Karlsruhe Institute of Technology

# Evaluated data file for neutron irradiation of Ta-181 at energies up to 200 MeV

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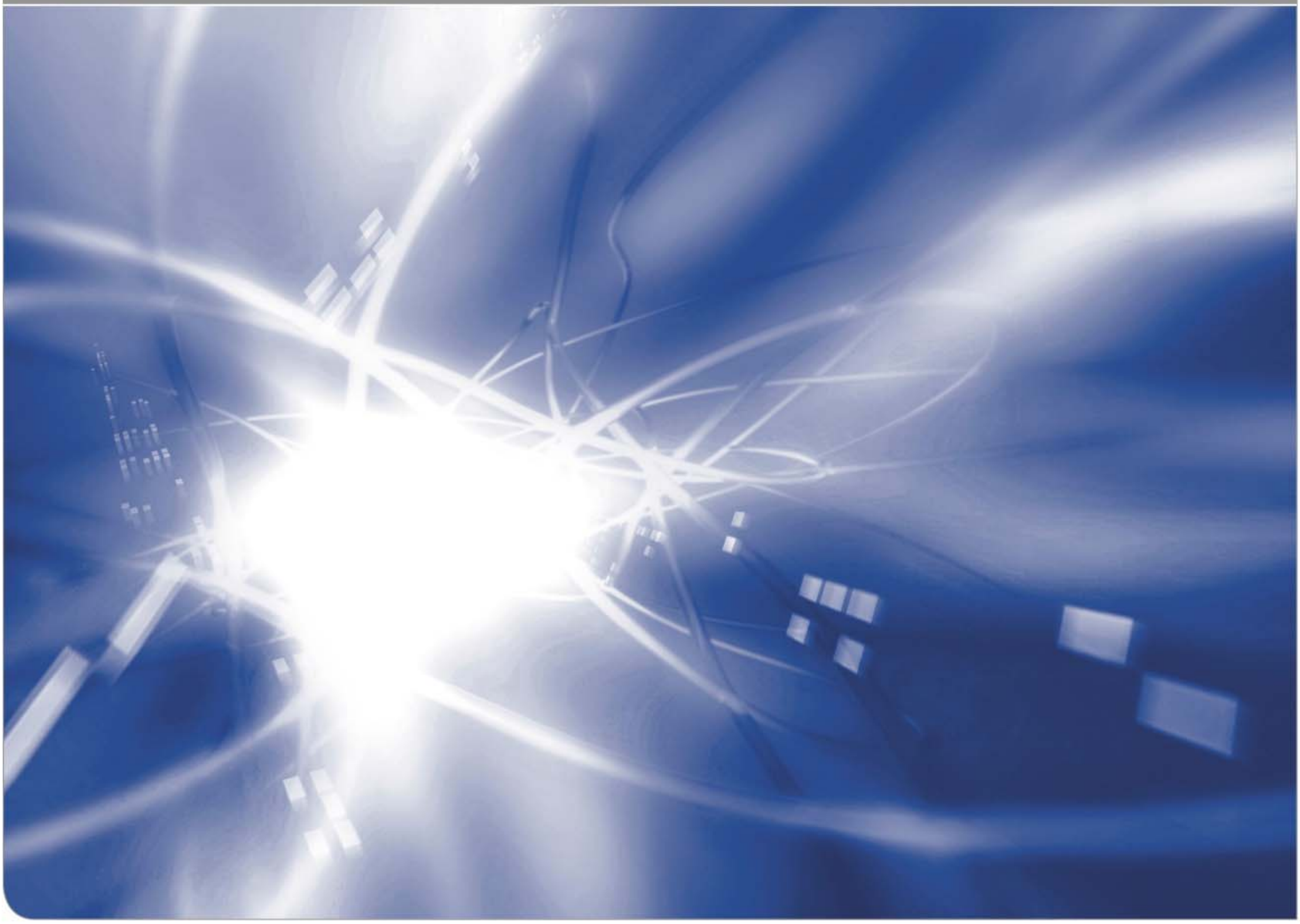

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## Abstract

New evaluated data file for $^{181}Ta$ irradiated with neutrons at energies up to 200 MeV has been prepared.

The data evaluation has been done using the results of calculations, measured data, systematics predictions, and covariance information. Calculations have been performed using a special version of the TALYS code implementing the geometry dependent hybrid model and models for the non-equilibrium light cluster emission.

The TEFAL code and the FOX code from the BEKED package have been used for the formatting of the data.

CONTENTS

## 1. INTRODUCTION

The evaluated data file for $^{181}$Ta obtained at KIT fifteen years ago [1,2] is now part of the JEFF-3.3 library [3]. Since then, the data have been used many times and successfully for various applications and research.

In recent years, new measurements have appeared and calculation methods have been improved.

The aim of this work is to obtain new evaluated data for $^{181}$Ta, which reflect the progress in the development of calculation methods and the new experimental information obtained. This work is a continuation of the data evaluation performed in Refs.[4-6].

The calculation of the values to be included in the “general purpose” file was carried out using a TALYS-G code [7-9], which is the special version of the TALYS code [10,11] providing calculations with geometry dependent hybrid model [12,13].

Section 2 briefly describes the evaluation procedure concerning nuclear model calculations, the use of experimental data, the combination of results of calculations and measurements, and the recording the evaluated data file. Section 3 discusses the evaluated data for $^{181}$Ta.

## 2. BRIEF DESCRIPTION OF EVALUATION PROCEDURE

The preparation of the evaluated data file included calculations using theoretical models, analysis of measurements, data evaluation combining experimental and calculated data, and recording the data in ENDF-6 format.

Details can be found in Refs.[4,5].

### *2.1 Nuclear model calculations*

The geometry dependent hybrid model [12] and models for the non-equilibrium cluster emission [7,13] have been implemented in the TALYS-1.95 code [11], similar to how it was done for the TALYS-1.7 code [8]. The brief discussion is presented in Ref.[4]. The obtained version of the TALYS code [9,11] was used for calculations.

The parameters of optical model parameters from Ref.[14] were slightly modified after the search of optimal parameters providing the best agreement between calculated angular distributions and experimental data.

The covariance matrices for cross-sections have been calculated applying the Monte Carlo method from Ref.[15].

### *2.2 Processing of calculated data*

Recording of preliminary data file in the ENDF-6 format has been performed using the TEFAL-1.92 code [16].

### *2.3 Use of experimental data*

Experimental data from Refs.[17-201] have been analysed and in most cases been applied for the preparation of evaluated data file for $^{181}$Ta. The citations are based on EXFOR records [202]. The detected errors or inconsistencies in measured data have been reported to IAEA Nuclear data Section. In some cases, errors of measured data were updated or specified using available information.

### *2.4 Use of systematics*

The systematics from Ref.[203] has been used to correct calculated (n,t) reaction cross-section.

The data obtained in Ref.[204] have been applied for the improvement of calculated total light particle, p, d, t, $^{3}$He, α-particle- production cross-sections. Data [204] are results of the evaluation of the atomic mass number dependency of corresponding cross sections at neutron incident energy 96 MeV, similar to the usual evaluation of the energy dependence of reaction cross sections for a fixed nucleus. See details in Refs.[204,205]. Data [204] are shown in figures as "*reference data*".

### *2.5 Evaluation*

The evaluation of the data has consisted of the appropriate combination of experimental or systematic data and calculation results using covariance information.

The code from Ref.[206] implementing the generalized least-squares method was applied for numerical calculations.

### *2.6 Recording data in ENDF-6 format*

Evaluated data have been properly integrated in the final data file using the FOX code from the BEKED package [207]. More details are in Ref.[4].

Obtained data file has been tested using codes from Ref.[208] and the COVEIG code [209], and processed using the NJOY [210] code.

## 3. DATA OBTAINED

The Section describes the evaluated data obtained for the $^{181}$Ta and presents the comparison with measured data, the systematics, and data from various libraries and results of calculations.

The following data libraries are used in this report: EAF-2010 [211], JENDL-4.0 [212], JENDL-4/HE [213], JENDL/AD-2017 [214], JENDL-HE [215], ENDF/B-VIII [216], TENDL-2019 [217,218], and JEFF-3.3 [3].

### *3.1 Total cross-section*

The total cross-section for $^{181}$Ta obtained in this work, data from different libraries, and measured data are shown in Fig.1 at the energies above the resonance region up to 200 MeV and in Fig.2 at neutron energies from 10 to 200 MeV. For better view, the TENDL-2019 data and some experimental data are shown after averaging over selected energy groups.

The calculated cross-sections together with measured data provided the basis for the evaluation are shown in Figs. A1-A3 in the Appendix.

### *3.2 Cross-section and angular distributions for elastic scattering*

The evaluated elastic scattering cross-section is shown in Figs.3,4. The data from different libraries differ markedly from each other, which is especially evident in Fig.4.

The elastic scattering angular distributions, $d\sigma/d\Omega$, are shown in Figs.5-11.

Other figures of interest, Figs.A4,A5, are given in the Appendix.

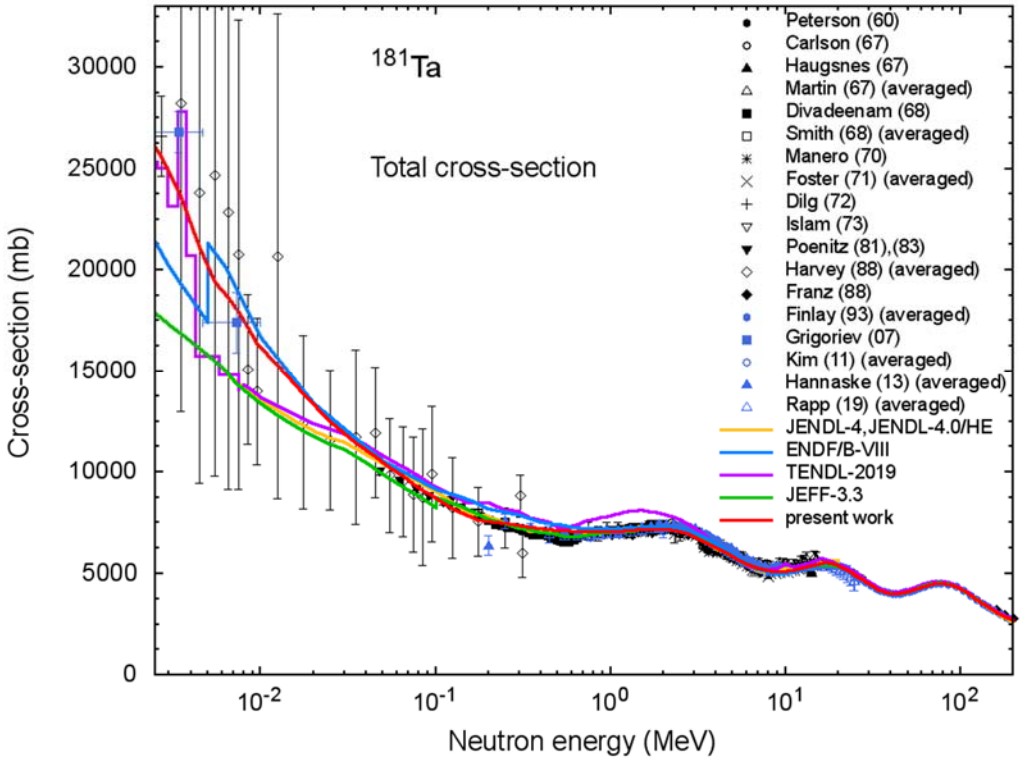


Fig.1 Total cross-section for $^{181}$Ta at neutron incident energies from $2.5x10^{-3}$ MeV to 200 MeV obtained in the present work, measured data, and data taken from different libraries. See explanations in the text.

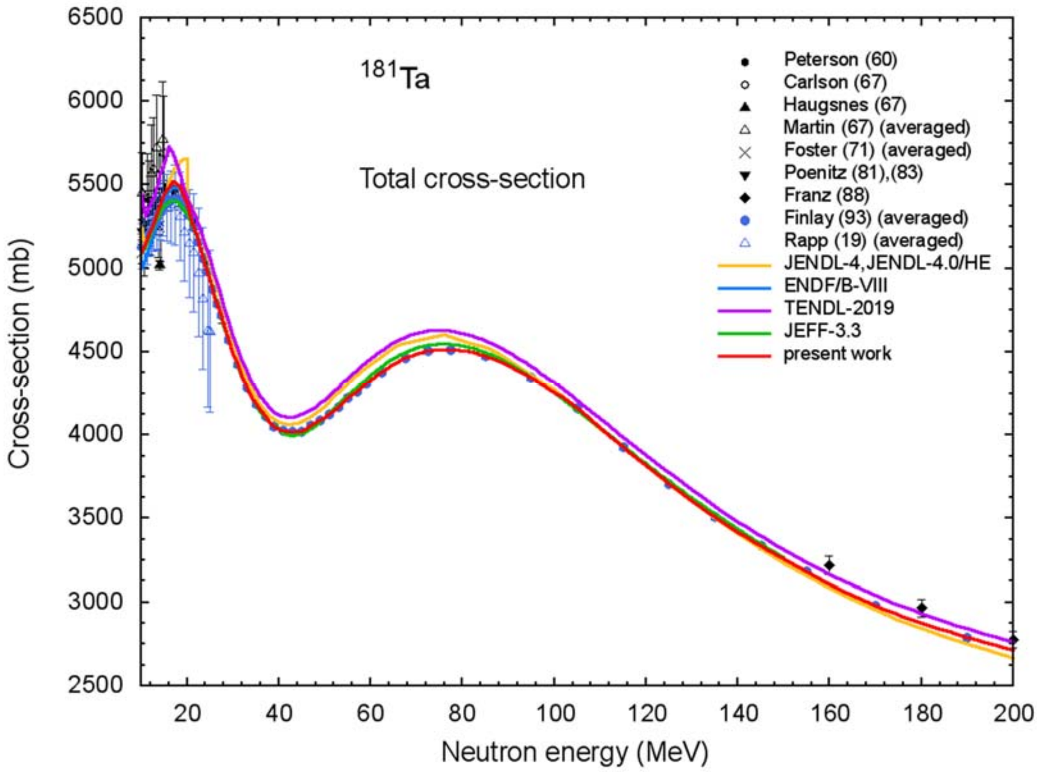


Fig.2 Total reaction cross-section for neutron irradiation of $^{181}$Ta at neutron incident energies from 10 to 200 MeV. See comments to Fig.1

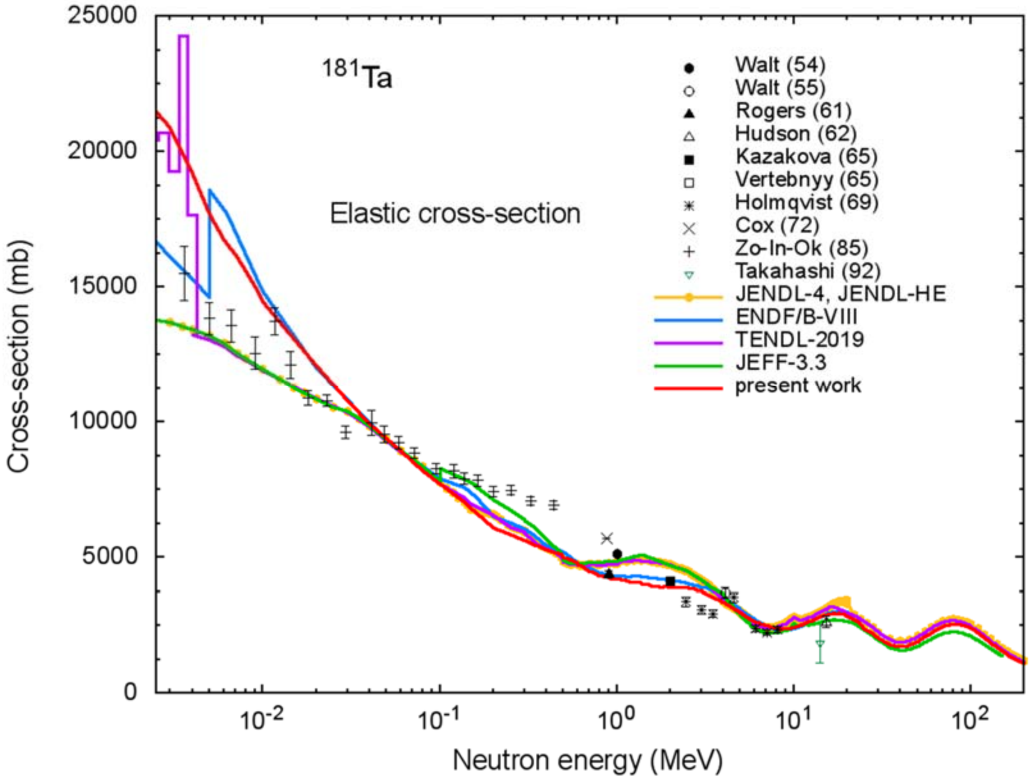


Fig.3 Cross-section for elastic neutron scattering for $^{181}$Ta evaluated in the present work, measured data, and data taken from different libraries at neutron incident energies from 2.5x10$^{-3}$ MeV to 200 MeV.

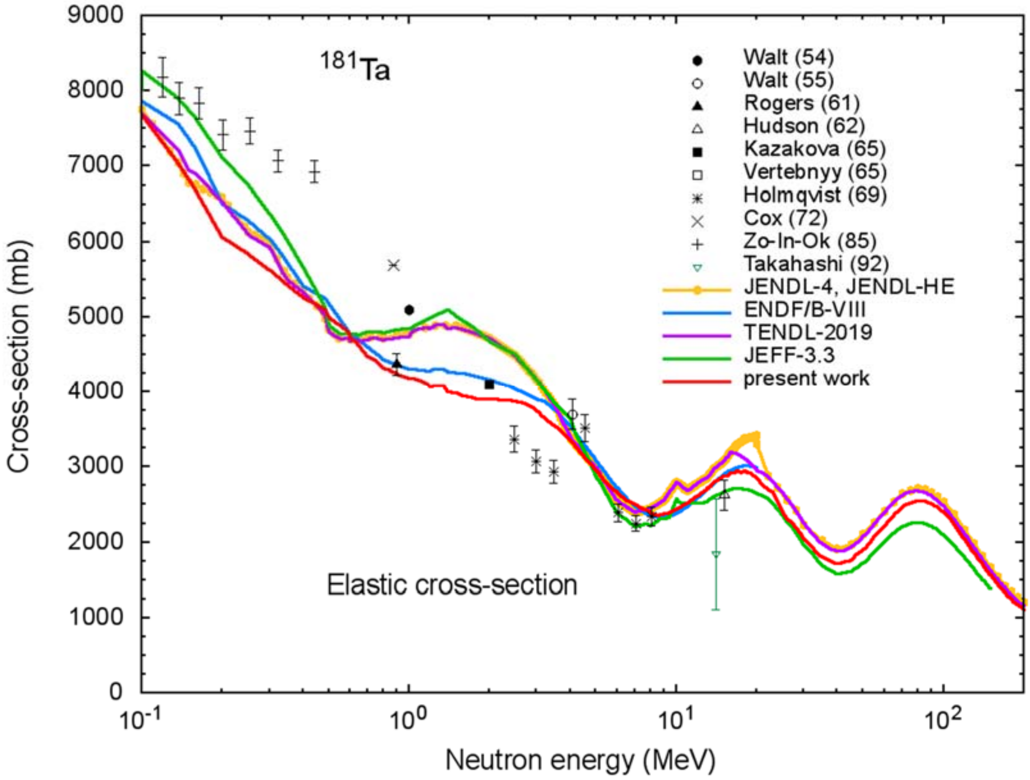


Fig.4 Cross-section for elastic neutron scattering for $^{181}$Ta at neutron incident energies from 0.1 to 200 MeV. See comments to Fig.3.

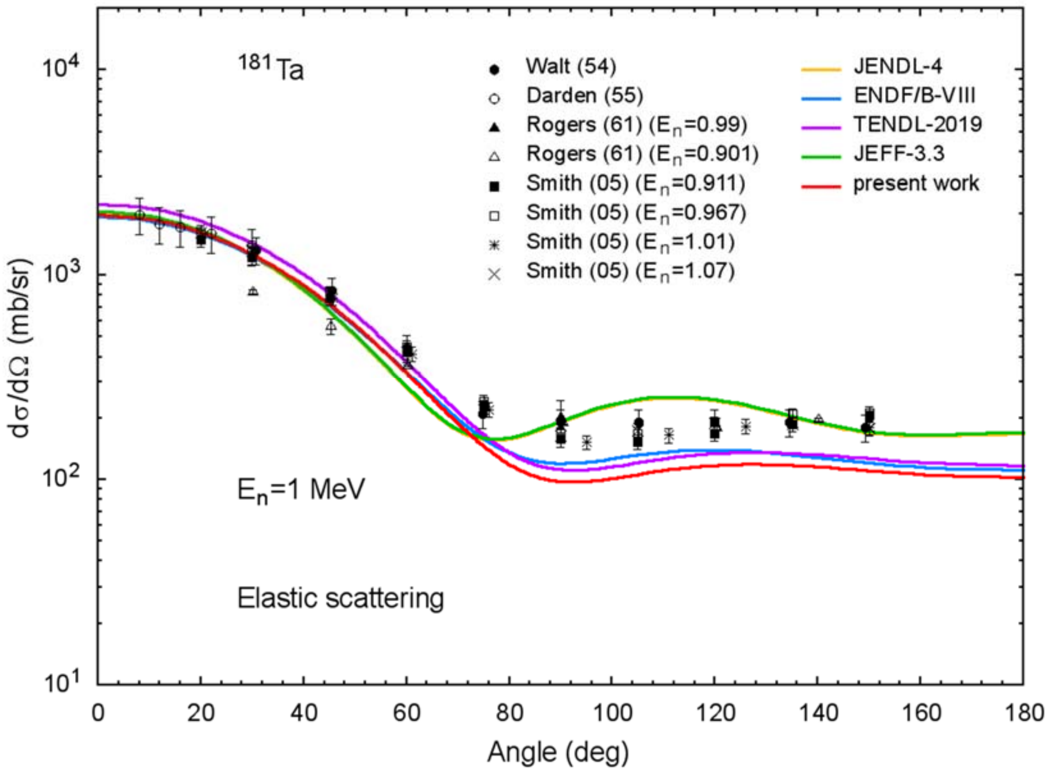


Fig.5 Elastic scattering angular distribution of neutrons for $^{181}$Ta at the incident energy 1 MeV.

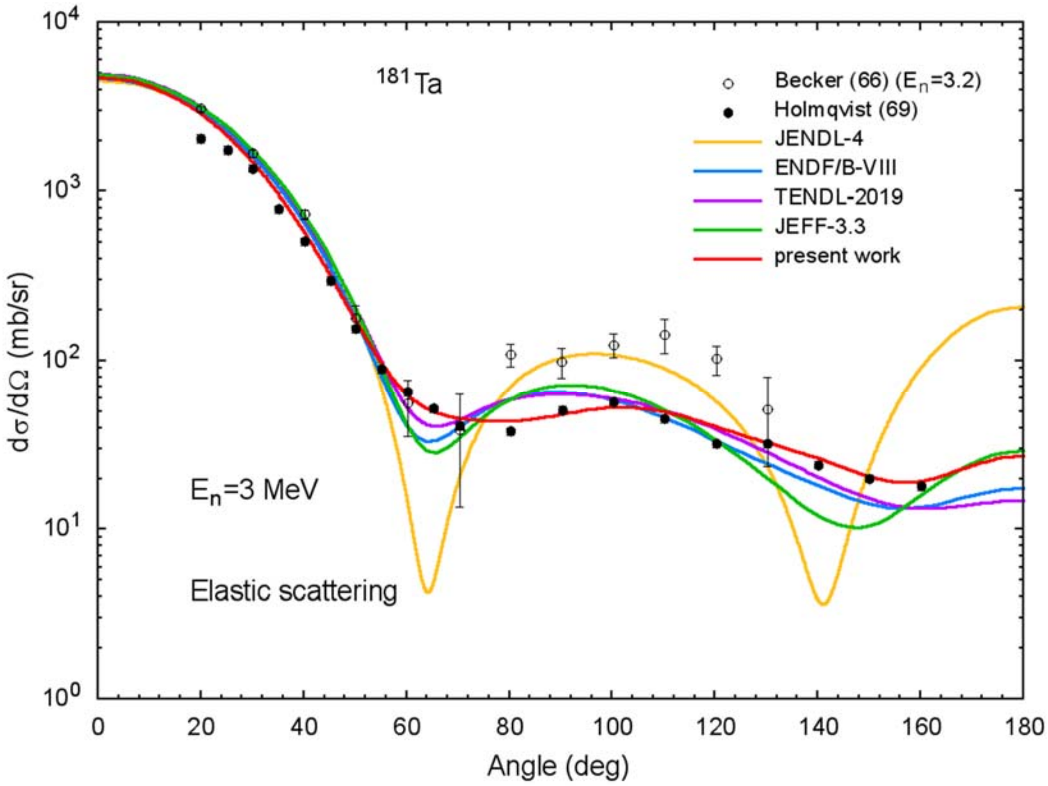


Fig.6 Elastic scattering angular distribution of neutrons for $^{181}$Ta at the incident energy 3 MeV.

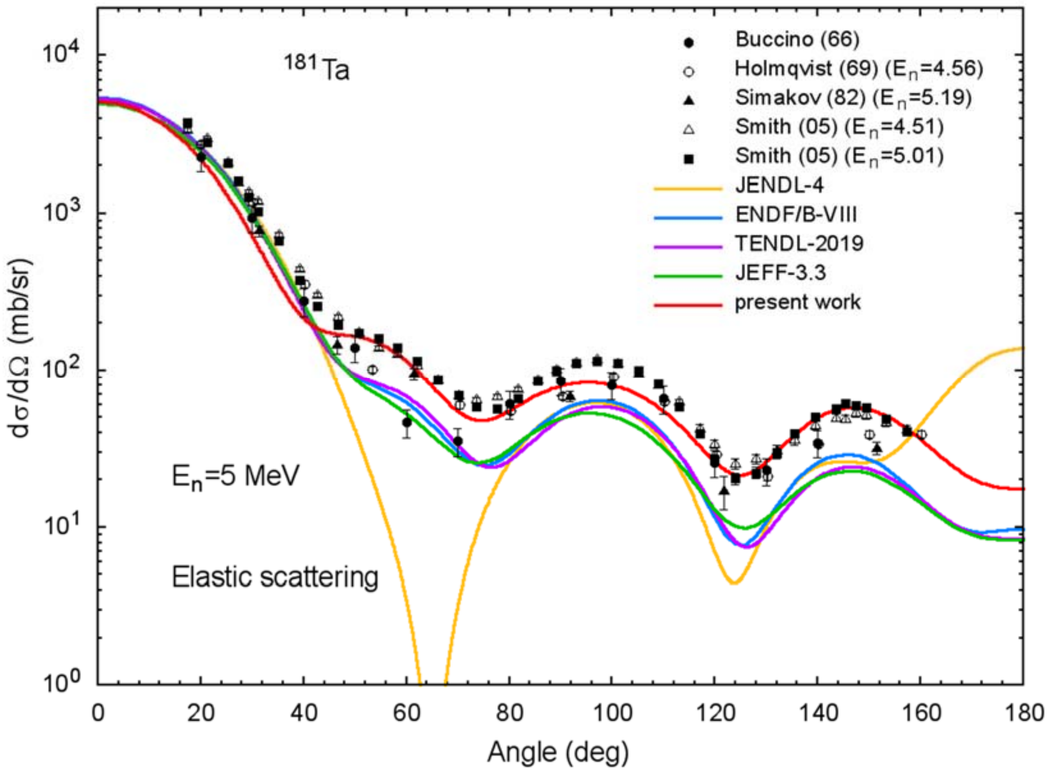


Fig.7 Elastic scattering angular distribution of neutrons for $^{181}$Ta at the incident energy 5 MeV.

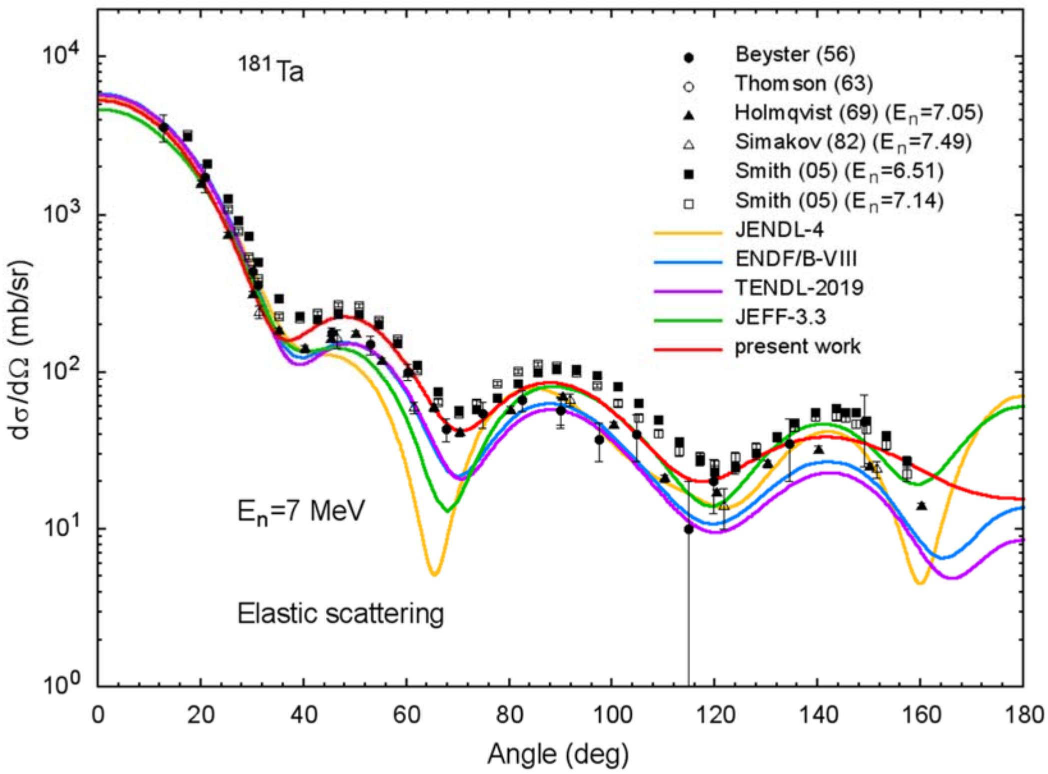


Fig.8 Elastic scattering angular distribution of neutrons for $^{181}$Ta at the incident energy 7 MeV.

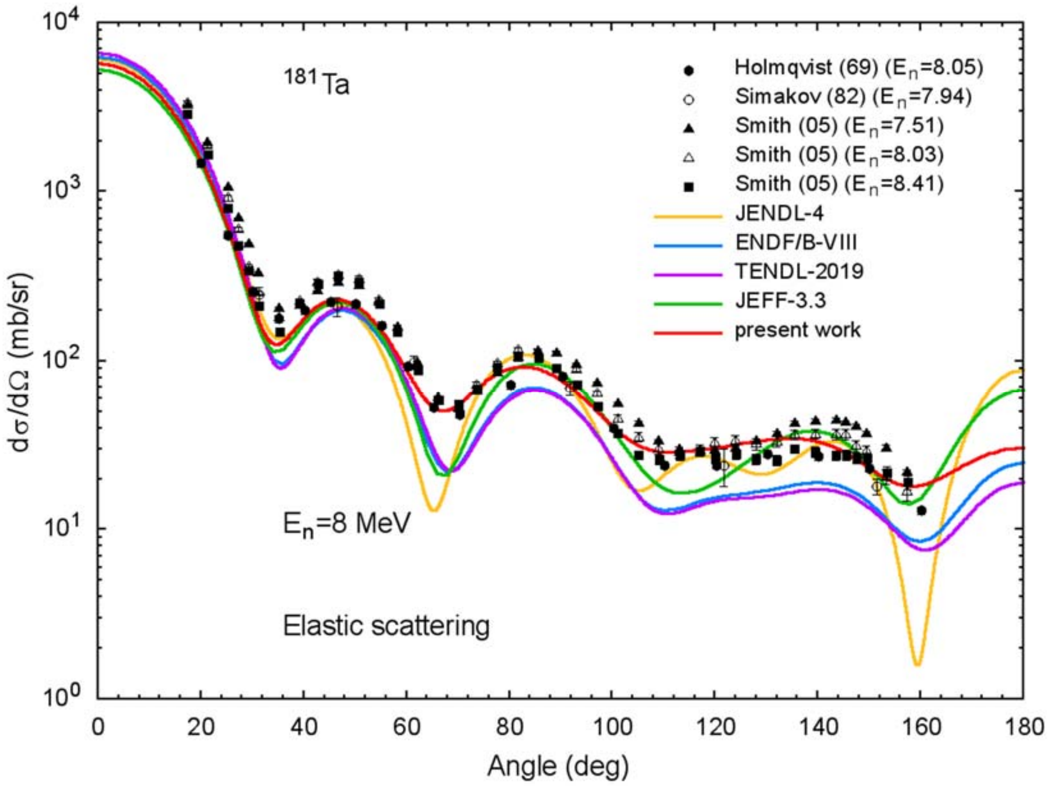


Fig.9 Elastic scattering angular distribution of neutrons for $^{181}$Ta at the incident energy 8 MeV.

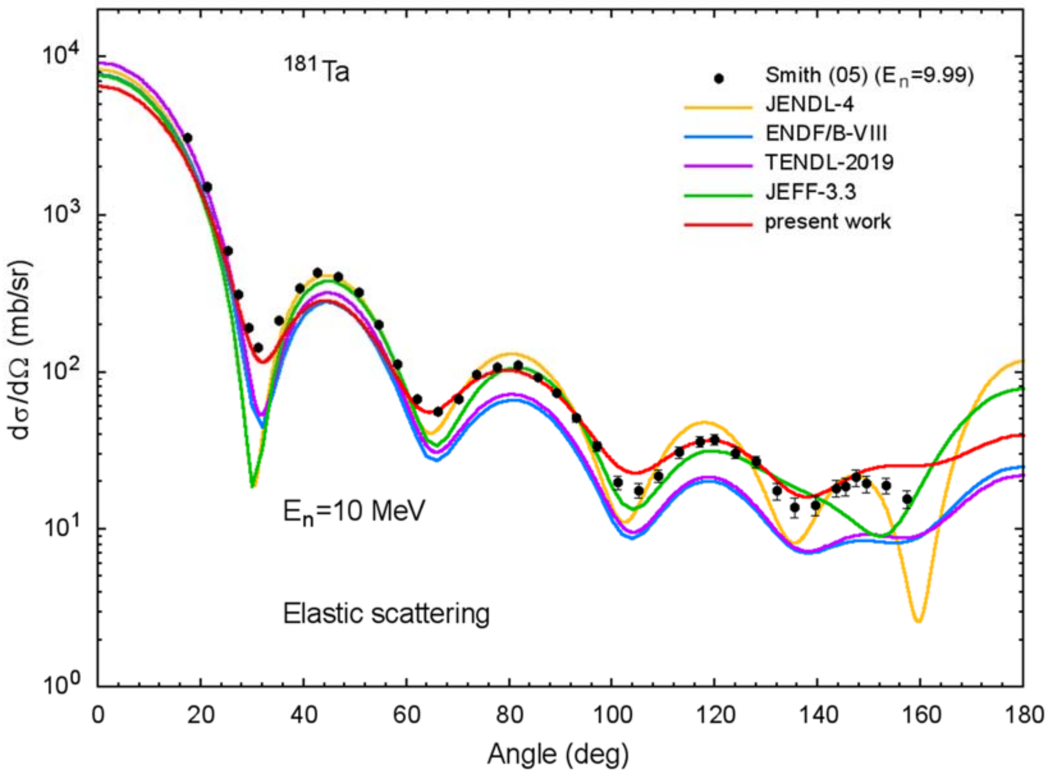


Fig.10 Elastic scattering angular distribution of neutrons for $^{181}$Ta at the incident energy 10 MeV.

