

Determination of the shielding power of different materials against gamma radiation

Chow Wing Yan, Yeung Chun Lap
S.K.H Tsang Shiu Tim Secondary School

Wong Ka Wing
Baptist Lui Ming Choi Secondary School

E-mail correspondence: monica_chow@yahoo.com, yeung_chun_lap@hotmail.com, jasonkwong@yahoo.com.hk

Supervisor: Dr. Francis C. C. Ling
Department of Physics, The University of Hong Kong

ABSTRACT

In the research, the shielding power of different materials against gamma radiation was studied by using HP-Ge detector. First, the HP-Ge detector had to be calibrated and the properties of HP-Ge detector had to be studied. We did it by finding the most suitable shaping time and the efficiency of the detector. Then, the main experiment was carried out. Three calibrated sources were used in the experiment; they were Co-60, Na-22 and Cs-137. Different materials were used in the experiment; they were lead, aluminium and plastic sheets with different thickness. By putting different materials between the detector and the source, the rate of gamma radiation was measured. Our result is that the larger the mass thickness of the materials is, the higher the shielding power of the materials is, which is consistent with the theoretical result.

INTRODUCTION

Gamma rays (γ -rays) are electromagnetic waves. Their wavelengths run from about 10^{-10} m to well below 10^{-14} m, with corresponding frequency range from 3×10^{18} Hz to more than 3×10^{22} Hz. γ -rays are produced by many radioactive substances. They can also be found in nuclear reactors and in cosmic radiation. There are many useful applications of gamma ray such as radiotherapy, medical tracer and sterilization. Nevertheless, when γ -rays are absorbed by a living organism (e.g. human), they may cause serious effects. Therefore, it is necessary to find out some substances that can effectively absorb and block γ -rays. The penetrating power of γ -rays, however, is very high so that most substances cannot effectively absorb them. In this experiment, we have to find out and compare the shielding powers of different materials against gamma radiation.

A. Calibration of the HP-Ge detector

METHODOLOGY

Our experiment was to determine the shielding power of different materials against gamma radiation. Before the main experiment could be carried out, the HP-Ge detector using for detecting gamma radiation was calibrated.

When some gamma photons enter the detector from the radioactive source, interaction occurs and electron holes are liberated. The preamplifier of the HPGe detector amplifies the signal pulses produced by electron holes and the MCA output the energy spectrum of gamma radiation on the computer.

The area of the pulses under energy spectrum is directly proportional to energy of gamma photons that interacts with the detector. Therefore we can get the result of total energy by taking definite integration of the graph. Shaping time is the time interval that is used for integration. A good shaping time will lead to the formation of an energy spectrum with high resolution; the shaping time cannot be too long or too short. (Appendix II)

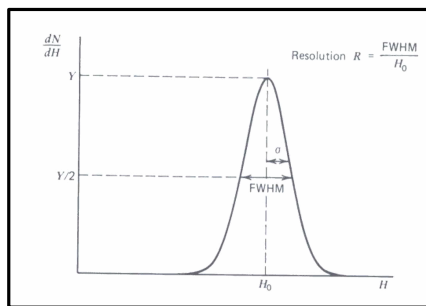


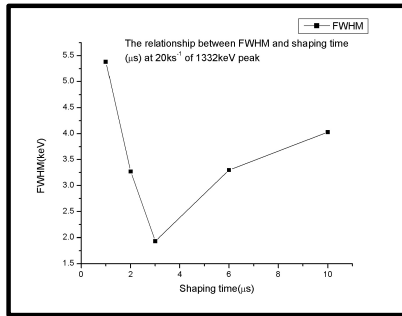
Figure 1 --- the graph showing what FWHM is

A concept of full width at half maximum (FWHM) is used to determine whether the energy spectrum has good resolution or not. FWHM is defined as the width of the distribution at a level that is just half the maximum co-ordinate of the peak. (Fig. 1)

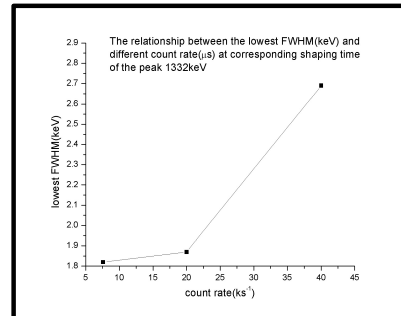
The smaller the FWHM is, the higher the energy resolution is. Therefore the detector will be able to distinguish between two radiations whose energies lie near each other with small FWHM.

