Experimental determination of neutron flux from the ^{7}Li(d,n) reaction at KG-2,5 accelerator by the activation method

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Abstract

In this paper the procedure of measuring the neutron flux generated by the reaction ^{7}Li(d,n) at the cascade generator KG-2.5 of IPPE is described. The energy dependence of the efficiency of GeLi detector is determined. The spectra of gamma rays have been measured after irradiation of Au detector by fast neutrons. The neutron flux have been experimentally determined in the high-current cascade accelerator KG-2.5 by activation method in a given operation mode of the accelerator.

Determination of neutron flux

The activation method of measuring neutron spectra use a link between the induced activity of detector-monitors and neutron flux [1]. This link is expressed by the following equation:

$$S_{peak} = \frac{m}{\lambda \cdot A} \cdot \varepsilon_{\gamma} \cdot f \cdot g \cdot N_a \cdot (1 - e^{-\lambda \cdot t_{irr}}) \cdot e^{-\lambda \cdot t_d} \cdot (1 - e^{-\lambda \cdot t_m}) \cdot K \cdot \int \varphi(E) \sigma(E) dE, \qquad (1)$$

S_{peak} – the peak area of specific gamma-line
m – mass of the activation monitor in grams,
λ – decay constant,
A – atomic weight of the monitor,
ε_γ – Ge detector efficiency for a particular gamma-line,
f – isotopic purity of the activation monitor,
g – the intensity of the particular gamma-line,
N_a – Avogadro constant,
t_{irr} – irradiation time of the activation monitor,
t_d – delay time of gamma-ray measurements,
t_m – gamma-ray measurement time,
K – scale factor,
$\varphi(E)$ – the energy spectrum of neutrons in relative units,
$\sigma(E)$ – cross section of reaction (barn).

The procedure used to determine all the parameters of equation (1) is described below.

The spectrum of neutrons from the ^{7}Li(d,n) reaction

For measuring the energy spectrum of neutrons from a thick lithium target needed to determine the neutron flux the method of the time of flight was used at the accelerator EG-1 of IPPE operating in the nanosecond pulsed mode. Interruption and subsequent grouping of the ion beam was performed at the entrance of the accelerating beam-line tube which provided a pulsed ion beam to the target of the accelerator with the necessary timing and magnitude of the current pulse ~ 1 mA [2]. The duration of the current pulse was ~ 3 ns, the repetition period was 1.8 ms. In order to cover a wide range of neutron energies from 0.1 to 20 MeV the flight base length of 5.9 and 4.2 m were used. The neutron source and detector were in different rooms separated by a wall of heavy concrete with a thickness of 2 m that allows to obtain an acceptable ratio of effect to the background.

As a neutron detector lithium glass NE-905 was used with a thickness of 3 mm and a diameter of 50 mm with a photomultiplier FEU-30. In a series of experiments was also used scintillator neutron detector with stilbene crystal with a diameter of 60 mm and a length of 60 mm. The use of lithium glass allowed to carry out the measurement of neutron spectra in the 0.1-2 MeV region. The processing of apparatus spectrum was carried out using specially designed programs to transform apparatus neutron spectra in the energy scale [2].

The irradiating activation detector was located at an angle of 0° relative to the direction of the deuterons beam. The neutron spectrum from the reaction $^{7}Li(d,n)$ at an angle of 0° and cross section of reaction $^{197}Au(n,2n)^{196}Au$ [3] which was used as activation monitor in the present experiment are shown in Figure 1.

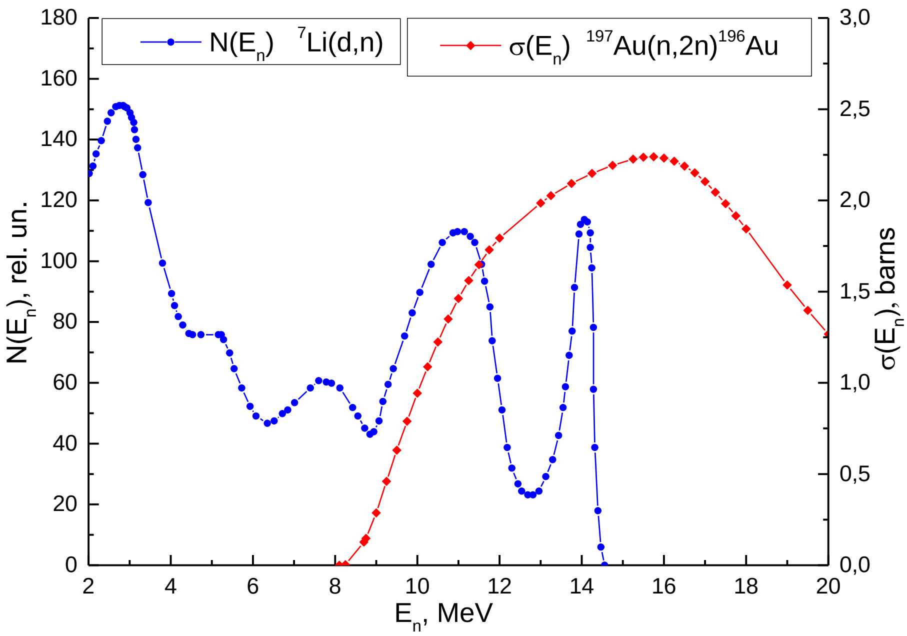

Figure 1. The spectrum of neutrons from reaction $^{7}Li(d,n)$ at 0^{o} and cross section of reaction $^{197}Au(n,2n)^{196}Au$.

