World Journal of Nuclear Science and Technology, 2014, 4, 59-64
Published Online April 2014 in SciRes. http://www.scirp.org/journal/wjnst
http://dx.doi.org/10.4236/wjnst.2014.42010

Scientific Research

Development of 24 and 59 keV Filtered Neutron Beams for Neutron Capture Experiments at Dalat Research Reactor

Pham Ngoc Son[1], Vuong Huu Tan[2], Phu Chi Hoa[3], Tran Tuan Anh[1]

[1]Nuclear Research Institute, Dalat, Vietnam
[2]Vietnam Agency for Radiation and Nuclear Safety, Hanoi, Vietnam
[3]The University of Dalat, Dalat, Vietnam
Email: pnson.nri@gmail.com

Received 25 December 2013; revised 29 January 2014; accepted 13 February 2014

Abstract

External filtered neutron beams have been developed at the horizontal radial channels No. 4 of Dalat research reactor. In the material composition of the neutron filters, the primary material components of Iron, Aluminum, Nickel and Vanadium are used to obtain the mono-energetic neutron beams of 24 and 59 keV, with low level of Gamma and slow neutron background. A computer code and Monte-Carlo simulation technique were applied to optimize the filter configurations and to deduce the neutron energy distributions in the filtered beams. A hydrogen-filled proton recoil detector and the activation method with Gold foils were used to measure the neutron energy spectrum and flux of each beam at sample position. The results of experimental neutron fluxes are 6.1×10^5 and 5.3×10^5 n/cm^2/s for 24 and 59 keV beams, respectively.

Keywords

Research Reactor, Filtered Neutron, 24 keV, 59 keV

1. Introduction

In the present development of nuclear science and technology, the high accuracy experimental data on neutron interaction with nuclei and elements are necessary in the development of nuclear theoretical models and in compilation of evaluated nuclear data files, which are the basis data for reactor designing and safety analysis, and for nuclear applications in medicine, industry, nuclear astrophysics [1], etc. The research works on nuclear data have been studied for many years with great achievements. However, until now, for a large number of nuclei,

How to cite this paper: Son, P.N., *et al.* (2014) Development of 24 and 59 keV Filtered Neutron Beams for Neutron Capture Experiments at Dalat Research Reactor. *World Journal of Nuclear Science and Technology*, **4**, 59-64. http://dx.doi.org/10.4236/wjnst.2014.42010

the experimental nuclear data are deficiency or inconsistent, and in some cases, the measured nuclear data show differences among each other laboratories. The most difficult situation and large uncertainty of experimental neutron cross sections are in the keV energy region [1] [2]. The reason is lack of high flux and high resolution neutron beam installations, which can provide the measurements of precise neutron cross sections in this energy range.

In order to improve the quality of neutron induced reaction cross sections, several high energy resolution facilities by neutron time of flight (TOF) technique have been developed based on utilization of a high intensity spallation neutron source. A new beam line for accurate neutron capture cross sections measurements with used a high resolution 4π Ge spectrometer has been developed at the J-PARC facility [3]. The neutron time-of-flight facility GELINA, with a neutron flight path lengths ranging from 10 m to 400 m, has been especially designed for neutron-induced reaction cross section measurements [4]. An inexpensive aspect of neutron sources for reaction cross studies is the use of filtered neutron beams from research reactors. The filtered neutron beam at RPI LINAC utilized an iron filter has been used to measure the neutron total cross section of Beryllium and graphite samples [5]. The filtered neutron beam at the Kyiv Research Reactor has been applied for precise measurements of neutron total cross sections [6].

The aim of this research is to apply the neutron filter technique [6] [7] to provide new neutron beams of mono-energies at 24 and 59 keV for neutron capture and total cross sections measurements, and related research at the horizontal channels No. 4 of Dalat research reactor (DRR).

2. Calculation of Neutron Filtered Spectra

For calculation of neutron spectra formed after transmitted through filters, a computer code, called CFNB (Calculation for Filtered Neutron Beams), were developed using VC++6 compiler. This code can be used to calculate the filtered neutron spectrum with a combination of materials that used as neutron filters. The calculation of transmitted neutron spectrum can be performed as the following expressions:

$$\Phi_o(E) = \Phi_i(E) \cdot \exp\left(-\sum_k \rho_k d_k \sigma_{tk}(E)\right). \tag{1}$$

The relative intensity of the filtered neutron peak is calculated by the following ratio.

$$I = \frac{\int_{E_l}^{E_h} \Phi_o(E)\,\mathrm{d}E}{\int_{10^{-5}eV}^{20MeV} \Phi_o(E)\,\mathrm{d}E}, \tag{2}$$

where: $\Phi_o(E)$ the neutron spectrum after transmitted through filters, $\Phi_i(E)$ the initial neutron spectrum before filters, ρ_k nuclear density of k^{th} filter component (nuclide/cm^3), d_k length of k^{th} filter component (cm), $\sigma_{tk}(E)$ total neutron cross section of k^{th} filter component (barn), I relative intensity of primary neutron peak, E_l, E_h low level and high level of primary neutron peak region.

