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Method for energy scale calibration of the scintillation detector at registration of recoil protons

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A method of the energy scale calibration of scintillation detectors in the proton energy range 1 to 14 MeV has been developed. The method is based on comparison of maxima of calculated and experimental spectra of recoil protons obtained due to scattering of quasi-monochromatic neutrons from the $d(T,n)^4He$ and $d(D,n)^3He$ reactions on hydrogen nuclei contained in the converter. The energy scale calibration of a CsI(Tl) detector has been carried out using the $d(T,n)^4He$ reaction. It is found that the proton energy dependence of the detector specific light yield has a square polynomial form.

Разработан метод калибровки энергетической шкалы сцинтилляционных детекторов в диапазоне энергий протонов 1–14 МэВ. Метод основан на сопоставлении максимумов расчетных и экспериментальных спектров протонов отдачи, получаемых в результате рассеяния квазимонохроматических нейтронов из $d(T,n)^4He$ и $d(D,n)^3He$-реакций на ядрах водорода, содержащихся в конверторе. Проведена калибровка энергетической шкалы CsI(Tl)-детектора с использованием реакции $d(T,n)^4He$. Найдена зависимость световыхода детектора от энергии протонов в виде полинома второй степени.

The scintillation detectors are widely used to detect ionizing radiation for scientific and applied purposes [1]. The spectral characteristics of such detectors depend on the energy and type of the radiation being detected as well as on the kind and concentration of activating additives, manufacturing technology, etc. [1,2]. Therefore, the manufacturing and usage of scintillation detectors is associated with the necessity to research their spectral characteristics, in particular, the radiation energy dependence of the light yield. When using such detectors to registrate charged particles, the nonlinear character of the light yield is to be taken into account. That nonlinearity is increased with the increasing particle mass and charge. Therefore, to determine the energy of a registered particle, it is necessary to calibrate the energy scale of scintillation detectors. Usually, it is performed by using the charged particle accelerators [3–5]. But there are a number of problems connected with the availability of accelerators having the necessary energy range, providing of low accelerated particle beam intensity, the necessity to place the detector in the vacuum chamber, etc.

We have developed a method for the energy scale calibration of scintillation detectors using recoil protons emitted from the surface of thin hydrogen-containing converter under irradiation with quasi-monochromatic neutrons with $E_n \sim 14$ or 2.5 MeV. The method is based on the kinematic dependence of recoil proton energy on the angle of neutron-on-proton scattering [6]. In this approach, the calibration is carried out by comparison of maxima of experimental and calculated spectra. The

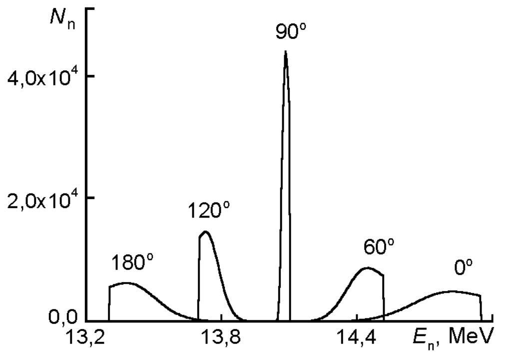

Fig. 1. Calculated neutron spectra from the $d(T,n)^4He$ reaction.

method provides the calibration of the detector energy scale in the range of proton energy $E_p = 1-14$ MeV and has a number of advantages as compared to the traditional calibration using charged particle accelerators. Namely, the scintillation detector is in the open air and the necessary intensity of recoil protons is defined by the experiment geometry and parameters.

The purpose of this work was to develop an energy scale calibration method for scintillation detectors at registration the recoil protons and also to carry out the energy scale calibration of a CsI(Tl) detector.

The technique of recoil proton spectra measurement was realized basing on the fast neutron source "NG-200" NSC KIPE [7], equipped by TiT and TiD targets. The $d(T,n)^4He$ or $d(D,n)^3He$ reaction runs under irradiation of the targets with accelerated deuterium ions, thus providing quasi-monochromatic neutron beams with $E_n \sim 14$ or 2.5 MeV, respectively. The direction of accelerated deuteron motion sets the axis relative to which the characteristic angles θ are laid off. The escape of each neutron out of the target is accompanied by the charged particle escape in the opposite direction. This fact was used in order to determine the neutron flux by the registration of accompanying charged particles (^4He or ^3He) using an α-monitor located at $\theta = 170°$ [8].

