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MEASUREMENT OF (n,t) CROSS SECTIONS ON LIGHT NUCLEI

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Abstract: (n,t) reactions on ^{9}Be, ^{10}B and ^{14}N were investigated via vacuum extraction and gas phase β^- counting of accumulated tritium. For ^{9}Be(n,t)^{7}Li reaction integral cross sections were measured using d(Be) breakup neutrons (E_d = 17.5 to 30.0 MeV). The data agree within 20 % with the average cross sections derived from the excitation function of this reaction and the neutron spectral distributions. The ^{10}B(n,t)2α reaction cross section at thermal neutron energy was found to be low (12.0 ± 2.5 mb). The ^{14}N(n,t)^{12}C reaction cross sections were measured over the neutron energy range of 5.0 to 10.6 MeV. The excitation function shows fluctuation and three peaks can be distinguished. The trend is attributed to the decay properties of the excited nuclear levels involved.

((n,t) reaction, tritium extraction, gas phase β^- counting, cross section, excitation function, integral data, excited nuclear level)

Introduction

A knowledge of (n,t) reaction cross sections on light mass nuclei is of considerable significance for tritium breeding in fusion reactors as well as for tritium build-up in the upper atmosphere, the vicinity of a reactor core, shielding and absorber materials. In the medium and heavy mass regions the (n,t) reaction is rather rare [cf. 1-3] and studies are generally of fundamental interest.

The Q-values of (n,t) reactions on all the stable isotopes of elements between Li and F are given in Table 1. The reactions ^{6}Li(n,t)^{4}He and ^{10}B(n,t)2α can be induced even by thermal neutrons; in all the other cases fast neutrons are needed.

Table 1. Q-values of (n,t) Reactions on some Light Nuclei

Nuclear Reaction	Q-value (MeV)
^{6}Li(n,t)^{4}He	+ 4.78
^{7}Li(n,n't)^{4}He	- 2.47
^{9}Be(n,t)^{7}Li	- 10.40
^{10}B(n,t)2α	+ 0.32
^{11}B(n,t)^{9}Be	- 9.56
^{12}C(n,t)^{10}B	- 18.93
^{13}C(n,t)^{11}B	- 12.42
^{14}N(n,t)^{12}C	- 4.02
^{14}N(n,t)3α	- 11.29
^{15}N(n,t)^{13}C	- 9.90
^{16}O(n,t)^{14}N	- 14.48
^{17}O(n,t)^{15}N	- 7.79
^{18}O(n,t)^{16}N	- 13.34
^{19}F(n,t)^{17}O	- 7.56

For (n,t) reactions on several of the light mass nuclei angular distribution studies have been performed. The information available on total tritium emission cross sections, especially as a function of neutron energy, was rather small. For tritium breeding calculations in fusion blanket designs the status of the ^{6}Li(n,t)^{4}He reaction cross sections is adequate. In the case of ^{7}Li(n,n't)^{4}He reaction, however, there was considerable discrepancy. Our recent measurements and a critical appraisal of all the existing data showed [4] that the discrepancy in the evaluated data arose mainly due to a combination of inelastic neutron data and tritium counting data. The recent tritium data are more consistent and now the discrepancy seems to have been removed [4]. The ^{9}Be(n,t)^{7}Li reaction was investigated earlier in the 14 MeV region [5-7] and with breakup neutrons [8]. Recently its excitation function has been measured in the energy range of 12.9 to 19.6 MeV [9]. For the ^{10}B(n,t)2α process cross sections were available at a few energy points [5,6,8,10,11]. We reported its excitation function in the energy range of 2.5 to 10.6 MeV [12]. For all of the other processes listed in Table 1 very little experimental work has been done. We investigated the (n,t) reactions on ^{9}Be, ^{10}B and ^{14}N. The experimental technique involving vacuum extraction and gas phase anticoincidence β^- counting of accumulated tritium was the same as described earlier [13].