The initial neutron spectrum $\Phi_i(E)$ before transmission through the filters was measured by the multi-foils activation method [8] and calculated by using the Monte Carlo code MCNP-5 [9]. The measured data was used to normalize and validate for MCNP and CFNB calculation spectrum. The result of initial neutron energy distribution is shown in **Figure 1**.

The nuclear data used for calculations in CFNB code is from JENDL3.3 [10], 300˚K files. The code has been tested in good agreement with results obtained from Monte Carlo code MCNP-5. The calculated output spectra for 24 keV and 59 keV in peak energy region are presented in **Figure 2** and **Figure 3**.

3. Creation of Neutron Filters for 24 and 59 keV Beams

For 24 keV neutron filer, the composite neutron filter consisted of 0.2 g/cm^2 ^{10}B, 20 cm Fe, 30 cm Al and 35 g/cm^2 S was used to receive the mono-energetic beam with the average energy of 24 ± 1.8 keV. The relative intensity of 24 keV beam was 96.7%. The absolute neutron flux at sample position was measured by activation method with standard foil of ^{197}Au in a 1mm thick Cd cover. The measured value of flux was 6.1×10^5 n/cm^2/s.

For 59 keV neutron filter, the composite neutron filter consisted of 0.2 g/cm^2 ^{10}B, 10 cm Ni, 15 cm V, 5 cm

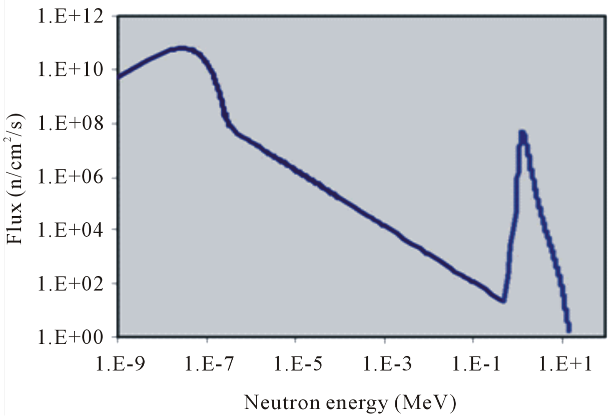

Figure 1. The initial neutron energy spectrum $\Phi_i(E)$ at the horizontal channel No. 4 of Dalat reactor.

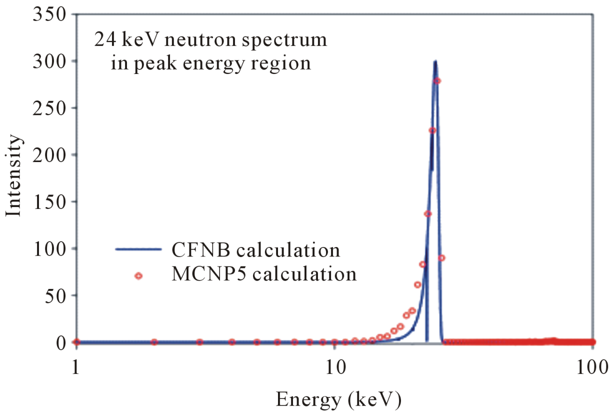

Figure 2. Calculated 24 keV filtered neutron spectrum.

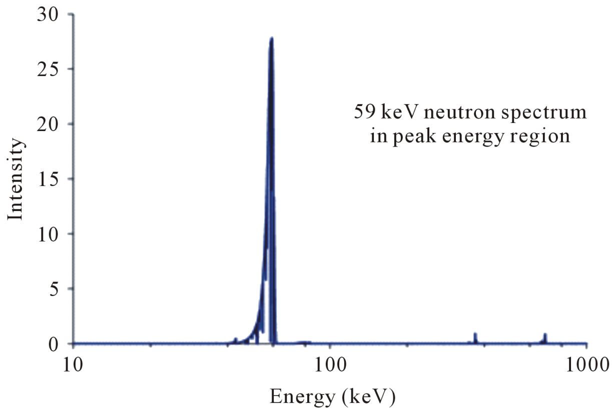

Figure 3. Calculated 59 keV filtered neutron spectrum.

