A NEW DESIGN OF THERMAL NEUTRON BEAM AT THE DALAT NUCLEAR RESEARCH REACTOR

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Abstract: This paper presents a new design of a thermal neutron beam at the horizontal channel No.1 of the Dalat Nuclear Research Reactor by using the MCNP6 code. The thermal neutron beam is the result of installing a combination of Sapphire and Bismuth crystal filters. Due to lacking the thermal neutron cross-section data of crystalline filters, we used NJOY2016 code to generate the cross-section files for Sapphire and Bismuth, then updated the compatible library files into MCNP6 library. The filter configurations having different thickness were investigated for obtaining the optimal value of thermal neutron flux and thermal neutron flux to high-energy neutron flux ratio R-value. In addition, we changed the beam guide structure from cylindrical collimator to conical collimator for increasing the neutron flux at the sample position. The comparison of simulation results using a different combination of filters at the same thickness showed the advantages of Sapphire crystal in the aspect of producing higher thermal neutron flux and R-value.

Keywords: *MCNP6, NJOY2016, thermal scattering law, neutron filter*

1. Introduction

Neutron filter technique is commonly used for producing neutron beams at nuclear research reactors in the world. The filters are a combination of materials at different forms such as free gas, crystal, and powder. In the Dalat Nuclear Research Institute (DNRI), the neutron filter technique has been developed and applied for supporting fundamental research and neutron activation analysis experiments with the neutron beam energy at thermal, $2\ keV, 24\ keV, 59\ keV$, and $148\ keV$. For the thermal neutron beam, a combination of silicon and bismuth single crystal filter has been applied base on the characteristics of thermal inelastic scattering of a neutron with single crystal materials. Recently, the FILTER-7 computer code was used for searching the optimal design of the filters, which archived the thermal neutron flux at $1.6 \times 10^6\ n/(cm^2.s)$ and the cadmium ratio RCd(Au) at 420 [1]. However, some study on nuclei having a low thermal cross section, the higher thermal neutron flux is needed for increasing the reaction rate. Additionally, eliminating high energy neutron at the sample position can improve the accuracy for experiments on the thermal neutron beam. Therefore, to increase the thermal neutron flux having high purity, after investigating the properties of filter materials and referring to others studies on thermal neutron filter [2], [3], [4], we decided to use the MCNP code to design a new thermal neutron beam at the horizontal channel No.1 of the DNRI by using the combination of sapphire and bismuth single crystals instead of silicon and bismuth one.

In this work, we used the Monte Carlo computer code MCNP6 [5] to simulate the characteristics of neutron spectra irradiated sample position after transmitted the filters at the different thickness. The MCNP6 uses the ENDF/B-VII neutron cross-section files as ACE format, which were processed from the ENDF library files by the NJOY code. To describe the interaction of neutron with moderators or crystal materials in thermal energy region, the thermal neutron scattering files are used to provide neutron cross-section data for some popular materials [6]. Due to lacking thermal neutron scattering cross-section of sapphire and bismuth crystals in the MCNP6 library, we used the NJOY2016 [7] code to generate the cross-section files using phonon frequency distribution of elements from [8]. The new library files were processed as a compatible format then updated into the MCNP6 library. By changing the thickness of the filters, the correlation of thermal neutron flux and the ratio R-values was obtained. The new filter configuration was designed base on the optimal thermal neutron flux and R-value.

2. Methodology

2. 1. Preparing the total thermal neutron cross-section library files

Total thermal neutron cross-section of crystallized materials is the summation of absorption cross-section and scattering cross-section. The scattering cross-section includes three part: incoherent elastic, coherent elastics, and inelastic. For a single crystal material, the elastic cross-section is normally neglected [9]. Then, the inelastic scattering cross-section plays an important role in interactions of the thermal neutron with these materials. The thermal neutron cross-section files of materials were generated by the NJOY2016 code. The module LEAPR was used to calculate and import the inelastic cross-section data to the THERMR module for merging and processing absorption cross-section with scattering cross section. Fig 1 shows the total thermal cross-section of sapphire processed by the NJOY 2016 code compared to free atom total cross-section and experimental results Exp 01 [4] and Exp 02 [2].

