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Analysis of Neutron Radiation Absorption Capacity of Coir Fiber Composite Board as A Neutron Radiation Shield

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ABSTRACT

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Research has been conducted on the radiation shielding capability of coir fiber composite boards to determine the extent of neutron radiation absorption as it passes through the created radiation shield. This study aims to ascertain whether coir fiber can be used as a filler in the production of radiation shields. Initial analysis was conducted using SEM-EDX, FTIR, and XRD testing. The results indicated that the primary component of coir fiber is carbon at 70.68%, which is structured in chemical bonds of cellulose, hemicellulose, and lignin. Additionally, coir fiber retains a crystalline region observed at the peak of $2\theta=22.4°$, with a crystallinity degree of 35.46%, suggesting its potential for neutron radiation absorption. After fabricating the composite board, it was tested using the Neutron Activation Analysis method to evaluate its neutron radiation absorption capability. The analysis results showed that the absorption capacity of the composite board at a fiber mass fraction of 2.0 g ranged from 59.4 to 97.8%; at 3.0 g from 64.3 to 98.3%; and at 4.0 g from 73.5 to 99.3%. The linear attenuation coefficients (μ) for each coir fiber fraction were found to be 3.84; 4.13; and 4.80 cm-1, with half-value layers of 0.18; 0.17; and 0.14 cm, respectively, demonstrating that coir fiber can be utilized as a filler for neutron radiation shielding. The results of this study can add new information regarding the development of radiation protection systems with new materials that can minimize the body's exposure to ionizing radiation in the future.

1. INTRODUCTION

The development of nuclear radiation applications has been continuously evolving year by year, extending into various industrial sectors such as medicine, agriculture, geophysics, and scientific research, thereby necessitating a deeper study of radiation shielding (Tyagi, Singhal, Routroy, Bhunia, & Lahoti, 2021). Given the role of nuclear utilization, the advancement of radiation protection systems is crucial, with one significant area of research being radiation shields. Radiation shields are tools or materials designed to protect individuals and equipment from the effects of radiation. Their primary purpose is to minimize the absorption of ionizing radiation by the body and the associated effects.

Based on the potential effects of radiation, nuclear radiation protection is deemed vital for user safety (Chen, Bourham, & Rabiei, 2015; Erdem, Baykara, Doĝru, & Kuluöztürk, 2010). Traditionally, materials such as lead, iron, graphite, polyethylene, and concrete have been widely used as shields against nuclear radiation (Abdullah et al., 2022; Shams, Eftekhar, & Shirani, 2018). Among these, concrete is commonly employed for nuclear radiation shielding (Kharita, Takeyeddin, Alnassar, & Yousef, 2008; Zarvianti, Fitriyani, Surya Bery, Khalid Rivai, & Sulistioso,

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2017) because it effectively reduces the intensity of radiation, particularly gamma radiation, which has strong penetration capabilities (Naikwadi, Sharma, Bhatt, & Mahanwar, 2022). Additionally, concrete can also serve as a shield against fast neutron radiation (Adeli, Shirmardi, & Ahmadi, 2016). Some studies even suggest that various types of concrete mixtures are suitable and potentially effective as radiation shields (El-Samrah, Abdel-Rahman, & El Shazly, 2018; Papachristoforou & Papayianni, 2018). Concrete is considered highly ideal for shielding against gamma rays or neutrons (Azreen, Rashid, Haniza, Voo, & Mugahed Amran, 2018). However, the use of concrete as a nuclear radiation shield has drawbacks such as its large dimensions and density exceeding 2600 kg/m^3, making it relatively expensive to implement (More, Alsayed, Badawi, Thabet, & Pawar, 2021). This situation highlights the need to investigate other more efficient materials that can be used as nuclear radiation shields due to the increasing application of nuclear radiation.