Al and 100 g/cm^2 S was used to receive the mono-energetic beam with the average energy 59 ± 2.7 keV. The purity of beam was 92.3%. The absolute neutron flux at sample position was 5.3 × 10^5 n/cm^2/s, measured by activation method, in which, the standard foil of ^{197}Au was covered in a 1 mm thick Cd case.

4. Results and Conclusion

The filtered neutron beams with mono-energies of 24 and 59 keV have been developed presently at the Dalat research reactor. These neutron beams were tested by measuring spectra with a proton recoil counter LND 281 (Gas filling H + CH4 + N2, diameter 38.1 mm, length 254.0 mm, gas pressure 4.3 atm) in compacting with a 16K-multi channel spectrometer. The neutron energy spectra for 24 and 59 keV were obtained from the corresponding proton recoil pulse high response functions by the differential technique [11] [12]. The response function of proton-recoil distribution $f\left(E_p\right)$ is related to the neutron spectrum $\Phi\left(E\right)$ as the following formula:

$$\Phi\left(E\right)=-\frac{1}{NT}\frac{E}{\sigma\left(E\right)}\left|\frac{\mathrm{d}f\left(E_p\right)}{\mathrm{d}E_p}\right| \tag{3}$$

where $\sigma\left(E\right)$ is the neutron-proton scattering cross section and N is the number of the hydrogen atom in the effective volume of counter; T is the measuring time. Thus, the neutron spectrum $\Phi\left(E\right)$ would be obtained from the differential data of measured response function $f\left(E_p\right)$. A measured $f\left(E_p\right)$ spectrum of the 24 keV filtered neutron beam is presented in **Figure 4**.

The results of filtered neutron spectra measurements are shown in **Figure 5** and **Figure 6**. The absolute neutron flux of each beam at sample position was measured by the activation method with used standard foils of ^{197}Au (99.999%) covered in a 1 mm Cd cover. The material information of filters and the results of measured neutron fluxes are shown in **Table 1** and **Table 2**.

As a result of this work, the new neutron filter compositions for 24 and 59 keV have been created and installed complementally to the existing filters for thermal neutron beam at the horizontal channel No. 4 of the Dalat research reactor. The beams were tested, that showed qualified features for applications in neutron cross section measurements and related applications.

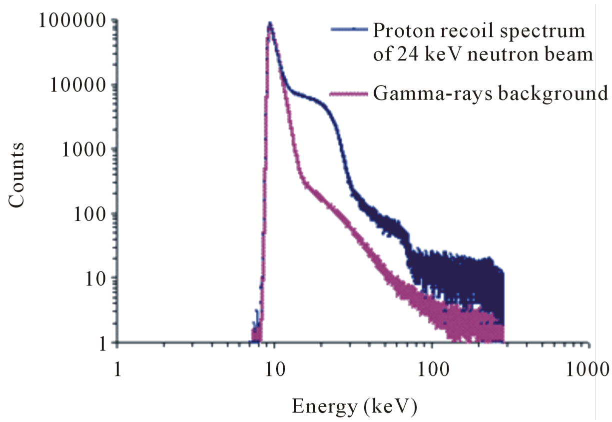

Figure 4. Measured proton recoil response function of 24 keV filtered neutron beam.

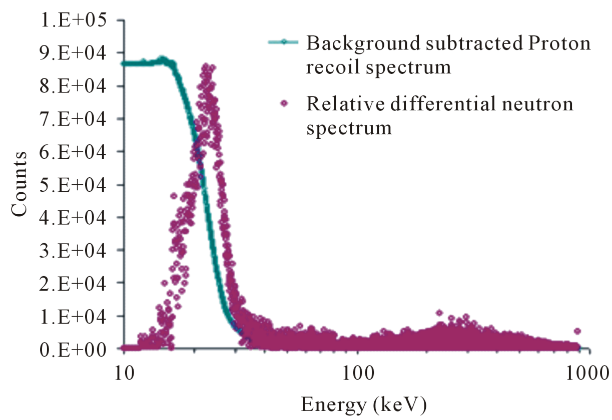

Figure 5. Measured neutron spectrum for 24 keV beam by proton recoil proportional counter.

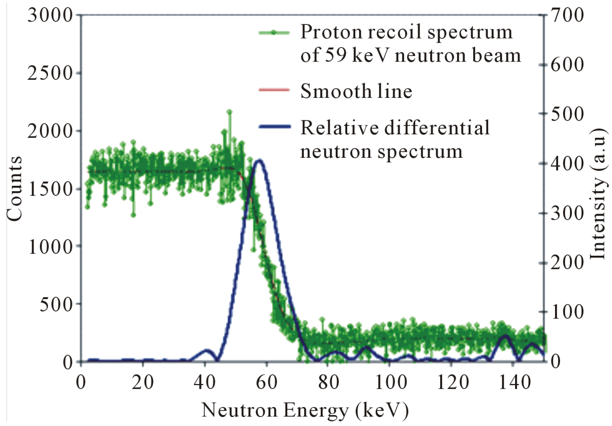

Figure 6. Measured neutron spectrum for 59 keV beam by proton recoil proportional counter.