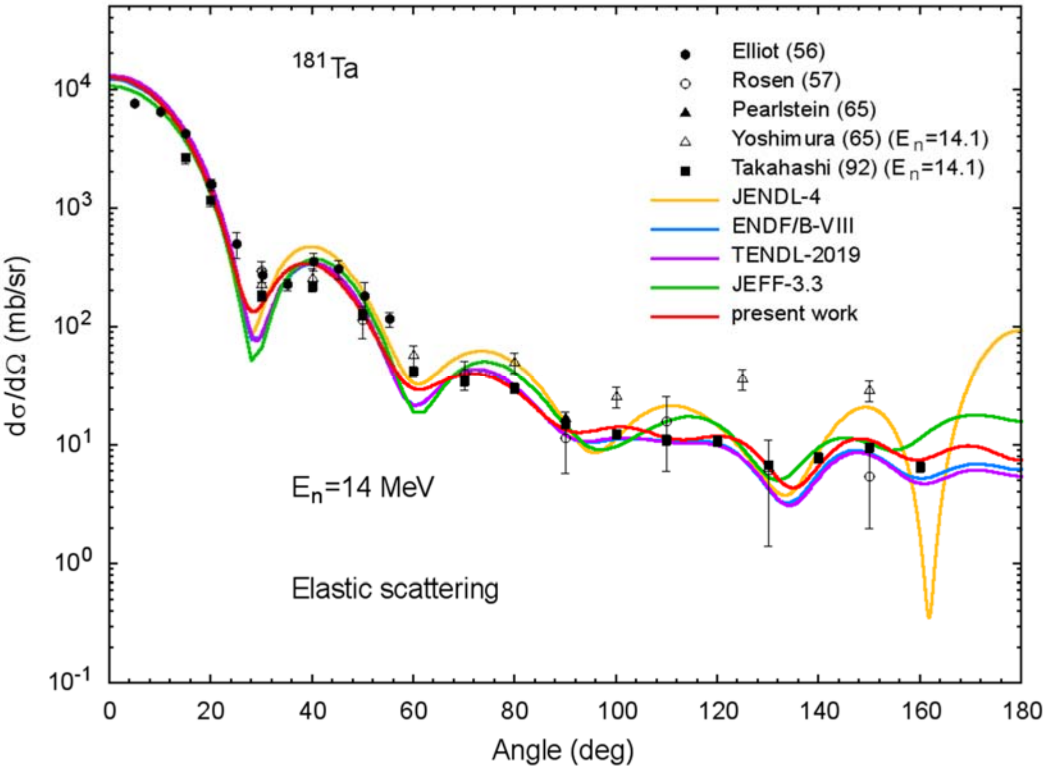


Fig.11 Elastic scattering angular distribution of neutrons for $^{181}$Ta at the incident energy 14 MeV.

In general, there is a relative good agreement between the obtained $d\sigma/d\Omega$ values and the measurement data. However, at some angles the agreement is far from ideal and leaves open the possibility of further improvement of evaluated data.

### *3.3 Inelastic scattering cross-section*

Cross sections for inelastic scattering for reactions with excitation of different levels are shown in Figs.12-25. The reactions correspond to MT numbers 51-58,60-62. Obtained sums of the cross sections for some levels are shown together with measured data in Figs.15, 18, 22.

Measurements for individual levels, Figs. 12-14, 16, 17, 19-21, 23-25 were performed in the early 70s, and the sums, Figs.15, 18, 22 , were measured relatively recently, in 2005 and 2011. The evalaution of the measured sum, Figs. 15, 18, 22, in this work was given special attention. This is the reason for the deviation of the evaluated cross-sections from experimental data for individual levels and the better agreement between the evaluated data and the measured sums, as the comparison of data in Figs.13, 14 and Fig.15 (sum), Figs. 16,17 and Fig.18 (sum), and Figs. 19-21 and Fig.22 (sum) shows.

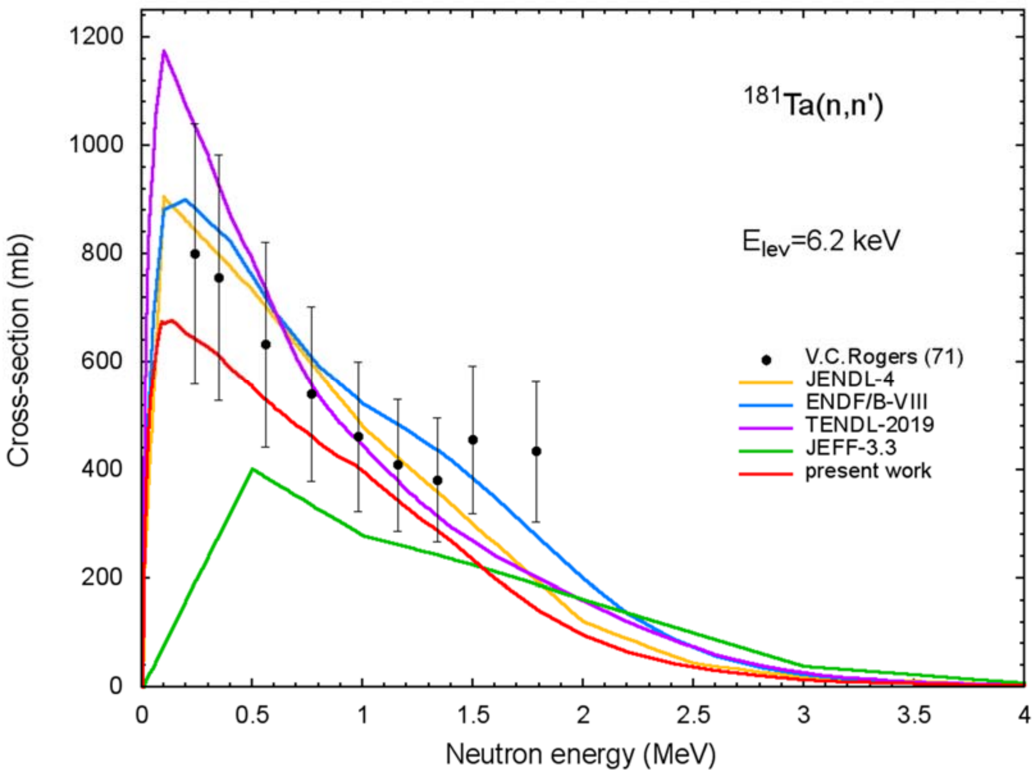


Fig.12 The inelastic scattering cross-section with the excitation of the level 6.2 keV. The corresponding MT number is equal to 51.

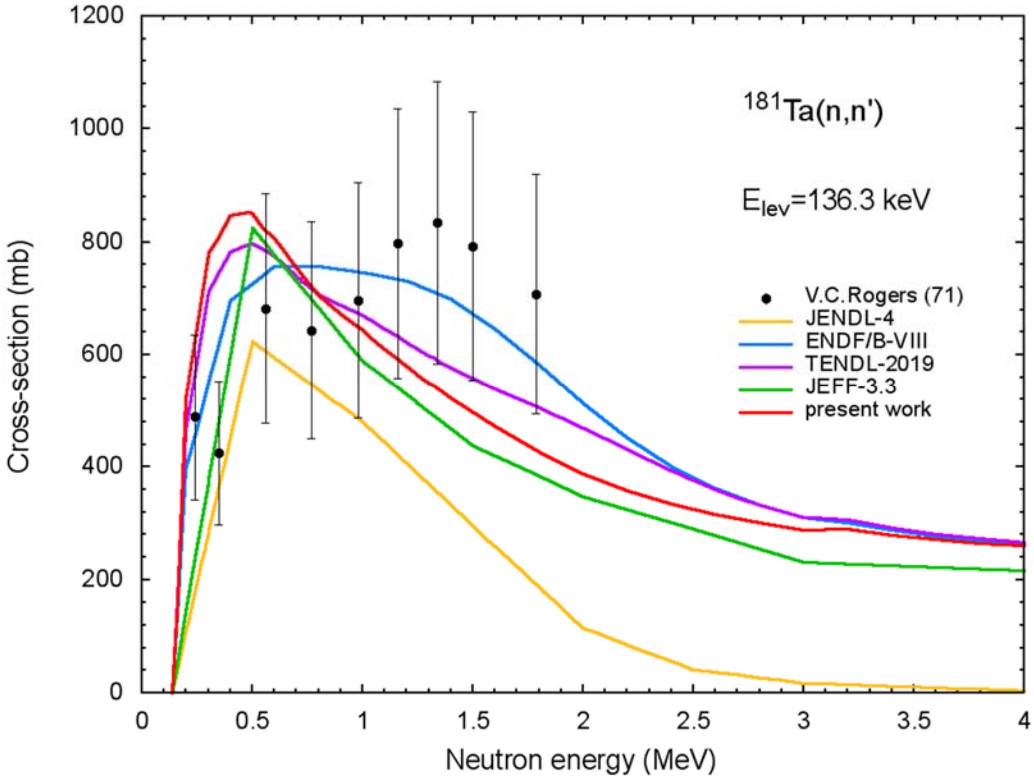


Fig.13 The inelastic scattering cross-section with the excitation of the level 136.3 keV. The corresponding MT number is equal to 52.

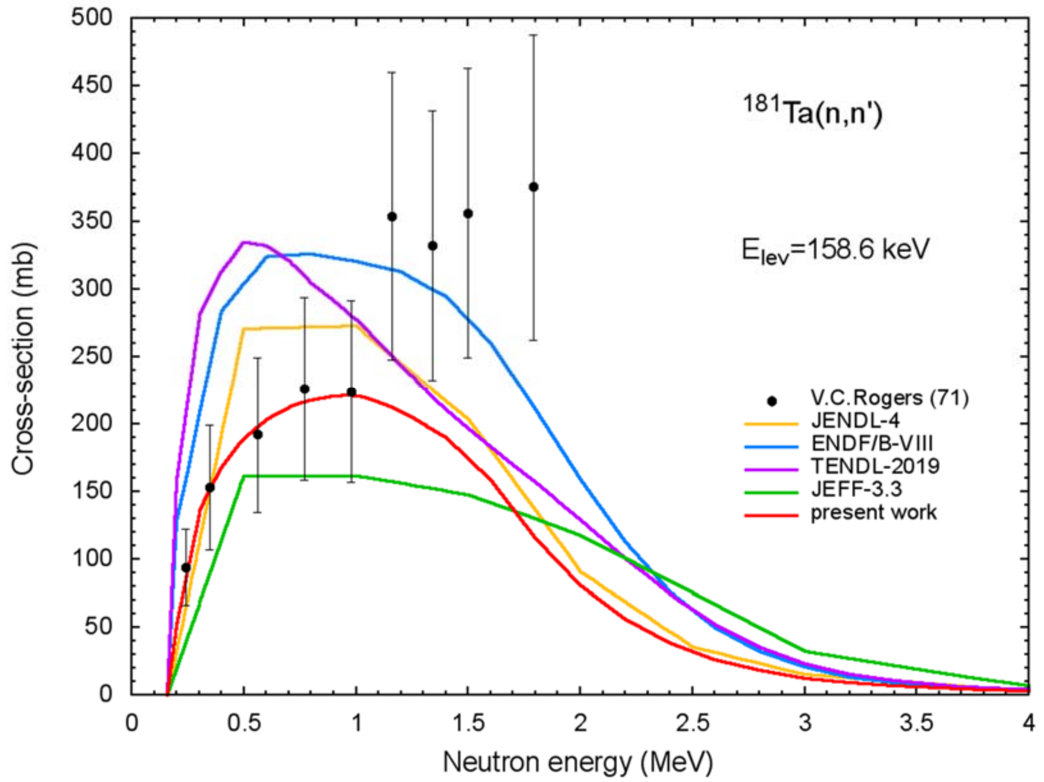


Fig.14 The inelastic scattering cross-section with the excitation of the level 158.6 keV. The corresponding MT number is equal to 53.

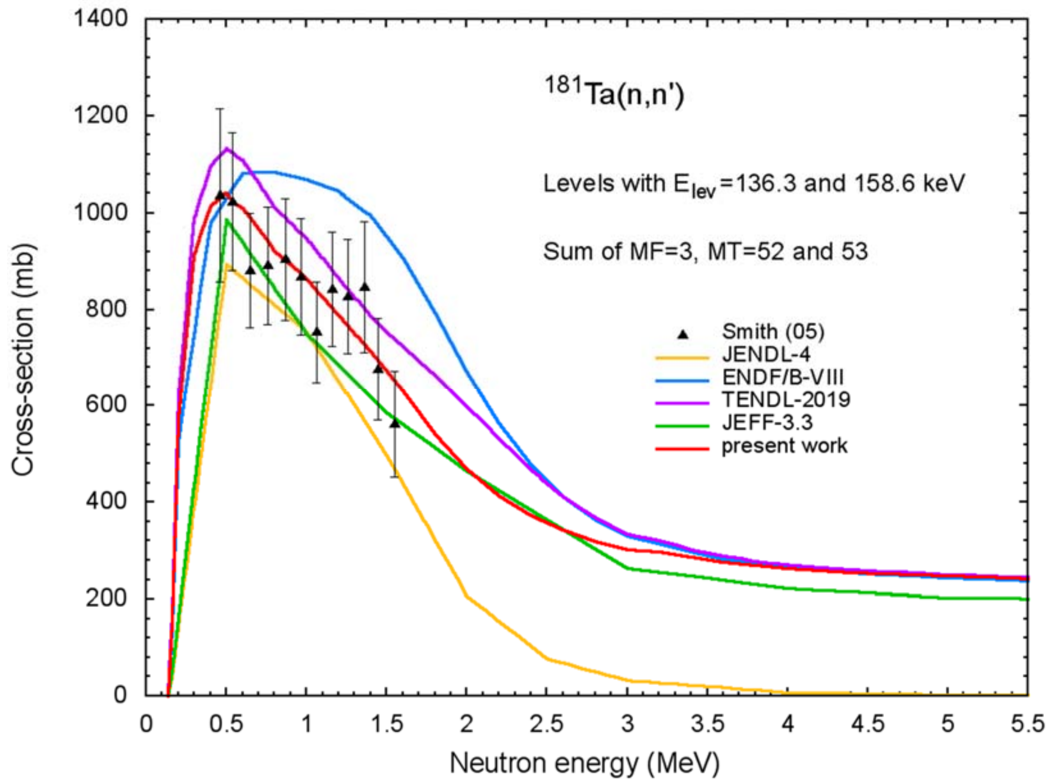


Fig.15 The sum of inelastic scattering cross-section with MT numbers 52 and 53.

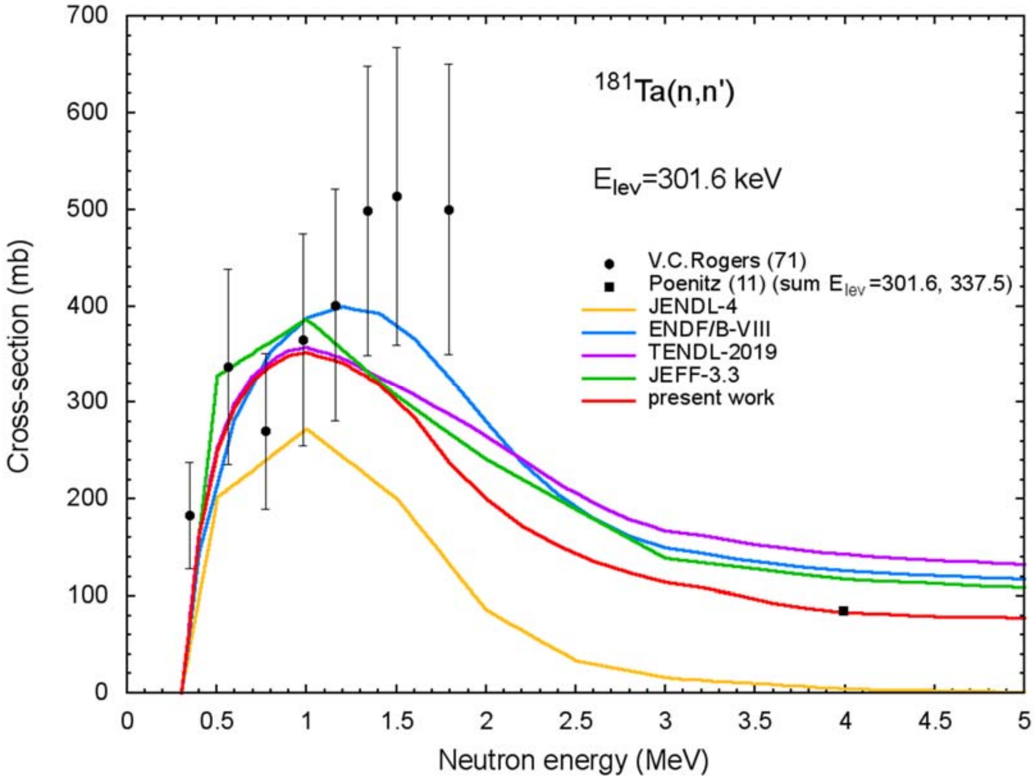


Fig.16 The inelastic scattering cross-section with the excitation of the level 301.6 keV. The corresponding MT number is equal to 54

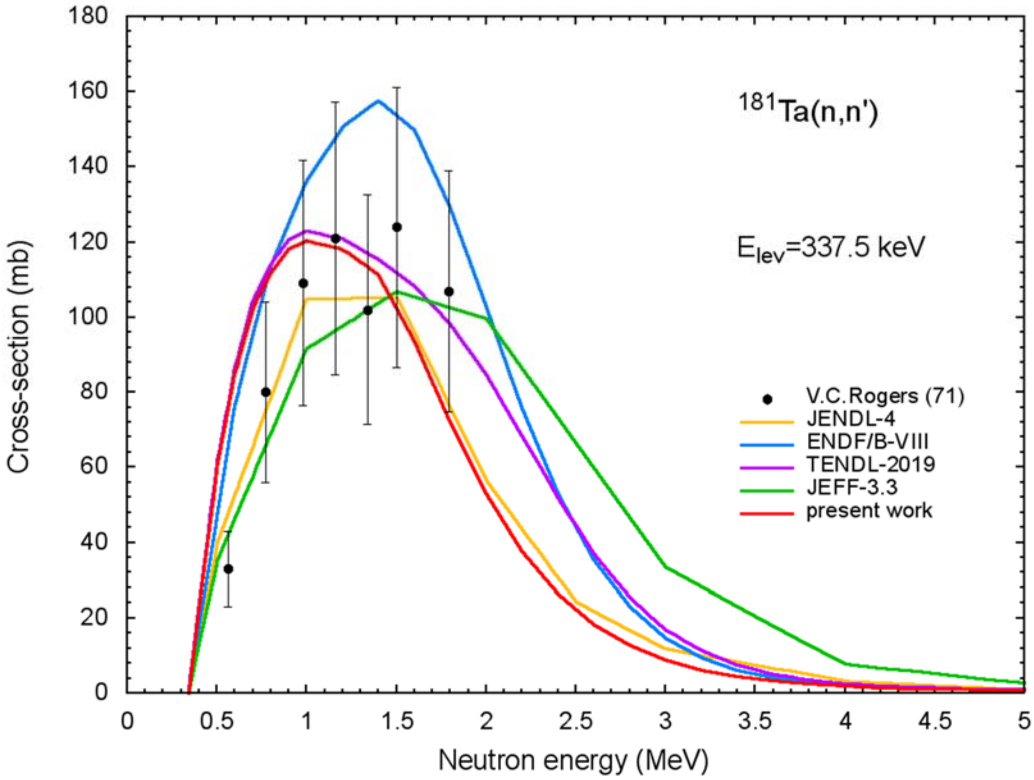


Fig.17 The inelastic scattering cross-section with the excitation of the level 337.5 keV. The corresponding MT number is equal to 55.

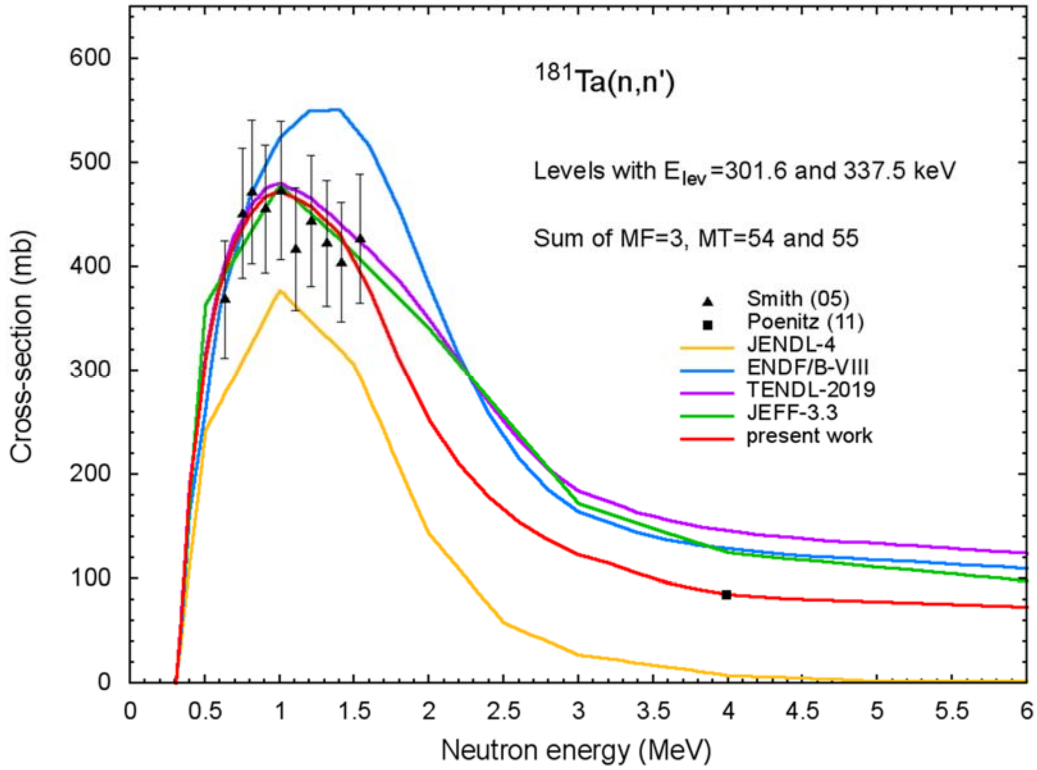


Fig.18 The sum of inelastic scattering cross-section with MT numbers 54 and 55.

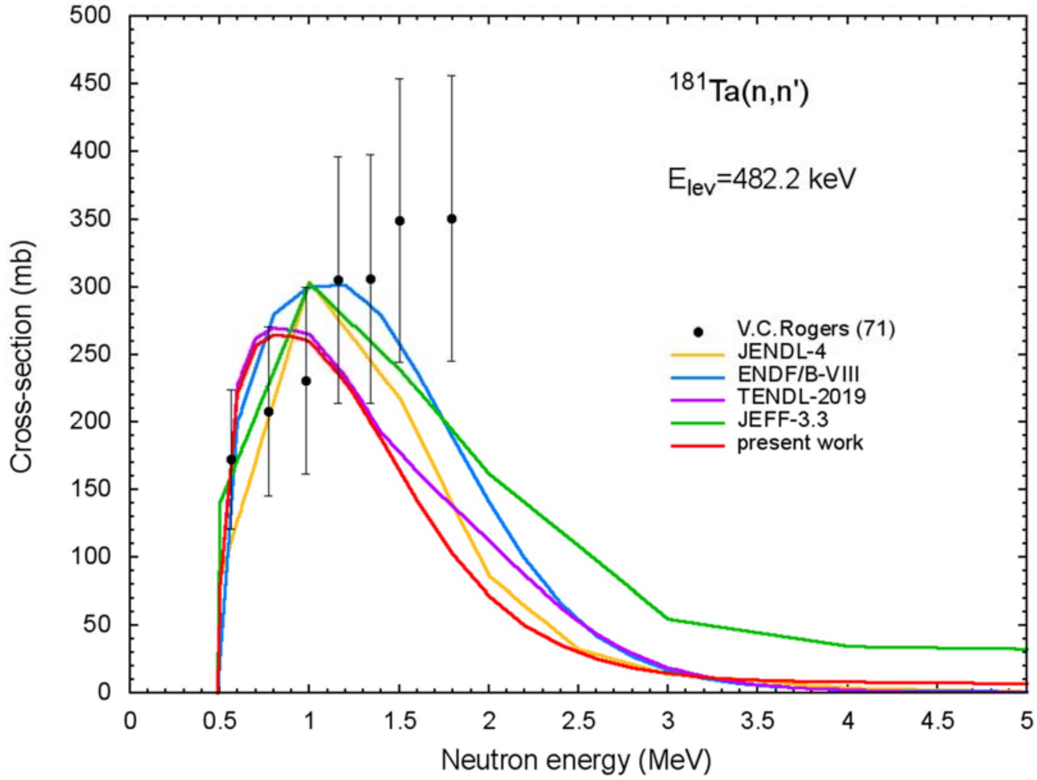


Fig.19 The inelastic scattering cross-section with the excitation of the level 482.2 keV. The corresponding MT number is equal to 56.

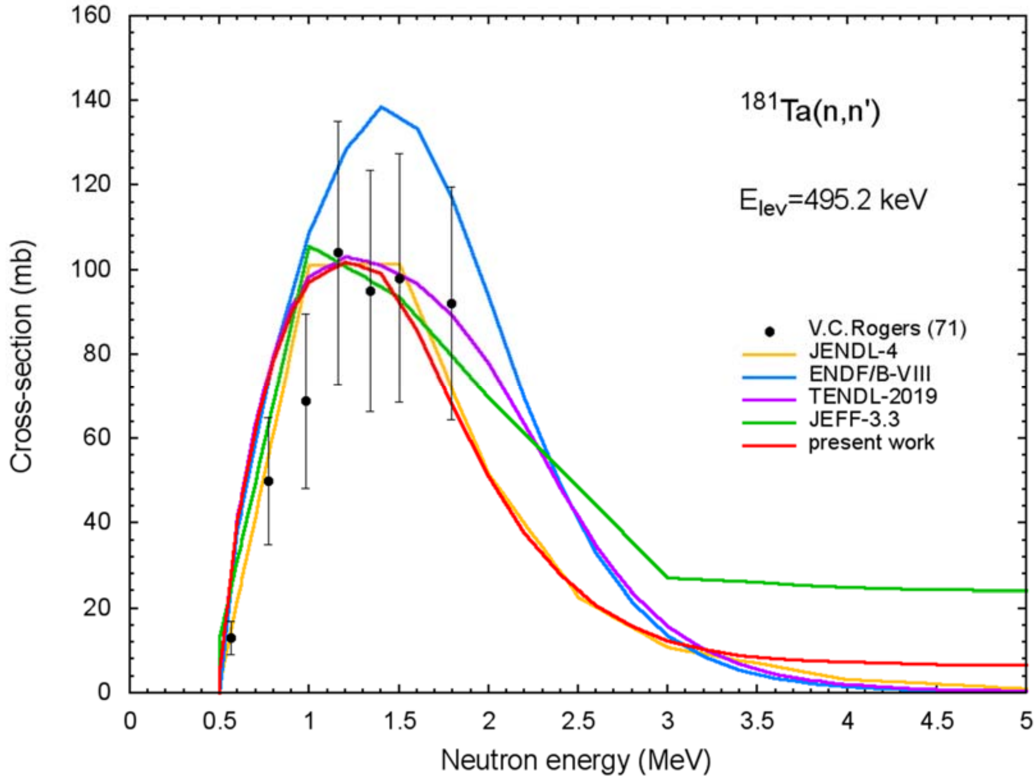


Fig.20 The inelastic scattering cross-section with the excitation of the level 495.2 keV. The corresponding MT number is equal to 57.

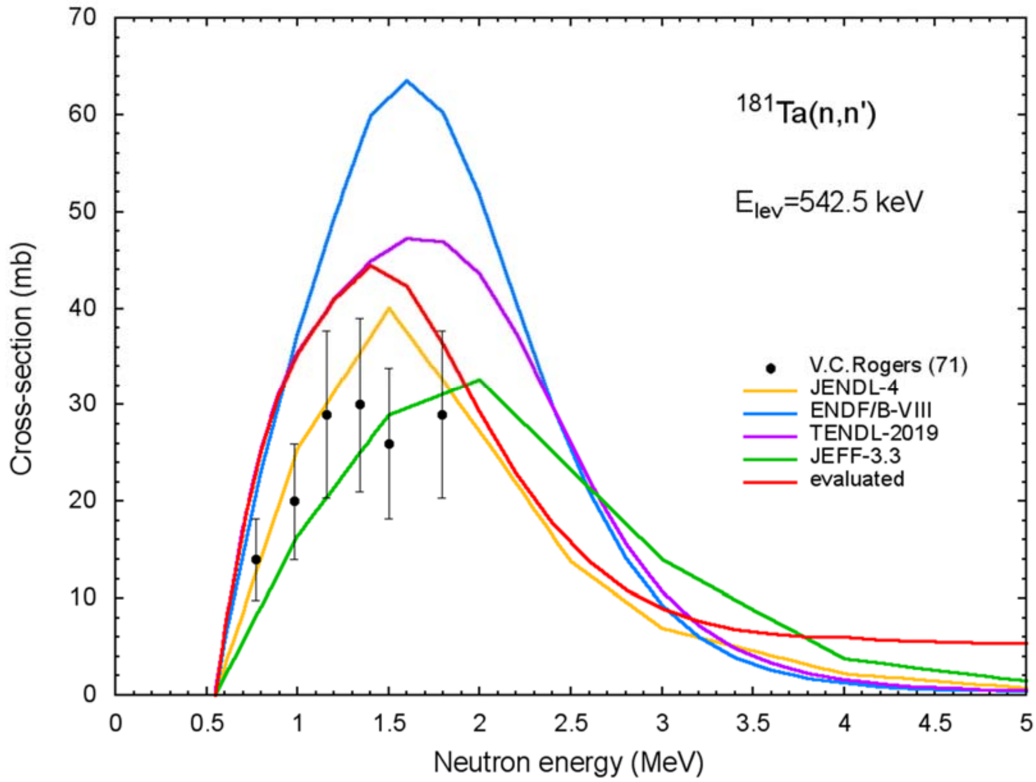


Fig.21 The inelastic scattering cross-section with the excitation of the level 542.5 keV. The corresponding MT number is equal to 58.

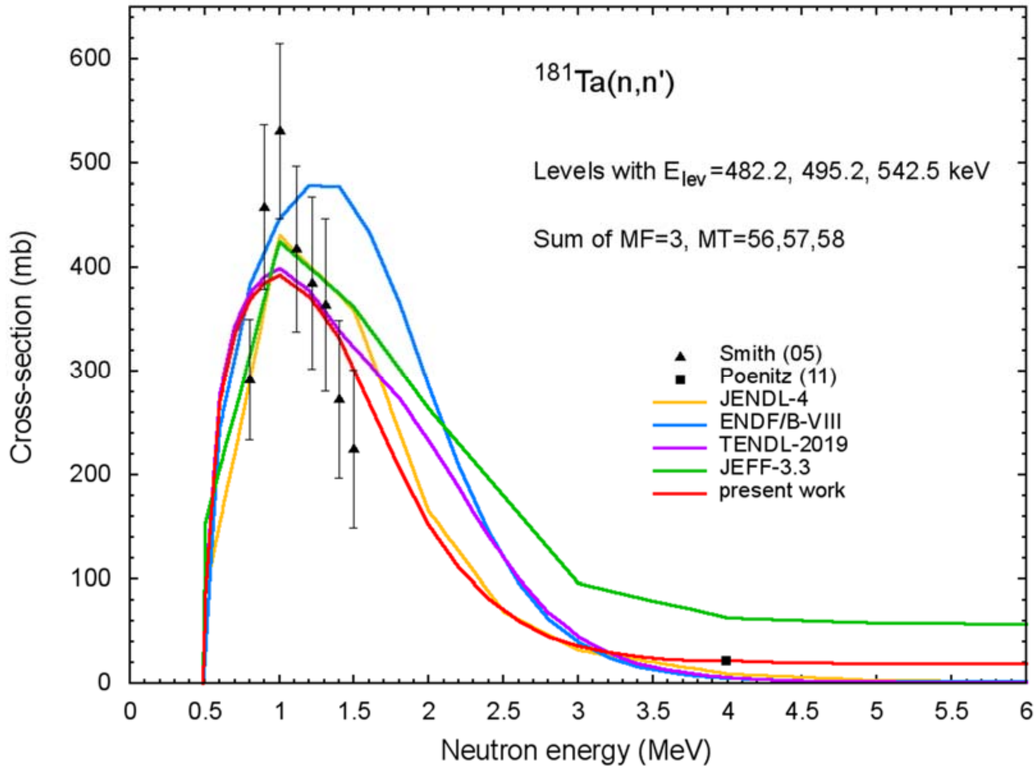


Fig.22 The sum of inelastic scattering cross-section with MT numbers 56, 57, and 58.

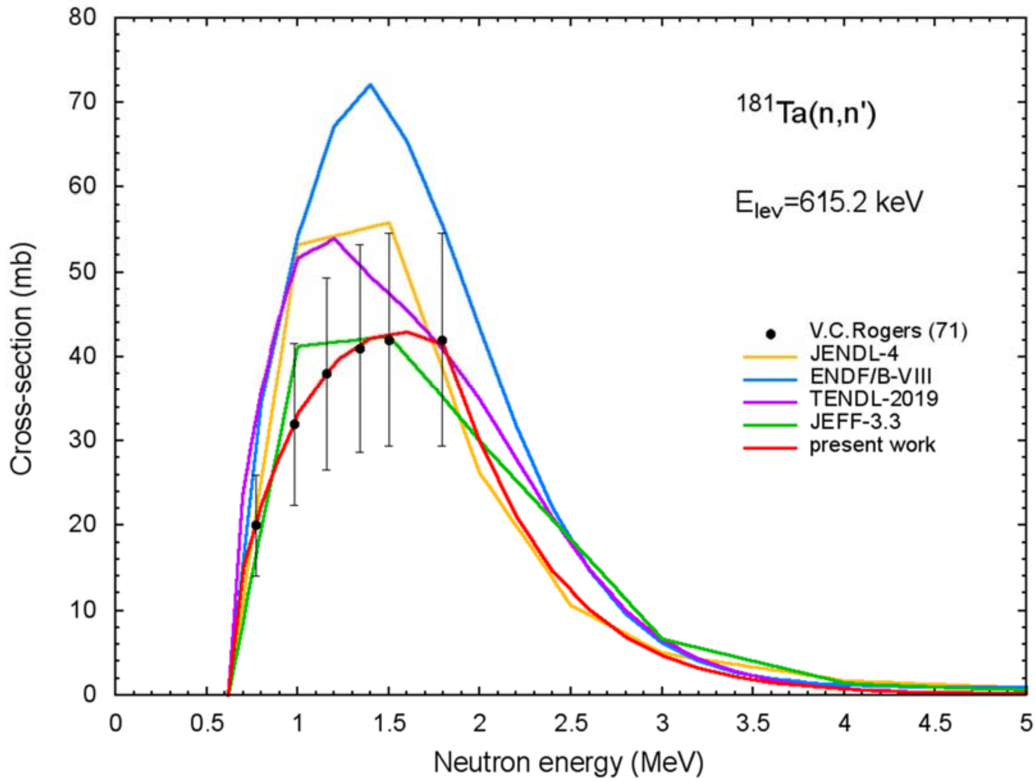


Fig.23 The inelastic scattering cross-section with the excitation of the level 615.2 keV. The corresponding MT number is equal to 60.

