Simulation for reducing the γ-ray background in the EAR2 at n_TOF

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1 Introduction

1.1 n_TOF facility

The n_TOF (neutron time-of-flight) facility at CERN is an experimental facility for precise measurements of neutron-induced reaction cross sections over a wide range of neutron energies [1][2]. Fig. 1 shows the layout of the n_TOF facility. A pulsed 20 GeV/c proton beam from the Proton Synchrotron (PS) at

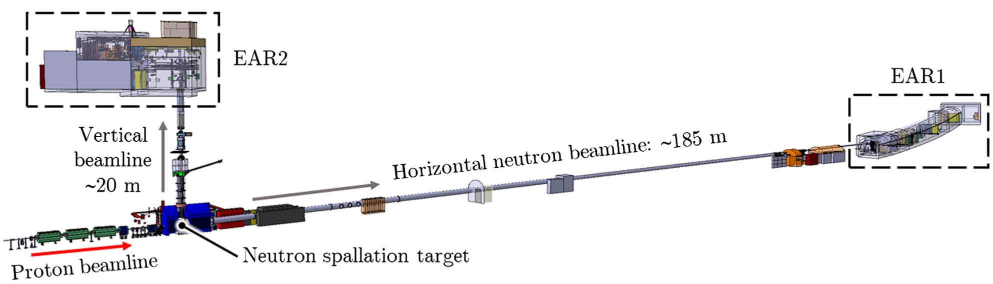

Figure 1: Layout of the n_TOF [3].

CERN hits a Pb spallation target, producing various secondary particles. Of the secondary particles produced, neutrons are the most abundant particles and are used to measure neutron capture cross sections in the experimental area at n_TOF. As shown in Fig. 1, the n_TOF facility has two beamlines: EAR1 and EAR2. In this study, we focused on the EAR2 beamline, which extends vertically from the spallation target.

1.2 EAR2

EAR2 is one of the beamlines at the n_TOF facility and extends vertically for 20 m from the spallation target [4]. Fig. 2 shows the layout of EAR2. Neutrons produced at the spallation target are first slowed down using borated water, pass through a collimator, and then hit the target nucleus. The γ rays produced in this interaction are detected to measure the neutron reaction cross section. However, during the actual measurement, not only the desired γ rays are detected, but also γ rays produced when neutrons interact with the collimator or the walls of the experimental area. These act as background and can reduce the measurement accuracy, so it is important to remove or reduce them.

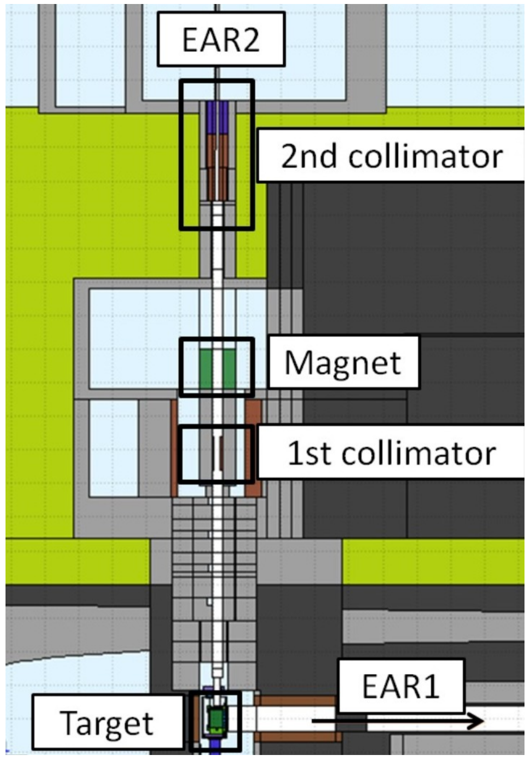

Figure 2: Layout of the EAR2 at n_TOF [5].

