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Barium Sulfate Epoxy Mixture Effects on Attenuation of Short Wavelength Radiation

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ABSTRACT

Radiation protection against short wavelength radiation have beeen studied by using Barium sulfate-Epoxy mixture. The outcome of this research showed a good new information about the ability of barium sulfate-Epoxy mixture to protect the humans and environment against short wavelength rays. There is an easy procedure, low cost and available materials to construct the shielding instead of that high cost shielding. Increasing barium sulfate ratios in barium-epoxy mixture leads to increased gamma ray attenuation with decreasing gamma photon energy. The results of high attenuation of gamma ray is due to the prevent of the ray to transimitted through the mixture. A new procedure for radiation protection are used in the labs and work places, which were used the radioactive materials. Short wavelength radiation causes hazards on health of humans and environment, the measurement of gamma photons transmission through barium-epoxy mixture are investigated. The count of CPS is done by maestro software after applying the mixture on cement block. There were two decay energys of gamma ray emitting at 59.5 keV and 26.3 keV. The scattering of gamma ray was studied at various angles.

Introduction

There are three factors which are used to control the amount or dose of radiation received from a source. The radiation exposure can be managed by a combination of these factors;

- Time: reducing the time of an exposure leads to reduction of the effective doses proportionally.
- Shielding: refers to a mass of absorbing material placed around a reactor or other radioactive source in order to reduce the radiation to safe humans [1]-[5].

Radiation protection is a very important field and many researchers have tried to approach the best methods for protection from radiation during the last centuries. The studies mostly concentrated on protection against electromagnetic radiation due to its serious risk to humans, and then on the methods of protection against gamma rays, and it’s scattering [6].

An electronic dose conversion unit was developed to estimate the environmental dose rate directly without using an MCA (multichannel analyzer). The experimental test of the new system with standard gamma sources showed good agreement with the calculated exposure dose rate. Therefore, the developed system using a NaI(T1) detector and the electronic dose conversion unit can be used to monitor the low-level range of environmental radiation accurately and reliably. The requirements of high performance shielding material are to maximize the number of electrons per unit mass, the nuclear reaction cross section per unit mass and the production of secondary particles. Thus, the transmitted LET (linear energy transmission) spectra of hydrogen showed acceptable universal attenuation at low keV/m measurement resulting in good attenuation of biological effects independent of biological model, which was used. The source used is Cesium-137 for 0.662 MeV. It is found that the count average of gamma photons increases when the scattering material thickness increases [7].

The phantom experiment suggests that fetal irradiation during maternal chest CT can be reduced substantially with barium shielding. Scattered radiation was attenuated at 13% and 21% with 2% of barium sulfate, and it attenuated to 87% and 96% with 40% barium sulfate, as calculated in the near and far fields respectively. The extrapolated attenuations for 5%–40% barium sulfate suspensions indicated that beyond a 30% suspension, attenuation increased further only slightly [8].

Increased concrete density is obtained by complex use of waste products of heavy silicate–lead glasses (brand DF) production as dispersed cement filler, disperse superlasticizer (SP) carrier, fine and coarse fillers. It was found the optimal ratio of solution filling with optical glass additive makes 8% – 12.5% from cement weight. Increase of glass share up to 20% and more leads to decrease the durability of fine sand solution. Also, the compression resistance of this concrete is 92 MPa at (W/C=0.24) before it collapses when granite filler at water-cement relation (W/C=0.29) [9].

Another research measured the doses of x – ray that pass through different mixture of the blocks and showed that the protection could be improved by increasing the ratios of barium sulfate. So, the results indicated that when the ratios of barium sulfate increases, the dose of x- ray decreases. High energy (70 KV) and low energy (47 KV) of x –ray machine was used. The ratios of barium sulfate-cement were (0%, 25%, 30%, 35%, 40%, 45% and 50%) in various thicknesses of the blocks (2, 4, 6, 8 and 10 mm), so the results for high energy at various thicknesses and ratios of barium sulfates were between 388 and 26.1 µ sv/h and for low energy was between 113 and 0.99 µ sv/h. The thickness of the mixture blocks affected on x–ray transmission [10].

