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Neutron Beam Estimation and Collimator Design for RAON_nTOF

E.J. Lee [a*], C.W. Lee [b], S.C. Yang [b], J.C. Kim [c] , Y.W. Lee [b], G.S. Cho [a]
[a]Dept. of Nuclear and Quantum Engineering, Korea Advanced Institute of Science and Technology., 291 Daehak-ro, Yuseong-gu, Daejeon 305-701, Republic of Korea
[b]*Nuclear Data Center, Korea Atomic Energy Research Institute, 111, Daedeok-daero 989beon-gil, Yuseong-gu Daejeon 305-353, Republic of Korea*
[c]*Institute for Basic Science, 70, Yuseong-daero 1689-gil, Yuseong-gu, Daejeon, 305-811, Republic of Korea*
[*]*Corresponding author:leej0715@kaist.ac.kr*

1. **Introduction**

A heavy ion accelerator at the Neutron Science Facility (NSF) requires a collimator to focus the neutron beam and to reduce the background noise. Thus it is critical to have an optimal collimator design. To achieve optimal collimator design, The Monte-Carlo N Particle Extended (MCNPX) program was used for the conceptual design study of the collimator and analyze its performance. At NSF, neutrons were produced by interactions of 53MeV deuteron (d) beam on a beryllium (Be) target. Because of the low neutron production rate, MCNP simulation including neutron production from ion beam and neutron transport through the collimator in a calculation is inefficient and it is too difficult to obtain reliability with a low relative error for calculation result. As a result, we suggested the simulation method that making a new neutron source term describes an actual d+Be source and parameters for the estimating neutron source term were deduced.

2. Methods and Results

2.1 Beryllium Target

The thickness of the beryllium target is important when making the maximum number of neutrons. Only the neutrons with traveling on a forward direction are considered, however, since those neutrons are the ones that actually affect the performance of a collimator. The shape of a target was predetermined and its design is then optimized by changing the thickness and the radius. As a result, a target with a 9 mm of thickness and a 2 cm of radius is selected.

2.2 Neutron Angle Group

Neutrons produced from the reaction of deuteron beam on the beryllium target are emitted to all direction. We assumed that neutrons have the same solid angle with the same energy distribution because the neutrons are emitted isotropically from the target. Therefore, it is important to find the solid angle group to make the neutron source similar to that of neutrons from the d+Be reaction.

In preliminary study for the collimator design, the neutron source term was formed with 5° interval that started from the 2.5°. Neutrons from 92.5° to 180° angle are set to one group because neutrons toward back of the target do not affect the collimator design.

However, when the angle of neutrons that entered directly from the target to the collimator is calculated, it had angles of 1.7° and 8.5°.

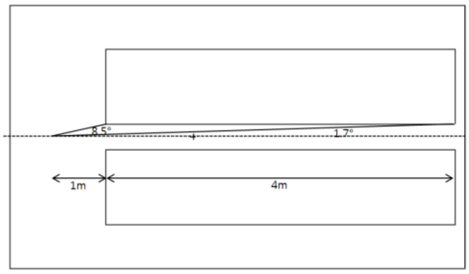


Fig.1. Schemetic of the source and concrete collimator. Collimator hole has 15 cm of radius.

With the previous source, a neutron beam with an angle between 0° and 2.5° can interact with a collimator or directly passes the collimator hole without having any interaction. As a consequence, it is possible that the simulation result of neutrons emitted from the previous source can lead to a misleading result when compared to actual neutrons produced from the d+Be reaction. What this suggests is that we need to divide the angle with a smaller interval. From MCNPX simulation, we found the optimal angle interval to be 1.7°.

Meanwhile, the neutrons over 8.5° solid angle, which directly entered the collimator, are completely shielded along the 4 m in length of concrete wall. To have a more efficient simulation, angles from 10.2° to 180° are bound to one group since they have almost no effect on collimator design.

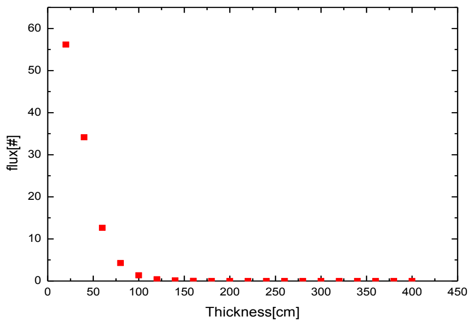


Fig.2. Penetration of the neutron beam in concrete. The neutron beam has energy 0 to 53 MeV.

