Scintillation neutron detector with dynamic threshold

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Abstract

Scintillation neutron detectors with hydrogen are a common tool for neutron spectroscopy. They provide good time resolution, neutron-gamma discrimination and high efficiency of neutron counting. The real open problems connected with application of these detectors are in the energy range >10 MeV. There are no standard neutron spectra known with high accuracy for this energy range. Therefore, traditional methods for experimental investigation of the efficiency function fail for these neutrons. The Monte Carlo simulation cannot provide reasonable accuracy due to unknown characteristics of the reactions for charged particle production (p, α and so on, light output, reaction cross-sections). The application of fission chamber with fissile material as a neutron detector did not help to solve the problem.

We may avoid many problems if we use the traditional neutron detector with non-traditional data analysis. In this report we give main relations, and demonstrate the method for Cf-source. Experimental detector efficiency is compared with MC simulation.

Introduction

The total characterisation of neutron detector can be realised if the property of the neutron source is known. Standard neutron source on the basis of ^{252}Cf with timing of fission fragments was used in Kornilov, *et al.* (2009). All neutron detector characteristics (efficiency, light output for protons, pulse height resolution, and response function versus input neutron energy) were investigated with high accuracy.

^{252}Cf is a standard neutron source very useful for practical applications. The only problem is the "high-energy limit". Neutrons with energy >10 MeV have very low intensity, and this energy range is practically unavailable for experimental research.

Reaction of (n,p) scattering, which is the main process in hydrogen neutron detector, is the standard. This fact stimulated the Monte Carlo simulation of neutron interaction with detector and estimation of its efficiency. However, there are some obstacles for realisation of these calculations with high accuracy. The contribution of (n,α)(Q = -5.7 MeV) reaction at neutron energy >10 MeV relative to (n,p) scattering is ~10%. The alpha particle produces a small pulse height just near the detector threshold or less. The light output for the alpha particle is unknown. The second problem is the scattering in the detector environment. The estimation of the intensity of this process and neutron angular energy distribution is a rather difficult task. Thus the extrapolation of the MC calculation to neutron energy ~20 MeV can be done with accuracy not less than ~10%, or even higher.

This big, old problem stimulated several directions for investigation. Neutrons from symmetric reactions [for example ^{6}Li(^{6}Li,n), Q = 9.449 MeV] have the same yield, and energies for symmetric angle in CMS (by definition). Due to proper selection of ion energy and Q-value, neutron will cover wide energy range in LS according to reaction kinematic. So, if you will start from low energy where the efficiency can be measured relative to ^{252}Cf, we may reach ~20 MeV energy, and solve this problem.

However, the yield of the neutrons with excitation of ground state and first levels is very small, and did not allow to realise this good idea (Kornilov, *et al.*, 2014).

Meadows (1991), Massey, *et al.* (1988), and Di Lullo, Mossey and Grimes (2008) changed the direction to reach the main goal – increase the accuracy of neutron efficiency estimation. They used an ionisation fission chamber as a neutron detector. The obvious advantage of this method is connected with high accuracy for efficiency calculation using a very simple relation. The disadvantage is very long experimental runs.

Kornilov, Massey and Grimes (2013) concluded that until now the data spread for neutron standard fields [Be(d,n), B(d,n) and Al(n,n)] has been very high (~20%), and do not allow us to use these neutron sources for detector calibration.

We do not see any experimental methods to measure neutron detector efficiency in the energy range up to 20 MeV with high accuracy. Can we suggest a new idea, realise a new method to increase accuracy for a calculating procedure? Is it possible to connect the advantage of using a fission chamber as a neutron detector (accurate calculation of the detector efficiency in whole energy range <20 MeV), and traditional hydrogen scintillation detector (high absolute efficiency)? We try to answer these questions in the present report.

