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RESEARCH ARTICLE - PHYSICS

Multilayer Shields' Buildup Factor for Gamma Ray Exposure

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Abstract

Iron discs were coated on both sides with distinct layers of W, Bi, and Pb powders. Three multilayer samples (coated Fe plates with W), (coated Fe plates with Bi), and (coated Fe plates with Pb) were produced by stacking ten powder-coated Fe discs on top of one another and sealing them with epoxy. The average particle sizes for W, Bi, and Pb were found to be 35, 40, and 30 nm, respectively, based on the images obtained using the scanning electron microscopy (SEM) test. Using a gamma spectrometry system with a NaI (Tl) detector, the transmission factor (T %), radiation protection efficiency (RPE), and built-up factor (B) have been calculated for four distinct gamma energies. For all samples, T% increased as energy increased, and the powder utilized will determine how comparable the data are.RPE% was 20% for lead-coated iron samples at 1332 MeV, the highest of all the samples. At lower energies, the RPE% for most samples was greater than 70%, and as energy increased, it steadily declined. According to the results, the gamma-ray buildup factor and gamma energy have an inverse relationship.

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Keywords: Gamma ray, Buildup Factor, attenuation, multilayer, protection.

Introduction

The most common ionizing radiation that is known to be harmful to human health and genetics is X-rays and gamma-rays. When radiation is exposed to organs or tissues, it loses some its energy through different kinds of interactions and this loss of energy may ionize the atoms of the cell, destroying the normal chemical equilibrium of the cell and eventually can bring death to the cell [1].

The primary purpose of nuclear shields is to protect people from radiation by attenuating and reducing the intensity of radiation. As a result, the theme of radiation shields has become increasingly important in our daily lives, particularly in light of the significant advancements in science that have focused on the use of radioactive materials and other radiation sources in medical and agricultural fields, as well as other scientific fields like the construction of nuclear reactors and reactor research in the field of power generation. It is necessary to look at alternative efficient shielding methods that might offer a certain degree of protection at a minimum cost, as resources are becoming increasingly rare and the cost and availability of materials for radiation shielding is a problem.

In current work, multilayer shielding is used. These shielding sometimes requires the use of a number of materials, each with their own distinct set of properties, to provide effective protection against a broad range of ionizing radiation types. Nanomaterial's have the capability of playing a function in multi-layer radiation shielding by introducing new materials and ways for increasing the efficacy of present shielding materials. Numerous researchers have looked at the use of Nano composite materials, which combine traditional shielding elements with Nano scale particles to create novel hybrid composites with enhanced radiation shielding qualities [2].

The buildup factor is correction factor that takes into consideration the increase in radiation transmission through shielding material that is observed because of scattered radiation. Radiation gets a chance to interact with the atoms in a shielding material as it travels through it. It is either absorbed or scattered when this occurs. Both situations result in the production of secondary radiation, such as beta or gamma. In addition, the radiation particles' direction may alter throughout the scattering process. Eventually, a small portion of the scattered particles passes through the shied. The buildup is the term for this phenomenon. Ignoring this component might lead to significant mistakes in shielding computations [3].

Factor (B) for multilayer shielding is more complex than in single-layer shielding [4]. This is because absorption and scattering can produce a flux with an energy spectrum when a monoenergetic radiation flux travels through the first layer. This complicates the process of finding out the attenuation factor for the shielding calculation (cross sections, linear attenuation, mass attenuation coefficient). As a result, several researches have been conducted using simulations and tests to determine the accumulation factor for various multilayer shielding designs[5].

The kind of radiation, its intensity, the type of shielding material, and the geometry involved all affect the buildup factor[6]. The thickness of each layer and the arrangement of the materials also have a major impact [7]. Buildup factor (B) can be calculated using the following relation[8].

$$B = \frac{I_b/I_{ob}}{I_g/I_{og}} \quad \text{-------------- (1)}$$

Where I_b is the intensity of the entire beam in the presence of the shield (bad geometric arrangement), I_{ob} is the total beam intensity in the absence of the shield (bad geometric arrangement), I_g is the entire beam's intensity during the presence of the shield and collimator (good geometric arrangement). I_{og} is the overall beam's intensity with the single collimator (good geometric arrangement).