Our goal was to find the most suitable shaping time such that the value of FWHM can be minimized. One calibrated source of Co-60 with energy peaks of 1170 KeV and 1332 KeV was used. Different count rates (by moving the distance between the source and the detector) and the corresponding different shaping times were studied. FWHM was obtained from the computer program. Then the graphs of FWHM against shaping time at different count rates were plotted and the lowest FWHM and the corresponding shaping time of each graph were taken.

RESULTS



Graph 1 --- the relationship between FWHM and the shaping time at count rate 20 ks^{-1} of the energy peak of 1332



Graph 2 --- the relationship between the lowest FWHM and different count rate at corresponding shaping time at energy peak of 1332KeV

DISCUSSION

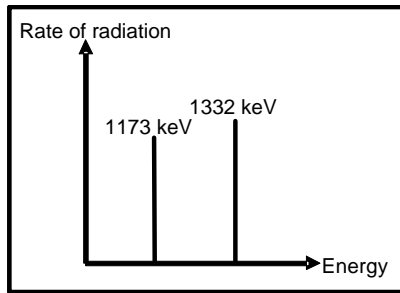


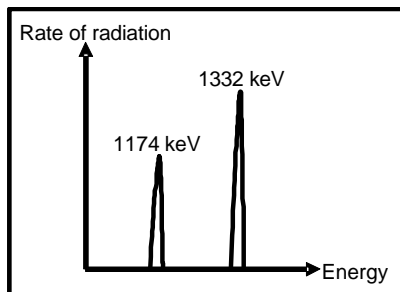
Figure 2

Take ^{60}Co as an example, it emits gamma radiation with 2 different energies. They are 1174 keV and 1332 keV respectively. Ideally, two straight lines (Figure 2) should be obtained as the source only emits radiation of definite energies.



Figure 3

However, random noise form surrounding, limitation of the detector, setting of shaping time and other problems result in imperfect energy resolution. (Figure 3)



The smaller the FWHM is, the better the detector will be able to distinguish between two radiations whose energies lie near each other. Figure 4 shows the energy spectrum of gamma radiation of ^{60}Co with a high resolution.

We have found the best shaping time for different count rates (12 ks⁻¹, 16 ks⁻¹, 20 ks⁻¹, 40 ks⁻¹). For all the count rates, we found that 3 μs is the best shaping time. The shaping time was to be used in the experiment.

Furthermore, from graph (2), we discovered that if the count rate is smaller, the value of the lowest FWHM is smaller.

B. Determination of the efficiency of the HP-Ge detector

METHODOLOGY

Three calibrated sources were used; they were Co-60 with energy peaks 1170keV and 1332keV, Na-22 with energy peaks 511keV and 1275keV, Cs-137 with energy peaks 662keV. All the sources have an absolute activity of 1 μCi. Shaping time of 3μs was used in all measurements.

The relationship between the absolute activity and the count rate is given by the formula

$$R = \frac{kAc}{d^2}, \quad [1]$$

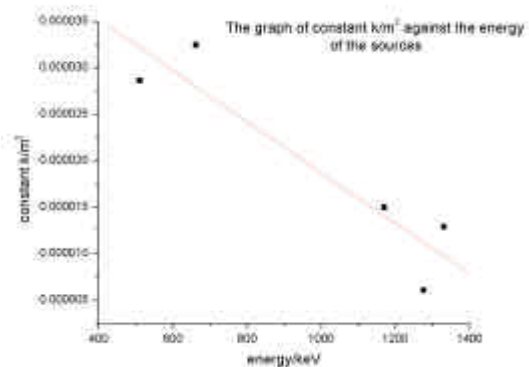
where R is the count rate of radiation, k is the efficiency constant of the detector, A_c is the absolute activity of the source, and d is the distance between the source and the detector.