Special selection of the detector's events

The detector consists of an NE213 scintillator with a diameter of 12.7 cm and a depth of 5.08 cm. The scintillator is coupled with an RCA 4522 photomultiplier tube with a 12.7 cm diameter photocathode (Randers-Pehrson, *et al.*, 1983).

Modern techniques allow us to collect all detected events in list mode. Thus each event is available for off-line analysis. For realisation of this method we should have the following information for each event: time-of-flight (TOF), pulse height (PH) and pulse shape (PS). After traditional neutron-gamma selection we may analyse only neutron events.

The response function for 8 MeV neutrons produced with D(d,n) reaction is shown in Figure 1.

The calculation was made with a code developed in PTB (NRESP) (Dietze and Klein, 1982), and modified in Kornilov, *et al.* (2009). An additional selection requires the following information: PH_0, $PH_{\min}$ and $PH_{\max}$.

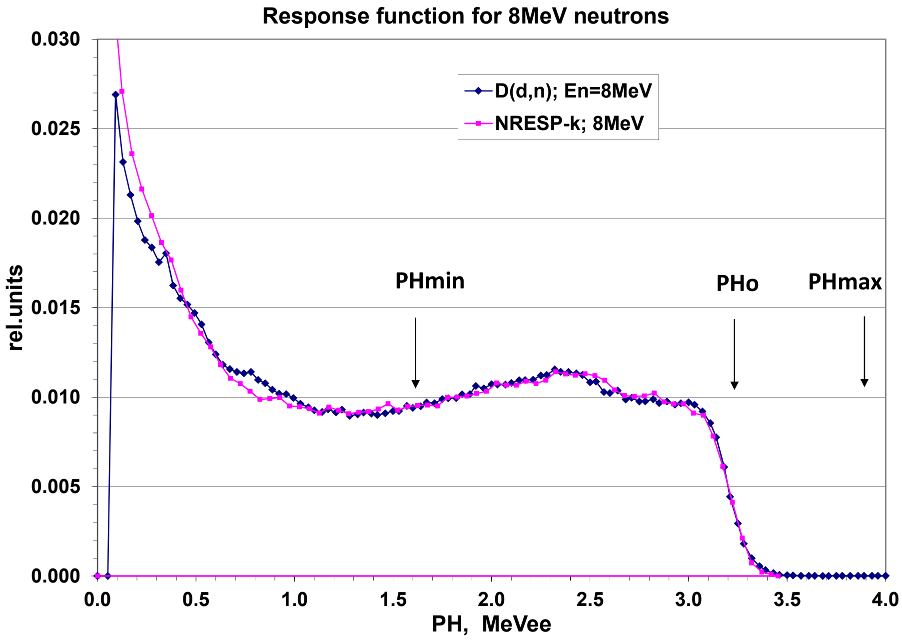
PH_0 is the highest proton energy for the selected neutron energy. PH_0 = L(E), where $L(E)$ is proton light output. We also incorporate $PH_{\min} = E^{*}\cos(\theta)^2$, and $PH_{\max} = PH_0 + 3^{*}\sigma(PH_0)$. The angle θ may be selected in such way as to remove all unwonted events. In this analysis we used θ = 45°.

The selection of events for each neutron energy was made with the simple equation:

$$PH_{\min} < L < PH_{\max} \qquad (1)$$

Functions $L(E)$, and $\sigma(L)$ are very important and should be measured for each detector. Both dependences were measured with "white" neutron spectrum from reaction B(d,n) in thick target, E_d = 7.44 MeV, angle of neutron emission 60°. It is important to highlight that we do not need information about spectrum shape. The high neutron yield at high energy is the only request for reaction selection.

