

SIMULATION OF NEUTRON ENERGY SPECTRA OF FILTERED THERMAL NEUTRON BEAM

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Article history

Received: May 22nd, 2020

Received in revised form: June 18th, 2020 | Accepted: September 24th, 2020

Abstract

In this paper, simulation calculations of the energy spectra distribution of thermal neutrons transmitted through a filter section of sapphire and bismuth crystals were carried out. Techniques used sapphire and bismuth as neutron filters. The PHITS (Particle and Heavy Ion Transport System) simulation code was used to characterize the neutron energy spectra based on the material design parameters, geometrical structure, and shielding thickness.

Keywords: Bismuth; Neutron filter; PHITS; Sapphire.

DOI: [http://dx.doi.org/10.37569/DalatUniversity.10.3.712\(2020\)](http://dx.doi.org/10.37569/DalatUniversity.10.3.712(2020))

Article type: (peer-reviewed) Full-length research article

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MÔ PHỎNG PHỔ NĂNG LƯỢNG NEUTRON CỦA CHÙM NEUTRON NHIỆT TRUYỀN QUA PHIN LỌC

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Lịch sử bài báo

Nhận ngày 22 tháng 5 năm 2020

Chỉnh sửa ngày 18 tháng 6 năm 2020 | Chấp nhận đăng ngày 24 tháng 9 năm 2020

Tóm tắt

Trong bài báo, các tính toán mô phỏng về phân bố phổ năng lượng của các neutron nhiệt truyền qua phin lọc của tinh thể sapphire và bismuth đã được thực hiện. Kỹ thuật neutron phin lọc sử dụng bismuth, sapphire đã được áp dụng. Mô phỏng PHITS (Particle and Heavy Ion Transport System) đã được áp dụng để mô tả đặc điểm của phổ năng lượng neutron dựa trên các tham số thiết kế vật liệu, cấu trúc hình học, và độ dày lớp che chắn.

Từ khóa: Bismuth; Kỹ thuật neutron phin lọc; PHITS; Sapphire.

DOI: [http://dx.doi.org/10.37569/DalatUniversity.10.3.712\(2020\)](http://dx.doi.org/10.37569/DalatUniversity.10.3.712(2020))

Loại bài báo: Bài báo nghiên cứu gốc có bình duyệt

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1. INTRODUCTION

Neutron filter techniques have been used with nuclear reactors in many countries, such as Ukraine, the USA, Russia, Japan, Korea, and Vietnam. These techniques have been applied to research on experimental prompt gamma neutron activation analysis and boron neutron capture therapy. Neutron filter techniques have been used at the Dalat Nuclear Research Institute, and some filtered neutron beams have been investigated and developed (Phạm, Vương, Phù, & Trần, 2014; Vương, Phạm, Nguyễn, Trần, & Nguyễn, 2014). Bismuth and sapphire crystal filters have been previously investigated by Turkolgu (2012).

The PHITS calculation program (Sato et al., 2018) is a particle transport simulation program developed on the basis of the Monte Carlo simulation method by Hiroshi Takemiya's group at the Center for Computational Science and Electronic Systems of the Japanese Atomic Energy Agency (JAEA). PHITS simulates the transport and collision of nearly all particles, including neutrons, protons, photons, ions, and electrons with energy spectra from 10^{-4} eV to 1 TeV.

In this study, we used the PHITS code (Sato et al., 2018) to study and calculate the energy spectral characteristics and thermal neutron flux corresponding to the new bismuth and sapphire filters in the neutron channel of the Dalat Nuclear Research Reactor.

2. PHITS CALCULATION

The basic steps to create a new filter in the horizontal channel of the research reactor include

- Calculating to choose the size and combination of the most suitable materials to make the filter so that the neutron spectrum has as high a relative intensity as possible (from 85 to 97%).
- Processing, installing filters, and collimating neutron flow.

The cornerstone of the thermal neutron filter technique (Gritzay et al., 2007) is the use of a sufficiently large amount of monocrystalline material with a minimum distribution in the neutron total cross-section in the energy region near $E_n=0.0253$ eV.

The PHITS code (Sato et al., 2018) was developed in collaboration between JAEA, RIST, KEK, and several other institutes. We used the PHITS code to calculate and pick the parameters of size, density, material combination, and energy spectrum distribution for the horizontal neutron channel of the Dalat Nuclear Research Reactor.