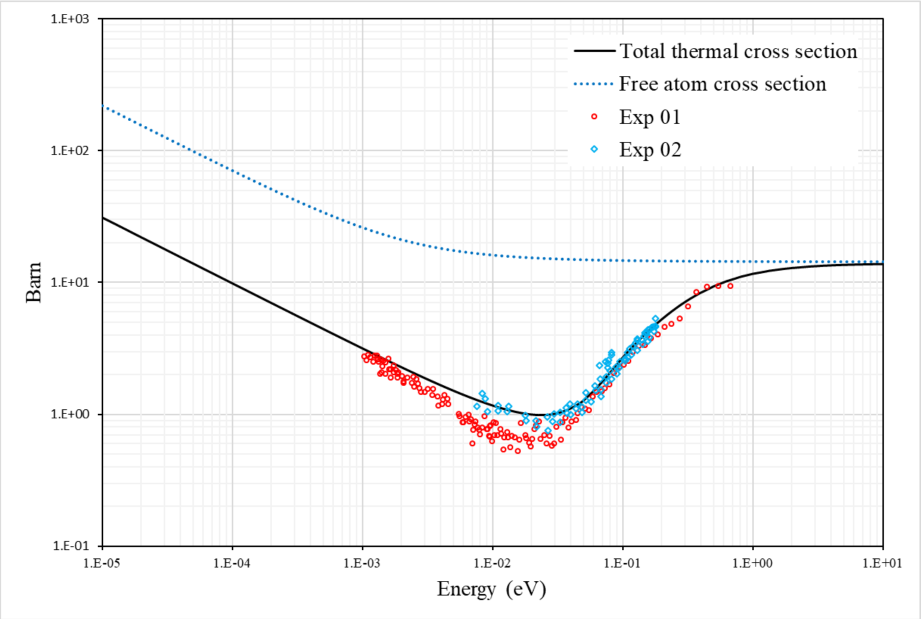

Fig 1. Total thermal neutron cross-section of Sapphire calculated by NJOY2016

The new cross-section files were updated into MCNP6 library by using the xsdir file provided by the MCNP6 code, and the MT card was applied for $S(\alpha, \beta)$ treatment of isotopes in crystal filters.

2. 2. Simulation configuration

The horizontal channel No.1 of DNRI was approved to open for developing a new thermal neutron beam, which utilized for neutron scattering studies. By the success of designing and manufacturing previous neutron beams [10], we changed the cylindrical beam collimators to conical one for increasing neutron flux at the sample position. The collimators are neutron and gamma absorber materials placed alternatively to minimize radiation dose. In addition, 5cm of Bismuth crystal filter was inserted for reduced gamma background. The collimators length have to satisfy the requirement for ensuring the isotropic property of the neutron beam. Fig 2 shows the vertical cross-section of the channel No.1 modeled in this simulation.

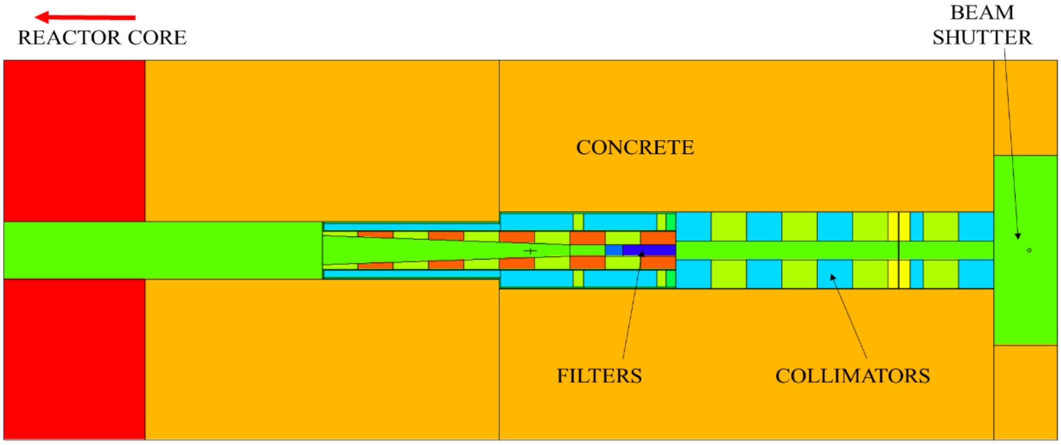

Fig 2. Simulation geometry configuration of the channel No.1.

