Transactions of the Korean Nuclear Society Autumn Meeting
Changwon, Korea, October 30-31, 2025

Neutron Shielding Efficiency Evaluation for Developing Improved Bio-Shield Concrete using Neutron Beam Facility at KAERI

Jinyu Kim [a*], Bo-Young Han [a], Gwang-Min Sun [a]
[a] *Korea Atomic Energy Research Institute, HANARO Utilization Division, 111, Daedeok-daero 989beon-gil, Yuseong-gu, Daejeon, Republic of Korea 34057*
[*] *Corresponding author: jinyukim@kaeri.re.kr*

***Keywords :** neutron shielding efficiency, 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.

Korea Hydro & Nuclear Power Co., LTD. (KHNP), through joint research with Korea Institute of Civil Engineering and Building Technology (KICT) and Korea Atomic Energy Research Institute (KAERI), is developing improved concrete materials that meet these requirements. KICT has produced concrete samples with various mixes that meet these requirements, and the neutron shielding efficiencies of these concrete samples were evaluated using the neutron beam facility of research reactor HANARO at KAERI.

2. Methods and Results

In this section the method, experimental setup, and results for evaluating the neutron shielding efficiency of concrete samples using a neutron beam facility are described.

2.1 Method for Evaluating Neutron Shielding Efficiency

Neutron shielding efficiency ε_{NS} is defined as follows:

(1)
$$\varepsilon_{NS} = \frac{C_0 - C_i}{C_0}$$

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.

2.2 Concrete Samples

Fig. 1 shows concrete samples produced by Institution B. There are five in total: a sample with a typical composition (Ref), two samples containing boron nitride (BN2 and BN3), and two samples containing boron carbide (BC1 and BC2). The primary purpose of these samples was to compare the neutron shielding efficiency between the typical concrete samples and the boron-containing concrete samples, and between the samples containing boron nitride and boron carbide. All concrete samples had the same size, with an area of 15×15 cm² and a thickness of 4 mm.

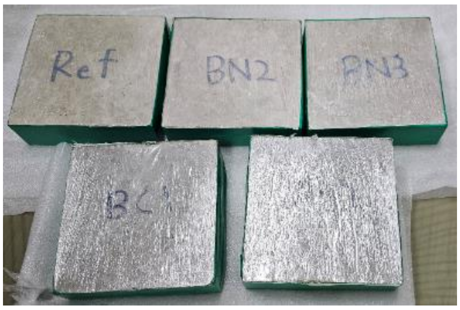

Fig. 1. Concrete samples produced by KICT

2.3 Experimental Setup

To calculate the neutron shielding efficiency, the neutron count rate should be measured, and for this purpose, a ^{3}He proportional counter tube was used (Fig. 2). The tube diameter is approximately 5 cm, which is approximately one-third of the sample's length of 15 cm. A 3-D printer was used to make a holder to position the tube at the center of the sample. The neutron source used was the Ex-core Neutron irradiation Facility (ENF) at KAERI [1]. The neutron beam in ENF has a wavelength of 1-6 Å, which, when converted to energy, is approximately 0.002-0.082 eV, and includes cold, thermal, and epithermal neutrons. Among them, thermal neutron is the dominant type. The distance from the neutron beam port to the sample is approximately 1 m, and custom-made HDPE collimators were installed between them to focus the neutron beam, 45 cm away from the neutron beam port. To shield neutrons and external gamma rays other than the neutron beam, the detector was surrounded by lead bricks and HDPE bricks. The centers of neutron beam port, detector, and sample were aligned (Fig. 3), and a stand made of profile was constructed to hold the materials needed for the experiment. The final experimental setup, complete with shielding, is shown in Fig. 4.

Fig. 2. ^{3}He proportional counter tube used as neutron detector with holder

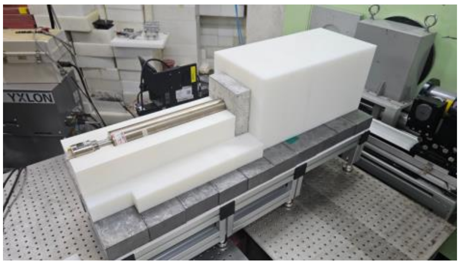

Fig. 3. Alignment of the centers of neutron detector, sample, and neutron beam

Fig. 4. Experimental setup for evaluating neutron shielding efficiency of the concrete sample

The DAQ device used in this experiment, along with the neutron detector, was a TDC64 from Notice Korea, with a maximum trigger rate of approximately 916 kHz (Fig. 5). This values was obtained testing the TDC64 with pulse generator. The experiment was configured to ensure that the measured neutron count rate was lower than this value. The neutron count rate was set to approximately 92 kHz with this experimental configuration when no sample was present, while the neutron count rate when a sample was present was approximately 60-80 kHz.

