

# TRITIUM PRODUCTION CROSS SECTION FOR NEUTRON INTERACTION WITH $^{10}\text{B}$ NUCLEI

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## **Abstract**

Tritium production reactions are important for the safe operation of nuclear power plant. The  $^{10}\text{B}$  isotope widely used in practice both for nuclear reactor power control and for shielding from thermal neutrons. The  $^{10}\text{B}(n,\alpha)^4\text{He}$  reaction is one of the main reactions which is responsible for tritium production in nuclear reactors. The method using gaseous target has been developed in the IPPE. It allows to register sum of kinetic energies of all charged reaction products to distinguish wanted events from background.

## **Introduction**

Natural boron consists of two isotopes -  $^{10}\text{B}$ (20%) and  $^{11}\text{B}$ (80%). Boron-10 has very high absorption cross-section of thermal neutrons (about 3000 barn) and therefore it is usually used as a material for reactor power control rods. Tritium is produced in the reaction  $^{10}\text{B}(n,\alpha)^4\text{He}$  as a result of neutron interaction with boron. Tritium production reactions are important for the safe operation of nuclear power plant. Tritium has a high mobility, and so it easily penetrates through constructional materials. It is known that tritium can easily replace hydrogen in a human body.

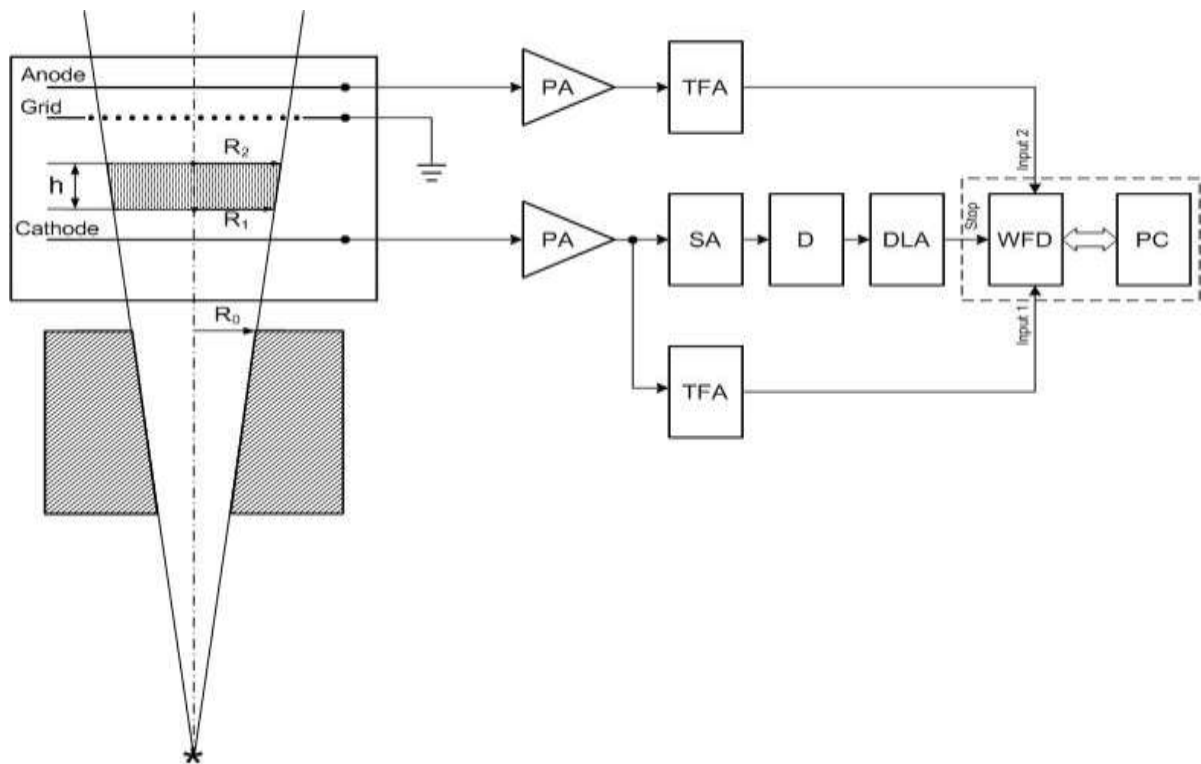
In order to estimate the rate of tritium production it is necessary to know the cross sections for relevant reactions.