^{9}Be(n,t)^{7}Li Reaction

The aim of the present measurements was to perform integral tests on the (n,t) excitation function reported recently [9]. For this purpose high-purity Be sheets (10x10x5mm) were irradiated with breakup neutrons produced in the interaction of high energy deuterons with a Be-converter. Six primary deuteron energies between 17.5 and 30.0 MeV were chosen. The shapes of the neutron spectra in the forward direction are well characterized [cf. 14]. The mean neutron flux density in each case was determined via the ^{27}Al(n,α)^{24}Na reaction. From the measured absolute tritium activity and the mean neutron flux density the average (n,t) cross section was determined. The results are given in Table 2. Besides the experimental integral data, the average (n,t) cross section was also deduced from the excitation function of ^{9}Be(n,t)^{7}Li reaction [9] and neutron spectral distribution [14]. For this purpose the excitation function was extrapolated up to 25 MeV. Beyond 25 MeV, however, due to the onset of the (n,tn) process no extrapolation of the experimental curve was attempted. The average (n,t) cross sections deduced by this method are also given in Table 2. A comparison of the two sets of average cross sections shows an agreement within about 20 %. Considering the various uncertainties involved in the two types of integral data, this agreement may be regarded as satisfactory.

Table 2. Integral Data for ^{9}Be(n,t)^{7}Li Reaction

E_d on Be-converter (MeV)	Average experimental (n,t) cross section (mb)	Average deduced (n,t) cross section* (mb)
17.5	3.2 ± 0.4	2.7 ± 0.4
20.0	4.6 ± 0.7	4.1 ± 0.7
22.5	6.3 ± 1.1	5.0 ± 1.0
25.0	8.6 ± 1.5	6.8 ± 1.4
27.5	11.0 ± 2.0	
30.0	13.5 ± 2.6	

*Deduced from ^{9}Be(n,t)^{7}Li excitation function and neutron spectral distribution.

^{10}B(n,t)2α Process

We measured the cross section of this process at thermal neutron energy. At this energy the pure α-emission processes, ^{10}B(n,α_0)^{7}Li and ^{10}B(n,α_1)^{7}Li* (0.478 MeV level), are very dominant, their cross sections being 257 and 3580 barn, respectively. The α-emission process with a total cross section of 3837±9 barn is important, on the one hand, as a primary neutron standard and, on the other, in boron neutron capture therapy. The tritium emission process ^{10}B(n,t)2α is possibly of secondary importance but a determination of its cross section is of value, especially in view of the prevailing discrepancy. Cserpák et al [11] used thermal neutrons from a ^{252}Cf source and reported a cross-section value of 50±6 mb. In a preliminary report Reedy et al [15] described a measurement using thermal neutrons from a reactor and gave a value of 890±90 mb. In the meantime this preliminary result has been withdrawn. Very recently Kavanagh and Marcley [16] used a ^{10}BF$_3$ gas proportional counter. It was exposed to thermal neutrons from a ^{252}Cf source and from the pulse height spectrum a cross-section value of 7±2 mb for the ^{10}B(n,t)2α process was obtained.

In the present work we mixed B_2O_3 (Suprapur, Merck) with ZnO (99.9999 %, Aldrich) homogenously in a ratio of 1:18. The mixture was first degassed and then a 115 mg portion was sealed in a small high-purity quartz ampoule (3 mm inner ϕ x 40 mm long). ZnO was used as an internal flux monitor via the ^{64}Zn(n,γ)^{65}Zn reaction (σ = 780±20 mb). The amount of ZnO used was much higher compared to B_2O_3 in order to avoid large depression in thermal neutron flux distribution due to very high thermal neutron absorption cross section of boron. A second ampoule containing 110 mg degassed ZnO was used as a blank. Both the ampoules were irradiated together for 22 h in a pure thermal column ("Trommelmagazin") of the research reactor DIDO at a thermal neutron flux density of 2 x 10^{12} cm^{-2}s^{-1} ($\phi_{th}/\phi_f = 10^4$). Comparing the ^{65}Zn activity in both the ampoules a thermal neutron flux depression of 22.6 % in the B_2O_3+ZnO mixture was found. Tritium was separated from both the irradiated materials and counted in the gas phase. From the results the tritium contribution originating from B_2O_3 was determined. Assuming the Li impurity in B_2O_3 to be 1 ppm (20 times higher than that given by the Supplier) the tritium contribution through the impurity was estimated to be < 0.2 %. From the measured tritium count rate the cross section of the ^{10}B(n,t)2α process was calculated. It amounted to 12.0±2.5 mb.