The neutron filters were placed at the middle of the beam guide. By changing the sapphire filter thickness with a step of 5cm for each configuration, we investigated the optimal thermal neutron flux and R-value by using the tally F4. The neutron source spectrum was calculated from the simulation of the reactor core by criticality KCODE card. Similarity, we simulated the same geometry configuration by changing the sapphire filter to silicon filter for comparing the performance of two filters.

2. 3. Results and discussions

The relative neutron flux spectra at the sample position were calculated and compared to the original neutron spectrum as the Fig 3. In case of no neutron filter, the neutron spectrum remains the same distribution and the neutron flux decreases by the distance from the source. With the present of filters, there is a significant decreasing of neutron flux above the thermal region, while thermal flux is less decline. Therefore, the R-value is higher than the non-filter case, which is the consequence of low thermal total cross-section of crystalized filters. At the same thickness, the sapphire filter gives better thermal neutron beam with higher thermal neutron flux and R-value. In addition, the sapphire filter can stop the neutron energy at 54 keV and 148 keV, which can transmit through the silicon filter by two corresponding negative dips on the total cross-section [11].

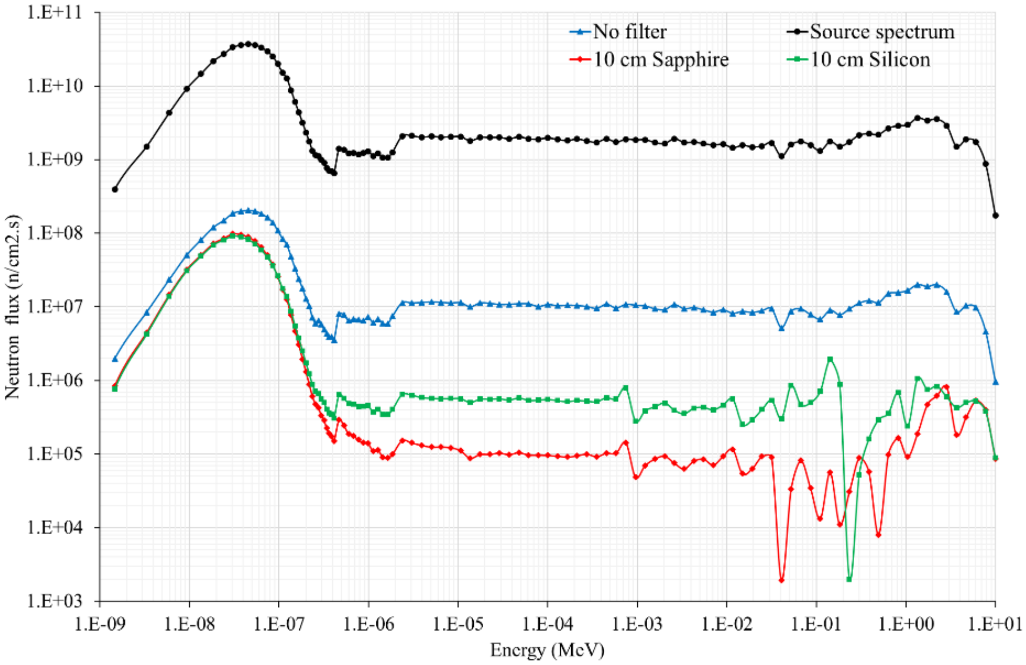

Fig 3. Simulation neutron spectra at the sample position

By increasing thickness, the filters can increase the capability of capturing neutron energy above thermal region while allowing transmission of the thermal neutron, which increases the R-value, or in other words, the purity of the thermal neutron beam. Fig 4 shows the correlations of thermal neutron flux and filter thickness between sapphire and silicon crystal. In all cases, the sapphire filter gives higher thermal neutron flux as well as the R-value.

