EPJ Web of Conferences **146**, 11044 (2017) DOI: 10.1051/epjconf/201714611044
ND2016

Neutron transmission measurement for natural W at nELBE

T.-Y. Song[1,a], J.W. Kim[1], H.I. Kim[1], S.-C. Yang[1], C.W. Lee[1], Y.-O. Lee[1], A.R. Junghans[2], R. Beyer[2], T. Kögler[2], R. Schwengner[2], R. Hannaske[2], L. Wagner[2], T.P. Leinhardt[2], M.P. Takacs[2], R. Massarczyk[2], S. Müller[2], A. Ferrari[2], K. Schmidt[2], M. Röder[2], D. Bemmerer[2], T. Szücs[2], and A. Wagner[2]

[1] Korea Atomic Energy Research Institute, PO Box 105, Yuseong, Daejeon, Korea
[2] Helmholtz-Zentrum Dresden-Rossendorf, Postfach 510119, 01314 Dresden, Germany

Abstract. Korea has developed a Helium Cooled Ceramic Reflector Test Blanket Module (Ko HCCR TBM) related to the ITER project. Tungsten is considered as a prime candidate for the plasma facing materials in fusion reactors, and for the structure material of Ko HCCR TBM. KAERI (Korea Atomic Energy Research Institute) has been evaluating neutron cross sections of tungsten isotopes for neutron energy of up to 150 MeV based on nuclear reaction codes and available measurement data. New experimental data were measured at nELBE of HZDR (Helmholtz-Zentrum Dresden-Rossendorf) for a comparison with the evaluated and existing measurement data. The neutron source nELBE adopts a 40 MeV superconducting electron linac and a liquid Pb target for time-of-flight measurements. The nELBE neutron source uses no moderator and provides fast neutrons. An electron bunch length of 5 ps and a compact target provide a good neutron energy resolution with a relatively short flight length compared to other time-of-flight neutron sources. Transmission data of a natural tungsten sample were measured with a flight path length of 852.1 cm and a repetition rate of 101.56 kHz. The neutron total cross section of natural tungsten was obtained for an energy range of 100 keV to 10 MeV.

1. Introduction

The International Thermonuclear Experimental Reactor (ITER) has been developed to demonstrate the feasibility of electricity-producing fusion power stations. One of the goals of ITER is to test tritium breeding blankets which are needed for tritium production. Different types of tritium breeding blankets have been developed, and one of them is the Helium Cooled Ceramic Reflector Test Blanket Module developed by Korea (Ko HCCR TBM) [1]. Reduced Activation Ferritic/Martensitic (RAFM) steel has been developed as the structure material for the first and side walls of Ko HCCR TBM [2]. Tungsten is considered as a prime candidate of plasma facing materials in fusion reactors and an element of RAFM steel of Ko HCCR TBM.

The neutron reaction cross sections of tungsten have been updated in the recent versions of the evaluated nuclear data libraries such as ENDF/B-VII.1 [3], JEFF3.2 [4] and JENDL4.0 [5]. The Korea Atomic Energy Research Institute (KAERI) has also been evaluating the neutron total, elastic scattering, and inelastic scattering cross sections of tungsten for neutron energy of up to 150 MeV based on nuclear reaction codes and the available measurement data [6].

To verify the data evaluated by KAERI, new experimental data of tungsten total cross sections were measured at nELBE of HZDR (Helmholtz-Zentrum Dresden-Rossendorf). Since nELBE provides a facility for the cross section measurements using fast neutrons produced by a photo-neutron reaction without a moderator, the neutron total cross section of natural tungsten was measured in the energy range between 100 keV and 10 MeV. The measured data were compared with other experimental data and the data evaluated by KAERI.

2. Experimental method

ELBE is a superconducting electron accelerator that accelerates electrons to a maximum of 40 MeV with variable micropulse repetition rates. The maximum micropulse repetition rate is 13 MHz which provides a maximum average beam current of 1 mA.

