ISSN: 0067-2904

# Effect of Barium Sulfate Nanoparticles with Organic Alcohol on the Ionizing Radiation Shielding

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Received: 1/5/2022 Accepted: 23/9/2022 Published: 30/7/2023

**Abstract**

In this study, the gamma ray shielding properties of shields prepared from polyvinyl alcohol as a base material reinforced with barium sulfate nanoparticles at different reinforcement ratios (5,15,25,35,45 %) and thickness 1 cm were studied. To determine the acceptability of these shields for use in gamma ray protection, some parameters including linear attenuation coefficient (μ), mean free path (λ), and half value layer (HVL) were determined using $^{133}Ba$, $^{22}Na$, $^{137}Cs$, and $^{60}Co$ radioactive sources that produced gamma rays with energies of (356, 662, 1173, 1275 and 1332 KeV). The (NaI (Tl)) gamma system was employed for this purpose. The fabricated shields' effective atomic number was also determined. The findings demonstrated that as the reinforcement ratios of the nano-barium sulfate were raised, the linear attenuation coefficient and the effective atomic number of the shields inceased . The mass attenuation coefficient , mean free path and the half value layer decreased as the nano-barium sulfate reinforcement ratios increased.

**Keywords:** $BaSO_4$, Radiation Shielding, Attenuation Coefficients, HVL, $Z_{eff}$

# تاثير كبريتات الباريوم جسيمات نانوية مع كحول عضوي على دروع الاشعاع المؤين

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**الخلاصة**

في هذا العمل، تم دراسة خصائص التدريع لأشعةكاما من الدروع المصنعة التي تتكون من كحول البوليفينيل كمواد أساسية معززة مع كبريتات الباريوم النانوية مع نسب تدعيم مختلفة (5%،15%،25%،35%،45٪)، وسمك 1سم ، لتحديد مدى ملاءمة هذه الدروع للاستخدام في الحماية من أشعة كاما، تم قياس بعض المعلمات مثل معامل التوهين الخطي ($\mu_l$)، معدل المسار الحرة ( λ ) ووقيمة طبقة النصف ( HVL) باستخدام مصدر ($^{133}Ba$ , $^{22}Na$ ,$^{137}Cs$ and $^{60}Co$) ينبعث منها أشعة كاما بطاقة ( 356 ,662, 1173, 1275, 1332 كليو الكترون فولت ). لهذا الغرض، تم استخدام كاشف الوميضي ((NAI (TL) ) كما تم احتساب العدد الذري الفعال من الدروع المصنعة. أظهرت النتائج أن معامل التوهين الخطي والعدد الذري الفعال للدروع يزداد بزيادة نسب التدعيم لكبريتات الباريوم النانوية . لاحظنا أيضا أن معامل التوهين الكتلي ,معدل المسار الحر وقيمة طبقة النصف يقل بزيادة نسب التدعيم لكبريتات الباريوم النانوية.

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## 1. Introduction

The most essential task of shielding is lowering exposure for individuals in radiation-rich areas. Radiation shielding, also known as radiological shields, serves numerous purposes. Addressing the problem of radiation shields, which affected many aspects of our daily lives, especially in light of the great progress in science based on the use of radioactive isotopes and nuclear reactor facilities, as well as other scientific fields such as nuclear technology and power generation [1]. This technique created overlapping materials from different materials to achieve gamma-ray shielding capability.

In earlier work, the linear attenuation coefficient and half value layer of poly methyl methacrylate (PMMA) and bismuth trioxide ($Bi_2O_3$) were assessed using gamma sources ($^{137}$Cs, $^{133}$Ba and $^{60}$Co). The findings demonstrated that the addition of $Bi_2O_3$ significantly improved the gamma shielding capability of PMMA compounds and had a substantial impact on the determination of the linear mass attenuation factor and half value layer. PMMA/$Bi_2O_3$ compounds have demonstrated as potential gamma-shielding materials [2]. The ionizing radiation shielding performance features of waterborne polyurethane (WPU) composites embedded with tungsten trioxide ($WO_3$) and bismuth trioxide ($Bi_2$O3) were examined. The results showed that the protective characteristics of the compounds against gamma rays improved with $WO_3$/$Bi_2O_3$ loading, and that the nanocomposites were more capable of attenuating gamma rays than the microcomposites. [3]. In this work, polyvinyl alcohol and barium sulfate nanoparticles in various concentrations were used to make shields. Gamma sources were used in routine shielding research to look into the shielding characteristics.