The available experimental data for  $^{10}\text{B}(n,\alpha)^4\text{He}$  reaction cross section are scarce and discrepant, the data reported in different sources being inconsistent both in shape and absolute values. There are large discrepancies in the estimates of the cross section for this reaction given by the different libraries.

## **Experimental method**

The cross section for break up reaction was carried out at the accelerator EG-1 in IPPE. The  $\text{D}(d, n)$  reaction was used to get the monoenergetic neutrons. The neutrons were generated in solid titanium target saturated with deuterium, with thickness of  $1 \text{ mg/cm}^2$ , deposited on a copper backing.

The investigation of the reaction cross section was performed using an ionization chamber with the Frisch grid. Block diagram of the chamber and the electronics is shown in this figure 1.



**Figure 1.** Block diagram of experimental setup. PA – preamplifier, TFA – timing filter amplifier, D – discriminator, SA – spectroscopy amplifier, DLA – delay line amplifier, WFD – waveform digitizer, PC – personal computer.

Signals from the electrodes of the chamber after amplification were fed to the wave form digitizer, which transformed the analog signal into digital signal. The digitized signals were stored on the hard disk for offline analysis. During processing the information on amplitudes of anode and cathode signals, and also the moments of the beginning and the ending of these signals was taken. This information allowed us to decrease a background. The measurement of the  $(n,\alpha)$  reaction cross section was carried out relatively to the  $^{10}\text{B}(n, \alpha)$  reaction cross section taken from [1]. The cross section of  $^{10}\text{B}(n, \alpha)$  reaction [1] was measured for neutron energies up to 5.6 MeV. The obtained values of  $^{10}\text{B}(n,\alpha)$  reaction cross section had a good agreement with the values of cross section that was given in library JEF 2.2. So we used the values from JEF 2.2 library for neutron energies exceeding 5.6 MeV.

The chamber was filled with a mixture of 95% Kr + 5%  $\text{BF}_3$ . Boron contained in the working gas was used as a target.

Using a collimation of fast neutrons in combination with digital signal processing methods allows us to form some gas cell in the sensitive volume of the chamber. Only those events which originated from the cell were taken into account in determining the reaction cross section.

It should be noted that the monitor reaction  $^{10}\text{B}(n, \alpha)^7\text{Li}$  proceeded in the same nucleus and in the same gas cell, thus guarantying the correct measurement of the ratio of events.

For the monitor reaction we can write the following expression.

$$N_{\alpha} = N_B * \sigma_{\alpha} * F \quad (1)$$

where  $N_{\alpha}$  – is the number of obtained events of monitor reaction,  $N_B$  - is the number of boron atoms in a gas cell,  $\sigma_{\alpha}$  – is the cross section of  $^{10}\text{B}(n,\alpha)^7\text{Li}$  reaction,  $F$  – is a neutron flux.

The number of events of  $^{10}\text{B}(n,\alpha)^4\text{He}$  reaction was determined using the following expression:

$$N_T = N_B * \sigma_T * F \quad (2)$$

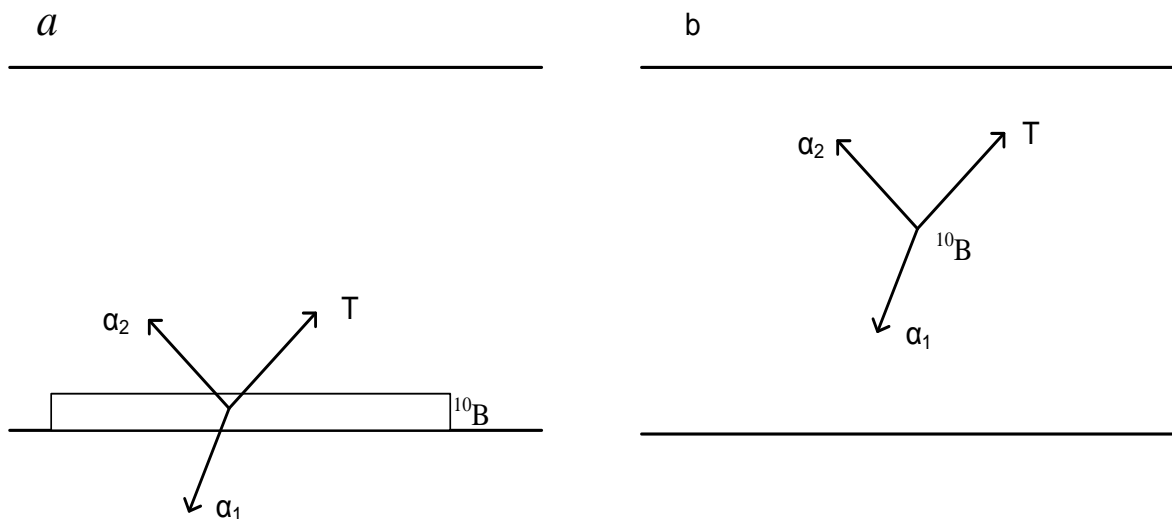
where  $N_T$  – is the number of obtained events of  $^{10}\text{B}(n,\alpha)^4\text{He}$  reaction,  $\sigma_T$  – is the cross section of  $^{10}\text{B}(n,\alpha)^4\text{He}$  reaction.

Solving a system of equations we get the following expression:

$$\sigma_T = \frac{N_T}{N_{\alpha}} \sigma_{\alpha} \quad (3)$$

From a practical point of view it is very important that the result of measurements does not depend on the absolute number of boron atoms and the degree of enrichment of using sample.

Classical spectrometers with solid target are widely used for the (n, $\alpha$ ) reaction investigation. As far as this reaction has three particles in the output channel, one or two particles can be absorbed in the target backing in the case of using a solid target (fig.2a). In this case the energy which particles can deposit in the sensitive volume of the detector can vary in a wide range. In such a case the events will not produce a narrow peak. In this condition the events corresponding to the  $^{10}\text{B}(n,\alpha)^4\text{He}$  reaction will not form a narrow peak and will be mixed with events corresponding to registration of  $^7\text{Li}$  from  $^{10}\text{B}(n,\alpha)^7\text{Li}$  reaction in a sensitive volume of the chamber (fig.3).

