

AVERAGE RESONANT CAPTURE CROSS SECTION OF ^{181}Ta AT 59 keV FILTERED NEUTRON BEAM

V. A. Libman, O. O. Gritzay, V. F. Razbudey

Institute for Nuclear Research, National Academy of Sciences of Ukraine, Kyiv, Ukraine

Radiative capture cross section for tantalum was measured at filtered neutron beam with average energy about 59 keV. Activation method was used. Filter was mostly formed by sulfur, vanadium and nickel-58. The obtained value of capture cross section is 0.480 ± 0.041 barn. The result is in agreement with data of other authors averaged on our filtered neutron spectrum as well as with the averaged on the same spectrum point-wise capture cross section from the evaluated nuclear data libraries. The correction analysis is also presented.

1. Introduction

This work is sequential in the series of experiments for determination of the tantalum capture cross section, using filtered neutron beams. Foregoing series was started in 2004 in neutron physics department of KINR NASU. The first result – capture cross section for $^{181}\text{Ta}(n, \gamma)^{182}\text{Ta}$ reaction at 2 keV neutron energy – was presented at NPAE-2006 [2]. The experimental geometry, methodical approach and corrections were described in detail in that article, than we concentrate our attention on differences between present and previous experiments.

This experiment also was done at the 2nd experimental horizontal channel of the Kiev Research Reactor.

Remind that the Request List [1] requires the value of neutron capture cross section for tantalum with the accuracy at least 10 % for energy range from 0.025 eV to 1 MeV.

2. Review of the similar projects and results

Before us, only several laboratories in the world had measured the radiation neutron cross section on tantalum nuclei. Measurements were done in different times, by the different methods, and using the different equipment. Here, we will regard the results that were done at the energy ranges close to ours:

- One of such experiments was done at the FEI, Obninsk, Russia by M. V. Bokhovko, V. N. Kononov, N. S. Rabotnov et al. in 1996 [5]. Neutrons were taken from the $^7\text{Li}(p, n)^7\text{Be}$ reaction. The impulse Van de Graff accelerator EG-1 was used. For the neutron energy selection, the 1.2 m TOF method was applied. Neutrons in the 22 - 450 keV energy range were detected by Li-6 glass detector and NaJ(Tl) detectors.

- The project like the above was done in 1982 at the Karlsruhe, Germany by G.Reffo, F.Fabbri, K. Wisshak et al. [6]. Neutrons were also taken from the $^7\text{Li}(p, n)^7\text{Be}$ reaction. The impulse 3 MeV Van de Graff accelerator was used. The cross section for the $^{181}\text{Ta}(n, \gamma)^{182}\text{Ta}$ was defined in the 11.8 - 60.2 keV energy range. Neutron energy selection was done by the 90 m TOF method. Neutrons were detected by Moxon - Rae detector.

- The project similar the first was also performed at the FEI, Obninsk, Russia by V. N. Kononov, B. D. Jurlov, E. D. Poletaev et al. in 1977 [7]. The same facility and detectors were used; the neutron energy range was in the limits 5 - 350 keV.

- One more experiment was performed also in Obninsk, Russia at the FEI by the research group of V. N. Kononov, Ju. Ja. Stavisskij, V. E. Kolesov et al. in 1965 [8]. The Cockroft - Walton pulsed accelerator of protons with maximum energy of protons 1.2 MeV was used. The neutron energy range – from 33 to 156 keV.

- In addition, other experiment was made by J. A. Miskel, K. V. Marsh, M. Lindner et al. at LLNL, USA in 1962 [9]. Used facility is the impulse Van de Graff accelerator. The activation method was used. The neutron source – $^7\text{Li}(p, n)^7\text{Be}$ reaction. The neutron energy range – from 32 to 247 keV.

The other projects were done outside of our energy range.

3. Experiment procedure

For determination of the neutron capture cross section for tantalic nuclei, we choose the activation method again. The reason of our choice described in [2] where was shown clear that this method is the best for average resonant capture (ARC) cross section measurements.

The experiment scheme is also the same as in [2] and shown in Fig. 1. Remind some methodical details, directed on improvement of measurement accuracy and on reducing of some correction factors:

- Neutron beam collimation was such that the whole sample was in a beam, but the beam did not touch the shield constructions (28 mm sample diameter, 32 mm beam diameter, and 51 mm inner shield diameter).