2 Purpose

In this study, we focused on the area near the exit of the second collimator in the EAR2 beamline and evaluated, using FLUKA and Flair, which materials can reduce the background more effectively. Since the geometry up to the second collimator has already been established [5], we focused on the exit region. Fig. 3 shows the exit of the second collimator in EAR2, which is the focus of this study. As shown in Fig. 3, Lithium Polyethylene (Li-PE) is installed at the exit of the second collimator to capture neutrons. This is done to remove γ rays that are produced when neutrons enter the experimental area and interact with walls or other materials. The installed Li-PE is a cylinder with a radius of 49 cm from the beam center and a height of 20 cm. As seen in the right image of Fig. 3, the Li-PE has a hole for placing the vacuum system tube.

In this study, we investigated which materials placed on top of the Li-PE

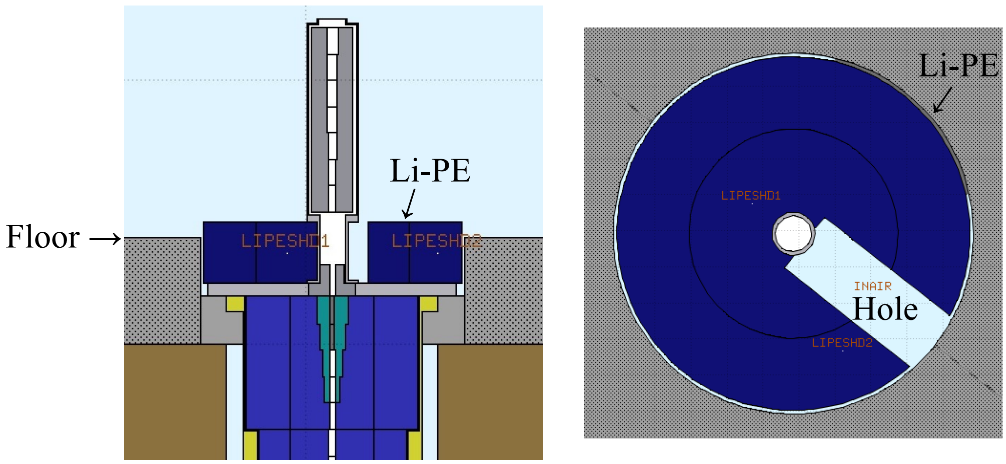

Figure 3: Layout of the second collimator at EAR2. The left shows a side view, and the right shows a top view. The dark blue part is Li-PE. As shown in the figure, the Li-PE has a hole for placing the vacuum system tube.

layer can reduce the γ-ray background. Specifically, we compared cases where Polyethylene(PE), Boron Polyethylene(B-PE), or Lithium Polyethylene(Li-PE) are added, and the case where nothing is added, using simulations with FLUKA and Flair to evaluate the γ-ray fluence.

3 Simulation

3.1 FLUKA and Flair

In this study, we used FLUKA and Flair for the simulations. FLUKA is the main program that simulates particle transport and interactions based on the Monte Carlo method. Flair is a graphical interface that works with FLUKA, providing a visual environment to easily create, edit, and check geometries and simulation results.

3.2 Geometry

Fig. 4 shows the setup when a new material is added on top of the Li-PE at the exit of the second collimator in this study. The added material is assumed to be a cylinder with a height of 20 cm and a radius of 49 cm.