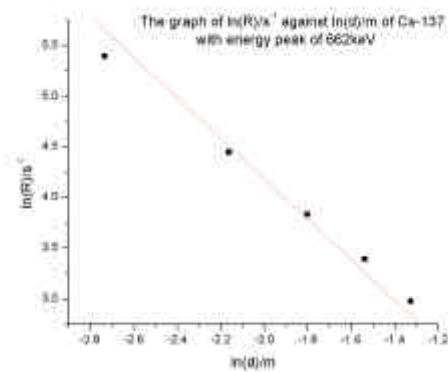
By measuring the count rate of radiation with varying distance, the value of k could be found. In these experiments, d was varying from 6.5cm to 26.5cm. The time required for the spectra is dependent on the error. That is,

$$\frac{\sqrt{N}}{N} \leq 0.05, \quad [2]$$

where N is the number of counts of photons.

RESULTS





Graph 3 shows the y-intercept is $\ln(kA)$. The constant k could thus be calculated. Graph 4 shows the efficiency of different energy is plotted against energy spectra.

Graphs of $\ln R$ against $\ln d$ with radiation of different energy were plotted. The slopes of the graphs are set to be -2 . A straight line is obtained that indicates there is a constant efficiency at a certain energy peak.

A graph of efficiency against corresponding energy peak is also plotted. The graph shows a general trend that the higher the energy peak is, the lower the efficiency is.

DISCUSSIONS

In fact, since gamma rays have high penetrating power (i.e. they can travel large distances), the detector has less than 100% efficiency. It then becomes necessary to have a precise figure for the detector efficiency in order to relate the number of pulses counted to the number of photons incident on the detector. From the above results, it is known that efficiency of the detector is a function of energy. At higher energies the relationship between efficiency and energy is dominated by the average path length in the active volume of the detector.

The efficiency decreases with increasing energy because the probability that the photon will interact within the detector also decreases with energy [2]. The result suggests that lower energy peak of photon radiation is preferred to achieve higher efficiency and better resolution.

C. Determination of the shielding power of different materials against gamma radiation

METHODOLOGY

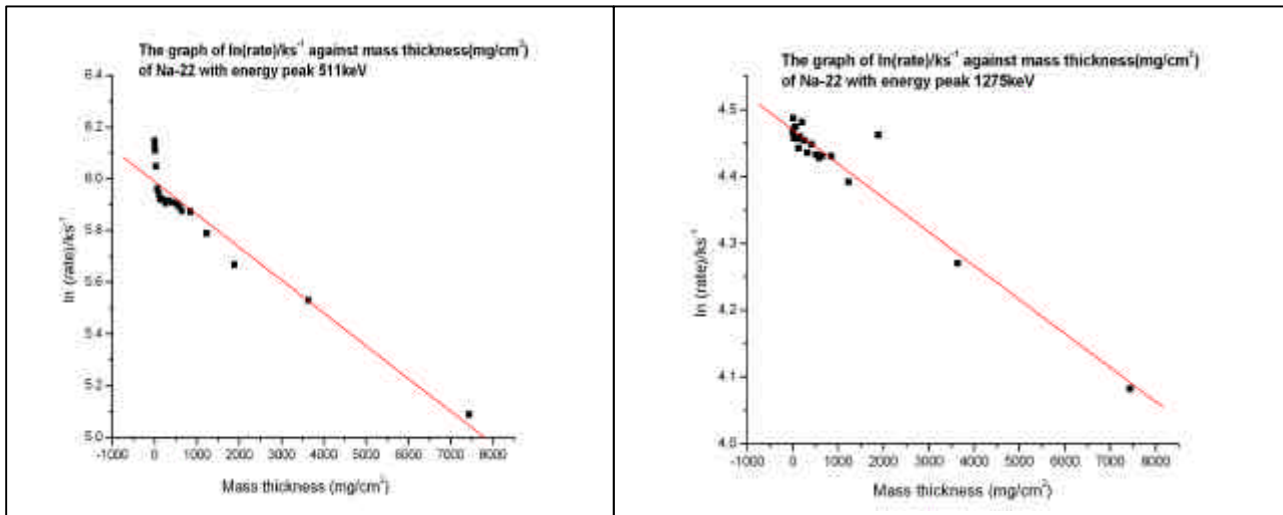
By measuring the rate of gamma radiation at a fixed time when different materials are placed between the source and detector, the relationship of shielding power of materials against gamma radiation can be determined.