- The irradiated samples were protected from background neutrons of the reactor hall. Neither neutrons, scattered on constructive elements, nor neutrons from other experimental installations could not get the samples and be captured.

- Permanent monitoring of neutron flux during all irradiation time was realized by neutron spectrometer with ^3He -counter as a detector. Flux was controlled every hour during 3 000 s. The ^3He -peak area was then used as weigh function for averaging of irradiation flux.

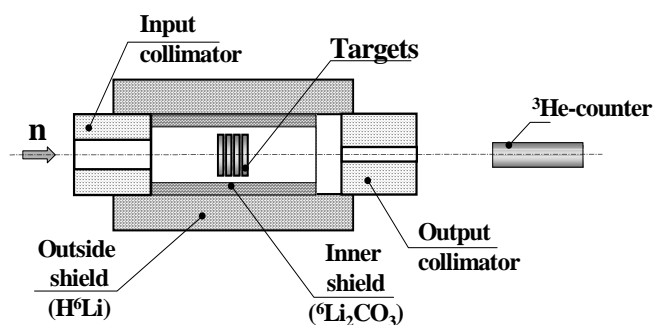


Fig. 1. Scheme of tantalum targets irradiation.

The main part of the filtered neutron spectrum is the first line in Fig. 2, the energy range is $53.1 \div 61.2$ keV. The energy distribution center of this line is at 58.89 keV; its relative intensity is 94.36 % of the entire neutron flux. Besides, in the spectrum (see Fig. 2) there are other impurity lines: namely 3 groups of lines in energy range $1 \div 40$ keV (0.01 %), $70 \div 230$ keV (0.11 %) and $235 \div 1570$ keV (5.52 %).

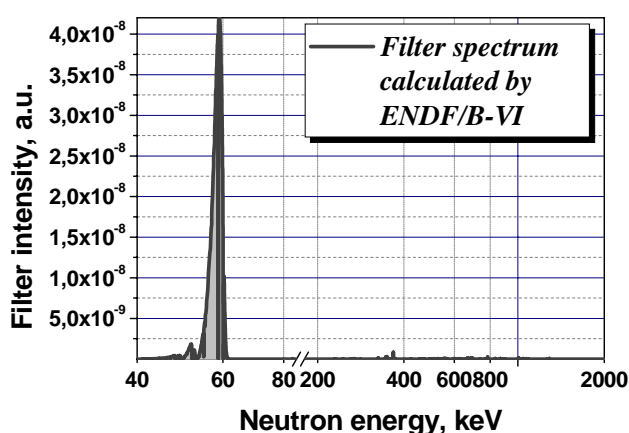


Fig. 2. Calculated spectrum of the filtered neutron beam.

targets was done at the 2nd horizontal channel of the reactor. The targets were set up as a single pile from eight disks, dispose one by one. Exposing the eight disks, not just one, allows us to take into account an effect of a resonance self-shielding in tantalum. Activation of tantalum samples was done in two stages during 62 and 84 hours. Then the targets were removed to the clean zone for the further measurements.

4. Measurement of the activated Ta samples

The radioactive isotope ^{182}Ta received due to $^{181}\text{Ta}(n, \gamma)^{182}\text{Ta}$ reaction decays into the tungsten (^{182}W) with the 114.74 days half-life.

Gamma spectra of the irradiated samples were measured by the same gamma-spectrometer with Ge(Li)-detector as [2].

The measured sample was located at the 5 cm distance above of the detector cap. The measurements were carried out by series. Each series consists of 16 measurements. Each of eight samples was measured twice: «face» down and «face» up. A «face» is the sample side, turned to incident neutrons during irradiation. Before and after each measurement series the background spectrum was controlled. Acquisition time for each spectrum was 50 000 s. The spectra were measured in a clean zone (gamma background was less than 0.07 mR/h).

5. Capture cross section determination

The defining of capture cross section was done in compliance with the same technique as [2] namely in two steps. At first of all gamma ray spectra were processed and then cross section values for $^{181}\text{Ta}(n, \gamma)^{182}\text{Ta}$ reaction were computed using obtained peak areas.

