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J. Černý[1], Z. Dlouhý[2], Z. Doležal[1], M. P. Ivanov,
P. Kubik[1], E. A. Kuznetsova, Yu. E. Penionzhkevich,
E. A. Sokol, J. Švejda[1], I. Wilhelm[1]

NEUTRON RESPONSE FUNCTION FOR A DETECTOR WITH ^{3}He COUNTERS FOR THE 0.39–1.54 MeV NEUTRON ENERGY RANGE

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[1] Institite of Particle and Nuclear Physics, Faculty of Mathematics and Physics, Charles University, 2180 00 Prague 8, Czech Republic

[2] Nuclear Physics Institute, Academy of Sciences of the Czech Republic, 250 68 Rež near Prague, Czech Republic

Черны И. и др. E7-2004-102

Нейтронная функция отклика детекторов с ^{3}He-счетчиками для нейтронов с энергиями в диапазоне от 0,39 до 1,54 МэВ

Экспериментально изучены функции отклика двух сборок нейтронных детекторов, каждая из которых включала 39 ^{3}He пропорциональных счетчиков в полиэтиленовом замедлителе, для моноэнергетических нейтронов в диапазоне энергий от 0,39 до 1,54 МэВ. Получены экспериментальные данные о чувствительности скорости счета нейтронов к изменениям энергии нейтронов и толщины полиэтиленового замедлителя. Экспериментальные значения эффективностей сравниваются с расчетами с использованием программ переноса нейтронов.

Работа выполнена в Лаборатории ядерных реакций им. Г. Н. Флерова ОИЯИ.

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Neutron Response Function for a Detector with ^{3}He Counters for the 0.39–1.54 MeV Neutron Energy Range

An experimental study was carried out of the neutron response functions of two neutron detector arrays, each consisting of 39 ^{3}He proportional counters with a polyethylene moderator for monoenergetic neutrons within the 0.39–1.54 MeV neutron energy range. Experimental data on the sensitivity of neutron counting to a change in neutron energy and the influence of the thickness of polyethylene moderator were obtained. The experimental efficiency curves were compared with the calculated response functions generated by a neutron transport code.

The investigation has been performed at the Flerov Laboratory of Nuclear Reactions, JINR.

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INTRODUCTION

Studies of beta-delayed neutron emission from neutron-rich nuclei are carried out by using different types of detectors. These studies require a neutron detection system of high efficiency, good energy and angular resolution and the granularity sufficient to enable multi-neutron decay measurements. The main advantages of a polyethylene moderated multi-counter neutron detector system are a practically zero energy threshold, the absence of cross-talk, a low sensitivity to gamma quanta, and the fact that it can be made of detectors of high neutron registration efficiency [1–4]. Systems with ^{3}He proportional counters can be used for obtaining the average energies of the delayed neutron spectra for chemically and mass-separated sources [5] and the angular distributions of neutrons [6].

Beta-delayed neutrons from different emitters range in energy from hundreds of keV up to several MeV; for example, single beta-delayed neutrons from ^{14}Be have an energy of 290 keV [7]; and the energy of beta-delayed neutrons from ^{15}B takes several values, the main ones are 1.77 and 3.2 MeV [8]. This implies that the registration efficiency of a neutron detector should remain constant over a wide energy range or the detector should provide information on neutron energy to make correction to measured results. Different approaches to the calibration of neutron detectors have been previously described: the neutron sources Am/Li [3, 4], RaBe, ^{124}SbBe, ^{24}NaBe, ^{24}NaD$_2$O [5], spontaneous fission of ^{252}Cf [5, 10, 11] or sources of beta-delayed neutrons [9, 10] were used.

In the present work, we have measured the response functions of two neutron detector arrays, each with 39 ^{3}He proportional counters, for monoenergetic neutrons within the 0.39–1.54 MeV neutron energy range. The main goals of the measurements were to obtain experimental data on the sensitivity of neutron counting to varying neutron energies and the influence of the thickness of the polyethylene moderator. The experimental data will be used for constructing optimal neutron detector arrays with modules [6] for studies of the properties of beta-delayed neutrons from fission fragments within the framework of projects DRIBs [12] and ALTO [13].

1. NEUTRON DETECTOR ARRAYS

The detection assemblies are shown in Fig. 1, each array consisted of 39 modules [6] arranged in six layers. In the first assembly, all the modules were identical and each of them consisted of a hexagonal polyethylene unit (distance between parallel planes was 50 mm) with a cylindrical cavity (32 mm in diameter) for a counter of neutrons. The length of the counter and the polyethylene moderator was 50 cm. The counters were filled with ^{3}He up to a pressure of 7 atm. In the second assembly, the polyethylene was removed from the modules of the 2nd and 4th rows.

