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# NEW METHOD OF ANALYSIS OF INTERMEDIATE ENERGY NEUTRON SPECTRA (1 keV $\leq E_n \leq$ 100 keV)

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The new method of intermediate energy neutron spectrometry is proposed. The method is based on the analysis of the $\gamma$-line shape of the primary transition during capture of the investigated neutrons in a special converter. This method allows both pulsed and continuous neutron fluxes (fields) to be analysed.

The investigation has been performed at the Laboratory of Neutron Physics, JINR.

## Новый метод анализа спектров нейтронов промежуточных энергий (1 кэВ $\leq E_n \leq$ 100 кэВ)

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Предлагается новый метод спектрометрии нейтронов промежуточных энергий, основанный на анализе формы $\gamma$-линии первичного перехода при захвате исследуемых нейтронов специальным конвертером. Метод позволит анализировать как импульсные, так и стационарные нейтронные потоки (поля).

Работа выполнена в Лаборатории нейтронной физики ОИЯИ.

The new method for analysis of spectra of intermediate energy neutrons, i.e., over the 1—100 keV energy interval, is described. The method is based on the idea of how to study the resolution of time slowing-down spectrometers over the keV energy interval suggested by one of the authors of [1]. In principle, intermediate energy neutron spectra can be investigated by the time-of-flight method, but this is only possible at pulsed neutron sources with a nanosecond range. Other methods of spectra analysis of neutron flux (field) shapes applied for investigations of fast neutrons, including the proton recoil method, measurement of the energy of emitted charged particles following a capture of the investigated neutrons, threshold reactions, etc., (see [2]) do not practically work in the intermediate energy region.

The reported method is based on the determination of the $\gamma$-line shape of the germanium $\gamma$-spectrometer used to register **primary** gamma-ray transitions during radiative capture of intermediate energy neutrons in a special converter. When energy dispersion of the captured neutrons is approximately equal to or larger than the energy resolution of the $\gamma$-spectrometer, the shape of the $\gamma$-line amplitude is distorted due to difference in the captured neutron energies, i.e., a change in the excitation energy of decayed nucleus states in the converter material at a fixed final state of the measured $\gamma$-transition.

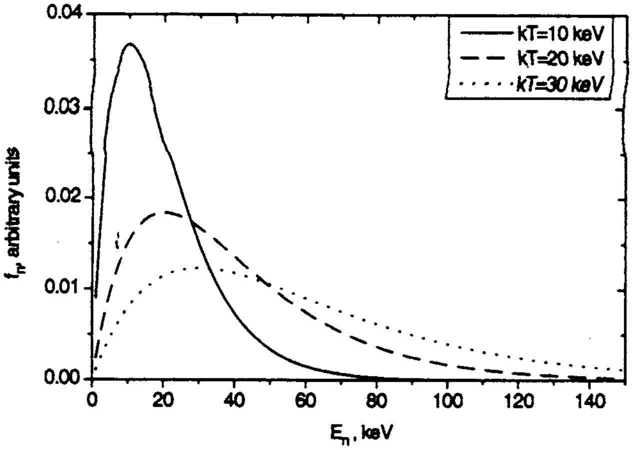


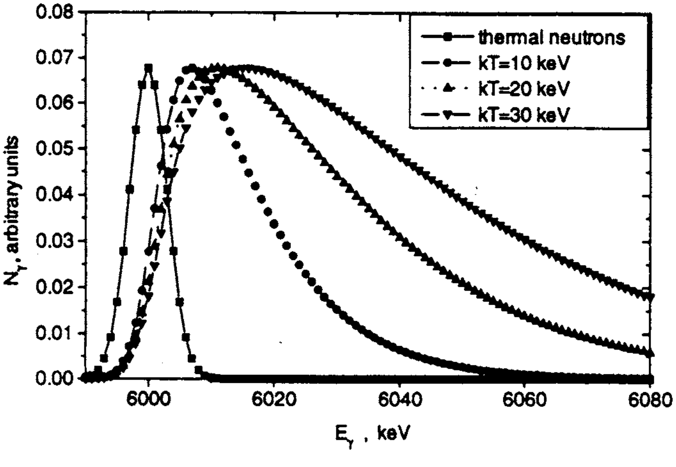
Fig.1. Maxwellian neutron spectra

*If an intense (and hence,* $E1$-multipolarity) primary γ-transition with the energy $E^i_{\gamma 0}$ to the i-th final level of the excited nucleus appears following a thermal neutron capture ($E_n \cong 0$) by a converter nucleus with the atomic weight $A$, the energy of an analogous transition following the capture of an $E_n$ neutron is:

$$E^i_\gamma = E^i_{\gamma 0} + [A/(A+1)] \cdot E_n. \tag{1}$$

As a converter, one is recommended to use an isotope with a smooth behaviour of the partial (for the given γ-transition) capture cross section of neutrons from the investigated spectrum. This can be the cross section of a partial transition following a direct radiative capture (light or nearly magic nuclei) or the radiative neutron capture cross section averaged over many neutron resonances. In the latter case, it is necessary to have the converter with an average level spacing $D << 1$ keV. Then the energy dependence of the averaged partial capture cross section of neutrons with an orbital momentum $l = 0$ ($s$-neutrons) is (see, e.g., [3]):

$$\langle \sigma^i_{n\gamma}(E_n) \rangle_s \sim E_n^{-1/2}. \tag{2}$$



Since the gamma-registration efficiency and the resolution power of the spectrometer for captured neutrons are practically constant ($E^i_{\gamma 0}$ is about 5 MeV and its variations do