The data below were obtained using ~14 MeV neutrons from the $d(T,n)^4He$ reaction. The calculated neutron spectra for various angles θ [8] are shown in Fig. 1. The calculations were performed for the accelerated deuteron energy $E_d = 150$ keV. As it can been seen, the neutron spectrum at $\theta = 90°$ has the least dispersion. Therefore, all experiments were carried out at this angle for which the average neutron energy was equal to $E_n = 14.09$ MeV.

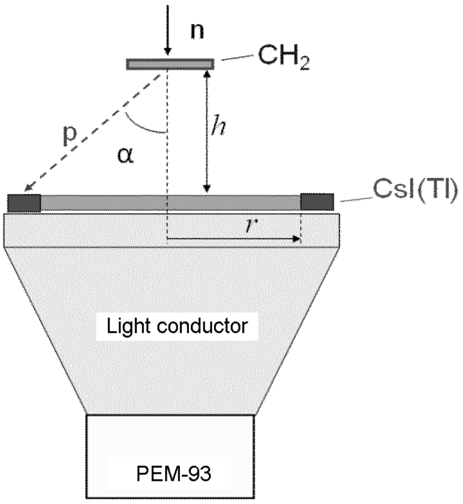

Fig. 2. Schematic representation of experimental layout.

The experimental layout [9,10] is shown schematically in Fig. 2. The neutrons bombard orthogonally a polyethylene disk (10 mm diameter and 1 mm thickness). The recoil protons scattered at the angle φ to the direction of neutron beam are registered by the ring CsI(Tl) detector (outer diameter 40 mm, inner diameter 33 mm and thickness 1.5 mm) coupled with a PEM-93 PMT. The experiments were performed on the spectrometric equipment designed in the CAMAC standard coupled with a PC-controlled peak analyzer ATSP-USB-8K-P. The spectrometer was calibrated using isotope sources ^{60}Co and ^{137}Cs and also 511 keV γ-line obtained at the neutron irradiation of a fluoroplastic sample at $E_n \sim 14$ MeV.

The measurement was performed twice for each distance h at identical indications of the α-monitor: with the converter (effect + background) and without it (background). The spectra of recoil protons (effect) were derived by spectrum subtraction. As an example, Fig. 3 shows the experimental spectrum (dots) of recoil protons measured at $h = 71$ mm. The maximum was defined by smoothing experimental points (see Fig. 3).

Maxima in experimental spectra were compared to those in the spectra calculated using the model developed in [11,12]. In this model, the experimental conditions were simulated by the Monte-Carlo method. According to the (n,p)-reaction kinematics, the recoil proton energy E_p is related to the neutron energy E_n as [6]:

$$E_p = E_n \cos^2\varphi, \quad (1)$$

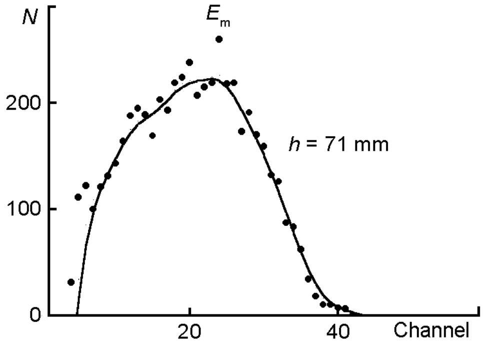

Fig. 3. Experimental spectrum of recoil protons for h = 71 mm.

where the angle φ is defined by the radius r and the converter-detector distance h (Fig. 2).

The proton energy losses were used to form the amplitude spectrum of recoil protons which simulated the experimental spectrum. Besides, the detector energy resolution was taken into account by convolution of the calculated spectrum (dN/dE) with the energy resolution function of the detector $g(E-E')$:

$$\left(\frac{dN(E')}{dE'}\right) = \int_{E1}^{E2} \frac{dN(E)}{dE}\, g(E - E')dE. \qquad (2)$$

Thus, the energy resolution of the detector is found as a Gaussian:

$$g(E - E') = \frac{1}{\sigma_D\sqrt{2\pi}}\exp\left(-\frac{(E - E')^2}{2\sigma_D^2}\right), \qquad (3)$$

where the σ_D value is determined experimentally.

The recoil proton spectra calculated for three h values are shown in Fig. 4. The dots are the calculated spectrum of recoil protons. The smooth curves result from convolution of this spectrum with Gaussian according to (2) and (3) for parameters $\sigma_D = 0.5$, 1, and 1.5 MeV. The best possible fit of calculated and experimental spectra was obtained for $\sigma_D = 1$ MeV.

