a portion of its energy is transferred to kinetic energy of the electron. The kinetic energy of the electron is then dissipated by it interacting with the material, by exciting and ionizing the atoms along its path. Whereas most of the gamma ray's energy is transferred to the electron in the photoelectric effect, only a fraction of its energy is transferred in the Compton effect. The fraction of energy transferred depends on the Compton scattering angle θ and the initial energy of the gamma ray, E_0. If the energy of the gamma ray before it is scattered is E_0 and the energy of the scattered gamma ray is E, then E_0 and E are related by the Compton scattering relationship

$$\frac{1}{E}-\frac{1}{E_0}=\frac{1}{mc^2}(1-\cos\theta) \qquad (2)$$

where m is the mass of the electron and c is the speed of light. The scattering angle θ is the angle between the direction that the scattered gamma ray travels relative to the direction that the initial gamma ray was traveling. See Figure 2. The energy given the electron is the difference between E_0 and E, E_0-E, and the fraction of the energy of the initial gamma ray transferred to the electron is $\frac{E_0-E}{E_0}$ and is given by

$$\frac{E_0 - E}{E_0} = \left[\frac{E_0 \left(1 - \cos\theta\right)}{mc^2 + E_0\left(1 - \cos\theta\right)} \right]. \tag{3}$$

A graph of the fraction of gamma ray energy transferred to the electron in Compton scattering as a function of scattering angle and gamma ray energy is shown in Figure 3. The values for the fraction of energy transferred for a given initial gamma ray energy depends on the scattering angle and can range from a minimum value of 0 to a maximum value of nearly 1 for gamma ray energies greater than 10 MeV.

In pair production, the gamma ray photon's energy is used to form an electron-positron pair. The rest energy of an electron, and also of a positron, is mc^2 where m is the mass of the electron or positron and c is the speed of light. The rest energy of an electron or a positron is 0.511 MeV, so that for an electron-positron pair a minimum energy of 1.02 MeV is needed and pair production is not observed below this energy. The additional energy above this theshold energy is used to give the electron and positron kinetic energy so that energy is conserved and

$$E_\gamma = 2mc^2 + e^+_{\text{Kinetic Energy}} + e^-_{\text{Kinetic Energy}} . \tag{4}$$

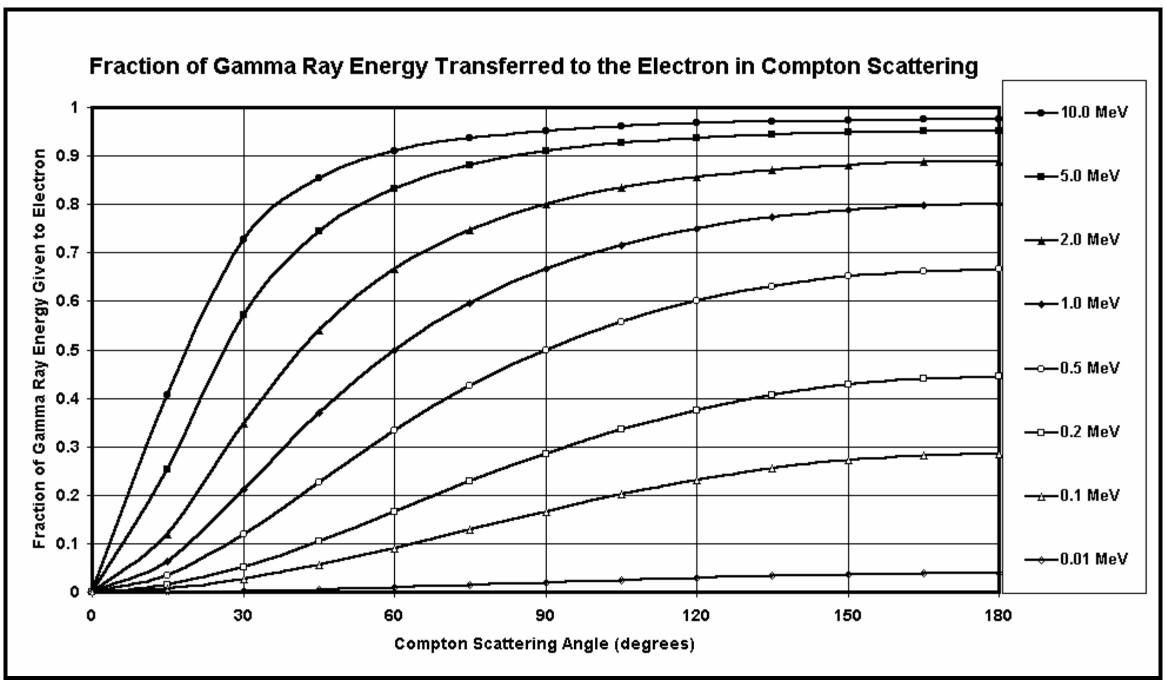


Figure 3. Graph of fraction of gamma ray energy transferred to electron in Compton scattering as a function of scattering angle and initial gamma ray energy.

In the case of gamma rays, the attenuation of radiation is due to a combination of absorption and scattering in a material. The attenuation of gamma ray intensity is due primarily to combinations of the photoelectric effect, the Compton scattering effect, and pair production. In each case, the photon energy is absorbed by the energy being transferred to kinetic energy of an electron or an electron-positron pair. Figure 4 shows the absorption component due to each of the 3 processes and the total absorption due to the sum of these separate components.