Consequently, we have four neutron sources; a d+Be source, a 5° interval source, a 1.7° interval source and the previous source. We compared three sources except the previous source. The previous source is set up by a different program with MCNPX due to the neutron generation problem of MCNPX. Nonetheless, we still compared d+Be source with a 5° and 1.7° interval source to decide which source would be more reasonable to be used when designing the actual collimator.

Then, we compare the flux of each source at three different regions; at the output of collimator-end hole, at the collimator-end without the collimator hole and the radial distribution of the entire collimator-end. In this simulation, the collimator is simply made of concrete wall with 4 m in length and has a hole with a radius of 15 cm. The source (or the target) is located at 1m apart from the collimator.

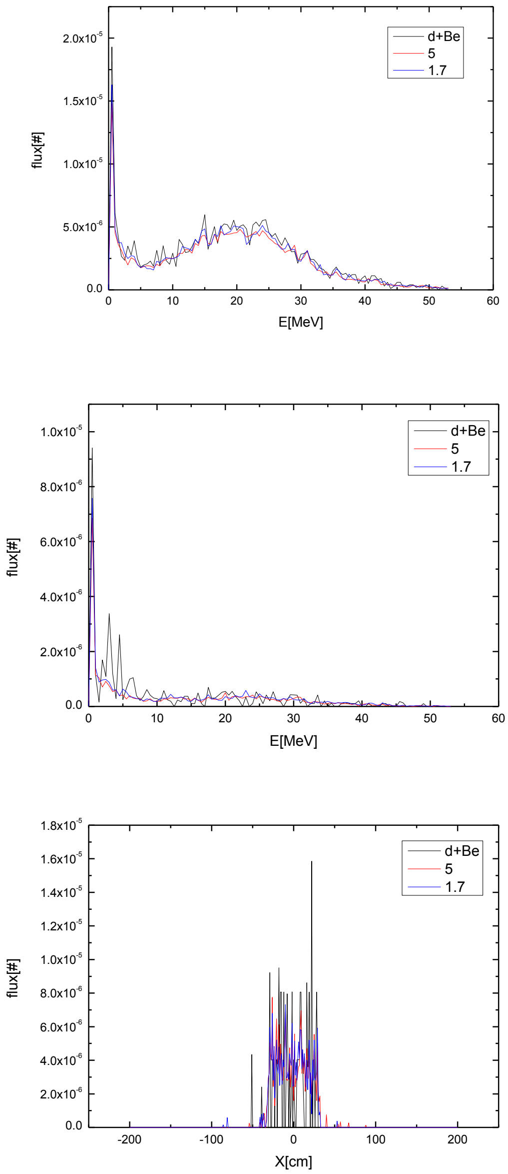


Fig.3. Flux of the three sources at three regions.

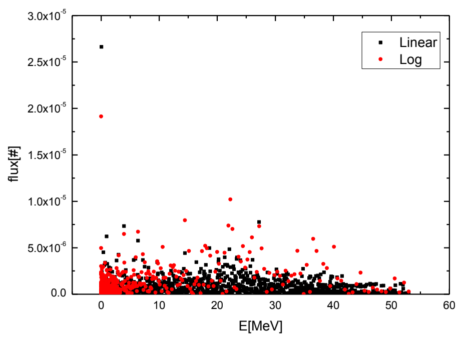
Table I: Sum of difference between an actual d+Be source and the made sources.

collimator-end hole		collimator-end without the collimator hole		radial distribution of the entire collimator-end	
5	1.7	5	1.7	5	1.7
3.47×10^{-5}	2.23×10^{-5}	1.02×10^{-5}	6.99×10^{-6}	1.18×10^{-4}	1.18×10^{-4}

From the simulation, we found that the source with 1.7° interval shows a more exact value when compare to that of d+Be source.

