

CAPTURE CROSS SECTION OF $^{181}\text{Ta}(n, \gamma)^{182}\text{Ta}$ REACTION AT 2 keV FILTERED NEUTRON BEAM

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Radiative capture cross section for tantalum was measured at filtered neutron beam with average energy about 2 keV. Activation method was used. Filter was mostly formed by scandium and ^{60}Ni . The obtained value of capture cross section is 6.54 ± 0.36 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

Values of the cross sections for the interaction of quasi-monochromatic neutrons with different nuclei are of some interest for calculation and estimation of cross sections, and for improvement of our nuclear structure knowledge. Isotope ^{181}Ta is a heavy deformed nucleus. It is located nearby the *s*-strength function maximum and *p*-strength function minimum. The evaluated nuclear data libraries BROND-2, CENDL-2, ENDF/B-VI, JENDL-3.3 and JEF-3, contain the data for neutron capture cross section of tantalum, but the discrepancies between the experimental data, used for the library estimations, in the at the 0.5 ÷ 3.5 keV energy range, reach as much as 10 - 20 %.

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

That is why we planned and then performed the series of experiments for determination of the tantalum capture cross section, using filtered neutron beams. All our available filters are in the energy range from 2 to 149 keV. In this paper we present the first results of this series: the capture cross section of tantalum for neutrons with the average energy 1.97 keV. This experiment was done at the 2nd experimental horizontal channel of the Kiev Research Reactor during last 2 years.

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 by German scientists K. Wisshak, F. Voss, and F. Kappler in 1990 [2]. Neutrons were taken from the $^7\text{Li}(p, n)^7\text{Be}$ reaction. The impulse Van de Graff generator with the 3 MeV maximum energy was used. For the neutron energy selection, the 1 m TOF method was applied. Neutrons in the 3 - 200 keV energy range were detected by the 4π Ba-F detector.

- The project like the above, was done in 1983 at the Oak Ridge National Laboratory by the research group led by R. L. Macklin's [3]. The cross section for the $^{181}\text{Ta}(n, \gamma)^{182}\text{Ta}$ was defined in the 2.6 - 1900 keV energy range. The TOF method with the 40 m flight path at the linear electron accelerator was used.

- The similar project was also performed by M.C. Moxon and E.R. Rae in Karlsruhe, Germany, at the linear accelerator in 1968 [4]. Neutron energy selection was done by the 90 m TOF method. Neutrons were detected by Moxon-Rae detector (MOXR); the neutron energy range was in the limits 0.1 - 20 keV.

- One more experiment was performed in Dubna at JINR by the research group of V.A. Konks, Yu. P. Popov and F. L. Shapiro in 1964 [5]. The neutron energy range – from 0.3 eV to 45 keV.

The other projects were done for either thermal neutrons or for the energy range above 200 keV.

3. Experiment procedure

3.1. Choice of the method

For determination of the neutron capture cross section for tantalic nuclei in the reaction $^{181}\text{Ta}(n, \gamma)^{182}\text{Ta}$ the following methods can be used:

Method of cross sections difference. The difference between $\sigma_{n,\text{tot}}$ (total cross section of interaction of

neutrons with nuclei) and $\sigma_{n,sc}$ (scattering cross section) is measured. In our neutron energy range (0.24 - 3.01 keV) we can neglect all other reactions except for the scattering and radiation neutron capture; but errors of the obtained value would not satisfy the Request List requirements through small precision of the scattering cross section.

Direct measurement of capture cross section, i.e., an immediate measurement of a number of newly created ^{182}Ta nuclei during the target irradiation. The main disadvantage of this method is a necessity to know the absolute intensities of gamma-transitions, normalized on a single neutron capture, or the assurance that all gamma-transitions are included. But the ^{182}Ta nucleus has such complicated and uncompleted decay scheme of capture states that even for thermal neutrons [6, 7] many gamma-transition intensities are undefined. That is, to determine capture cross section with a desired precision is problematic as well by this method.