Figure 1: Experimental and calculated RF (pulse height distribution) for "monoenergetic neutrons"

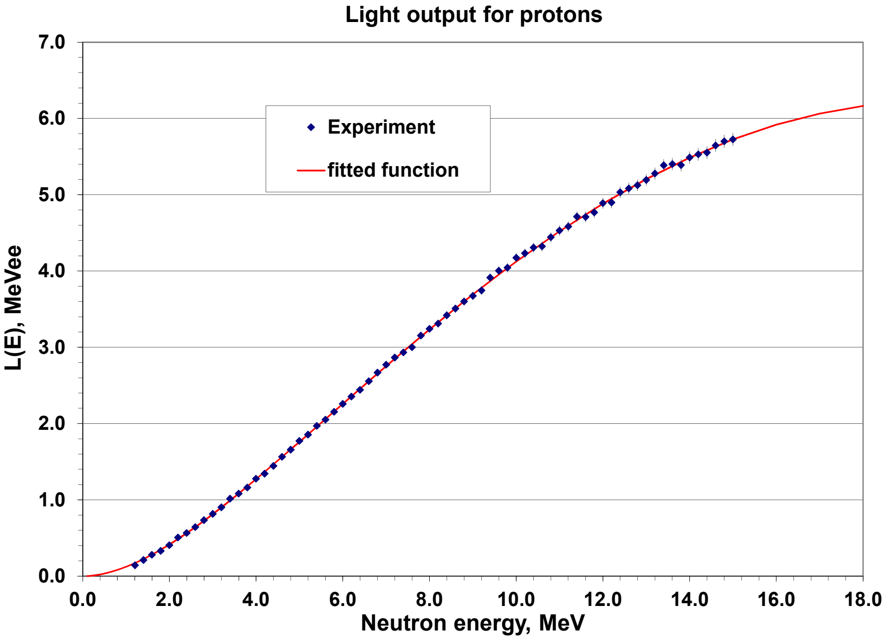


The light output data were fitted with Eq. (2) (Kornilov, *et al.*, 2009):

$$L(E) = (a_0 + a_1 * E)\frac{E^2}{E + E_0} \quad (2)$$

where a_0, a_1 and E_0 are fitted parameters. The a_1 parameter is connected with the non-linearity of electron pulses (saturation in PM tube).

Figure 2: Experimental and calculated light output $L(E)$ dependences



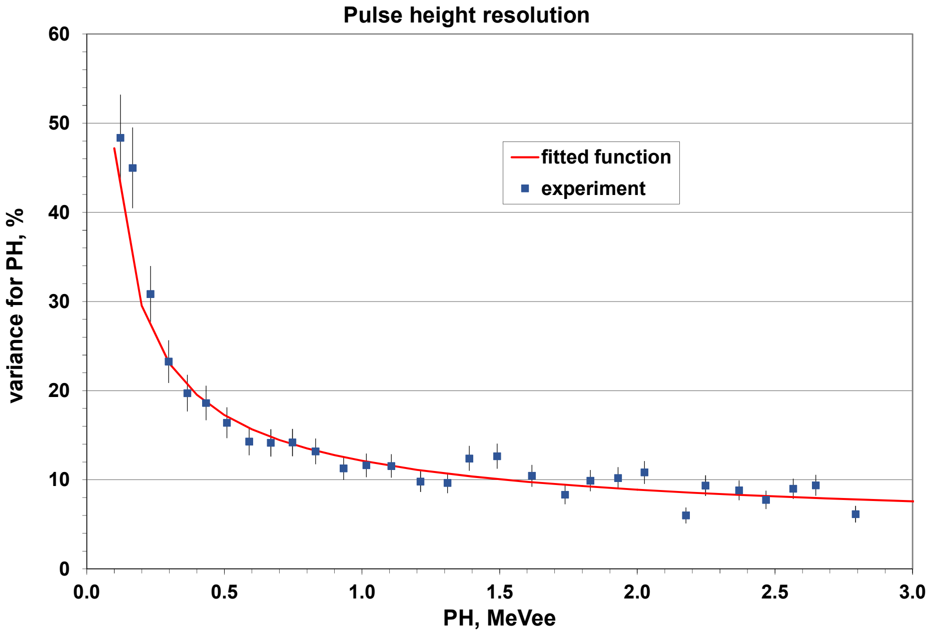
Pulse height resolution function was measured in the same experiment, and was described by Eq. (3):

$$\sigma = L\left(\alpha^2 + \frac{\beta^2}{L} + \left(\frac{\gamma}{L}\right)^2\right)^{0.5} \qquad (3)$$

where $\alpha = 0.04$, $\beta = 0.11$, $\gamma = 0.10$.