2.3Neutron Energy Group

After the angle group is set, the energy groups of the neutron source need to be divided with an appropriate value. The previous source has energy of 53 MeV which was then divided with an interval of 1 MeV. However, this still is not enough to describe the neutrons emitted from the actual deuteron-beryllium reaction. To improve the quality of simulated neutrons, we selected four energy groups: 1060 groups in a linear scale, 106 groups in a linear scale, 1000 groups in a log scale and 100 groups in a log scale. Then we measured the spectrum behind the same concrete collimator. In simulation, when compared to the actual d+Be source, we found that the neutron source divided into 1060 and 1000 energy groups shows a more accurate result when compared to that of 106 and 100 groups. Nonetheless, there are some uncertainties need to be considered when making the selection between linear scale and log scale. In log scale, it ranges from 1×10^{-5} MeV to 53 MeV but it uses 550 groups in between 1×10^{-5} MeV and 0.05 MeV. Then only 450 groups are used in between 0.05 MeV and 53 MeV. In linear scale, however, 1060 group starts from 0.05 MeV to 53 MeV. What this concludes is that linear scale can give more accurate result when the energy is above 0.05 MeV. The log scale can derive low energy neutron source specifically, but not above 0.05 MeV. Large errors are predicted above 0.05 MeV energy with the log scale. The errors of linear and log scale neutron source against d+Be source are shown in Fig.4.



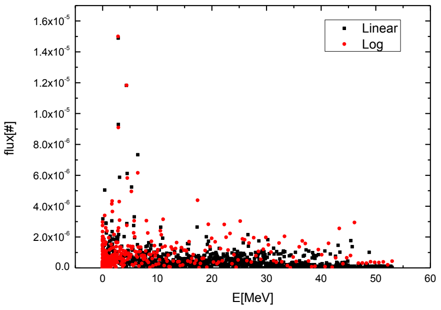


Fig.4. The errors of the linear and log scale neutron sources against an actual d+Be source at collimator-end hole, at the collimator-end without the collimator hole.

Linear scale energy group shows a more reliable data in high energy range, whereas the log scale shows a more reliable data in low energy range. To see whether the neutrons with energy below 0.05 MeV have a significant effect on a collimator design, we simulated the same experiment with neutrons with energies below 0.05 MeV, as shown in Fig 5.

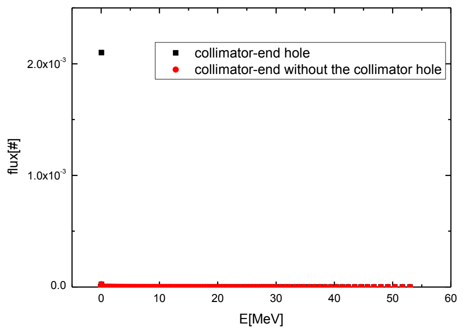


Fig.5. Flux of the neutrons below 0.05 MeV at collimator-end hole, at the collimator-end without the collimator hole.

The number of neutrons penetrating the collimator is negligible and neutrons emitted through the collimator hole are only 2.1×10^{-3} per one neutron. In a real d+Be source, the percentage of the neutrons below 0.05MeV are only 0.65%. This means that only 13×10^{-6} neutrons that started from the source with energies below 0.05 MeV are detected at the end of the collimator hole.

As a result, neutrons below 0.05 MeV are negligible and the log scale energy groups are no longer in consideration. Thus, the linear neutron source energy group is selected. When designing the collimator, however, reducing the low energy neutrons after the scattering within the collimator must be taken into an account. To do so, the flux spectrum is expressed as a log scale to contain the information on low energy neutrons below 0.05 MeV.

2.4 Collimator Design

Aforementioned, there is some low estimation in MCNPX producing neutron through the d+Be reaction. Thus, the source must be produced through another program using a new energy and an angle group. Unfortunately, the modified source is not completed yet; therefore, we proceed the collimator design simulation using the previous source to examine the tendency.

There are two representative collimator designs: a ring type and a sandwich type [1,4]. Iron and borated polyethylene are two typical materials that are used for building collimators. Iron is usually used for scattering material and borated polyethylene plays a role of a moderator or an absorber [1,2,3]. In this experiment, 5% borated polyethylene is chosen among the various type of borated polyethylene [4,6]. Five types of collimator are compared via MCNPX code: a solely concrete, a ring type, a single iron, a single borated polyethylene and a sandwich type. The spectrum is measured at the output of collimator-end hole, at the collimator-end without the collimator hole and the radial distribution of the entire collimator-end which are shown in Fig 8, 9, 10 and 11.

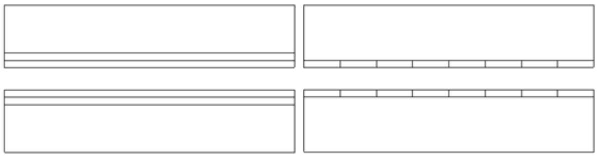


Fig.6. Schematic of the two representative collimator designs. Ring type (left) and sandwich type (right).

When designing a collimator, we need a standard to select a proper design. To do so, we first check the neutrons passing the collimator hole directly without having any interaction which is shown in Fig 7.