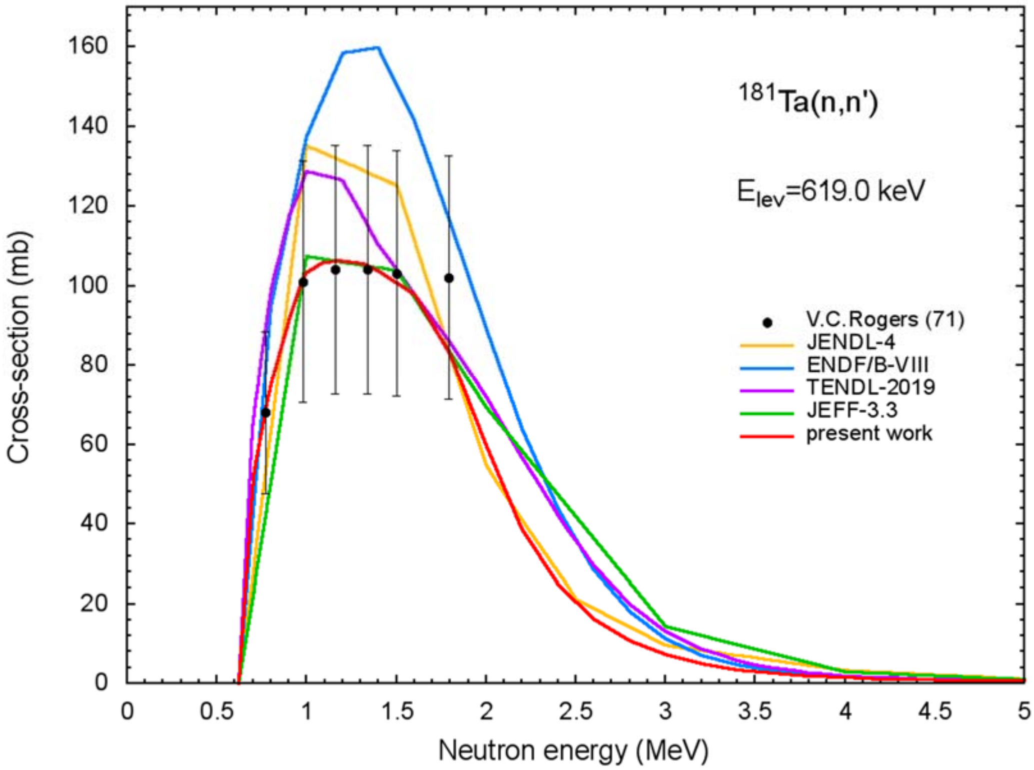


Fig.24 The inelastic scattering cross-section with the excitation of the level 619.0 keV. The corresponding MT number is equal to 61.

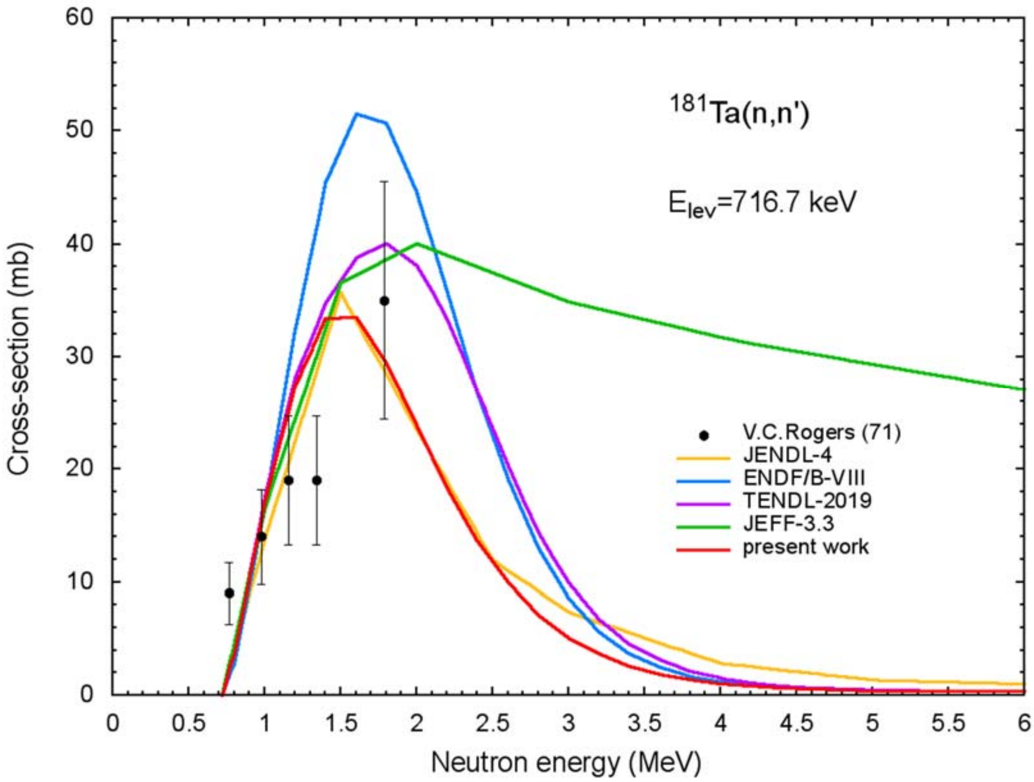


Fig.25 The inelastic scattering cross-section with the excitation of the level 716.7 keV. The corresponding MT number is equal to 62.

The total value of inelastic scattering cross section is shown in Fig. 26. The data evaluated in this work are noticeably higher than the experimental data at the energy around 14 MeV. This is a result of fitting the calculated neutron energy distributions to the measured data in the hard part of the spectrum, see Section 3.5, which corresponds to neutron emission in the continuum.

Other figures of interest, FigsA6-A20, including calculated values are shown in the Appendix.

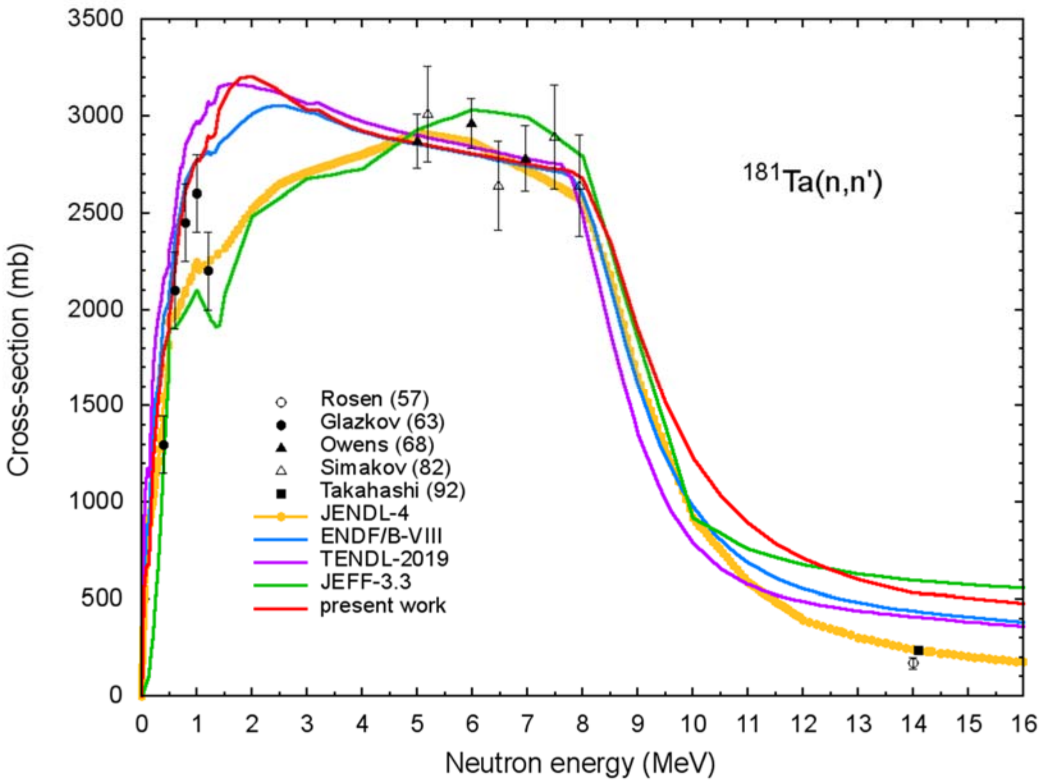


Fig.26 Inelastic scattering cross-section corresponding to MT number equal to 4.

### *3.4 Cross-sections for various reactions*

The (n,$\gamma$) reaction cross-section is shown in Fig.27-30. The cross-section in the whole energy range above the resonance region up to 200 MeV is shown in Fig. 27, and, for better illustration in different energy ranges and scales, in Figs.28-30. The obtained evaluated cross-sections are in agreement with the data of the latest experiments.

The cross-section of the reaction with the formation of isomer $^{182m2}$Ta is shown in Fig. 31.

For more information, see the Appendix, Fig.A21-A25.

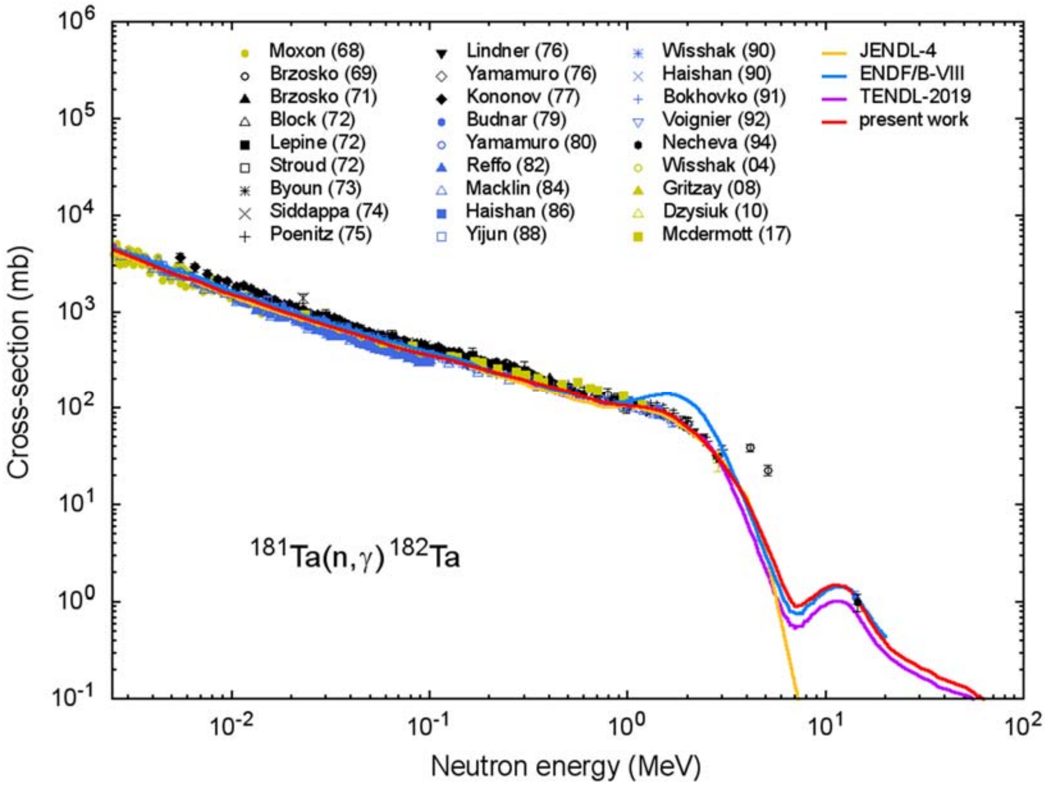


Fig.27 Cross-section for (n,$\gamma$) reaction

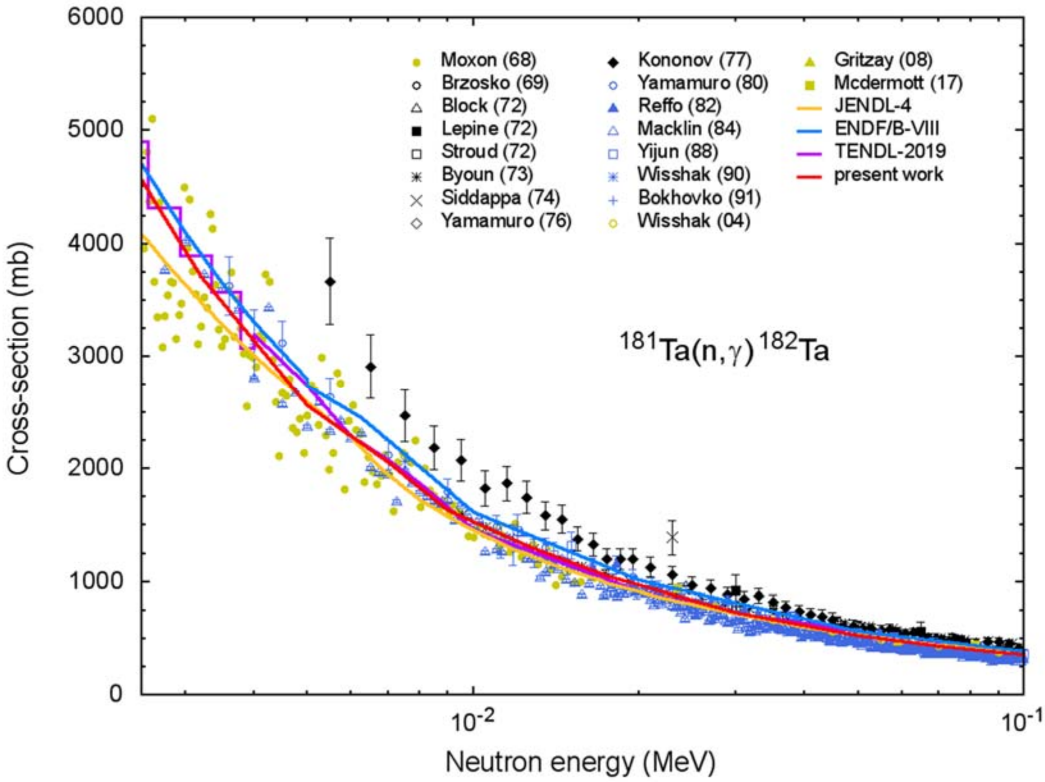


Fig.28 Cross-section for (n,$\gamma$) reaction at the energies above the resonance region up to 100 keV

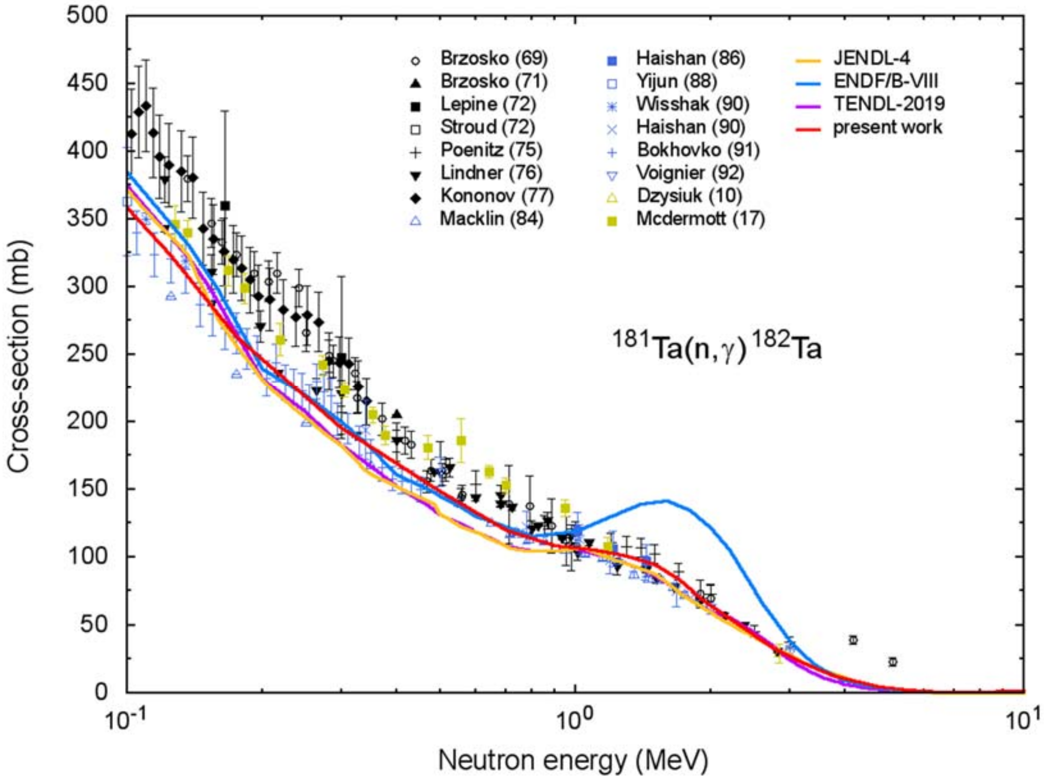


Fig.29 Cross-section for (n,$\gamma$) reaction at the energies from 0.1 to 10 MeV.

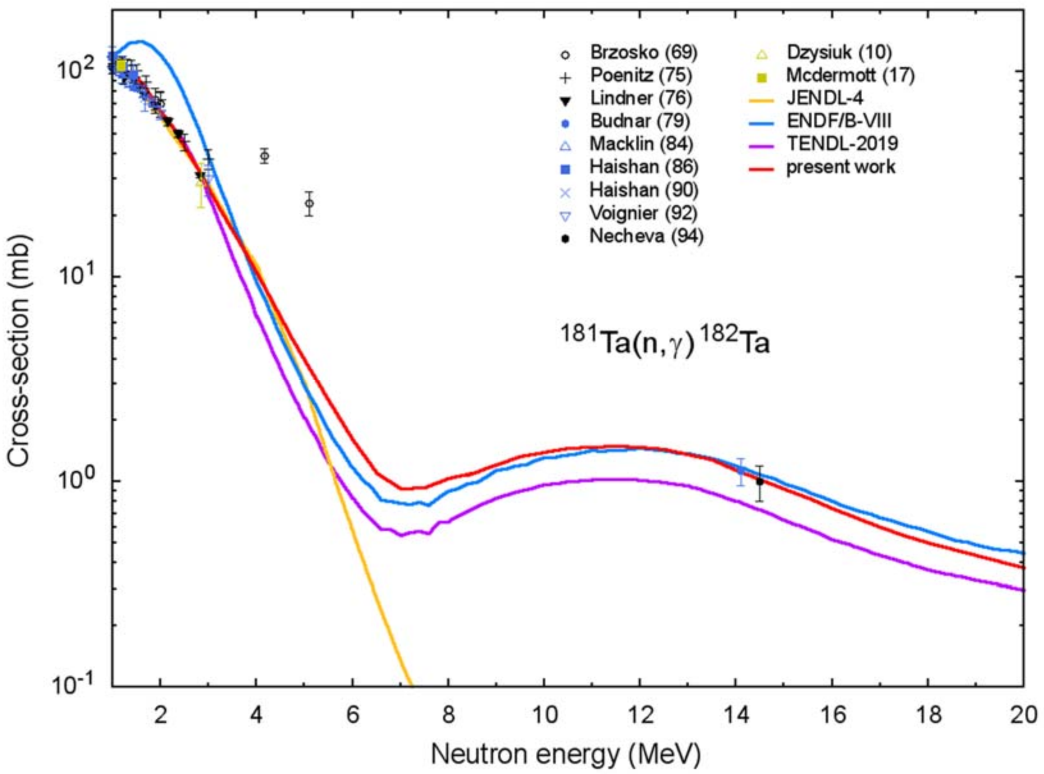


Fig.30 Cross-section for (n,$\gamma$) reaction at the energies from 1 to 20 MeV.

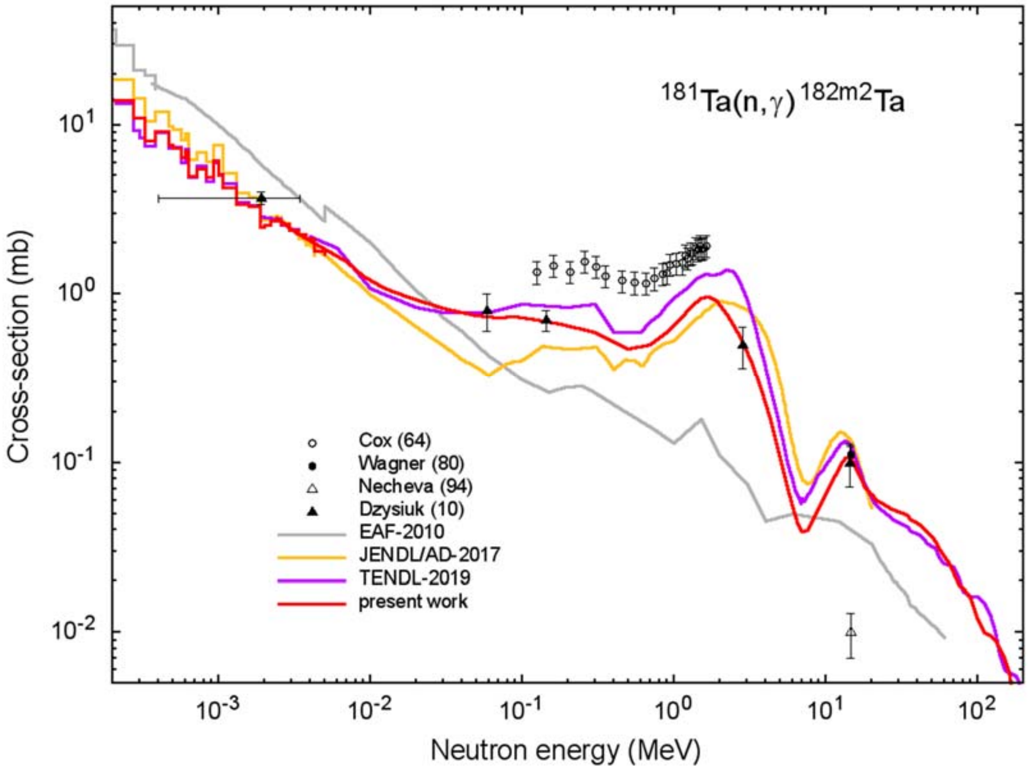


Fig.31 Cross-section for $^{181}Ta(n,\gamma)^{182m2}Ta$ reaction.

The (n,2n) reaction cross-section is shown in Figs.32,33, the production cross-section for $^{180g}Ta$ in Figs. 34, 35.

Figure 36 illustrates the (n,3n) reaction cross-section and Fig. 37 the (n,6n) reaction cross-section. The calculated cross-sections for the (n,6n) reaction did not change.

The calculated cross-sections for (n,2n) and (n,3n) reaction are given in the Appendix, Fig.A26-A32.

The evaluated sum of cross-sections of (n,d) and (n,np) reactions leading to the production of isomer $^{180m}Hf$ is shown in Figs.38,39. The calculated values are given in the Appendix, Fig.A33,A34.

The cross-section for $^{181}Ta(n,n\alpha)^{177m}Lu$ reaction is presented in Fig.40. The only available experimental data for the reaction were not used for evaluation, since the measured values were higher than calculated sum of the cross sections for the production of $^{177}Lu$ in the ground state and all isomers in the (n,nα) reaction.

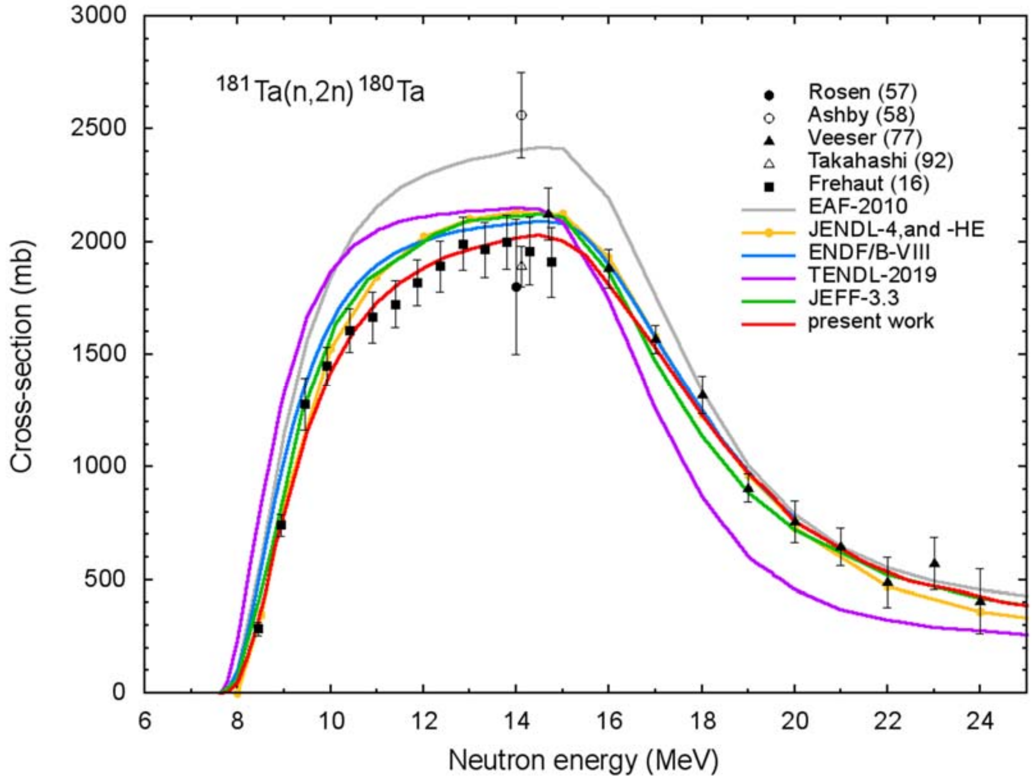


Fig.32 Cross-section for (n,2n) reaction at neutron energies up to 25 MeV.

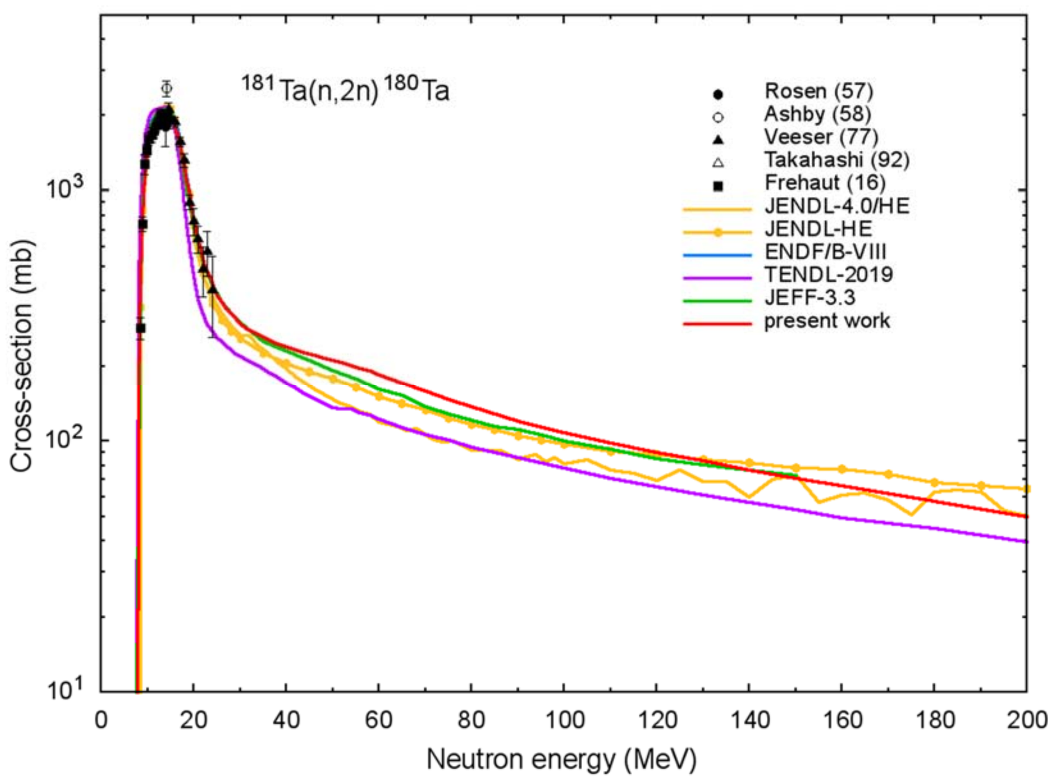


Fig.33 Cross-section for (n,2n) reaction at neutron energies up to 200 MeV.

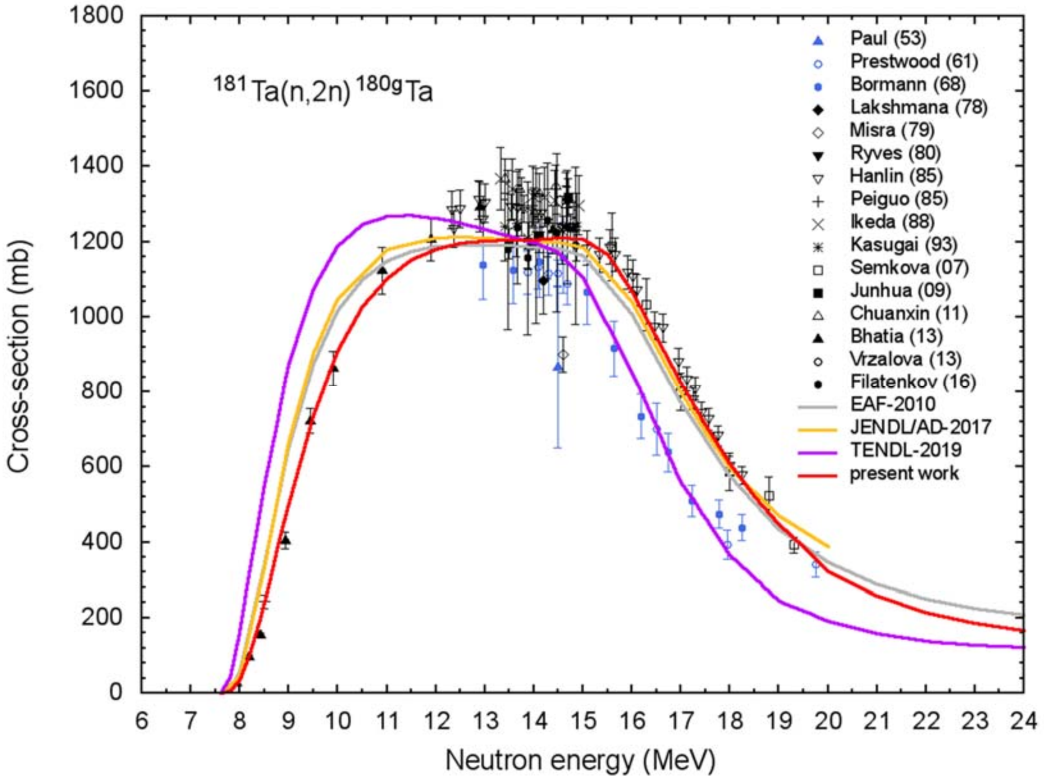


Fig.34 Cross-section for $^{181}$Ta(n,2n)$^{180g}$Ta reaction at neutron energies up to 25 MeV.

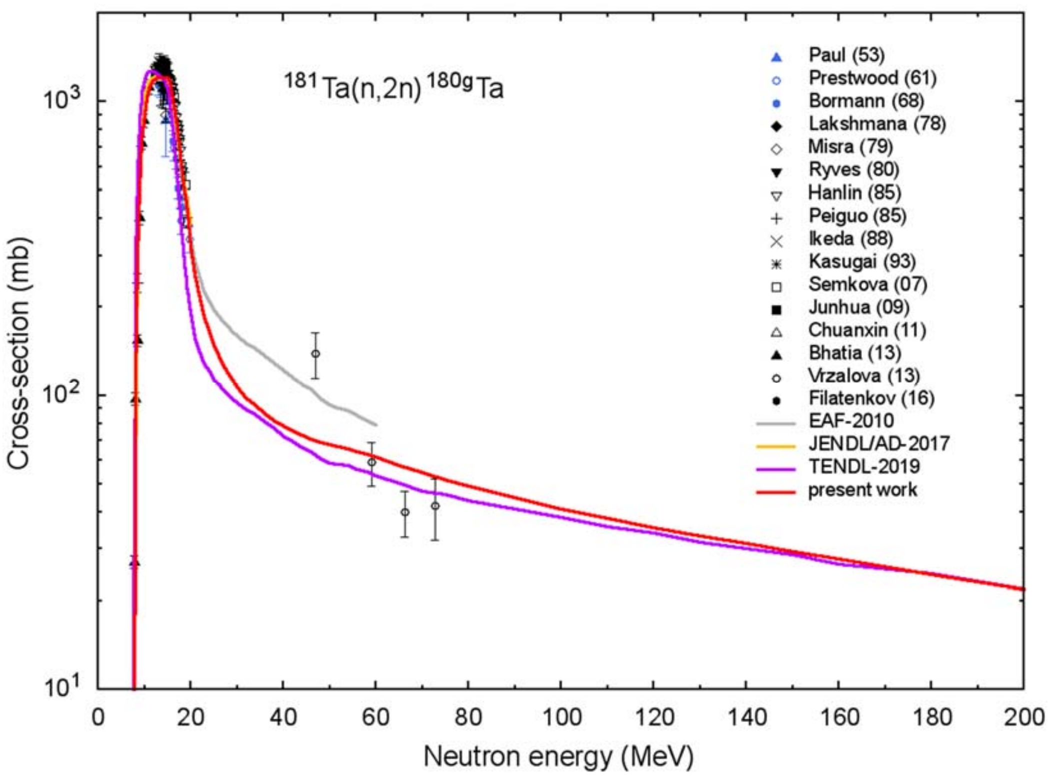


Fig.35 Cross-section for $^{181}$Ta(n,2n)$^{180g}$Ta reaction at neutron energies up to 200 MeV.