Research published by Gosset, Herter, & Motte (2018) indicates that materials with low atomic number contents such as boron, carbon, and hydrogen possess the ability to absorb radiation, especially neutrons. This presents a unique challenge in developing new materials for radiation protection. Indonesia has a wealth of natural materials that are potential candidates for radiation shielding, such as palm oil shells, wood, and natural fibers due to their specific hardness levels. Research is needed to assess the absorption capacity of these natural materials as radiation shields (Yanyah & Sutanto, 2015). Currently, studies are being conducted using non-toxic, lightweight, and inexpensive natural materials for radiation shielding (AbuAlRoos, Baharul Amin, & Zainon, 2019; Kurudirek, 2017). One such natural material is fiber. Natural fibers are a highly prospective commodity for future development and have been utilized as reinforcement materials in biocomposites to replace synthetic fibers due to their lightweight physical properties, non-abrasiveness, combustibility, non-toxicity, affordability, and biodegradability (Rajesh & Pitchaimani, 2018). In this study, coir fiber is used as a filler in composite boards due to its high carbon content, which is believed to enhance its capability to absorb neutron radiation. Therefore, the purpose of this study is to evaluate the potential of coir fiber as a filler in composite boards that function as a radiation shield, especially against neutron radiation, by examining the characteristics of the material and its neutron absorption capacity.

2. METHODS

This research was divided into two stages. The first stage involves the characterization of coir fiber to assess its potential as a filler in neutron radiation shields using methods such as SEM-EDX, FTIR, and XRD. The SEM-EDX test was conducted to determine the percentage of the main elements constituting the coir fiber, while FTIR provided information related to the chemical bonds within the fiber, and X-ray diffraction (XRD) was used to identify the crystalline regions present in the coir fiber.

The second stage focused on the fabrication of coir fiber composite board samples. In this phase, the coir fiber intended for use as a filler is first cleaned with distilled water and then soaked in a 0.5 M NaOH solution for one hour before being air-dried. After drying, the coir fibers were cut into 10 cm lengths. They were then immersed in a polyester resin solution mixed with MEKP catalyst and cast into molds with a thickness of 0.25 cm. The mixture was compacted and allowed to cure at room temperature for 18 hours. The intensity of the neutron beam transmitted through the test material is determined by the material's attenuation coefficient using Lambert-Beer's law, as expressed in Equation (1).

$$I = I_0 e^{-\mu x} \tag{1}$$

where I = neutron beam intensity after passing through sample (n/cm^{-2}), I_0 =neutron beam intensity before passing through sample (n/cm^{-2}), μ = attenuatuon of neutron (cm^{-1}) and x = thickness of material (cm). From the equation above, the absorption value of the thermal neutron radiation shielding material can be obtained as shown in Equation (2) below:

$$\text{Absorption capacity} = \frac{I_0 - I}{I_0} \times 100\% \tag{2}$$

In addition to absorption capacity, a commonly used concept to describe a material's ability to absorb nuclear radiation is the Half Value Layer (HVL). The HVL is defined as the thickness of an absorbing material required to reduce the radiation intensity by 50% after passing through that material. The HVL value can be calculated using Equation (3).

$$HVL = \frac{ln2}{\mu} \quad (3)$$

3. RESULT AND DISCUSSION

Analysis of Energy Dispersive X-ray Spectroscopy (EDX)

The SEM-EDX analysis was conducted to determine the elemental composition and atomic percentage of the coir fiber. The results, as presented in Table 1, indicated that the main elements constituting coir fiber are Carbon, Oxygen, Sodium, Silica, and Calcium, with average atomic percentages obtained from three tests as follows: Carbon 70.68%, Oxygen 28.43%, Sodium 0.60%, Silica 0.15%, and Calcium 0.14%. The detailed results of the elemental composition are shown in Table 1.

Table 1. Results of SEM-EDX Analysis

Fitting Coefficient : 0.1468

Element	(keV)	Mass%	Error%	Atomic%	K
C K	0.277	65.41	0.02	71.97	75.0393
O K	0.525	32.96	0.19	27.22	22.5588
Na K	1.041	0.96	0.07	0.55	1.1644
Si K	1.739	0.27	0.05	0.13	0.4260
Ca K	3.690	0.40	0.07	0.13	0.8114
Total		100.00		100.00	

(a) First test

Fitting Coefficient : 0.1371

Element	(keV)	Mass%	Error%	Atomic%	K
C K	0.277	64.28	0.02	70.92	73.7502
O K	0.525	34.20	0.17	28.32	23.9841
Na K	1.041	0.88	0.07	0.51	1.0696
Si K	1.739	0.22	0.04	0.10	0.3463
Ca K	3.690	0.42	0.06	0.14	0.8497
Total		100.00		100.00	

