Total neutron cross section for ^{181}Ta

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Abstract. The neutron time of flight facility nELBE, produces fast neutrons in the energy range from 0.1 MeV to 10 MeV by impinging a pulsed relativistic electron beam on a liquid lead circuit [1]. The short beam pulses ($\sim$10 ps) and a small radiator volume give an energy resolution better than 1% at 1 MeV using a short flight path of about 6 m, for neutron TOF measurements. The present neutron source provides $2 \cdot 10^4$ n/cm^{2}s at the target position using an electron charge of 77 pC and 100 kHz pulse repetition rate. This neutron intensity enables to measure neutron total cross section with a 2%–5% statistical uncertainty within a few days. In February 2008, neutron radiator, plastic detector [2] and data acquisition system were tested by measurements of the neutron total cross section for ^{181}Ta and ^{27}Al. Measurement of ^{181}Ta was chosen because lack of high quality data in an anergy region below 700 keV. The total neutron cross – section for ^{27}Al was measured as a control target, since there exists data for ^{27}Al with high resolution and low statistical error [3].

1 Introduction

Global greenhouse effect induced by CO_2 emission has become the most significant ecological problem of modern world in recent years. The main CO_2 emission comes from fossil fuel burnings (oil, coal). As a search for renewable energy sources is intensified, nuclear energy is identified as the alternative for the fossil burning processes. The main problem for the present nuclear reactors is a radioactive waste management. Future Generation IV nuclear reactors and accelerator driven systems are required to produce smaller amount of radioactive waste and to burnup existing radioactive waste.

The primary goals of the GenIV nuclear reactors are to: improve nuclear safety, improve proliferation resistance, minimize waste and natural resource utilization, decrease the cost to build and run such plants. The six most promising GenIV nuclear reactor models were selected for the further development, by the Generation IV International Forum GIF Ref. [4]. Three from the six recommended reactor models will work with fast neutrons. Furthermore, in order to increase economical efficiency the very-high-temperature reactor is supposed to work at temperatures up till 1100 °C, which makes possible hydrogen production. All other suggested models need to work in a temperature range between 500 °C and 1000 °C. One of the most critical points in early stage of GenIV reactor development is a research for support materials, these materials need to be temperature resistant and radiation damage resistant. Tantalum and its alloys are prospective supporting materials or coating materials for GenIV reactors, due to tantalum high melting point (3017 °C) and high corrosion resistance [5]. Additionally, there is a lack of high quality data below 700 keV for total neutron cross section for ^{181}Ta, therefore, we made
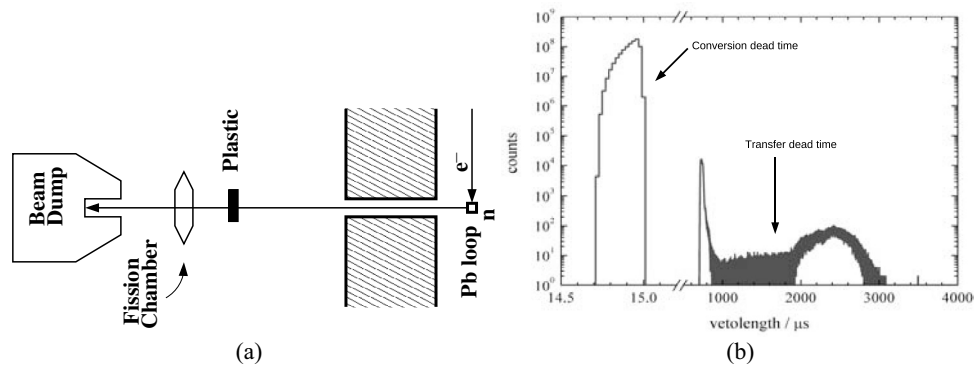
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Fig. 1. (a) A schematic view of detector setup. **(b)** A simulated *conversion* dead time and *transfer* dead time spectra.

the first test of neutron TOF facility nELBE by performing neutron transmission experiment with a [181]Ta absorber.

