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Investigation of Density and Thickness of Geopolymer Concrete as Gamma Ray Radiation Shielding Application

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Abstract: This study focused on the investigation of the density and thickness of geopolymer (GP), which consist of various material, including sand, clay, brick, cement, ceramic, and granite as their major composition. When radiation is exposed with high doses, it may be preferable to have something that can attenuate or penetrate the radiation. GP concrete remains an issue to consider as one of the alternatives for radiation protection material. It is selected in this research to determine the potential of geopolymer to become a radiation shielding material. The preparation of GP concrete involved different percentages of material and mass with the addition of the same volume of binding agent, which is polyvinyl alcohol (PVA). The two main parameters were focused on in this work, including their density and thickness. The materials were dried under sunlight before being grinded, sieved, and compressed into the form of a pallet. The GP pallets were then sintered at 1100°C in order to ensure their mechanical properties. As it was complete, all the samples were irradiated using Co-60. OD-02 survey meter was used to identify dose rate analysis. GP 6, which consist of the major material which is 10% sand, 10% clay, 20% brick, 20% cement, 20% ceramic, and 20% granite, have revealed to have a better particle matrix and ability as a geopolymer candidate to attenuate and penetrate Co-60 radiation. In terms of thickness, GP10 shows better performance in attenuating gamma ray shielding as it has the thickest geopolymer, which is 17.35 mm. In short, in the present, GP was able to be a shielding candidate for gamma-ray radiation shielding.

Keywords: Geopolymer, Gamma Ray, Shielding, Density, Thickness

1. Introduction

Radiation is energy that emits from a source and moves through space at the speed of light. This kind of energy has so many advantages for society scientists have been researching it extensively for a long time. Since ionization radiation can enter our bodies and provide images of our bones, it is useful in X-rays [1]. However, radiation exposure, particularly high doses of ionizing radiation, can damage the cells in our bodies and increase the risk of cancer [2]. In order to lower radiation levels to levels that

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are safe for people, radiation shielding involves a barrier between radiation sources and the materials around them. Understanding attenuation and penetration is crucial when talking about radiation protection because they are important concepts in radiation knowledge. Attenuation is the process of reducing the intensity of an X-ray beam or other radiation [3]. A bean's photon absorption or deflection may reduce the outcome. Numerous variables, including the atomic number of the absorber and the beam energy, might affect it. The quantity of radiation attenuated by a specific absorber thickness is measured by an attenuation coefficient, μ [3].

One alternative for radiation protection materials is GP concrete. It is chosen in this study to examine GP's potential as a radiation-shielding material. This geopolymer material was mainly produced using various types of material, including silicon and aluminum, with the addition of an alkaline solution [4]. Therefore, since GP concrete is widely available, its production must be inexpensive [5].

In this context, GP material was chosen as each of the materials consists of a different number of attenuation coefficients. It was believed that the addition of various materials in GP could increase the attenuation coefficient itself and improve the performance of GP to absorb gamma-ray radiation. This can be done by irradiating several GP prepared with a gamma radiation source, Co-60, in order to observe their performance as radiation shielding.

The aim of this research was to fabricate a GP concrete with different material ratio percentages for gamma ray shielding. Next, to measure its GP ability to shield gamma rays with various densities and thicknesses. In this project, the materials for GP samples, including clay, sand, brick, cement, ceramic, and granite, are collected from Kota Tinggi, Johore, Malaysia. At the end of this work, all results and data for all specimens were compiled and compared together for better results.

2. Materials and Methods

In this project, there are four important parts of methodology, which are the preparation of PVA solution as the binding agent, preparation of the sample, physical measurement of GP samples, and exposure of GP samples to Co-60 radiation. The preparation of PVA was started by mixing 50g of PVA powder with 200ml of distilled water. The mixing process was conducted by using a magnetic stirrer for 30 minutes. The preparation of the sample was started as all the material were dried under outdoor sunlight for 24 hours. The next step was followed by a grinding process using a ball mill for 24 hours and a sieving process using 100µm siever. After all, the GP was weighed with specific mass and added with a drop of PVA prepared; all the GP were pressed using a Hydraulic Pressure Machine under three tan of pressure for 2 minutes and sintered using a Box Furnace for 1 hour duration with 1100°C of temperature and 5°C/min rate of heating and cooling. The measurements of physical GPs involving their density and thickness were taken. Next, all the GPs were irradiated with Co-60 respectively for 1 hour, and the results were observed.