Fig.2. The 6 MeV γ-line shapes registered by the Ge(Li)-detector for the capture of the neutrons from Maxwellian spectra, as well as thermal neutrons

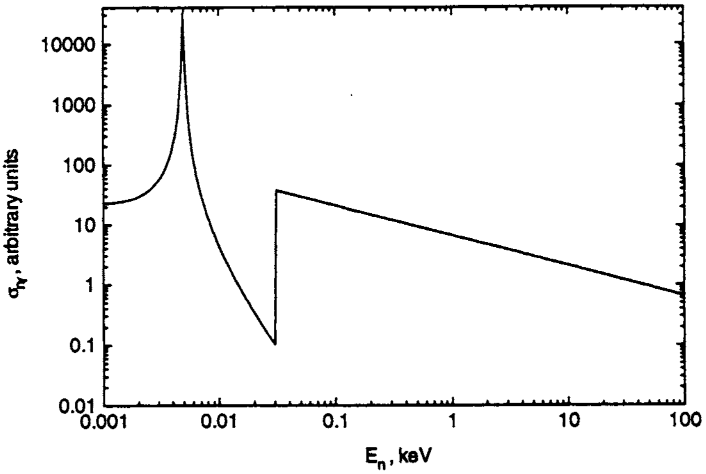


Fig.3. The energy dependence of the capture cross section of a converter

not exceed 100 keV), the amplitude spectrum of the γ-line is a product of the neutron flux $f_n(E_n)$ by the partial capture cross section, both being the functions of neutron energy. The observed spreading of the product is governed by the spectrometer resolution function $\varphi_0(E_\gamma)$ for γ-lines from thermal neutron capture

$$N_\gamma(E_\gamma)dE_\gamma = k \cdot \varphi_0(E_\gamma)dE_\gamma \cdot \langle\sigma(E_n)\rangle \cdot f_n(E_n), \tag{3}$$

where the coefficient $k$ is determed by the experimental geometry, registration efficiency and the measurement time, and $E_\gamma$ differs from $E_n$ by a constant (see (1)).

The computer modelled results obtained with the proposed method are presented in Figs. 1 and 2. The Maxwellian neutron spectra at temperatures $kT = 10$, 20, 30 keV are shown in Fig.1. Figure 2 represents the correspondig responses of the Ge(Li) spectrometer with the resolution 4 keV for the 6 MeV γ-transition energy. The calculations were performed for the converter made of the material with neutron resonance parameters like those of gold. The energy dependence for the radiative capture cross section is shown in Fig.3. In calculations, we only used the energy dependence of *s*-wave neutrons.

To obtain the shape of the neutron flux energy distribution, it is necessary to solve an inverse problem for equation (3).

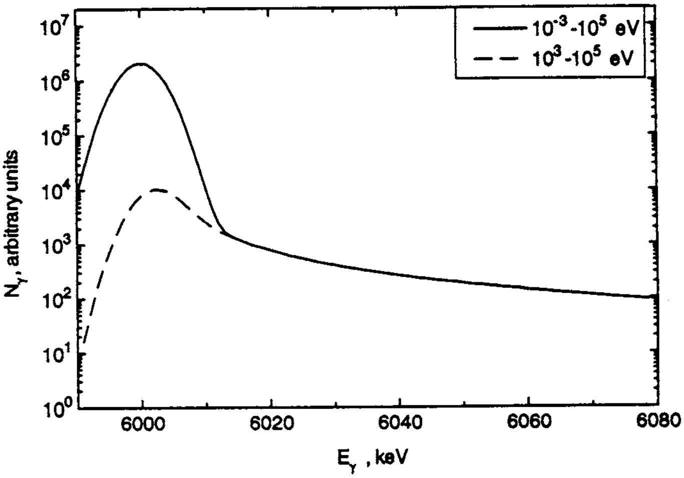


Fig.4. The same as in Fig.2, for the neutron spectrum with the $1/E_n$ distribution over two energy regions

According to preliminary estimation of the efficiency of this method to register one γ-quantum, about $10^3 - 10^4$ neutrons captured in the converter are needed. At the same time, the registered γ-quantum does not only indicate that a capture event has occurred but also provides information on the energy of the captured neutron. The proposed method, unlike the time-of-flight method, does not need long flight paths which reduce the efficiency of the method by several orders of magnitude (e.g., the flight path of 30 m allows one to use only $10^{-7}$ of the total neutron flux).

The proposed method can be used to analyse fluxes from stationary or pulsed neutron sources both inside and outside different moderators and other construction materials. Figure 4 illustrates the γ-shape at 6 MeV observed following capture of neutrons with the energy distribution $f_n(E_n) \sim 1/E_n$.

The method can by very useful for dosimetry of intermediate energy neutrons, for protection physics, as well as for investigations of averaged cross sections for partial γ-transitions.

## References

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