

Analysis of Barite Concrete as a Potential Neutron Radiation Shielding Material for BNCT Facilities

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ABSTRACT This research aimed to determine the potential of barite concrete as a neutron radiation shielding material in the development of boron neutron capture therapy, by obtaining its neutron attenuation coefficient. Barite concrete samples were supplied by the Center of Accelerator Science and Technology in Yogyakarta, Indonesia. The experiment consisted of two parts, namely density analysis and determination of the neutron attenuation coefficient. For the latter, plutonium-beryllium was used as the neutron source, while a high purity germanium detector was used to measure the neutron radiation level. The results showed that barite concrete with a 2130 kg.m⁻³ density had a neutron attenuation coefficient of 0.0871 cm⁻¹.

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1. INTRODUCTION

With the development of nuclear technology and its widespread use in various fields of research, industry, and medicine, protection against radiation has become of paramount importance. In this context, the radiation rate of radioactive sources must be minimized. These forms of radiation generally involve alpha, beta, gamma, and neutron radiation. Protection against radioactive rays encompasses placing a physical barrier between the radioactive ionization source and the object of the radiation exposure, for which the reduction in radiation exposure is intended (Amirabadi et al. 2013).

Boron neutron capture cancer therapy (BNCT) is a recently developed, radiation-based treatment method in medicine, using neutrons as its radiation source. Neutrons have the highest energy among other radiations. They are produced by a fission reaction that may produce two or three new fast neutrons (Sardjono 2015). Fast neutrons can be very destructive to human tissue, thus necessitating a physical barrier that is able to reduce the amount of neutron radiation exposure (World Nuclear Association 2010).

A variety of materials have been used to ensure people and the environment are protected against nuclear radiation, such as lead, iron, graphite, water, polyethelene, and concrete. Of these materials, concrete is one of the best and most widely used for the manufacture of gamma and neutron radiation shielding, because, in addition to having the proper structural properties of the material, there is wide flexibility in the choice of materials used to build it. This leads to the manufacture of concrete with different densities and different combinations. The ease of fabrication, and low cost of construction and maintenance of concrete is another advantage of using concrete as radiation shielding (Amirabadi et al. 2013).

Heavyweight concrete is usually used as radiation shielding because it may attenuate radiation exposure. Concrete qualifies as heavyweight when it has a specific gravity higher than 2600 kg/m³; similarly, an aggregate with a specific gravity higher than 3000 kg/m³ qualifies as a heavyweight aggregate (Çullu and Ertas 2016). One such example of heavyweight concrete is barite (BaSO₄) concrete. This is due to the high atomic weight of barium (Ba). The Center Accelerator Science and Technology (PSTA-BATAN) in Yogyakarta, Indonesia, has concrete samples formed from barite aggregate (barite concrete). Radiation analysis of barite concrete, by determining its attenuation coefficient of neutrons, is presently needed to assess the suitability of this concrete in BNCT.

2. MATERIALS AND METHODS

The purpose of this research was to determine the amount of neutron exposure attenuated by barite concrete. The experiment was carried out in the Center of Accelerator Science and Technology, Yogyakarta, Indonesia. A flowchart of this research is shown in Figure 1. This study was limited to determining the neutron attenuation coefficient of barite concrete in general. As such, the barite concentration in the concrete mixture is not detailed.

A sample of barite concrete, obtained from PSTA-BATAN, served as the object of the experiment. The geometry of this sample was that of a block, with a length of 25 cm, width of 6 cm, and height of 25 cm (Figure 2). Plutonium-beryllium (PuBe), which was made available from the reactor sector of the Center of Accelerator Science and Technology, Yogyakarta, was used as the neutron source. A high purity germanium (HPGe) neutron detector was used to measure the neutron radiation level because of its high sensitivity to radiation.

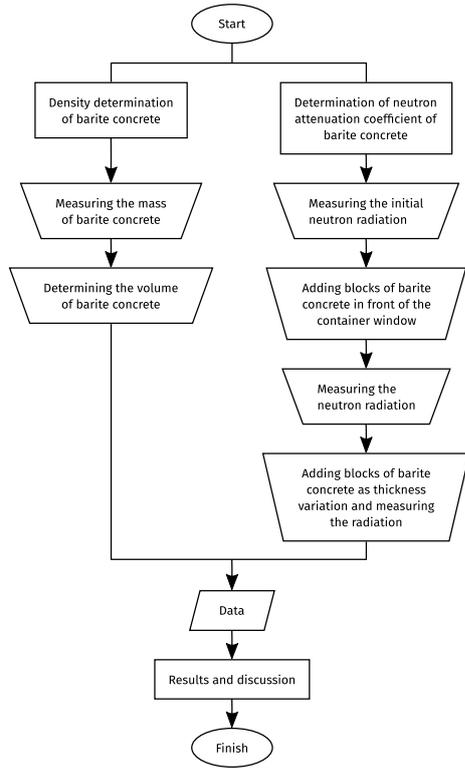


FIGURE 1. Flowchart of the research.

