The energy spectrum of neutrons from ^{7}Li(d,n)^{8}Be reaction at deuteron energy 2.9 MeV

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Abstract. The neutron beams generated at the electrostatic accelerators using nuclear reactions T(p,n)^{3}He, D(d,n)^{3}He, ^{7}Li(p,n)^{7}Be, T(d,n)^{4}He, ^{7}Li(d,n)^{8}Be, ^{9}Be(d,n)^{10}B are widely used in neutron physics and in many practical applications. Among these reactions the least studied reactions are ^{7}Li(d,n)^{8}Be and ^{9}Be(d,n)^{10}B. The present work is devoted to the measurement of the neutron spectrum from ^{7}Li(d,n)^{8}Be reaction at 0° angle to the deuteron beam axis on the electrostatic accelerator Tandetron (JSC "SSC RF – IPPE") using activation method and a stilbene crystal scintillation detector. The first time ever ^{7}Li(d,n)^{8}Be reaction was measured by activation method. The target was a thick lithium layer on metallic backing. The energy of the incident deuteron was 2.9 MeV. As activation detectors a wide range of nuclear reactions were used: ^{27}Al(n,p)^{27}Mg, ^{27}Al(n,α)^{24}Na, ^{113}In(n,n')^{113m}In, ^{115}In(n,n')^{115m}In, ^{115}In(n,γ)^{116m}In, ^{58}Ni(n,p)^{58m}Co, ^{58}Ni(n,2n)^{57}Ni, ^{197}Au(n,γ)^{198}Au, ^{197}Au(n,2n)^{196}Au, ^{59}Co(n,p)^{59}Fe, ^{59}Co(n,2n)$^{58m+g}$Co, ^{59}Co (n,g)^{60}Co. Measurement of the induced gamma-activity was carried out using HPGe detector Canberra GX5019 [1]. The up-to-date evaluations of the cross sections for these reactions were used in processing of the data. The program STAYSL was used to unfold the energy spectra. The neutron spectra obtained by activation detectors is consistent with the corresponding data measured by a stilbene crystal scintillation detector within their uncertainties.

1. Activation method

The activation method of measuring neutron spectra use a link between the induced activity of detector-monitors and neutron flux. The reaction are divided into two groups by the nature of the interaction of neutrons with substances: those reactions which are more sensitive to low-energy neutrons - (n,γ), (n,f) and reactions that are essential for neutron energies above a certain value called the energy threshold of the reaction (reaction threshold). The main threshold reactions are reactions of neutron capture with emission of a charged particle (n,p) and (n,α), inelastic neutron scattering (n,n$'$), the neutron capture reaction with the emission of two neutrons (n,2n) and fission reaction (n,f).

The rate of monitor reactions are determined by RRC program [2]. An algorithm to determine the reaction rates of irradiating monitors on unsteady ion current also was implemented in the RRC program. In this case the time dependence of the ion current is approximated by a piecewise linear function normalized to unity. The decay data for radioactive nuclei are included into the program EFGL and RRC from the library decay.lib. The values of half-life, $T_{1/2}$, gamma ray energy, $E\gamma$, and yields per a decay, I(Eγ) for each radioactive nucleus were taken from [3,4]. The data on the cross sections of all monitor reactions were taken from the international dosimetry file IRDF-2002 [5].

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2. Experiment and neutron spectrum from the ^{7}Li(d,n)^{8}Be

The rate values of the following nuclear reactions were measured by activation method to determine the energy spectrum generated in the lithium target by deuterons with 2.9 MeV: ^{27}Al(n,p)^{27}Mg, ^{27}Al(n,α)^{24}Na, ^{113}In(n,n$'$)^{113m}In, ^{115}In(n,n$'$)^{115m}In, ^{115}In(n,γ)^{116m}In, ^{58}Ni(n,p)^{58m}Co, ^{58}Ni (n,2n)^{57}Ni, ^{197}Au(n,γ)^{198}Au, ^{197}Au(n,2n)^{196}Au, ^{59}Co(n,2n)$^{58m+g}$Co, ^{59}Co(n,p)^{59}Fe, ^{59}Co(n,2n)$^{58m+g}$Co. The irradiation of the activation monitors by neutrons from the reaction of Li(d,n) was carried out at 0° to the axis of the ion beam of the IPPE Tandetron accelerator. The energy of the incident deuteron was 2.9 MeV. Setup scheme is shown in Fig. 1.

