EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Proposal to the ISOLDE and Neutron Time-of-Flight Committee

The (n,α) reaction cross section measurement for light isotopes

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Abstract

We propose to measure the (n,α) reaction cross section for a set of light isotopes (^{16}O, ^{10}B, ^{12}C, ^{14}N, ^{19}F) at the Experimental Area 1 (EAR-1) of the n_TOF neutron time of flight facility at CERN using gaseous targets. This will be the first time of time of flight measurement of the excitation function for these isotopes. The best resolution for incoming neutron energy can be reached. This reaction affects the reactivity of the reactor and produces a gaseous product, which can significantly alter properties of construction materials. This reaction is the substantial part of the absorbed dose estimations in the biological tissue being irradiated with fast neutrons (oxygen, nitrogen and carbon). Furthermore, some of these reactions figure in the response function of the fast neutron detectors (carbon and fluorine). The reaction (n,α) on the ^{10}B is used as a standard and therefore any clarification of its cross section can lead to a reassessment of data from a large number of works where it was used as the standard. Using of gaseous target will give us possibility to reach up to 10^{22} atoms in the target.
The aim of the first stage of experiment is to determine the ^{16}O(n,α) reaction cross section in the neutron energy region from 3 to 15 MeV.

Requested protons: 2×10^{18} protons on target, (split into 2 runs over 1 year)
Experimental Area: EAR1

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1 INTRODUCTION AND MOTIVATION

The cross section data for the (n,α) reaction on light isotopes, such as oxygen, carbon, nitrogen, fluorine and boron are of great practical importance since these elements are contained in the reactor core in large amounts (oxide, carbide and nitride fuel, fluorides in the molten salt reactors). This reaction affects the reactivity of the reactor and produces a gaseous product, which can significantly alter the properties of construction materials. This reaction is a substantial part of the absorbed dose estimations in the biological tissue being irradiated with fast neutrons (oxygen, nitrogen and carbon). The reactions on carbon and fluorine influence the response function of the fast neutron detectors. The reaction (n,α) on ^{10}B is used as a standard and therefore any clarification of its cross section can lead to a reassessment of data from a large number of works where it was used as a standard. Moreover (n,α) reaction cross section for these isotopes, especially for neutron energies greater than 5 MeV, was insufficiently studied, resulting in a large discrepancy of existing experimental data and estimations of different libraries.

The disadvantage of electrostatic accelerators of using in experiments is a large energy spread of neutrons. The obtained excitation functions are convolutions of the cross sections and energy distributions of neutrons. This complicates the interpretation of the results, especially if the cross section has a resonance structure. Another disadvantages of electrostatic accelerators are the limited set of neutron energies and the presence of parasitic reactions (especially when accelerated deuterons are used), leading to the appearance of background neutrons. That is why such neutron source cannot provide monoenergetic beams in 9-14 MeV neutron energy range. Production of neutrons with energies above 14 MeV is also a problem.

The need of additional measurements of ^{16}O(n,α)^{13}C reaction cross-section was underlined during NEMEA-7/CIELO workshop [1]. The current situation with the experimental data for this reaction is shown in Figure 1. Most of the data were obtained at the middle of last century using the electrostatic accelerators. There is a significant difference between different authors' data [2-7] both the absolute value of the cross section and the shape of the excitation function. The current situation with the experimental data is also reflected in the theoretical estimations given in various libraries (see Figure 2). Furthermore the inferred (n,α) cross sections from R-matrix analyses of ^{16}O+n total cross section data disagree with all experimental data. Evaluations therefore adjust the (n,α) channel to a certain choice of (n,α) data.