2.1 Particle Matric of Geopolymer Concrete

In this section, the particle matric was divided into two parts, which is the density and thickness parameters of GP. The various density of GP has different percentage of the material consisting of clay, sand, cement, brick, ceramic, and granite with the same total mass, which is 10g, respectively, for each GPs. For the various thicknesses of GP, it contains the same particle matric as GP6, which is 10% sand, 10% clay, 20% cement, 20% brick, 20% ceramic, and 20% granite with various total masses of GP which are 4g, 6g, 8g, and 11g. Thus, GP particle matric for density and thickness parameters were illustrated in Table 1 and Table 2.

Table 1: Particle matric of geopolymer concrete for density parameter

GP	Mass of material (g)						Total mass (g)
	Clay	Sand	Cement	Brick	Ceramic	Granite	
GP1	10	-	-	-	-	-	10
GP2	5	5	-	-	-	-	10
GP3	2.5	2.5	5.0	-	-	-	10
GP4	2.5	2.5	2.5	2.5	-	-	10
GP5	2.0	2.0	2.0	2.0	2.0	-	10
GP6	1.0	1.0	2.0	2.0	2.0	2.0	10

Table 2: Particle matric of geopolymer concrete for thickness parameter

GP	Mass of material (g)						Total mass (g)
	Clay	Sand	Cement	Brick	Ceramic	Granite	
GP7	0.4	0.4	0.8	0.8	0.8	0.8	4
GP8	0.6	0.6	1.2	1.2	1.2	1.2	6
GP9	0.8	0.8	1.6	1.6	1.6	1.6	8
GP10	1.1	1.1	2.2	2.2	2.2	2.2	11

2.2 Methods of density measurement

For density measurement of GP, 6 specimens of GP, including GP1, GP2, GP3, GP4, GP5, and GP6 were observed based on their weight, thickness, and diameter to fulfill its density measurement. The density for each of the GP specimens was calculated by using Eq. 1 [6]:

$$\text{Bulk density (g/mL)} = M/V_0 \qquad \text{Eq. 1}$$

where, M = mass in gram

V_0 = volume in milliliters

2.3 Methods of thickness measurement

The measurement of thickness involving GP7, GP8, GP9, and GP10 were measured using Digital Vernier Caliper to observe their thickness. As stated before in Table 1, the particle matric of GP6 was chosen for the mixture of GPs in this part that consists of 10% sand, 10% clay, 20% cement, 20% brick, 20% ceramic, and 20% granite.

3. Results and Discussion

3.1 The density measurement for the geopolymer sample

Based on Equation 1, the density was calculated with the presence of mass, thickness, and diameter of each GP. Each GP has different material composition in it, as shown in Table 1, while 10g was selected as their constant total of mass. There were 6 specimens related to density measurement. Table 3 illustrates the density of GP related, and Figure 1 shows the GPs prepared.

Table 3: The density measurement of geopolymer

GP	Mass (g)	Thickness (cm)	Diameter (cm)	Volume (g/cm^3)	Density (g/cm^3)
GP1	9.6816	1.593	2.011	5.06	1.914
GP2	9.3161	1.514	2.004	4.78	1.951
GP3	9.5510	1.586	1.978	4.87	1.960
GP4	9.4534	1.515	2.013	4.82	1.961
GP5	8.6439	1.334	1.998	4.18	2.067
GP6	8.5531	1.391	1.891	3.91	2.190

Figure 1: The GPs prepared with different density

Based on Table 3, the mass presented was slightly decreased from the initial mass which is 10g. The decrease of the mass value occurred because all the GP undergoes weight loss during pressing and sintering process [7] [8]. The density measurement was inversely proportional to the volume of GP. In comparison to other GPs, GP1 had the maximum volume of 5.059 cm^3 but the lowest density, 1.914 g/cm^3. As more other materials were added to the GP, the density value of each GP gradually increased from GP1 to GP6 [9]. Among the GPs, GP6 had the smallest volume, 3.906 cm^3, and the highest density, 2.190 g/cm^3. Accordingly, GP6, which contains 20% of brick, cement, ceramic, and granite and 10% of clay and sand, would like to show a better reading of dose rate as material shielding compared to other GPs in order to achieve the previously mentioned purpose.