The dots obtained by comparison of experimental and calculated data are shown in Fig. 5. The experimental and calculated spectra of recoil protons are obtained in the h range 15 to 71 mm. The curve corresponds to the proton energy dependence of the light yield for the CsI(Tl) detector. The direct line is indicated by dots for comparison. The proton energy is laid off along the X axis, the values for the points are obtained by determining maxima of calculated recoil proton spectra. The maxima values for experimental spectra in channels are laid off along the Y axis. The ordinate axis corresponds to the light yield value for the CsI(Tl) crystal in relative units. The minimum value in the proton energy scale measured at $h = 15$ mm was determined by γ-background induced by the fast neutrons on constructional materials. The errors are statistical ones of experimental spectra and inaccuracies in definition of maxima position in experimental and calculated spectra of recoil protons.

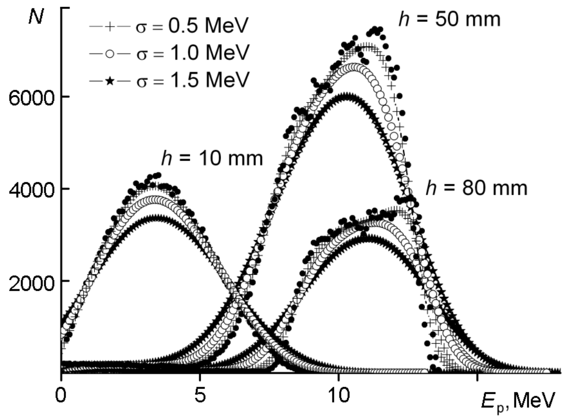

Fig. 4. Calculated recoil proton spectra.

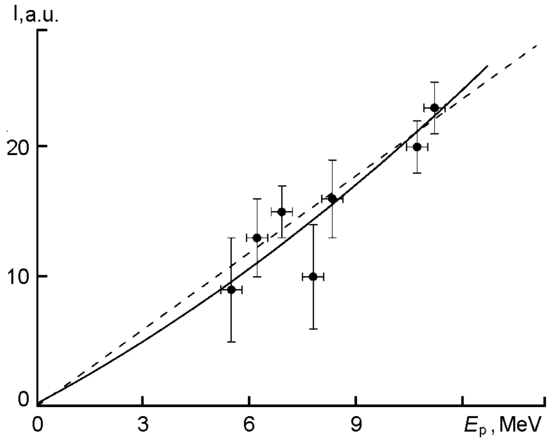

Fig. 5. Energy scale calibration of the CsI(Tl) detector.

The data presented in Fig. 5 confirm the nonlinearity of the energy dependence of the CsI(Tl) detector light yield. The energy scale calibration of the detector has been carried out by square polynomial fit with taking into account the experimental and calculated errors. The experimental technique allows to improve the accuracy of the experimental data by optimization of the experiment geometry and the recoil proton registration modes. In addition, the experimental data can be obtained at a much lower γ-background in the recoil proton energy range 1–3 MeV using the $\mathrm{d(D,n)^3He}$ reaction.

To conclude, an original method of the scintillation detector energy scale calibration by using the recoil protons has been developed. The method makes it possible to research the proton energy dependence of the scintillation detector light yields in the range 1–14 MeV operatively. The energy scale calibration of a CsI(Tl) detector has been carried out using the $\mathrm{d(T,n)^4He}$ reaction. It was found that the proton energy dependence of the detector specific light yield has a square polynomial form.

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Метод калібрування енергетичної шкали сцинтиляційних детекторів при реєстрації протонів віддачі

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Розроблено метод калібрування енергетичної шкали сцинтиляційних детекторів у діапазоні енергій протонів 1–14 МеВ. Метод оснований на зіставленні максимумів розрахункових та експериментальних спектрів протонів віддачі, одержаних у результаті розсіяння квазімонохроматичних нейтронів з реакцій $\mathrm{d(T,n)^4He}$ й $\mathrm{d(D,n)^3He}$ на ядрах водню, що міститься у конверторі. Проведено калібрування енергетичної шкали детектора Cs(Tl) з використанням реакції $\mathrm{d(T,n)^4He}$. Знайдено залежність світловиходу детектора від енергії протонів у вигляді полінома другого ступеня.