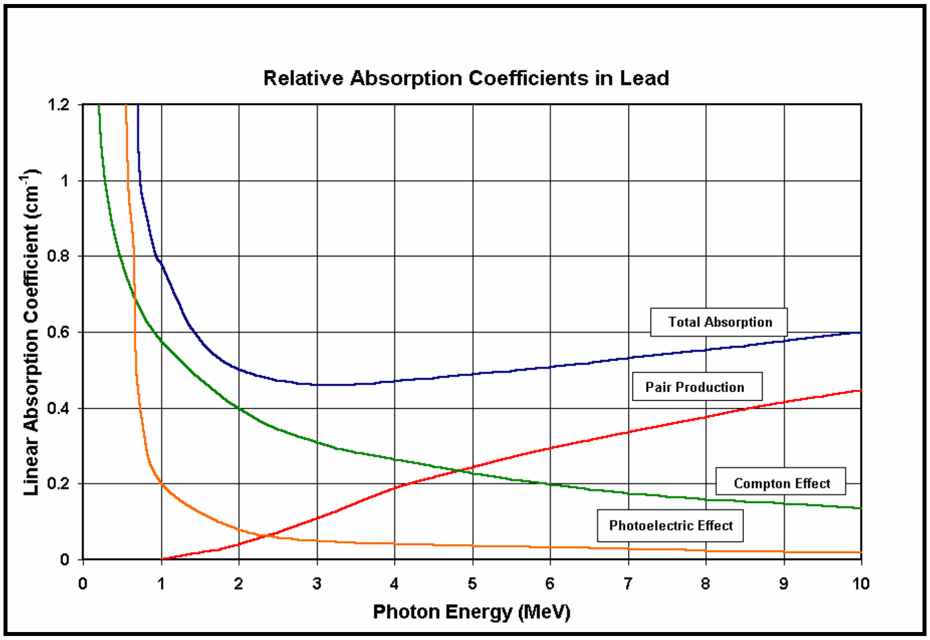


Figure 4. The linear absorption coefficient for the photoelectric effect, the Compton effect, pair production, and the total sum of each these components.

The photoelectric effect and pair production are processes in which the gamma ray's energy is mostly absorbed in the material. The Compton effect involves both scattering and absorption. In the measurement of attenuation with a Geiger counter, a scattered gamma ray photon that has also transferred a portion of its energy to the material by the Compton effect can be detected and counted as if none of its energy had been lost and none had been absorbed by the material. In other words, a scattered gamma ray photon that has had a portion of its energy absorbed is counted the same as an unabsorbed photon. It is important then to minimize the detection of scattered gamma rays. This can be done by having the detector only detect the gamma rays over a small solid angle in the forward direction where the scattered gamma rays haven't lost much of their energy to an electron. This can be accomplished by having the source, absorber, and detector well separated from each other and by limiting the size of the area of the absorber to about the same size as the area of the detector window. See Figure 5. With scattering minimized, the attenuation of radiation can be treated with linear probability theory.

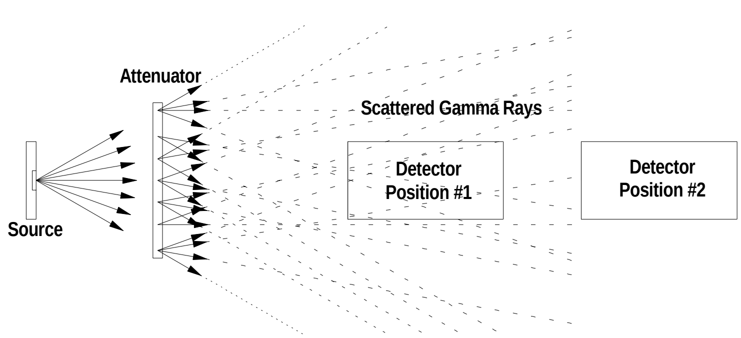


Figure 5. Diagram illustrating how locating detector further away from the source and attenuator can reduce the detection of scattered gamma rays.

Figure 6 shows a cross section of an absorbing material of thickness x with an intensity of radiation I_0 incident perpendicularly to the face of the material. As the radiation is absorbed in the material, the intensity will be I_1=I(x’) as it enters a thin slice of the material of thickness Δx’ located a distance x’ from the entrance face. Assuming that the material absorbs some of the radiation, the intensity of the radiation as it leaves the slice is I_2=I(x’+Δx’) and will be less. The change in intensity ΔI will be I_1-I_2 and will be a decrease (negative) that is proportional to the thickness of the thin slice, Δx’, and the intensity of the radiation, I(x’), so that

$$\Delta I\left(x'\right)=-\mu I\left(x'\right)\Delta x' . \tag{5}$$

The constant of proportionality is μ and is called the linear attenuation coefficient. Its value is dependent on the gamma ray photon energy. Equation (5) is the standard relationship for a change in a quantity that is proportional to that quantity and is the basis for the typical exponential relationship. Equation (5) can be rearranged as

$$\frac{\Delta I}{I}=-\mu\Delta x' \tag{6}$$

and rewritten as the differential equation,

$$\frac{dI\left(x'\right)}{I\left(x'\right)}=-\mu dx' . \tag{7}$$

By applying the boundary conditions, I(0)=I_0 when x’=0, the methods of integral calculus yields the familiar solution

$$I\left(x\right)=I_0e^{-\mu x} . \tag{8}$$

I(x) is the value of the photon intensity when x’=x, but the functional dependence of I on x is usually not explicitly written, and Equation (8) is written simply as

$$I = I_0 e^{-\mu x}\,. \tag{9}$$

The functional dependence of I on the absorber thickness x is implied implicitly.