6. Processing of the obtained spectra

The main requirement for gamma-spectra processing code is the most possible correctness in definition of areas under FAPs. After the testing of several codes, we selected the WinSpectrum v.2.0 code. Advantages of this software were described in [2].

Gamma ray spectrometers as placed at the 2nd horizontal channel as placed in the clean zone were calibrated using etalon sources from the standard set OSGI-3-2 following the same procedure as [2].

▪ The use of sample pile gave us an opportunity to take into account a neutron resonance self-shielding in the sample.

The tantalum targets were made of natural tantalum foil and had the 28.0 mm diameter and 0.1 mm thickness. A pile of eight targets was used. Average weight of one target was 0.851 g. The abundance of the ^{181}Ta in natural tantalum is 99.988 %. The same as at 2 keV filter B-10 target was used [2].

The spectrum of neutrons was formed by filter consist of mostly vanadium, sulfur and ^{58}Ni . The neutron spectrum after the filter was calculated using the ENDF/B-VI data using the Filter-5 code (Fig. 2).

This filter was used to determine the cross section of the $^{181}\text{Ta}(n, \gamma)^{182}\text{Ta}$ reaction in the $54.8 \div 60.1$ keV energy range. Taking into account the contribution of the impurity lines in the capture cross section will be presented later during discussion of the corrections (see part 7).

Neutron flux definition procedure was the same as at 2 keV filter [2], excepting the value of the $^{10}\text{B}(n, \alpha)^7\text{Li}^*$ reaction cross section (2.35 b), and neutron flux monitoring measurement (3 000 s during each hour of exposition).

3.1. Activation of the ^{181}Ta samples

The cross section of the $^{181}\text{Ta}(n, \gamma)^{182}\text{Ta}$ reaction was determined by the activation method, using the natural tantalum targets. The irradiation of the tantalum

For determination of sample activities, eleven gamma lines of tungsten-182 were selected:

- seven “soft” lines with energies 100, 152, 156, 179, 222, 229 and 264 keV and
- four “hard” lines with energies 1121, 1189, 1221 and 1231 keV.

All selected FAP’s were corrected on self-absorption of gamma-rays in sample before sample activity determining. Correction was done as described in details below (see part 7 Corrections).

The activity of each sample was determined independently using each gamma line the same as [2]. Then all obtained activities were recalculated to the finish of irradiation time, and were averaged for each sample.

The “observed” cross section values for $^{181}\text{Ta}(n, \gamma)^{182}\text{Ta}$ reaction for each orientation of each sample were calculated the same way as [2]. Then the calculated cross sections were averaged over all 11 gamma-lines for each sample to obtain the value of capture cross section for each sample.

Further, we extrapolate the “observed” cross sections to zero thickness of tantalum to find the real value of capture cross section. In details see below in part 7 Corrections and in [2].

7. Corrections

The “observed” cross sections, calculated at the previous processing step, were corrected over several effects: self-absorption of gamma-rays (similarly [2]), invest of impurity lines of the filtered neutron beam, backward neutron scattering and resonance self-shielding of neutrons.

- *Impurity lines of the filtered neutron beam.* A share of the main neutron line in the total spectrum is 94.36 %. There are also the other impurity lines in the spectrum: 3 groups of lines in energy ranges $1 \div 40$ keV (0.01 %), $70 \div 230$ keV (0.11 %) and $235 \div 1570$ keV (5.52 %) (see Fig. 2). Therefore, the obtained cross section for tantalum responds to the entire filter spectrum. To estimate a share of cross section from the impure lines, we performed a numerical simulation. We took the cross section point-wise data for the $^{181}\text{Ta}(n, \gamma)^{182}\text{Ta}$ reaction from the evaluated nuclear data libraries (BROND-2, CENDL-2, ENDF/B-VI and JEF-3.0) and averaged them over total neutron spectrum after the filter and over the main filter line. The averaging was done using the PREPRO2002 package. The averaging over the whole neutron energy range (0.2 - 1570 keV, see Fig. 2) and over the main energy neutron line (53.1 \div 61.2 keV) gave us the following results (Table 1).