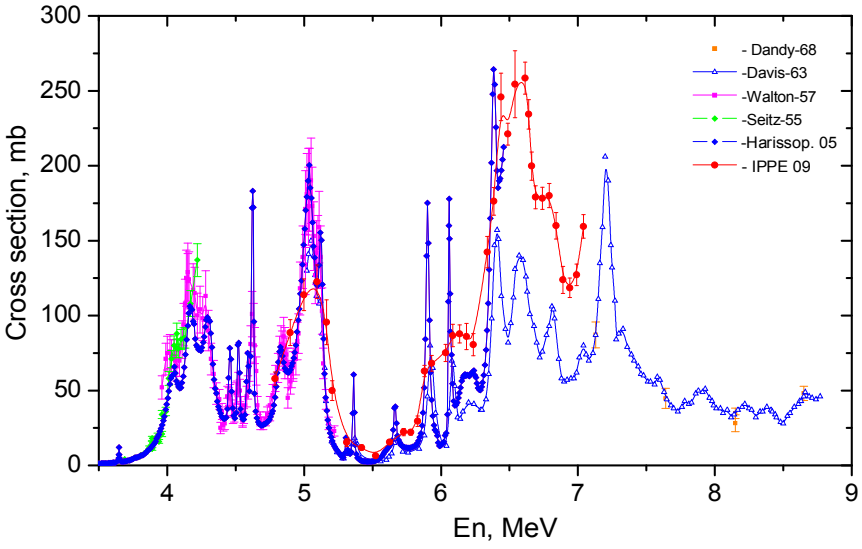

Figure 1. Status of experimental data for 16O(n,α)13C reaction.

2 EXPERIMENTAL SETUP

The method was developed by joint efforts of IRMM and IPPE groups [7-8]. It is based on the use of gaseous target localized in a cell inside the ionization chamber, with digital signal processing being used to acquire data (see Figure 3). The detector is a double ionization chamber with common cathode. Both chambers are filled with gas which includes the isotope under study. In our case it was a mixture of 95% Kr + 5% CO_2. Charged particles produced due to interaction of neutrons with oxygen nuclei were registered. The main chamber with Frisch grid was used to detect the products of the reaction under study. The monitor chamber contained a 238U layer, and the neutron flux was monitored by fission fragments emitted from the layer.

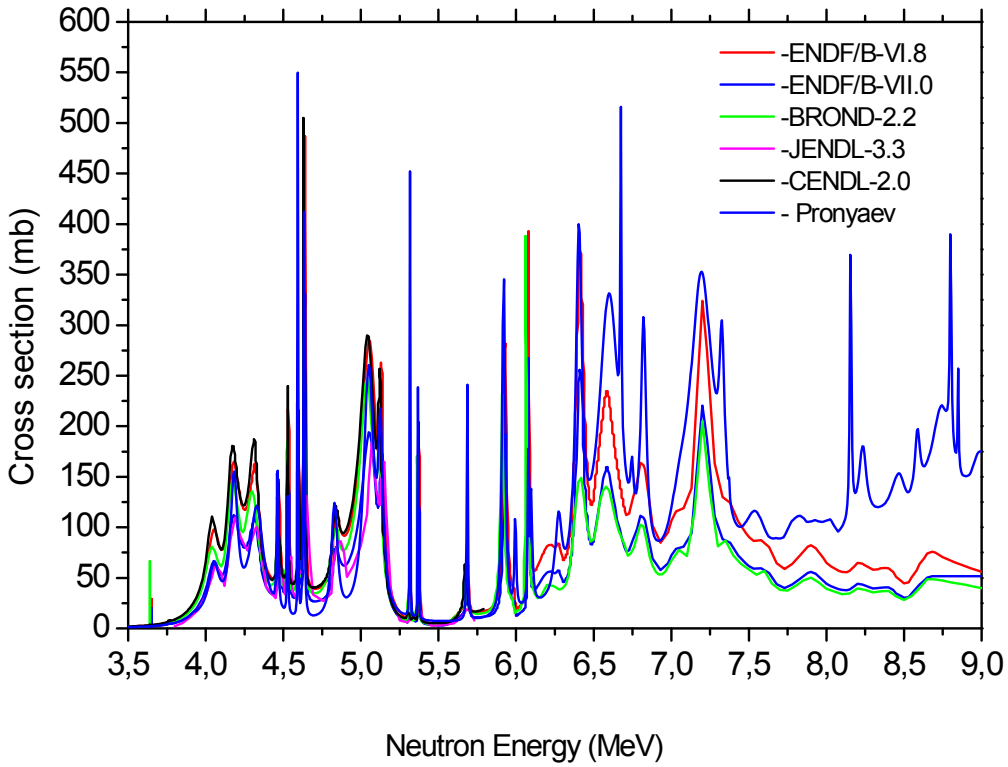

Figure 2. Status of evaluation for $^{16}O(n,\alpha)^{13}C$ reaction.