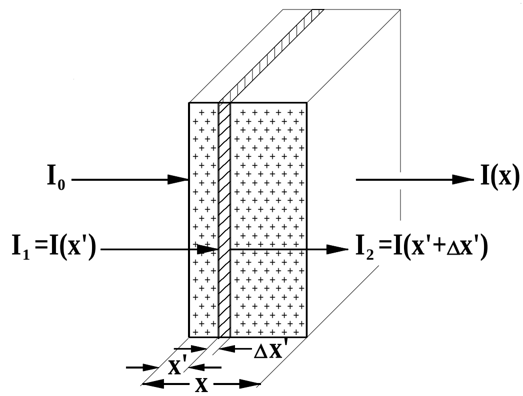


Figure 6. Cross section of absorbing material of thickness x with incident radiation intensity I_0.

If the natural logarithm is taken on both sides of Equation (9), then

$$\ln(I) = \ln(I_0) + \ln(e^{-\mu x})\,, \tag{10}$$

and

$$\ln(I) = \ln(I_0) - \mu x\,. \tag{11}$$

This equation is in the form of an equation for a straight line, y=a+bx, where y=ln(I), $\ln(I_0)$=a, b=-μ, and x=x. If ln(I) is plotted as a function of x, then the results should be a straight line whose slope is negative and has the value μ.

Another useful concept is the half-value thickness, $X_{½}$, which is the value of the absorber thickness that will reduce the intensity by a factor of 2. When $x=X_{½}$, $I=½I_0$ and the following relationships lead to Equation (17):

$$I\left(X_{½}\right) = \frac{1}{2} I_0 = I_0 e^{-\mu X_{½}}\,, \tag{12}$$

$$2^{-1} = e^{-\mu X_{½}}\,, \tag{13}$$

$$\ln(2^{-1}) = \ln(e^{-\mu X_{½}})\,, \tag{14}$$

$$-1\ln(2) = -\mu X_{\frac{1}{2}} \ln(e), \tag{15}$$

$$\ln(2) = \mu X_{\frac{1}{2}}, \tag{16}$$

and

$$\mu = \frac{\ln(2)}{X_{\frac{1}{2}}} = \frac{.693}{X_{\frac{1}{2}}}. \tag{17}$$

Yet another useful concept is the mass attenuation coefficient μ_m where the thickness of a slab of attenuator material is replaced by a new quantity called the mass thickness. If a mass of material m has a uniform cross section A and length x, the volume density ρ is defined as

$$\rho = \frac{m}{V} = \frac{m}{A \times x} \tag{18}$$

and the length x can be written as

$$x = \frac{1}{\rho} \times \frac{m}{A} = \frac{1}{\rho} \times x_m \tag{19}$$

where x_m is defined as the mass thickness. By substituting this value for x into Equation (9) and by defining the mass attenuation coefficient as $\mu_m = \frac{\mu}{\rho}$ a new relation,

$$I = I_0 e^{-\mu \frac{1}{\rho} x_m} \tag{20}$$

is formed that yields

$$I = I_0 e^{-\mu_m x_m}. \tag{21}$$

The linear thickness is then measured in terms of the mass thickness in units of mass per unit area (g/cm^2, etc.) and the mass attenuation coefficient has the inverse units of 1/(mass/area) ($1/gm/cm^2$). Just as Equation (9) could be written in the form of Equation (11) by taking the natural logarithm of both sides, Equation (21) can be written as

$$\ln(I) = \ln(I_0) - \mu_m x_m. \tag{22}$$

which is also in the form of an equation for a straight line, y=a+bx, where y=ln(I), $\ln(I_0)$=a, b=-μ_m, and x=x_m. If ln(I) is plotted as a function of x_m, then the results should be a straight line whose slope is negative and has the value of μ_m. The concept of a half-value for mass thickness, $X_{m½}$, is the same as the concept for a half-value for linear thickness. It is value of the mass thickness that will reduce the intensity by a factor of 2. So when $x_m=X_{m½}$, then $I=½I_0$ and

$$I\left(X_{m\frac{1}{2}}\right) = \frac{1}{2} I_0 = I_0 e^{-\mu X_{m\frac{1}{2}}} . \quad (23)$$

Using the same mathematical operations that was used for the linear thickness,

$$\mu_m = \frac{\ln(2)}{X_{m\frac{1}{2}}} = \frac{.693}{X_{m\frac{1}{2}}} \quad (24)$$

and

$$X_{m\frac{1}{2}} = \frac{.693}{\mu_m} . \quad (25)$$

Equation (21) and the concept of a mass attenuation coefficient are useful because attenuation is found to be mostly dependent on the mass of the absorber material and μ_m is nearly independent of the type of material. A graph of μ_m versus gamma ray energy for lead is shown in Figure 7.