Table 1. The filter components for neutron beams.

Neutron beam	Material components	Length or mass density of the filters
24 keV	^{10}B	0.2 g/cm^2
	Fe	20 cm
	Al	30 cm
	S	35 g/cm^2
59 keV	^{10}B	0.2 g/cm^2
	Ni	10 cm
	V	15 cm
	Al	5 cm
	S	100 g/cm^2

Table 2. The physical parameters of neutron beams.

Energy (keV)	FWHM (keV)	Flux n/cm^2/s	Purity (%)
24	1.8	6.1×10^5	96.72
59	2.7	5.3×10^5	92.28

Acknowledgements

This research is funded by Vietnam National Foundation for Science and Technology Development (NAFOSTED) under grant number "103.04-2012.59".

References

[1] Goriely, S. (2002) Nuclear Reaction Data Relevant to Nuclear Astrophysics. *Journal of Nuclear Science and Technology*, **Supplement 2**, 536-541.

[2] Gritzay, O., Kolotyi, V., Pshenichnyi, V., Gnidak, M., Kalchenko, O., Klimova, N., *et al*. (2007) Neutron Filter Technique and Its Use for Fundamental and Applied Investigations. *Proceedings of* 6*th Conference on Nuclear and Particle Physics*, Luxor, 17-21 November 2007, 361-372.

[3] Kiyanagi, Y. (2011) Accurate Neutron Nucleus Reaction Measurement Instrument (ANNRI) for Capture Cross Section Measurements at J-PARC. *Journal of the Korean Physical Society*, **59**, 779-784.

[4] Borella, A., Gunsing, F., Kopecky, S., Ivanov, I., Mihailescu, C., Moxon, M., *et al.* (2007) Advances in Neutron-Induced Resonance Reaction Cross Section Studies at GELINA. *Proceedings of the International Conference on Nuclear Data for Science and Technology ND*2007, Nice, 22-27 April 2007, 546-550.

[5] Danon, Y., Block, R.C., Rapp, M., Saglime, F., Barry, D.P., Drindak, N.J., Hoole, J. and Leinweber, G. (2007) High-Accuracy Filtered Neutron Beam and High-Energy Transmission Measurements at the Gaerttner Laboratory. *Proceedings of the International Conference on Nuclear Data for Science and Technology ND*2007, Nice, 22-27 April 2007, 401-402.

[6] Simpson, O.D. and Miller, L.G. (1968) A Technique to Measure Neutron Cross Sections in the Low keV Energy Region. *Nuclear Instruments and Methods*, **61**, 245-250. http://dx.doi.org/10.1016/0029-554X(68)90236-X

[7] Greenwood, R.C. and Chrien, R.E. (1976) Filtered Reactor Beams for Fast Neutron Capture γ-Ray Experiments. *Nuclear Instruments and Methods*, **138**, 125-143. http://dx.doi.org/10.1016/0029-554X(76)90157-9

[8] De Corte, F., Moens, L., Sordo-EL Hammami, K., Simonits, A. and Hoste, J. (1979) Modification and Generalization of Some Methods to Improve the Accuracy of α-Determination in the $1/E^{1+\alpha}$ Epithermal Neutron Spectrum. *Journal of Radioanalytical Chemistry*, **52**, 305-316. http://dx.doi.org/10.1007/BF02521281

[9] MCNP (2005) A General Monte Carlo N-Particle Transport Code. Version 5-1.40, Los Alamos National Laboratory, Los Alamos.

[10] Shibata, K., *et al*. (2002) Japanese Evaluated Nuclear Data Library Version 3 Revision-3: JENDL-3.3. *Journal of Nuclear Science and Technology*, **39**, 1125-1136. http://dx.doi.org/10.1080/18811248.2002.9715303

[11] Knauf, K. and Vorbrugg, W. (1991) The Response of a Cylindrical Proton Recoil Proportional Counter to Neutrons Impinging Perpendicularly to Its Axis. *Nuclear Instruments and Methods*, **A305**, 419-422. http://dx.doi.org/10.1016/0168-9002(91)90561-4

[12] Verbinski, V.V. and Giovanni, R. (1974) Proportional Counter Characteristics and Applications to Reactor Neutron Spectrometry. *Nuclear Instruments and Method*, **144**, 205-231. http://dx.doi.org/10.1016/0029-554X(74)90536-9