Na-22 with energy peak 511keV and 1275keV and absolute activity of 15 Ci is used as a source. The distance between the source and the HPGe detector is 32.2cm.

Twenty 5.5cmX5.5cm samples of materials (lead 0.25, lead 0.125, lead 0.064, lead 0.032, Al 0.125, Al 0.1, Al 0.09, Al 0.08, Al 0.063, Al 0.05, Al 0.04, Al 0.032, Al 0.025, Al 0.02, plastic 0.04, plastic 0.03, poly 10 mil, poly 5mil, Al foil 1mil, Al foil 0.7 mil) are placed 2cm from the source respectively. The count rates of gamma radiation are measured at a fixed time (about 100s). And shaping time of 3 μ s is used in all measurements.

RESULTS

The graphs of $\ln(\text{Rate})/ks^{-1}$ against mass thickness(mg/cm^2)of Na-22 with energy peak and 511keV and 1275keV are plotted, and the Rate is the count rate of gamma radiation divided by the time used. The mass thickness is density of material multiples thickness [3].



Graph 5
 slope of peak 511keV= -1.2687×10^{-4}
 y-intercept= 5.9892 ks^{-1}

Graph 6
 slope of peak 1275keV= -5.0568×10^{-5}
 y-intercept= 4.47014 ks^{-1}

DISCUSSION

From the experiment, the $\ln(\text{rate})$ is found to be proportional to the mass thickness (mg/cm^2) of materials. Theoretically, the attenuation law for a gamma rays [4] is

$$I/I_0 = e^{-(\mu/\rho)\rho t} \quad , \quad [4]$$

where I is the number of transmitted photons, I_0 is the number of transmitted photons with an absorber, ρt is mass thickness (mg/cm^2), μ/ρ is mass attenuation coefficient, ρ is density of the medium, μ is τ (photoelectric) plus σ (Compton) plus κ (pair).

The result of the experiment is similar to the theoretical one.

From the graph of Na-22 peak 1275keV plotting $\ln(\text{rate})$ against mass thickness, the results can fitted into a straight line with its slope 5.0568×10^{-5} and the y-intercept 4.47014 ks^{-1} .

By measuring the count rate of gamma radiation by the detector without any material between, the $\ln(\text{rate})$ is 4.47751 ks^{-1} . It is very similar to the theoretic one. (y-intercept of the graph = 4.47014 ks^{-1}) (As $\ln I = -(\mu/\rho)\rho t + \ln I_0$)

Moreover, we can conclude that the shielding power of materials against gamma radiation depends on the mass thickness (ρt) of the material but not only depends on the material.

CONCLUSION

The shielding power is related to the mass thickness of the material. The larger the mass thickness of the materials is, the higher the shielding power of the material is. Lead is most widely used for shielding because of its high density. Thickness of a few centimeters of lead can have a large mass thickness to shield gamma radiation, for example in our experiment; lead 0.25 can absorb about 50% gamma radiation. However, other materials can have the same shielding power as lead if they have sufficient thickness.