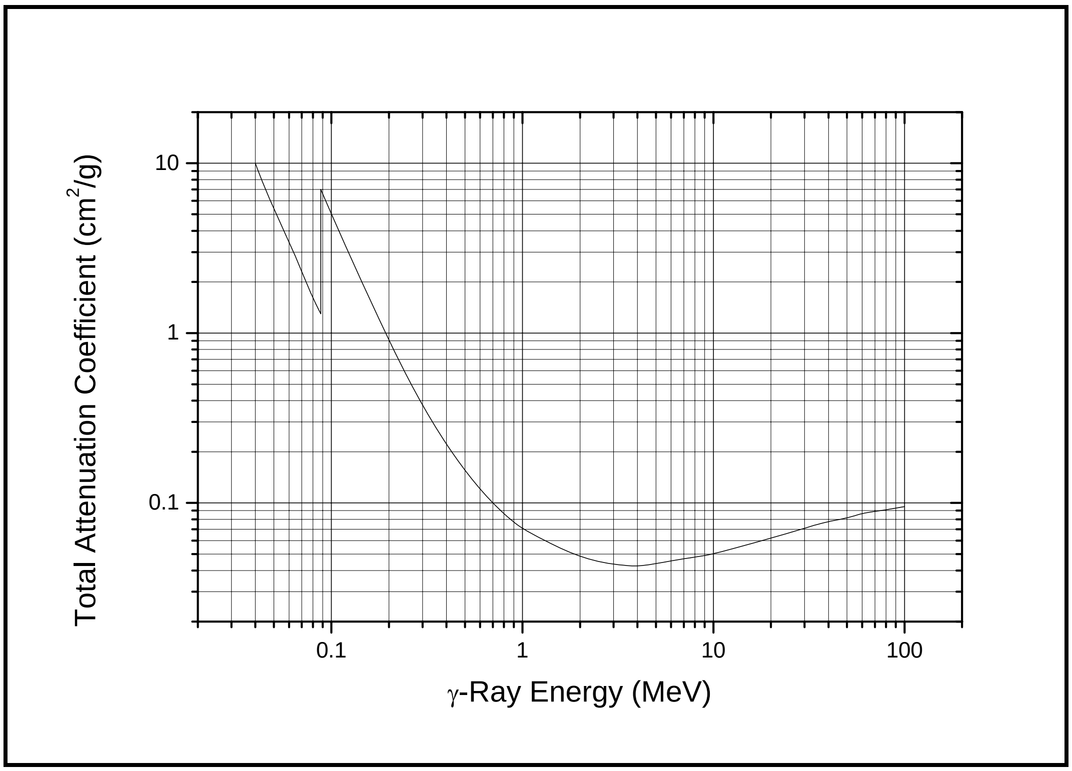


Figure 7. Total mass attenuation coefficient versus gamma ray energy.

In order to fully understand the attenuation of radiation experiment, one must understand the radioactive decay schemes for the sources that are used in the experiment. Radioactive sources emit multiple types of particles, with varying energies and lifetimes, and in doing so, change their makeup in the nucleus and change their elemental and isotopic character. The sources used in this experiment are strontium-90 (Sr-90 or ${}^{90}_{38}Sr$) and cesium-137 (Cs-137 or ${}^{137}_{55}Cs$), and their decay schemes are illustrated in Figures 8 and 9.

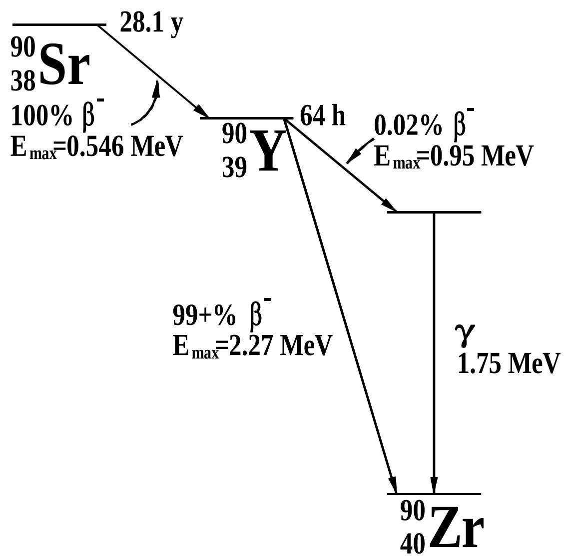


Figure 8. Decay scheme for strontium-90.

Strontium-90 (${}^{90}_{38}Sr$) has atomic number 38, is a beta emitter, and has a half-life of 28.1 years. It only emits beta particles that have a maximum energy of 0.546 MeV. ${}^{90}_{38}Sr$ decays to yttrium-90 (${}^{90}_{39}Y$) which only lives for a relatively short time of 64 hours. ${}^{90}_{39}Y$ also decays by beta emission, but by two different paths. Most of the time, greater that 99% of the time, it emits a 2.27 MeV beta particle down to the ground state of zirconium-90 (${}^{90}_{49}Zr$). The rest of the time, 0.02% of the time, it emits a 0.95 MeV beta particle to a metastable state of ${}^{90}_{49}Zr$ which in turn emits a 1.75 MeV gamma ray to the ground state of ${}^{90}_{49}Zr$. This latter path can be neglected since it occurs with so small a frequency.