The Beer-Lambert formula for the change in radiation intensity with change in material thickness is used to evaluate gamma-ray attenuation using the following equation for each radiation-matter interaction [4,5]:

$$I = I_0 e^{-\mu x} \quad \ldots(1)$$

X is the thickness (cm),$I$ and $I_0$ are the final and initial intensities, respectively, and μ is the linear attuation coefficient (cm). This exponential relationship demonstrates that the material does not include a specific gamma radiation range. As a result, the mean free path, which measures the average distance between consecutive photon reactions, as given by the following equation, can be recognized [6]:

$$\lambda = \frac{1}{\mu} \quad \ldots(2)$$

The following formula explains the Half-Value Layer (HVL) as the thickness of shield material required to reduce the radiation intensity to half of its intitial intensity:

$$X_{1/2} = \frac{0.693}{\mu} \quad \ldots(3)$$

The effective atomic number ($Z_{eff}$) can be defined as[7]:

$$\sigma_m = \mu_m \frac{\sum_i n_i A_i}{N_A} \quad \ldots(4)$$

$$\sigma_a = \frac{\sigma_m}{\sum_i n_i} \quad \ldots(5)$$

$$\sigma_e = \frac{1}{N_A} \sum_i \frac{f_i A_i}{Z_i} \mu_i \quad \ldots(6)$$

$$Z_{matrix} = \frac{\sigma_a}{\sigma_{el}} \quad (7)$$

$$Z_{eff} = \frac{\sigma_a}{\sigma_{el}} \quad (8)$$

## 2. Experimental Work

Samples were prepared using nano barium sulfate $BaSO_4$ with polyvinyl alcohol (PVOH or PVA), which is a water-soluble synthetic polymer. It has the ideal formula $CH_2CH$ (OH)] n]. All chemicals were accurately weighed using a sensitive 0.0001 g precision electronic balance in weight ratios of (0.5, 0.15, 0.25, 0.35, and 0.45% w/v) according to the $BaSO_4$ concentration after the PVA solution in a beaker. It was stirred with 300 ml of water at 70 °C for 1 hour. After the first gel phase development was achieved, a clear solution was produced and blended with BaSO4. A controlled fan effectively mixes the mixture before transferring it to an ultrasonic mixer to complete the mixing operation. This device was used for approximately 15 minutes to obtain the optimal formula. The mixture was mixed well to free it of gaps, then the mixture was transferred to a mold designated for pouring and was left to dry for 10 days at room temperature.

## 3. Results and Discussion

The linear attenuation coefficients were measured experimentally using Equation (1) by detecting the radiation intensity before and after the shields were placed. using The (NaI (Tl)) gamma spectray system. Table(1) illustrates the calculated values of the linear attenuation coefficients for the prepared shield. It should be observed that the linear attenuation coefficient is proportional to the density of the composite materials, so that the mass of the prepared shield increases as the concentration of the reinforced material increases. This is due to a increase in the effective atomic number of the prepared shield, which improves the linear attenuation coefficient, as illustrated in Figure (1).

The linear attenuation coefficients reduced as the photon energy increased, as can be observed. Furthermore, due to the dominance of the photoelectric effect, the linear attenuation coefficient reduces fast as photon energy fall (e.g. 356 keV, 662 keV). Compton scattering and pair production are common at 1173 keV, 1234 keV, and 1333 keV, respectively [8]. The values of the mass attenuation coefficients are clearly dependent on the concentration of the shielding material and the incident photon energy. The values of the mass attenuation coefficient decrease as the concentration of $BaSO_4$ increases, which is due to a increases in the mass of the prepared shield and therefore an increase in the density of the prepared shield. The results also revealed that as photon energy rises, mass attenuation coefficients reduce, with photoelectric absorption making up the largest portion of the total mass attenuation coefficients. The behavior of the mass attenuation coefficients in the higher energy range may be attributed to incoherent scattering. Furthermore, the energy of the incoming photon influences the variation of the effective atomic numbers. Extreme values of this parameter can be obtained in the low energy region, where photoelectric effect processes predominate.

another important factor of gamma ray protection effectiveness is the mean free path values which can be obtained from Equation (2). It was noted that by increasing the concentration of the reinforced material, mean free path decreased, which means that the performance of the material for the prepared shield for radiation protection is better, and this factor also increased with the increasing of gamma ray energy. This indicates that the material provides good protection from radiation. Figure (2) shows the behavior of m.f.p with $BaSO_4$ concentration of the prepared shield.