(b) Second test

Fitting Coefficient : 0.1891

Element	(keV)	Mass%	Error%	Atomic%	K
C K	0.277	62.17	0.02	69.14	69.9210
O K	0.525	35.62	0.16	29.74	26.7627

Na K	1.041	1.27	0.06	0.74	1.5775
Si K	1.739	0.49	0.04	0.23	0.7826
Ca K	3.690	0.46	0.06	0.15	0.9561
Total		100.00		100.00	

(c) Third test

Fourier Transform Infrared Spectroscopy (FTIR) Analysis

The FTIR analysis in this study was conducted over a spectral range of 650–4000 cm^{-1} to identify the presence of carbon within the chemical bonds of cellulose, hemicellulose, and lignin, as illustrated in Figure 1.

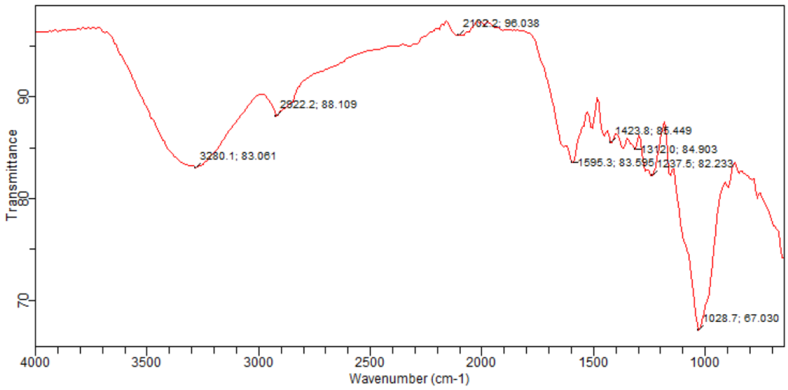

Figure 1. FTIR of coir fiber

Figure 1 displayed the FTIR analysis results for coir fiber, indicating that the primary components of coir fiber are Carbon, Hydrogen, and Oxygen, structured in the form of cellulose, hemicellulose, and lignin. The presence of carbon and hydrogen is considered an initial indication of neutron radiation absorption capability, as reported by Gosset et al (2018), highlighting that elements with low atomic numbers such as Carbon and Hydrogen can effectively absorb neutron radiation. This analysis underscores the potential of coir fiber as a viable material for applications requiring neutron radiation shielding due to its chemical composition.

X-Ray Diffraction (XRD) Analysis

The XRD analysis of coir fiber was performed using CuKα radiation (λ = 1.5406 Å) over a 2θ range of 20° to 80°. The objective was to determine whether coir fiber possesses a crystalline structure, as natural materials, including natural fibers, typically exhibit amorphous characteristics. The diffraction pattern of the coir fiber can be observed in Figure 2.

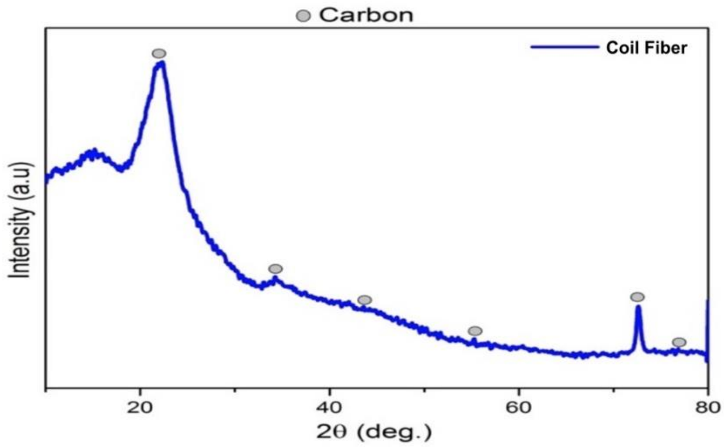

Figure 2. XRD of coir fiber

Based on the analysis presented in Figure 2, it was evident that coir fiber predominantly exhibits an amorphous structure; however, it still contained regions with crystalline structure, specifically at 2θ angles of 22.4° and 72.7°. At the peak of 22.4°, the carbon was identified in the form of cellulose, with a crystallinity degree of 35.46%. This finding aligned with the results reported by Chalid et al. (2017), which indicated a crystallinity degree of 37% for coir fiber at 2θ = 22.5°. The degree of crystallinity suggests that coir fiber could potentially be utilized as a natural fiber filler in the production of composite boards for neutron radiation shielding applications.