3.2 The thickness measurement for geopolymer samples

The measurement of GP thickness was measured using Digital Vernier Caliper. All the GPs were prepared accordingly, as demonstrated in Table 2. There were 4 specimens that related to achieving previously aimed states, including GP7, GP8, GP9 and GP10. Table 4 shows the thickness measurement of the GPs, and Figure 2 illustrates the GPs prepared.

Table 4: The thickness measurement of geopolymer

GP	Mass (g)	Thickness (mm)
GP7	3.8972	6.45
GP8	5.7871	9.51
GP9	7.6242	12.53
GP10	10.5221	17.35

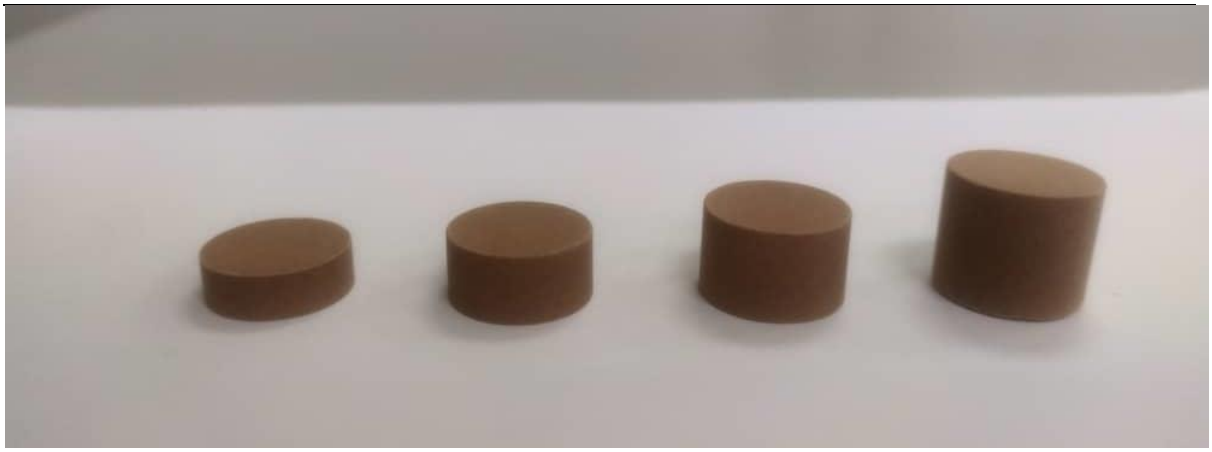
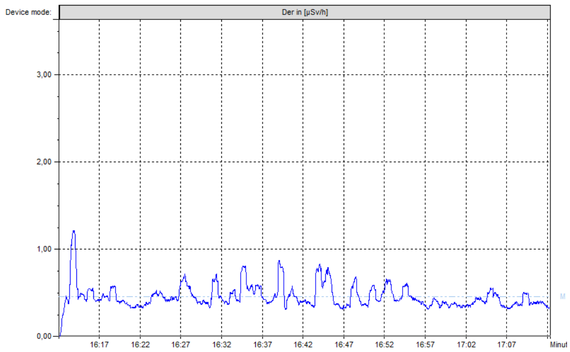


Figure 2: The GPs prepared with different thickness

The mass for GP7, GP8, GP9, and GP10 were selected differently to obtain a random value of thickness despite having the same ratio and percentages of GP mixture, which is composed of 10% clay, 10% sand, 20% brick, 20% cement, 20% ceramic, and 20% granite. For GP7, GP8, GP9, and GP10, the initial GP mass was 4g, 6g, 8g, and 11g. The weight of the GP is lost throughout the preparation procedure. Each GP's thickness gradually increased as mass increased [10] from GP7 to GP10. With a mass and thickness of 3.8972 g and 6.45 mm, GP7 had the lowest values. GP10 displays the highest value of thickness because its mass, at 10.5221g and 17.35mm, was the largest. Due to its greater GP thickness than GP7, GP8, and GP9, GP10 would be a good GP shielding material.

