Evaluating Linear Attenuation Coefficient for Bio-Shield Concrete using Thermal Neutron Beam Facility at KAERI

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***Keywords :** neutron shielding efficiency, linear attenuation coefficient, concrete, neutron beam facility, research reactor

1. Introduction

Concrete used in nuclear power plant buildings shields workers from radiation emitted by the reactors, protecting them from various physical hazards and preventing radiation-related accidents. Therefore, concrete used in nuclear power plants must possess sufficient radiation shielding performance and physical strength. Furthermore, with the recent decommissioning of retired reactors, concerns have grown about radioactive waste, including steel and concrete, surrounding the reactors. Consequently, future concretes require relatively low radioactivity properties compared to existing concretes.

To this end, Korea Hydro & Nuclear Power Co., LTD. (KHNP), the Korea Institute of Civil Engineering and Building Technology (KICT), and the Korea Atomic Energy Research Institute (KAERI) are conducting joint research. In June 2025, the neutron shielding efficiency of five concrete samples with different compositions was evaluated using a thermal neutron beam of Ex-core Neutron Irradiation Facility (ENF) at KAERI. The evaluation values were compared and it was found that adding boron compounds to a 4-cm-thick concrete sample improved the shielding efficiency by more than twice compared to a sample without boron compounds. [1]

In this work, the neutron shielding efficiency of concrete samples of various thicknesses was evaluated and the linear attenuation coefficient for neutrons was estimated from these values. And the linear attenuation coefficient values for concrete samples with different compositions were compared.

2. Methods and Results

In this section, the method, experimental setup, and results for evaluating the neutron shielding efficiency and linear attenuation coefficient of various concrete samples using ENF are described.

2.1 Method for Evaluating Neutron Shielding Efficiency

Neutron shielding efficiency ε_{NS} and linear attenuation coefficient μ defined as follows:

(1) $$\varepsilon_{NS} = \frac{C_0 - C_i}{C_0} = 1 - B \cdot Exp(-\mu d)$$

where C_0 and C_i are neutron count rates without and with concrete sample. That is, the neutron count rate is measured when there is a sample and when there is no sample, and the neutron shielding efficiency is calculated from this. *B* is build-up factor and *d* is thickness of the concrete sample.

2.2. Experimental Setup

The method for evaluating neutron shielding efficiency was the same as in the previous experiment. Therefore, the experimental setup is briefly described. The experiment was conducted in ENF facility at KAERI [2]. The thermal power of HANARO was 27 MW. Fig. 1 shows the experimental setup for this experiment. The neutron source used was a neutron beam at ENF, mostly thermal neutrons. The neutron detector is 3He proportional counter. The centers of neutron beam port, sample, and detector were aligned. Lead and HDPE bricks were used for shielding external gamma rays and neutrons other than the neutron beam. In this setup, the measured neutron count was 8.0×10^6 without sample and $(2.6\text{-}6.2)\times10^6$ with sample.

Fig. 1. Experimental setup for evaluating neutron shielding efficiency of a concrete sample.

2.3. Concrete Samples

In this experiment, a total of 11 different compositions of concrete samples made by KICT were evaluated (Fig. 2). Among them, there are 7 types without added boron compounds (Ref, Ref2, RefW, 1A, A, SA, SH) and 4 types with added boron compounds (BN5, BC2, BC5, BC10). The boron compounds-added samples have the same composition as Ref but with the addition of boron compounds (boron nitride (BN), boron carbide (BC)). The number in the name of the boron compounds-added concrete sample indicates the added amount of boron compound as a percentage of the mass of Ref. For example, BC5 means that 5% of boron carbide was added to the mass of Ref. To evaluate the linear attenuation coefficient, four different thicknesses (4, 6, 8, and 10 cm) of each composition were prepared.

Fig. 2. Concrete samples tested in this work (44 in total). The white samples are concretes without boron compounds, and the samples with green borders are concretes with boron compounds added.