The excitation function of ^{10}B(n,t)2α process covering the neutron energy range from thermal to 12.2 MeV is shown in Fig. 1. Results in the energy range of 2.5 to 12.2 MeV were discussed earlier [12]. Our value at thermal energy is in agreement with a recent measurement [16]. We feel that the long standing discrepancy is now solved.

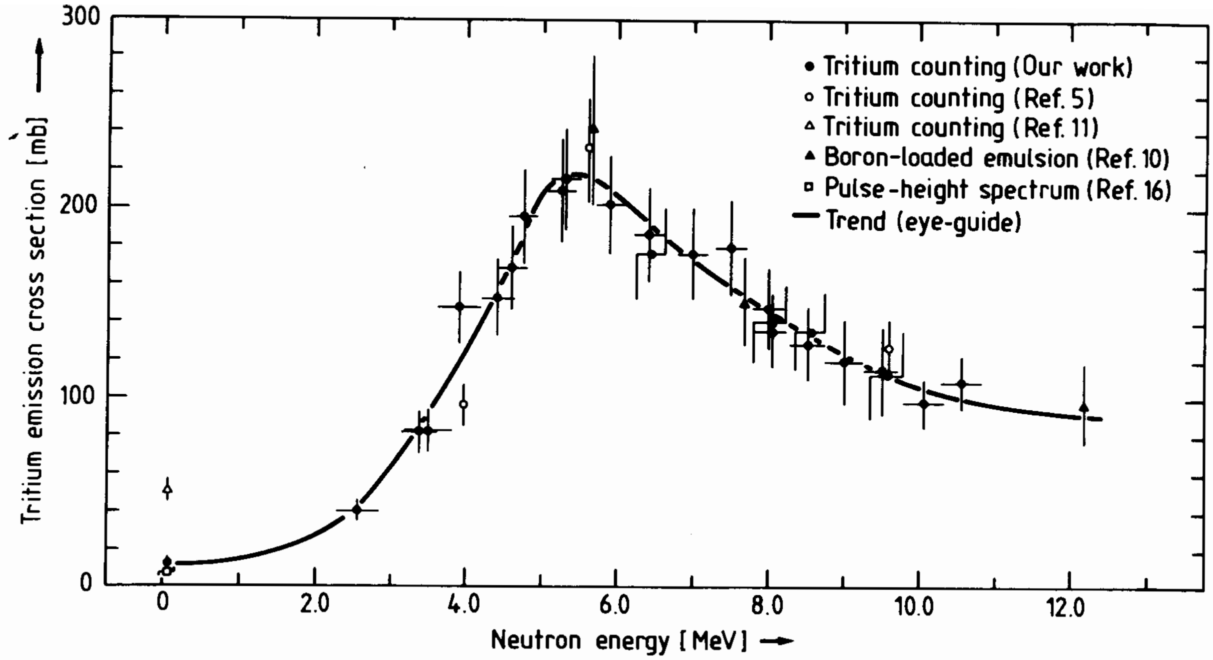

Fig. 1. Excitation function of ^{10}B(n,t)2α process (see also Ref. [12]).