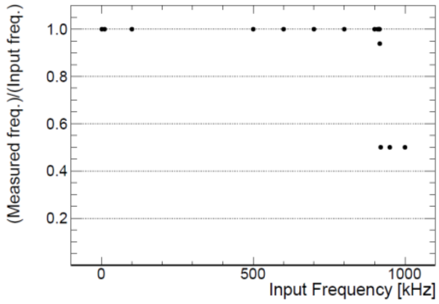

Fig. 5. Result of testing maximum trigger rate of DAQ device TCD64, using pulse generator

Neutron count rate was measured for 1 minute for each sample, and neutron count rate without sample was measured before and after the measurement with sample. That is, neutron count rate was measured a total of 5 times when sample was present and a total of 6 times when sample was absent. The measured neutron count was 5.5×10^{6} without sample and $(3.7 - 4.7) \times 10^{6}$ with sample.

2.4 Results

After completing the experimental setup and neutron count rate measurements, data analysis was performed. First, measurements without samples were compared (Fig. 6). The average of the six measurements within 3 h was approximately 92 kHz, and the fluctuation was approximately 0.3% as calculated by root mean square deviation (RMSD). Next, neutron shielding efficiency was evaluated and compared using the neutron count rate measurements with and without samples (Fig. 7). The neutron shielding efficiency of a 4-cm-thick concrete sample containing boron was approximately 30%, which was approximately twice as high as that of a sample without boron. Meanwhile, the neutron shielding efficiencies of the concrete samples containing boron showed similar values within statistical error (Fig. 8).

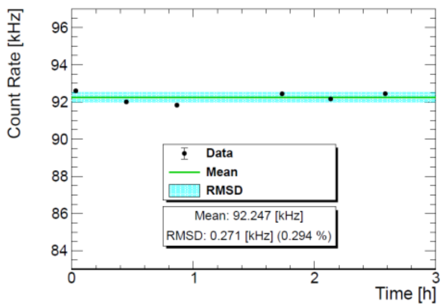

Fig. 6. Stability of neutron count rate without concrete sample

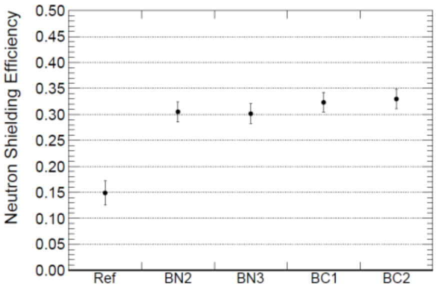

Fig. 7. Evaluated neutron shielding efficiencies of the concrete samples

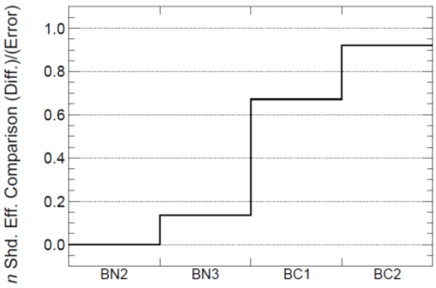

Fig. 8. Comparison of the neutron shielding efficiency difference and the error, based on the value for the sample BN2

3. Conclusions

The neutron shielding efficiencies of the concrete samples were evaluated and compared using the neutron beam facility ENF at KAERI. In this experimental configuration, the neutron beam in ENF was maintained generally with a fluctuation of approximately 0.3%. The neutron shielding efficiency of concrete samples with a thickness of 4 cm was approximately 30% when containing boron and approximately 15% when not containing boron. The neutron shielding efficiencies of concrete samples containing boron was found to be similar within the statistical error. These results suggest that the inclusion of boron in concrete has a significant effect on neutron shielding performance, and that the neutron shielding performance is similar regardless of the type of boron compound when the amount of contained boron is the same.

In the future, we plan to evaluate the uncertainties for the neutron shielding efficiency and evaluate the neutron shielding efficiency of concrete samples with different thicknesses but the same composition to evaluate the linear attenuation coefficiency for concrete samples of that composition.

REFERENCES

[1] M.S. Kim et al., Development and characteristics of the HANARO neutron irradiation facility for applications in the boron neutron capture therapy field, Physics in Medicine and Biology 52 (2000) 2553-2566.