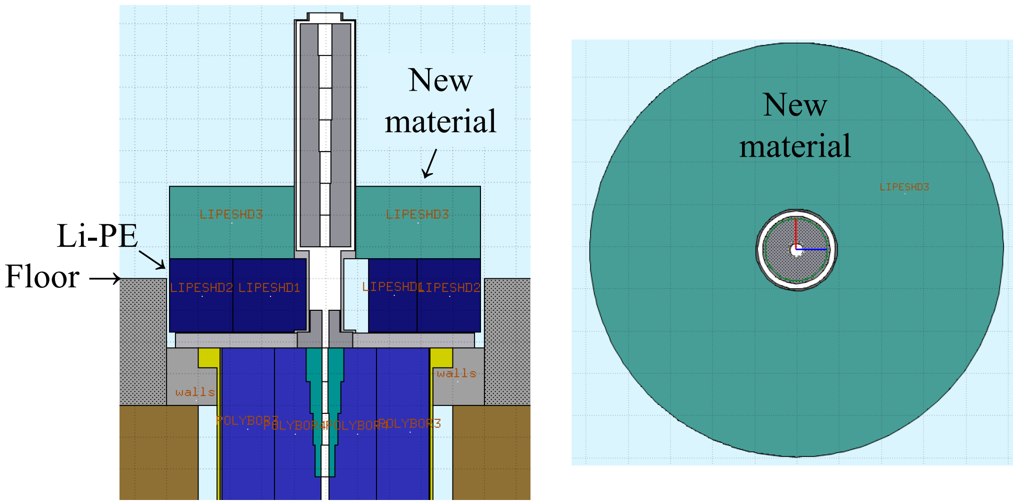

Figure 4: Layout of the added material. The left shows a side view, and the right shows a top view. The green part is added material.

3.3 Material

In this study, we compared how the γ-ray background changes when the following three materials are added on top of the Li-PE layer at the exit of the second collimator in EAR2, and when nothing is added.

1. Polyethylene (PE)
2. Boron-Polyethylene (B-PE)
3. Lithium-Polyethylene (Li-PE)

These materials were chosen based on their ability to slow down neutrons and their γ-ray production characteristics. Both PE and B-PE are effective moderators because of their high hydrogen content. In standard PE, most moderated neutrons are captured by hydrogen nuclei, which results in 2.2 MeV capture γ rays. In B-PE, many captures occur on ^{10}B instead, producing 478 keV γ rays. Although both materials lead to secondary γ-ray production, the lower-energy γ rays from boron capture are easier to shield compared to the 2.2 MeV γ rays from hydrogen. Li-PE has a large cross section for the ^{6}Li(n,p) reaction, so it is also effective for capturing neutrons, and since the reaction produces protons and tritons, it does not increase the

γ-ray background significantly. However, Li-PE is expensive, so it is necessary to check how much more effective it is compared to the other materials.

3.4 Particle information file

For the simulation, we used an ASCII file containing particle information, which included only particles flying from the spallation target toward EAR2. This file was produced by a previous simulation. In this study, we used a dedicated FLUKA routine to extract only the particles that enter the second collimator from the ASCII file.

4 Results

The left graph in Fig. 5 shows the γ-ray fluence for each geometry projected in the z-direction, with the radius from the beam center on the horizontal axis. The right graph is an enlarged view of the left graph for the radius from

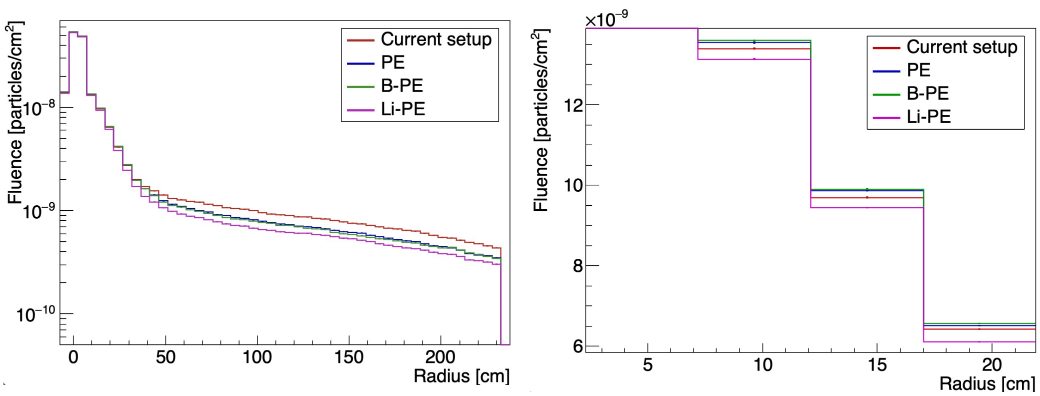

Figure 5: The graph shows the fluence of γ rays. The horizontal axis represents the distance from the beam center (radius), and the vertical axis represents the number of γ rays scored, projected in the z-direction. The left graph uses a logarithmic scale, while the right graph is an enlarged view of the 5–20 cm region from the left graph and uses a linear scale.