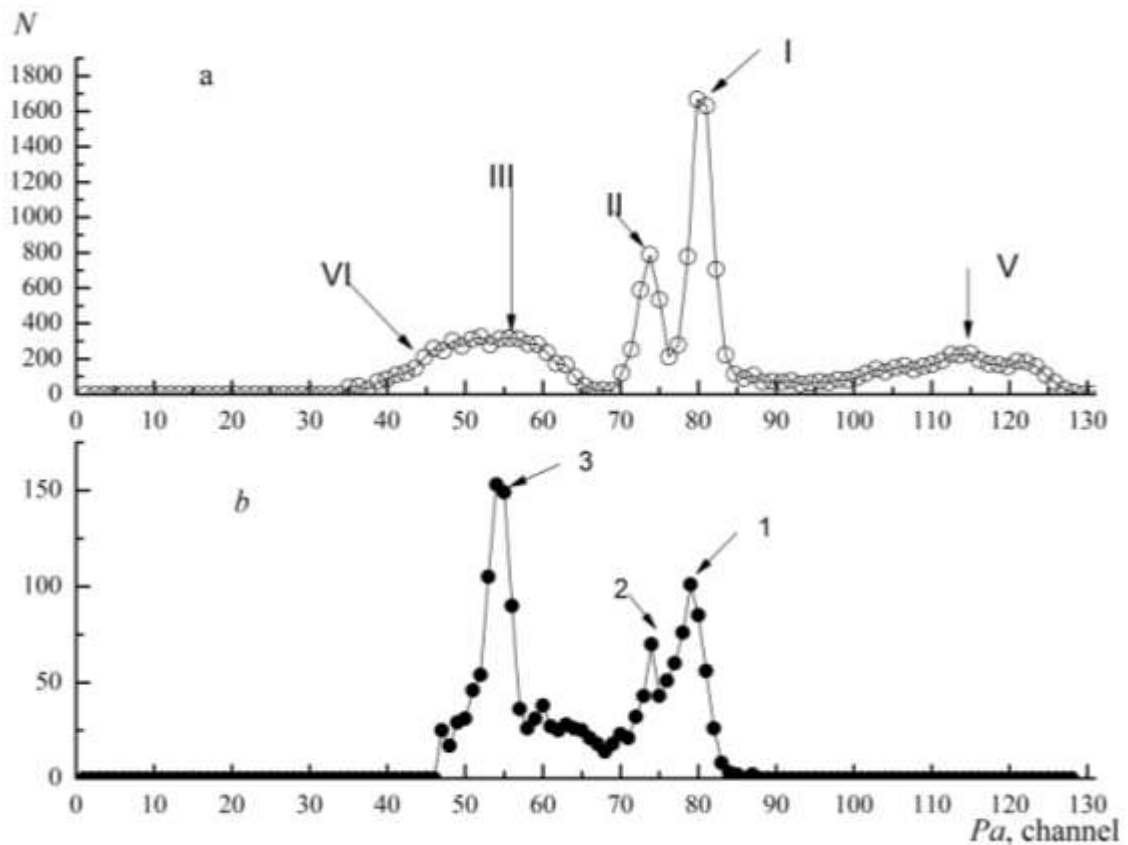


**Figure 2.** a - diagram of particle escape using solid target; b - diagram of particle escape using gaseous target.

In case of using gaseous target, all three particles will be stopped in a sensitive volume of chamber and consequently the amplitude of the signal will be proportional to the sum of kinetic energies of all the reaction products which equal to  $E_n - Q$ , ( $Q = 0,328$  MeV,  $E_n$  – neutron energy). So a peak corresponding to the events of  $^{10}\text{B}(n,\alpha)^4\text{He}$  reaction will be clearly seen in the amplitude spectrum (fig.3).

The method of forming a gas cell inside the sensitive volume of the ionization chamber has the following advantages: 1) it is possible to suppress the wall effect; 2) the background from the electrode of chamber is reduced; 3) the number of atoms of the substance under study, using a simple gas laws can be determined.

The spectra of anode signals for solid and gaseous targets are shown in figure 3.



**Figure 3.** Spectrum of anode signals of ionization chamber.

a – using solid target:

b – using gaseous target.

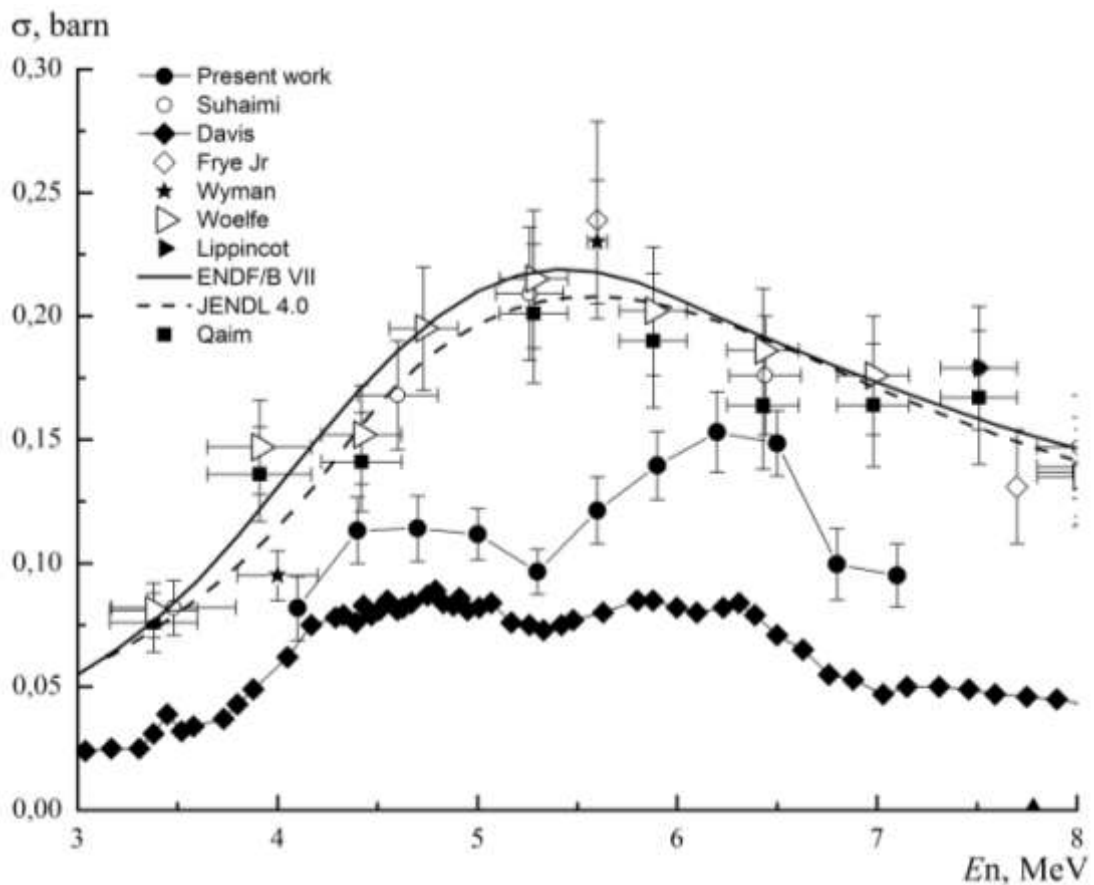
I –  $^{10}\text{B}(n,\alpha_0)$ ; II –  $^{10}\text{B}(n,\alpha_1)$ ; III –  $^{10}\text{B}(n,t)$ ; VI –  $^7\text{Li}$ ; V –  $^7\text{Li} + \alpha$