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The reason for studying radiation protection by using gamma ray source is that gamma ray has high penetration and causes diffuse damage throughout the body, such as radiation sickness, and increasing of incidence of cancer rather than burns [11]. Gamma ray energy between 3 MeV and 10 MeV causes most biological damaging forms.

The issue of this research is to propose the best radiation protection against gamma ray by using BE mixture. The measurements of gamma ray transmission through samples were performed before and after applying the mixture of BE. This research provides high attenuation on gamma ray during its transmission through the mixture of BE. Also, this research focuses on the scattering of gamma photon from the mixture of BE and the affects of these scatterings on environment and human safety. The other advantage is to compares the reduction of transmission and scattering of gamma ray through barium sulfate and other materials. The investigation suggests the best mixture ratios of barium sulfate–epoxy to get high protection and attenuation of gamma ray by increasing the absorption and scattering of gamma photons.

Methodology

Barium sulfate and epoxy material were gotten from Medical Physics laboratory, School of Physics, Universiti Sains Malaysia. Cement blocks with dimensions 5×5 cm and 4 mm thickness were prepared. An empty small plate was used to weigh barium sulfate and epoxy. During painting of BE mixture on cement blocks, the paint should be spread uniformly on cement block in order to get correct reading of CPS. The samples must be kept carefully after painting till drying to avoid any volatile materials.

Since barium sulfate is not radioactive material, it is easy to be used. Barium sulfate was gotten from a physics lab in a container which is enough for this work. Also, epoxy material was gotten from the same lab in a container. Empty small plate used (which its weight has measured by electronic balance) in order to put barium sulfate and epoxy in it to weight barium sulfate and epoxy weight. Also, this plate can be used to mix barium sulfate with epoxy in order to get BE mixture. However, the ratios of barium sulfate to epoxy in BE mixture were 10%, 20%, 30%, 40% and 50%.

The ratios of barium sulfate were five ratios because they were enough to show the difference of the records of the detector that are shown by gamma equipment. When combining the mixture on the plate, it must be well mixed to make sure that barium sulfate is mixed equally with epoxy resin. During painting BE mixture on cement blocks, the paint should be spread equally on cement block in order to get correct records of CPS.

The practical studies proved that the scintillated detector responds to the temperature, and the main change which was seen in response function is by changing the location of the peak toward less value when the temperature is increased. When the curve of calibration line of the detector NaI(TI) decreased, the temperature increased especially between 20–50 °C. So, the researcher must be eager to keep temperature constant between 20–25 °C in order to get correct readings of the detector at the same temperature. Therefore, the counts were performed at the times when the air conditioner of the lab was working, and the setting of the air conditioner at the same temperature was performed.

Gamma ray equipment is important in physics labs because it provides short wavelength radiation with modern software programs that could be used to measure the number of gamma photons which reach to the detector. This equipment of gamma ray consists of setting up of gamma ray equipment followed the lab regulations as shown in Figure 1. Am-241 is used to produce gamma ray by beta particles decays. Am-241 is a synthetic element and its atomic number is 95, and its half life is 432.2 years.