A bunch length of about 5 ps and a compact liquid Pb target [7] can provide a fast neutron beam with a good energy resolution at a short time-of-flight length [8]. The neutron production rate was calculated to be about 10^{13} neutrons/s in the case of an average beam current of 1 mA at 40 MeV [9]. Figure 1 shows the neutron spectrum measured by a ^{235}U fission chamber of PTB (Physikalisch-Technische Bundesanstalt) [8]. The neutron total, inelastic scattering, and fission cross sections can be measured at nELBE.

Figure 2 shows the new nELBE neutron source and measurement hall with a neutron detector for the total cross section measurements [8]. Compared with the old facility [10], the new facility has a more spacious measurement hall (6 m × 10 m × 6 m) to reduce the background coming from scattered neutrons. Before the new facility was constructed, the total cross sections of Au and Ta had been measured at the old facility [10]. The first transmission measurement at the new facility was performed for W, Au and Fe samples with an electron beam energy of 30 MeV.

Samples were put in a sample changer located at the inner collimator wall. The empty target and three samples

[a] e-mail: tysong@kaeri.re.kr

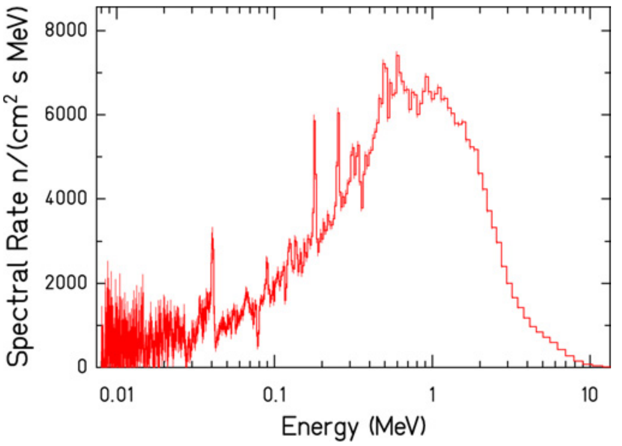

Figure 1. Neutron spectrum measured by a fission chamber from PTB [8].

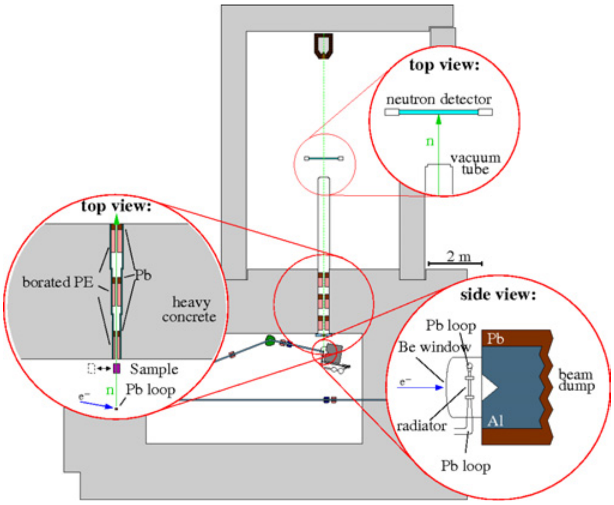

Figure 2. Experimental setup for the transmission measurement.

were moved in and out of the neutron beam with a period of 300, 600, or 900 s. A 3 cm long Pb absorber was put in front of each target to reduce gamma rays. The measurement times for the W sample and empty target were 45 h and 51 h, respectively. The electron beam current was a few hundred nA. The W sample had a cylindrical shape with a diameter of 2.53 cm and a length of 1.59 cm. The repetition rate was 101.56 kHz which corresponds to a pulse interval of 9.846 μs and the lowest neutron energy of 3.9 keV.

A plastic scintillator (Eljen EJ-200) was positioned at a time-of-flight length of 852.1 cm. The time-of-flight length was measured and adjusted by resonances of the Fe total cross sections. The size of the detector was 4.2 cm (width) ×20.0 cm (length) ×1.1 cm (thickness).

The low detection threshold of about 15 keV was adopted for neutron detection. Since the detection threshold was low, two high-gain photomultiplier tubes (Hamamatsu R2059-01) were used for a coincidence trigger. The detector was surrounded by 1 cm thick lead shielding to reduce the background. The diameters of the neutron inlet and outlet of the collimator hole were 2 cm and 3 cm respectively. The diameter of the neutron beam at the detection position was about 7.6 cm. The neutron beam-line was kept in a vacuum.