Experimental and calculated resolution functions are given in Figure 3.

Figure 3: Experimental and calculated resolution functions



Experimental and calculated efficiencies

The absolute efficiency NE213 detector was measured with ^{252}Cf neutron source (Kornilov, *et al.*, 2009). Fission fragment count rate was 2.28e4 1/s, total time resolution 2.4 ns, flight path 4.108 m. Time channel width was 0.209 ns (4 096 channels). Run time was ~100 h. Effect count rate ~1 1/s, and total background ~120 1/s.

The MC simulation was realised with code NEFF7-DYTH modified from NEFF7 (Dietze and Klein, 1982). It is interesting to realise how new selection changes traditional TOF distributions.

The TOF spectra with neutron-gamma selection are given in Figure 4 This spectra were collected with following conditions: $\cos(\theta) = 0.1$, $PH_{\max} = 20$ MeV$_{ee}$. Thus, the spectra have traditional shapes.

The selection condition $\cos(\theta) = 0.1$ and $PH_{\max} = PH_0 + 3^*\sigma(PH_0)$ change results very much. Time-independent background as in Figure 4 was transformed to time-dependent function (Figure 5) at low-energy range.

The working selection $\cos(\theta) = 0.707$ and $PH_{\max} = PH_0 + 3^*\sigma(PH_0)$ changed very much as did the high energetic part of TOF distribution (Figure 6). Background was reduced (practically concealed) in comparison with data in Figure 4.