The radiation protection efficiency (RPE%), which is a parameter that may be used to examine an absorber sample's shielding effectiveness, is provided by the following equation [9]:

$$RPE\% = \left(1 - \frac{I}{I_0}\right) * 100 \quad \text{---------- (2)}$$

Where I_0 is the intensity of incident radiation and I is the intensity of transmitted radiation. The quantity of photons transferred through the artificial materials is determined by the transmission factor (I/I_0) [10]. Both quantities RPE% and transmission factor (I/I0)% were calculated for the prepared samples to evaluate their shielding properties.

Many methods were utilized to deposit nanoparticles including hydrothermal technique and Rapid breakdown anodization [11],[12]. Current paper is used to deposit the three Nano powders due to its properties and it is easy to work with and does not require expensive or complex equipment.

This study aims to investigate shielding properties of multilayer samples, like T% , RPE% and the buildup factor for multilayer samples.

Experimental part

Materials and Methods

Pb, Bi, and W nanoparticles were bought from Guangzhou Hongwu Material Technology Co., Ltd. Their particle sizes are 30, 36 and 40 nm respectively).The three powders were put on individually iron discs (with radius and thickness equal to 1.25 cm and 0.08 cm respectively) using the casting procedure, covering the discs' two surfaces with powder. The coated and stacked Fe discs on top of each other are displayed in Fig. 1.

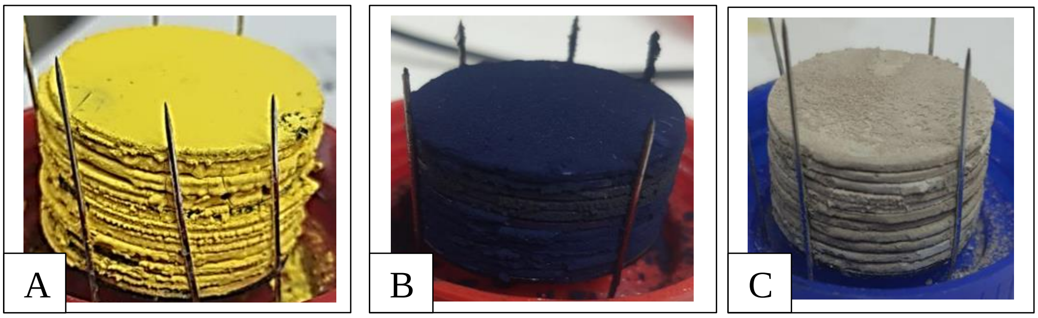

Figure.1. coated iron with A: W powder B: Bi powder and C:pb powder

Else ware reports on the specifics of shielding property measurement [13]. Four radioactive sources were used: Am-241 [59.04keV], Cs-137 [661.6 Kev], Co-60 [1137keV], and Co-60 [1332keV] in addition to an HPGe detector. Model NAIS-3x3, a sodium iodide scintillation detector, was used. An aluminum-encased NaI (Tl) crystal, a photomultiplier tube, a preamplifier, stabilization electronics, an internal magnetic/light shield, a high-voltage power supply (HVPS), and an 8-pin Mirion-specific connector made comprised the detection system. Using of SEM enabled the identification of both the surface topographies and the particle sizes.

For the goal of analyzing the buildup factor of the fabricated shields, collimator was employed to build the good geometric arrangement that by lifting it we obtain the bad geometric arrangement. The lead material collimator has a circular hole with a diameter of 5 mm in the middle.

In Figure 2, the collimator in front of the attenuator is removed to provide the broad beam geometry.