Activation method, when gamma-transition intensities of a daughter nucleus are measured. This method is convenient by the following:

- First, the decay scheme of a daughter nucleus (in our case ^{182}W) is much simple and more investigated, so that there is no need to consider all gamma-transitions, because the intensity of each transition is normalized by a single act of decay and is known with good accuracy.

- Second, the capture of neutrons, in the case of filtered neutron beam, is realized in resonance region, this is, so called, average resonance capture (ARC). So, the level population and the gamma transition intensities depend on energy of neutron line and its width. At the same time, the daughter nucleus ^{182}Ta disintegration does not depend on its formation method, that is, neither from energy, nor from width of neutron filter line and this essentially simplifies our task.

- Third, the target activity can be measured after irradiation in so-called “clean” zone, where the background conditions are much better.

That is, this method gives us a possibility to get a larger reliability of the results and a better statistical precision. That is why the activation method was chosen by us for determination of the capture cross section.

3.2. Scheme of Experiment

The experiment scheme is shown in Fig. 1. Here a few remarks are given on methodical details, especially some peculiarities, directed on improvement of measurement accuracy and on reducing of some correction factors:

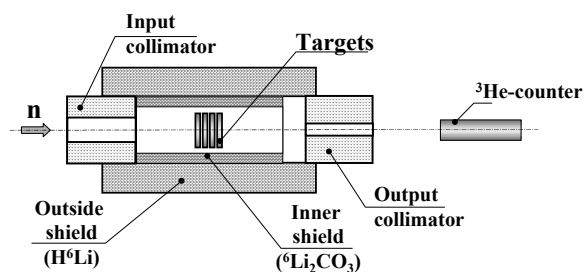


Fig. 1. Scheme of tantalum targets irradiation.

with ^3He -counter as a detector. Flux controls every hour during 1000 s. The ^3He -peak area was then used as weigh function for averaging of irradiation flux.

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

The irradiation process of the tantalum targets is shown on the scheme (Fig. 1). The neutron beam (**n**) was directed by the entry collimator (**Input collimator**) onto the pile of tantalum targets (**Targets**) in such way that all targets were inside of the beam; the outgoing collimator system (**Output collimator**) focused a neutron beam to the monitoring spectrometer ^3He counter.

3.3. The ^{181}Ta and ^{10}B targets

The tantalum targets were made of natural tantalum foil and had the 28.0 mm diameter and 0.2 mm thickness. A pile of four targets was used. The abundance of the ^{181}Ta in natural tantalum is 99.988 %.

The B-10 target used to define the neutron flux value, was made of the boric powder, enriched by ^{10}B isotope. The target is placed inside the container with 28 mm diameter. The container was made of CAB-1T

aluminum alloy; the front and back walls were of 0.2 and 0.3 mm thicknesses, respectively. The thickness of a boric sample was 1 mm. Ratio of boron – 97.1 %; enrichment by ^{10}B – 85 %. The detailed characteristics of the targets are given in Table 1.

Table 1. Target parameters

Targets	Material	Diameter, mm	Thickness, mm	Mass, g	Enrichment, %	Notes
B28	Boron	28.0	1	0.6732	85	Passport 22-76
Ta30	Tantalum	– " –	0.2	1.9275	99.988	Natural
Ta31	– " –	– " –	– " –	1.8878	– " –	– " –
Ta32	– " –	– " –	– " –	1.9302	– " –	– " –
Ta34	– " –	– " –	– " –	1.8961	– " –	– " –

3.4. The neutron spectrum

The spectrum of neutrons was formed by filter consist of mostly scandium and ^{60}Ni . The neutron spectrum after the filter was calculated using the JENDL-3.3 data using the Filter-5 code (Fig. 2).