The (HVL) results obtained from Equation (3) were produced for shield samples prepared using barium sulfate nanoparticles with polyvinyl alcohol to investigate their shielding ability. Figure (3) illustrates the variation of HVL with the concentration of barium sulfate nanoparticles in the prepared shield. The HVL values increased as gamma ray energy increased. Furthermore, increasing the concentration of barium sulfate nanoparticles in the prepared shield decreased HVL.

**Table 1** The linear and mass attenuation coefficients, mean free path and half value layer of prepard shields

| Parameter | Concentrations of $BaSO_4$ | 356 (KeV) | 662 (KeV) | 1173 (KeV) | 1275 (KeV) | 1332 (KeV) |
|---|---|---|---|---|---|---|
| $\mu_l$ ($cm^{-1}$) | 5% | 0.1546 | 0.1276 | 0.0858 | 0.0637 | 0.0609 |
| | 15% | 0.1568 | 0.1336 | 0.0925 | 0.0752 | 0.06878 |
| | 25% | 0.1837 | 0.1385 | 0.1005 | 0.0779 | 0.0742 |
| | 35% | 0.2010 | 0.1455 | 0.111 | 0.0825 | 0.0768 |
| | 45% | 0.2120 | 0.1518 | 0.1253 | 0.08561 | 0.0810 |
| $\mu_m$ | 5% | 0.113856 | 0.093972 | 0.063188 | 0.046912 | 0.04485 |
| | 15% | 0.116968 | 0.091141 | 0.063711 | 0.051301 | 0.046921 |
| | 25% | 0.115379 | 0.086989 | 0.063144 | 0.048928 | 0.046604 |
| | 35% | 0.115369 | 0.083513 | 0.063122 | 0.047353 | 0.044081 |
| | 45% | 0.11022 | 0.078922 | 0.063103 | 0.044509 | 0.042112 |
| $\lambda$ (m.f.p) | 5% | 6.468305 | 7.836991 | 11.65501 | 15.69859 | 16.42036 |
| | 15% | 6.377551 | 7.48503 | 10.81081 | 13.29787 | 14.53911 |
| | 25% | 5.443658 | 7.220217 | 9.950249 | 12.83697 | 13.47709 |
| | 35% | 4.975124 | 6.872852 | 9.009009 | 12.12121 | 13.02083 |
| | 45% | 4.716981 | 6.587615 | 7.980846 | 11.68088 | 12.34568 |
| HVL (cm) | 5% | 4.482536 | 5.431034 | 8.076923 | 10.87912 | 11.37931 |
| | 15% | 4.419643 | 5.187126 | 7.491892 | 9.215426 | 10.0756 |
| | 25% | 3.772455 | 5.00361 | 6.895522 | 8.896021 | 9.339623 |
| | 35% | 3.447761 | 4.762887 | 6.243243 | 8.4 | 9.023438 |
| | 45% | 3.268868 | 4.565217 | 5.530726 | 8.094849 | 8.555556 |