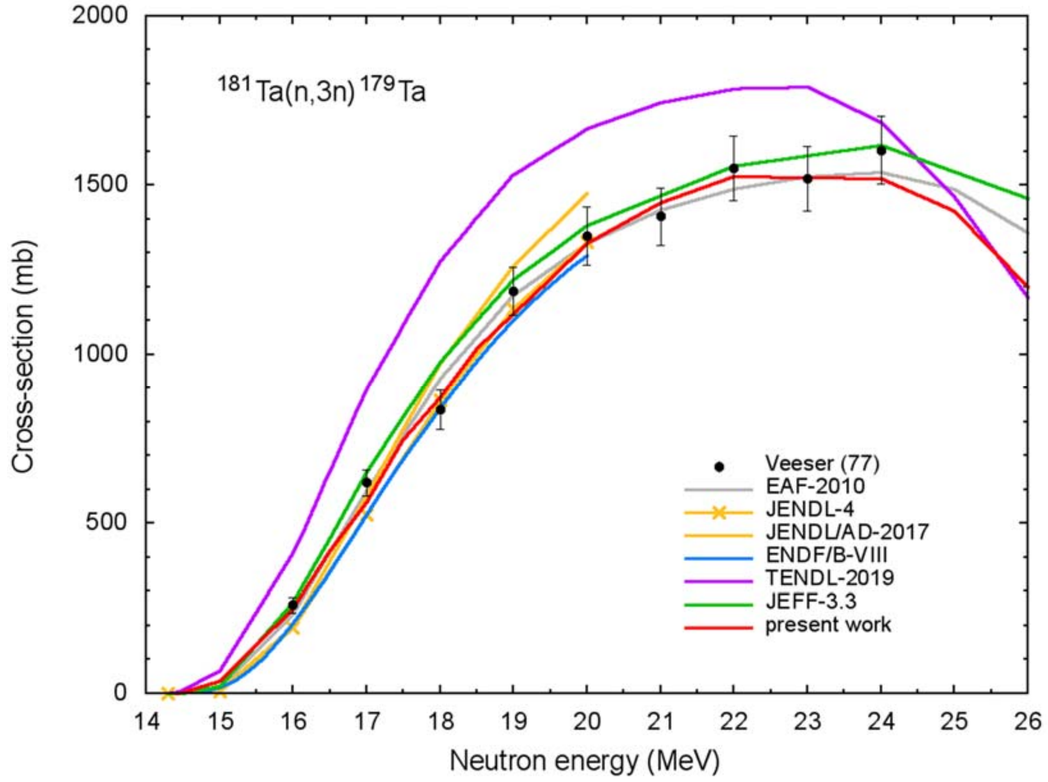


Fig.36 Cross-section for (n,3n) reaction.

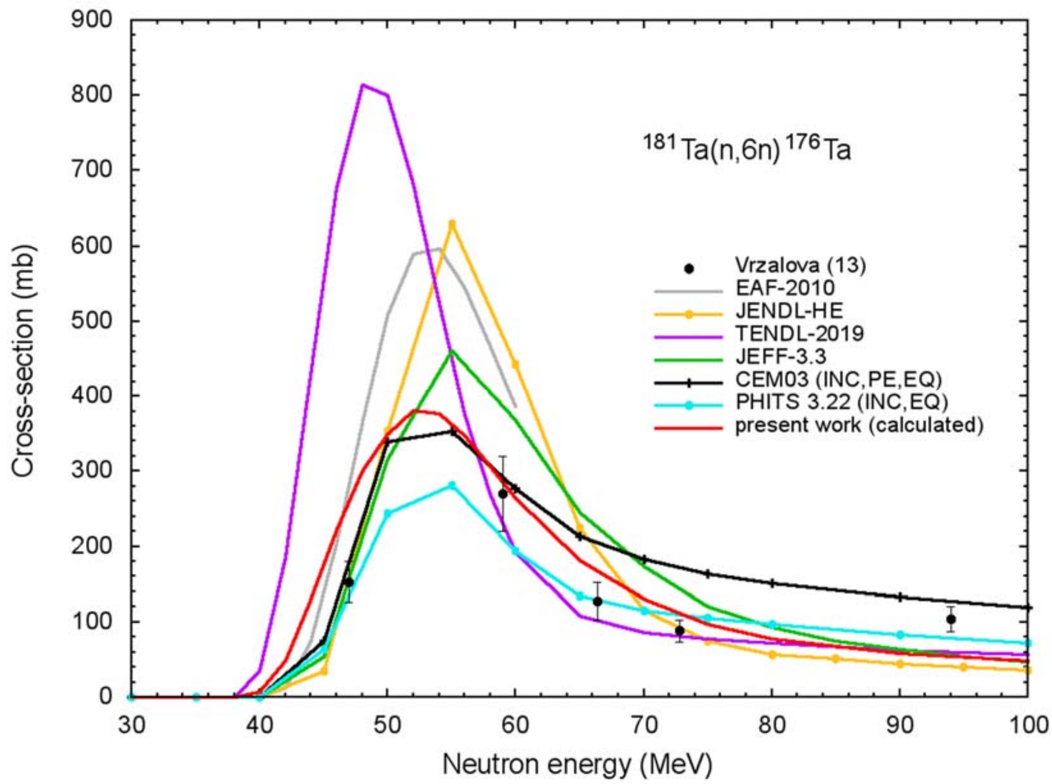


Fig.37 Cross-section for (n,6n) reaction. See Section 3.7 for a brief explanation of CEM and PHITS calculations.

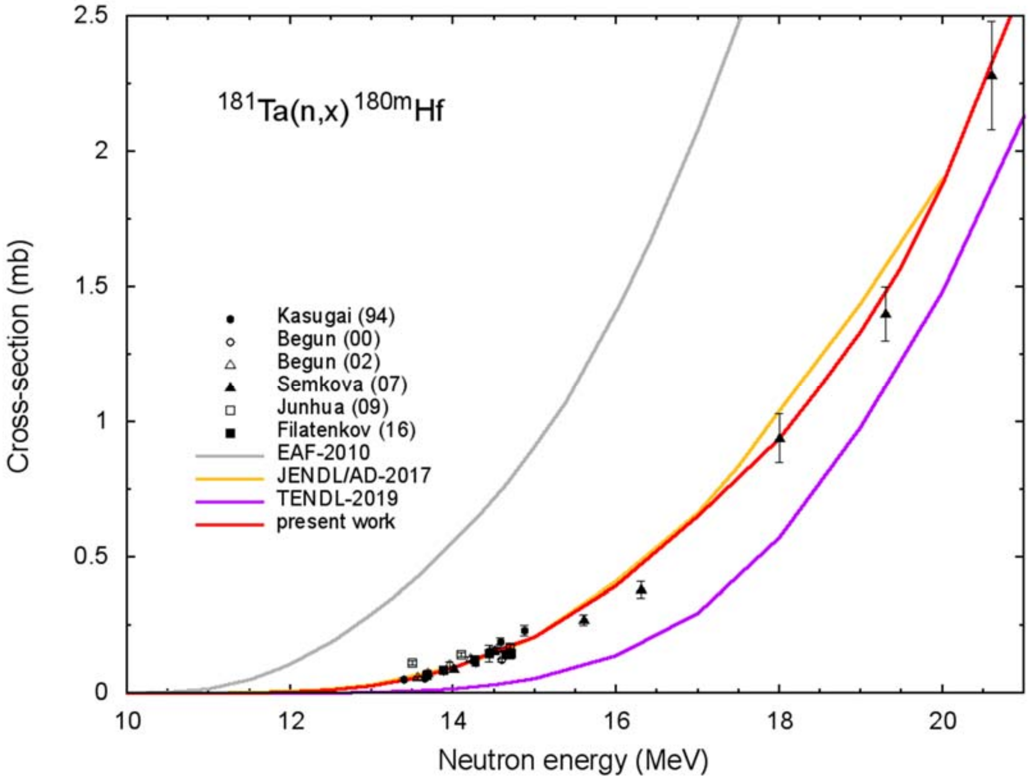


Fig.38 Cross-section for production of $^{180m}Hf$ in reactions (n,d) and (n,np).

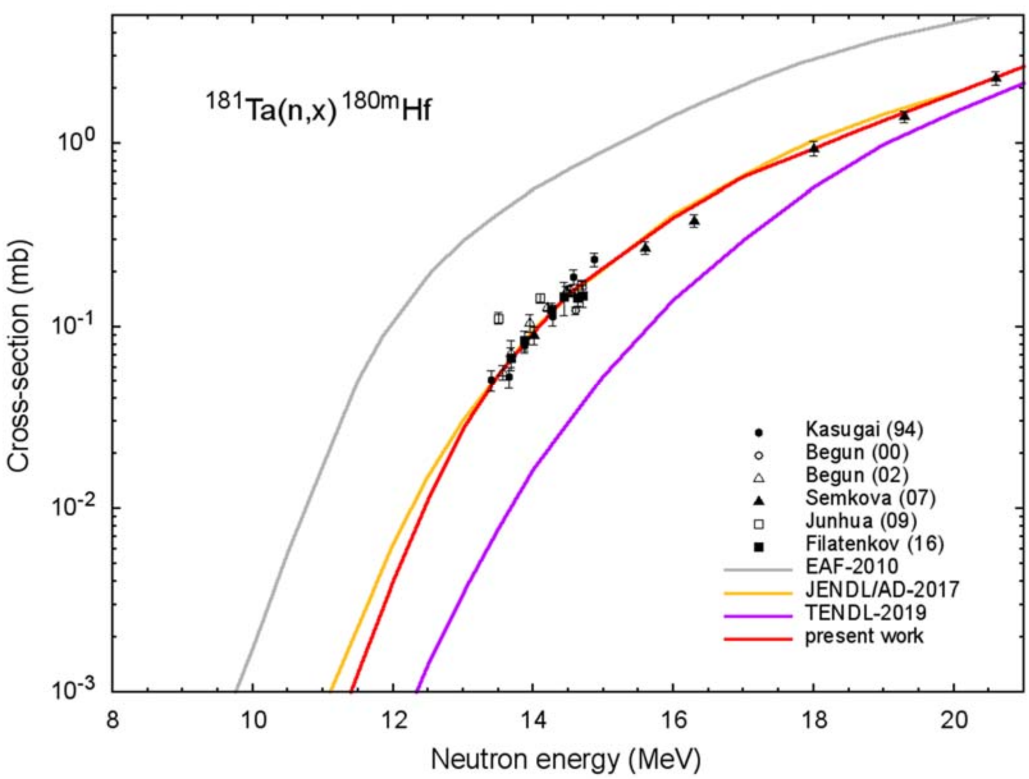


Fig.39 Cross-section for production of $^{180m}Hf$ in reactions (n,d) and (n,np).

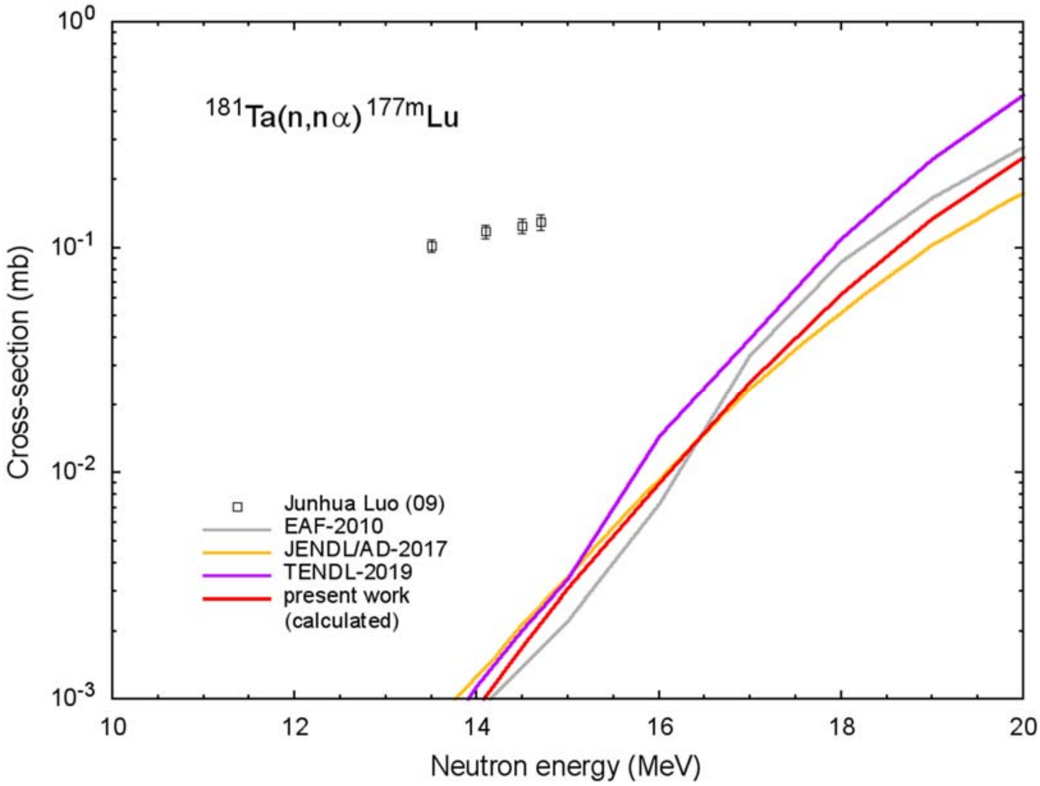


Fig.40 Cross-section for production of $^{177m}Lu$ in the reaction (n,nα).

The cross-sections for (n,p), (n,α), and (n,t) reactions including the yields of isomers are shown in Figs.41-51. Data are shown on a linear and logarithmic scale for better illustration. Systematics data in Fig.49 were obtained using Ref.[203]. Experimental data for the reaction $^{181}Ta(n,t)^{179m2}Lu$, Fig.51, were not taken into account for evaluation because of probably overestimated measured values of cross-sections. The idea is suggested by comparison of data in Fig. 51 and the (n,t) reaction cross-sections in Fig. 49.

The calculated values used for the evaluation are presented in the Appendix, Figs.A35-A44.

### *3.5 Neutron energy distribution*

The obtained neutron energy distributions are compared with experimental data and data from different libraries in Figs.52-59. The SPKA7 [219] and NJOY [210] codes were applied to calculate neutron spectra using data written in ENDF/B format.

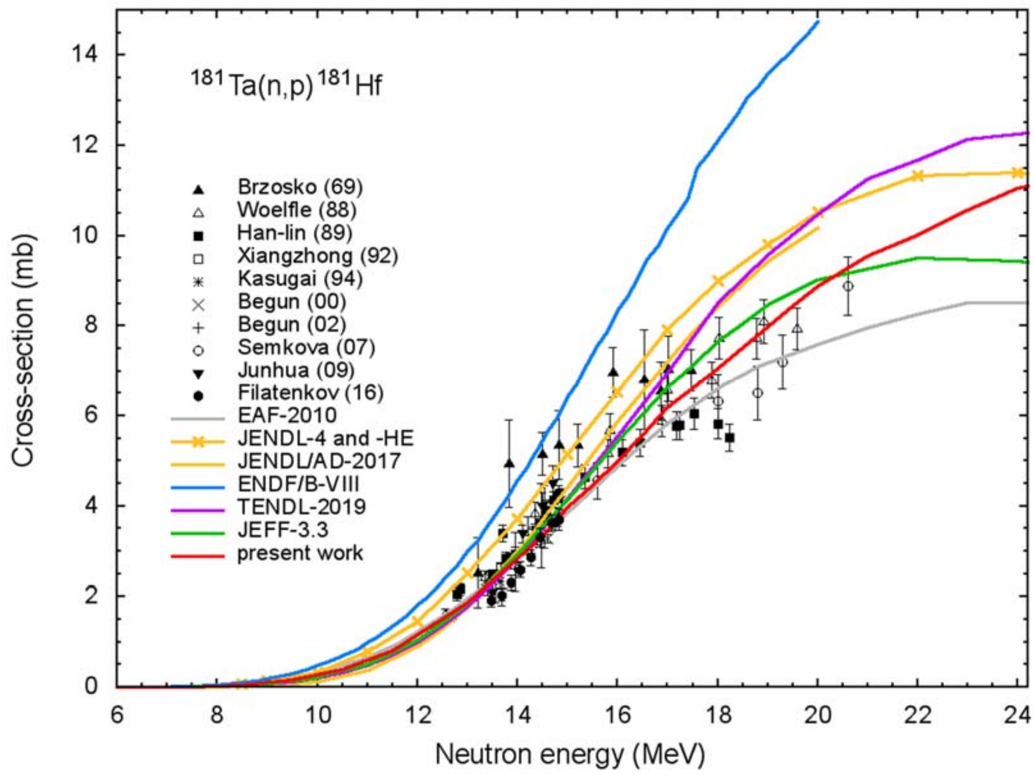


Fig.41 Cross-section for (n,p) reaction.

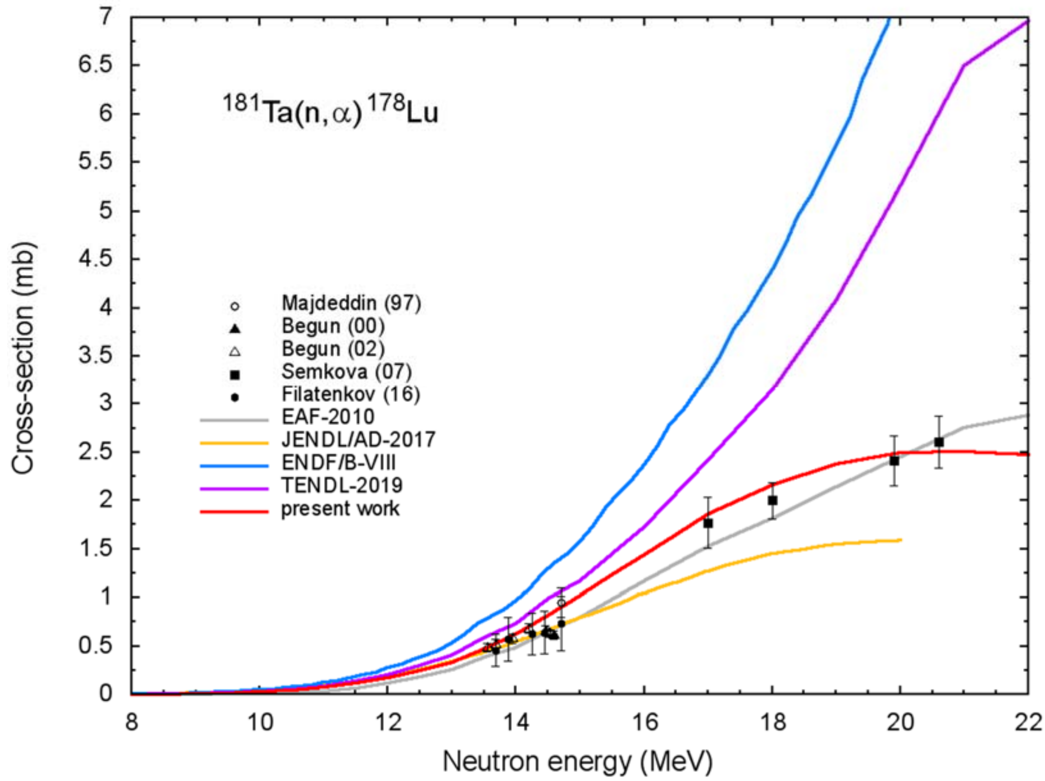


Fig.42 Cross-section for (n,α) reaction.

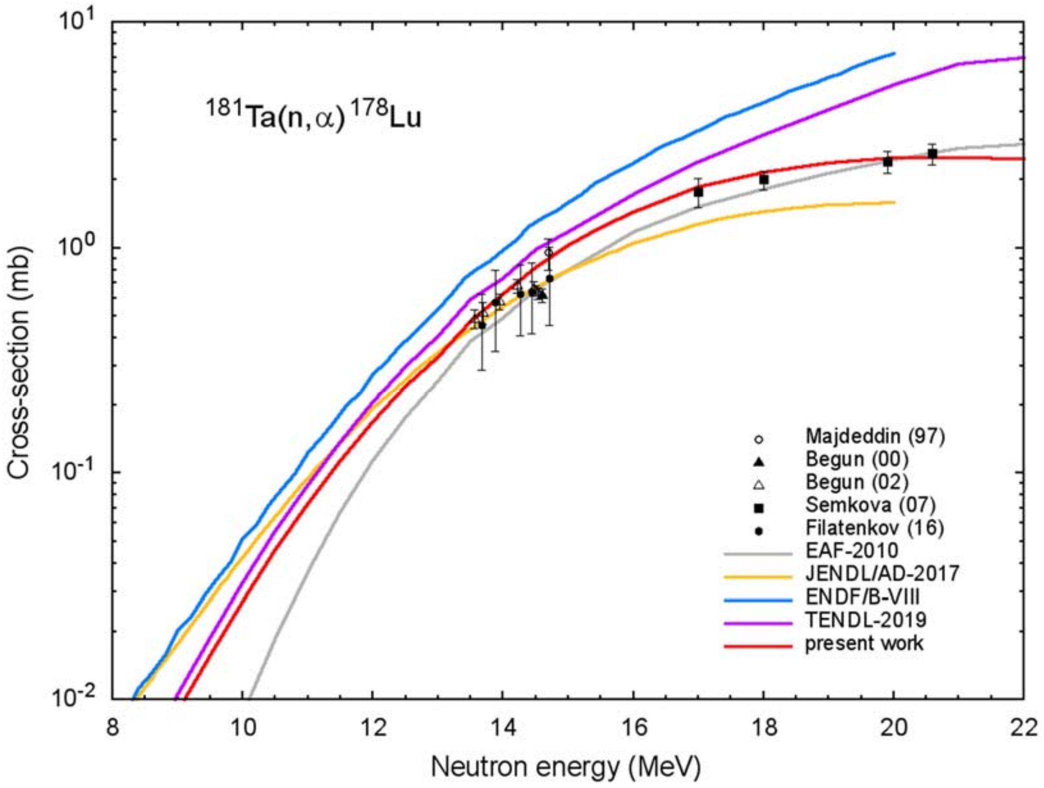


Fig.43 Cross-section for (n,α) reaction.

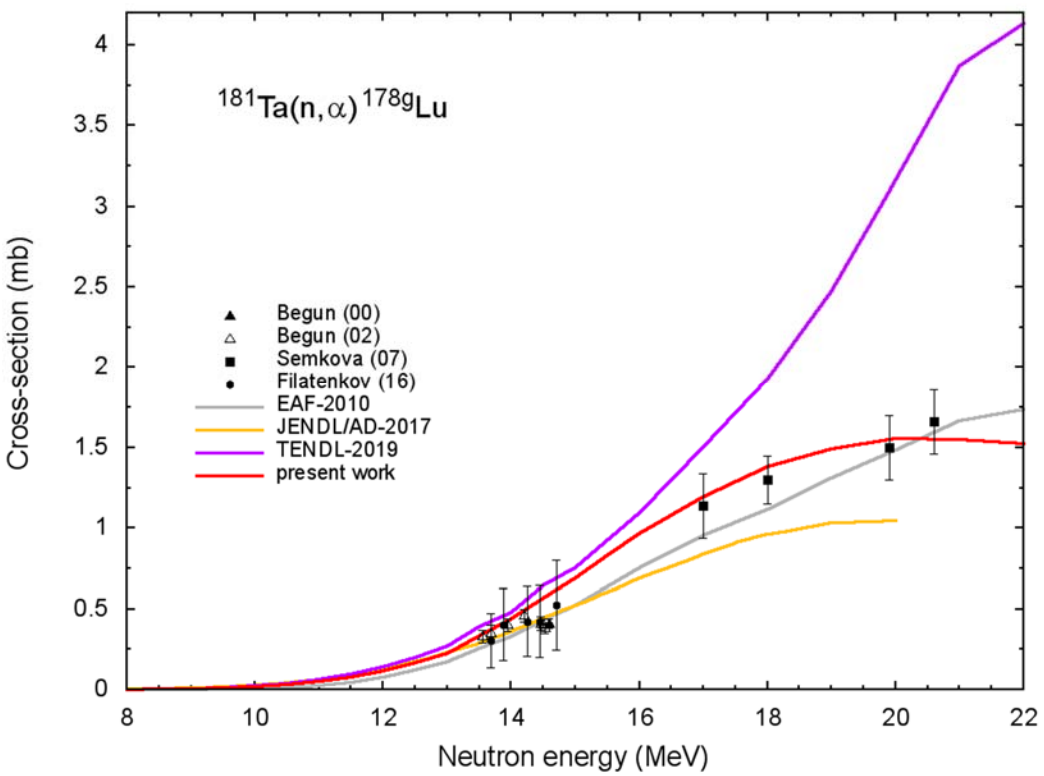


Fig.44 Cross-section for $^{181}$Ta(n,α)$^{178g}$Lu reaction.

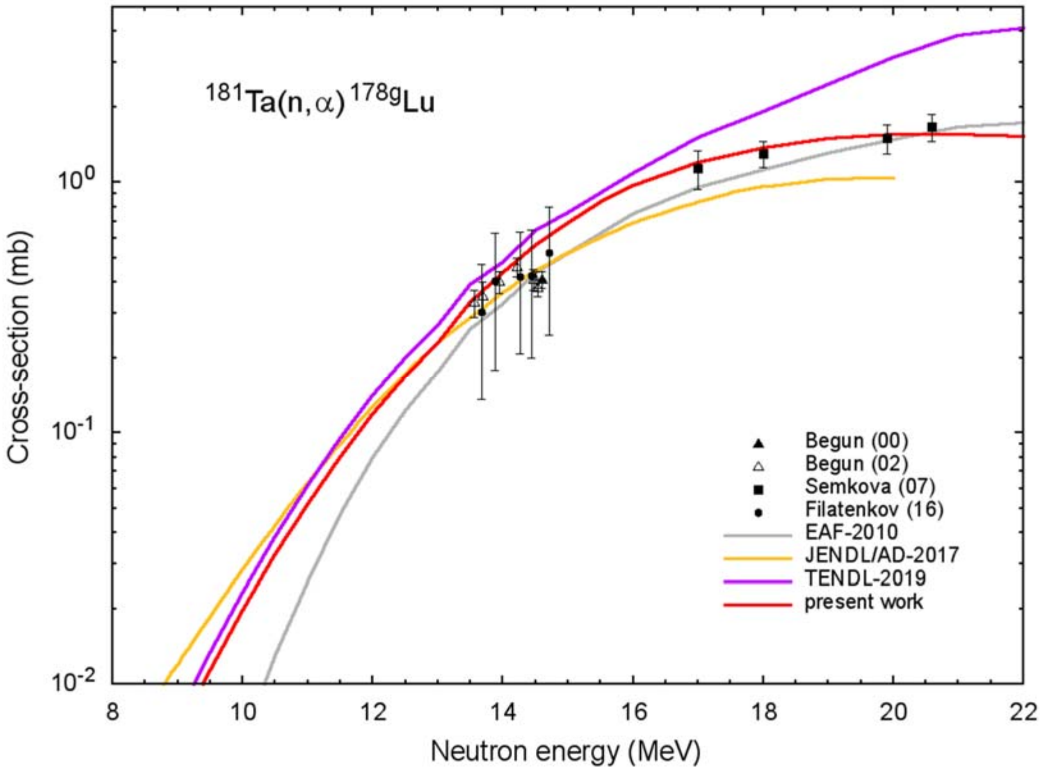


Fig.45 Cross-section for $^{181}$Ta(n,α)$^{178g}$Lu reaction.

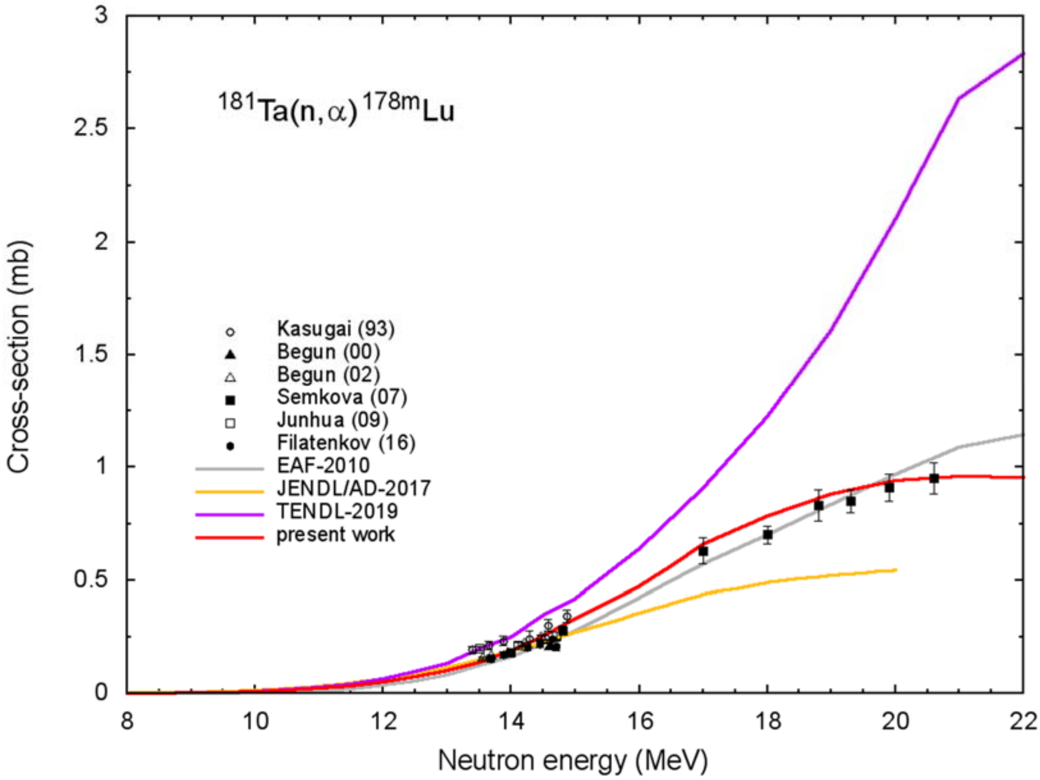


Fig.46 Cross-section for $^{181}$Ta(n,α)$^{178m}$Lu reaction.

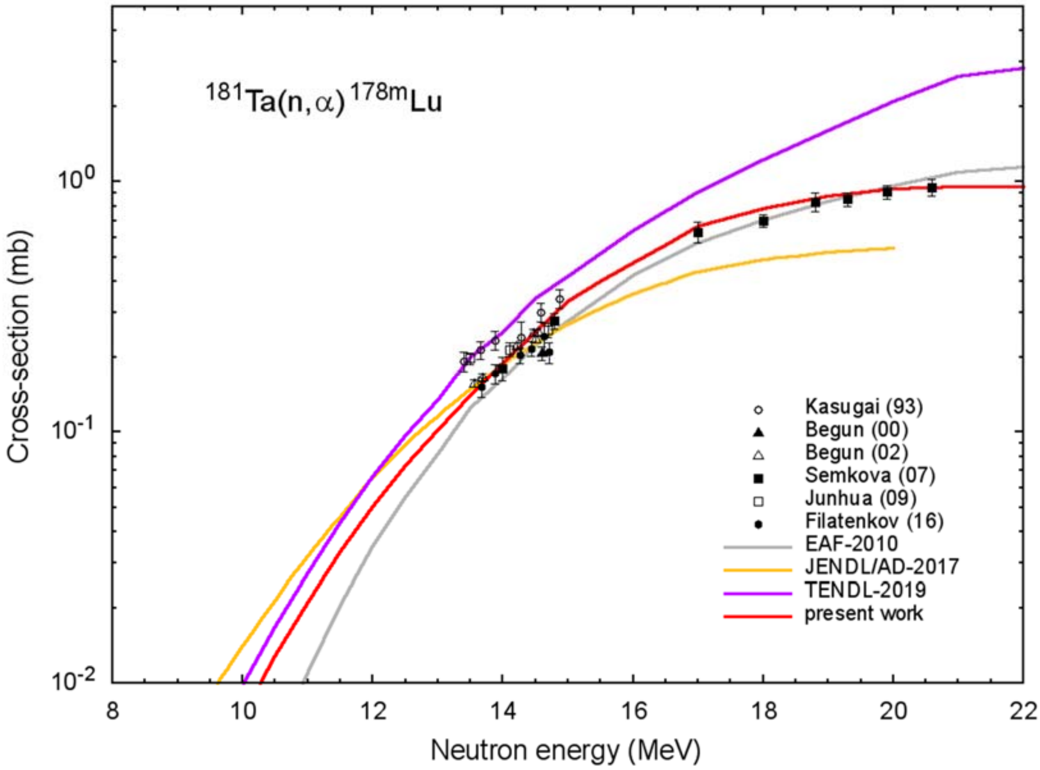


Fig.47 Cross-section for $^{181}Ta(n,\alpha)^{178m}Lu$ reaction.

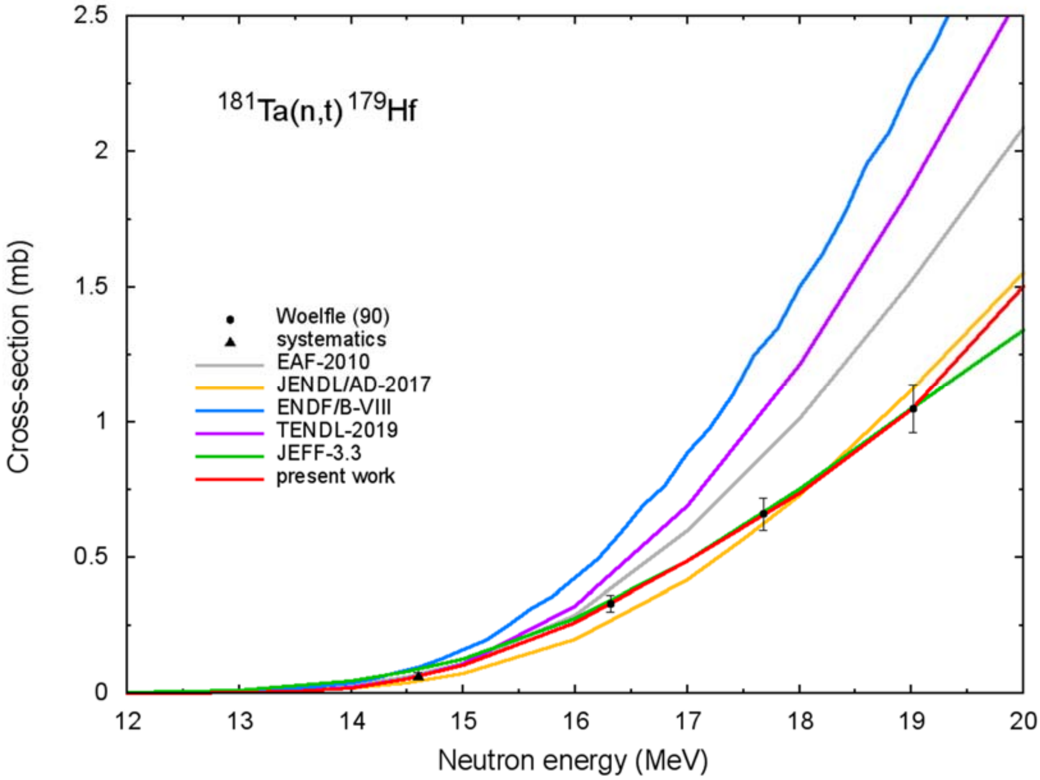


Fig.48 Cross-section for (n,t) reaction.