Since ${}^{90}_{39}Y$ has a very short half life, the rate it emits beta particles depends on the rate that it is produced and that rate is determined by the half life of ${}^{90}_{38}Sr$. Essentially, for each decay of ${}^{90}_{38}Sr$ there are 2 gammas emitted one following shortly after the other but with statistical probability dependent on the amount of ${}^{90}_{39}Y$ built up at equilibrium. Since the ${}^{90}_{38}Sr$ beta particle is of lower energy, less than 25%, the first absorbers will filter these particles out first and will leave the ${}^{90}_{39}Y$ beta particles to be attenuated and measured.

Cesium-137 ($^{137}_{55}Cs$) has a half life of 30 years and decays by beta emission to two states of barium, a metastable state, $^{137m}_{55}Ba$, and $^{137}_{55}Ba$ in the ground state. Most frequently, 93.5% of the time, the cesium decays to the barium metastable state by the emission of a low energy, 514 keV beta particle. The metastable state is short lived (half life=2.55 minutes) and subsequently emits a 661.6 keV gamma ray in a transition to its ground state. Cesium is usually thought of as a gamma emitter, but actually, the gamma ray comes from the barium daughter nucleus. It is this gamma ray that is used for the attenuation of radiation experiment. The beta particles are easily absorbed by the lead filters and are of no consequence in the measurements.

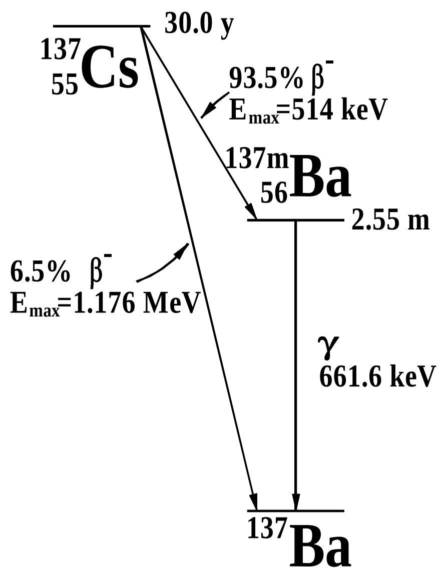


Figure 9. Decay scheme for cesium-137.

Apparatus

The apparatus is shown in Figure 10 and consists of: (1) a Cesium-137 (Cs-137) gamma ray source, (2) a Strontium-90 (Sr-137) beta particle source, (3) lead and polyethylene absorbers of various thicknesses, (4) a Geiger-Mueller tube with stand to hold sources and attenuators, (5) a Nucleus scaler/timer unit to count and time the radioactive decays, and (6) a computer with Excel spreadheet program.

Figure 10. Apparatus and setup for performing the attenuation of radiation experiment.

Procedure

Preliminary Preparation

1. The LND, Inc. Model 723 Geiger-Mueller tube used in this experiment has an operating voltage of 900 volts. Make sure the high voltage on the scaler/timer unit is set to 900 volts (the two knobs set to 800 volts and 100 volts respectively). The end window of the tube is made of mica and has an areal density (mass thickness) of 2.0 mg/cm^2 (2.0×10^{-3} g/cm^2). The effective diameter of the window is 2.86 cm that gives it an effective area of 6.42 cm^2. Mica has a density of about 2.88 g/cm^3.

CAUTION: The window is extremely thin, and can be easily punctured so that the 900 volts on the center wire is exposed, thus posing an electrical health hazard. Avoid contact with the window to avoid the possibility of a serious electrical shock.

2. Turn on the power to the scaler/timer unit with the power rocker switch. Push the stop and reset rocker switches to initialize the unit.

3. In this experiment, the geometry for making the measurements will be poor because the source, absorber, and detector will be in close proximity to each other. Ideally, the detector should be at some distance from the absorber so that it only looks in the forward scattering direction and most of the scattered gamma rays miss the detector. With the detector close to the attenuator, there is an increased probability of having

photons scatter from the edges of the absorber into the detector. Nevertheless, the results should be very satisfactory and clearly demonstrate the principles.

4. In the first part of this experiment with the attenuation of gamma rays, the measurements will be made by measuring the time for a fixed number of counts. From Poisson Statistics for a large number of counts, the uncertainty in counts is equal to ± the square root of the average number of counts collected, i.e. $\sigma = \pm\sqrt{\overline{N}}$ where σ is the uncertainty and $\overline{N}$ is the average number of counts. In the case here, the number will be 5000 and the uncertainty will be $\sqrt{5000} = 71$. This represents an uncertainty of $\frac{71}{5000} \times 100\% = 1.4\%$ and the measurements should be very good statistically.

5. Open up an Excel Spreadsheet by clicking on the Excel icon on the desktop of the computer. In Sheet 1, label the columns as illustrated in Figure 11.

6. With all sources removed from proximity of the detector, make a background measurement. On the scaler/timer unit set the mode switch to preset time by switching the toggle switch to the left. Set the preset time knob to 5 minutes and start the scaler by pushing start rocker switch to on.

7. Record the number of background counts N_B in Cell C1 of your spreadsheet and compute the number of counts per second I_B in Cell C2. ($I_B = N_B/300$).

