A Preliminary Study on the Conceptual Design and Response Analysis of a Long Counter for High Energy Neutron Monitoring at RAON NDPS

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1. Introduction

The Nuclear Data Production System (NDPS) at Rare isotope Accelerator complex for ON-line experiments(RAON) generates a wide spectrum of neutrons, ranging from 80 MeV quasi-monoenergetic neutrons to white neutrons with continuous energy distributions up to 98 MeV, by accelerating 83 MeV protons and 98 MeV deuterons. [1] In such high-flux and high-energy environments, conventional scattering-based detectors, such as organic scintillators, face significant limitations in precise absolute flux analysis due to pulse pile-up and gamma-ray contamination. [2]

In contrast, Long Counters provide a substantial advantage for absolute flux measurements by maintaining a flat response function across a broad energy range. [3] However, standard Long Counters are typically designed for energies below 20 MeV, failing to meet the high-energy requirements of the NDPS. Therefore, this study utilizes the MCNP6 code to perform a preliminary design and parametric analysis aimed at developing a high-energy optimized Long Counter tailored to the specific characteristics of the NDPS facility.

2. Methods and Results

In this research, neutron behavior analysis was conducted on the geometric model illustrated in Figure 1 using the MCNP6 simulation code. A He-3 proportional counter was utilized as the central detector for the long counter, with high-density polyethylene (HDPE) serving as the moderator. Specifically, to improve detection efficiency in the high-energy neutron region, neutron multipliers were introduced to induce (n, xn) reactions; simulations for Pb, Cu, and W were performed to compare their respective material properties. The neutron source was partitioned into 20 logarithmic intervals across an energy range of 0.1 eV to 100 MeV. It was configured as a parallel planar source with an area identical to the incident surface of the detector. The detector response was derived by tallying the (n, p) reaction rates within the He-3 gas.

To derive optimal design parameters, an extensive parametric study was conducted by defining the moderator's radius and front/back thickness, the geometric dimensions of the He-3 detector (radius and height), and the insertion thickness of the neutron multiplier for each material as primary variables. The energy-dependent response function was calculated for all variable combinations, and a normalization process using Equation (1) was performed to correct for systematic effects resulting from changes in the source area. In this context, R represents the Response Function, C denotes the (n, p) reaction rate obtained from MCNP6, and A_{src} signifies the area of the incident source.

$$R(E) = C(E) \times A_{src} \tag{1}$$

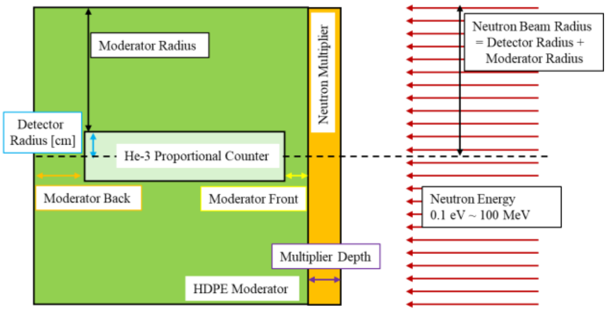

Fig. 1. Long Counter Simulation Geometry

The results of the parametric study in this research are presented in Figures 2 and 3. First, regarding the geometric variations of the moderator, as the radius and back thickness increased, the response in the low-energy region below 1 MeV decreased, while the high-energy response tended to increase (Figures 2-A and B). This is analyzed to be due to the increased frequency of scattering and back-scattering of high-energy neutrons within the thickened moderator, resulting in a higher number of moderated neutrons entering the detector (He-3). Specifically, the peak appearing in the 1 MeV region indicates that a front moderator thickness of 5 cm is optimal for the thermalization of neutrons in that energy range. When the front thickness was varied, the low-energy response decreased sharply as the thickness increased, and the peak position shifted toward higher energies (Figure 2-C), which is attributed to the energy filtering effect caused by the high scattering and absorption cross-sections of hydrogen nuclei.