The energy dependence of the efficiency of Ge(Li) gamma-spectrometer

The energy dependence of the efficiency of Ge(Li) gamma-spectrometer $\varepsilon(E_\gamma)$ was determined on the basis of experimental data for discrete values of the energy and intensity of gamma rays. The calibration of the spectrometer efficiency of total absorption of gamma rays was carried out using the standard gamma-ray sources "OSGI". The distance between the standard source and Ge (Li) detector and the diameters of the standard source and activation monitors were identical.

The value of the efficiency $\varepsilon(E_\gamma)$ of the total absorption of gamma rays with energy E_γ was determined from the equation:

$$\varepsilon\left(\mathrm{E}_\gamma\right) = S_S(E_\gamma)/(A_S \cdot e^{-\lambda \cdot t_d} \cdot I(E_\gamma) \cdot t_m) \ ,$$

where $S_S(E\gamma)$ – counts at the peak of total absorption of gamma rays with energy E_γ, registered during time interval t_m ;

A_S – absolute activity of standard source at the time of certification;

λ - decay constant of standard source;

$I(E_\gamma)$ - the yield of gamma rays with energy E_γ per disintegration of a radioactive nucleus of standard source;

t_d – elapsed time from the moment of certification of the source to the beginning of measuring quantities $S_S(E\gamma)$.

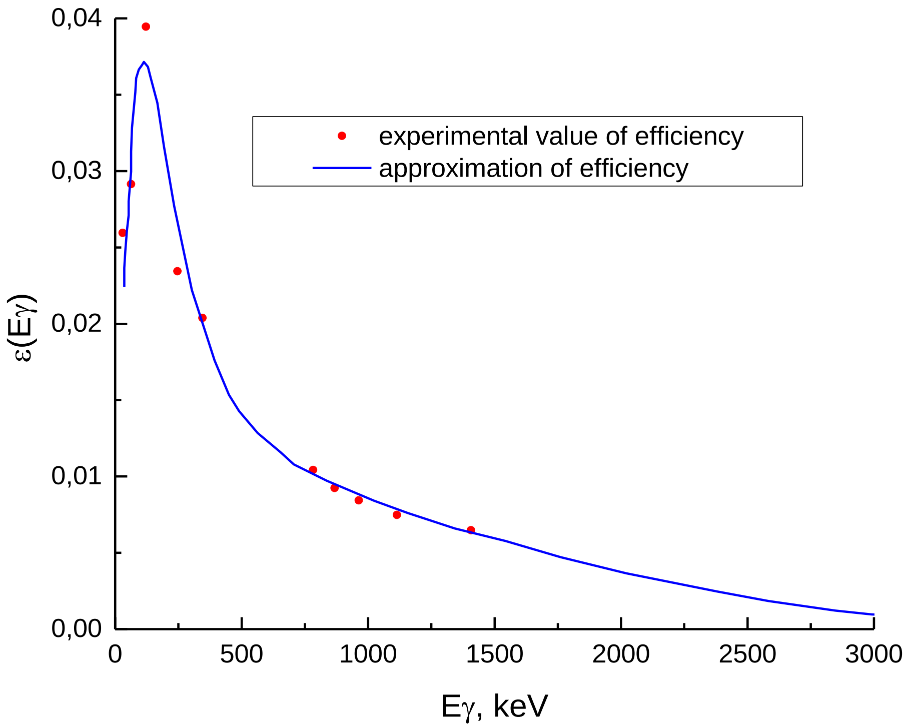

Figure 2. The efficiency of Ge(Li) gamma-spectrometer.

The efficiency of the total absorption of gamma rays with energy $E\gamma$ were calculated on the basis of the measured values $S_S(E_\gamma)$ and parameters A_S, $I(E_\gamma)$, λ, t_d, t_m. The function $\varepsilon(E_\gamma)$ was determined by fitting the experimental data for different E_γ. The results of determination of the efficiency of Ge(Li) detector were shown ~~at~~ in figure 2.

The irradiation of the monitor

The irradiation of the Au detector (activation monitor) was carried out at cascade high-current accelerator KG-2.5 of IPPE. The detector was irradiated continuously for five hours by neutrons from reaction ^{7}Li(d,n) with deuteron energy E_d=1.5 MeV. A current of deuteron ion was 170 μA.