Analysis of Neutron Radiation Absorption by Composite Shields

The composite boards were designed to assess their effectiveness in neutron radiation shielding. After irradiation, the boards were chopped to measure the reduction in neutron beam intensity as it passed through varying thicknesses of the coir fiber composite. The results of this assessment are presented in Table 2.

Table 2. Data on the Counting of Coir Fiber Boards as Neutron Radiation Shields

Thicknesses of the coir fiber composite (mm)	Counting/minute			
	Mass fraction of coir fiber (gr)			
	0	2	3	4
Io	10352	10417	10333	10506
2,5	7238	4227	3688	2782
5	5243	1542	1314	765
7,5	4376	613	433	247
10	4009	234	171	74

The data from the coir fiber composite shielding against neutron radiation can be analyzed in conjunction with Table 2, which illustrated the extent of neutron radiation intensity reduction as shown in Figure 3. The graph clearly indicated that as the mass fraction and thickness of the coir fiber composite increase, a greater number of neutrons are absorbed.

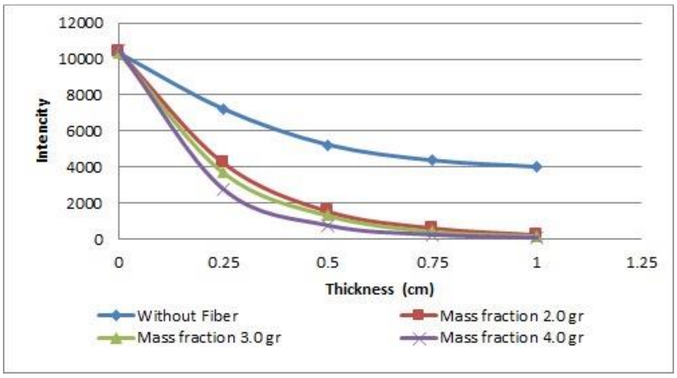

Figure 3. Neutron Radiation Absorption Capacity of Coir Fiber Composite

Figure 3 demonstrated how the mass fraction of coir fiber within the composite board enhances its ability to absorb neutron radiation, as evidenced by the significant reduction in neutron intensity after passing through the coir fiber composite. This suggested that coir fiber possesses inherent capabilities for neutron radiation absorption.

To determine the absorption capacity of coir fiber composite boards for neutron radiation, the attenuation of neutrons is analyzed. When neutrons interact with a material, the radiation is not entirely absorbed; instead, it experiences attenuation or a reduction in intensity. In other words, attenuation refers to the weakening of radiation intensity after passing through a material. The data clearly showed that the absorption capacity of the composite board increases with the addition of coir fiber, as depicted in Figure 4. This highlights the positive impact of incorporating coir fiber on the shielding effectiveness against neutron radiation.

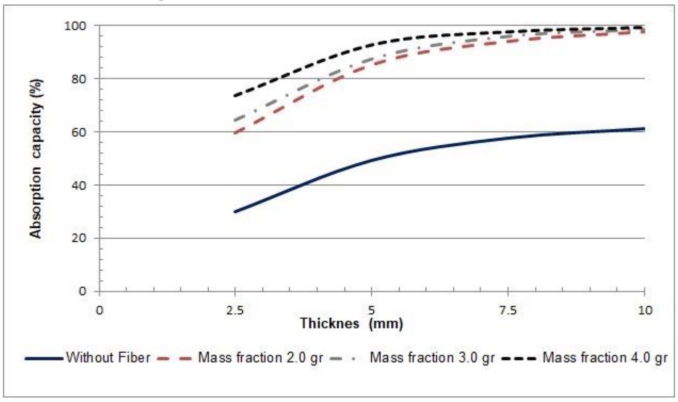

Figure 4. The Effect of Adding Coir Fiber on Absorption Capacity

Based on the analysis of the absorption capacity of coir fiber composite boards in absorbing neutron radiation, it was evident that the neutron absorption is influenced by both the mass fraction of coir fiber and the thickness of the composite board. At a fiber mass fraction of 2.0 g, the absorption rate ranges from 59.4% to 97.8%; at 3.0 g, it ranges from 64.3% to 98.3%; and at 4.0 g, it ranges from 73.5% to 99.3%. Notably, at a thickness of 1.0 cm, nearly all neutron radiation is absorbed by the coir fiber composite shield.