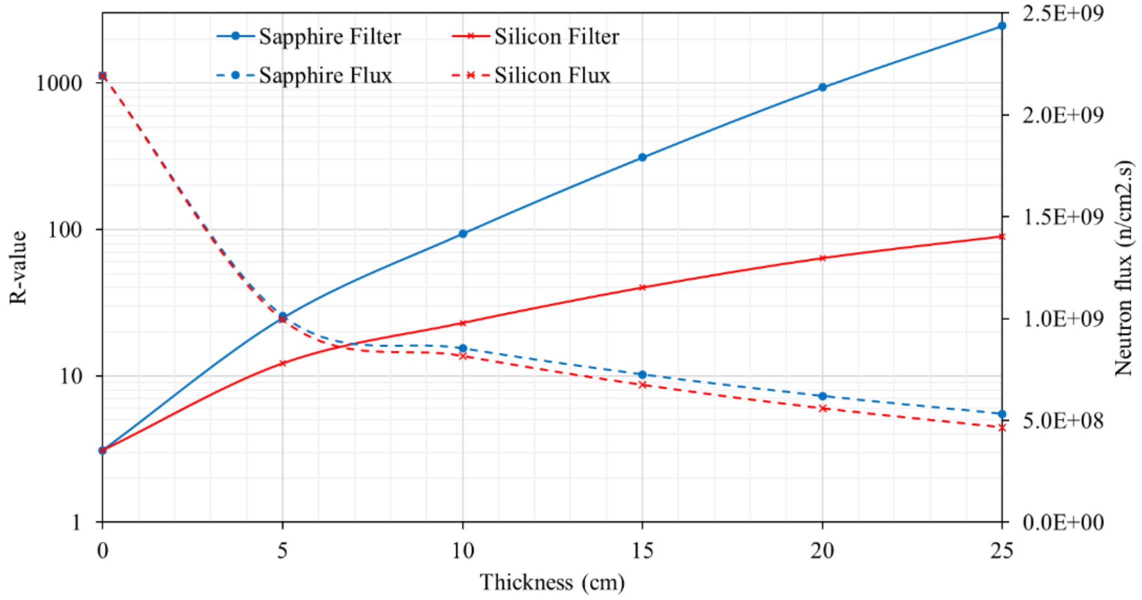

Fig 4. Thermal neutron flux and R-value vs filter thickness

Table 1 shows more detail about the simulation results of the R-values of filters at the different thickness. From the table, the 15cm thickness sapphire filter gives R-value about 7.7 times higher than silicon filter, which proved the advantage of sapphire filter on silicon filter.

Table 1: R-values of filters at different thickness

Filter thickness (cm)	R-value	
	Sapphire filter	Silicon filter
0	3.10	3.10
5	24.82	12.16
10	93.42	22.94
15	310.17	39.98
20	931.58	63.43
25	2089.66	90.42
30	3979.22	122.81
35	6776.75	160.20
40	10661.13	202.61

3. Conclusions

According to simulation results, the sapphire crystal filter can create a better thermal neutron beam having higher purity as well as thermal neutron flux compared to the silicon filter. The optimal filter configuration was selected at 15 cm thickness of sapphire crystal following the criteria: R-value, thermal neutron flux, and filter cost. Besides providing results for the feasibility study of design a new thermal neutron beam, the simulated neutron spectra are also the important input parameters for studying radiation dose in shielding design of the facility. However, the neutron flux spectra in this simulation are the relative values; the accurate value of neutron flux will be measured by the activation method after installation the filters.