Figure 4: TOF distributions without an additional selection

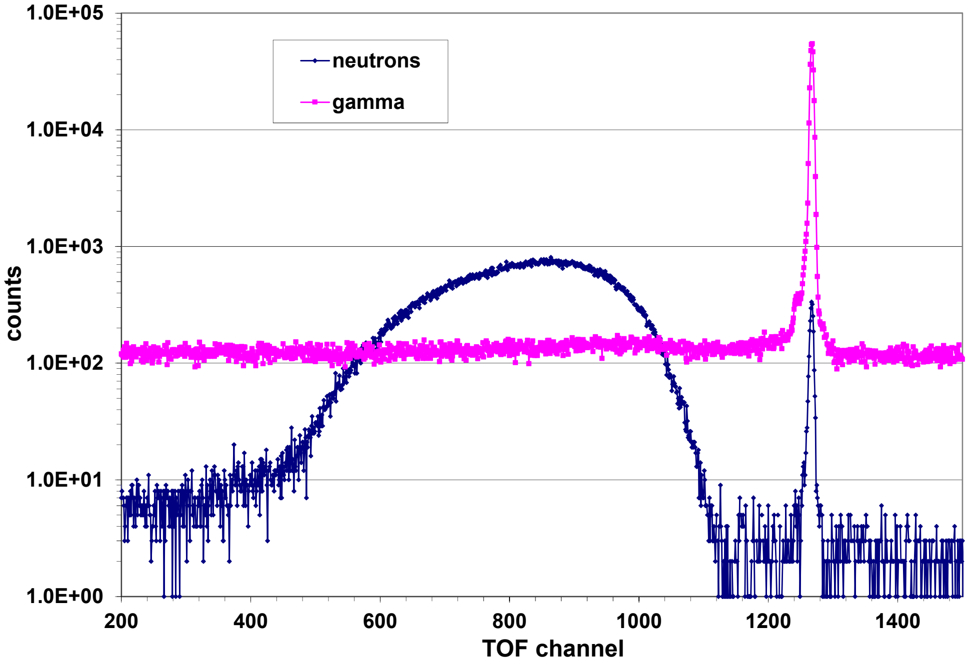


Figure 5: Selection for high-energy limit

cos(θ) = 0.1, $PH_{\max} = PH_0 + 3^*\sigma(PH_0)$

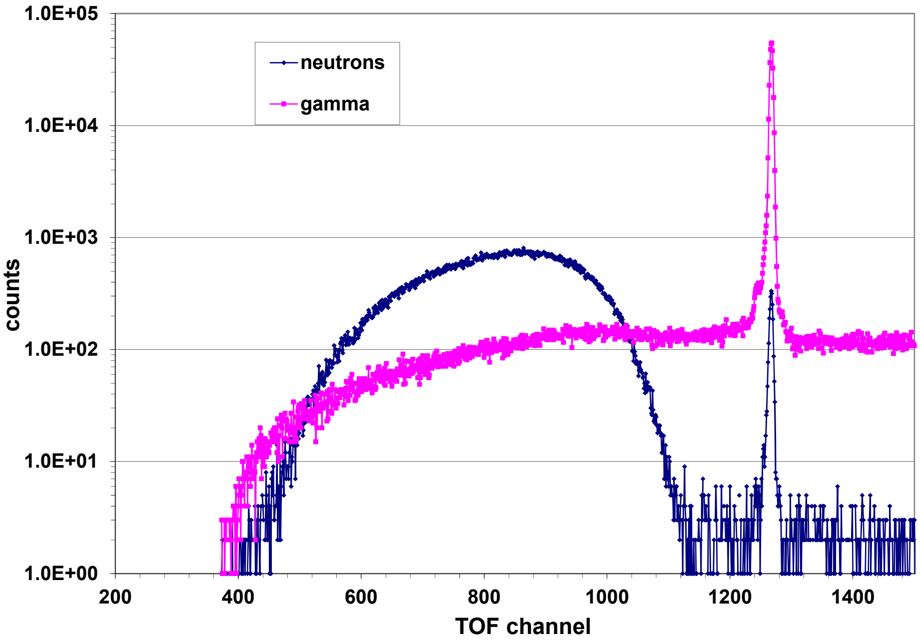
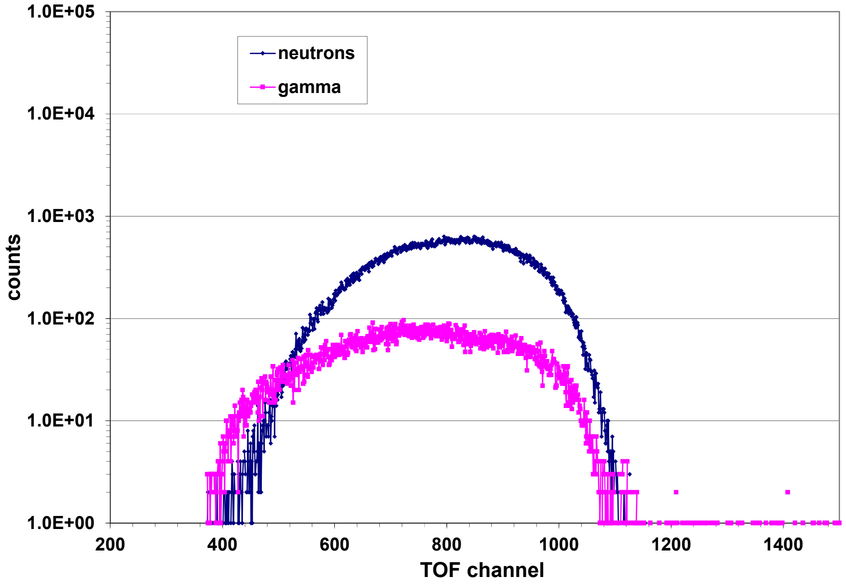