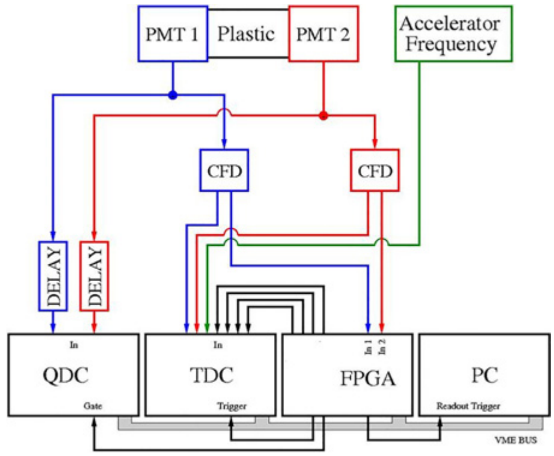

Figure 3. Schematic of the DAQ electronics for the transmission measurement.

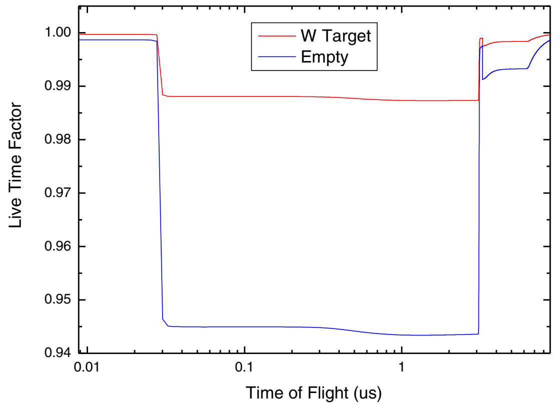

Figure 4. Time-of-flight channel dependent live time factor.

3. Data analysis

The DAQ system of the transmission measurement is shown in Fig. 3. The time-of-flight spectrum was based on the sum of the time signals of two PMTs. The information of the time-difference of two PMTs was used to remove the background. The resolution of a multi-hit multi-event TDC was upgraded to 24.4 ps/channel from 97.6 ps/channel of the previous measurement. The dead time was measured event-wise with a general purpose VME board called FPGA (CAEN V1495) [11]. The dead time was reduced compared to the DAQ system of the previous measurement [10] since the readout scheme of TDC and QDC was improved. The PMTs having a high gain (2×10^7) cause after-pulses. In order to suppress triggering on after-pulses, the FPGA trigger logic was programmed to have a 3µs dead time after each coincidence. In this way, all after-pulses from the gamma-flash in the neutron time of flight region can be effectively suppressed. To improve the suppression of after-pulses, an additional filtering was applied in the process of analysis. If a coincidence event occured within the length of the programmable time window (up to 9.5 μs before the triggering event), it was discarded as a possible after-pulse.

Figure 4 shows the measured live time correction factors, which depend on the time-of-flight channel. By the improvement of DAQ system, the live time factor was increased by a factor of 2 compared to the previous measurement [10].

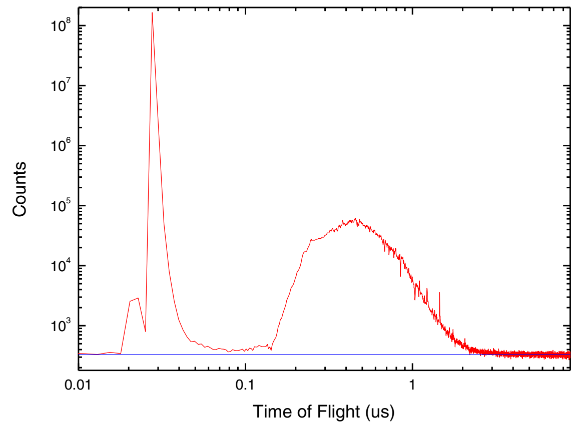

Figure 5. Time-of-flight spectrum for W sample target. Straight line is the background.