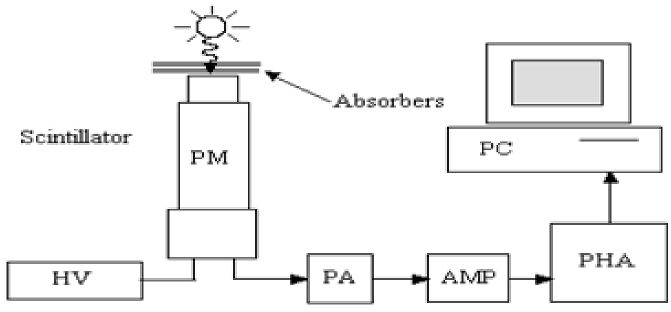

Figure 1. The Connection of Gamma Ray Equipment

NaI(TI) detector is used to measure the number of gamma photons which transmit through the sample toward the detector. Sodium iodide detector NaI(TI) presents a great efficiency for gamma photons and x-ray detection. This detector consists of two parts. These two parts are flickering material and optical multiplier. The scintillated material produces photons when it absorbs the nuclear radiation, but the optical multiplier which is in front of the crystal consists of optical cathode and a group of dynodes.

It is possible to control amplifier and high voltage power supplier by amplifier and high voltage supplier instrument which has small lights to evaluate the voltage.

The computer which was used in this work is necessary because it has two important pieces of software. They are Mestro-32 software model A65-B32 powerful MCA emulation software and multi channel analyzer (MCA-3) model FADC and version 3.07 which is an advanced multi channel analyzer with a built-in ultra-fast ADC with 500 ns conversion time and 8 k conversion range. It is important to insulate the detector and the source using the lead or iron shielding to prevent gamma rays.

The time of a sample exposure to gamma ray must be selected for each sample. Setting up of the time was done via MCA-3 software that shows the live time which means the time of activity of the detector. Also, MCA-3 shows real time which is the time that does not depend on the detector activity. The time that was used for measurements of gamma ray transmission was 600 seconds (10 minutes) and the position of the source at the angle 0° to the detector. This time was enough for 0° angle to get clear peaks in Maestro software which refers to number of gamma photons received by the detector. However, setting up of the time was 3000 seconds for the samples that were put at 20°and 30° angles, 3500, 4000 and 5000 seconds for 45°, 70° and 90° respectively.

The calibration of MCA-3 software has been set up in order to calibrate the channel and energy of the peak by Maestro software.

The voltage at high voltage power supply (3102D) is set up to be used as an operating voltage, in order to get the value of the voltage which is suitable to do the experiment. The range of the voltage of high voltage power supplier 3102D was 0–2000 V. The relation between the CPS with voltage is shown in Fig. 2. It can be seen that voltages between 400–1000 V lead to semi-stability of the curve which is stability area for the detector. Therefore, selection of any of these voltages was possible to use in this experiment. The voltage used was 900 V which was used for all counting of this work.

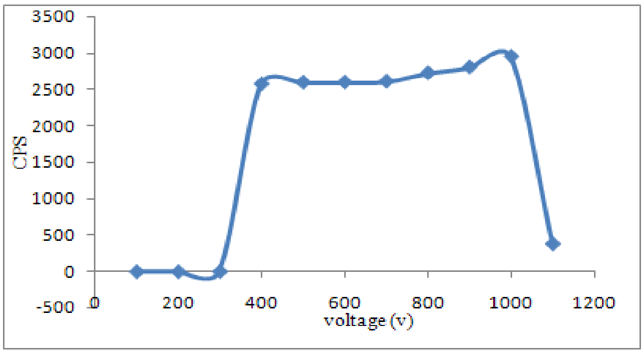

Figure 2. Cps for Various Volts of HV Supplier

The source was put at 0° angle without absorber (sample) as shown in Figure 1. Then, the detector was warmed for 10 minutes; the time set up at 600 s, and was set up for the calibration. MCA-3 software switches on to start counting during the specified time. At 0° angle, two peaks 59.537 keV and 26.345 keV were shown.

The sample was placed between the source and the detector, the same steps that were mentioned above, and was repeated for each sample. Sodium iodide detector NaI(TI) detector was used to detect gamma photons which transmit through the samples due to its great detection efficiency for gamma photons and x-ray [12].

In this work, there were different ratios of barium sulfate (10%, 20%, 30%, 40% and 50%) in the mixture of BE which were coated cement blocks in order to measure the transmission and scattering of gamma photon through the painted samples.