3. CALCULATION MODEL

Bismuth and sapphire were selected to form a filter combination for obtaining neutrons with an average energy of 0.0253eV. Bismuth is an additional material used to

decrease the intensity of gamma rays through the filter. The cone collimator has been designed for the horizontal channel of the Dalat Nuclear Research Reactor.

The simulation model with the collimation shape designed for the horizontal neutron channel of the Dalat Nuclear Research Reactor is shown in Figure 1.

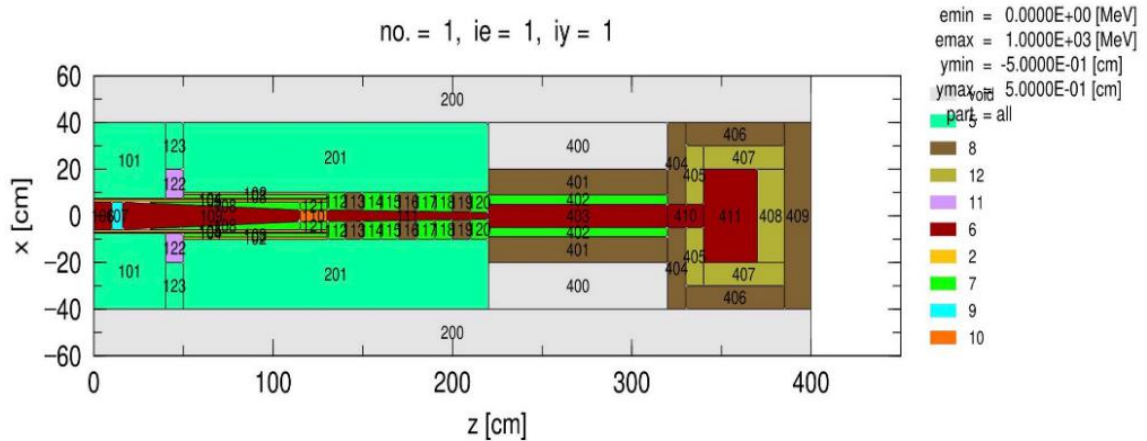


Figure 1. Model of the filtered neutron guidance system in horizontal channel No.1 for calculations with the PHITS program

4. RESULTS OF SIMULATIONS

Simulation results for the thermal neutron flux, the ratio of the thermal/epithermal neutrons, and the relative intensities of thermal neutrons are given in Tables 1, 2, and 3. The energy spectra of thermal neutrons are shown in Figures 2-4.

From the calculations, it was found that the thermal neutron flux of the cone collimation was 1.6 times higher than that of the cylindrical collimation. The flux of thermal neutrons, the ratio of thermal/epithermal neutrons, and the relative intensities of thermal neutrons depend very strongly on the filter components such as crystal or normal filters. For crystal bismuth and sapphire filters, the thermal neutron relative intensity parameter is much higher than that of normal bismuth and sapphire filters.

Table 1. Characteristic parameters of neutron spectra for crystal and normal cones using bismuth-6cm and sapphire-15cm filters

Cone	Thermal neutron flux (n/cm ² /s)	Fast neutron flux (n/cm ² /s)	Full spectrum flux (n/cm ² /s)	Thermal/epithermal ratio	Thermal neutron relative intensity
Crystal	9.36E+07	1.16E+06	9.47E+07	80.97	98.78%
Normal	7.68E+05	1.11E+06	1.88E+06	0.69	40.95%

Table 2. The characteristic parameters of neutron spectra for crystal cones and cylinders using bismuth-6cm and sapphire-15cm filters

Collimation	Thermal neutron flux (n/cm ² /s)	Fast neutron flux (n/cm ² /s)	Full spectrum flux (n/cm ² /s)	Thermal/epithermal Ratio	Thermal Neutron relative intensity
Cone	9.36E+07	1.16E+06	9.47E+07	80.97	98.78%
Cylinder	5.80E+07	7.11E+05	5.87E+07	81.60	98.79%

Table 3. The characteristic parameters of neutron spectra for a crystal cone with a filter using bismuth-6cm and sapphire crystal lengths ranging from 0cm to 20cm