File Edit View Insert Format Tools Chart Window Help

	A	B	C	D	E	F	G	H	I	J
1	Background Count, N_B		253							
2	Background Count Rate, I_B		0.8433333							
3										
4	Measurement Number	Additional Attenuator Combination	Absorber Thickness (inches)	Absorber Thickness (cm)	Absorber Mass Thickness s (g/cm^2)	Time for 5000 Counts (min)	Time for 5000 Counts (sec)	Count Rate	Corrected Count Rate, I	ln(I)
5	1	0	0	0.000	0.000	2.56	153.6	32.55	31.71	3.46
6	2	2	0.062	0.157	1.787	3.73	223.8	22.34	21.50	3.07
7	3	3	0.125							
8	4	2+3	0.187							
9	5	4	0.25							
10	6	4+2	0.312							
11	7	4+3	0.375							
12	8	4+3+2	0.437							
13	9	4+4	0.5							

Figure 11. Example of Excel spreadsheet for gamma ray attenuation experiment showing absorbers and combinations of absorbers for the measurements with lead and Cs-137.

Note: This experiment takes some time to make all the measurements. Your time can be used more efficiently by going ahead with the analysis sections while data is being collected. The Excel spreadsheet program will automatically up-date the results as new data are entered.

Attenuation of Gamma Rays

1. The procedure is to measure and record the count rate of detected gamma rays as a function of the mass thickness of various absorbers that are placed between the source and detector.

2. Obtain a Cs-137 source (orange disk) from the instructor and place it in the source slide holder with the label side up. Place a #2 lead attenuator (0.062 inches, 1.80 g/cm^2) on top of the source and slide holder to cover the source to absorb the beta particles that are emitted as the cesium decays. Slide the source and source holder with the #2 lead attenuator on top of the source into the fourth slot from the top of the source/attenuator slide holder and detector stand. This combination of source and attenuator will serve as the source to which additional attenuators will be added.

3. On the scaler/time unit set the mode switch to **PRESET COUNT** by switching the toggle switch to the right. Set the **PRESET COUNT** knob to 5000 counts.

4. Start the counter with the start switch on the scaler. The scaler will measure and display the time in minutes after it has collected 5000 counts and stopped. The smallest time unit displayed is a hundredth of a minute, 0.01 minute. Record the time in column F of your spreadsheet along with the values of the linear thickness and mass thickness of the absorber used for the measurement in columns D and E. (For this measurement, measurement #1, the thickness will be zero.)

5. Repeat the previous step by adding a second #2 absorber (0.062 inches thick) to a second slide holder and insert it in the stand between the source and detector. Record the time in column F, the linear thickness in columns D and the mass thickness in column E of the spreadsheet.

6. Repeat these measurements until all the absorbers and combinations of absorbers listed in the Excel spreadsheet in Figure 11 have been used. In each case record the time to collect 5000 counts, the linear thickness, and the mass thickness of the lead in the appropriate spreadsheet columns.

7. When completed, return the source to the front of the lab and to the instructor. Remove all the attenuators and place them in their proper locations in their storage box.

Analysis of Results for the Attenuation of Gamma Rays

1. Make sure that the linear thickness and mass thickness is computed for each of the absorbers and combinations of absorbers and recorded in columns D and E. Recall that the mass thickness is just the normal thickness multiplied by the density of the material. Lead has a density of 11.34 g/cm^3 so that a 0.0625 inch thick lead absorber has a normal thickness of 0.15875 cm and a mass thickness of 0.15875 cm x 11.34 g/cm^3 =1.800 g/cm^2.

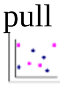
2. In column G compute the time in seconds from the times recorded in minutes in column F. A formula, ***=F5*60***, can be entered in cell G5 and then copied down to G13.

3. In column H compute the count rate for each of the measurements by dividing the 5000 counts detected by the time recorded in column G. A formula, ***=5000/G5***, can be entered in cell H5 and then copied down to H13.

4. In column I compute the corrected count rate by subtracting the background count rate found in cell C2 from each on the count rates determined in column H. A formula, ***=H5-$C$2***, can be entered in cell I5 and then copied down to I13.

5. Since Equation (22) is the form of a linear equation and graphical analysis using linear regression can be used to find the coefficients, use column J to compute the natural logarithm of corrected count rates found in column I. A formula, ***=LN(I5),*** can be entered in cell J5 and then copied down to J13.

6. In the following steps, ln(I) will be graphed as a function of the mass thickness, x_m. According to the theory, the graph should result in a straight line whose slope is $-\mu_m$. All the points on the graph will seem to lie along a straight line, but if carefully examined, the graph will appear to have two distinct linear portions, one with a steeper slope near the very beginning defined by the first 2 or 3 data points and a second defined by the rest of the points. The linear portion with the first few points and steeper slope is due to barium and lead x-rays. These are quickly filtered out with the small attenuators and don't contribute to the measurements with the thicker absorbers. The graphical analysis will need to display this difference and the data for the different portions will need to be analyzed separately. The slopes will be found by linear regression using the trendline feature of Excel, but to do this, the data will need to be broken into two components.