Different thicknesses of BE mixture on cement block was performed in order to get high radiation protection. Cement block was painted with 1 mm of BE mixture which had 50% of barium sulfate to epoxy. The mixture of BE was painted for a second time (after drying the first cost) on the same cement block which means that BE mixture thickness is 2 mm. The thickness of BE mixture increased up to 4 mm.

There were comparisons of the transmission of gamma photon through barium sulfate with other materials (salt, sand and cement) for the angle 0° and at time 600 sec. The scattering of gamma photon off these materials with the angle at 20° and at the time 3000 s was also performed.

The transmission of gamma photon through epoxy and other materials (paint and cement contact glue) for the angle 0° and at the time 600 sec were compared. Scattered gamma photons from these materials were measured at the angle 20° and at the time 3000 sec.

The transmission of cement blocks have compared with other blocks (wood, Al, Perspex) at angle 0° and time 600 sec, and the scattered gamma photon was performed at angle 20° and the time 3000 sec. The transmission and the scattering of gamma photon through different thicknesses of cement block (2, 4, 6, 8 and 10 mm) were also preformed.

Cement block consists of multi coated cement layers were performed in this work. The used cement layers were painted by BE mixture and pasted with each other in order to make cement block contents of multi coated cement layers. The thickness of each cement layer was 2 mm and the BE mixture that used has 50% of barium sulfate to epoxy. Coated cement layers necessary to increase gamma ray attenuation.

Cement block contain multi holes was important method that applied in this study. The radius of each hole was around 1mm. The maximum numbers of used holes were 6 holes. These holes painted by BE mixture which contains 50% of barium sulfate to epoxy.

The biggest thickness of cement block (10 mm) was used in the last method of this experiment. This cement block had the highest ratio of barium sulfate (20%), and it was painted with different thicknesses of BE mixture that contained 50% of barium sulfate to epoxy.

Results and Discussion

$BaSO_4$ can be used as a radiation protection material against gamma ray. Barium sulfate was compared with other materials such as salt, sand and cements to prove that it is the most suitable material.

Gamma ray transmission through the air (without absorber) was measured by the detector Na(TI), so the value of gamma ray transmission that reached the detector was 2755 CPS and 327 CPS for the peaks of 59.5 keV and 26.3 keV, respectively. Then, the transmission of gamma ray attenuated through salt was 1639 CPS and 192 CPS for the peaks 59.5 keV and 26.3 keV, respectively. The measurements of gamma ray attenuation through sand material showed different values of CPS; CPS of gamma ray transmission through sand recorded at 1583 CPS for peak of 59.5 keV and 187 CPS for peak of 26.3 keV. The attenuation of gamma rays through sand was higher than the attenuation through salt. Gamma ray transmission through cement material was 1494 CPS for peak of 59.5 keV and 177 CPS for peak of 26.3 keV. The results of gamma ray attenuation through cement resulted in high attenuation of gamma ray. The measurement of gamma ray attenuation through barium sulfate was the best because there was highest attenuation of gamma ray through barium sulfate. The values of CPS for gamma ray transmission through barium sulfate recorded at 45 CPS for peak 59.5 keV and 6 CPS for peak 26.3 keV, which shows that there was high attenuation of gamma ray through barium sulfate.

Gamma photon scattered by salt, sand, cement and barium sulfate was measured. The value of CPS of gamma ray scattering by barium sulfate was 0.47 CPS which was the lowest scattering. The scattering of gamma ray by cement was 0.51 CPS, by salt was 0.70 CPS, and then the highest of 0.82 CPS by sand. In conclusion, barium sulfate caused the lowest value of gamma photon scattering compared to others, as gamma photon scattering by all of these materials is less than 1 CPS. On the other hand, it means that the barium sulfate is a suitable material which can be used for protection against gamma rays because it results in high absorption and low scatter. The highest attenuation of gamma rays through barium sulfate was due to their lowest scattering and high absorption. So, barium sulfate was the best material that can be used for radiation protection against short wavelength rays.