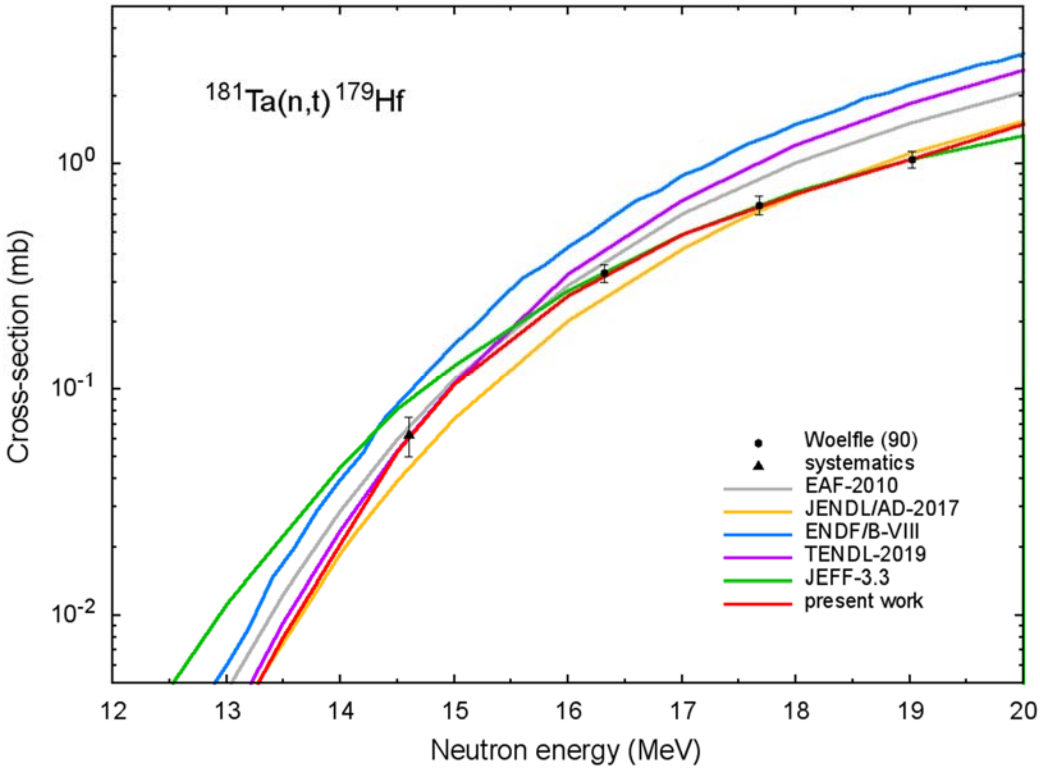


Fig.49 Cross-section for (n,t) reaction.

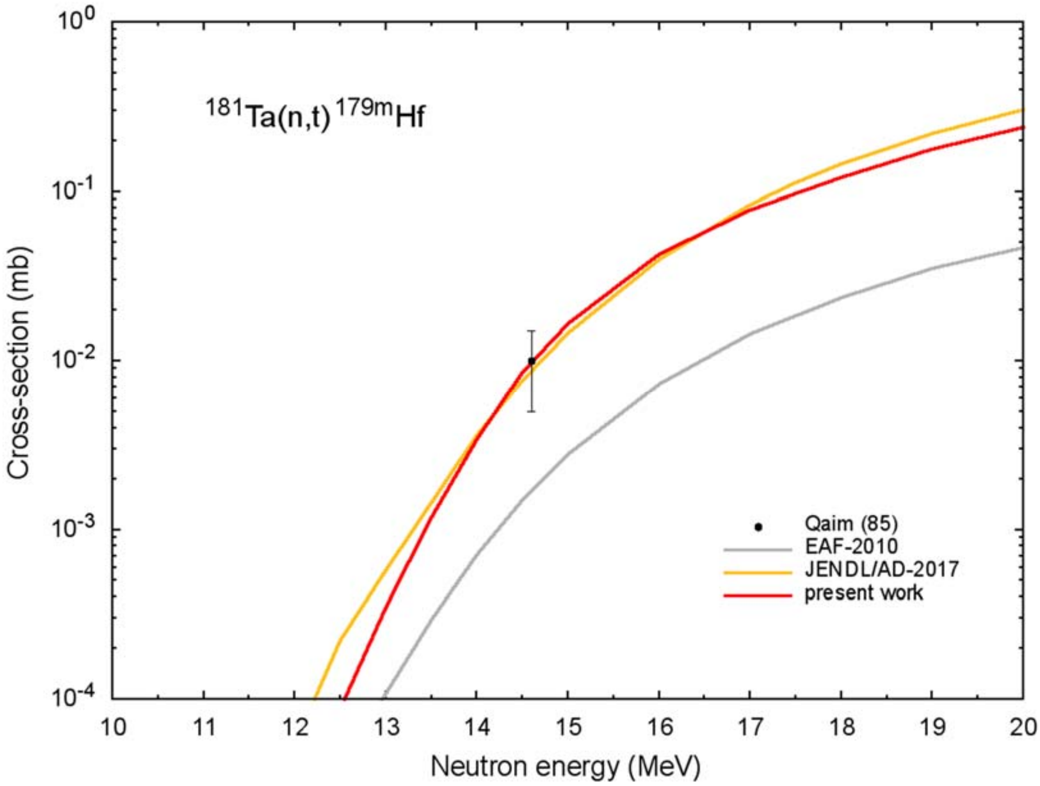


Fig.50 Cross-section for $^{181}Ta(n,t)^{179m}Lu$ reaction.

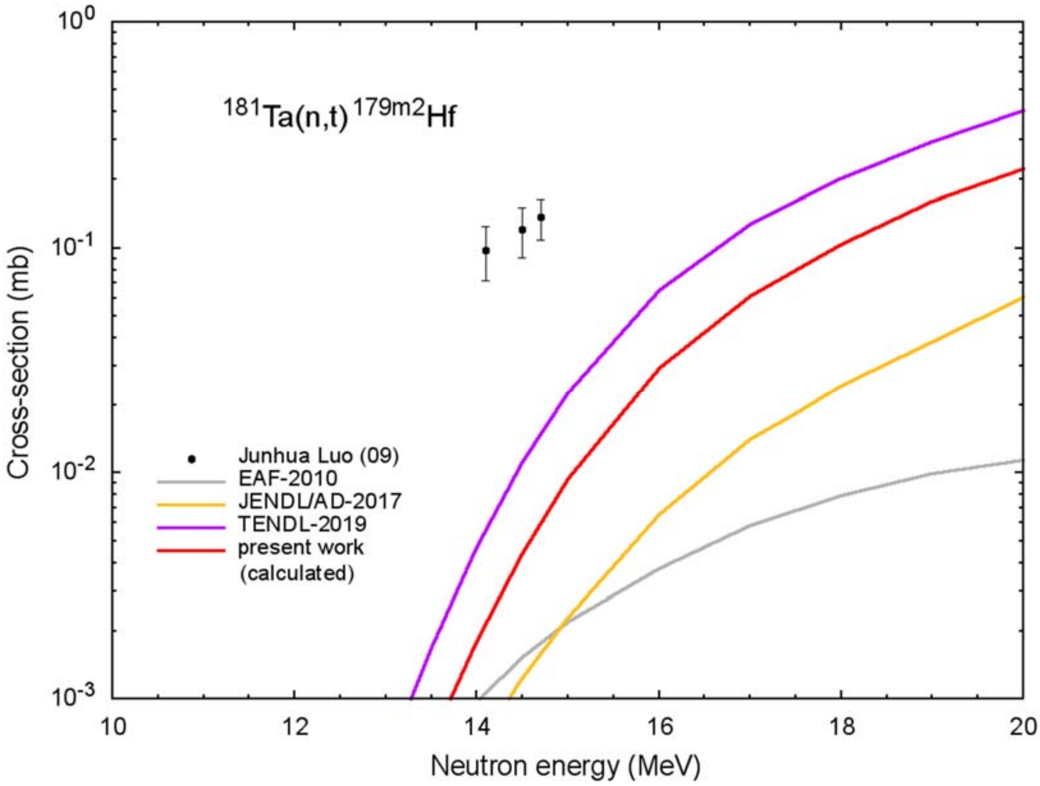


Fig.51 Cross-section for $^{181}Ta(n,t)^{179m2}Lu$ reaction.

Another comparison of the evaluated and experimental neutron energy distributions, as well as an illustration of the scatter of evaluated data from various libraries are given in the Appendix, Figs. A45-A60.

### *3.6 Photon energy distribution*

Examples of obtained photon energy distributions for neutron irradiation of $^{181}Ta$ are shown in Figs.60,61.

The spectra have been calculated using the SPKA7 code [219].

The photon spectra obtained in this work are included in the file dated October 2020. It cannot be ruled out that the values will be changed in the future.

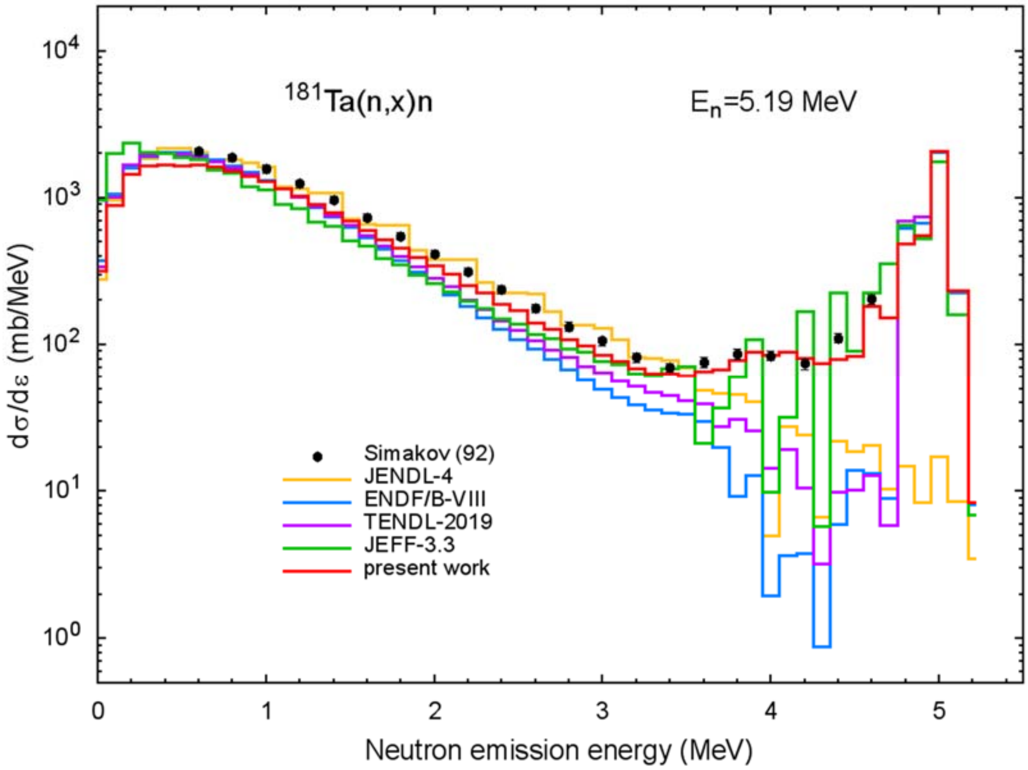


Fig.52 Neutron energy distribution for 5.19 MeV incident neutrons.

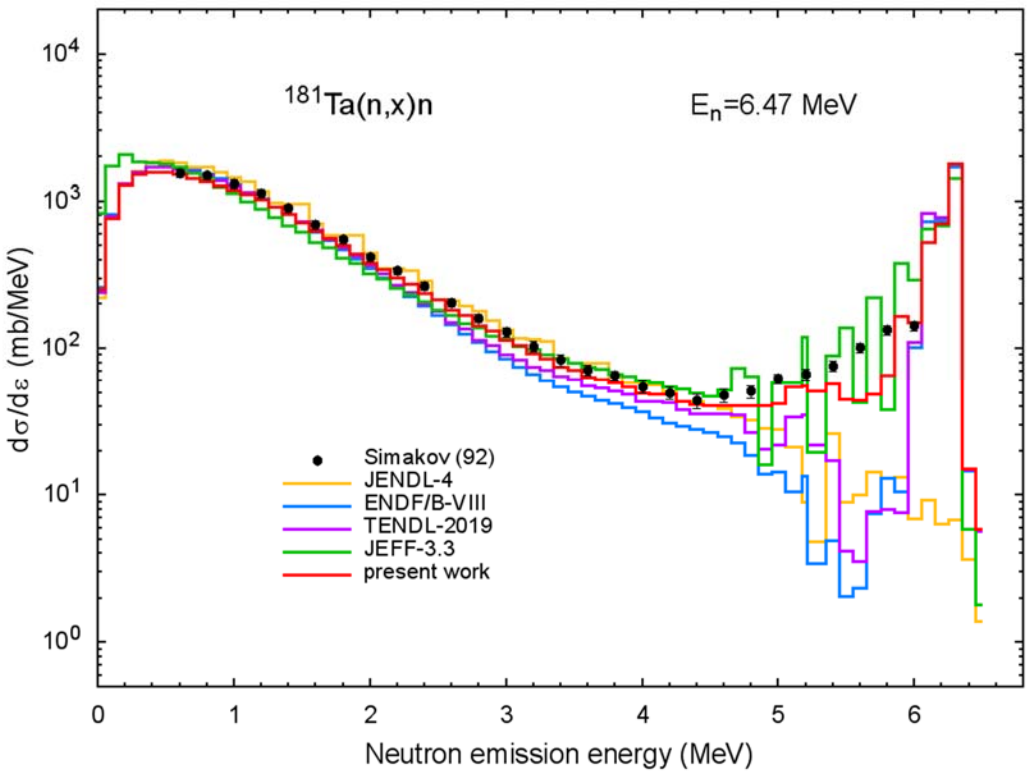


Fig.53 Neutron energy distribution for 6.47 MeV incident neutrons.

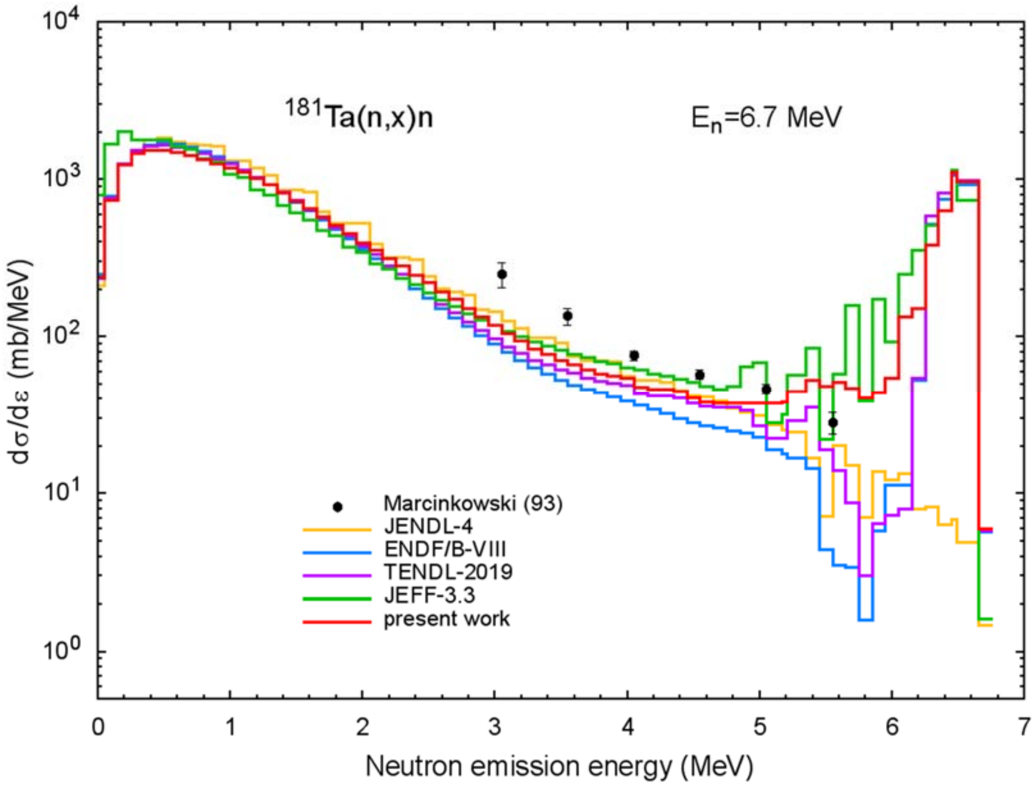


Fig.54 Neutron energy distribution for 6.7 MeV incident neutrons.

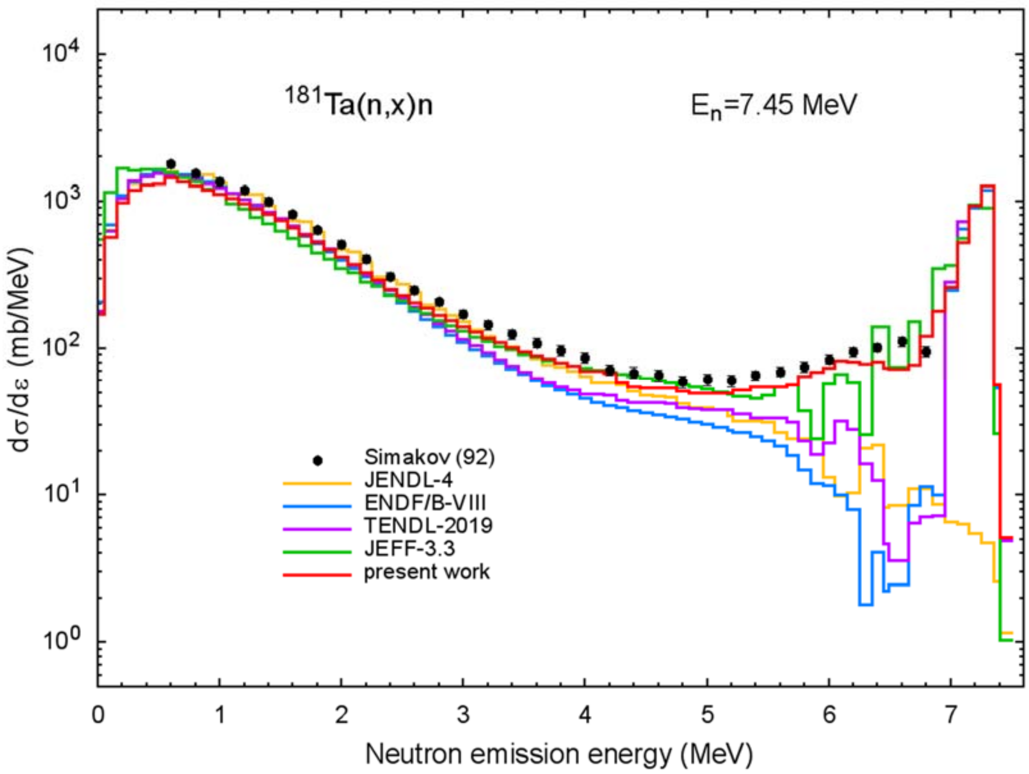


Fig.55 Neutron energy distribution for 7.45 MeV incident neutrons.

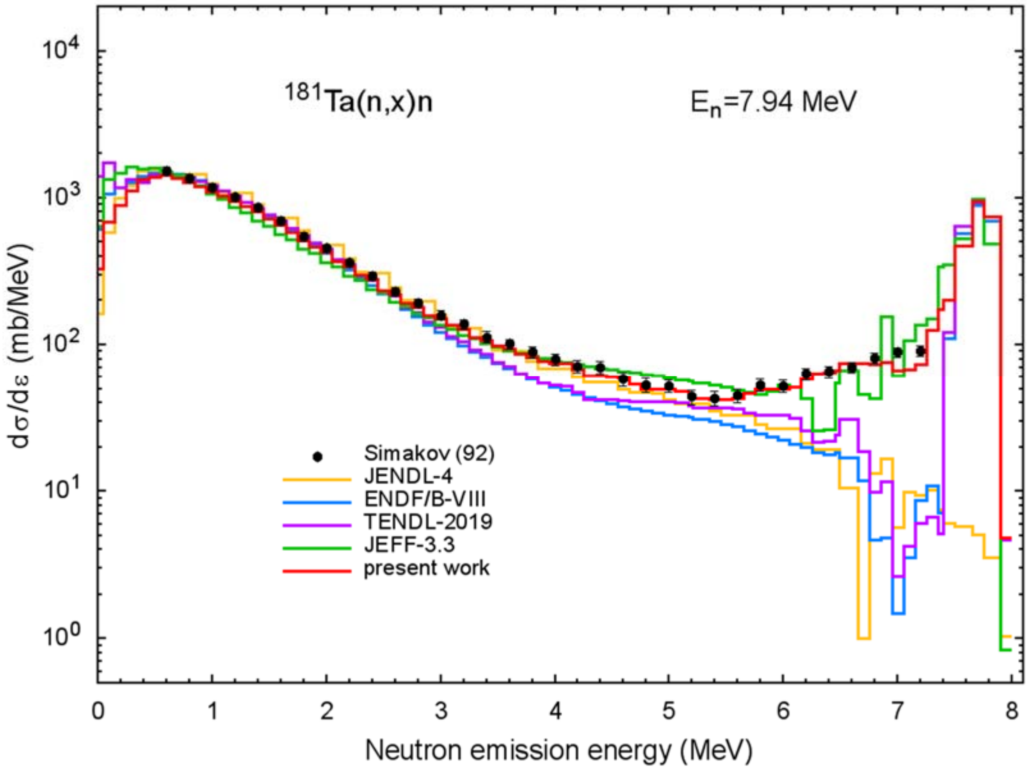


Fig.56 Neutron energy distribution for 7.94 MeV incident neutrons.

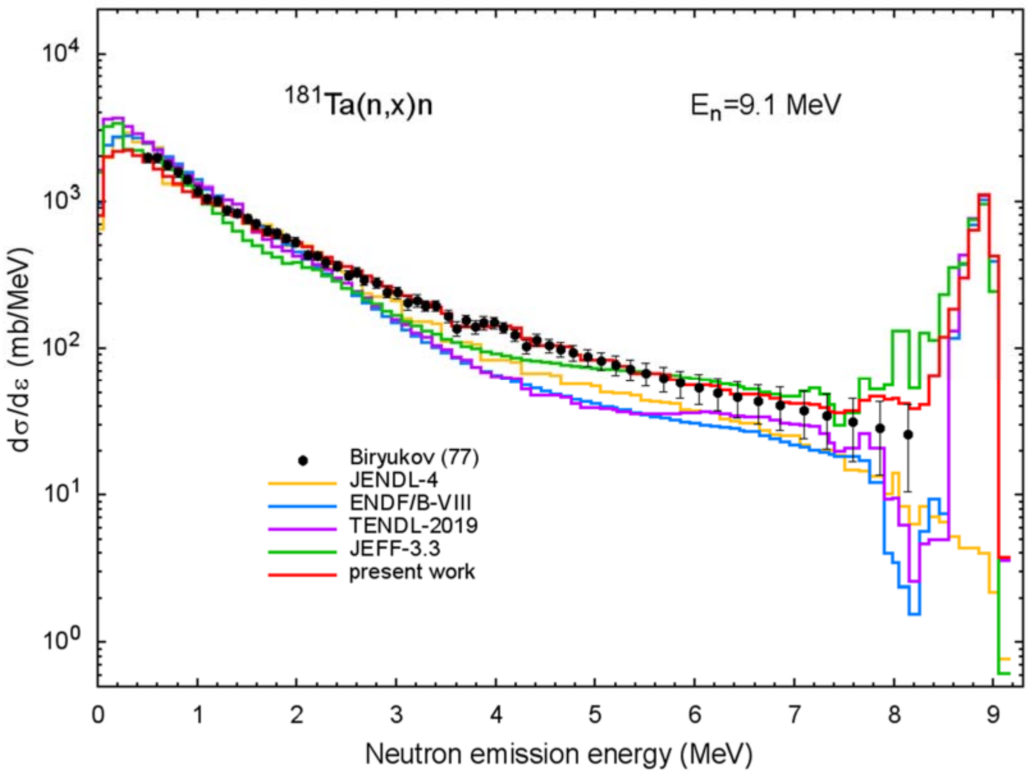


Fig.57 Neutron energy distribution for 9.1 MeV incident neutrons.

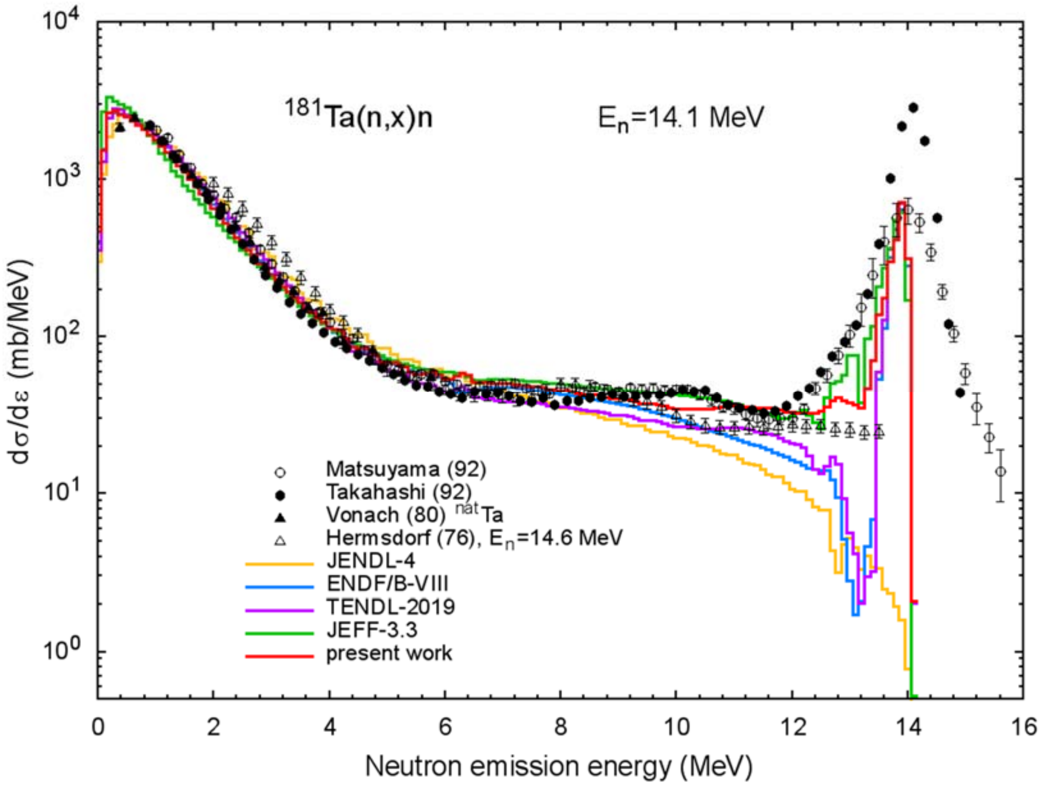


Fig.58 Neutron energy distribution for 14.1 MeV incident neutrons.

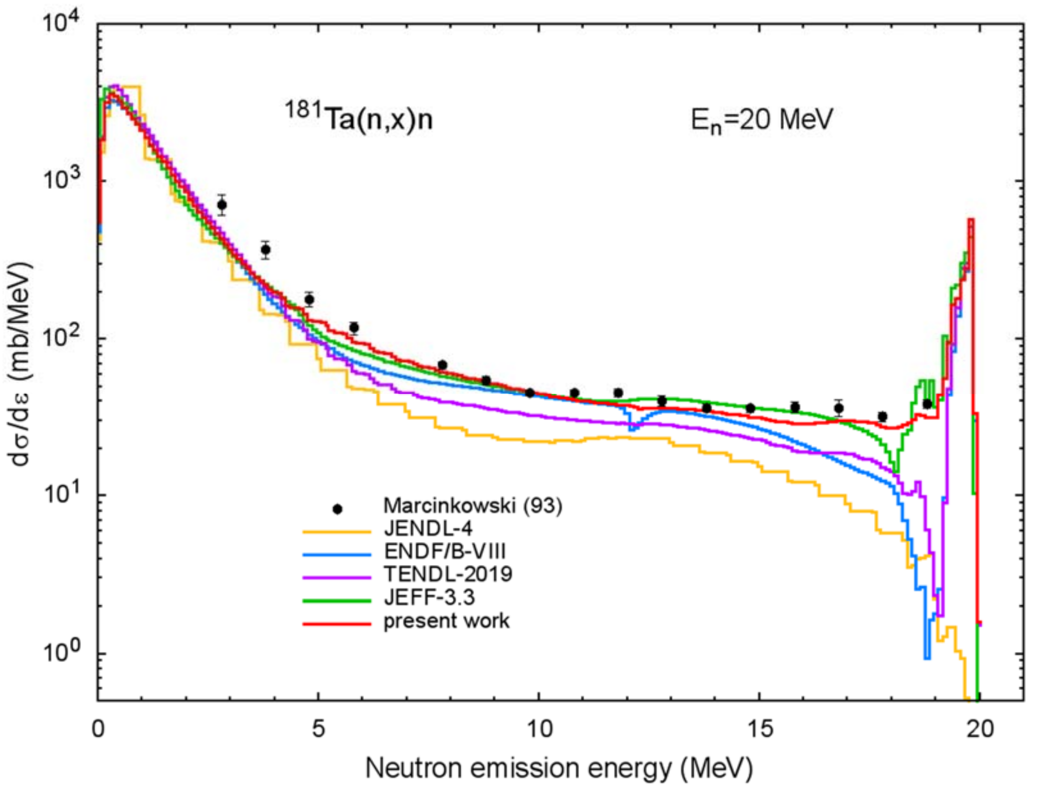


Fig.59 Neutron energy distribution for 20 MeV incident neutrons.

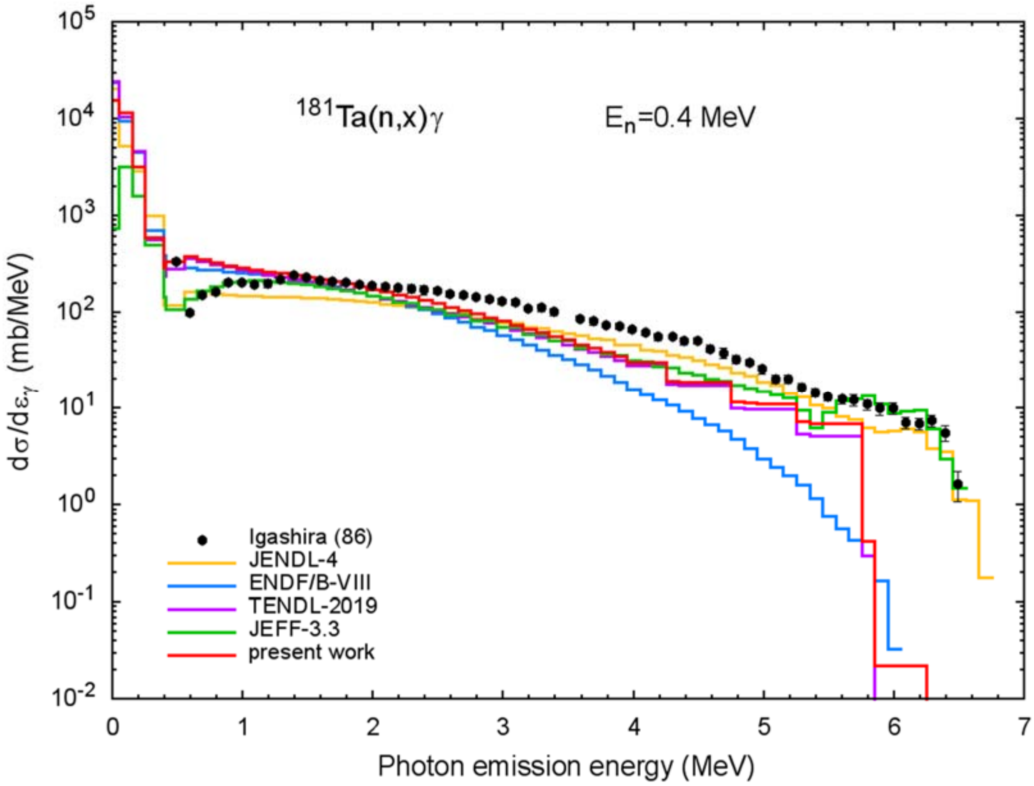


Fig.60 Photon energy distribution for 0.4 MeV incident neutrons.

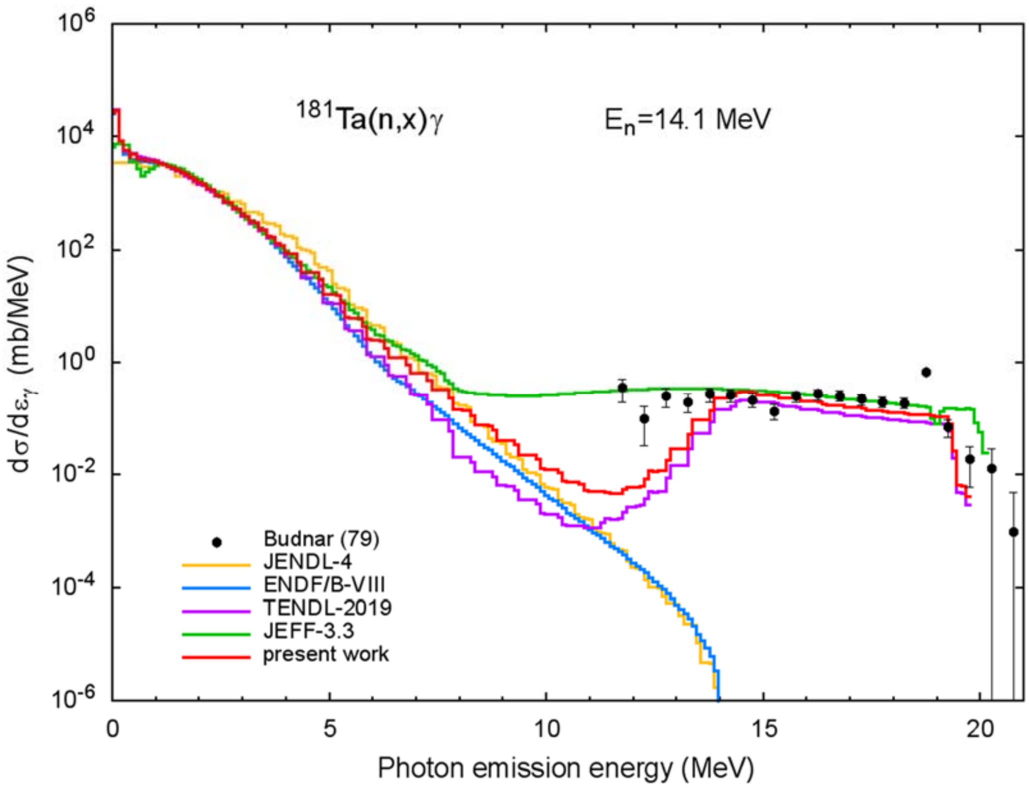


Fig.61 Photon energy distribution for 14.1 MeV incident neutrons.

### *3.7 Light particle production cross-sections*

Evaluated neutron-, proton-, deuteron-, triton-, $^{3}$He-, and α-particle production cross-sections are shown in Figs.62-67.

For illustration, Figs.62-67 show systematics data at 96 MeV [204], cross-sections from different libraries and results of calculations performed with the intranuclear cascade evaporation model implemented in the CASCADE code [220,221], DISCA-C code [222], and PHITS 3.22 code [223], and intranuclear cascade model combined with pre-equilibrium exciton and evaporation models implemented in the CEM03 code [224,225].

In general, the energy dependence of obtained cross sections seems reasonable.