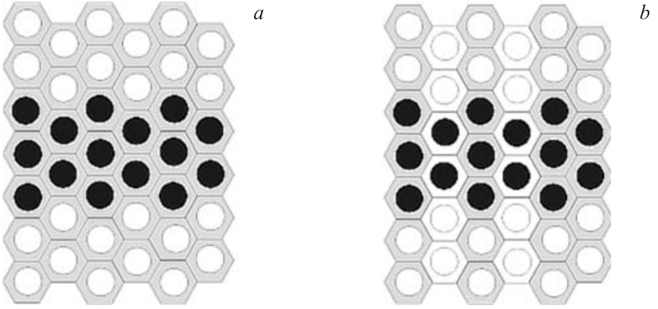

Fig. 1. Scheme of ^{3}He neutron detector arrays: a) with complete moderator; b) without moderator in the 2nd and 4th rows

2. ENERGIES OF NEUTRONS AND INTENSITY MONITORING

The experiments described here were performed with the Van de Graaff electrostatic accelerator HV2500AN at Charles University, Prague, Czech Republic.

Monoenergetic neutrons were produced as secondary particles from $^3\mathrm{H}(p,n)^3\mathrm{He}$ reaction on a Ti-T target (0.2 mg/cm^2) with a molybdenum backing. The target was mounted at an angle of 45° to the incident beam of protons, so the real thickness of the target was about 0.28 mg/cm^2. The energies of protons we used and the corresponding neutron energies are shown in table.

Neutron energies E_n versus proton energies E_p

E_p, MeV	1.2	1.3	1.4	1.7	1.8	2.0	2.2	2.3
E_n, MeV	0.39	0.50	0.61	0.93	1.03	1.23	1.44	1.54

The energy spread of protons due to the energy loss in the target and the corresponding energy spread of neutrons were calculated to be not more than 30 keV. The proton energy spread for the beam of the accelerator did not exceed 2 keV. The neutron detector arrays were mounted at a distance of 3 m from the tritium target and at the proton beam axis and were seen at an angle of ±6° from the target. The neutron energy spread due to the angular spread was about 10 keV.

Relative measurements of the energy of neutrons and intensity monitoring were made with a stilbene crystal detector of diameter 3.0 cm and 2.2 cm thick connected to a Philips XP-2020 photomultiplier tube and placed in front of neutron detector arrays. Using a stilbene scintillation crystal gives an efficient way to discriminate between incident gamma rays and neutrons by means of pulse shape discrimination (PSD). We applied a PSD method, which is based on charge

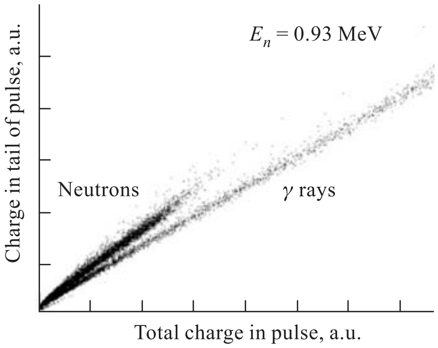

Fig. 2. Two-dimensional spectrum of total charge versus charge in the tail of a pulse obtained on a stilbene crystal for neutrons of the energy E_n = 0.93 MeV

integration of the pulse current over two different time intervals using a charge-integrating QDC. The method is described in [14] and the same electronics was used in the current experiment.

Plotting the charge in the tail of a pulse against the total charge brings to the two-dimensional spectra in Fig. 2 for an incident proton energy of 1.7 MeV and the respective neutron energy of 0.93 MeV. One can see a separation between the neutron (upper locus) and gamma rays (lower locus) in Fig. 2. Owing to the spectrum we can make a contour around the neutron locus and obtain a one-dimensional energy spectrum of neutrons, i.e. determine the experimental neutron response function and calculate the neutron counts for the respective locus. The corresponding one-dimensional spectrum is shown in Fig. 3.

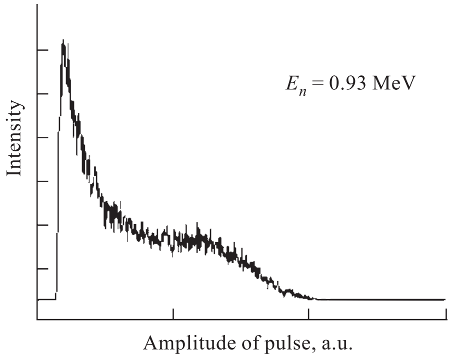

Fig. 3. One-dimensional spectra obtained on a stilbene crystal for neutrons of E_n = 0.93 MeV

The process of neutron scattering on protons at a neutron energy up to 10 MeV is isotropic in a center-of-mass coordinate system. So the response function of a detector based on the simple hydrogen scattering of monoenergetic neutrons in this energy range should have a rectangular shape, extending from zero to the full incident neutron energy [15]. But due to different distortion mechanisms [16] we can see that the one-dimensional spectrum has a significant deviation from a pure rectangular shape. The relative neutron energies determined by using the crossing of the extrapolated right part of the spectra with the x axes are shown in Fig. 4. One can see that the accuracy of determination of neutron energies with this method is quite good and we really have monoenergetic neutrons with an energy spread of not more than about 35 keV.