These results further reinforced that coir fiber can serve as an alternative filler material in neutron radiation shields. To meet the requirements for effective radiation shielding, it was necessary to determine the attenuation coefficient of the composite board. Using Equation 1, it could calculate the attenuation coefficient for the coir fiber composite board, as illustrated in Figure 5.

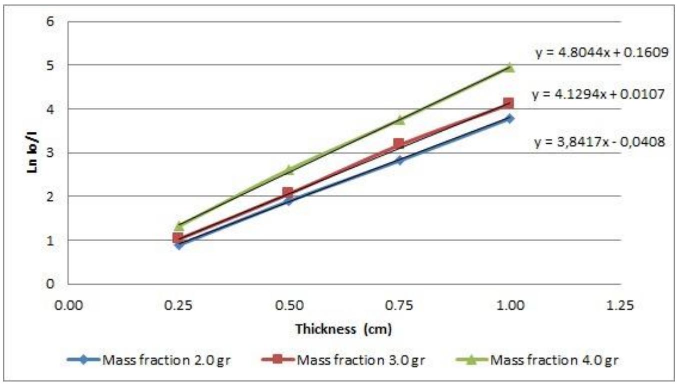

Figure 5. Linearization Graph of Neutron Absorption

From Figure 5, it can be observed that the ability of coir fiber composite boards to absorb neutron radiation increases with the addition of the board's thickness. The analysis showed that a higher mass fraction of coir fiber in the composite board enhances its radiation absorption capacity, as indicated by the increasing linear attenuation coefficients (μ) of the coir fiber composite board, which are 3.84, 4.13, and 4.80 cm^{-1}, respectively.

Using Equation (3), the thickness of the radiation shield made from coir fiber composite required to reduce neutron radiation by 50% can be determined. The results indicate that the half-value layer (HVL) for each mass fraction of coir fiber used is 0.18, 0.17, and 0.14 cm. These findings demonstrate that the mass fraction of coir fiber in neutron radiation shields can enhance their ability to absorb neutron radiation.

4. CONCLUSION

Based on the testing and analysis of coir fiber as a filler in neutron radiation shields, it can be concluded that coir fiber is a natural fiber that can serve as an alternative material for neutron radiation absorption. The absorption capacity of composite boards at fiber mass fractions of 2.0 gr ranged from 59.4-97.8%; at 3.0 gr from 64.3 to 98.3% and at 4.0 gr from 73.5-99.3% with linear attenuation coefficient (μ) for each coil fiber fraction is 3.84; 4.13 and 4.80 cm^{-1} and HVL of 0.18; 0.17 and 0.14 cm. The greater the mass fraction of coir fiber in the radiation shield, the more effective it becomes at absorbing neutron radiation.

REFERENCE

Abdullah, M. A. H., Rashid, R. S. M., Amran, M., Hejazii, F., Azreen, N. M., Fediuk, R., … Idris, M. I. (2022, July 1). Recent Trends in Advanced Radiation Shielding Concrete for Construction of Facilities: Materials and Properties. Polymers. MDPI. https://doi.org/10.3390/polym14142830

AbuAlRoos, N. J., Baharul Amin, N. A., & Zainon, R. (2019, December 1). Conventional and new lead-free radiation shielding materials for radiation protection in nuclear medicine: A review. Radiation Physics and Chemistry. Elsevier Ltd. https://doi.org/10.1016/j.radphyschem.2019.108439

Adeli, R., Shirmardi, S. P., & Ahmadi, S. J. (2016). Neutron irradiation tests on B4C/epoxy composite for neutron shielding application and the parameters assay. Radiation Physics and Chemistry, 127, 140–146. https://doi.org/10.1016/j.radphyschem.2016.06.026

Azreen, N. M., Rashid, R. S. M., Haniza, M., Voo, Y. L., & Mugahed Amran, Y. H. (2018). Radiation shielding of ultra-high-performance concrete with silica sand, amang and lead glass. Construction and Building Materials, 172, 370–377. https://doi.org/10.1016/j.conbuildmat.2018.03.243