7. To graph all the points, choose ***Insert*** from the Excel main menu bar and then ***Chart . . .*** from the pull down menu. Choose ***XY (Scatter)*** for the Chart type and the points only option, , from Chart sub-type selections. Click on ***Next*** and then click on the ***Series*** tab of the Chart Source Data window. Click the ***Add*** series button and type ***All Points*** in the ***Name*** text input box. Type ***=Sheet1!$E$5:$E$1***3 in the ***X Values*** text input box and ***=Sheet1!$J$5:$J$1***3 in the ***Y Values*** text input box and then click on ***Next***.

8. In the ***Chart Options*** window click on the ***Titles*** tab and type in ***Mass Thickness (g/cm²)*** and ***Ln(I)*** in the ***Value X axis*** and ***Value Y axis*** text boxes. Under the ***Gridlines*** tab check both the x and y ***Major gridlines*** options and then click on ***Next***.

9. In the Chart Location window, choose the ***As new sheet*** option and then click on ***Finish***.

10. Examine the points on the graph to see if they lie along a straight line. Choose ***Chart*** from the Excel main menu bar and ***Add Trendline . . .*** from the pull down menu. Choose ***Linear*** from the ***Trend/Regression type*** selections under the ***Type*** tab. Under the ***Options*** tab, click on the ***Display equation on chart*** option and then ***OK***. Re-examine the data points with regard for how well they fit the trendline. Notice that except for the first few points, the data seems to lie along a straight line.

11. Repeat Step 7 to create another graph of your data. However, type ***First Portion*** in the ***Name*** text input box, ***=Sheet1!$E$5:$E$7*** in the ***X Values*** text input box, and ***=Sheet1!$J$5:$J$7*** in the ***Y Values*** text input box to only plot the first portion of your data.

12. Add the second portion of your data to the chart by clicking on ***Chart*** on the Excel main menu bar and then choosing ***Source Data*** . . . from the pull down menu. Under the ***Series*** tab, choose ***Add*** and type ***Second Portion*** in the ***Name*** text input box, ***=Sheet1!$E$7:$E$13*** in the ***X Values*** text input box, and ***=Sheet1!$J$7:$J$13*** in the ***Y Values*** text input box.

13. Add trendlines to the two separate groups of data by clicking on ***Chart*** and ***Add Trendline . . .*** from the main and pull down menus. Make sure that ***First Portion*** is highlighted under the ***Type*** tab and then under the ***Options*** tab, click on the ***Display equation on chart*** option. Click on OK and then repeat this procedure again, except selecting and highlighting ***Second Portion*** under the ***Type*** tab.

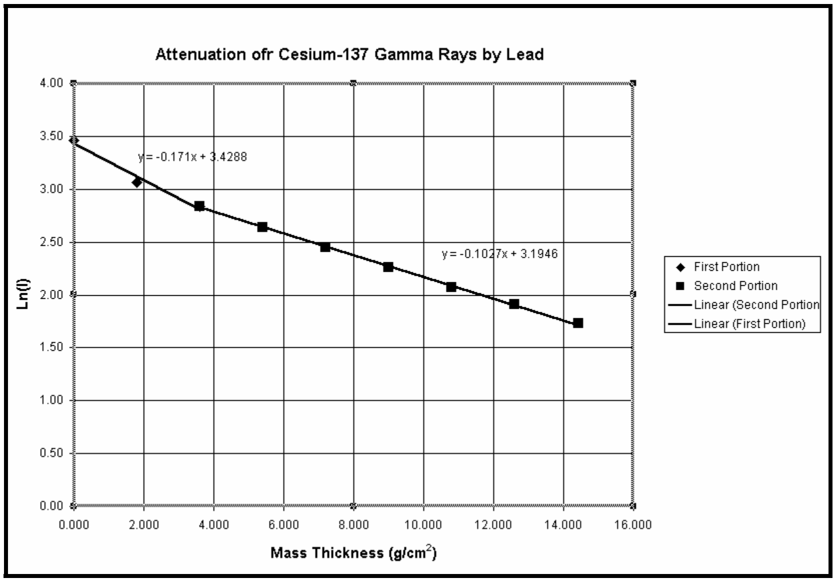


Figure 12. Example graph of gamma ray attenuation by lead.

14. This graph should look something the one in Figure 12. The data ranges suggested above for the first and second portions may not be consistent with your data. If not you can edit the ranges by choosing ***Chart*** from the main menu and then ***Source Data . . .*** .

15. The slope of the trendline for the second portion of the graph is negative and is equal to $-\mu_m$, the mass attenuation coefficient. Record the value of the slope taken from the equation of the trendline in a convenient cell in sheet 1. Use another adjacent cell in the same row or column to label this value.

16. By reading values from the graph in Figure 7 determine the value for the total mass attenuation coefficient for 0.6616 MeV gamma rays and record this value in a cell next to the slope value. Label an adjacent cell to identify the value.

17. Calculate the percent difference between the slope value and the graphical value, and record this value properly labeled.

18. Examine the data in columns E and I and determine the mass thickness that reduces the count rate by a factor of 2. From Equation (25) and your measured value for μ_m, calculate the value of the half mass thickness, $X_{m½}$ and compare it to the value you determined from the data. A plot of your data on semi-log graph paper and a linear fit of the data would be a better way to determine this value since a table of numbers is too discrete and a graph is continuous.