The calculated light charged particle production cross-sections are shown in the Appendix, Figs.A61-A65.

### *3.8 Photon production cross-sections*

Total photon production cross-section is shown in Fig.68 above resonance energy range.

The spread of the values obtained by different authors is quite large.

### *3.9 Fission cross-section and fission product yields*

Fission reaction cross sections were calculated using the CEM03 and PHITS 3.22 codes. Calculations with PHITS were performed using two sets of input parameters, default, and with a value of “ifission” equal to 2. The evaluated (n,f) cross-sections were obtained using experimental data from Ref.[174]. The fission cross sections is shown in Fig.69.

The fission product yields were evaluated as follows: i) the yields calculated using CEM and PHITS with two values of the input parameter “ifission” equal to 1 and 2 were normalized to the evaluated (n,f) cross-section (Fig.69); ii) yields obtained by various methods were averaged; 3) the curves for nuclide yields were smoothed using the code from Ref.[226], if necessary; (4) the obtained fission product yields were normalized again using evaluated values of (n,f) cross section.

An example of the obtained mass distributions of fission products is shown in Fig.70 for the three incident neutron energies.

The yields and fission cross sections were recorded in the file MF=10, MT=18. To record the fission cross-section, the value of the IZAP parameter was formally set to 180000.

### *3.10 Atomic displacement cross-section*

Figure 71 shows obtained displacement cross-sections together with data from different libraries and the results of calculation. To obtain cross-sections, the data of the libraries have been processed with the program NJOY. The calculated displacement cross-sections for elastic neutron scattering have been added to cross-sections calculated with CASCADE, DISCA-C, and CEM03 codes.

### *3.11 Covariance matrices*

Obtained cross-sections were provided with covariance information. Fig.72 shows examples of calculated covariance matrices for the inelastic scattering cross-section and (n,2n) reaction cross-section.

## 4. CONCLUSION

New general purpose data files was prepared for $^{181}$Ta at incident neutron energies up to 200 MeV. The data evaluation has been performed using the results of calculations, available measured data, systematics predictions, and applying a covariance information.

Calculations have been performed using a special version of the TALYS-1.95 code implementing the geometry dependent hybrid model and models for the non-equilibrium light cluster emission.

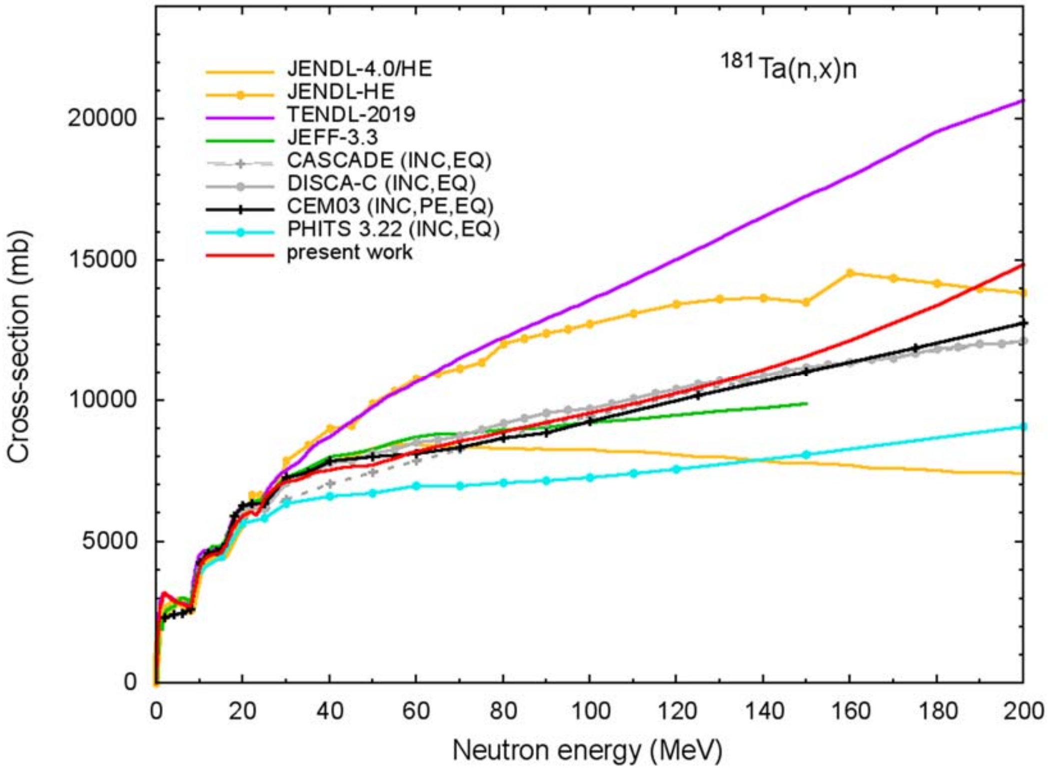


Fig.62 Neutron production cross-section.

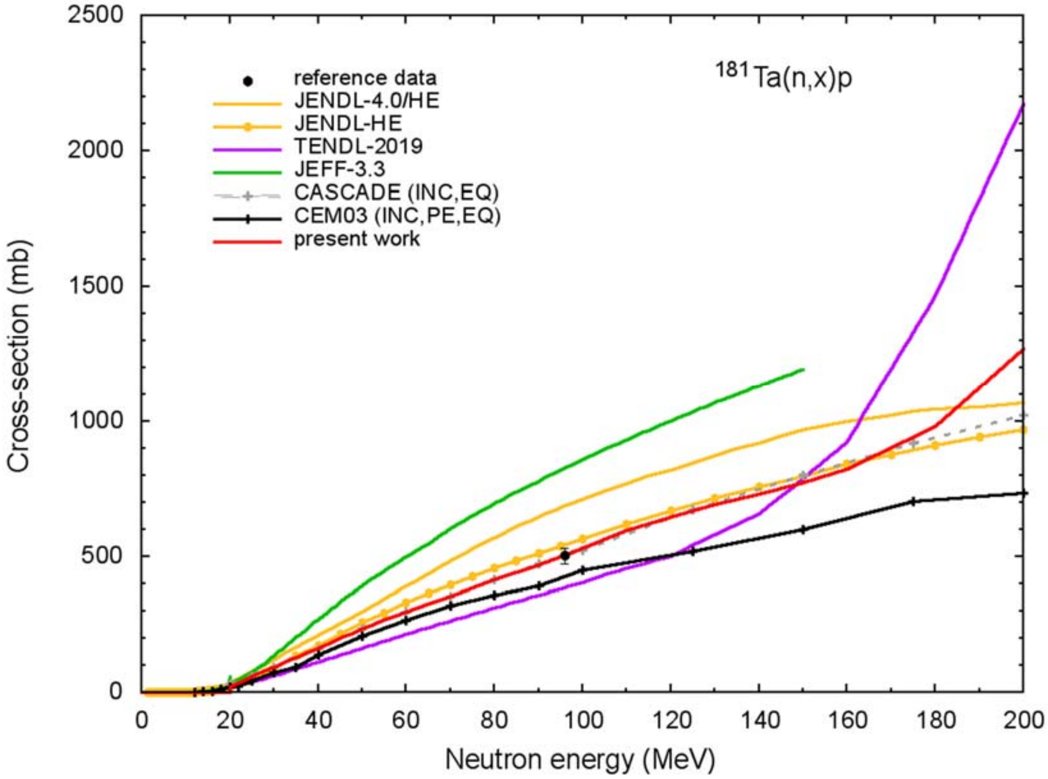


Fig.63 Proton production cross-section.

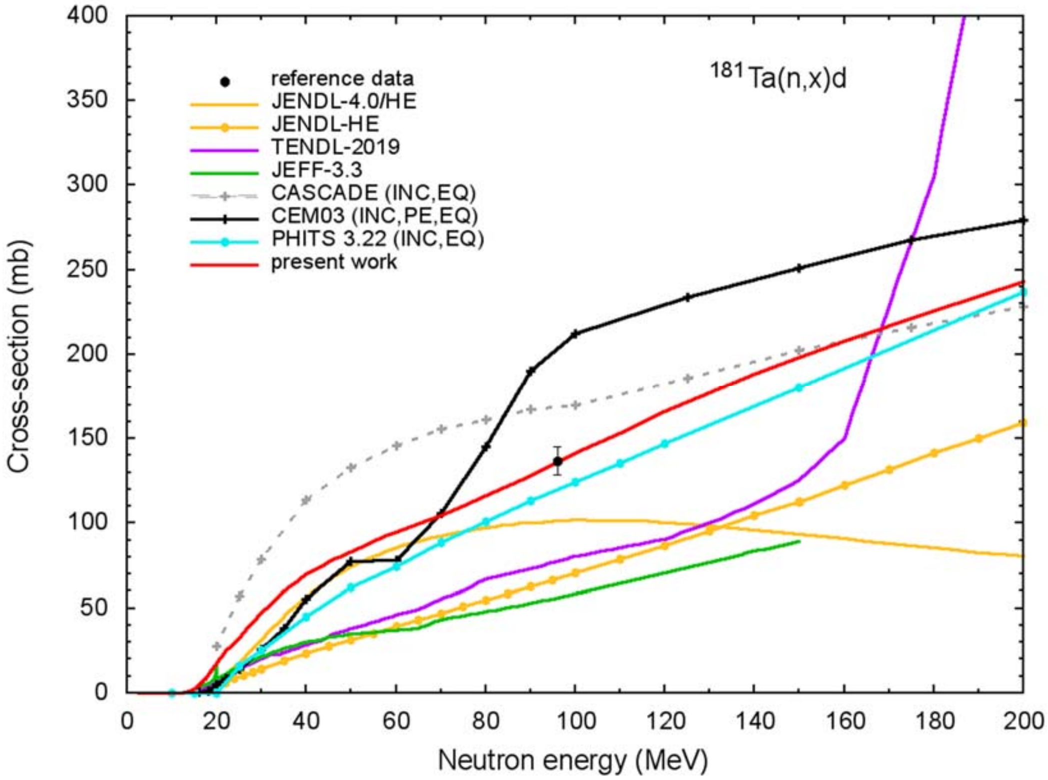


Fig.64 Deuteron production cross-section.

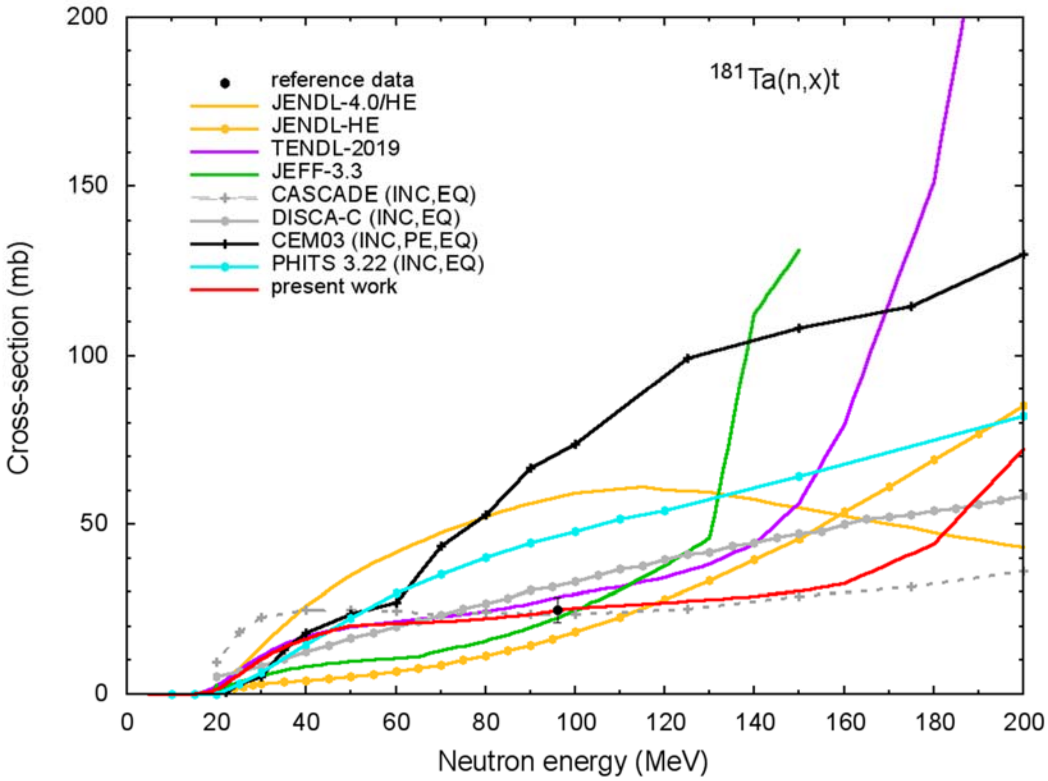


Fig.65 Triton production cross-section.

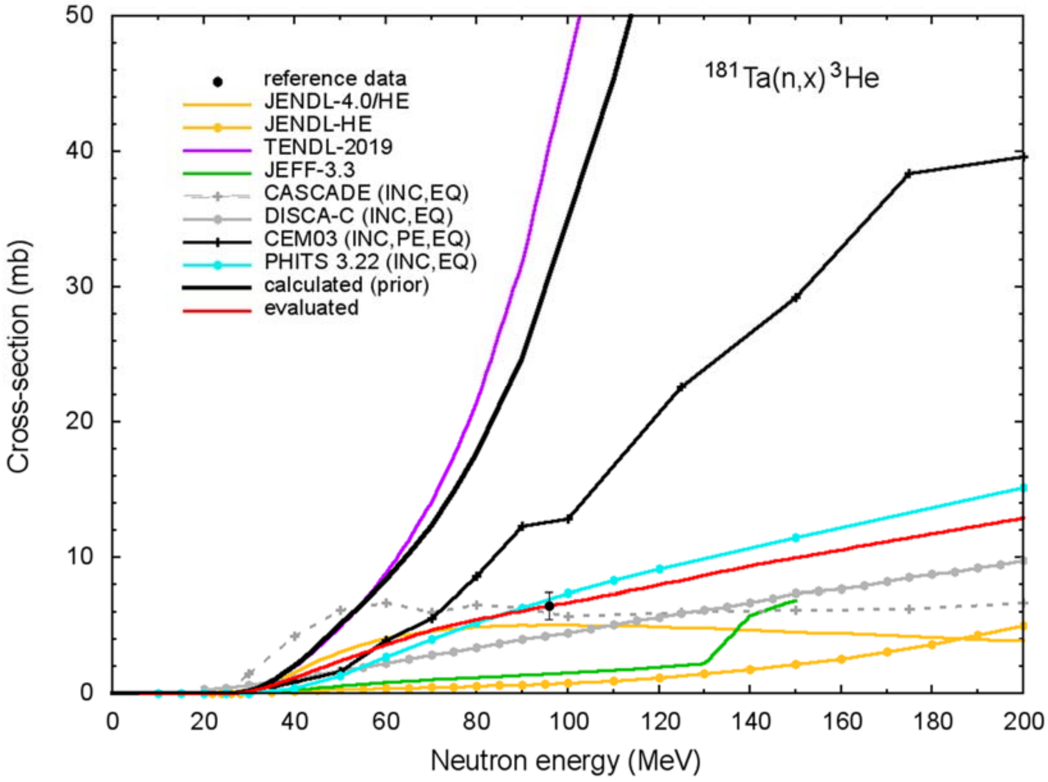


Fig.66 $^{3}$He production cross-section.

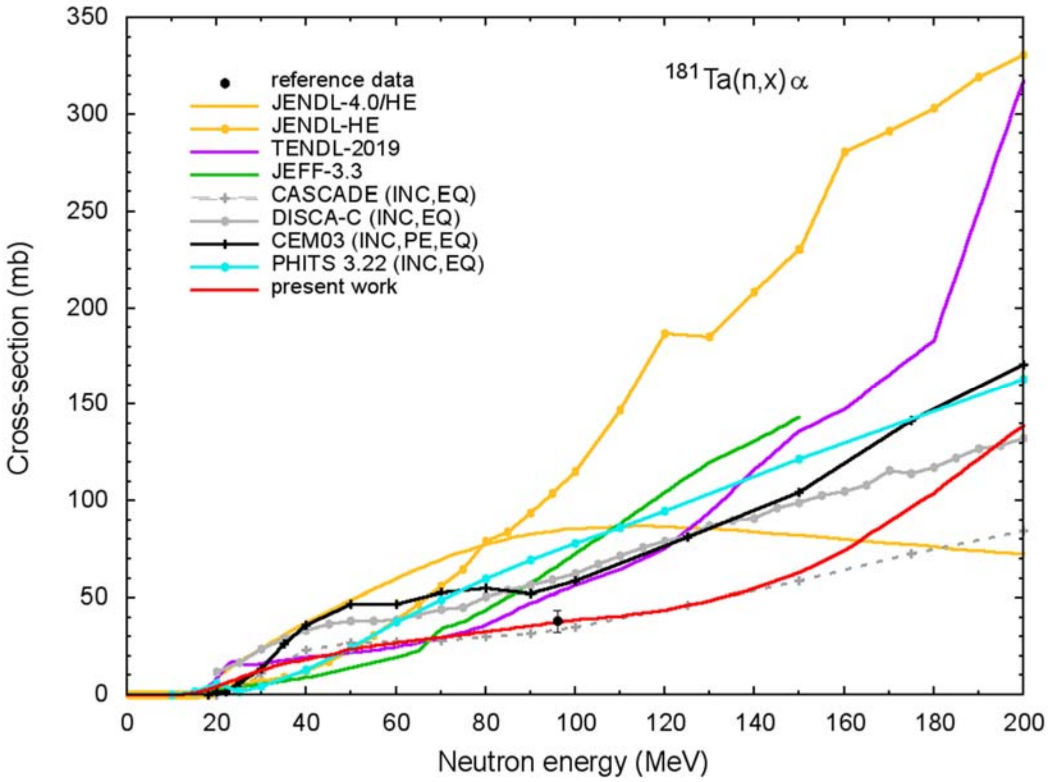


Fig.67 α-particle production cross-section.

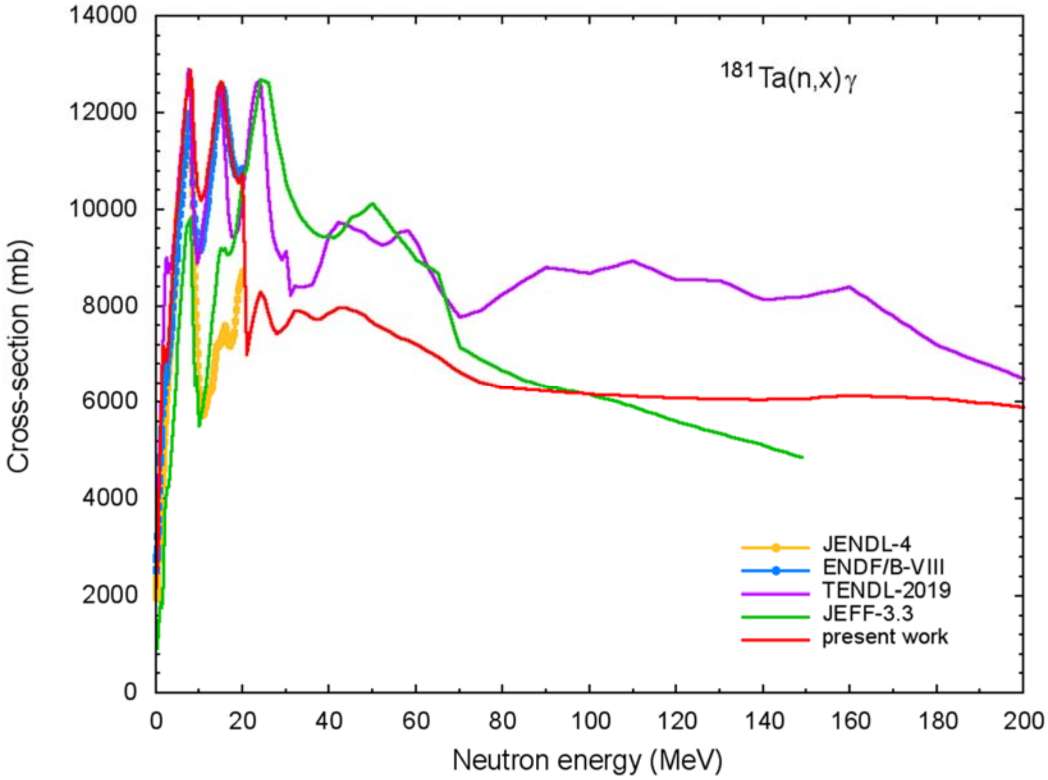


Fig.68 Photon production cross-section.

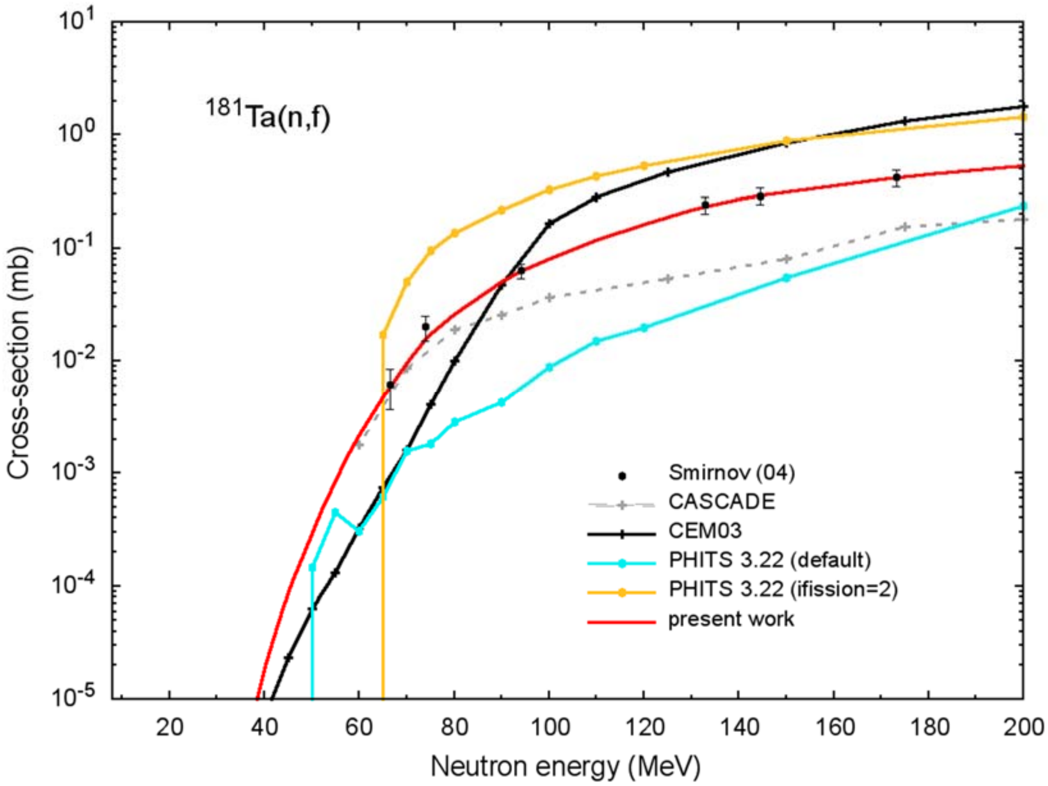


Fig.69 Fission cross-section calculated using different codes, measured in Ref.[174], and evaluated in the present work.

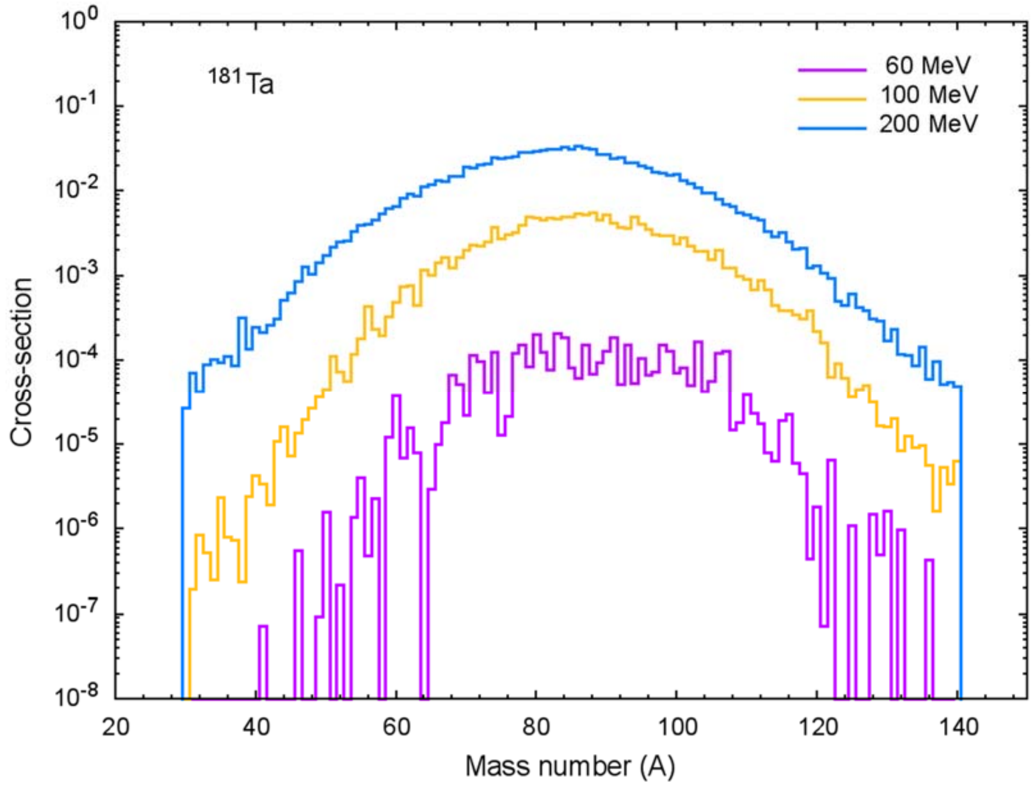


Fig.70 A-distribution of fission products evaluated in the present work at different incident neutron energies.

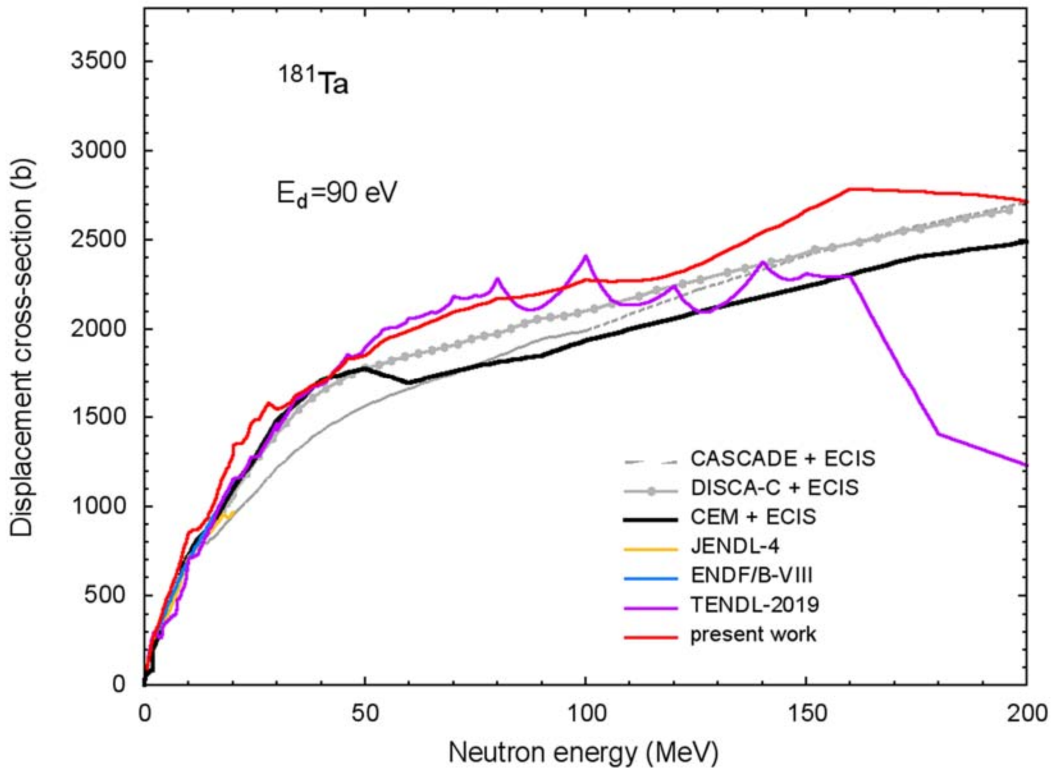


Fig.71 Atomic displacement cross-section.

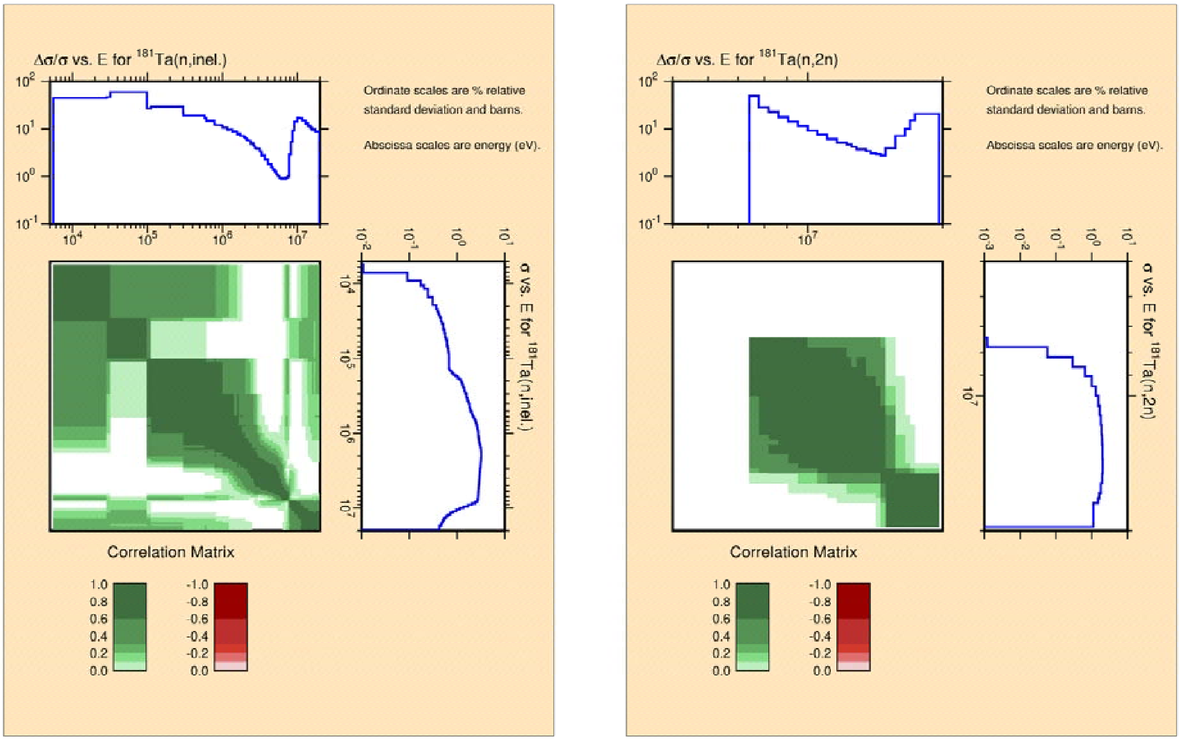


Fig.72 Example of covariance matrices calculated for neutron inelastic scattering cross-section (n,n)' and (n,2n) reaction cross-section. Plots were prepared using the NJOY code.


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## APPENDIX

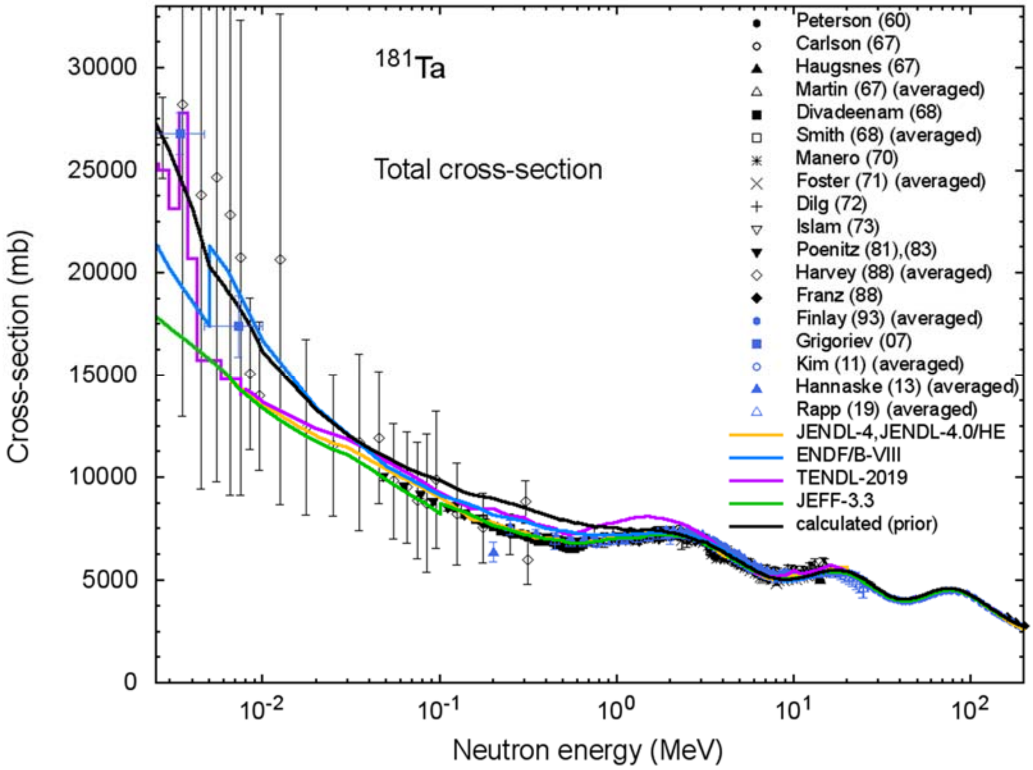


Fig.A1 Total cross-section for $^{181}$Ta at neutron incident energies from $2.5x10^{-3}$ MeV to 200 MeV. See explanations in the text.