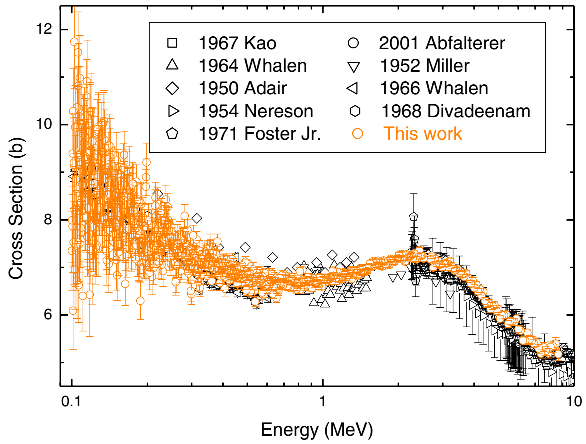

Figure 6. Measured total cross section of W (708 data points) compared with other experimental data.

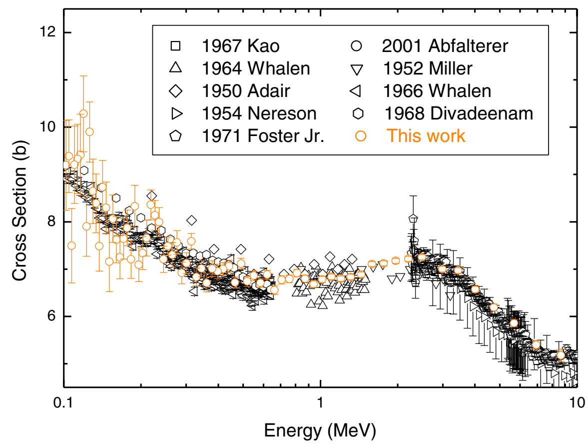

Figure 7. Measured total cross section of W (71 data points) compared with other experimental data.

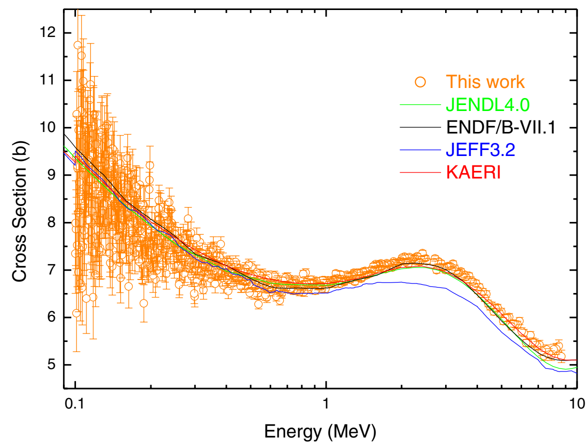

Figure 8. Measured total cross section of W compared with evaluation data (0.1 MeV <E <10 MeV).

After the time-of-flight spectrum was corrected by the live time correction factor shown in Fig. 4, channels were rebinned from 24.4 ps/bin to 2.44 ns/bin. Figure 5 shows the rebinned time-of-flight spectrum of the tungsten target case. When the TDC channels were converted into the time-of-flight, the gamma peak channel (t = 28.4 ns) was obtained by Gaussian fitting of the gamma flash distribution. After the time-of-flight spectra of the tungsten sample and empty target cases are obtained, the total cross section can be produced by Eq. (1):

$$T = R_{tungsten}/R_{empty} = exp(-nl\sigma_{tot}) \quad (1)$$

where T is the transmission ratio, R is the count rate of signal, n is the atom density of sample, l is the length of sample, and σ_{tot} is the total cross section.

The signal count can be obtained by subtracting the background from the total count. The background is constant over the entire time-of-flight range. Therefore, the average value of the time-of-flight distribution between 5.7 μs and 8.2 μs was used as the background.

4. Results and discussion

Figures 6 and 7 show the results of the total cross section measurement compared with other experimental data.