2 The experimental setup

The electrons are accelerated up tp 40 MeV using the superconducting Electron Linac for beams with high Brilliance and low emittance ELBE [6]. The bremsstrahlung radiation is induced by impinging a high intensity electron beam on a liquid lead loop [1], and fast neutrons are generated via the (γ,n) reactions. Owing to an electron bunch length of less than 10 ps, and small dimensions of the neutron radiator ($\sim 1\,cm^3$ Ref. [1]), we are able to achieve high time – of – flight resolution with a short flight – path of 6 m. Schematic view of experimental area and position of a detector system are given in Fig. 1(a). Neutrons are isotropically emitted from the radiator and guided by a conical collimator (entrance diameter is 2 cm, length 2.4 m, and exit diameter is 3 cm Ref. [6]). A proton – recoil plastic detector developed in house [2] was used as neutron detector. The detector is made from fast plastic – scintilation material EJ200. Originally the detector is developed for measurements of outgoing netrons for neutron inelastic experiments, therefore it is cutted in large area stripes of $1000 \times 42 \times 11\,mm^3$. For a determination of position of the proton-recoil reaction and better timing resolution, the scintillators are readout by two Hamamatsu[2] R2059-01 2 inch. photomultiplier tubes (PMTs), one at each end. The achieved time resolution (FWHM) is better than 700 ps [2]. A VMEbus-based data acquisition system is used for readout of the detector, a 32-channel QDCs (CAEN V792) integrate the analog signals of both PMTs, used to readout the plastic detector, for 500 ns to obtain the light output signal and itroduces a *conversion* dead – time in order of 7–8 μs. One multihit multievent TDC (CAEN V1190A) is used to determine timing information, it collects 32 events and introduces a *transfer* dead time larger than 700 μs, during a readout of memory. The nELBE setup is developed dominantly for neutron inelastic scattering experiments and consists of the plastic detectors for neutron detection and BaF_2 detectors for emitted γ-rays detection. Therefore QDC CAEN V792 is exchanged later on with CAEN V874B TAPS (*conversion* dead time is in order of 15 μs), the same modules are used in BaF_2 branch too. A detailed description of the data acquisition system can be found in Ref. [2].

3 Neutron time-of-flight spectra

Our proton – recoil plastic detector can detect neutrons down to a few tenths of keV with high efficiency. A neutron with energy of 10 keV will need 3 μs for a flight path of 6.5 m. The first experiment is measured with a repetition rate of 101 kHz, which ensures that no overlap between neutrons originating from subsequent electron bunches occur. A target ladder in front of the collimator can hold
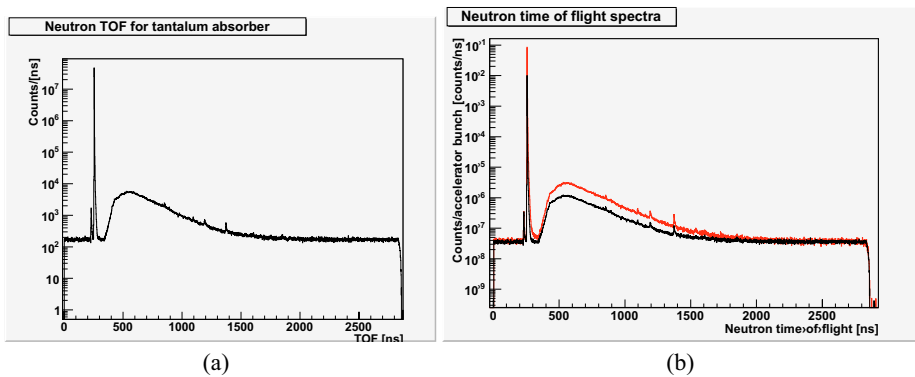
(a)   (b)

Fig. 2. (a) A typical TOF spectrum at nELBE.The spectra are completely dominated by γ – flash count rate. **(b)** A typical TOF specta at nELBE without target (red) and with traget (black). Spectra are normalized to the number of bunches when system was able to record data at given channel (ns). Please note that a background level for target – measurement and no – target measurement are the same.

5 different absorbers. For the experiment we used a 2.55 cm thick ^{181}Ta (99.988%) absorber and 4.00 cm thick ^{27}Al (100%) absorber. We accumulated spectra by changing absorbers, or without absorber, every hour. Average neutron and γ count rates for different runs showed good beam stability during the experiment.

Typical nTOF spectra for ^{181}Ta and no target are shown at Fig. 2(a). Clearly separated γ – flash and a white neutron spectra can be seen. It is clear that the γ – flash originating from radiator completely dominates the spectra. Neutrons make only 0.6% of total events for the no target measurement, 0.6% of total events for the ^{27}Al measurement and 3.2% of total events for the ^{181}Ta measurement. With an average *conversion* dead time around $8\,\mu$s, originating from QDC digitizing process, it is clear that a detection of a γ will prevent detection of a neutron in the same bunch. Therefore, every channel has different life – time, which has to be taken into proper account in the data analysis.