Chen, S., Bourham, M., & Rabiei, A. (2015). Neutrons attenuation on composite metal foams and hybrid open-cell Al foam. Radiation Physics and Chemistry, 109, 27–39. https://doi.org/10.1016/j.radphyschem.2014.11.003

El-Samrah, M. G., Abdel-Rahman, M. A. E., & El Shazly, R. M. (2018). Effect of heating on physical, mechanical, and nuclear radiation shielding properties of modified concrete mixes. Radiation Physics and Chemistry, 153, 104–110. https://doi.org/10.1016/j.radphyschem.2018.09.018

Erdem, M., Baykara, O., Doĝru, M., & Kuluöztürk, F. (2010). A novel shielding material prepared from solid waste containing lead for gamma ray. Radiation Physics and Chemistry, 79(9), 917–922. https://doi.org/10.1016/j.radphyschem.2010.04.009

Gosset, D., Herter, P., & Motte, V. (2018). Evaluation of damage in neutron irradiated boron carbide. Nuclear Instruments and Methods in Physics Research, Section B: Beam Interactions with Materials and Atoms, 434, 66–72. https://doi.org/10.1016/j.nimb.2018.08.021

Kharita, M. H., Takeyeddin, M., Alnassar, M., & Yousef, S. (2008). Development of special radiation shielding concretes using natural local materials and evaluation of their shielding characteristics. Progress in Nuclear Energy, 50(1), 33–36. https://doi.org/10.1016/j.pnucene.2007.10.004

Kurudirek, M. (2017). Heavy metal borate glasses: Potential use for radiation shielding. Journal of Alloys and Compounds, 727, 1227–1236. https://doi.org/10.1016/j.jallcom.2017.08.237

More, C. V., Alsayed, Z., Badawi, M. S., Thabet, A. A., & Pawar, P. P. (2021, June 1). Polymeric composite materials for radiation shielding: a review. Environmental Chemistry Letters. Springer Science and Business Media Deutschland GmbH. https://doi.org/10.1007/s10311-021-01189-9

Naikwadi, A. T., Sharma, B. K., Bhatt, K. D., & Mahanwar, P. A. (2022, March 14). Gamma Radiation Processed Polymeric Materials for High Performance Applications: A Review. Frontiers in Chemistry. Frontiers Media S.A. https://doi.org/10.3389/fchem.2022.837111

Papachristoforou, M., & Papayianni, I. (2018). Radiation shielding and mechanical properties of steel fiber reinforced concrete (SFRC) produced with EAF slag aggregates. Radiation Physics and Chemistry, 149, 26–32. https://doi.org/10.1016/j.radphyschem.2018.03.010

Rajesh, M., & Pitchaimani, J. (2018). Dynamic mechanical and free vibration behavior of natural fiber braided fabric composite: Comparison with conventional and knitted fabric composites. Polymer Composites, 39(7), 2479–2489. https://doi.org/10.1002/pc.24234

Shams, T., Eftekhar, M., & Shirani, A. (2018). Investigation of gamma radiation attenuation in heavy concrete shields containing hematite and barite aggregates in multi-layered and mixed forms. Construction and Building Materials, 182, 35–42. https://doi.org/10.1016/j.conbuildmat.2018.06.032

Tyagi, G., Singhal, A., Routroy, S., Bhunia, D., & Lahoti, M. (2021, February 15). Radiation Shielding Concrete with alternate constituents: An approach to address multiple hazards. Journal of Hazardous Materials. Elsevier B.V. https://doi.org/10.1016/j.jhazmat.2020.124201

Yanyah, A., & Sutanto, H. (2015). Penentuan Nilai Koefisien Serapan Bahan Dan Dosis Radiasi Pada Variasi Kombinasi Kayu Dan Aluminium. Youngster Physics Journal, 4, 87–92.

Zarvianti, E., Fitriyani, D., Surya Bery, W., Khalid Rivai, A., & Sulistioso, dan G. (2017). Karakterisasi Bahan Perisai Radiasi Neutron Ultra High Molecular Weight Polyethyene Dengan Filler Gd2O3 Menggunakan Teknik Radiografi Neutron. Jurnal Ilmu Fisika (JIF), 9, 1–6.