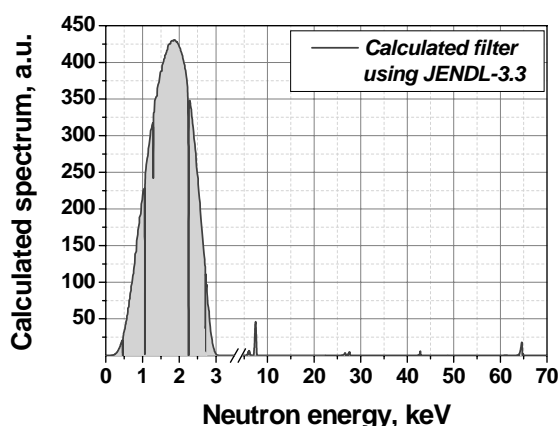


Fig. 2. Calculated spectrum of the filtered neutron beam.

The main part of the filtered neutron spectrum is the first line in Fig. 2, the energy range is 0.24 - 3.0 keV. The energy distribution center of this line is at 1.97 keV; its relative intensity is 95.47 % of the entire neutron flux. Besides, in the spectrum (see Fig. 2) there are other impurity lines: 6.2 + 7.5 keV (2.93 %), 27 keV (0.39 %), 43 keV (0.14 %), and a group of lines in the 48 - 66 keV range (1.08 %).

This filter was used to determine the cross section of the $^{181}\text{Ta}(n, \gamma)^{182}\text{Ta}$ reaction in the 0.24 - 3.0 keV energy range (0.46 - 2.90 keV at the 0.95 magnitude). 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).

3.5. Definition of the filtered neutron flux and its monitoring

To obtain the neutron radiation capture cross section for tantalum nucleus, it is necessary to know the neutron flux, that pass the interference filter and falls to the target. We resolved this task by two ways:

- definition of the neutron flux before and after exposing;
- flux monitoring during irradiation of targets.

The neutron flux at the target place was defined using the $^{10}\text{B}(n, \alpha\gamma)^7\text{Li}^*$ reaction. The neutron flux was defined by area of the full absorption peak of gamma rays with 478 keV energy (the excited state of ^7Li). Cross section of the $^{10}\text{B}(n, \alpha\gamma)^7\text{Li}^*$ reaction for neutrons that passed the filter, was calculated as an average of the point-wise cross sections, taken from the evaluated nuclear data libraries CENDL-2, ENDF/B-VI, JENDL-3.3 and JEF-3.0. An average was done over the shape of neutron filtered beam. The calculation was done by the PREPRO2002 software package. The received value of the cross section for $^{10}\text{B}(n, \alpha\gamma)^7\text{Li}^*$ reaction for our filter was found as 13.61 barn.

Simultaneously with the irradiation of the tantalum targets, the monitoring of the neutron flux has been done by the neutron spectrometer with ^3He -counter. These measurements have been carried out during 1000 s after each 2600 s of the total exposition. The received squares under the ^3He peaks were used as the weigh functions to determine the neutron flux, in which the pile of the tantalum targets has been placed during the exposition. The neutron flux, taken from the measurements due to the boric target before and after exposition, was averaged by this weigh function; and the average neutron flux have been determine during total time of the exposition.

3.6. 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 targets was done at the 2nd horizontal channel of the

reactor. The targets (see Table 1) were set up as a single pile from four disks, dispose one by one. Exposing the four 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 during 3.5 days (84 hours), then the targets were removed to the clean zone for the further measurements.

In order to protect the targets from the background neutrons, thermalized in the reactor hall, the pile was exposed inside the system of the protective screens (see Fig. 1). The external screen was made of paraffin with lithium hydride (${}^6\text{LiH}$), and the internal one – of lithium carbonate (${}^6\text{Li}_2\text{CO}_3$). Lithium, enriched by ${}^6\text{Li}$ to 85 % was used in both systems.

4. Measurement of the activated Ta samples

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

Gamma spectra of the irradiated samples were measured by gamma-spectrometer with Ge(Li)-detector. The spectrometer parameters were as follow:

- detector type – DGDK-45A;
- energy resolution – 3.4 keV at 1332 keV gamma-line;
- lead shield with 15 cm thickness.

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 8 measurements. In series each of four 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 10 000 s. The spectra were measured in a clean zone (gamma background was less then 0.07 mR/h).