The data acquisition system at the time of the experiment was recording only total dead – time information. In order to determine the dead time per data acquisition channel we needed to investigate the distribution of *conversion* dead time and *transfer* dead time. For this purpose we built a setup with the existing electronic modules used in the actual double time – of – flight setup, used for the inelastic scattering experiments. We used a 3MBq ^{226}Ra radioactive source and plastic detectors together with adapted electronics in order to simulate nTOF spectra. At same time we collected information about *conversion* dead time and *transfer* dead time. Typical dead time spectra obtained with this setup are shown at Fig. 1(b). From the figure it can be seen that *conversion* dead time is in range of $15\,\mu$s, and *transfer* dead time in range $700\,\mu$s till 3 ms. The investigation of dead – time spectra showed that shape of the spectra depends on the number of detectors in system, type of electronic modules, setted thresholds for QDC and CF and more. It became clear that an accurate correction, and with that an independent cross section measurement, can not be done without recorded dead time after every each data *conversion* and data readout. Therefore, the existing DAQ system has been modified to record these dead time information too, and it will be used for future neutron transmission experiments, and it is already used for neutron inelastic scattering experiments.

4 Total neutron cross section for ^{27}Al and ^{181}Ta

As mentioned earlier, during the experiment in February 2008 we collected neutron transmission data for ^{27}Al. This measurement is done in order to compare our the first test measurement with existing high – resolution experiments (Refs. Rohr [3] and Schwartz [7]). Since neutron transmission experiments were perfomed using QDC CAEN V792 and dead – time determination experiment by using CAEN V874B TAPS modules, we a had to assume that the shape of *conversion* dead – time distribution during the transmission experiment was the same as shape of *conversion* dead time distribution
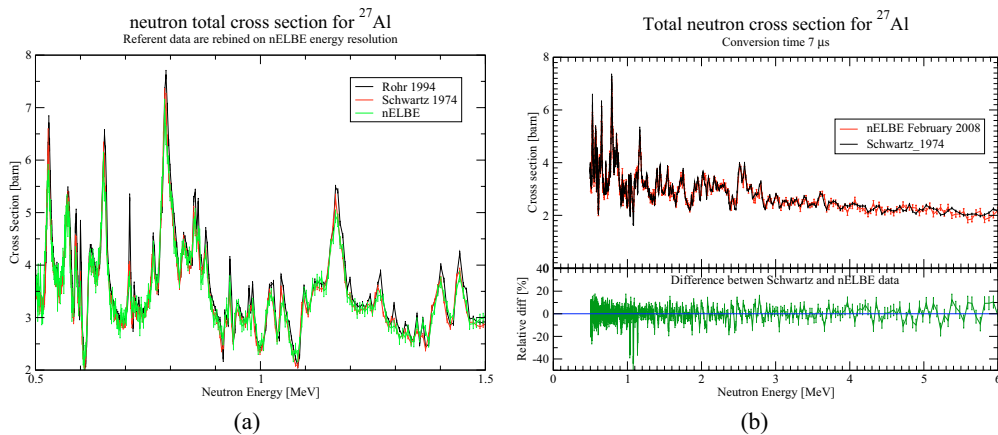
Fig. 3. (a) An hardening effect can be seen. Owning to its high time resolution, Rohr data have larger cross section at strong narow resonances. Reference data are rebined to nELBE energy resolution. **(b)** The difference between present data and Schwartz [7] data. Present data are systematically higher than Schwartz data for 1%.

obtained during dead – time determination experiment. However, the mean conversion time for these two modules differ, therefore, we will shift the mean value of the determined dead – time distribution up to a value where our measured total neutron cross section has the best agreement with published values for ^{27}Al. And after that use the adjusted *conversion* dead – time distribution with the same mean value in order to correct ^{181}Ta measurement and check agreement with published data for ^{181}Ta. Therefore, we will calibrate our tantalum data relatively to the aluminum.

Furthermore, in data analysis we need to consider that regardless to the excellent time resolution of nELBE facility (less than 1 ns), due to the flight path of 6.5 m, present energy resolution is between 0.2% and 2% in a neutron energy range between 0.2 MeV and 10 MeV. In this case our energy resolution is worse than at Geel [3] with a flight path of 388 m. This difference in energy resolution makes a problem to compare present data with Rohr *et al.* [3] because of "hardening" effect Ref. [8] in case of narrow resonances measurement. An example of the hardening effect can be seen from Fig. 3(a), ^{27}Al has strong narrow resonances, where total neutron cross section rapidly vary and can not be considered constant within our bin size. This is the case when the primary beam flux in the sample will not decrease exponential, some neutrons of certain energies will be removed more than others and a transmission experiment will provide an averaged cross section. In order to compare the present data with the previous, we first rebined Rohr [3] and Schwartz data [7] to our Energy resolution, see Fig. 3(a). From the same figure it can be seen much better agreement between present data and Schwartz data, due to the similar energy resolution, therefore from now on we will compare present data only with Schwartz data Ref. [7].