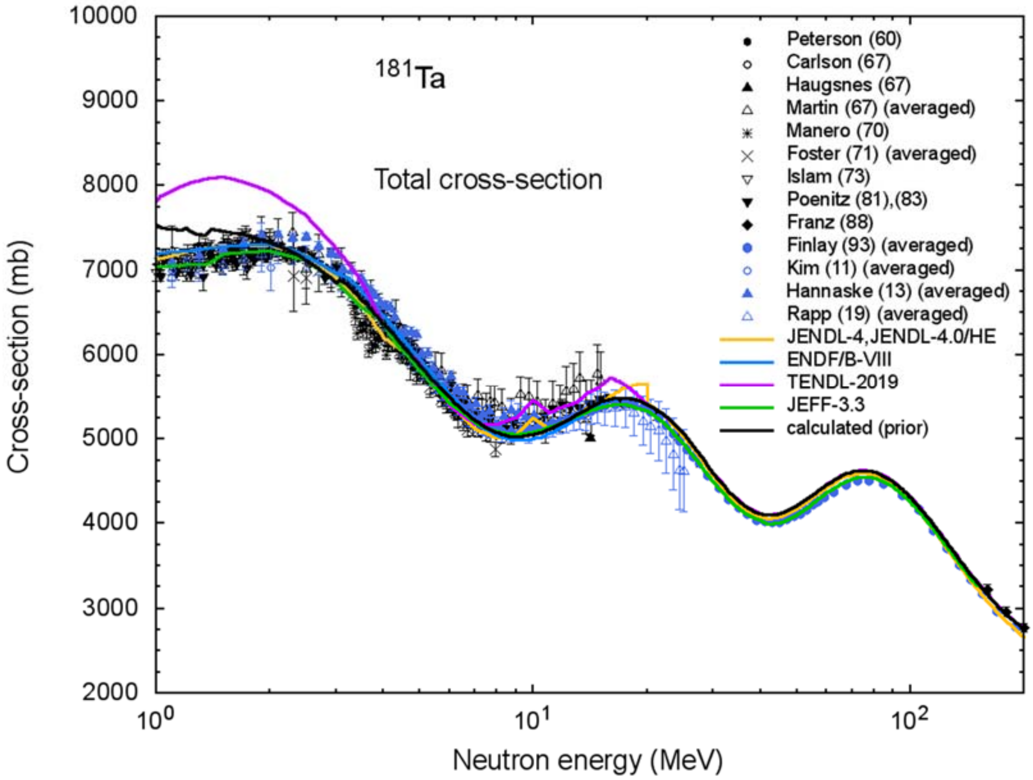


Fig.A2 Total reaction cross-section for neutron irradiation of $^{181}$Ta at neutron incident energies from 1 to 200 MeV.

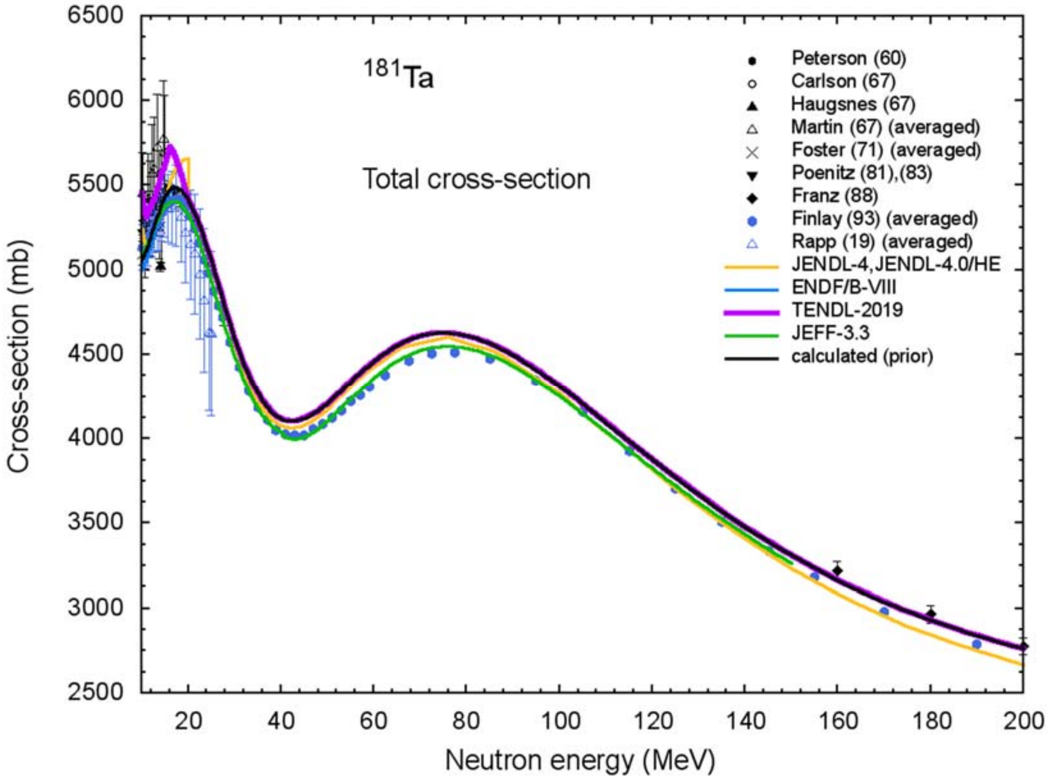


Fig.A3 Total reaction cross-section for neutron irradiation of $^{181}$Ta at neutron incident energies from 10 to 200 MeV.

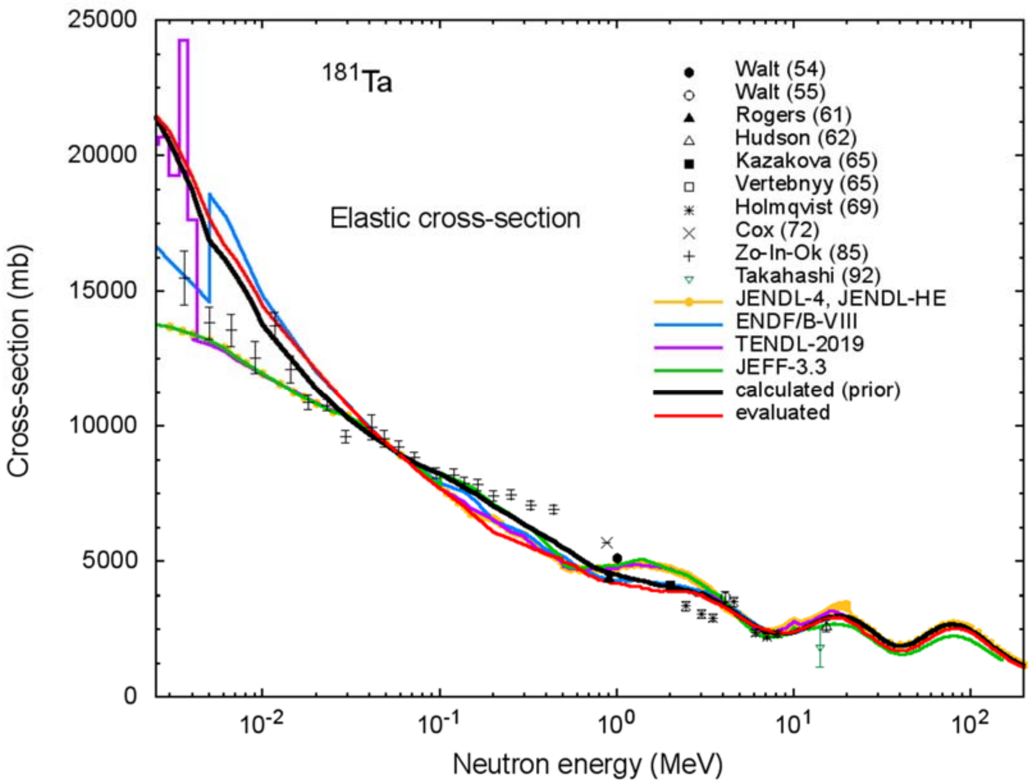


Fig.A4 Elastic cross-section for $^{181}$Ta at neutron incident energies from $2.5 \times 10^{-3}$ MeV to 200 MeV.

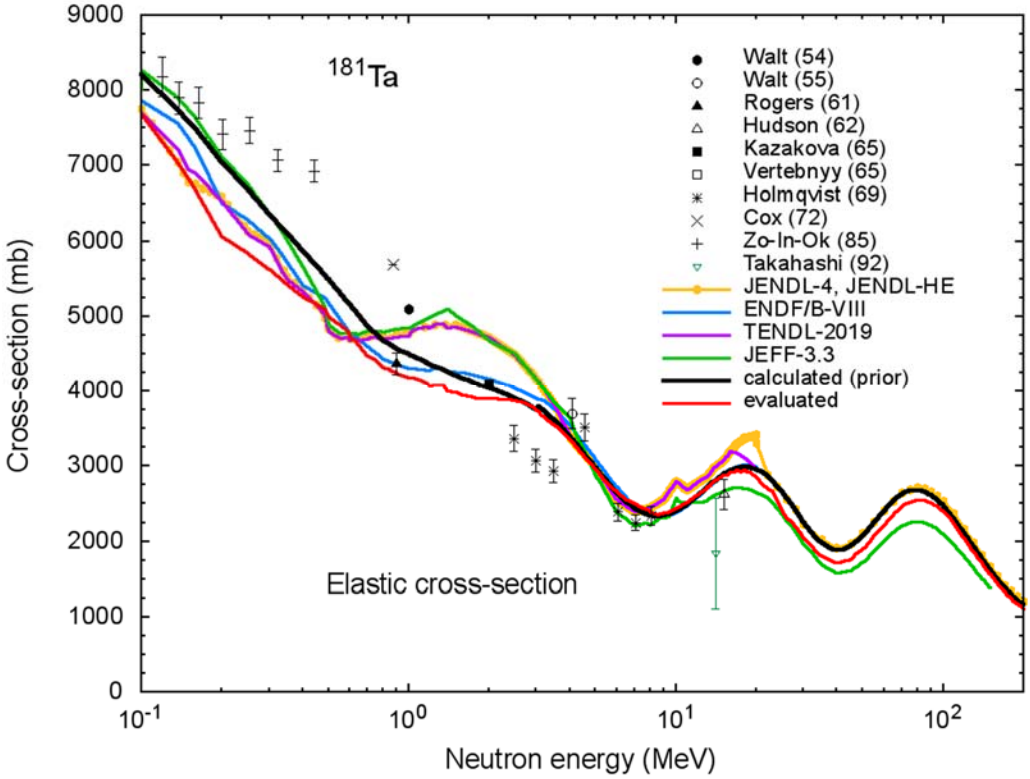


Fig.A5 Total cross-section for $^{181}$Ta at neutron incident energies from 0.1 MeV to 200 MeV.

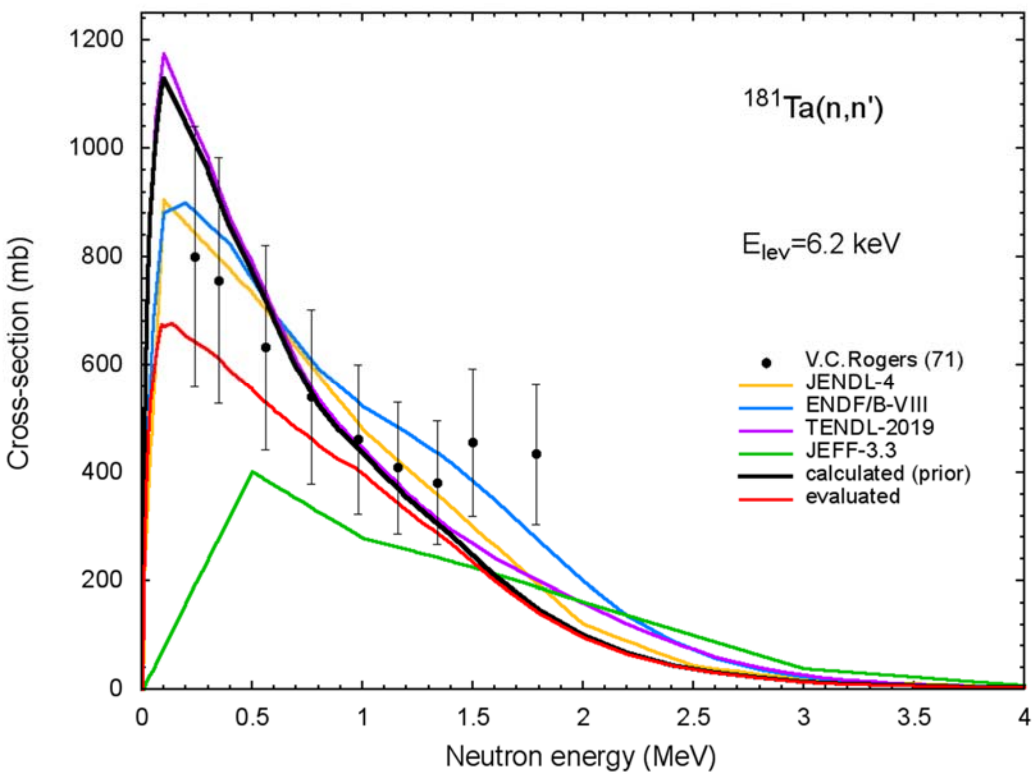


Fig.A6 The inelastic scattering cross-section with the excitation of the level 6.2 keV. The corresponding MT number is equal to 51.

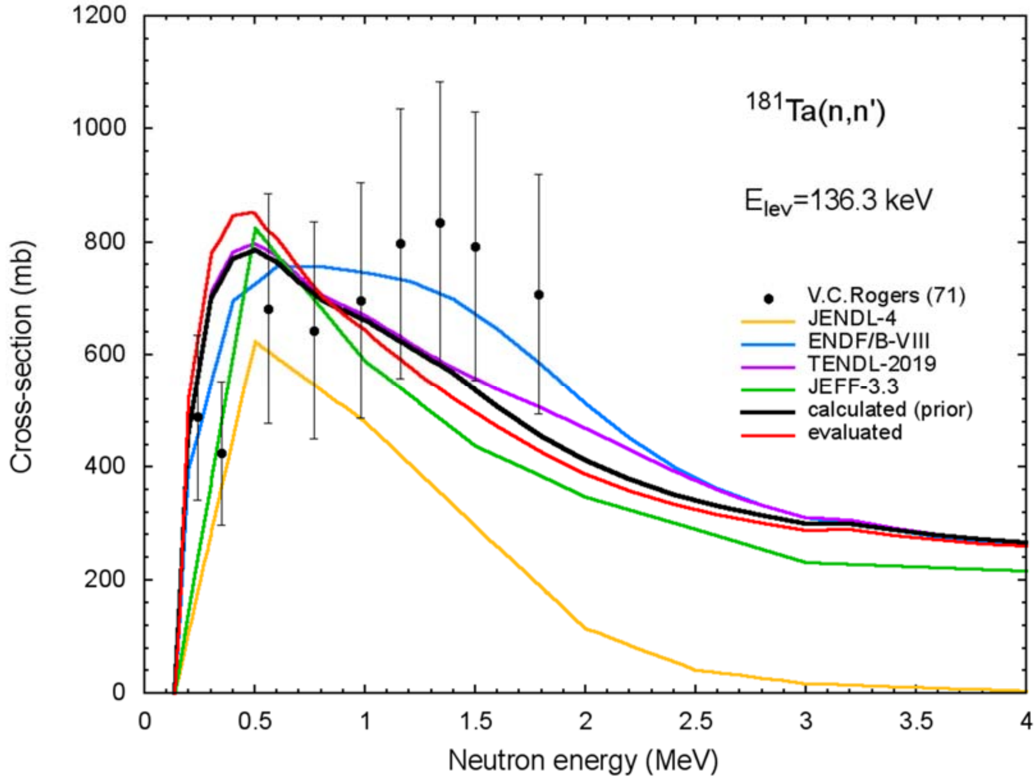


Fig.A7 The inelastic scattering cross-section with the excitation of the level 136.3 keV. The corresponding MT number is equal to 52.

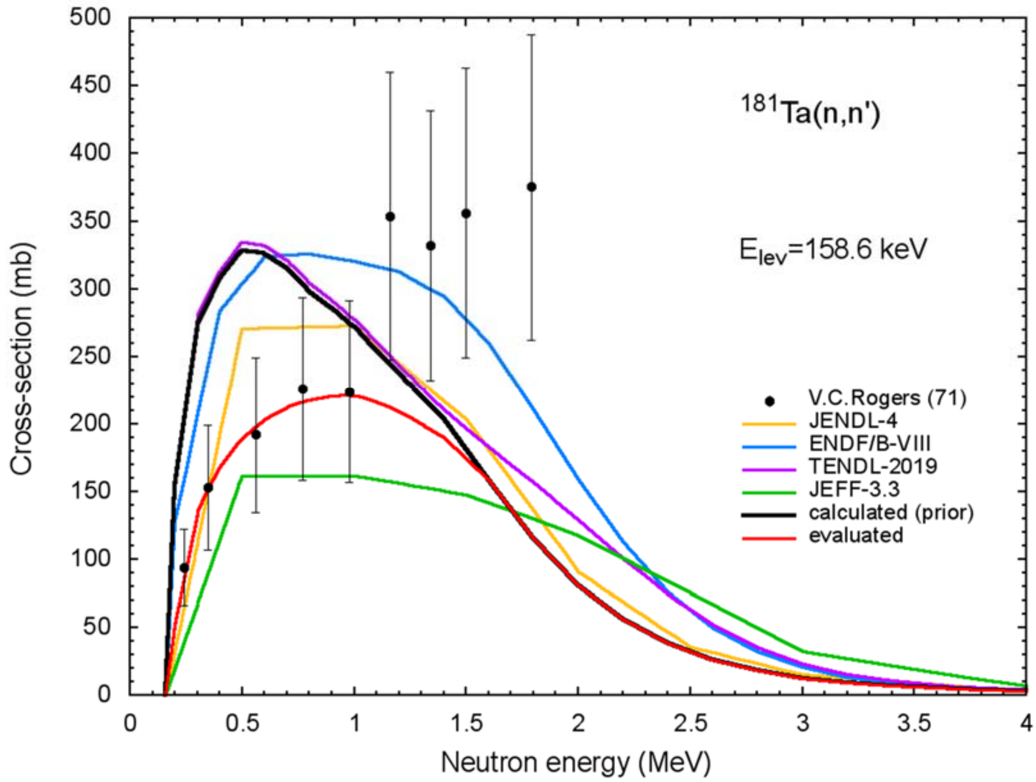


Fig.A8 The inelastic scattering cross-section with the excitation of the level 158.6 keV. The corresponding MT number is equal to 53.

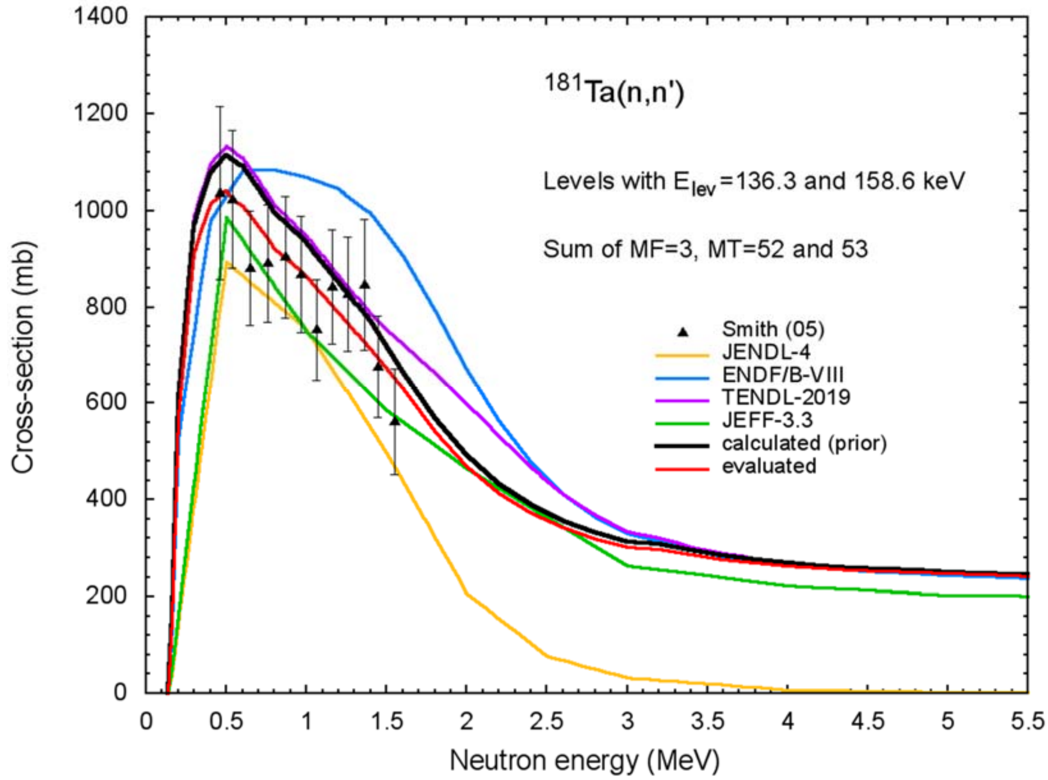


Fig.A9 The sum of inelastic scattering cross-section with MT numbers 52 and 53.

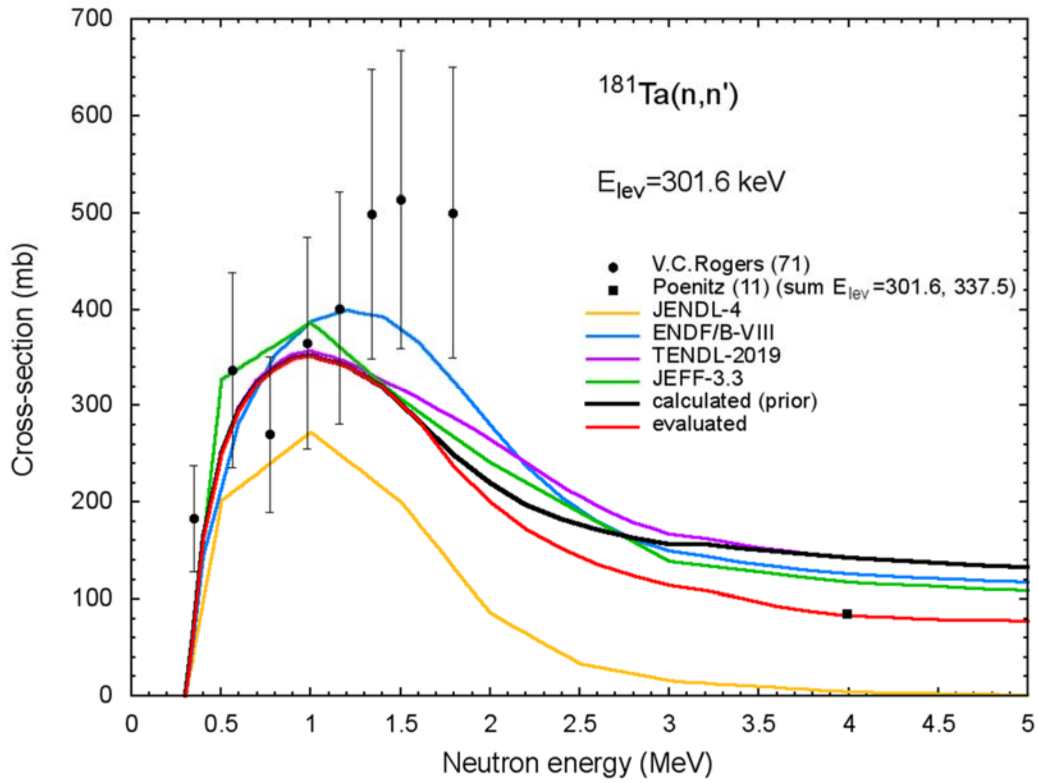


Fig.A10 The inelastic scattering cross-section with the excitation of the level 301.6 keV. The corresponding MT number is equal to 54

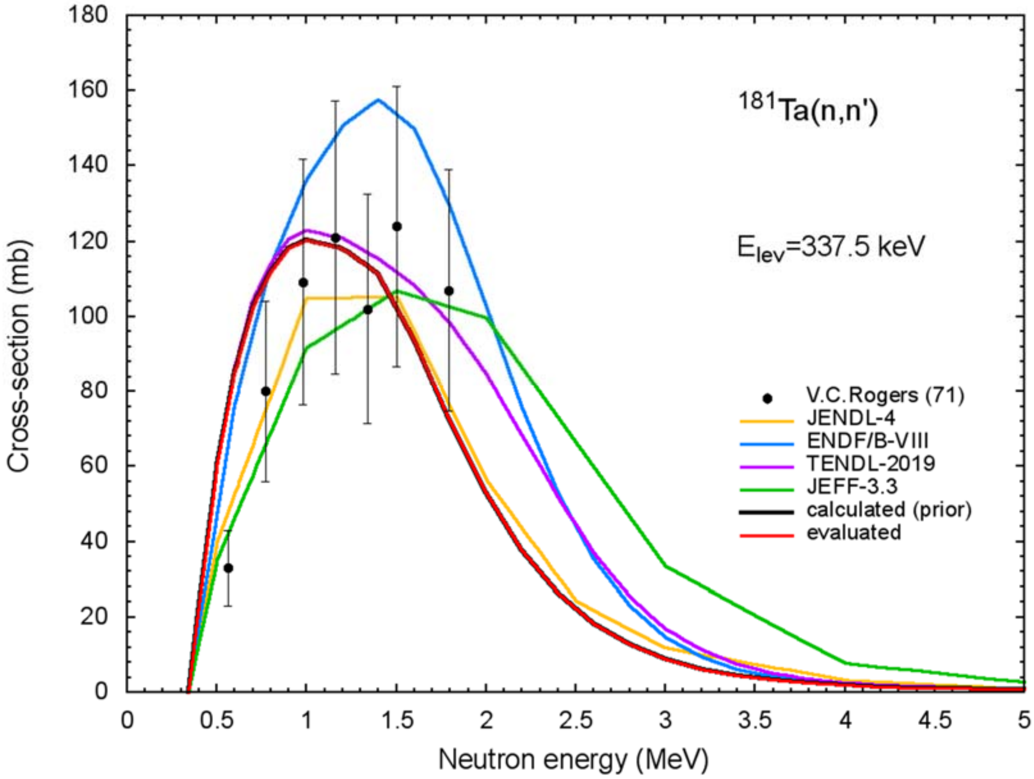


Fig.A11 The inelastic scattering cross-section with the excitation of the level 337.5 keV. The corresponding MT number is equal to 55.

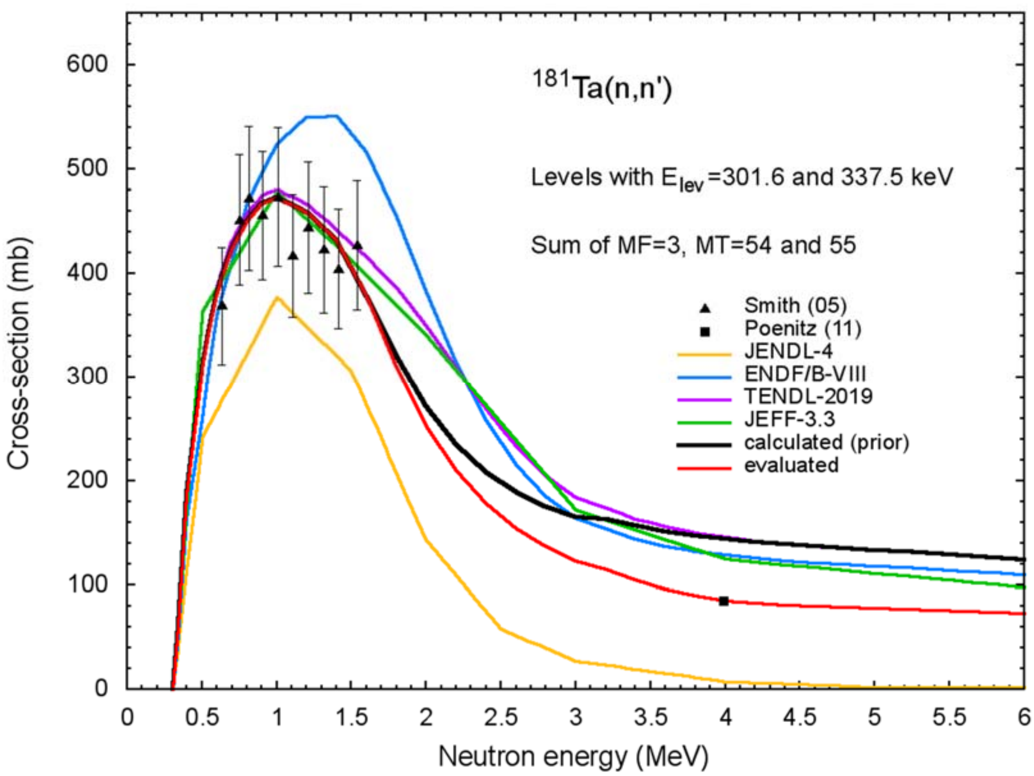


Fig.A12 The sum of inelastic scattering cross-section with MT numbers 54 and 55.

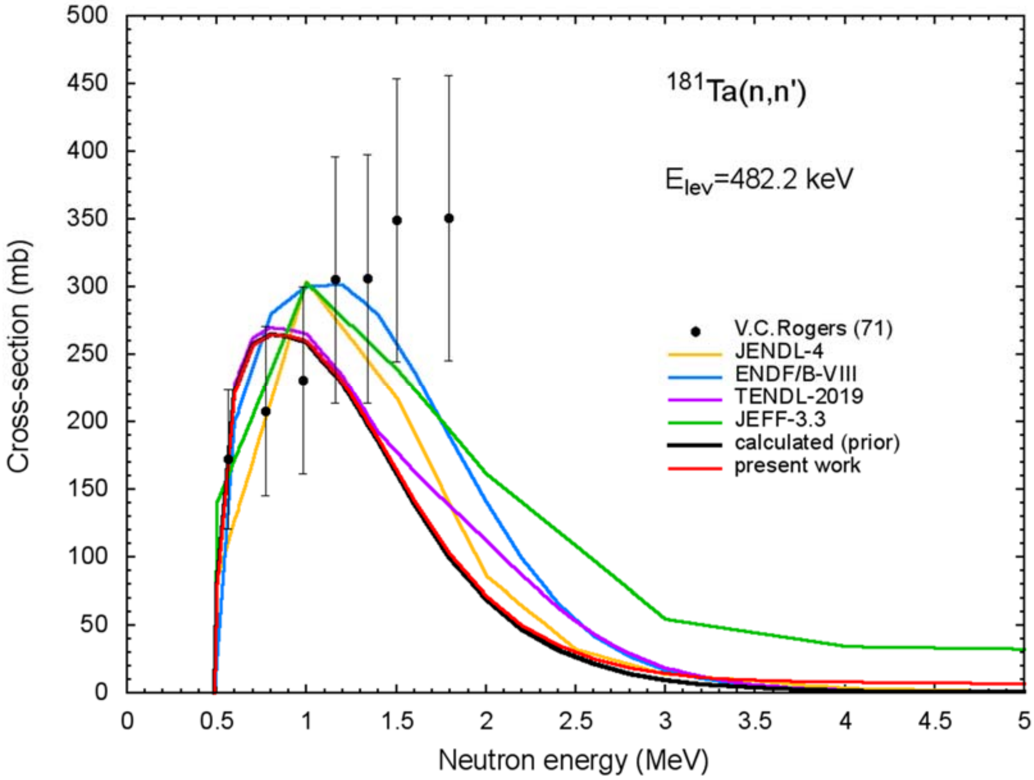


Fig.A13 The inelastic scattering cross-section with the excitation of the level 482.2 keV. The corresponding MT number is equal to 56.

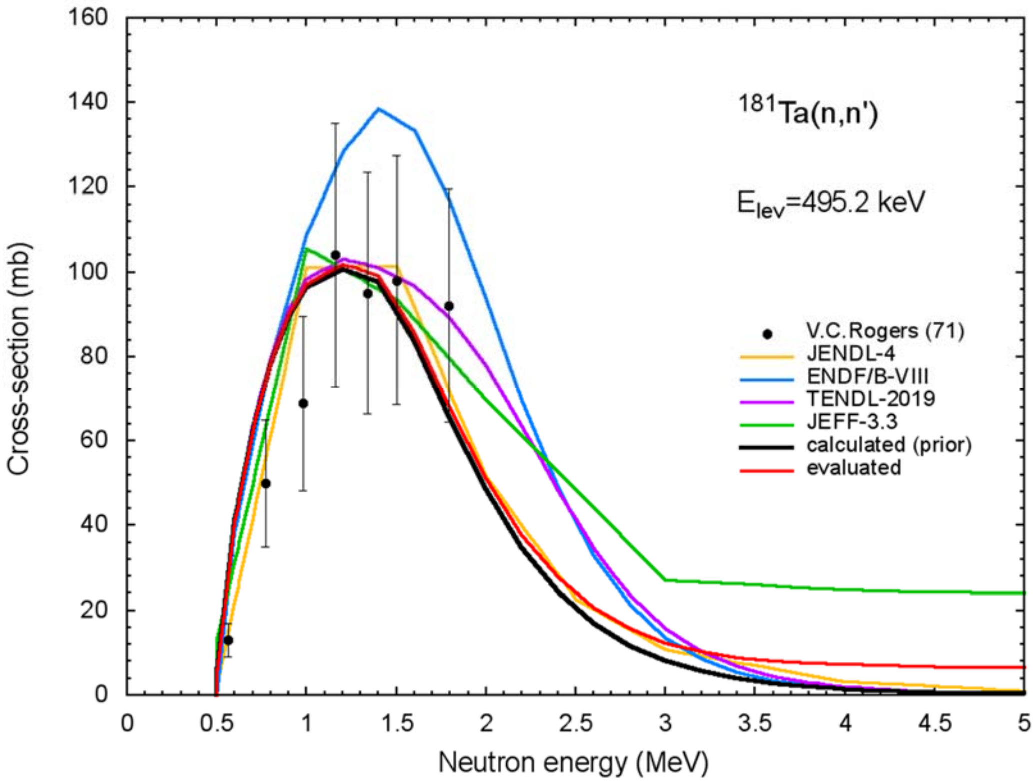


Fig.A14 The inelastic scattering cross-section with the excitation of the level 495.2 keV. The corresponding MT number is equal to 57.

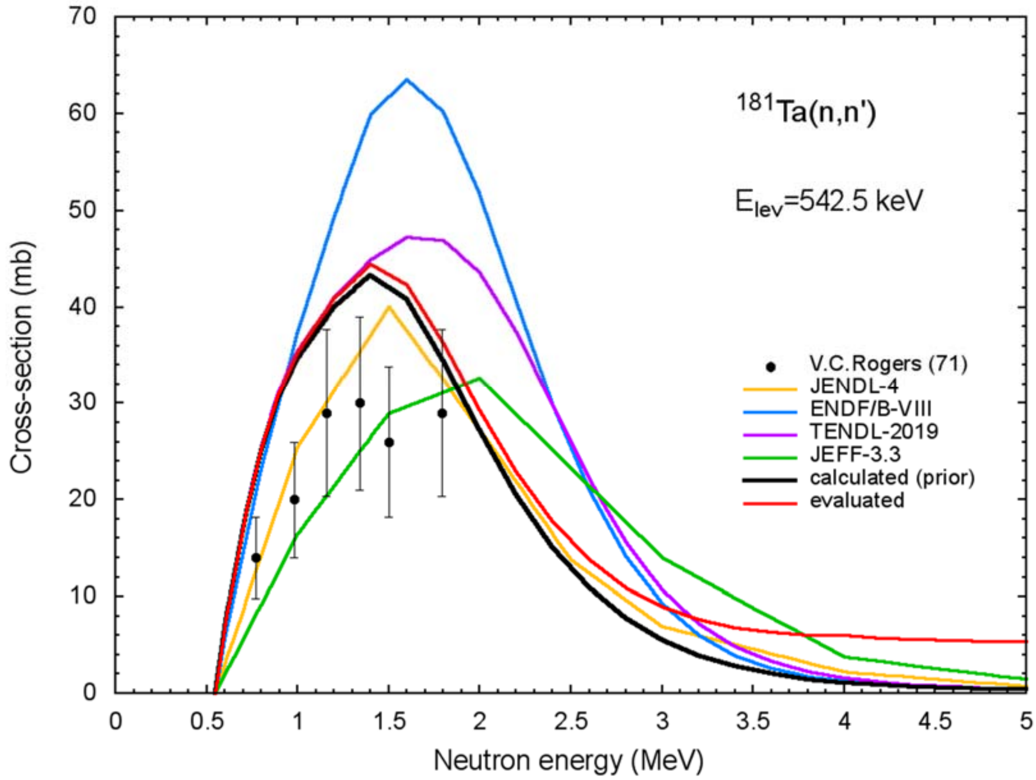


Fig.A15 The inelastic scattering cross-section with the excitation of the level 542.5 keV. The corresponding MT number is equal to 58.