by the fluence in the current setup.
From Fig. 5 and Fig. 6, we can see that in the outer region (Radius > 30 cm), adding PE, B-PE, or Li-PE reduces the γ-ray background compared to current setup. The simulation shows that PE and B-PE reduce the background

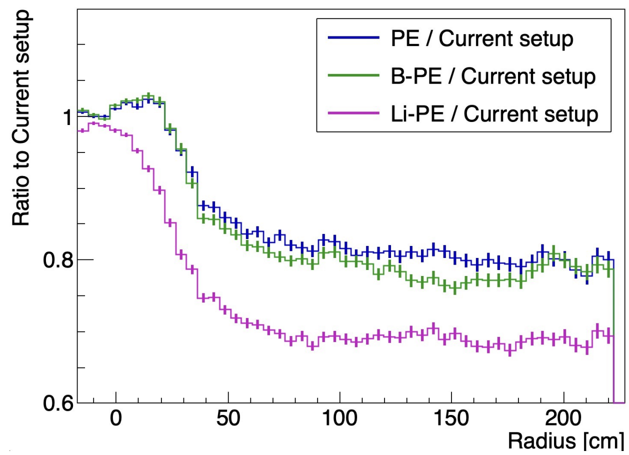

Figure 6: The graph of normalized γ-ray fluence. The horizontal axis shows the radius from the beam center, and the vertical axis shows the number of γ rays scored, projected in the z-direction and normalized by the values for the current setup.

to about 80% of the current setup case, and there is not much difference between these two. On the other hand, Li-PE reduces it further, to about 70% of the current setup. In the inner region (Radius $<$ 30 cm), adding Li-PE also reduces the background compared to current setup, while adding B-PE or PE increases the background. This result agrees with the higher background observed in the previous experiment. Comparing all geometries, Li-PE gives the lowest background. This is reasonable because the Li(n,p) reaction does not produce γ rays.

Next, Fig. 7 shows the γ-ray fluence at each neutron time of flight range from the spallation target and Fig. 8 shows the results with the newly added material are normalized to those from the current setup.

The motivation for applying these cuts was to investigate the variation of the neutron and γ-ray background fluence with the time of arrival of the particles in the experimental hall, since it has been experimentally observed that changes in the collimator shield can affect considerably the TOF distribution of the background measured by capture detectors [6]. For this purpose, a custom FLUKA user routine was used to process the ASCII input file and select only the particles within specific time-of-flight intervals, each of which corresponds to a neutron energy range, as shown in Table 1. From Figs. 7