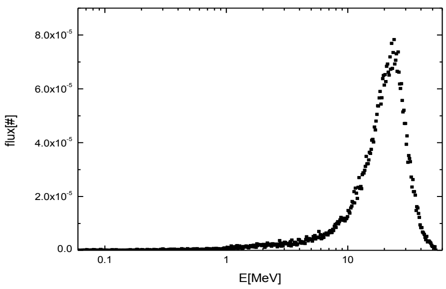


Fig.7. Neutrons directly pass the collimator-end hole without interaction

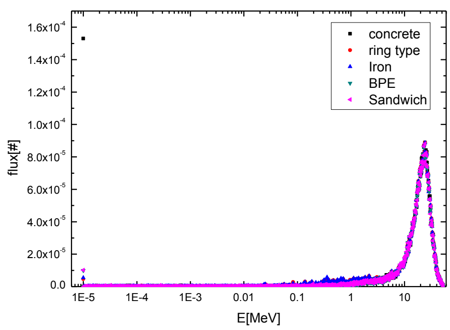


Fig.8. Neutron flux pass the five types of collimator-end hole.

Two spectrums above, show that there are few neutrons emitted at the end of collimator hole after the interactions within the collimator. We can see that scattered neutrons solely due to the collimator hole are quite low. Therefore, it is important to reduce the low energy neutrons that are close to 0 MeV. This is the main parameter when designing a collimator.

The low energy neutrons produced by scattering must be low. The concrete collimator shows the most low energy neutrons. Fig.9 shows the low energy region in a more detail.

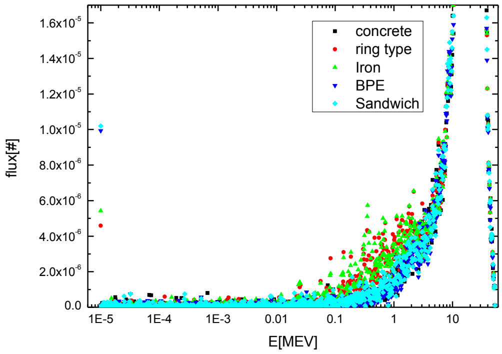


Fig.9. Neutron flux of the five collimators at collimator-end hole (axis scale changed).

The ring shaped collimator shows the lowest number of low energy neutrons.

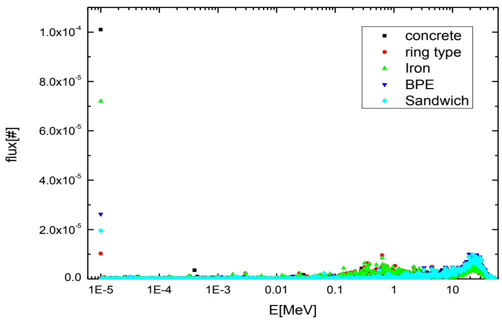


Fig.10. Neutron flux of the five collimators at the collimator-end without the collimator hole.

From Fig. 10, we observe that at the collimator-end without the hole, the ring type collimator emits the lowest number of scattered neutrons.

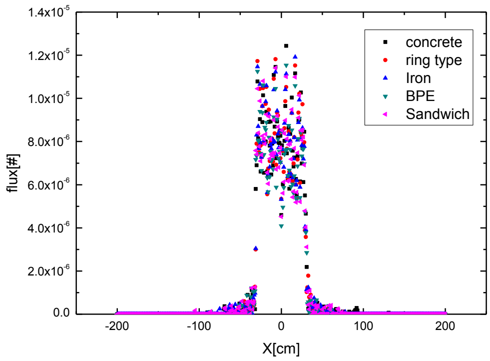


Fig.11. Radial distribution of the neutron the entire collimator-end.

In Fig. 11, we again see that the ring shaped collimator emitted the lowest number of scattered neutrons. Therefore, the ring shaped collimator that contains iron and borated polyethylene reduces the low energy neutrons the best in all three cases.

3. Conclusions

Through the MCNPX simulation, the target, the source term and the collimator design are optimized. The disk shaped target has a 9 mm of thickness with a radius of 2 cm. The source term has 1.7 ° interval angle group and 1060 linear energy group. In comparison of the collimator design with some representative collimator designs, the ring shaped collimator design contains iron inside, 5% borated polyethylene outside shows the best performance in reducing the scattering neutrons and thus has the minimum background noise. Furthermore, more specific case studies in each collimator design are needed because a number of possible collimators could be designed such as conical and double conical type [5].

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