3.3 Average dose rate and peak count of radiation

All the GPs were irradiated with Co-60 with 1µCi of activity as a gamma radiation source and detected by OD-02 Survey meter. The dose rate was measured by STEP OD-02 software, and the peak count of each dose rate measured was calculated. Figure 1 shows the graph of the dose rate for each GPs and direct Co-60, while Table 5 shows the average dose rate and peak count of gamma ray radiation.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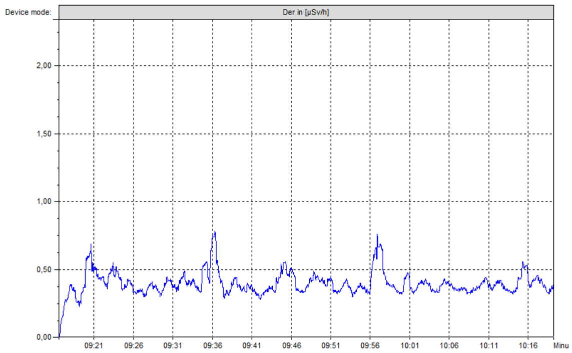
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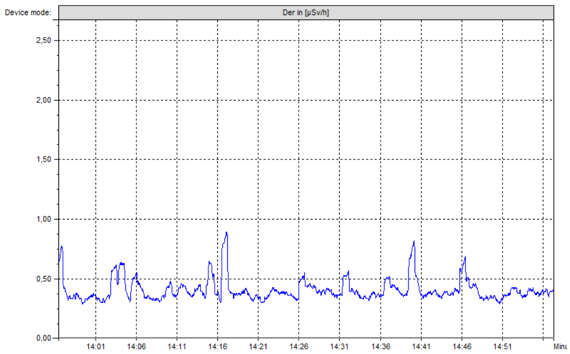
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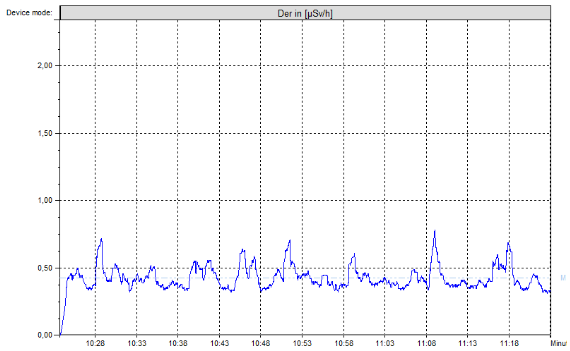
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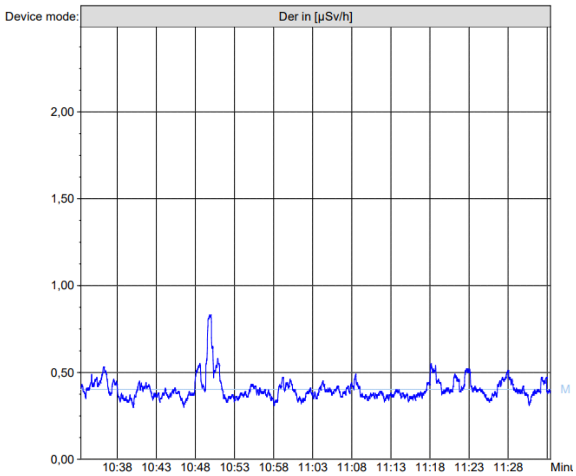
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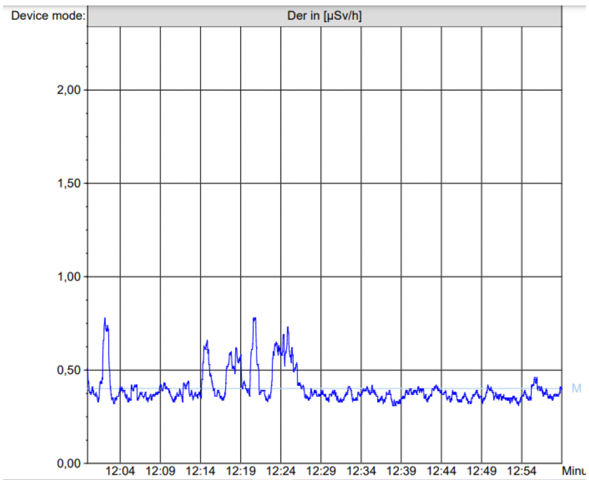
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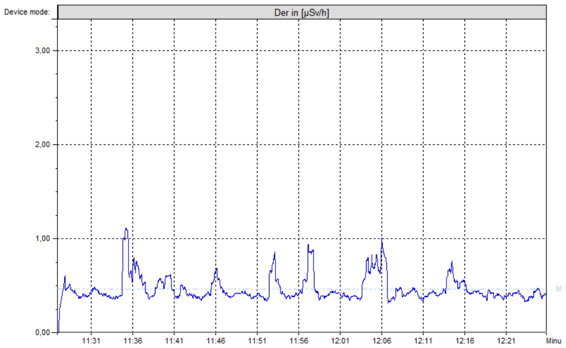