The original not gated spectra contain all events that triggered the detector system. Every of these events produced *conversion* dead time. For every time bin and for every event in that bin we randomly generate *conversion* dead time based on the *conversion* spectra from Fig. 1(b). This way we have information when the DAQ system was blocked and for how long, videlicet, we know for every time – bin when it was blocked. Consequently, for every each channel, we obtained information for how many accelerator bunches a channel was live. For the transfer dead time we assume an uniforme distribution, because transfer time is much wider (700 μs–3 ms) than an accelerator cyclus (10 μ).

As we explained before, for the transmission data analysis we needed to adjust the obtained *conversion* dead – time distribution Fig. 1(b), to a dead - time distribution corresponding to DAQ system with CAEN – V792 QDC. For that purpose we shifted the obtained *conversion* dead – time distribution for a constant value up a value what gives the best agreement with Schwartz data [7]. The best agreement is obtained for a *conversion* dead – time distribution of ∼7 μs, where an average difference between present data and Schwartz data was 1%, see Fig. 3(b). Furthermore, the value of ∼7 μs for the *conversion* dead time is in an agreement with nominal CAEN – V792 QDC *conversion* dead time between 7 μs and 8 μs.
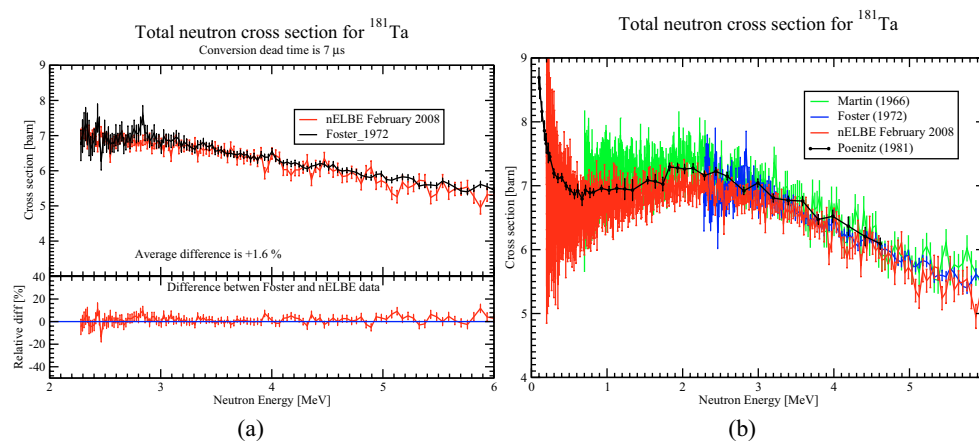
Fig. 4. (a) The difference between present data and Martin data. Present data are systematically lower than Ref. [9] for 1.6%. **(b)** Total neutron cross sesction for ^{181}Ta, present data are compared with previosly published data Refs. [9–11].

The *conversion* mean value for ^{27}Al is adjusted at 7 μs, and we used the same *conversion* - time distribution in order to analyze our ^{181}Ta data. We want to check does same parameter what corrected aluminum data can correct tantalum data. The best agreement we obtained with data published by Foster *et al.* [10], where we obtained cross section sistematically lower for 1.6 %. The present data in comparison with all previous data are given at Fig. 4(b) There are few publications for neutron total cross section at ^{181}Ta in fast energy region that we compare our results with, Refs. [9–11]. Experiments done by Martin [9] and Foster [10] have high resolution, however, there is a systematic shift, Martin's data are systematically higher than data given by Foster. Furthermore data given by Poenitz [11] has low energy resolution. We did not want to judge who from Foster or Martin has better data, we checked how much are we in agreement with every of them. After applying of the correction we found that we are in the excelent agreement with Foster data [9], see Fig. 4(a), systematically we are 1.6% lower than Martin.

5 Conclusion

The present data analysis done on a data set collected during February 2008 shown that in the case of high count rate TOF experiments it is necessary to collect and record dead – time data for each and each event in order to get correct dead time values for every channel. Therefore, if dead time per event can not be collected by a system, a minimum required information is to collect *conversion* dead – time spectra. As it is shown above this information is enough to analyze data. In our case we managed to reproduce dead – time spectra buy building up a dedicated setup. The *conversion* dead – time distribution was adjusted to the ^{27}Al data Ref. [7], by using this information we obtain total neutron cross section for ^{181}Ta in agreement with measurements Refs. [9–11]. We showed consistency of calculated cross sections for the correction for both absorbers. The data acquisition system at nELBE facility has implemented recording of dead time per events, therefore, procedure described above will not need to be perfomed. A new neutron transmission experiments for ^{181}Ta is scheduled, the future data will be an excellent cross – check for correctness of the described procedure.

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