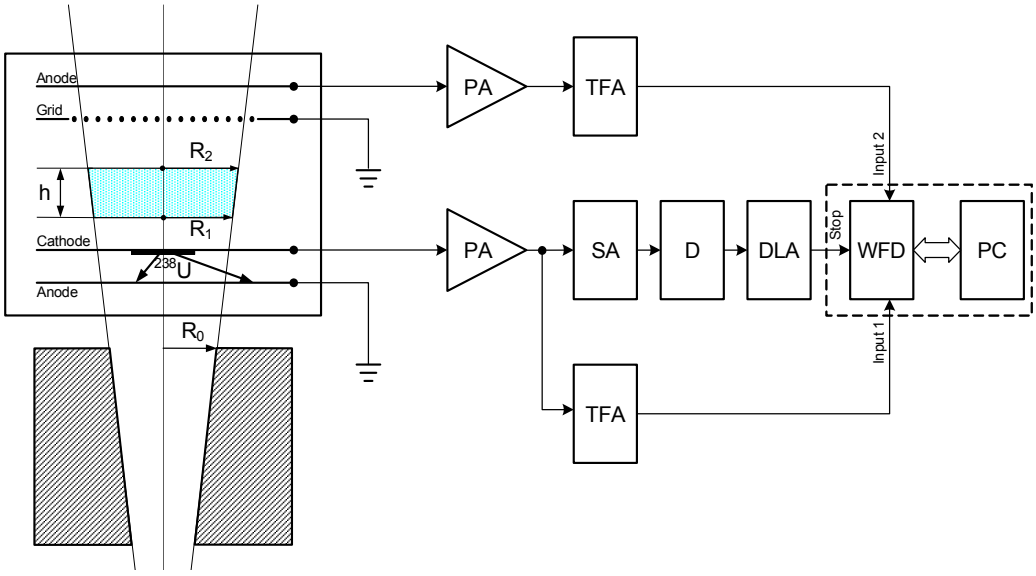

Figure 3. Experimental set up for (n,α) reaction investigation used at the electrostatic accelerators of IRMM and IPPE.

Amplified anode and cathode signals were digitized using LeCroy 2262 (80 MHz, 10 bit). The digitized signals are stored on pc hard disk and processed using software developed at IPPE. The main determined physical parameters were: the amplitude of the anode and cathode signals, the drift time of the electrons in the chamber and the anode signal rise time. Digital signal processing allows us to determine the location of a particle and to distinguish the reaction products by type. Such advantages help us to reduce the parasitic reactions background significantly. That is how we separate the events occurring on the structural elements of the detector and suppress the wall effect. Use of a gaseous target allows us to study reactions with more than one charged particle in the output channel [9]. This problem can not be solved in case of a solid target due to the fact that part of the reaction products is absorbed in the target backing and the response function becomes very difficult in this case.

All the reaction products emitted from a gaseous target are absorbed in the sensitive volume of the detector. That is why a clear peak corresponding to a sum of the reaction energy and the incident neutron energy is created in the registered spectrum. Gaseous targets can have a much greater number of atoms than the solid ones. Besides its use guarantees that all the energy of the reaction products is deposited in the sensitive volume of the detector contrary to the case of a solid target where the energy is partly absorbed in the target itself. That is why we can use this method for measuring small reaction cross-sections with low neutron flux. Another advantage of the method is that the number of nuclei in the target can be determined relatively easily even in the case of a non-radioactive sample.

The $^{16}O(n,\alpha)^{13}C$ reaction cross section experimental results obtained in IPPE are shown in Figure 4.