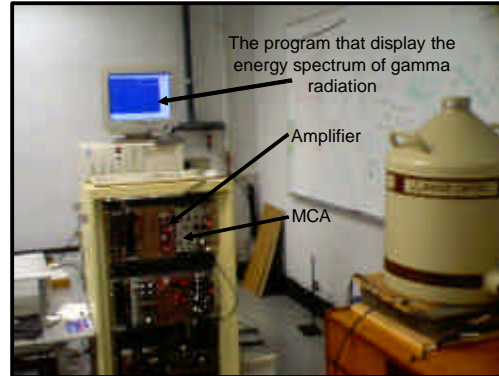
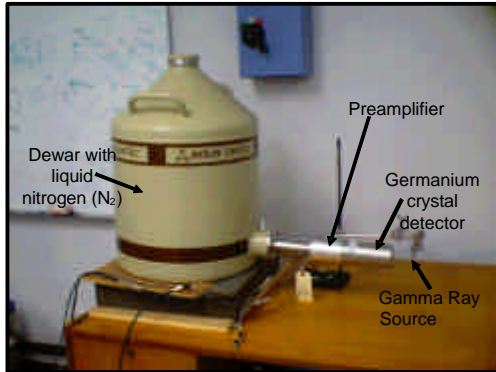
ACKNOWLEDGMENTS

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REFERENCES

- [1] Glenn F. Knoll, Radiation Detection and Measurement (3rd edition), p.116 (1999)
- [2] EG&G ORTEC, Modular Pulse-Processing Electronics and Semiconductor Radiation detectors, 1.54 (1998)
- [3] Grafton D. Chase, Stephen Rituper and John W. Sulcoski, Experiments in Nuclear Science (2nd edition) p.30, (1971)
- [4] Glenn F. Knoll, Radiation Detection and Measurement (3rd edition) p.53-54 (1999)

APPENDIX (I) Different parts of the HPGe detector



Gamma ray source

Although the source emits gamma rays, as the dose is very small, it is not harmful to people unless under prolonged contact. The source is stored in a safe with lead blocks surrounding it. After every experiment, our hands should be washed thoroughly.

Preamplifier

The use of a preamplifier is to amplify the signal pulses produced by electron holes. There are three characteristics of the pulses:

- 1) The rate of pulses is proportional to the rate of reaction. The proportion constant is equal to the efficiency of the detector which is different in each detector.
- 2) The amplitude of pulses is related to radiation energy.
- 3) The peak distribution is related to energy distribution in the energy spectrum.

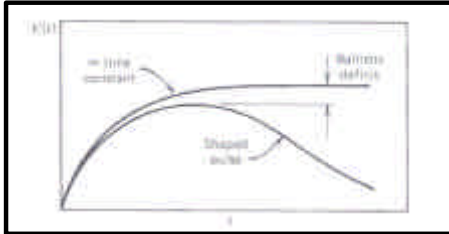
Amplifier

The signal pulses undergo further amplification in the amplifier. It also shapes the pulses.

MCA (Multichannel analyzer)

The function of MCA (multi-channel analyzer) is to calculate the data obtained and output the energy spectrum of gamma radiation on the computer.

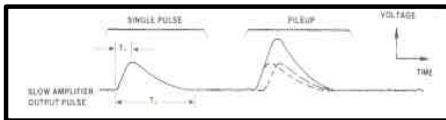
APPENDIX (II) Two factors affecting the determination of shaping time



Ballistic Deficit

When a gamma photon interact with the detector, electron holes are liberated in the detector. To collect all the charges entering the detector, ideally, a long shaping time which tends to infinity is desired.

However, there is a limit of the shaping time. Therefore the charge collected by the detector is less than the actual one. This is called Ballistic Deficit.



Pile-Up

When two gamma photons interact with the detector within the shaping time, interference occurs. The output pulse by the amplifier is, therefore, larger than a single pulse. To eliminate this error, a short shaping time is desired.

Conclusion

Ballistic Deficit favours a long shaping time while pile-up favours a short shaping time. For example, for the radiation with low count rate, Ballistic Deficit has a greater effect on the result. Long shaping time should be used. On the contrary, for the radiation with high count rate, the effect of pile-up is higher, and then short shaping time is needed.

Therefore, we have to find the optimum shaping time for different count rate.