2.4 Results

In the experimental setup introduced above, the neutron count for each sample and neutron beam was measured, and the neutron shielding efficiency was evaluated. The evaluated neutron shielding efficiency values of the samples with different thicknesses but the same composition were fitted using Eq. 1, as shown in Fig. 3, and the linear attenuation coefficient for concrete samples with a specific composition was evaluated based on the fit. (Here, the build-up factor in Eq. 1 was set as a free parameter since it has not yet been analyzed.) Fig. 4 compares the evaluated neutron shielding efficiency values for different compositions. (BC5 and BC10 were excluded due to fitting issues.) It was found that concrete samples with added boron compounds showed higher neutron shielding efficiency than those without added boron compounds. In addition, it was found that the neutron shielding efficiency increased as the concentration of boron compounds increased. In particular, when comparing samples BN5 and BC5, the neutron shielding efficiency of BC5 is slightly higher. This is because the molecular compositions are different (BN and B_4C), and thus the boron concentration of BC5 is higher.

Fig. 5 compares the linear attenuation coefficients evaluated through the fitting for samples of different compositions. The linear attenuation coefficients of samples containing boron compounds were found to be higher than those of samples without boron compounds. However, since the unanalyzed build-up factor was set as a free parameter during the fitting, the exact linear attenuation coefficient values will be presented later.

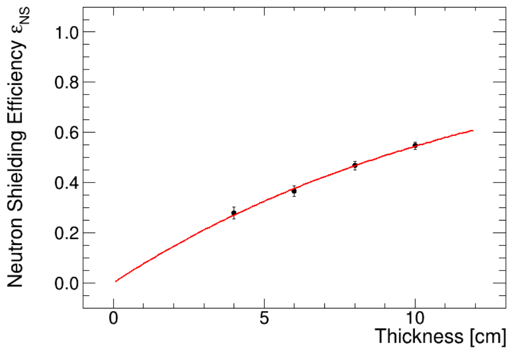

Fig. 3. Evaluated neutron shielding efficiency values and fitting function (Eq. 1) of the concrete sample (Ref). The fitting was done for the 11 different compositions of concrete sample types.

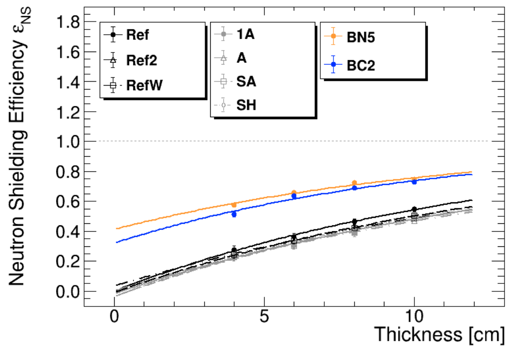

Fig. 4. Comparison of evaluated neutron shielding efficiency values and fitting functions for the 9 different compositions of concrete sample types.

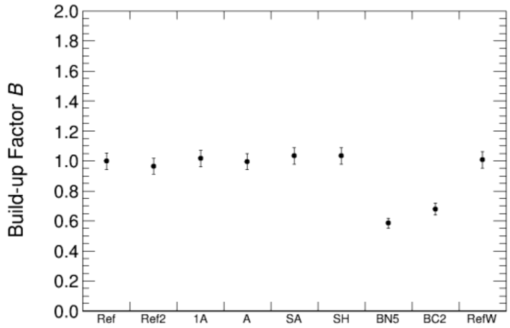

Fig. 5. Comparison of evaluated linear attenuation coefficient values for the 11 different compositions of concrete sample types.

3. Conclusions

The neutron shielding efficiency and linear attenuation coefficient of the concrete samples were evaluated and compared using the neutron beam facility

ENF at KAERI. The results showed that the neutron shielding efficiency and linear attenuation coefficient of concrete samples containing boron compounds are higher than those of samples without boron compounds.

In the future, we will conduct a build-up factor analysis to more accurately evaluate the linear attenuation coefficient. This will be used to estimate the neutron shielding efficiency of each composition in the actual concrete thickness (2 m) used in construction, and determine which concrete composition will be most effective.

REFERENCES

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