Sapphire filter	Thermal neutron flux (n/cm ² /s)	Fast neutron flux (n/cm ² /s)	Full spectrum flux (n/cm ² /s)	Thermal/epithermal Ratio	Thermal neutron relative intensity
0 cm	8.58E+08	4.09E+08	1.27E+09	2.10	67.71%
1cm	1.59E+08	6.63E+07	2.26E+08	2.40	70.63%
3cm	1.47E+08	3.42E+07	1.81E+08	4.31	81.15%
5cm	1.36E+08	1.82E+07	1.54E+08	7.47	88.20%
7cm	1.26E+08	9.92E+06	1.36E+08	12.69	92.70%
9cm	1.17E+08	5.54E+06	1.22E+08	21.04	95.46%
10cm	1.12E+08	4.20E+06	1.17E+08	26.77	96.40%
11cm	1.08E+08	3.19E+06	1.11E+08	33.92	97.14%
12cm	1.04E+08	2.47E+06	1.07E+08	42.23	97.69%
13cm	1.01E+08	1.91E+06	1.03E+08	52.71	98.14%
14cm	9.70E+07	1.48E+06	9.85E+07	65.57	98.50%
15cm	9.36E+07	1.16E+06	9.47E+07	80.97	98.78%
16cm	9.03E+07	8.99E+05	9.12E+07	100.41	99.01%
17cm	8.71E+07	7.17E+05	8.79E+07	121.55	99.18%
18cm	8.41E+07	5.73E+05	8.46E+07	146.76	99.32%
19cm	8.11E+07	4.68E+05	8.16E+07	173.41	99.43%
20cm	7.83E+07	3.71E+0	7.87E+07	211.11	99.53%