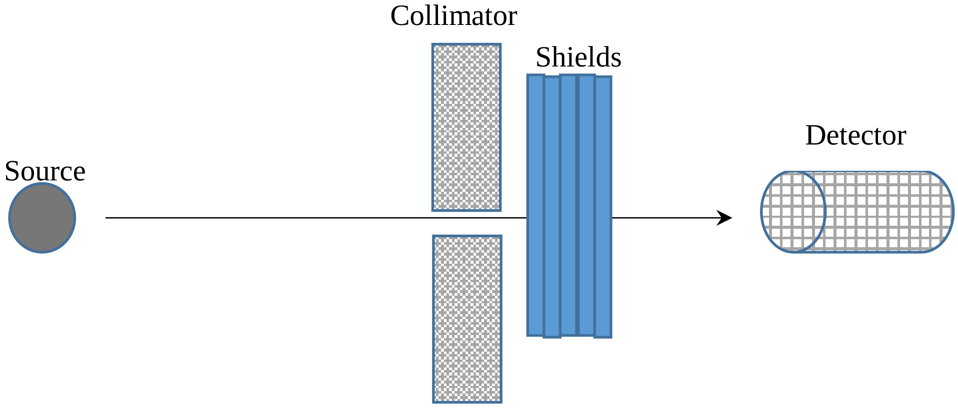

Figure2. The setup of shielding measurements

The thickness of each part is shown in Table 1.

Table 1. Some multilayer samples' parameters.

Sample type	The total thickness of the Epoxy layer(cm)	The total thickness of powder (cm)	The total thickness of iron layers (cm)	The total sample thickness (cm)
Fe plate + Epoxy	1.55	-------	0.88	2.43
Fe plate + (Pb) +Epoxy	0.648	0.882	0.88	2.41
Fe plate + (Bi) +Epoxy	0.826	0.714	0.88	2.42
Fe plate + (W) +Epoxy	0.862	0.678	0.88	2.42

Results and discussions

The SEM images in Fig. 3 verify the sizes of the used powder's nanoparticles. W, Bi, and Pb were found to have average particle sizes of 35, 40, and 30 nm, respectively. In comparison to microparticles, it was discovered that the nanoparticles improved the morphological characteristics and decreased the voids in the shields [14]. There will be a greater chance of radiation and nanoshielding material being collided. The nano shielding member's thickness and volume could be reduced compared to shielding members that include microscale particles. When nanoparticles are employed as shielding materials, the radiation's mean free path may be shortened, increasing the probability that the radiation will be absorbed (and decay), so providing an effective radiation shield[15].

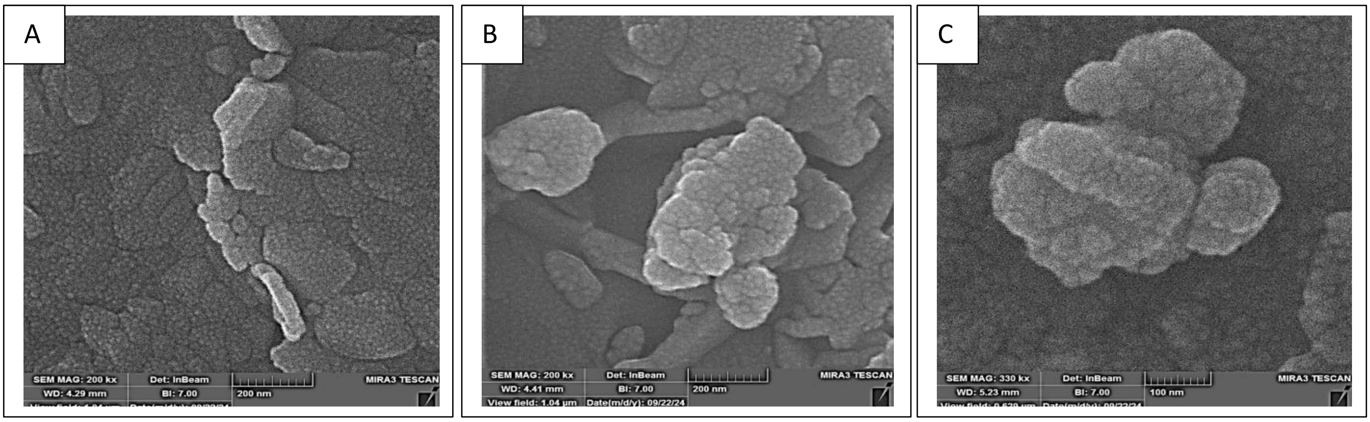

Figure.3. The used powders' nanoparticles: A) Pb, B) Bi, C) W.

