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FILTER OF QUASI-MONOCHROMATIC NEUTRONS WITH AVERAGE ENERGY 7.5 keV ON THE BASIS OF NATURAL COPPER

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Within the framework of realization of the INR NAS Ukraine program on the creation of quasi-monochromatic neutron filters in keV region, in the Neutron Physics Department in 2005 it was offered, developed and created a neutron filter on the base of natural copper with the average energy of neutrons 7.5 keV and line width on a half height about 95 eV. As a result of model calculations and experimental study of influence on the neutron spectrum of additional components, it was finally chosen such version of filter content: Cu, ^{60}Ni, Sc and ^{10}B. In accordance to calculations, a basic line makes 99.1 % from the spectrum selected by the filter. This filter was set at the horizontal channel GEK-8 on Kiev reactor WWR-M. The basic components of filter (Cu, ^{10}B) were placed in the first three disks of neutron shutter and additional ^{60}Ni, Sc – in extending collimator. Boric component was made of the amorphous boron enriched to 85 % ^{10}B. All collimating constructions were made of a lead and borated polyethylene. After optimization of filter content, with the purpose of verification of filter work, the measurements of total neutron cross section on carbon were carried out on three samples. The averaged cross section over three samples of carbon makes 4.70 ± 0.05 barns. This experimental result was compared with the data of other authors and evaluated libraries.

During the many years, the time of flight method was the basic method of research of neutron cross sections for neutron interactions with nuclei at research reactors. This method allows to enter only the beginning of keV region of reactor neutron spectrum. Research in the region of energies above a few keV was related to substantial difficulties, not speaking about more high energies already.

Neutron information in keV region is important both for understanding of mechanisms of nuclear processes and for the applied purposes. At the same time the receiving of this information is related to difficulties through the shortage of neutron sources in this energy region and through the problems of such neutrons registration.

In a reactor spectrum the part of such neutrons is rather considerable. Therefore, one of sources of neutrons receiving in the indicated energy region is the selection of neutrons with these energies from a reactor spectrum. The method of selection was found, is it is the method of neutron filters.

As it is well-known, the phenomenon of neutron filtration is conditioned by existence in the total neutron cross sections for some atomic nuclei of deep interference minimums which are the result of interference between the coherent waves of resonance and potential neutron scattering in these nuclei.

In the Institute for Nuclear Research of NAS Ukraine the work with the filtered neutron beams was fixed at the beginning of 70-ies. For the past years the large enough set of quasi-monochromatic neutron sources was created for energies from tens eV to several hundreds keV. Such works at the Kiev reactor WWR-M continue till now.

Within the framework of realization of the program of INR NAS Ukraine on the creation of quasi-monochromatic filters in keV energy region [1], during 2005 year in the Department of Neutron Physics it was offered then developed and created a neutron filter on the basis of natural copper with the average energy 7.5 keV. It became possible due to analysis of total neutron cross sections of atomic nuclei with the purpose of looking for candidates in the components of neutron filters. The attention was turned on, that deep interference minimums take place in the total neutron cross section of copper, in particular at energy about 7.5 keV [2, 3].

Calculations, carried out specially by the code FILTER-5, which is subsequent development of FILTER-L [1] code, developed in our department, showed that on the basis of natural copper it is possible indeed to create the enough intensive neutron filter with average energy 7.471 keV and spectrum line width less than 100 eV. The filter for such energy was created first. Calculated neutron spectrum for this kind of filter is presented in Fig. 1.

As it can be seen in Fig. 2, the other lines, besides for a basic line near 7.5 keV, also present in the spectrum. A basic line upon calculations contains 99.1 % of the spectrum selected by filter and has a width on the half height of about 95 eV. The presence of additional lines caused a necessity to find additional components in a filter, except for a copper, which would improve a spectrum (to suppress or considerably reduce these lines).

The natural copper of the brand M2 with the following chemical composition is the basis of filter: Cu-99.7 %, Bi-0.002 %, Sb-0.05 %, As-0.01 %, Fe-0.05 %, Ni-0.2 %, Pb-0.01 %, Sn-0.05 %, S-0.01 % and O-0.08 % [4]. For cutting of low-energy part of neutron spectrum it was used ^{10}B.