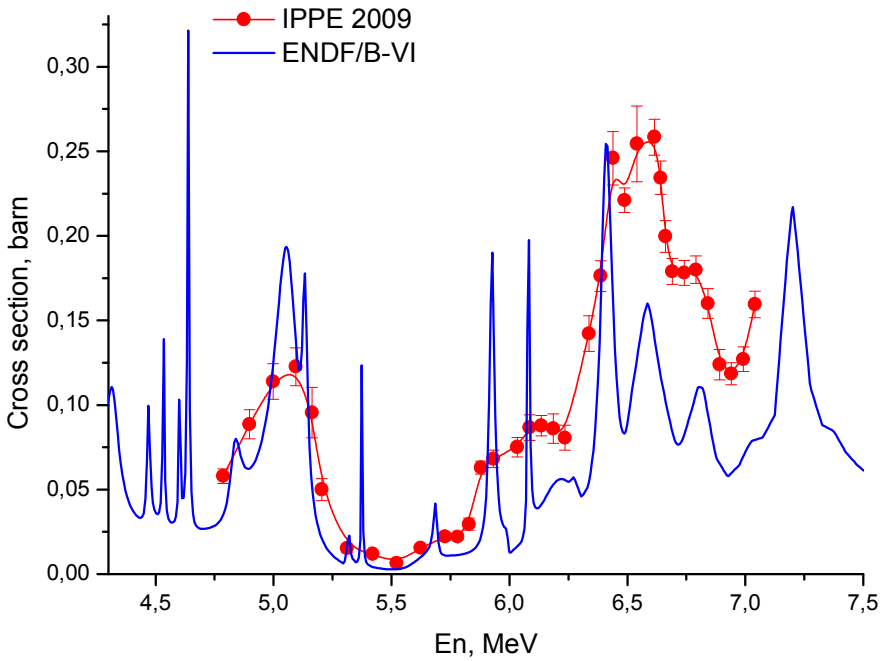

Figure 4. Experimental results for $^{16}O(n,\alpha)$ reaction.

Unfortunately the neutron energy resolution available in the performed measurements was relatively low (120÷200 keV) whereas the $^{16}O(n,\alpha)^{13}C$ reaction cross-section had narrow resonances. Consequently it was difficult to directly compare the measured results with theoretical evaluation. In order to make definitive conclusions on the consistency of the measured and evaluated excitation functions it is necessary to convolute theoretical curve with the actual neutron energy distribution. However, even

in this case, it is difficult to reveal the contribution of close narrow resonances in the excitation function. Another problem inherent in experiments on electrostatic accelerators is that monoenergetic neutrons comprise only a small fraction of all the neutron flux beyond some limited energy range (especially above 9 MeV). There is a unique opportunity to improve the quality of measured data fundamentally by use a pulse neutron source with a high intensity in the MeV energy range.

Computer simulations based on programs GEANT4 were made to estimate the parameters of the IPPE spectrometer for measurements in the n-TOF facility. One of the key parameters of the spectrometer is its time resolution. The experiment for time resolution determination was carried out by placing source of α-particles (^{237}Np) in the ionization chamber. Feature of this source is that γ-rays are accompanied with α-particles with high probability. Stilbene scintillation detector was placed near the chamber. We measured the time intervals between the time of α-particle appearance in the chamber and γ-quantum appearance in the scintillation detector. Time resolution of the chamber based on α-particles registration was 16 ns. In further calculations, this value is used as an estimate of time resolution of the spectrometer.

Dimensions of the chamber are enough to place a gaseous oxygen target weighting 1g. However, in the calculations mass of the oxygen target was 0.2g. The simulation was carried out using ^{16}O(n,α)^{13}C cross section taken from the library ENDF/B-VII.

In our evaluation we have limited the energy of neutrons to 20 MeV (time of flight of 3 μs) due to long enough process of charges collection in the ionization chamber (~ 1 μs), and need of some time to discharge after gamma flash. The convolution of obtained energy resolution with ENDF/B-VII data is shown in Figure 5. The initial data and its convolution with typical neutron flux for electrostatic generator is shown in the same figure for example. As is seen from the figure the use of IPPE digital spectrometer with 186 meter path length of n-TOF allows us to resolve resonances in the excitation function.

To determine the counts rate in the range of 16 ns, we used data provided by C.Guerrero [10]. Complete statistics in the 16 ns interval accumulated within one week on neutron energy is shown in Figure 6.