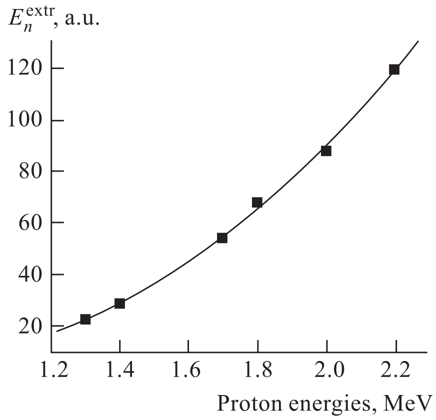

Fig. 4. The plot of relative extrapolated $E_n^{\rm extr}$ neutron energies versus proton energies

3. NEUTRON INTENSITY MONITORING WITH A ^{3}He COUNTER

We also used ^{3}He proportional counters without a moderator for monitoring incident neutron fluxes at neutron detector arrays. The ^{3}He proportional counter was placed in front of neutron detector arrays along the line connecting the centre of the array with the target. To estimate the neutron flux, we integrated the peak of thermal neutrons in the amplitude spectra of the pulses from the counter. This peak is mainly connected with the thermal neutrons originated in the array, floor and walls in the experimental room. We obtained good agreement in neutron flux monitoring for both types of detectors used.

4. RESULTS

The counting rates of the separate groups of neutron counters arranged in the central part of each layer of a detection assembly and a monitor detector were measured at different energies of incident neutrons. In Fig. 1, *a, b* these groups of neutron counters are marked with a black tone. The distributions of the counting rates (recalculated per one counter and normalized to the monitor counting rate) are shown in Fig. 5, *a, b* for neutron detector arrays with a complete moderator and without a moderator in the 2nd and 4th rows, respectively. The error of every point of the response function is less than the point size. A good sensitivity of both arrays to the changing of neutron energies is clearly seen, so the valid correlation of counting rate ratios for different rows of neutron counters with neutron energies was obtained. If the detection efficiency versus neutron energy curve for one row of counters is quite different from that for another row of counters, the ratio of counts for the two rows will be a function of neutron energies.

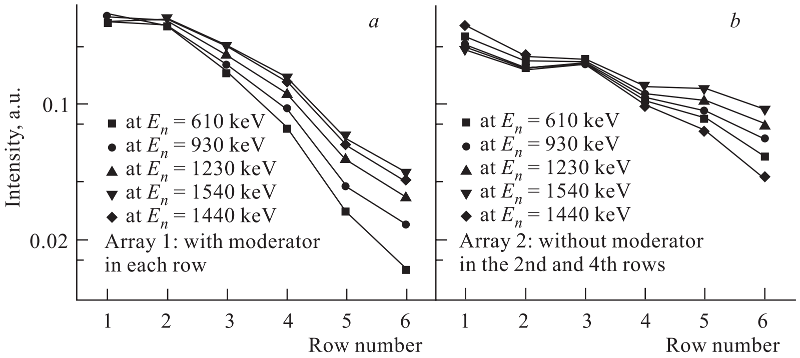

Fig. 5. Neutron response functions (distributions of the counting rates recalculated per one counter and normalized to the monitor counting rates) for detector array with a complete moderator (*a*) and without moderator in the 2nd and the 4th rows (*b*) at different energies of neutrons

It is seen from a comparison of two response functions (Fig. 5, *a, b*) that removing part of the moderator leads to the displacement of the maximum of the rate to the deeper layers of the counters and the total detector efficiency drops with decreasing of the volume of the moderator.

Plots of the efficiency of neutron detection versus incident neutron energy (in recalculation per one counter) depending on the number of detecting rows are shown in Fig. 6. The efficiency of the first array with all its counters is taken as 100% at a 1540 keV incident neutron energy. As visible, for detection assembly with a larger amount of moderator the efficiency of registration is systematically higher for all the neutron energies.