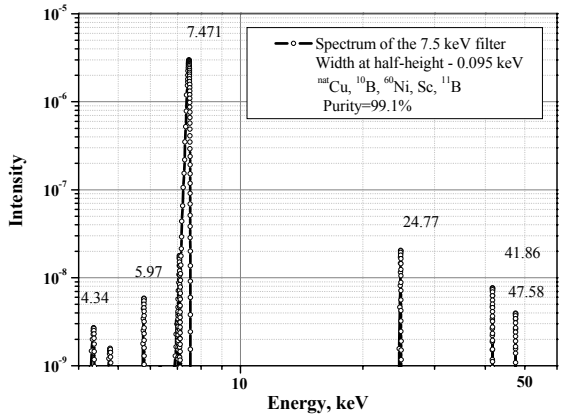

Fig. 1. Calculated neutron spectrum for filter on the basis of natural copper.

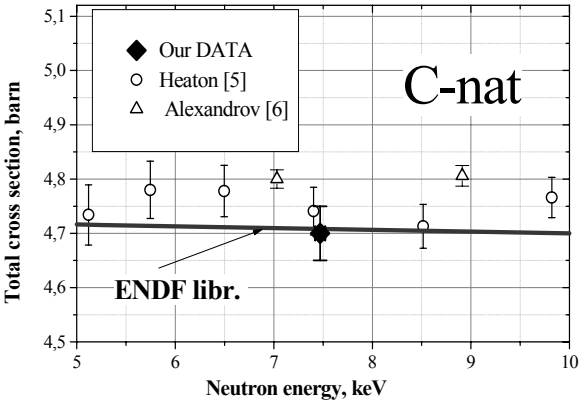

Fig. 2. Experimental and evaluated data for the C-natural total neutron cross section.

The practice existing in our department consist in placing of filter forming components within the limits of the first three disks of neutron shutter and extending collimator, and construction of filter was developed just within the account of this. The components of filter were placed in the disks of shutter as follows: disk III included the container with ^{10}B at the entrance of neutron beam and the collimating elements; disk II – a 200 mm copper in collimating constructions; and disk I – 200 mm copper and collimating materials. All collimating constructions in three disks are done from a lead and borated polyethylene.

Structurally, the filter was intended for the use on the horizontal channel GEK-8, because this channel is equipped with all necessities for the study of filter characteristics. Namely, the device for the change of standards at measurements of the total neutron cross sections allows to change the amount of material of additional component and bring them into a filter distantly. It enables to optimize filter content. The design with the code for neutron spectrum modelling gave the possibility to recommend Sc and ^{60}Ni as the additional components. Except for these, such additional components were entered also as Na and ^{54}Fe. We note, that ^{54}Fe caused practically complete screening of basic line due to enough strong resonance within the limits of 6 - 8 keV. Such the procedure was also used for energy calibration of spectrums. Sodium component for filter was made of NaCl, and boric – from amorphous boron with enrichment for ^{10}B to 85 %.

Additional components can be included both each separately and in any combination, and also to change the amount of each component. After optimization of filter composition, the final components were placed stationary in extending collimator. Finally, a filter has such composition: Cu, ^{60}Ni, Sc and ^{10}B. It was not recommended in future to include a component with Na in the content of filter, as some improvement of basic line 7.471 keV quality due to reducing of lines 4.34 and 5.97 keV was accompanied by substantial reducing of the basic line. More rational is subsequent increase of the component with ^{60}Ni (from 3.99 to 10.0 g/cm^2), that provides the improvement of quality of basic line from 98.67 to 99.0 % with unimportant reducing of main line intensity.

In the experimental filter spectrum without additional component, except for a basic line at 7.5 keV, the lines show up only about 13 and 25 keV. Line 13 keV in the final variant of filter was screened by ^{60}Ni, and contribution to the spectrum of 25 keV line involved near 1 %. Experimental half width of line 7.5 keV was about 700 eV.