Epoxy resin used in this work was mixed with barium sulfate in order to prepare a mixture of BE to be used for gamma ray protection. Epoxy and other resin materials (paint and cement contact glue) were necessary to investigate their attenuation of gamma ray by studying the scattering and transmission of this ray through these materials. The materials paint and cement contact glue can be used for painting because they are resin materials, so these two materials were suitable to be compared with epoxy resin.

The measurements of gamma ray attenuation through different material showed that the values of CPS of gamma ray transmission through paint material were 1287 CPS and 155 CPS for both peaks of 59.5 keV and 26.3 keV, respectively. The values of CPS for gamma ray transmission through cement contact glue were 1035 CPS and 140 CPS for both peaks. The results of gamma ray transmission through epoxy resin were 875 CPS for peak 59.5 keV and 128 CPS for peak of 26.3 keV which were the highest attenuation of gamma ray. So, the highest attenuation of gamma ray was recorded through epoxy resin which had higher absorption than paint and cement contact glue. The results of scattered gamma photon by epoxy, paint and cement contact glue materials were measured. The value of CPS for gamma ray scattering by epoxy resin material was 0.50 CPS which was considered the low value of gamma photon scattered. Scattering gamma ray using cement contact glue was 0.54 CPS which is considered the higher than painted material, which was 0.63 CPS. The measurements of scattering gamma ray showed that the smallest value of scattered gamma photon was by epoxy resin. The results show that epoxy resin is the best material to be mixed with barium sulfate and used as a protective material for short wavelength radiation due to their high absorption and low transmission and scattering properties due to its density.

The results of different ratios of $BaSO_4$ in the mixture of BE method show the different attenuation of gamma ray that transmitted through the mixture of BE, which was painted on cement blocks. Different attenuation of gamma ray was obtained by mixing different ratios of barium sulfate to epoxy resin. The ratios of barium sulfate to epoxy used were 10-90%, 20-80%, 30-70%, 40-60% and 50-50%. CPS of transmitted gamma photon was measured for different ratios of mixtures of barium sulfate to epoxy resin painted on cement blocks. Different values of CPS of gamma ray transmission were recorded through the barrier containing different ratios of barium sulfate to epoxy and shown in Figure 3.

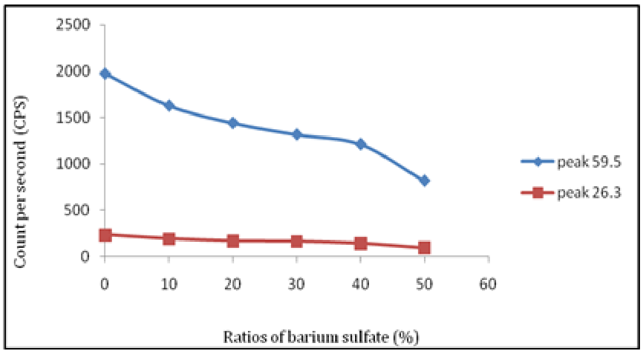

Figure 3. CPS of Gamma Ray Transmission for Different Ratios of $BaSo_4$

Figure 3 shows the different values of CPS values of gamma ray transmission that was transmitted through the mixture of BE that contained different ratios of $BaSO_4$. The transmission of gamma ray without coating the block of cement is 1975 CPS and 234 CPS for both peaks of 59.5 keV and 26.3 keV, respectively. A gradual reduction can be noticed when the block was coated by the mixture of 1630 CPS and 194 CPS for 10-90% ratio, 1442 CPS and 171 CPS, 1317 CPS and 166 CPS, 1212 CPS for peak 59.5 keV and 144 CPS for peak 26.3 keV and to reach the minimum transmission through the barrier of cement coated by BE of 50-50% ratio to be 817 CPS and 96 CPS for both peaks of 59.5 keV and 26.3 keV, respectively. It can be seen that the presence of BE with 50-50% ratio decreases the transmission of gamma ray by more than 50% of background radiation.