Figure 6: TOF spectra for working selection

$\cos(\theta) = 0.707$, $PH_{\max} = PH_0 + 3*\sigma(PH_0)$

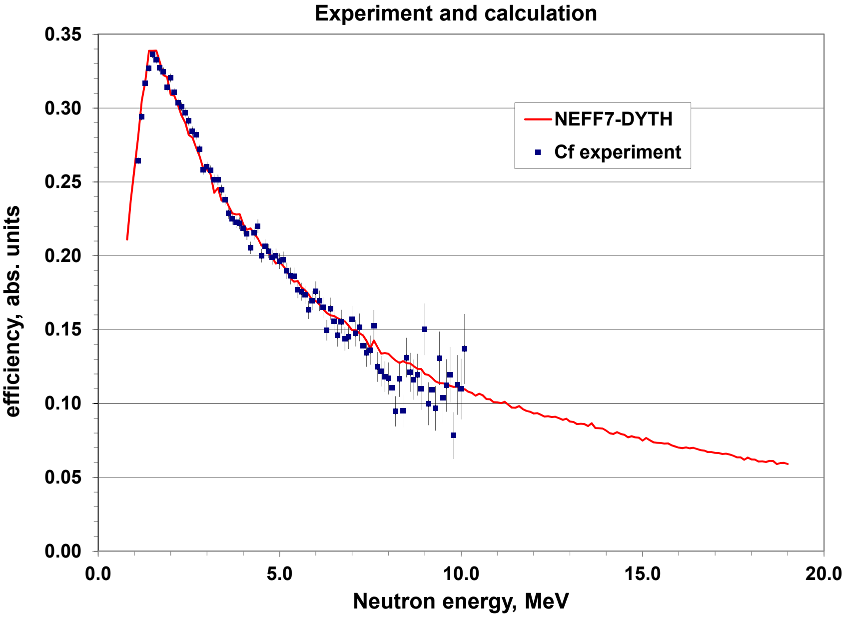


Experimental and calculated efficiency are shown in Figure 7. The average ratio is $R = E/C = 1.012 \pm 0.004$ for energy range 1.3-6 MeV. So, MC simulation reproduces the energy dependence and absolute value with high accuracy.

The resolution function is a very important parameter for MC simulation in the energy range $E_n < 2$ MeV. Calculated results are very sensitive to absolute value and energy dependence $\sigma(L)$.

Figure 7: Experimental and calculated efficiencies with dynamic threshold

MC simulation was multiplied with factor 1.012



Conclusions

- A method of dynamic threshold was developed for the NE213 detector and was investigated with a ^{252}Cf neutron source. "A dynamically biased neutron detector" was realised in 1971 (Brandenberger and Grandy) for background reduction in TOF experiments. Our realisation and motivation are quite different. It should be emphasised that successful realisation of this method is not possible without an experimental light output function for a particular detector.
- The unique peculiarity of this method is that its application removes events connected with the (n,α) reaction in an organic scintillator. This allow to increase an accuracy for extrapolation of calculated data in the high-energy range 10-20 MeV.
- This method also reduces time-independent background, the contribution of neutron scattering on the detector environment and time resolution.
- In the whole energy range <20 MeV only one reaction (n,p)-scattering is responsible for formation of the detector efficiency after application of the dynamic threshold. It seems that the contribution of multiple scattering inside the detector, and interaction with the detector environment are much reduced. In the energy range <8 MeV the agreement between experimental and calculated results is perfect. Hence, we may expect that extrapolation to the energy range 10-20 MeV may also be done with high accuracy. However, detailed investigation of the uncertainties in the whole energy range is an important direction for future activities.
- This method is very useful for experimental investigations of inelastic neutron scattering on Fe, ^{238}U nuclei at the incident energies 6-8 MeV, and ~14 MeV.

References

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