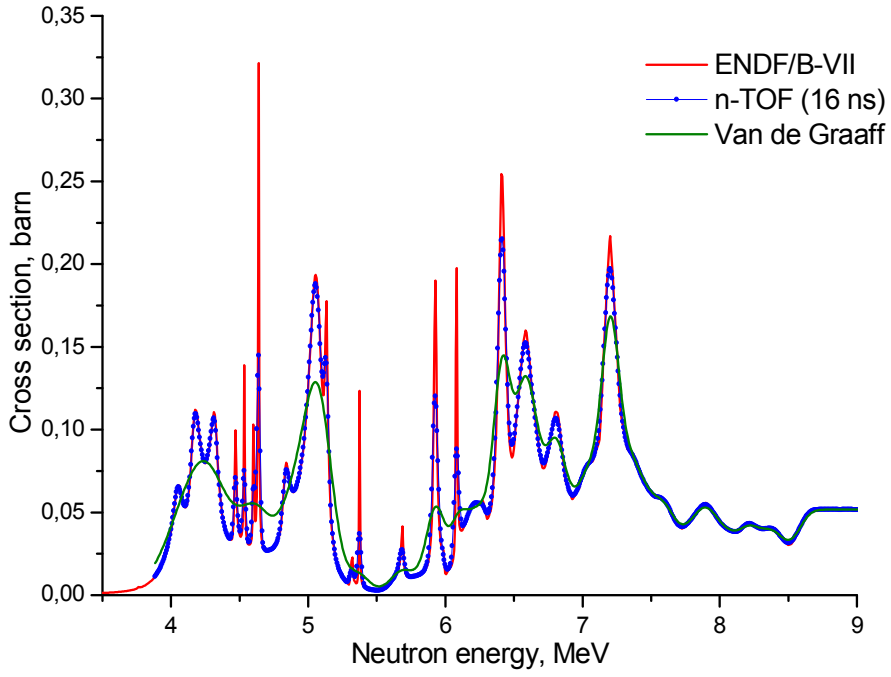

Figure 5. Shape of excitation function of 16O(n,α)13C reaction for different neutron sources.

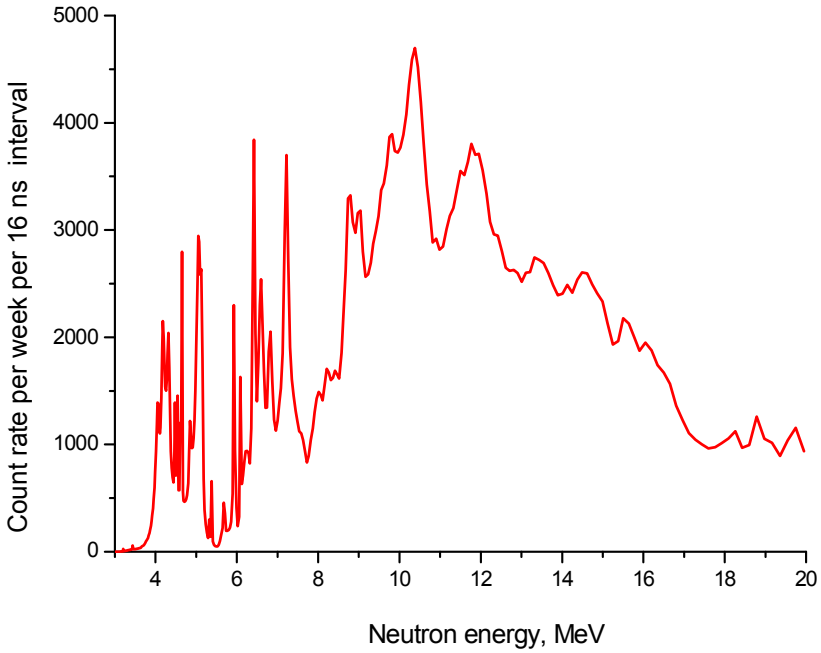

Figure 6. Count rate for oxygen gas target.

The time of flight technique will increase the accuracy of cross section measurements of the studied reactions and extend the neutron energy range.

3 OBJECTIVES AND BEAM TIME REQUEST

The goals of this proposal are:

- To produce a new version of digital charge particle spectrometer based on ionization chamber for n_TOF facility at CERN. All preparative tasks for manufacturing the spectrometer were performed in 2014.

- The test experiment at n_TOF EAR-1 can then be conducted in spring of 2015. The main experiment for $^{16}O(n,\alpha)^{13}C$ can be performed in autumn of 2015.

Summary of requested protons: 2×10^{18} protons.

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