Table 1 shows the attenuation percentage of gamma ray transmission by CPS of gamma ray transmission that was transmitted through barrier of cement block which coated by the mixture of BE with different ratios of barium sulfate-epoxy compared with CPS of gamma ray transmission transmitted through barrier of cement block without coating according to the following equation:

$$\text{the attenuation } \% = \frac{\text{the erfernce value} - \text{the calculate value}}{\text{the reference value}} \times 100\% \qquad (1)$$

CPS of gamma ray transmission through cement block without coating by BE is a reference value, and CPS of gamma ray transmission through cement block coated by different ratios of barium sulfate-epoxy is calculated and presented in Table 1. It showed that the attenuation percentage of gamma ray transmission for cement block without barium sulfate was 3.76% and 4.98% for the peaks 9.5 keV and 26.3 keV respectively. Then, the attenuation of gamma ray achieved with sample at the ratio 10-90% of barium sulfate-epoxy and then sequential increase of the ratios of BE, and accordingly the attenuation percentage of gamma ray transmission also increased. Thus, the attenuation percentage of gamma ray transmission increased to reach the maximum value with maximum attenuation through the sample which is coated by 50% of barium sulfate in BE mixture.

Table 1. Attenuation percentage of gamma ray transmission for different ratios of $BaSO_4$

Ratio of barium sulfate to epoxy (%)	Attenuation percentage (%)	
	Peak 59.5 keV	Peak 26.3 keV
0	3.76	4.98
10	20.60	21.41
20	29.75	30.84
30	35.80	32.83
40	40.93	41.37
50	60.17	60.92

The results showed that the attenuation of gamma ray is approximately at the same value for both peaks of gamma radiation. Due to the maximum attenuation achieved, it can be concluded that the mixture of 50% of barium sulfate is suitable and attractive for gamma radiation protection.

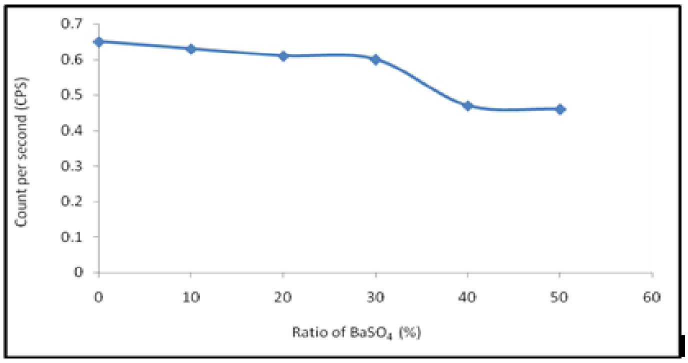

Figure 4. CPS of Scattered Gamma Photon for Different Ratios of $BaSO_4$

At different ratios of barium sulfate, the scattering of gamma photon at angle of 20^o was obtained and presented in figure 4. Gamma photon scattering is decreased by increasing the ratio of barium sulfate-epoxy. The greatest decrease of gamma ray scattering recorded with ratios 40-60% and 50-50% of barium sulfate-epoxy is 0.46 CPS.

Since the values of scattered of gamma photons are small, the attenuation percentage of gamma ray transmission is negligible. The results of absorbed gamma photon through different ratios of barium sulfate-epoxy can be obtained by using this equation [13]:

$$Absorption = attenuation - scattering \qquad (2)$$

And the attenuation can be found by

$$I/I_o = e^{-(\mu x/\rho)\rho x} \qquad (3)$$

Where, I_o is the initial beam intensity, I is the transmitted beam intensity, μ is the attenuation coefficient and x is the thickness of the matter. The negative sign indicates that the intensity of the transmitted beam is decreased when the material thickness increases. The attenuation coefficient depends on photon energy, so increasing of gamma ray energy leads to decreasing of attenuation coefficient [14].