The reduced amount of data is plotted in Fig. 7 for a better comparison with other experimental data. Only statistical uncertainties are included in the plots. The statistical uncertainties are 4.9%, 1.0%, 1.1% and 2.1% at 0.2 MeV, 1.0 MeV, 5.0 MeV and 8.0 MeV respectively. The total systematic uncertainty is about 1% due to the transmission normalization, target dimension, dead time correction, and background subtraction [10]. Systematic uncertainties due to inscattering and resonant self-shielding are negligibly small [10]. The neutron energy resolution was obtained by the simulation using MCNP5 [8]. The resolutions are 1.2%, 1.2% and 2.9% at 0.2 MeV, 1.0 MeV and 5.0 MeV, respectively.

As can be seen in Fig. 7, not much data have been measured for 0.65 MeV < E < 0.8 MeV and 1.5 MeV < E < 2.3 MeV. The present measurement can provide the total cross section data for these energy ranges. The present data agree with other experimental data within the uncertainties. Figures 8 and 9 show the measured cross sections compared with the evaluation data.

The present data agree with ENDF/B-VII, JENDL4.0 and KAERI's evaluation data within the uncertainties, but are generally higher than these evaluation data in an energy range between 1 MeV and 10 MeV. In case of JEFF3.2, the evaluation data are outside of the uncertainty range of the present data in the energy greater than 1 MeV. The evaluation data of KAERI are closest to the present data for 3.5 MeV < E < 8.0 MeV, whereas ENDF/B-VII is closest for 1.8 MeV < E < 3.5 MeV.

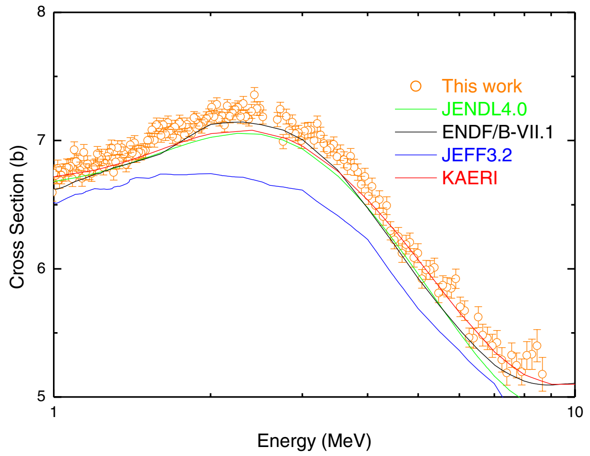

Figure 9. Measured total cross section of W compared with evaluation data (1 MeV < E < 10 MeV).

5. Conclusions

Tungsten is considered as an element constituting the structure materials of fusion reactors. Korea is one of the ITER members, and KAERI has been evaluating the neutron cross sections of tungsten for neutron energy of up to 150 MeV. New experimental data of the tungsten total cross sections were measured at nELBE in an energy range between 100 keV and 10 MeV to verify the data evaluated by KAERI. The present data agree with other experimental data within uncertainties. The present data agree with ENDF/B-VII, JENDL4.0 and KAERI's evaluation data within the uncertainties, but are generally higher than these evaluation data in an energy range between 1 MeV and 10 MeV. In case of JEFF3.2, the evaluation data are outside of the uncertainty range of the present data in the energy greater than 1 MeV. The present data agree especially well with the evaluation data of KAERI for 3.5 MeV < E < 8.0 MeV.

References

[1] D.W. Lee et al., Trans. Korean Nucl. Soc., Gyeongju, Korea, Oct. 25-26 (2012)
[2] K.I. Shin et al., Trans. Korean Nucl. Soc., Gyeongju, Korea, Oct. 25-26 (2012)
[3] M.B. Chadwick et al., Nucl. Data Sheets **112**, 2887 (2011)
[4] http://wwwndc.jaea.go.jp/jendl/j40/
[5] http://www.oecd-nea.org/dbforms/data/eva/evatapes/jeff_32/
[6] H.I. Kim et al., Nucl. Data Sheets **118**, 151 (2014)
[7] E. Altstadt et al., Ann. Nucl. Energy **34**, 36 (2007)
[8] A.R. Junghans et al., Nucl. Data Sheets **119**, 349 (2014)
[9] J. Klug et al., Nucl. Inst. Meth. A **577**, 641 (2007)
[10] R. Hannaske et al., Eur. Phys. J. A **49**, 137 (2013)
[11] http://www.caen.it/