5. Capture cross section determination

The obtaining of capture cross section was done in two steps: at first all gamma ray spectra were processed and then capture cross section values for ${}^{181}\text{Ta}(n, \gamma){}^{182}\text{Ta}$ reaction were computed using obtained peak areas. All measured experimental gamma ray spectra were treated in accordance with the following algorithm:

Step 1 – gamma spectra processing

- Preliminary analyses of spectra to select gamma lines for capture cross section computation.
- Finding of the full absorption peak (FAP) areas for selected gamma lines.
- Taking into account the self-absorption of gamma rays in samples and correction of FAP areas.
- Calculation of each sample activity using all selected lines.
- Obtained activities of tantalum samples were added to the finish of irradiation time.

Step 2 – obtaining of capture cross section value

- Computation of the “observed” cross section values for both orientation of each sample using the set of selected lines.
- Averaging of computed cross sections over all selected gamma-lines for each sample and receiving the values of “observed” cross section for each sample.
- Extrapolation of “observed” capture cross sections to zero thickness to find the real cross section value.

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.1.5 code. This software works in an interactive mode, i.e., it allows visually to control all stages of processing and to choose limits in FWHM, shape of a background distribution under peak, position of a peak center, parameters of both left and right peak “tails”, etc. This code was created and it continues to develop by M. V. Strilchuk (KINR, Nuclear Structure Department).

6.1. Calibration of the spectrometers

Gamma ray spectrometer with two Ge(Li)-detectors DGDK-32B was placed at the 2nd horizontal channel and was used to determine the incident neutron flux onto the targets. The spectrometer was calibrated on

energy and efficiency using the etalon sources ^{133}Ba and ^{152}Eu from the SOSGI-M standard set. The gamma-rays of these sources cover the energy range from 53 to 1408 keV. The efficiency of spectrometers was approximated with the Origin 6.1 software package using the empirical dependence

$$\varepsilon_{\gamma}^i(E_{\gamma}^i) = \exp\left\{a + b \cdot \ln(E_{\gamma}^i)\right\},$$

where $\varepsilon_{\gamma}^i(E_{\gamma}^i)$ – absolute efficiency as an energy function, a , b – dimensionless coefficients, E_{γ}^i – energy of the i^{th} gamma-line.

The $^{10}\text{B}(n, \alpha\gamma)^7\text{Li}^*$ reaction produced gamma-rays with energy 478 keV. The value of the absolute efficiency of gamma registration was $3.08(17) \cdot 10^{-5}$.

Gamma-ray spectrometer with the Ge(Li)-detector DGDK-45A was used for measuring the activated targets in the clean zone. Calibration of the gamma-spectrometer on energy and efficiency was done using etalon sources from the standard set OSGI-3-2. The following sources were used: ^{133}Ba , ^{60}Co , ^{137}Cs , ^{152}Eu , ^{228}Th , which covered the energy range from 53 to 2614 keV. The efficiency curve was approximated by the empirical formula using the code MicroCal Origin 6.1. This formula looks like this:

$$\varepsilon_{\gamma}^i(E_{\gamma}^i) = \exp\left\{a + b \cdot \ln(E_{\gamma}^i) + \frac{c}{(E_{\gamma}^i)^3}\right\},$$

where $\varepsilon_{\gamma}^i(E_{\gamma}^i)$ – absolute efficiency as an energy function, a , b , c – dimensionless coefficients, E_{γ}^i – energy of the i^{th} gamma-line.

Approximation error was $\delta\varepsilon_{\gamma} = 4.2\%$.

The measurements of irradiated samples were carried out both at working and stopped reactor, so background spectra were measured in two conditions, respectively. Then from the tantalic spectra the respective background spectra were subtracted, channel by channel.