<u>Attenuation of Beta Particles</u>

1. Place the strontium-90 source (green disk) with its lettering topside in a source holder tray and place it in the fifth slot (counting from the top slot) of the detector stand. No attenuator will be placed on top of the source as in the previous case since beta particles are the subject of this measurement.

2. In order to save time, these measurements will use a constant time period, and the counting period will be set to 1 minute. The uncertainty between measurements will change and will not be as good as the previous case, but the results will be acceptable and the savings in time will be needed. Switch the scaler/timer unit's toggle switch to **PRESET TIME** and adjust the time period to 1 minute with the adjustment knobs.

3. Open up Sheet 2 of your Excel workbook and label the columns as shown in Figure 13. The absorbers to be used for the attenuation of betas are made of polyethylene and are numbered. Figure 13 shows the attenuators and combinations of attenuators to be used in the measurements, with the initial measurement having no attenuator.

4. Enter the background count and background count rate from the previous experiment since these values should not have changed.

5. Place the attenuator holder into the number 3 slot of the stand and make 1 minute measurements of the beta particles for all the polyethylene attenuators and combinations shown in Figure 13. Record your results in the appropriate column.

File Edit View Insert Format Tools Data Window Help

	A	B	C	D	E	F	G	H	I	J
1	Background Count, N_B		253							
2	Background Count Rate, I_B		0.8433333							
3										
4	Measurement Number	Additional Attenuator Combination	Absorber Thickness (inches)	Absorber Linear Thickness (cm)	Absorber Mass Thickness (mg/cm^2)	Number of Counts. N	Time (seconds)	Count Rate (#/sec)	Corrected Count Rate, I	ln(I)
5	1	0	0	0.000	0.000	5968	60	99.47	98.62	4.59
6	2	4	0.030	0.076	73.000	4517	60	75.28	74.44	4.31
7	3	5	0.062	0.157	151.000	3432	60	57.20	56.36	4.03
8	4	6	0.125	0.318	305.000	1670	60	27.83	26.99	3.30
9	5	6+5	0.187	0.475	456.000	702	60	11.70	10.86	2.38
10	6	7	0.250	0.635	610.000	296	60	4.93	4.09	1.41
11	7	7+4	0.280	0.711	683.000	205	60	3.42	2.57	0.95
12	8	7+5	0.312	0.792	761.000	109	60	1.82	0.97	-0.03
13	9	7+6	0.375	0.953	915.000	89	60	1.48	0.64	-0.45
14										

Figure 13. Example spreadsheet for recording and analyzing data for the attenuation of beta particles by polyethylene.

6. Compute the mass thickness from the linear thickness, the count rate, the corrected count rate, and the logarithm of the corrected count rate as was done in the gamma ray absorption experiment. Polyethylene has a density of about 0.92 g/cm^3 (920 mg/cm^3) and is of much lower density than lead. It is more convenient to express the

mass thickness in units of mg/cm^3. The mass attenuation coefficient μ_m will have units of 1/(mg/cm^3) = cm^2/mg.

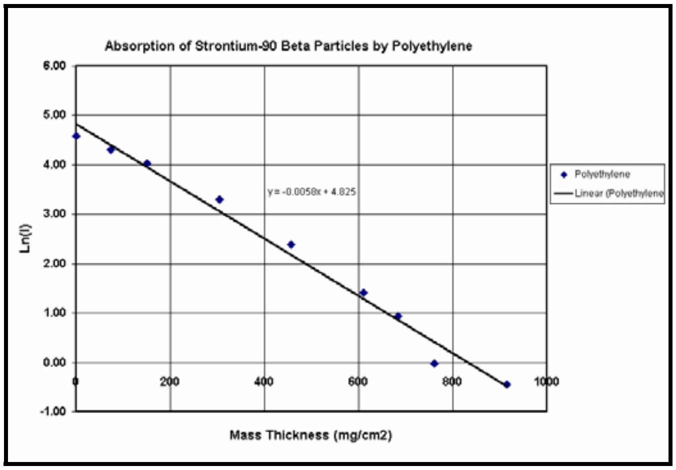


Figure 14. Example graph for attenuation of beta particles by polyethylene.

7. Make a graph of Ln(I) versus the mass thickness using the procedures in the previous section. In this case however, the data will not have to be divided into two portions for analysis.

8. Add a trendline to the graph and determine the slope and value for μ_m for polyethylene and 2.27 MeV beta particles. Record your results in your spreadsheet. The graph should look something like the one shown in Figure 14.

9. From your graph, estimate the maximum value of the mass thickness of polyethylene needed to stop the detection of all of the beta particles. This will be an estimate of the range of 2.27 MeV beta particles in polyethylene.

10. Determine the range of 2.27 MeV beta particles from the graph in Figure 1 and compare your estimate from the previous step with this value.

Questions

1. Show that $X_{m½} = \rho X_{½}$.

2. What is the range of 1 MeV beta particles in lead and polyethylene expressed in units of mass thickness?

3. What percent of the energy of a 1.0 MeV gamma ray is transferred to an electron if the gamma ray is Compton scattered at an angle of 60°?

4. What are the 3 primary processes for the energy of a 3.5 MeV gamma ray to be absorbed in lead and what is the relative effectiveness of each of these 3 processes in transferring energy to the material?

5. What thickness of lead is needed to reduce the intensity of 1 MeV gamma rays to 1/8 the initial intensity?