Four multilayer shielding samples' observed gamma ray spectra from various sources are graphically shown in Figure 4. We performed these tests with and without using a collimator. When the multilayer shielding was placed in front of the gamma-ray spectrum source, the only thing that changed was its intensity. The fact that the intensities are lower than the source intensities amply demonstrates how well all of the samples produced in this work attenuate gamma rays. It is clear from the peaks shown in the figure that the decrease in intensity is greater at lower energies and decreases with increasing energy of the incident rays.

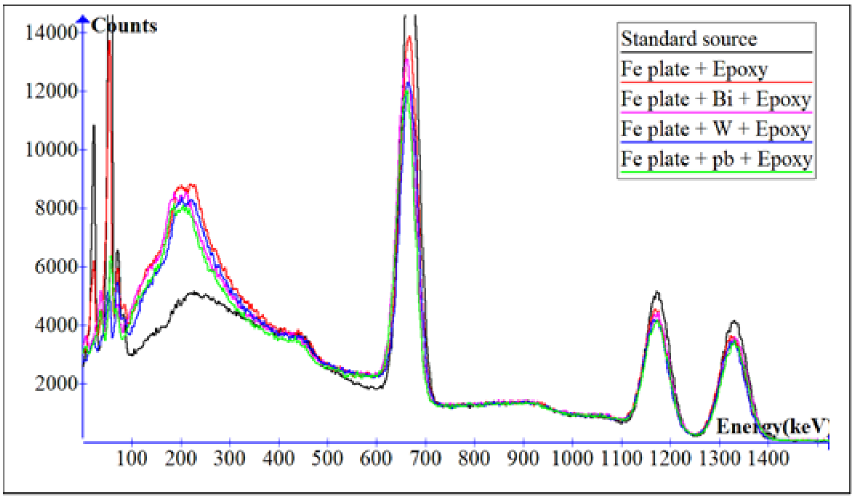

Figure. 4. Multilayer sample measured gamma ray spectra (without collimator).

The relationship between T% and energy is depicted in Figure 4.A., its increases rabidly during the low energy values and then, it reaches saturation with high energy levels. A comparison of the T% between uncoated iron with nanoparticles and those coated with one of the three nanoparticles reveals a reduction, which is indicative of these particles' ability to block gamma rays at all energies.

In order to assess the medium's effectiveness as a safe radiation protective material, it is common practice to estimate the radiation protection efficiency. This allows one to comprehend the medium's photon-blocking capacity [16].

Shielding qualities are weakened by the existence of vacancies, which also stops the radiation shielding effects from improving [17]. In the current work, RPE% data (Figure 5.B) reflect the amount of voids inside these samples. The sample with higher voids has lower RPE%. Because higher energy photons pass through the samples more readily, there is less photon attenuation by the shields, which results in a decrease in RPE. This outcome also suggests that the current specimens are more effective in blocking photons with lower energy.