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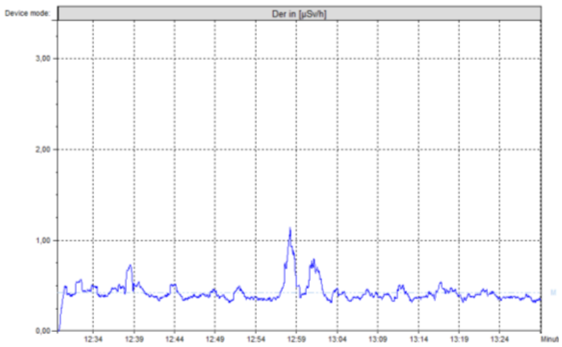

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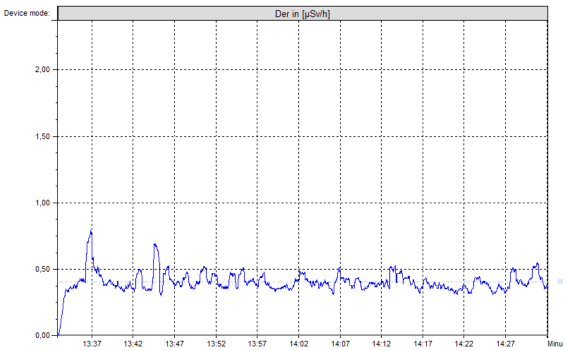
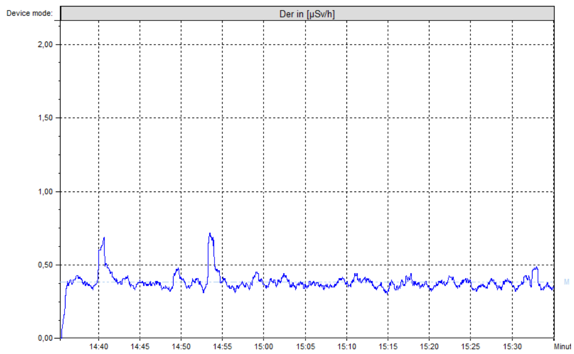


(i)



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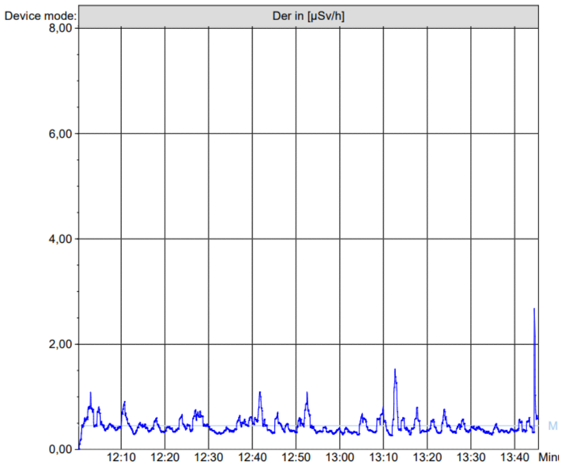