REFERENCES

1. Tan, V. and P. Son. *Thermal neutron radiative capture cross-section of 186W (n, γ) 187W reaction*. in *Journal of Physics: Conference Series*. 2016. IOP Publishing.
2. Tennant, D., *Performance of a cooled sapphire and beryllium assembly for filtering of thermal neutrons.* Review of scientific instruments, 1988. **59**(2): p. 380-381.
3. Stamatelatos, I. and S. Messoloras, *Sapphire filter thickness optimization in neutron scattering instruments.* Review of Scientific Instruments, 2000. **71**(1): p. 70-73.
4. Mildner, D. and G.P. Lamaze, *Neutron transmission of single-crystal sapphire.* Journal of applied crystallography, 1998. **31**(6): p. 835-840.
5. Goorley, J.T., et al., *MCNP6 User's Manual, Version 1.0.* Los Alamos National Laboratory, Los Alamos, 2013.
6. MacFarlane, R., *New thermal neutron scattering files for ENDF/B-VI release 2*. 1994, Los Alamos National Lab.
7. Macfarlane, R., et al., *The NJOY Nuclear Data Processing System, Version 2016*. 2017, Los Alamos National Lab.(LANL), Los Alamos, NM (United States).
8. Hawari, A., I. Al-Qasir, and K. Mishra, *Accurate simulation of thermal neutron filter effects in the design of research reactor beam applications.* PHYSOR-2006: Advances in Nuclear Analysis and Simulation, 2006.
9. Zahar, N., et al. *Study of sapphire and MgO as thermal neutron filters for the moroccan TRIGA research reactor beam*. in *Advancements in Nuclear Instrumentation Measurement Methods and their Applications (ANIMMA), 2013 3rd International Conference on*. 2013. IEEE.
10. Son, P.N., et al., *Development of 24 and 59 keV filtered neutron beams for neutron capture experiments at dalat research reactor.* World Journal of Nuclear Science and Technology, 2014. **4**(02): p. 59.
11. Anh, T.T., et al., *Characteristics of filtered neutron beam energy spectra at Dalat Reactor.* World Journal of Nuclear Science and Technology, 2014. **4**(02): p. 96.

THIẾT KẾ CHÙM NEUTRON NHIỆT MỚI TẠI LÒ PHẢN ỨNG HẠT NHÂN ĐÀ LẠT

PHAN BẢO QUỐC HIẾU, PHẠM NGỌC SƠN

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Tóm tắt: Bài báo này trình bày kết quả mô phỏng thiết kế chùm neutron nhiệt mới tại kênh ngang số 1 của lò phản ứng hạt nhân Đà Lạt sử dụng chương trình mô phỏng Monte Carlo MCNP6. Chùm neutron nhiệt được tạo ra bằng cách sử dụng tổ hợp phin lọc tinh thể Sapphire và Bismuth. Để nâng cao sự chính xác cho các tính toán mô phỏng, thư viện số liệu tiết diện tán xạ neutron nhiệt của các vật liệu tinh thể Sapphire và Bismuth đã được tính toán bằng chương trình NJOY2016 và cập nhật vào thư viện số liệu phản ứng hạt nhân theo định dạng của chương trình MCNP6. Ngoài ra, hình học của hệ chuẩn trực neutron được thiết kế cải tiến từ dạng hình trụ sang dạng hình cone nhằm tăng thông lượng neutron tại vị trí chiếu mẫu thực nghiệm. Trong quá trình tính toán mô phỏng, bề dày của các phin lọc được thay đổi để tìm ra giá trị tối ưu của thông lượng neutron nhiệt, tỉ số R giữa thông lượng neutron nhiệt với thông lượng neutron năng lượng cao, và đồng thời giảm phông gamma. Kết quả mô phỏng cho thấy với cùng bề dày, tổ hợp phin lọc Sapphire và Bismuth cho thông lượng neutron nhiệt cũng như tỉ số R cao hơn đáng kể so với tổ hợp phin lọc Sillicon và Bismuth. Cấu hình tổ hợp phin lọc mới thu được từ kết quả mô phỏng sẽ được thiết kế chế tạo và lắp đặt để phục vụ các thí nghiệm.

Từ khóa: *MCNP6, NJOY2016, quy luật tán xạ neutron nhiệt, phin lọc neutron, sapphire*