1 –  $^{10}\text{B}(n,\alpha_0)$ ; 2 –  $^{10}\text{B}(n,\alpha_1)$ ; 3 –  $^{10}\text{B}(n,t)$

It is seen from figure 3 that the peak corresponding to the  $^{10}\text{B}(n,\alpha)^4\text{He}$  reaction is absent if we use a solid target. In the case of using gaseous target the contribution of the  $^{10}\text{B}(n,\alpha)^4\text{He}$  reaction form a discrete peak which area can be determined with high accuracy.

### Experimental result

The measurements were performed for 11 different neutron energies in the range from 4.1 to 7.0 MeV. The results of the measurements are shown in the figure 4. The data of the other authors [2-6] and evaluated data from the libraries ENDF / B VII and JENDL are shown in this figure also.



**Figure 4.** Cross section of  $^{10}\text{B}(n,\alpha)^4\text{He}$  reaction in comparison with experimental data of other authors and data of libraries ENDF / B VII and JENDL.

The analysis of the presented data shows that the data obtained in the present work are significantly lower than the evaluation given by the libraries ENDF / B VII and JENDL. The differences between the data obtained in the present work and the evaluations given by the libraries are not limited only by the cross section values. The non-monotony of the excitation function is clearly visible from new experimental data of the studied reaction where

remarkable peaks in the cross section are observed at neutron energies of 4.5 and 6.5 MeV, and the minimum is clearly seen at the energy of 5.3 MeV. Available evaluations give a smooth curve of the cross section for the whole neutron energy range. The similar situation is for the obtained data discrepancy both in the absolute values and the form of the energy dependence when compared with those obtained by the other authors [2-6] except for the data obtained by a Davis group [4]. Despite the fact that the data [4] are significantly lower than the data obtained by all the other authors, including those of the present work, the shape of their excitation function has the same structure as in our experiment. The cross section obtained in the work [4] is lower than the data obtained in the present work and this can be explained if we analyze the data for  $^{10}\text{B}(n,\alpha)^7\text{Li}$  reaction also measured in that work. The comparison with the data obtained in a work [1] shows that it's also lower. The cross section ratio of the  $^{10}\text{B}(n,\alpha)^4\text{He}$  reaction to the  $^{10}\text{B}(n,\alpha)^7\text{Li}$  reaction is practically the same. We can assume that there was a systematic uncertainty associated with determination of the detection efficiency of events or the determination of neutron flux in a work [4]. The relative behavior both of these reactions in work [4] has been measured correctly.

To resolve the existing contradictions between the experimental data of different authors and the evaluations given in the libraries it is required to perform new experimental and computational efforts.

## References

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