Using this filter, the measurements of total neutron cross section were conducted by the method of transmission for three samples of carbon (n_1 = 0.01776 at/barn, n_2 = 0.03552 at/barn, n_3 = 0.05328 at/barn). The samples of carbon were disks with a diameter 30.4 ± 0.01 mm and thickness 1.0 ± 0.1 mm. Such samples were booked in England, the Goodfellow Cambridge Limited Company. For registration of neutrons the hydrogen counter LND-281 was used. The background conditions of measurements were defined by screening of neutron beam by the standard of polyethylene. The average value over three samples of carbon was found as 4.70 ± 0.05 barns. In Fig. 2 our data for carbon are compared with evaluated library information and experimental results of other authors [5, 6]. As it can be seen from this Figure, our data well conform to information of other authors and evaluated data.

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ФИЛЬТР КВАЗИ-МОНОЭНЕРГЕТИЧЕСКИХ НЕЙТРОНОВ СО СРЕДНЕЙ ЭНЕРГИЕЙ 7.5 кэВ НА ОСНОВЕ ПРИРОДНОЙ МЕДИ

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В рамках реализации программы ИЯИ НАН Украины по созданию фильтров квази-моноэнергетических нейтронов в килоэлектрон-вольтной области предложено, разработан и создан нейтронный фильтр на базе природной меди со средней энергией нейтронов 7.5 кэВ и шириной линии на половине высоты около 95 эВ. По результатам модельных расчетов и экспериментального изучения влияния на нейтронный спектр дополнительных компонент окончательно выбран такой вариант состава фильтра: Cu, ^{60}Ni, Sc и ^{10}B. Согласно расчетам, основная линия составляет 99.1 % от выделенного фильтром спектра. Фильтр установлен на горизонтальном канале ГЕК-8 Киевского реактора ВВР-М. Основные компоненты фильтра (Cu, ^{10}B) размещены в первых трех дисках шибера, а дополнительные ^{60}Ni, Sc – в выносном коллиматоре. Борная компонента изготовлена из аморфного бора, обогащенного до 85 % ^{10}B. Все коллимирующие конструкции изготовлены из свинца и борированного полиэтилена. После оптимизации состава фильтра с целью проверки его работы было проведено серию измерений полного нейтронного сечения углерода на трех образцах. Усредненное по трем образцам указанное сечение углерода составляет 4.70 ± 0.05 барн. Полученные экспериментальные данные были сопоставлены с данными других авторов и оцененными данными.

ФІЛЬТР КВАЗІ-МОНОЕНЕРГЕТИЧНИХ НЕЙТРОНІВ ІЗ СЕРЕДНЬОЮ ЕНЕРГІЄЮ 7.5 кеВ НА ОСНОВІ ПРИРОДНОЇ МІДІ

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У рамках реалізації програми ІЯД НАН України по створенню фільтрів квазі-моноенергетичних нейтронів у кілоелектрон-вольтній області запропоновано, розроблено та створено нейтронний фільтр на базі природної міді із середньою енергією нейтронів 7.5 кеВ і шириною лінії на половині висоти біля 95 еВ. За результатами модельних розрахунків та експериментального вивчення впливу на нейтронний спектр додаткових компонент остаточно вибрано такий варіант складу фільтра: Cu, ^{60}Ni, Sc та ^{10}B. Згідно з розрахунками основна лінія становить 99.1 % від виділеного фільтром спектра. Фільтр встановлено на горизонтальному каналі ГЕК-8 Київського реактора ВВР-М. Основні компоненти фільтра (Cu, ^{10}B) розміщено в перших трьох дисках шибера, а додаткові ^{60}Ni, Sc – у виносному коліматорі. Борну компоненту виготовлено з аморфного бору, збагаченого до 85% ^{10}B. Усі колімуючі конструкції виготовлено із свинцю та борованого поліетилену. Після оптимізації складу з метою перевірки роботи фільтра було проведено виміри повного нейтронного перерізу вуглецю на трьох зразках. Усереднений переріз по трьох зразках вуглецю становить 4.70 ± 0.05 барн. Отримані експериментальні дані було порівняно із даними інших авторів та оціненими даними.