All activation detectors (monitors) used for measuring the rates of these reactions were produced in the form of discs with a diameter of 10 to 12.2 mm. Geometrical thickness of monitors was in the range of 0.6 to 3.5 mm. All monitors used for measuring the rate of threshold reactions were made of chemically pure metal of the corresponding elements.

The obtained spectra of all nuclear reactions were processed in order to obtain the total absorption peak areas of the gamma rays of certain energy. The obtained values were used to calculate the rate of the corresponding reactions. The experimental results on the reaction rates obtained in the present work are presented in Table 1. These data were used as input parameters for the unfolding procedure of the energy spectrum of neutrons from the ^{7}Li(d,n)^{8}Be reaction with the help of STAYSLF program

Table 1. List of nuclear reactions and their reaction rates.

Reaction	Half-lives	Eγ, keV	Iγ,%	mass, g	Number of nuclei	Reaction rate	Uncertainty, %
^{58}Ni(n,p)^{58m}Co	70.8 d	810.76	99.45	0.49	$0.0342 \cdot 10^{23}$	$3.502 \cdot 10^{-16}$	1.28
^{58}Ni(n,2n)^{57}Ni	35.6 h	1377.71	81.7			$4.901 \cdot 10^{-18}$	2.82
		1919.99	12.3			$6.727 \cdot 10^{-18}$	1.75
^{113}In(n,n')^{113m}In	99.476 min	391.7	64.94	0.2	$0.00045 \cdot 10^{23}$	$2.327 \cdot 10^{-16}$	4.13
^{115}In(n,n')^{115m}In	4.486 h	336.24	45.8		$0.01 \cdot 10^{23}$	$2.876 \cdot 10^{-16}$	1.89
^{115}In(n,g)^{116m}In	54.29 min	1097.27	58.5		$0.01 \cdot 10^{23}$	$1.027 \cdot 10^{-16}$	6.75
		1293.69	84.8			$9.663 \cdot 10^{-17}$	2.73
^{197}Au(n,g)^{198}Au	2.69 d	411.8	95.62	1.15	$0.0352 \cdot 10^{23}$	$7.897 \cdot 10^{-17}$	1.25
^{197}Au(n,2n)^{196}Au	6.183 d	333.03	22.9			$6.259 \cdot 10^{-16}$	16.31
		355.73	87			$6.096 \cdot 10^{-16}$	1.32
^{59}Co(n,p)^{59}Fe	44.495 d	1099.25	56.5	1.35	$0.1381 \cdot 10^{23}$	$1.832 \cdot 10^{-17}$	1.49
		1291.59	43.2			$1.831 \cdot 10^{-17}$	2.49
^{59}Co(n,2n)$^{58m+g}$Co	70.86 d	810.76	99.45			$1.492 \cdot 10^{-16}$	5.07
^{59}Co (n,g)^{60}Co	5.271 y	1173.24	99.89			$5.811 \cdot 10^{-18}$	8.22
		1332.5	99.98			$5.900 \cdot 10^{-18}$	2.12
^{27}Al(n,p)^{27}Mg	9.458 min	843.76	71.8	0.09	$0.0201 \cdot 10^{23}$	$4.280 \cdot 10^{-17}$	1.82
^{27}Al(n,a)^{24}Na	14.997 h	1368.6	99.99			$4.187 \cdot 10^{-17}$	1.86