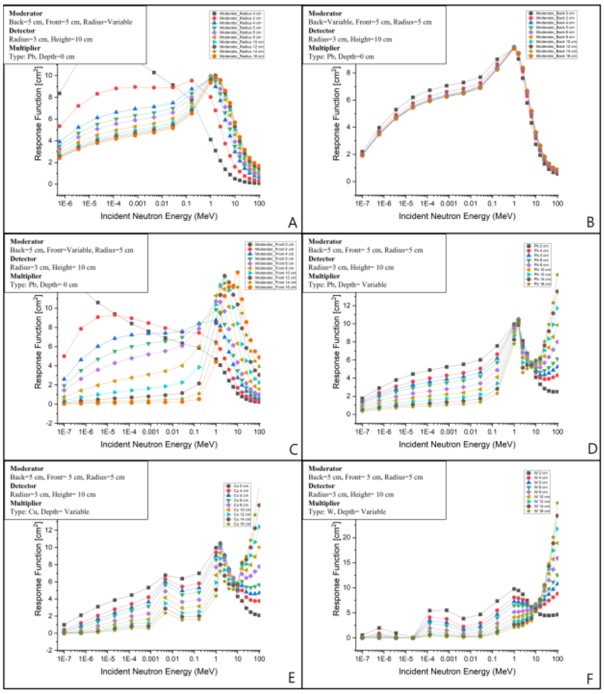

Fig. 2. Parametric Analysis of Neutron Response Functions for Various Moderator and Neutron Multiplier Configurations

The behavior analysis results for the neutron multiplier (Figures 2-D, E, and F) show that the response in the high-energy region increased sharply as the multiplier thickness increased, regardless of the material. This demonstrates that incident neutrons above 20 MeV react with high-Z materials to induce (n, xn) reactions, directly improving detection efficiency. In the case of copper (Cu), a characteristic peak was observed near 2.45 keV, which is attributed to the inherent scattering resonance effect of copper isotopes. On the other hand, tungsten (W) exhibited a behavior where the response converged to zero in the 10 to 100 eV range; this is analyzed as a self-shielding effect caused by strong capture resonance within that specific interval.

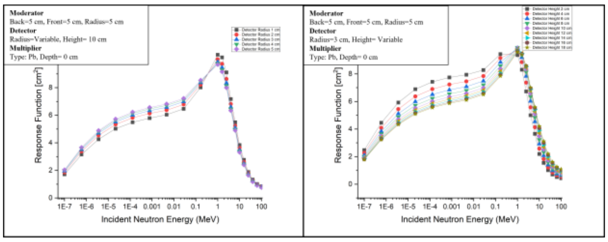

Fig. 3. Parametric Analysis of Neutron Response Functions for Various Detector Configurations

Finally, the effects of detector geometry variations are illustrated in Figure 3. An increase in the detector radius displayed a trend similar to the variations in moderator radius, though the sensitivity was relatively lower. On the other hand, as the detector height increased, the enhancement in high-energy response became significantly more prominent compared to the decrease in low-energy response. This is interpreted as the result of effectively improving the overall detection sensitivity by expanding the active volume for high-energy neutrons traversing the moderator.

3. Conclusions and Future Works

In this study, the physical effects of key geometric parameters of a Long Counter on its energy response function were systematically analyzed through Monte Carlo simulations. The results demonstrated that the introduction of a neutron multiplier is a crucial mechanism for significantly enhancing detection efficiency in the high-energy neutron region above 20 MeV. However, it was confirmed that a geometric trade-off exists regarding the attainment of overall response flatness; for instance, independent adjustments of specific variables often resulted in improved high-energy response accompanied by drastic changes in the low-energy response. This suggests that a more sophisticated, composite design is necessary to accommodate the unique white neutron spectrum of the NDPS facility. Accordingly, future research will explore hybrid configurations of various design variables. Specifically, we intend to derive a final geometry optimized for the NDPS facility by strategically incorporating voids within the moderator to precisely control energy filtering effects and by optimizing the placement and shape of the multiplier.

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