Both the density of the barite concrete and its neutron attenuation coefficient were determined. The general equation of density is described in Equation 1:

$$\rho = \frac{m}{V} \quad (1)$$

where ρ is the density, m is the mass of the barite concrete (kg), and V is the volume of the barite concrete (m^3).

The neutron attenuation coefficient of barite concrete was determined as in Equation 2:

$$I = I_0 e^{-\mu x} \quad (2)$$

where I is the intensity of radiation after passing through the barite concrete, I_0 is the initial radiation intensity, μ is the neutron attenuation coefficient of the barite concrete, and x is the thickness of the barite concrete. Equation 2 can be regressed as Equation 3:

$$\ln \frac{I}{I_0} = -\mu x \quad (3)$$

where $\ln \frac{I}{I_0}$ is the y axis, x is the x axis, and $-\mu$ is the gradient.

3. RESULTS AND DISCUSSION

3.1 Density of barite concrete

The barite concrete sample was a shaped block with a length and height of 25 cm and thickness of 6 cm. Thus, its volume was 3750 cm^3 . Its weight was 8 kg, as measured by the Chinese weight machine ZT-120 model scale. The density of the barite concrete can be determined using Equation 1, and the result of this equation consequently showed its density to be 2130 kg/m^3 .

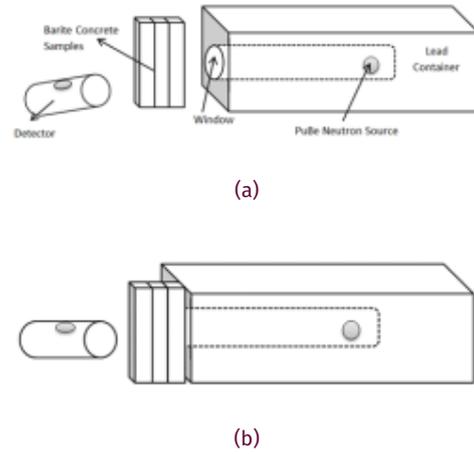


FIGURE 2. Scheme of: (a) neutron irradiation experiment equipment (top view), and (b) neutron irradiation data collection (side view).

The density of the assessed barite concrete was low, considering the weight of the barite and element barium. This may be due to the gradation of the concrete sample, in which there was only a slight amount of barite aggregate added in the mixture.

3.2 Neutron attenuation coefficient of barite concrete

The initial neutron radiation of the PuBe source was 519.2 Cps. The neutron attenuation coefficient of the barite concrete was determined using Equation 3, and is reflected in the linear regression of Figure 3. As Figure 3 shows, the neutron attenuation coefficient of the barite concrete was 0.0871 cm^{-1} with an intercept of -0.0501 cm^{-1} and a standard error of 0.00808 cm^{-1} . The results when compared with other coefficients of concrete attenuation are displayed in Table 1.

The magnitude of the density does not affect the neutron attenuation coefficient of the concrete; it is rather the content of hydrogen in the concrete that affects it. The hydrogen content in concrete is an important factor in its neutron shielding ability. Most of the hydrogen in concrete is normally present in the form of water and hydrated cement which aggregate, setting the free water flowing in the porous structure of the concrete. This water is evaporated at high temperatures and could reduce the concrete's performance in terms of radiation shielding (Abdullah et al.

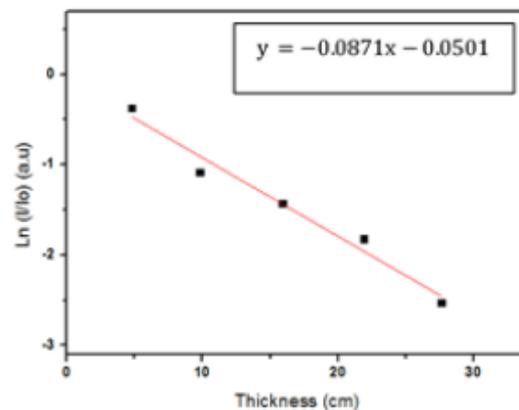


FIGURE 3. Graph relation thickness to $\ln(I/I_0)$ in the experiment of determining neutron attenuation coefficient of barite concrete.

TABLE 1. Neutron attenuation coefficient of various types of concrete.

Type of concrete	Researcher	Density (kg/m ³)	μ (cm ⁻¹)
Barite	Picha et al. (2015)	2910	0.101
Cooper Slag	Picha et al. (2015)	3060	0.025
Barite-Colemanite 5%	Mesbahi et al. (2013)	3240	0.117
Barite-Colemanite 10%	Mesbahi et al. (2013)	3060	0.112

2010). As such, an aggregate (such as barite) is added because it has the capability to avoid water crystallization that could eliminate the hydrogen content in the concrete mixture. The different types of aggregate affect its ability to avoid water crystallization.

4. CONCLUSIONS

Based on the results of the analysis of barite concrete's suitability as a neutron radiation shielding material for BNCT facilities, the following conclusions can be drawn: the neutron attenuation coefficient of barite concrete from a PuBe neutron source is 0.0871 cm⁻¹. In addition, barite in concrete aids in avoiding water crystallization that could eliminate its hydrogen content.

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