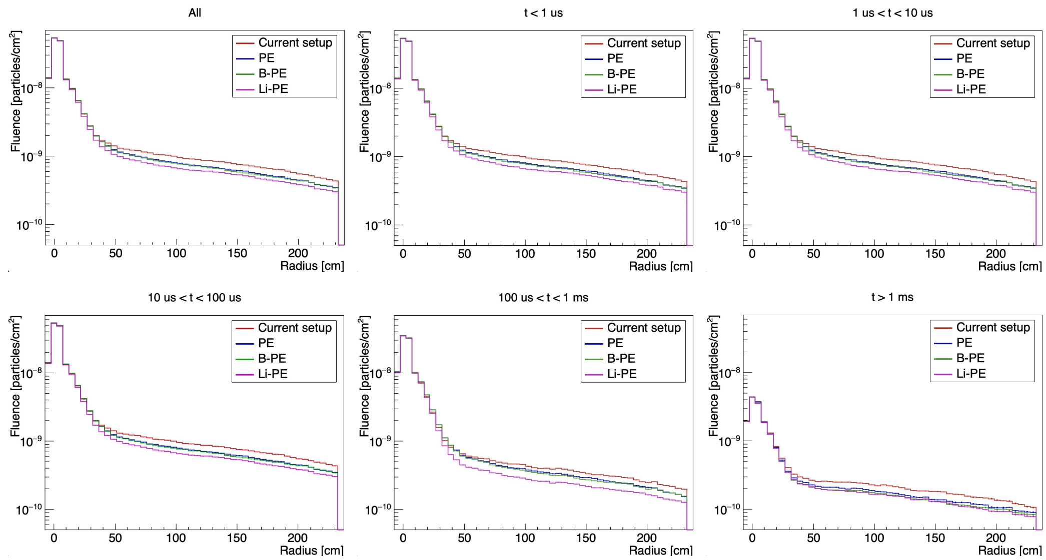

Figure 7: Fluence of γ rays at each neutron time-of-flight range. The vertical axis is displayed on a logarithmic scale.

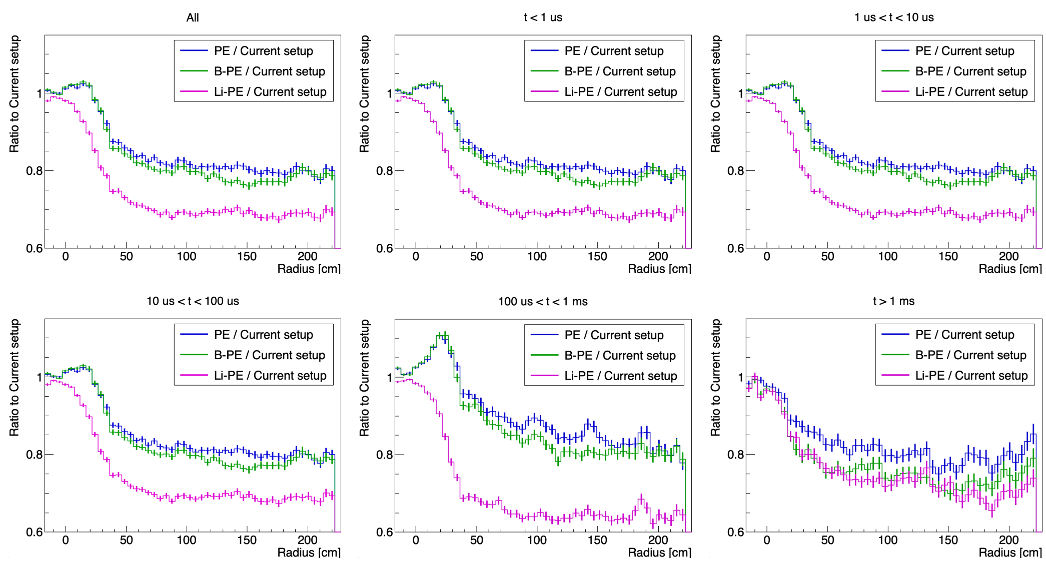

Figure 8: Fluence of γ rays at each neutron time-of-flight range, normalized to that from the current setup.

and 8, it can be seen that, regardless of time of flight, in the outer region

Table 1: TOF to neutron energy conversion.

TOF interval (μs)	**Neutron energy range**
< 1	> 2 MeV
1–10	2 MeV–20 keV
10–100	20 keV–200 eV
100–1000	200 eV–2 eV
> 1000	< 2 eV

(Radius > 30 cm), the cases with PE, B-PE, or Li-PE added can reduce the γ-ray background compared to the case without any additional material (current setup). And we can also see a tendency that, in the inner region (Radius < 30 cm), adding Li-PE decreases the background, whereas adding B-PE or PE increases the background compared to current setup.

5 Conclusion

In this study, I simulated different materials that can be placed at the exit of the second collimator in EAR2 of n_TOF to reduce the γ-ray background. From the γ-ray fluence, it was found that using Li-PE as an additional material gives the best reduction of the γ-ray background. Both PE and B-PE also show a reduction in the outer region, although in the inner region they tend to increase the background compared to the current setup. These results indicate that Li-PE is the most effective candidate among the tested materials, as it moderates and captures neutrons while avoiding the production of high-energy capture γ rays. However, since Li-PE is expensive, further studies should be carried out to quantify the cost-benefit balance and to evaluate its performance with respect to other detector response metrics, such as energy deposition.

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