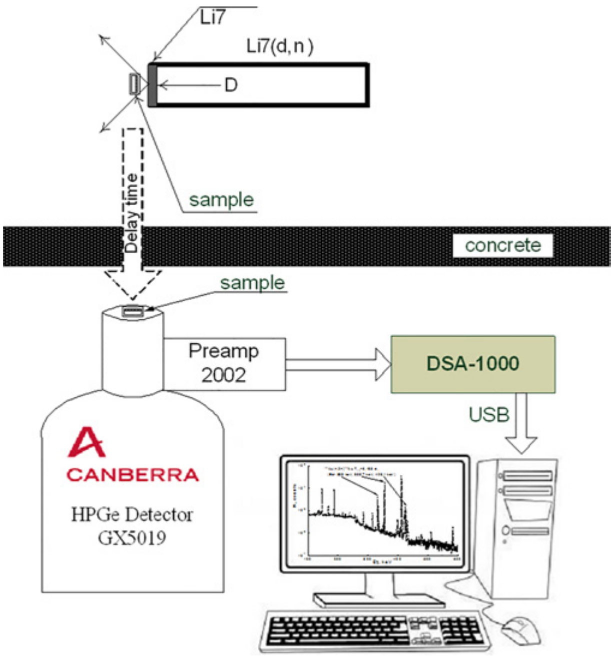

Figure 1. Scheme of the experimental setup.

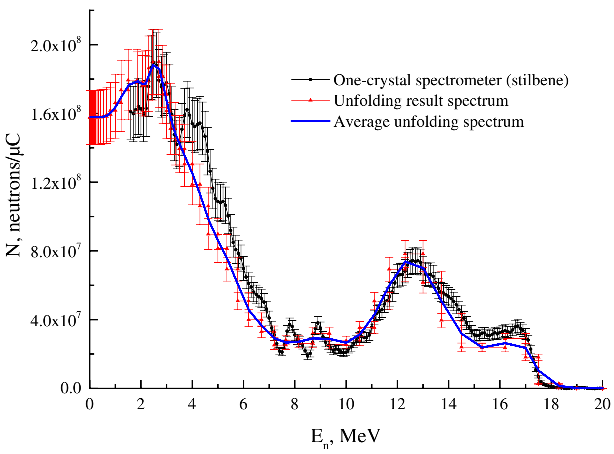

Figure 2. Comparison of the spectra obtained by the activation method and the spectrometer with a stilbene crystal.

which is based on the well-known program STAY'SL [6]. The STAYSLF program was used for the neutron spectrum unfolding from the reaction rates data. This unfolding method is based on the Bayesian approach. Figure 2 shows the result of unfolding of the spectrum obtained by activation method in comparison with the spectrum obtained by a spectrometer on the basis of the stilbene crystal. The energy spectrum $\frac{dN(E_n)}{dE_n}$ obtained with help of the spectrometer on the basis of a stilbene crystal is calculated by the following equation with the known efficiency $\varepsilon(E_n)$ of the spectrometer:

$$\frac{\mathrm{dN(E_n)}}{\mathrm{dE_n}} = -\frac{\mathrm{E_n}}{\varepsilon(\mathrm{E}_n)}\left[\frac{\mathrm{d^2N(E_p)}}{\mathrm{dE^2p}}\right]_{\mathrm{E_n=E_p}}, \quad (1)$$

where $\frac{\mathrm{dN(E_n)}}{\mathrm{dE_n}}$ - the spectrum of proton recoil.

3. Conclusion

Thus, as a result of the performed work, the spectrum of the neutrons from the ^{7}Li(d,n)^{8}Be reaction at an angle of 0° to the beam axis was measured by activation method that uses a link between induced activity of detectors and flux of neutrons. It is worth noting that ^{7}Li(d,n)^{8}Be reaction was measured by activation method for the first time ever. The advantage of this method over other methods is that the measurement of neutron spectrum can be carried out in the presence of high intensity gamma radiation. Figure 2 shows a good agreement in the range from 7 to 18 MeV between the activation spectrum with the spectrum obtained by using single-crystal spectrometer based on stilbene crystal. At the present time the studies on the possible reasons for the some discrepancy of neutron spectra obtained by activation method and the scintillation spectrometer in the range from 3 MeV to 7 MeV are carried out.

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