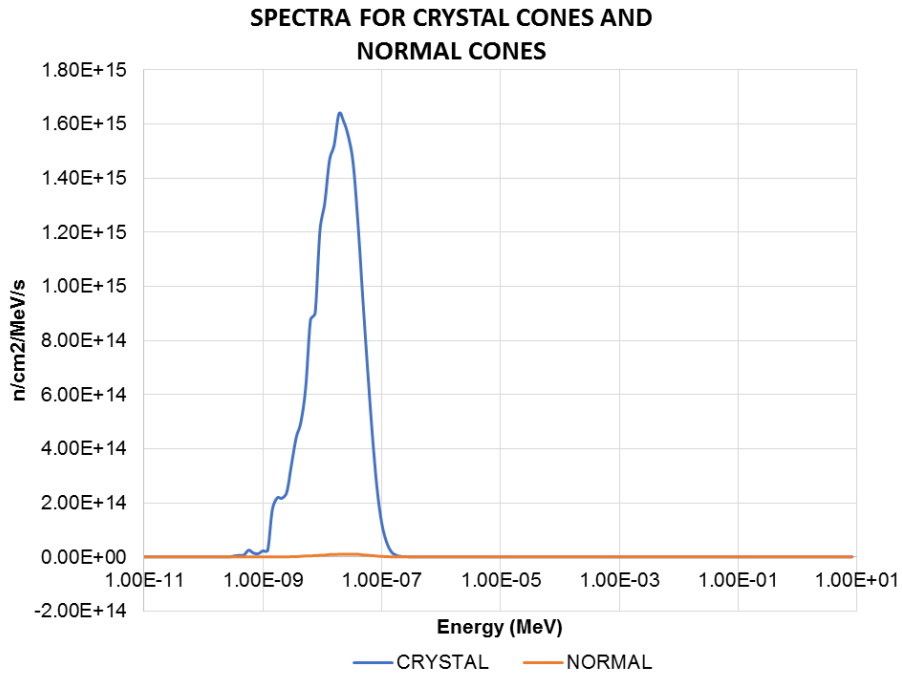


Figure 2. The monoenergetic neutron spectrum of a crystal cone and a normal cone

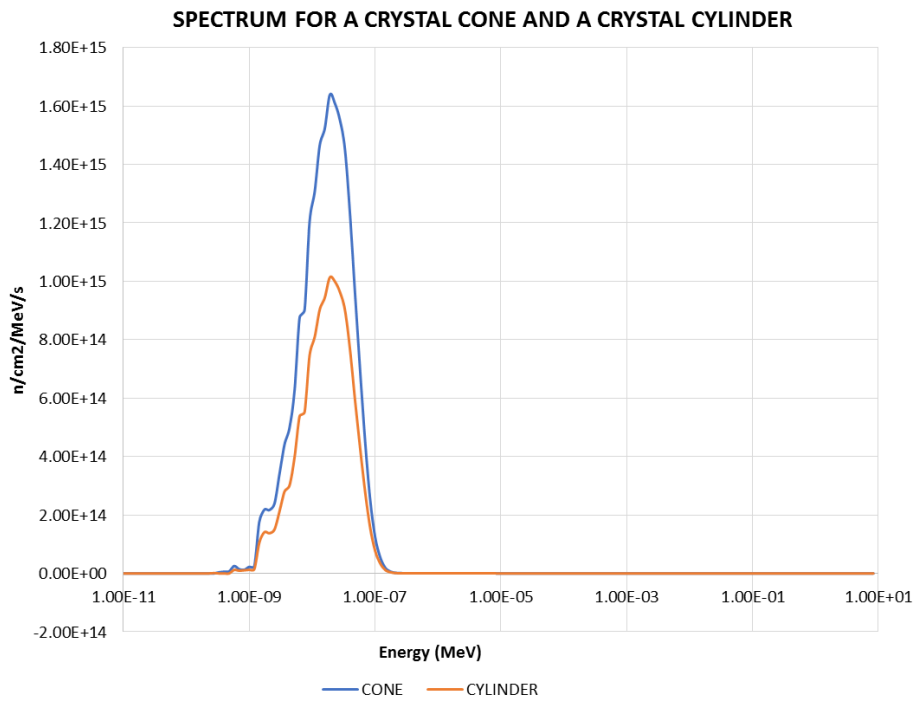


Figure 3. The monoenergetic neutron spectrum of a crystal cone and a crystal cylinder

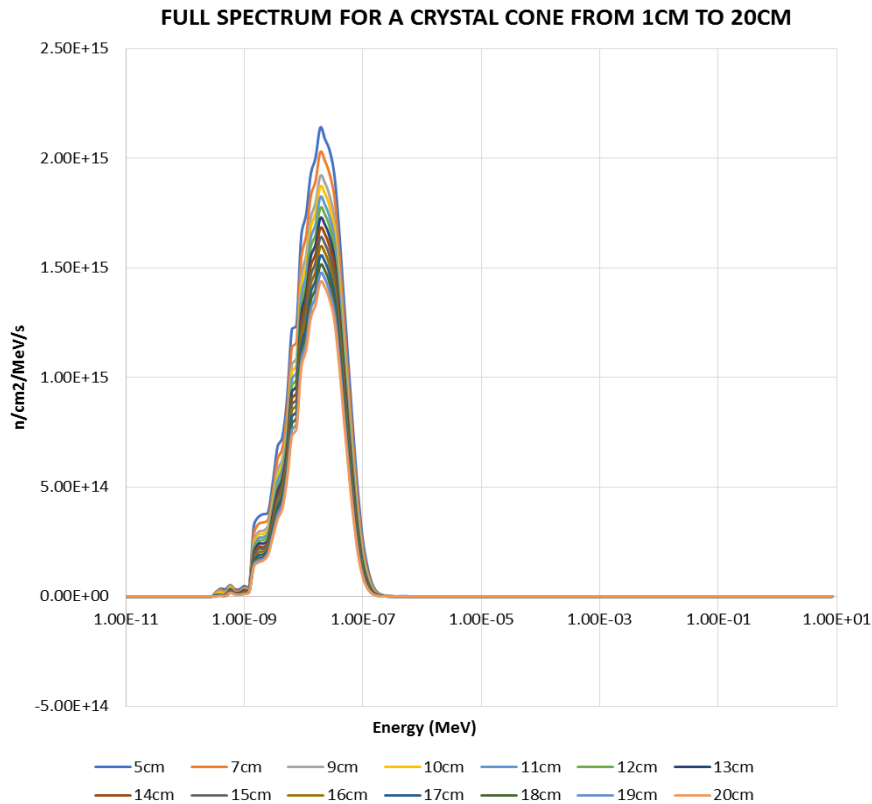


Figure 4. The monoenergetic neutron spectra of a crystal cone with a sapphire filter of various lengths

5. CONCLUSION

The calculations show that the cone collimation is more effective than the cylindrical collimation. In this paper, we choose to design with a cone-shaped collimator, 6 cm single-crystal bismuth filter, and a single-crystal sapphire filter with alternative lengths from 15 cm to 20 cm for estimation of the expected thermal neutron flux for various applications.

The results provide significant supporting information, such as neutron flux, thermal/epithermal ratio, and energy distribution, for the development of the thermal neutron channel in the horizontal channel of the Dalat Nuclear Reactor.

ACKNOWLEDGMENTS

This study was supported by the national project under grant number KC.05.08/16-20.

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