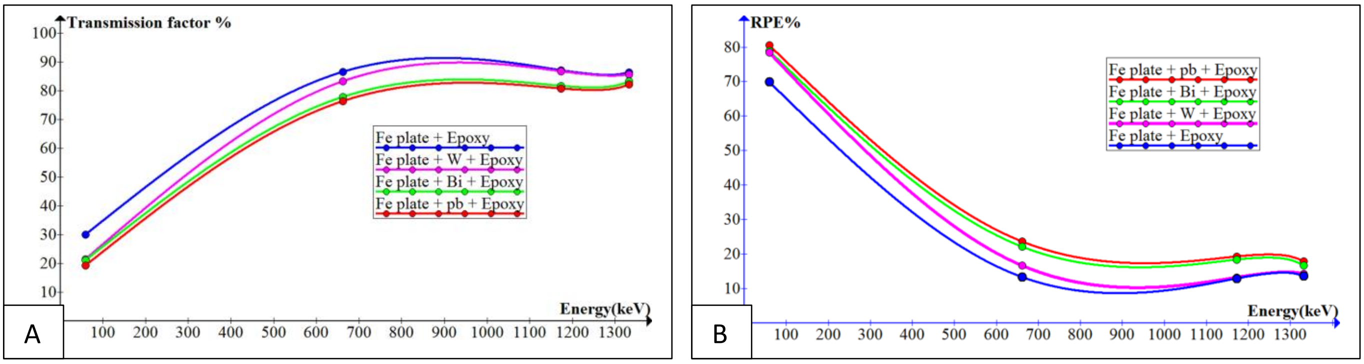

Figure. 5. A: T% and B: RPE% for multilayer samples (without collimator).

Figure.5 shows the relationship between the build factor and the energy. At a high energy level, the absorption buildup factor is at its lowest, this result in agreement with that obtained by[18] . The outcome of Fig.5 shows that there is an inverse relationship between the increase in energy and the gamma ray build up factor. This trend indicates that, because the Compton effect is inversely related to energy, the probability of the Compton effect decreases as energy within the investigated energy range increases. Compton scattering is the predominant photon interaction mechanism in the energy range of 0.1 MeV to 0.15 MeV, while photoelectric absorption is comparatively insignificant, resulting in huge build up factors. Huge numbers of Compton processes are needed to reduce the energy of these photons, which leads to the building up of photons. The photoelectric cross-section is known to be inversely proportional to $E^{7/2}$. It implies that low-energy photon absorption usually depends on the photoelectric effect. Hence, the buildup factor is negligible at low energy region (<0.06 MeV) [19]. The photons were not eliminated by the Compton process. However, it slowed them down because photons collided and scattered with electrons, which reduced the photons' kinetic energy and increased their collection of photons [20]. Secondly, there is an increase in the ability of the material to penetrate with Gamma radiation, which reduces the possibility of scattering with small angles.

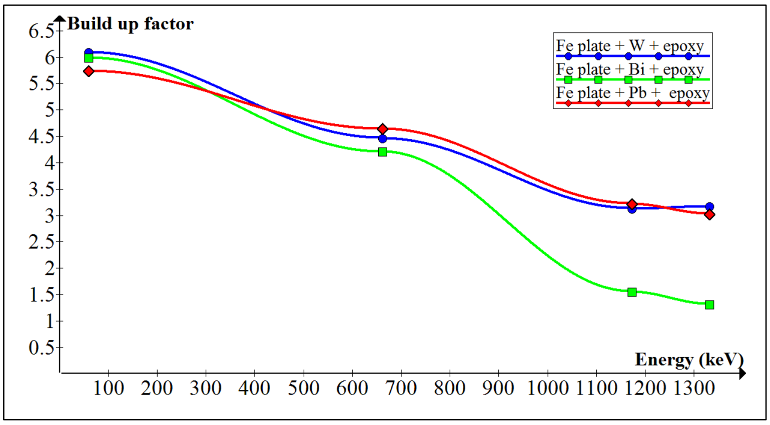

Figure. 6. Buildup factor versus photo energy.

Conclusions

i) T%, RPE% and Buildup factor are a function of both photon energy and the type of multilayer sample.
ii) The multilayer sample that was made from coated pb powder had the best shielding properties due to its relatively lowest particle' size.
iii) The research shows the importance of using nanomaterials in manufacturing shielding against gamma-rays. The smaller the particle size and the fewer voids in the powders used, the better the shielding.

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