6.2. Spectra processing

After energy calibration, background subtraction and identification of the energies the spectra were decoded; i.e., all the gamma rays from tungsten isotope ^{182}W and any others in spectra were identified. For determination of sample activities, nine gamma lines of tungsten-182 were selected:

- five “soft” lines with energies 152, 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. Then all obtained activities were recalculated to the finish of irradiation time, and were averaged for each sample. The activity of each sample at the moment finish of irradiation time, calculated for the i^{th} gamma-line, was defined with the formula

$$A_{t_0}^i = \frac{S_{FAP}^i}{I_{\gamma}^i \cdot \varepsilon_{\gamma}^i \cdot t_{acq}} \cdot e^{-\lambda \cdot t_D},$$

where $A_{t_0}^i$ – activity of the target obtained for the i^{th} gamma-line, Bq; S_{FAP}^i – area of the full absorption peak of the i^{th} gamma-line, events; I_{γ}^i – absolute intensity for the i^{th} gamma-line, γ /decay; ε_{γ}^i – absolute efficiency for the i^{th} gamma-line; t_{acq} – time of target measurement, s; t_D – delay time, i.e., time from the finish of irradiation to the beginning of measurement, s; λ – decay constant for ^{182}Ta , s^{-1} .

6.3. Capture cross section value determining

The “observed” cross section values for $^{181}\text{Ta}(n, \gamma)^{182}\text{Ta}$ reaction for each orientation of each sample were calculated by following formula:

$$\sigma_{ij}^{ob} = \frac{A_{ij}}{\Phi \cdot n_i^n \cdot (1 - e^{-\lambda \cdot t_e})},$$

where: A_{ij} – activity by j lines for i sample, reduced to the end of irradiation; Φ – neutron flux at the 1st sample, $\text{n/s}\cdot\text{cm}^2$; n_i^n – number of nuclei in i^{th} sample, nuc/b ; λ – decay constant, s^{-1} ; t_e – time of spectrum acquisition, s; σ_{ij}^{ob} – “observed” capture cross section determined with j lines for i sample, b.

Then the calculated cross sections were averaged over all 9 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**.

7. Corrections

The “observed” cross sections, calculated at the previous processing step, were corrected over several effects that have to be taken into account.

Self-absorption of gamma-rays. As the tantalic sample has a non-zero thickness the obtained activity has to be corrected on self-absorption of gamma-rays. To consider this effect, both the tabled and experimentally obtained attenuation coefficients of gamma-rays were used. An adjustment for self-absorption of gamma-rays was carried out with the formula:

$$k_{at}^i = \frac{\mu^i x}{1 - e^{-\mu^i x}},$$

where k_{at}^i – self-absorption coefficient for gamma-rays of the i^{th} gamma-line in the sample; μ^i – mass self-absorption coefficient of the i^{th} gamma-line, cm^2/g ; x – thickness of the target, g/cm^2 .

Impurity lines of the filtered neutron beam. A share of the main neutron line in the total spectrum is 95.47 %. There are also the other impurity lines in the spectrum: 6.2 + 7.5 keV (2.93 %), 27 keV (0.39 %), 43 keV (0.14 %), and a group of lines in the 48 - 66 keV range (1.08 %) (see Fig. 2). So, 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, JENDL-3.3 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 (0.24 - 71 keV, see Fig. 2) and over the main energy neutron line (0.24-3.01 keV) gave us the following results (Table 2).

Table 2. 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	6.060	6.292	3.8
CENDL-2	5.935	6.162	3.8
ENDF/B-VI	6.597	6.836	3.6
JENDL-3.3	5.935	6.162	3.8
Average	6.132	6.363	3.78

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.

Resonance self-shielding of neutrons in the tantalic samples. The neutron beam energy is about 2 keV. In this energy range, tantalum has tens resonances, 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 2.4, 7.3, 12, and 17 % respectively. The real value of cross section we received by extrapolation the “observed” cross section to zero thickness of sample.

The correction for scattered neutrons didn’t apply as:

- the neutron energy decreasing as a result of scattering for tantalic target is very small (about 43 eV) and it lays inside the width of neutron line (FWHM of neutron line is 1.4 keV);
- the neutrons, which leave the sample after scattering and hit into the shield, have to be moderated by paraffin and then to be captured by ^6Li ; so these neutrons have no chance to return into the samples and be captured by them.

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 (0.24 - 3.0 keV) and compared it with the similar experimental data of other authors. For comparison we used only M. C. Moxon [4] and V. A. Konks [5] data, averaging their results over our neutron spectrum (Fig. 3). These averaged data are presented in Table 3.