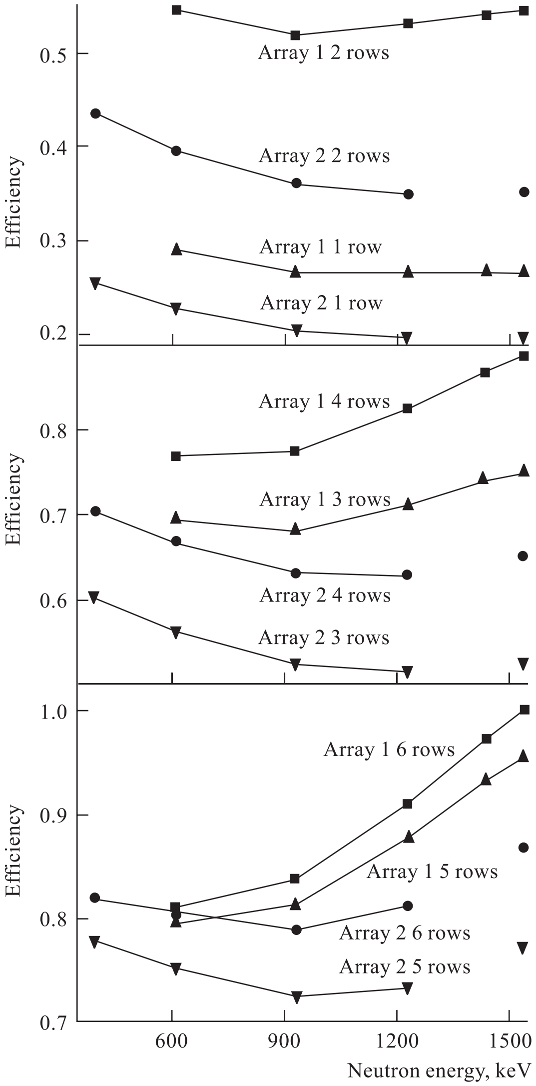

Fig. 6. Efficiency of neutron detection as a function of the energy of incident neutrons

As neutron energy increases, neutron registration efficiency increases. This can be explained by the fact that at low energies a considerable fraction of neutrons is reflected by the front layers of a detector and does not penetrate into the assembly, neutrons of higher energies penetrate deeper into the assembly and their losses due to reflection are smaller. The 4π detectors will register neutrons of small energies more effectively, because they do not abandon a detector due to the reflections in other internal layers, but neutrons of high energies will leave the assembly.

The experimental efficiency curves were compared with calculated response functions generated using the MCNP code [17] version B. During calculations good agreement with experimental information was achieved, calculations with a larger amount of moderator in a detector were conducted, the distance between the parallel planes of polyethylene hexahedrons being changed from 5 to 6, 7 and 8 cm. In Fig. 7 the calculated dependences of the efficiency of neutron registration on the thickness of the moderator for two neutron energies (0.61 and 1.54 MeV) are presented. As obvious from the graphs, the distance between the parallel planes of polyethylene hexahedrons about 6.5 cm is optimal. Taking into account that, in experiments with 4π detectors, neutrons get into a detector isotropically, the effective thickness of moderator in our modules is nearly optimal. It is also necessary to notice that the increase of the thickness of the moderator results in the increase of the neutron lifetime for a detector, and so in experiments on studying beta-delayed neutrons the background from random coincidences increases.

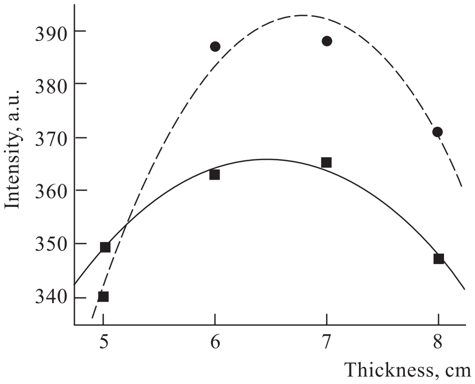

Fig. 7. Calculated dependences of neutron registration efficiency versus the thickness of moderator: ■ denotes the efficiency at E_n = 610 keV; ● denotes the efficiency at E_n = 540 keV; solid curve denotes polynomial fit of efficiency at E_n = 610 keV; dashed curve denotes polynomial fit of efficiency at E_n = 540 keV

Consequently, to ensure that neutron registration efficiency depends weakly on the energy of incident neutrons up to an energy of 1.5 MeV, a detector of neutrons must consist of no less than 4–5 layers of modules, consisting of neutron detectors (7 atm ^{3}He, 32 mm in diameter) and moderator surrounding one detector by a layer approximately 1 cm thick.

Neutrons of higher energies — from 3 to 5 MeV — can be obtained in a

(d, d) reaction on the same accelerator, and experiments on determination of the response function of an assembly of neutron counters for this range of energies will be conducted.

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141980, г. Дубна, Московская обл., ул. Жолио-Кюри, 6.
E-mail: publish@pds.jinr.ru
www.jinr.ru/publish/