Table 1. Results of numerical simulation to take into account the contribution of the impurity lines

Library	Averaging over the whole spectrum, b	Averaging over the main line, b	Part of impurity lines, %
BROND-2	0.4463	0.4624	3.61
CENDL-2	0.4302	0.4424	2.84
ENDF/B-VI	0.4302	0.4424	2.84
JEF-3.0	0.4722	0.4888	3.51
Average	0.445	0.459	3.20

The contribution into capture cross section from impurity lines was calculated as an excess the cross section averaged on the main line over the cross section, averaged on whole spectrum. This excess we considered as additional systematic inaccuracy of cross section.

- *Correctives for backward scattering* were computed by program package MCNP-4C for real irradiation conditions (see Fig. 1). The obtained values are about 1.7 % for 59 keV filter.

- *Resonance self-shielding of neutrons* in the tantalic samples. The neutron beam energy is about 59 keV. In this energy range, tantalum has tens resonance, and thus, so-called “observed cross section” depends on the sample thickness. To take into account this effect, we set up more than one target, but a pile of samples, to see the decreasing of neutron intensity in resonances, and consider the resonance self-shielding effect. Depending on the position of the sample in the pile, decreasing of the “observed” cross section was about 0.4, 1.8, 2.2, 3.0, 3.3, 5.1, 6.3 and 7.1 %, respectively. The real value of ARC cross section we received by extrapolation the “observed” cross section to zero thickness of sample.

8. Discussion

We defined the cross section of the $^{181}\text{Ta}(n, \gamma)^{182}\text{Ta}$ reaction for the energy range of our filter (53.1 \div 61.2 keV) and compared it with the similar experimental data of other authors. For comparison we used M. V. Bokhovko [5], G. Reffo [6], V. N. Kononov [7, 8] and J. A. Miskel [9] data, averaging their results over our neutron spectrum (Fig. 3). These averaged data are presented in Table 2.

We also compared our experimental result with the similar values from the evaluated nuclear data libraries BROND-2, CENDL-2, ENDF/B-VI and JEF-3.0, averaging them on the neutron energy distribution of our filter (0.2 - 1570 keV neutron energy range). All these data are presented in Table 2.

As one can see, our value $\sigma_{\text{exp}} = 0.480 \pm 0.041$ b lays to close to the averaged value taken as from libraries $\sigma_{\text{Lib}} = 0.459$ b as with experimental data [5 - 9].

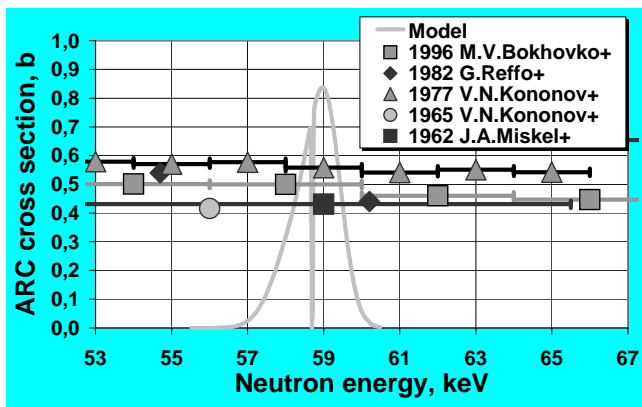


Fig. 3. Other authors data, averaged on neutron line shape of our filter.

Table 2. Comparison of averaged experimental data [5 - 9] and averaged libraries data with our experimental result

Author or library	Cross section, b	Uncertainty
M. V. Bokhovko [5]	0.500	0.025
G. Reffo [6]	0.440	0.050
V. N. Kononov [7]	0.558	0.047
V. N. Kononov [8]	0.416	0.042
J. A. Miskel [9]	0.431	0.043
BROND-2	0.4624	
CENDL-2	0.4424	
ENDF/B-VI	0.4424	
JEF-3.0	0.4888	
Lib. Aver.	0.459	0.023
Experiment	0.480	0.041

8. Conclusions

As a result of this work, we obtained the capture cross section of the $^{181}\text{Ta}(n, \gamma)^{182}\text{Ta}$ reaction. The cross section is averaged over the neutron spectrum of the filtered beam with the average energy 59 keV. The cross section of the $^{181}\text{Ta}(n, \gamma)^{182}\text{Ta}$ reaction is 0.480 ± 0.041 b. The final inaccuracy is 8.6 %, less than required by Request List [1].

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