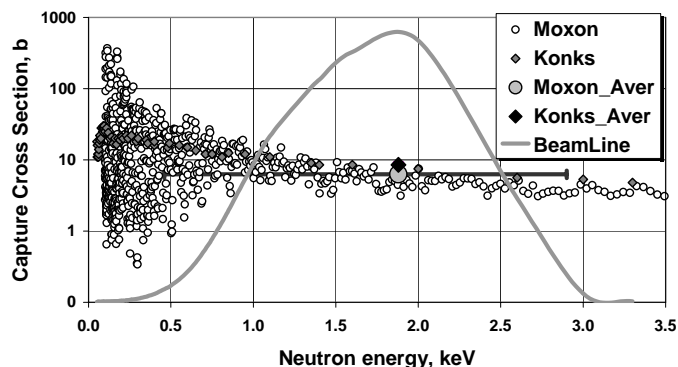


Fig. 3. Moxon [4] and Konks [5] data, averaged on neutron line shape of our filter.

We also compared our experimental result with the similar values from the evaluated nuclear data libraries BROND-2, CENDL-2, ENDF/B-VI, JENDL-3.3 and JEF-3.0, averaging them on the neutron energy distribution of our filter (0.203 - 70.81 keV neutron energy range). All these data are presented in Table 3.

As one can see from Table 3, our value $\sigma_{\text{exp}} = 6.54 \pm 0.36$ b lays to close to the averaged value taken from ENDF/B-VI $\sigma_{\text{ENDF}} = 6.60$ b.

Table 3. Comparison of averaged data [4, 5] and averaging libraries data with our experimental result

Author or library	Moxon [4]	Konks [5]	BROND-2	CENDL-2	ENDF/B-VI	JENDL-3.3	JEF-3.0	This work
Cross section, b	6.26 ± 0.26	8.52 ± 0.81	6.06	5.94	6.60	5.94	5.94	6.54 ± 0.36

9. Conclusions

As a result of our 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 1.97 keV. The cross section of the $^{181}\text{Ta}(n, \gamma)^{182}\text{Ta}$ reaction is 6.54 ± 0.36 b. The final inaccuracy is 5.4 %, less than required by Request List [1].

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СЕЧЕНИЕ РАДИАЦИОННОГО ЗАХВАТА РЕАКЦИИ $^{181}\text{Ta}(n, \gamma)^{182}\text{Ta}$ НА ФИЛЬТРОВАННОМ ПУЧКЕ НЕЙТРОНОВ С ЭНЕРГИЕЙ 2 кэВ

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Сечение радиационного захвата нейтронов танталом измерено на пучке фильтрованных нейтронов со средней энергией около 2 кэВ. Использован метод активации. Фильтр сформирован преимущественно из скандия и никеля-60. Полученное значение сечения захвата 6.54 ± 0.36 барн. Результат согласуется как с усредненными по нашему нейтронному спектру данными других авторов, так и с аналогично усредненными поточечными данными из библиотек оцененных ядерных данных. Приводится анализ учтенных поправок.

ПЕРЕРІЗ РАДІАЦІЙНОГО ЗАХОПЛЕННЯ РЕАКЦІЇ $^{181}\text{Ta}(n, \gamma)^{182}\text{Ta}$ НА ФІЛЬТРОВАНОМУ ПУЧКУ НЕЙТРОНІВ З ЕНЕРГІЄЮ 2 кеВ

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Переріз радіаційного захоплення нейтронів танталом було виміряно на пучку фільтрованих нейтронів із середньою енергією біля 2 кеВ. Використано метод активації. Фільтр сформовано переважно із скандію та нікелю-60. Одержано значення перерізу, що становить 6.54 ± 0.36 барн. Цей результат узгоджується як із усередненими по нашому нейтронному спектру даними інших авторів, так і з аналогічно усередненими поточковими значеннями перерізу з бібліотек оцінених ядерних даних. Наведено аналіз врахованих поправок.