Since scattered gamma photons are low, the attenuation of gamma rays can be equal to absorption of gamma photon for both peaks.

The attenuation of gamma ray can be calculated by subtracting the values of CPS of gamma ray transmission through the samples with different ratios of barium sulfate-epoxy painted on the cement blocks from the value of CPS of gamma ray transmission through cement block without coating. The CPS without coating was 2053.00 CPS for the peak of 59.5 keV and 247.27 CPS for the peak of 26.3 keV.

Measuring of gamma ray scattering at the angles 20°, 30°, 45°, 70° and 90° was performed and presented in Figure 5.

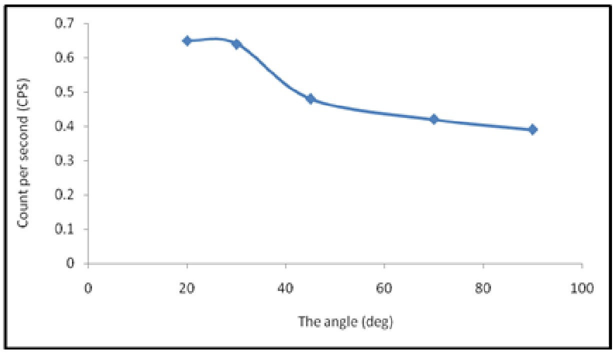

Figure 5. CPS of Scattered Gamma Photon for Different Angles

Figure 5 shows that the increase of scattering angle leads to decrease of gamma ray scattering. There was low decrease of gamma ray scattering at the angle 30°. At the angle 45°, there was relatively high decrease of gamma ray scattering, and CPS of gamma ray scattering recorded is 0.48 CPS. The lowest scattered of gamma photon at 90° angle was 0.39 CPS. Equation 2.3 showed that the energy of scattered photon decreased with increase of scattering angle (θ). The lowest scattered photon energies were at the angle 90°.

Different thicknesses of BE layers were performed in this project; 50% of barium sulfate-epoxy, which was the highest ratio, led to highest radiation protection used. The thickness of each layer of BE was around 1 mm. The relationship between the thickness of the BE layer and the attenuation of gamma ray is shown in Figure 6.

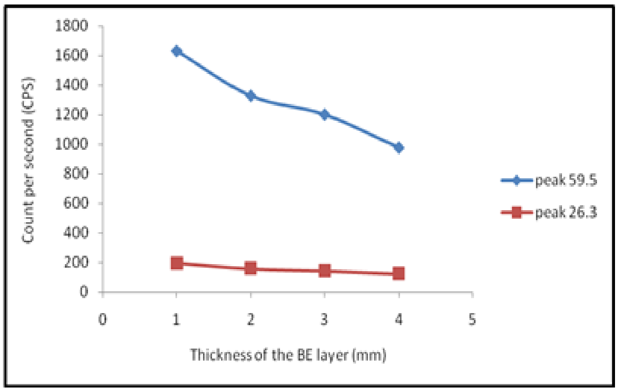

Figure 6. CPS for Gamma Ray Transmission for Different Thicknesses be Layer

There was a high reduction of gamma ray transmission through different thickness of BE layers as shown in Figure 6. The attenuation of gamma ray through the layers of BE were formed by investigating the transmission of gamma ray through the layers. The transmission of gamma rays through cement block without BE mixture was 2053 CPS and 247.27 CPS for both peaks of 59.5 keV and 26.3 keV, respectively. After painting 1 mm of BE mixture on the cement block, the transmission of gamma ray decreased to 1630.37 CPS for peak of 59.5 keV and 194.32 CPS for peak of 26.3 keV. The thickness of 2 mm of BE layer reduced gamma ray transmission to 1326.81 CPS for peak of 59.5 keV and 157.27 for peak of 26.3 keV. Also, there was high attenuation of gamma rays at the thickness 3 mm; gamma ray transmission through 3 mm of BE layer was 1199.35 CPS for peak 59.5 keV and 142.95 for peak 26.3 keV. Gamma ray transmission decreased to 975.3 CPS for peak 59.5 keV and 123.56 CPS for peak 26.3 keV through 4 mm of BE layer. Painting the sample (cement block) of more than four mm layer of BE is available but drying of the mixture becomes harder.