The HPGe-detector Canberra GX5019 was used as the spectrometer of induced gamma ray activity. An apparatus spectrum of gamma rays originated from ^{197}Au(n,2n)^{196}Au reaction in the Au sample after irradiation by the neutron flux is shown in figure 3.

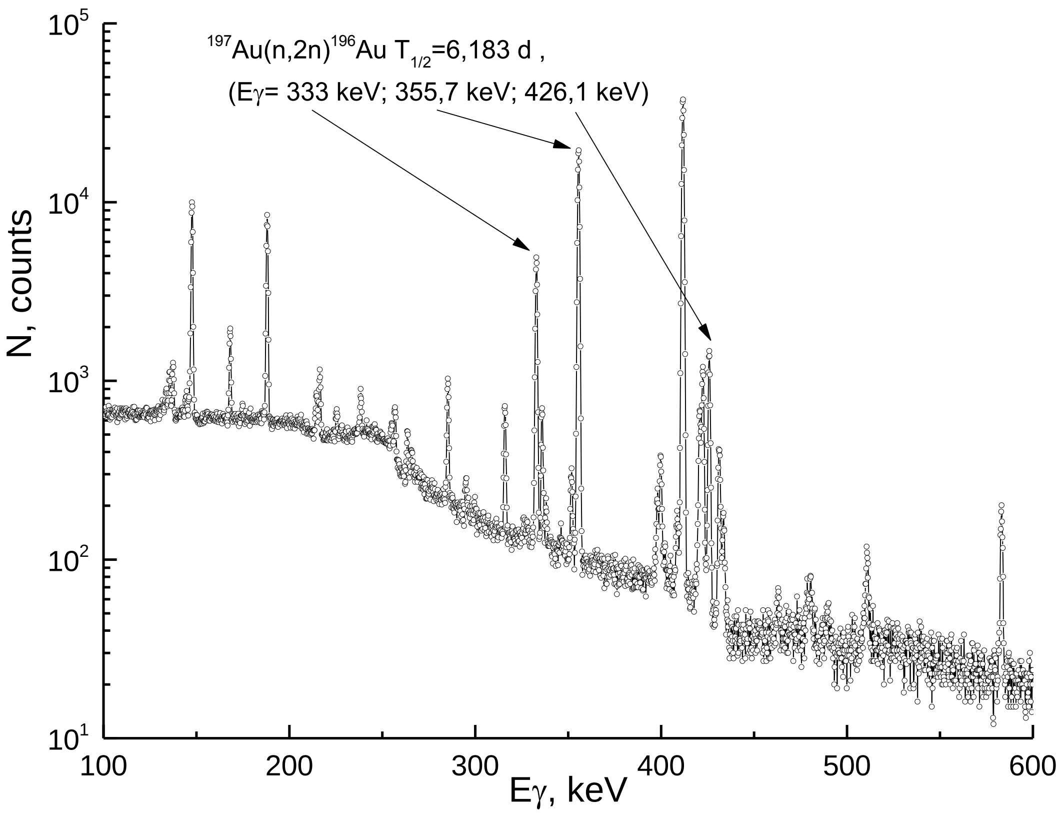

Figure 3. Apparatus spectrum of gamma rays from ^{197}Au(n,2n)^{196}Au reactions in the Au activation monitor after irradiation by the neutron flux.

The number of counts in the total absorption peak of gamma-rays were obtained from measurements on this detector and the subsequent processing of gamma-rays spectrum. The five measurements of irradiated monitors were carried out to increase the statistical accuracy of the determination of the induced activity.

Thus, we determined all parameters of equation (1), namely, the characteristics of the monitor, the characteristics of gamma-rays spectrometer, the time of irradiation, the delay time and the time of measurements, as well as the energy distribution of the cross section of the threshold reaction $^{197}Au(n,2n)^{196}Au$ and the energy spectrum of neutrons in relative units. All this allows us to obtain the scale factor K. Then neutron fluence Φ can be determined by expression

$$\Phi = t_{irr} \cdot \int K \cdot \varphi(E)dE .$$

The analysis of the activation gamma spectra of Au detector obtained under irradiation by neutron flux from the reaction $^{7}Li(d,n)$ on a thick target bombarded by deuterons with energy E_d=1.5 MeV and a current of ions I=170 μA during 5 hours allows to obtain the value of neutron fluence equal $2\cdot10^{14}$ neutrons/cm^2.

Conclusion

In this paper the procedure of measuring the neutron flux generated by the reaction $^{7}Li(d,n)$ at the cascade generator KG-2.5 of IPPE is described. The energy dependence of the efficiency of GeLi detector is determined. The Au detector was irradiated continuously for five hours by neutrons from reaction $^{7}Li(d,n)$ with deuteron energy E_d=1.5 MeV and a current of ion of 170 μA. The spectra of gamma rays have been measured after irradiation of Au detector. The neutron fluence have been experimentally determined at the high-current cascade accelerator KG-2.5 of IPPE by activation method in a given operation mode of the accelerator which was equal $2\cdot10^{14}$ neutrons/cm^2.

Reference List

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