^{14}N(n,t)^{12}C Reaction

This reaction was investigated previously over a small range of neutron energies [cf. 17,18] and with breakup neutrons [8]. We carried out extensive studies with quasi-monoenergetic neutrons of energies between 5.0 and 10.6 MeV. The details are given elsewhere [19] but the results are reproduced in Fig. 2 for a discussion. The cross section is appreciable even near the threshold and fluctuates over the whole investigated energy range. This fluctuation is attributed to the decay properties of the excited nuclear levels involved. Over the neutron energy range covered in our work the levels formed in the compound nucleus ^{15}N* have excitation energies between 15.8 and 21.5 MeV. It is known [cf. 20] that in ^{15}N several discrete excited levels between 15.8 and 19.5 MeV decay by triton emission. The probability of triton emission, however, varies in the decay of each excited level since there is a strong competition between ^{1}H, ^{3}H and ^{4}He emission. This is reflected in fluctuations in (n,t) cross sections. Due to the use of large irradiation samples the energy resolution of neutrons is rather poor. Nonetheless, we can distinguish three excitation energy regions, namely 16.6-17.0, 17.2-17.6 and 19.5 MeV, where the (n,t) cross section is high. Furthermore, directly near the threshold (E_x^* = 15.8 MeV) there seems to be a small peak. These peaks for the light nucleus ^{15}N* have some similarity with the slow neutron induced resonances in the medium and heavy mass compound nuclei.

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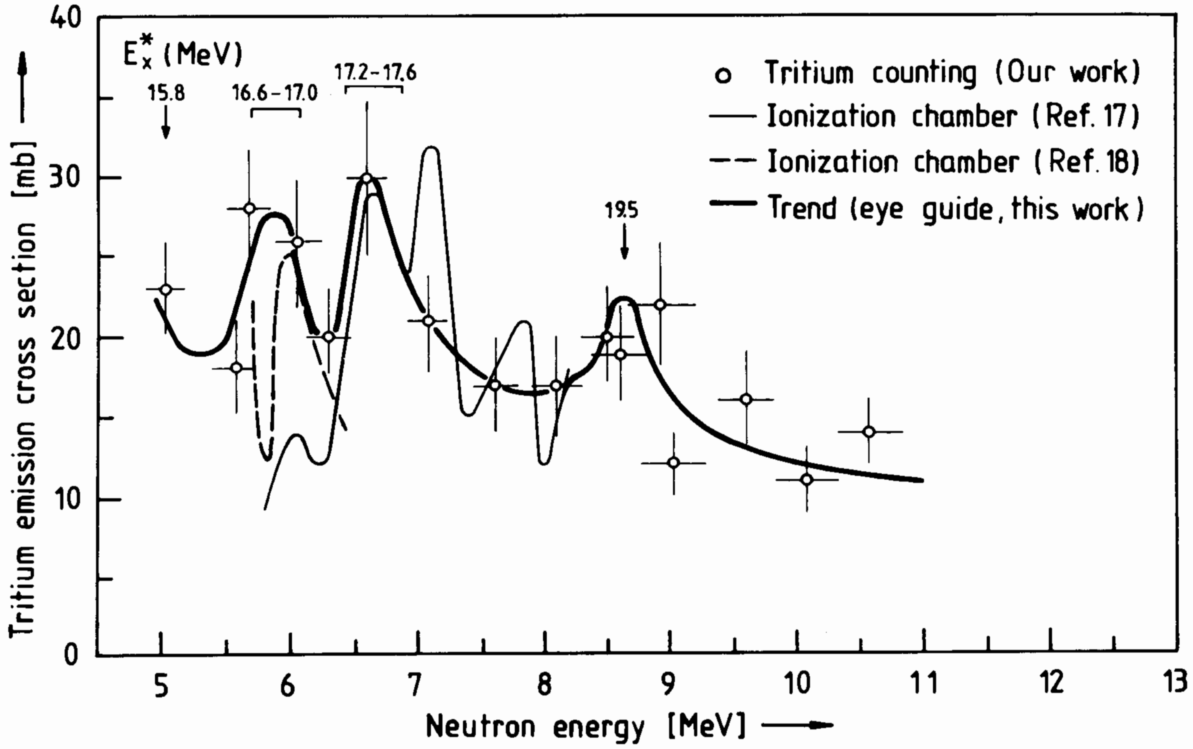

Fig. 2. Excitation function of $^{14}N(n,t)^{12}C$ reaction (see also Ref. [19]). The energy regions of the excited nucleus $^{15}N^*$ shown correspond to groups of levels decaying by triton emission.

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