(k)

Figure 3: The graph of dose rate for GP after being exposed to Co-60 for (a) GP1 (b) GP2 (c) GP3 (d) GP4 (e) GP5 (f) GP6 (g) GP7 (h) GP8 (i) GP9 (j) GP10 (k) direct Co-60

Table 5: The data of several peaks counted

GP	Average dose rate (μSv/h)	Maximum dose rate (μSv/h)	No peak count
GP1	0.46	1.21	12
GP2	0.45	0.78	11
GP3	0.45	0.58	10
GP4	0.43	0.78	10
GP5	0.40	0.83	9
GP6	0.40	0.78	8
GP7	0.47	1.11	12
GP8	0.43	1.14	8
GP9	0.40	0.79	7
GP10	0.38	0.72	4
Direct Co-60	0.45	2.68	15

As the source of the gamma-ray, Co-60 was irradiated directly to the OD-02 survey meter, and the highest peak count was observed, which is 15 counts. The project then irradiated the gamma source with the presence of GPs, resulting in a decrease in the reading of the peak count measured. This indicated that the presence of geopolymer was able to attenuate and penetrate radiation rays from Co-60.

The density of GP1, which was entirely made of 100% clay, has the most peak counts of 12 counts compared to other GP. It should be demonstrated why GP1 has the lowest ability to absorb ray radiation due to its density of 1.914 g/cm^3. The results were then followed by GP2, GP3, and GP4 with peak counts of 11 and 10 with density of 1.951 g/cm^3, 1.960 g/cm^3, and 1.960 g/cm^3. As a result, these GPs become more effective in attenuating gamma rays compared to GP1 when more materials are added. With densities of 2.067 g/cm^3 and 2.190 g/cm^3, GP5 and GP6 recorded 9 and 8 counts of peak. Although GP5 doesn't contain 20% granite like GP6, its performance was almost identical in terms of peak count and dose rate. However, in comparison to other GPs, GP6 continues to have the fewest peak counts, which is 8 counts. This demonstrated that GP6, which had a material composition of 10% sand, 10% clay, 20% brick, 20% cement, 20% ceramic, and 20% granite, was the best candidate for gamma radiation shielding material. As a result, GPs were able to have greater shielding properties as the density was increasing.

In terms of GP thickness, the data showed a trend whereby the number of counted peaks decreased with increasing GP thickness. GP7 has the most peak counted, which is 12 in total. This is reinforced by the fact that GP7 was the thinnest GP than GP8, GP9, and GP10, even though the particle matric for the other four GPs were selected the same. Therefore, GP7, with 6.45 mm thick, showed the highest peak counts. The data was then followed by GP 8 and GP 9, which counted 8 and 7 peaks. Both GPs were different in terms of thickness, which were 9.51 mm and 12.53 mm. The most effective radiation absorbers are GP10. The data above demonstrate the efficiency of GP10 in absorbing gamma radiation as it showed the lowest and smallest values of average dose reading and number of peak counts. It can be strengthened because GP10, which has a GP layer that is 17.35 mm thick, attenuates and penetrates gamma radiation at the highest level while tending to have the smallest reading of dose rate.

4. Conclusion

To sum up this project, the research on the higher density of GP revealed that it has a higher ability to attenuate gamma-ray radiation shielding. The addition of various materials in GP upgrades its bulk density of the GP. In this work, GP6 consists of 10% clay, 10% sand, 20% brick, 20% cement, 20% ceramic, and 20% granite, showing a better ability to attenuate and penetrate gamma-ray radiation shielding. Other than that, the thickness of GP also played a role in radiation shielding applications. By having a different thickness of GP, it shows the trend that the GP has a good performance to be a radiation shielding candidate as the thickness of GP increases. In this context, GP10 showed the best performance as gamma-ray radiation shielding as it had the highest thickness of GP, which is 17.35mm. Finally, the presence of GP has proven its competence and has the strength to attenuate and penetrate radiation. GP was capable of radiation shielding application materials.

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