Figure 7 shows decreasing of scattered gamma photons when the thickness of BE layer increases. The scattering of gamma ray at the thickness of 1 mm of BE layer was 0.82 CPS, and there was decrease of scattering of gamma ray to 0.75 CPS at thickness 2 mm BE layer. Then, the scattering of gamma ray decreased to 0.69 CPS at the thickness 3 mm of BE layer. The maximum decrease of gamma ray scattering at the thickness 4 mm was 0.65 CPS.

The different thickness of BE layer, which coated the 4 mm thickness of cement block showed that the increasing on BE layer thickness leads to high attenuation of gamma ray transmission and reduced gamma ray scattering.

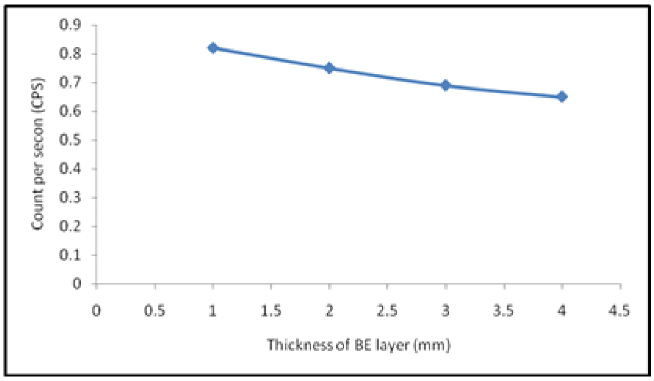

Figure 7. CPS of Scattered Gamma Photon for Different Thicknesses of be Layers

Conclusion

This study considered an appropriate method to measure the radiation scattering and transmission through materials in the principles of ionizing radiation interaction with materials. It has shown that the attenuation of gamma ray through barium sulfate was higher than any other material. Therefore, it could be a good shielding against gamma rays. Gamma photons are less scattered by barium sulfate than by other materials. This study showed that the mixture of BE behaves as a good barrier or shield against radiation during exposure of cement block to short wavelengths.

Epoxy resin was the best material which can be mixed with barium sulfate because it has high density and provides higher gamma ray attenuation than other resins. Epoxy resin was useful in preparing mucilaginous mixture (by mixing epoxy resin with barium sulfate) used as coating materials for radiation protection against short wavelengths. The cement block sample was used to paint with BE mixture because it was more suitable material than other blocks such as wood, aluminum or Perspex and easy to paint and fast drying.

The gradual increase on barium sulfate ratio in BE mixture leads to high gamma ray attenuation. This assures that the high possibility of barium sulfate is to prevent the radiation transmission. The high ratios of barium sulfate in BE mixture leads to high radiation protection which is close to 100% of gamma ray attenuation. There were different methods for using the BE. Increasing of BE mixture thickness was a good method which showed that the increasing of BE mixture thickness leads to higher attenuation of gamma ray. This method of different thicknesses of BE mixture was considered useful and suitable radiation protection that could be proven with high thickness of BE mixture.

The results of this study suggested that new methods of radiation protection can be used in the labs or working places, where radioactive materials are used. The transmission and scattering of gamma ray through BE were measured in order to find high attenuation of gamma rays. High radiation protection using any material needs to make high attenuation of the radiation with low scattering because the short wavelengths radiations cause hazards to human health and environment.

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