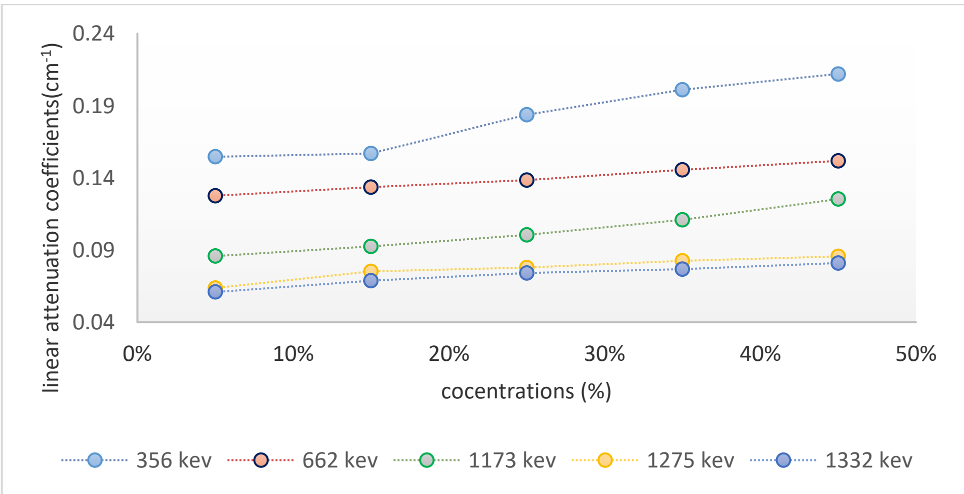


**Figure 1:** The linear attenuation coefficients of prepard shields as a function of concentration of $BaSO_4$ in (%)

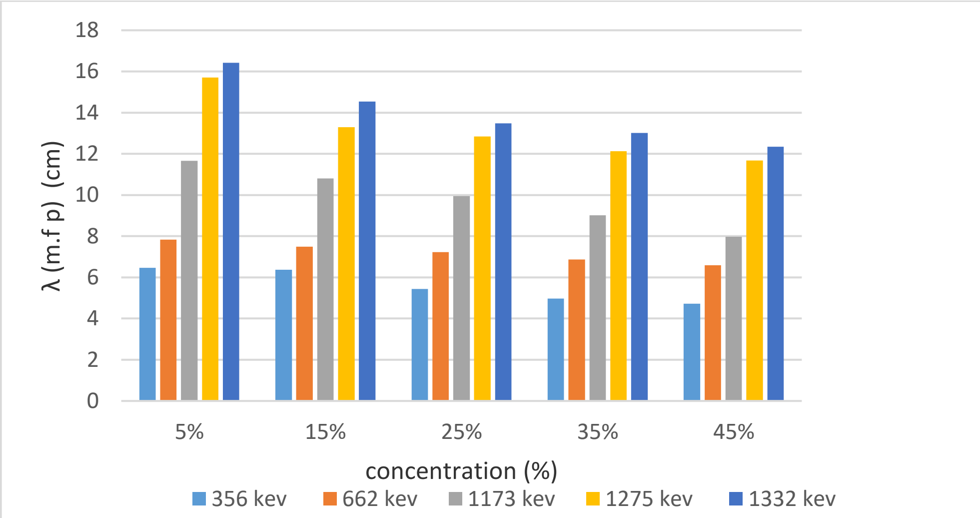


**Figure 2: T**he m.f.p of prepard shields as a function of concentration of $BaSO_4$ in (%)

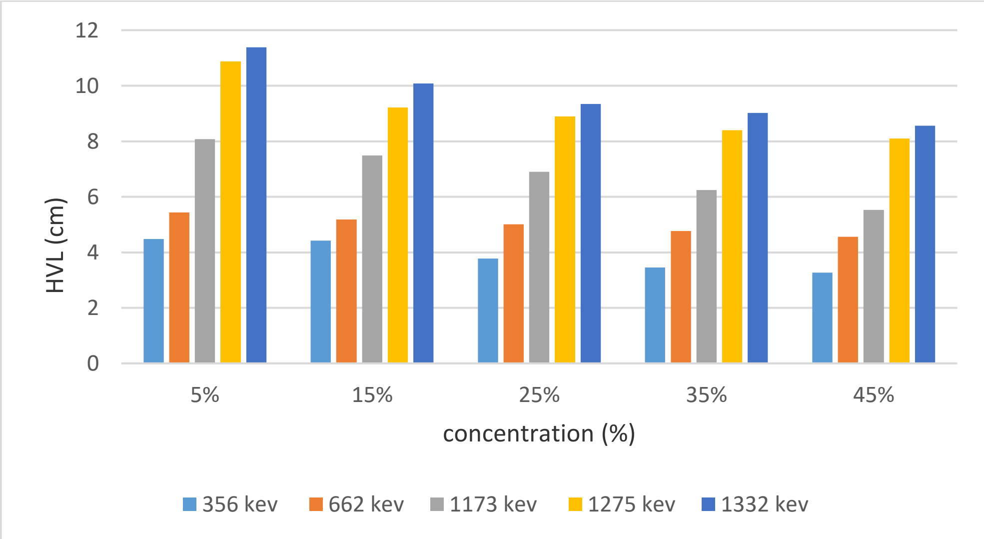


**Figure 3: T**he half value layer of prepard shields as a function of concentration of $BaSO_4$ in (%)

Table (2) illustrates the effective atomic number of the prepared shields, which is an important factor computed using the equations of the weight fraction of the composite materials for the atomic number.

**Table 2:** The effective atomic number of prepard shields

| Concentrations of $BaSO_4$ | $Z_{eff}$ |
|---|---|
| 5% | 6.23551 |
| 15% | 16.52665 |
| 25% | 26.8175 |
| 35% | 37.1085 |
| 45% | 47.3995 |

## 4. Conclusion

The linear attenuation coefficients, mean free path, and half-value layer values all changed as the amount of barium sulfate nanoparticles in the polyvinyl alcohol increased, which also has an impact on its mechanical properties and radiation shielding efficiency. The results showed that the investigated materials' elastic properties were improved with the addition of barium sulfate nanoparticles. The polyvinyl alcohol based on barium sulfate nanoparticles is more effective as a shielding material.

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