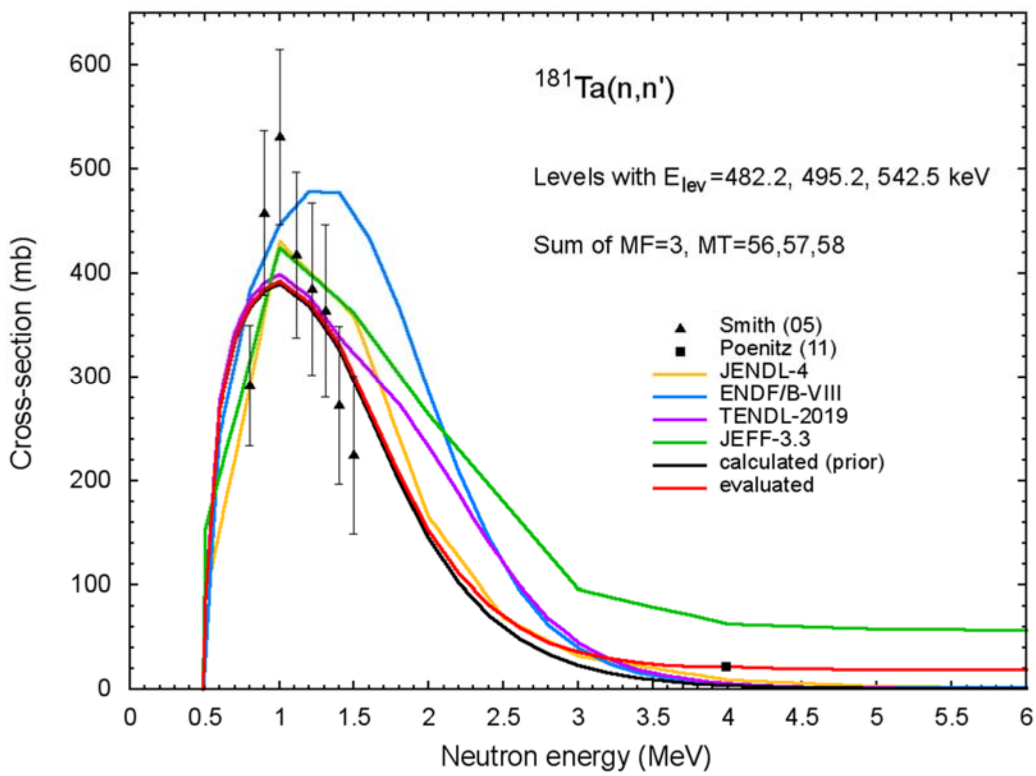


Fig.A16 The sum of inelastic scattering cross-section with MT numbers 56, 57, and 58.

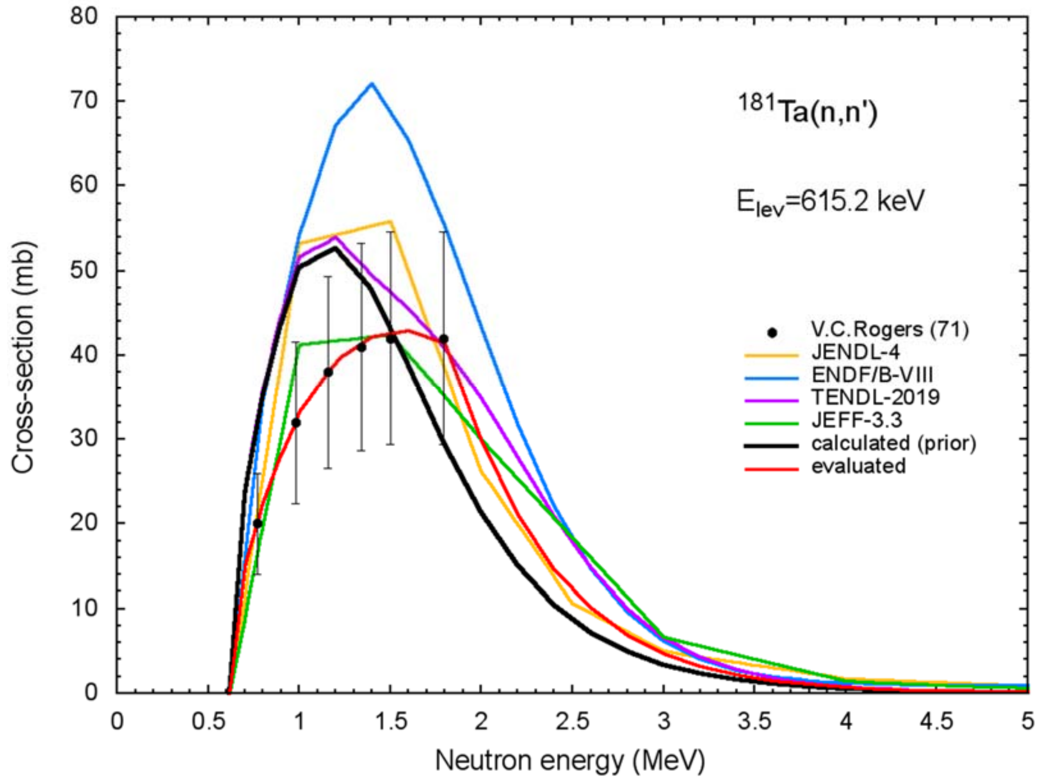


Fig.A17 The inelastic scattering cross-section with the excitation of the level 615.2 keV. The corresponding MT number is equal to 60.

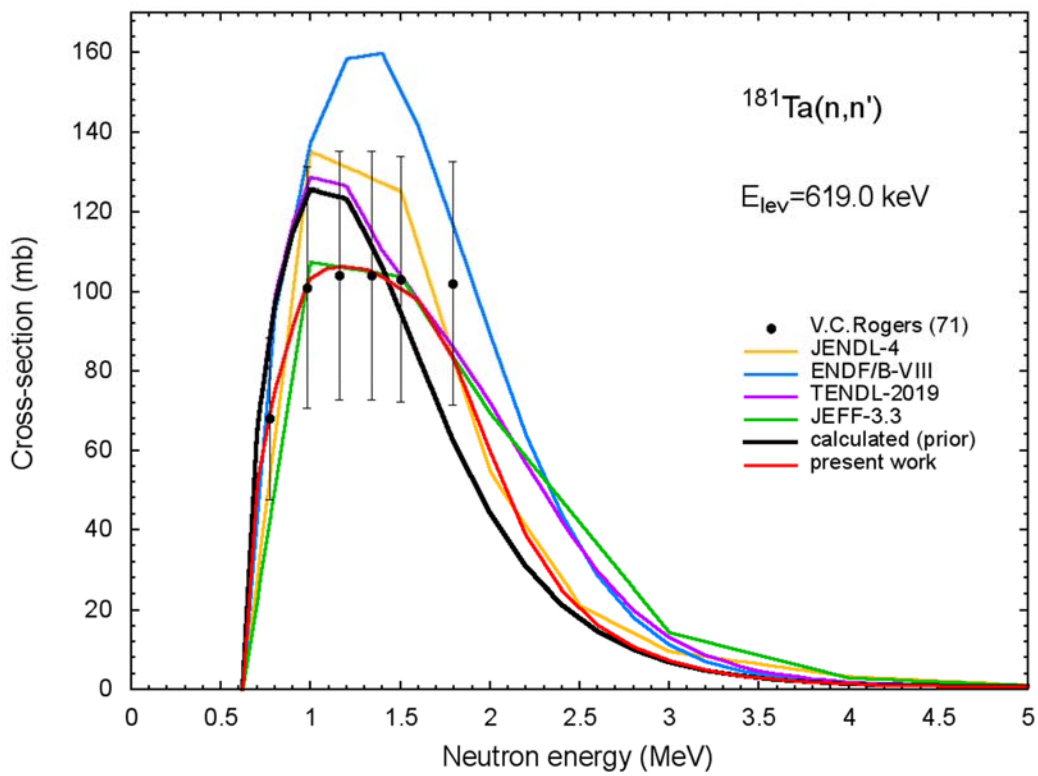


Fig.A18 The inelastic scattering cross-section with the excitation of the level 619.0 keV. The corresponding MT number is equal to 61.

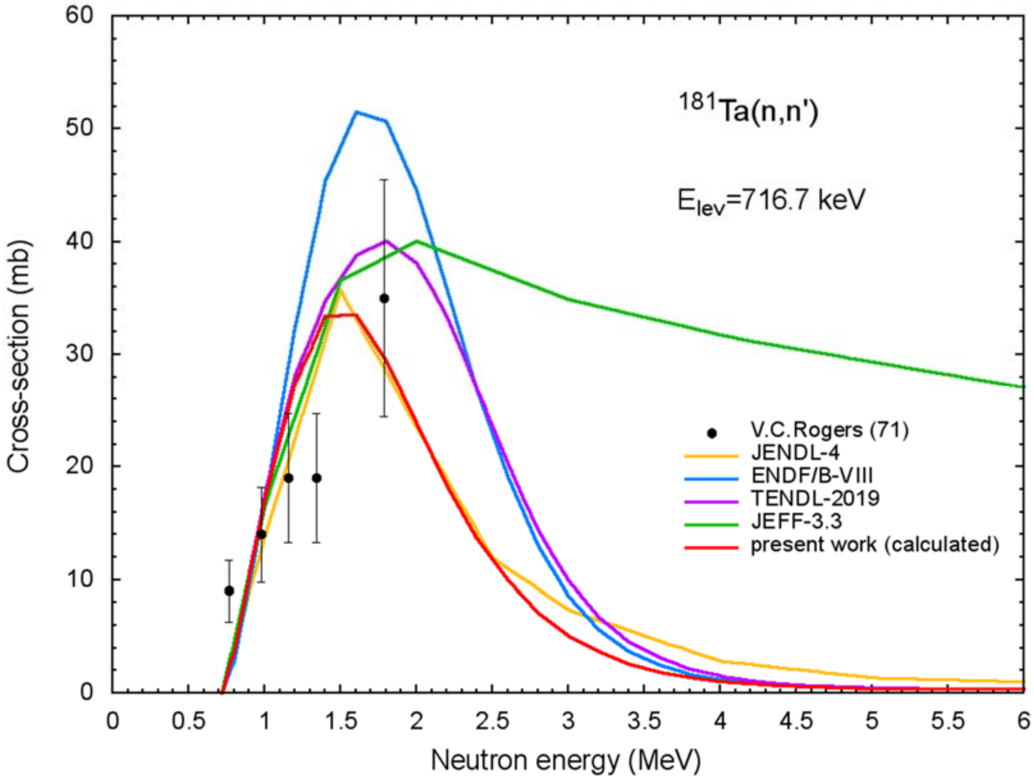


Fig.A19 The inelastic scattering cross-section with the excitation of the level 716.7 keV. The corresponding MT number is equal to 62.

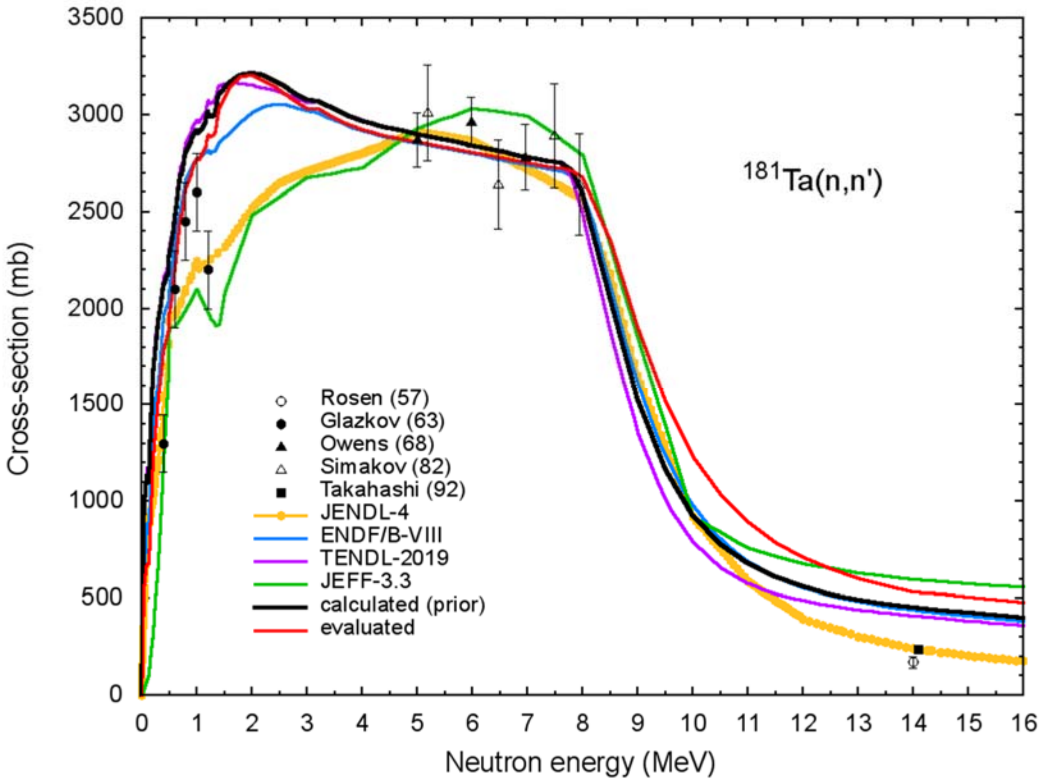


Fig.A20 Inelastic scattering cross-section corresponding to MT number equal to 4.

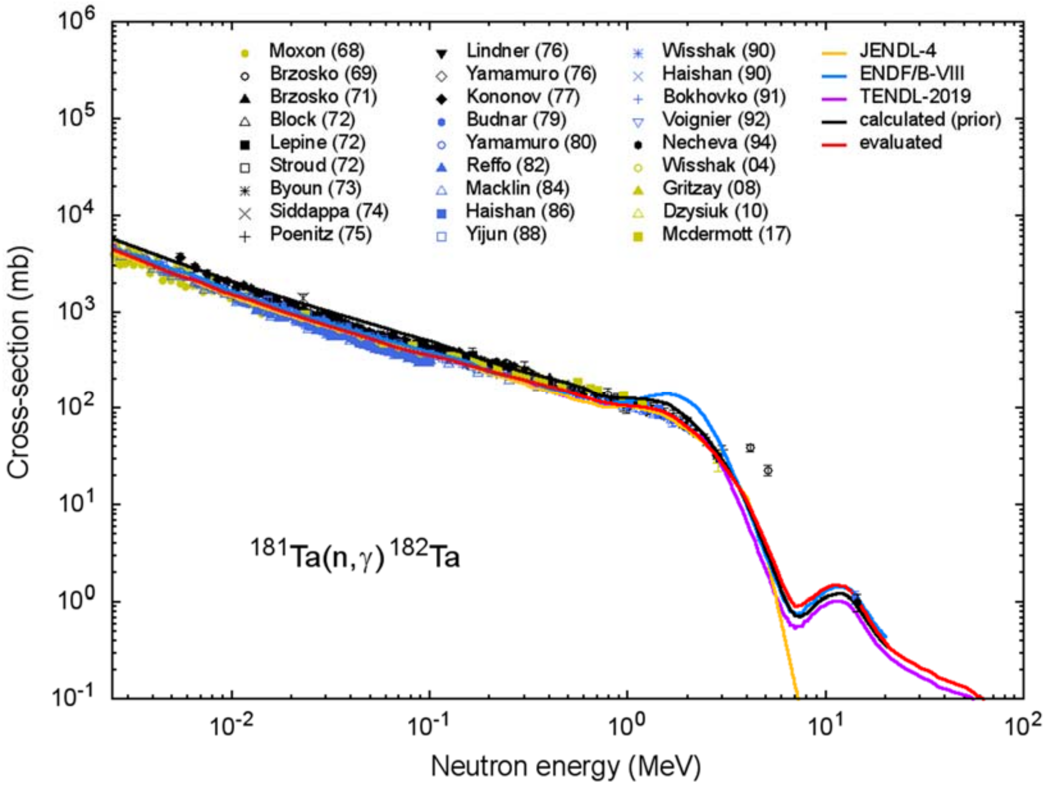


Fig.A21 Cross-section for (n,$\gamma$) reaction

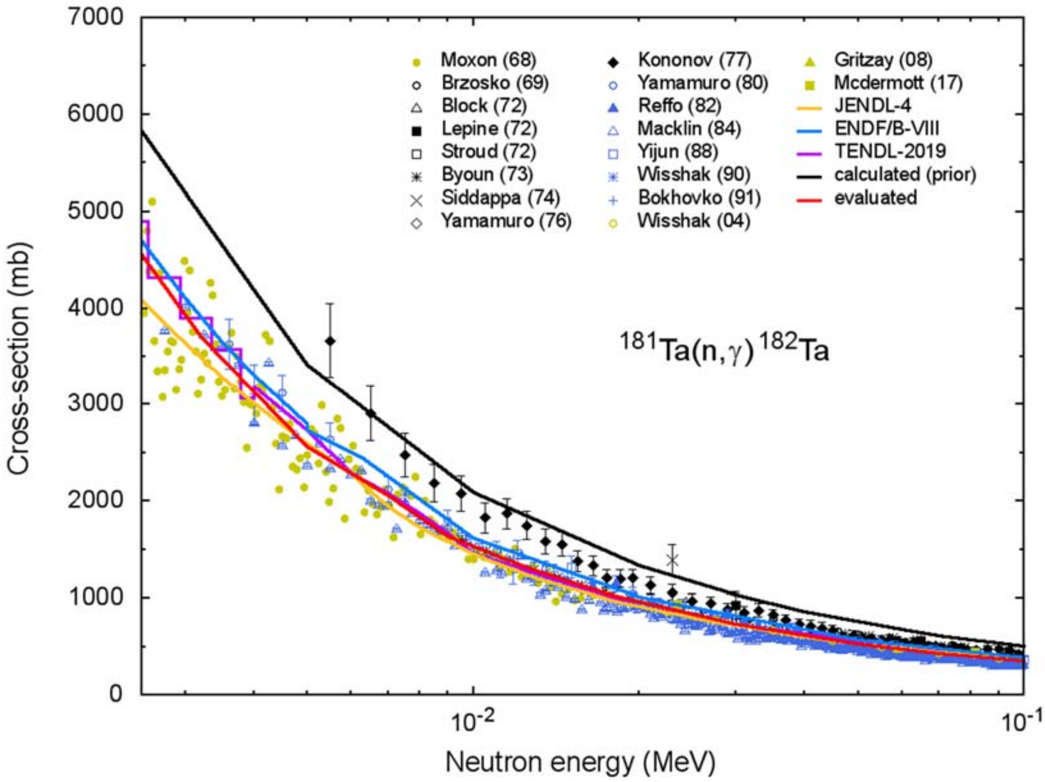


Fig.A22 Cross-section for (n,$\gamma$) reaction at the energies above the resonance region up to 100 keV

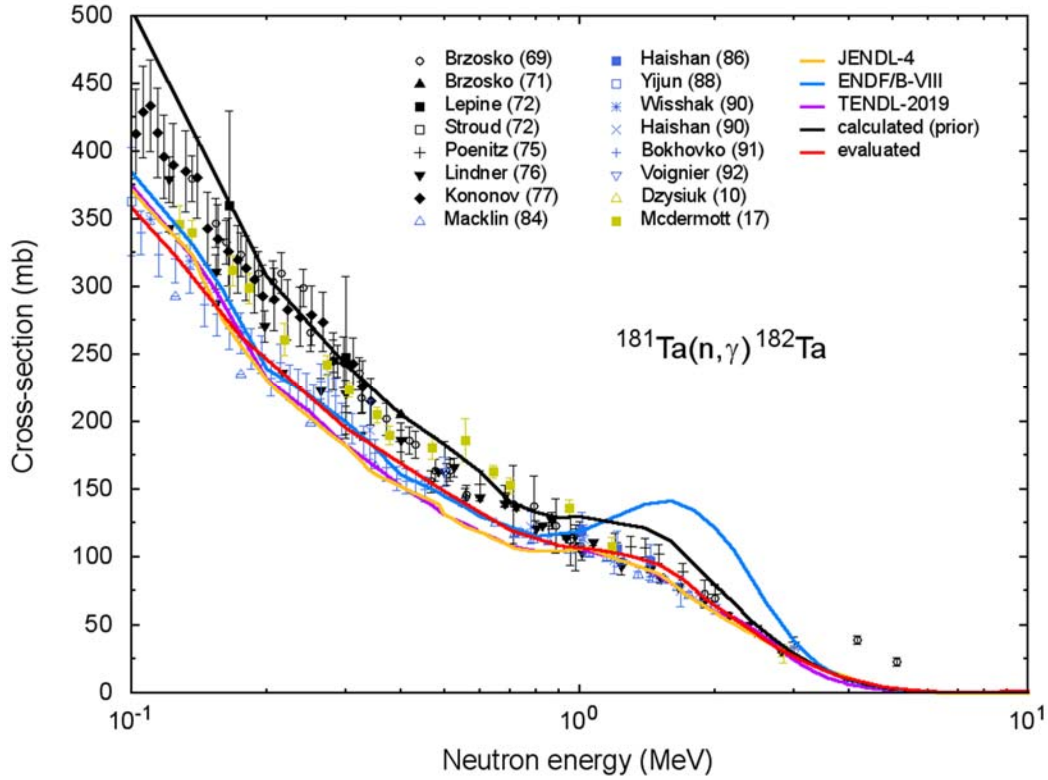


Fig.A23 Cross-section for (n,$\gamma$) reaction at the energies from 0.1 to 10 MeV

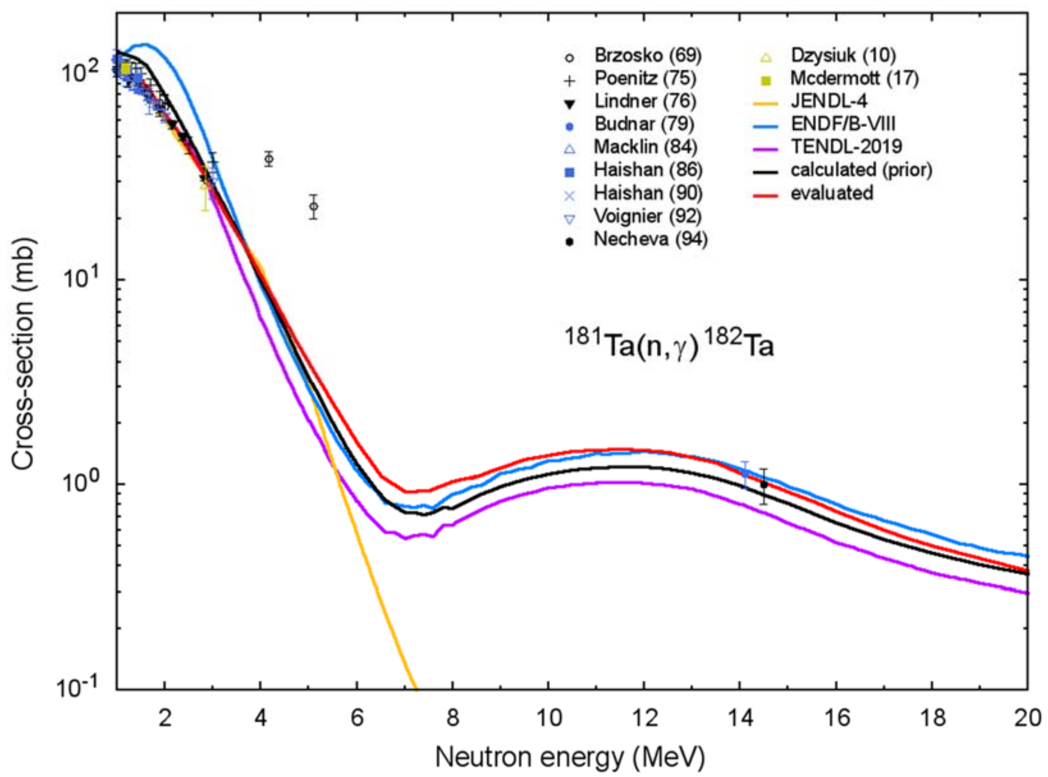


Fig.A24 Cross-section for (n,$\gamma$) reaction at the energies from 1 to 20 MeV

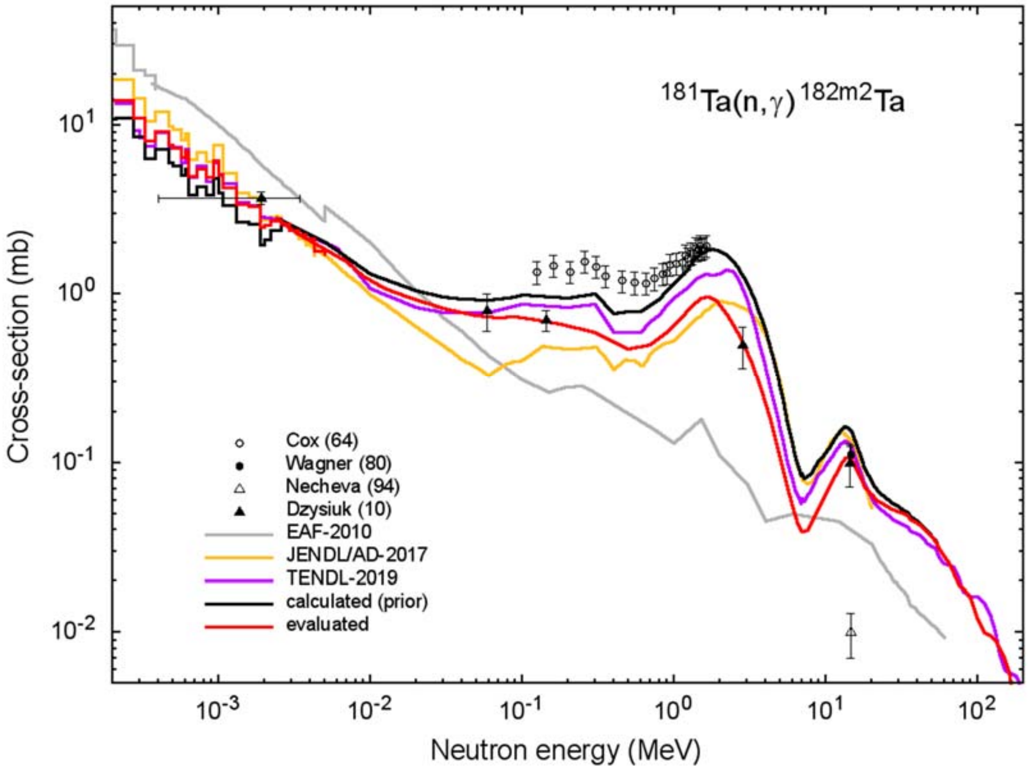


Fig.A25 Cross-section for $^{181}Ta(n,\gamma)^{182m2}Ta$ reaction

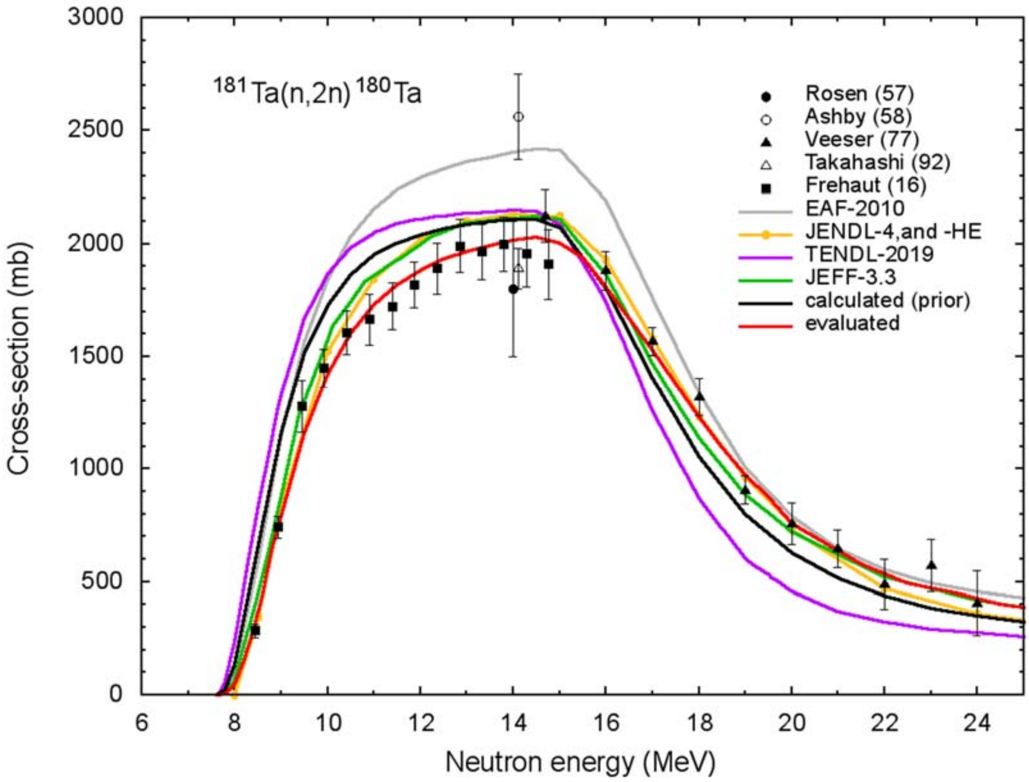


Fig.A26 Cross-section for (n,2n) reaction at neutron energies up to 25 MeV.

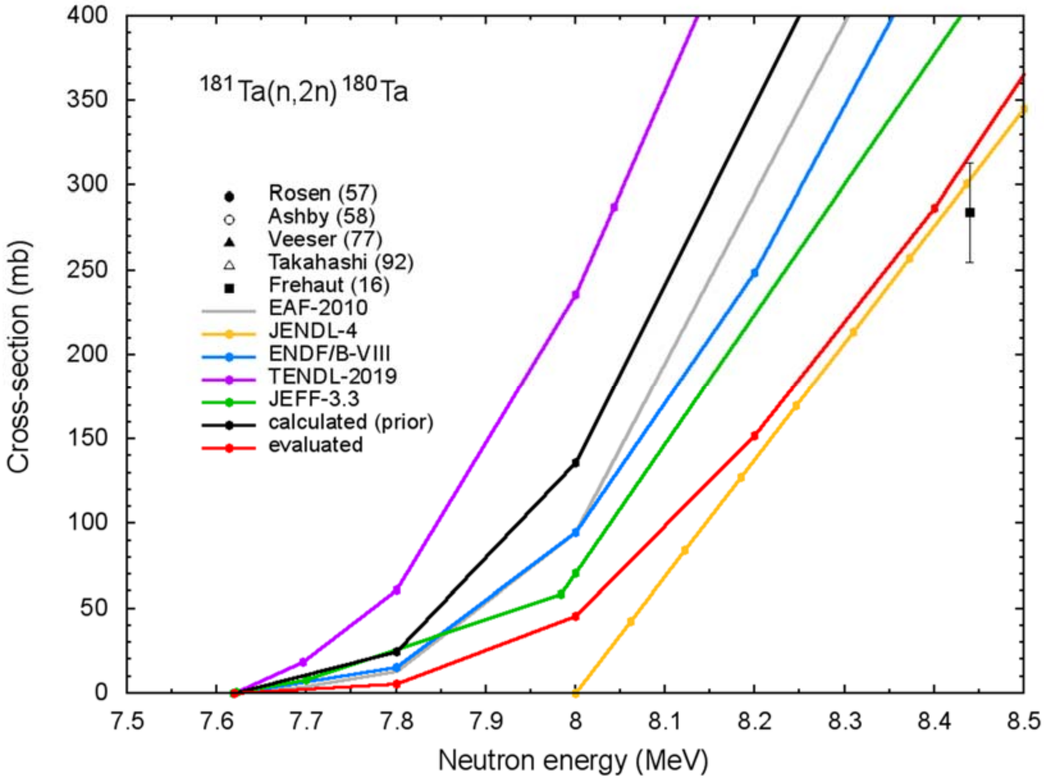


Fig.A27 Cross-section for (n,2n) reaction at neutron energies up to 200 MeV.

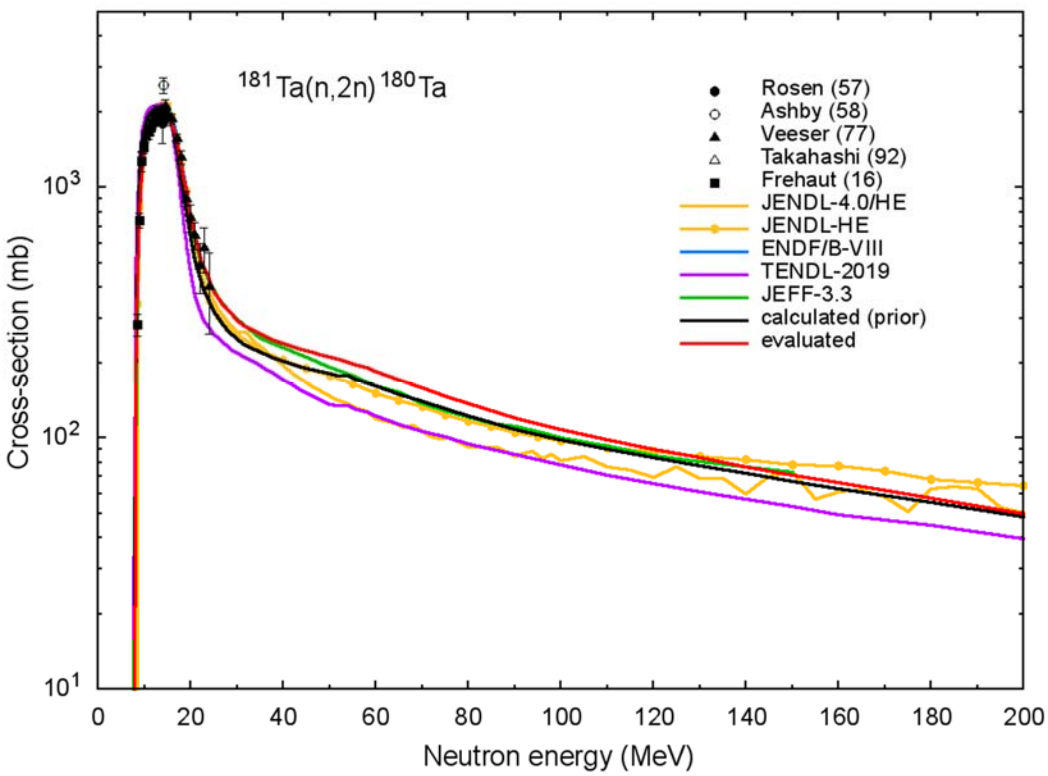


Fig.A28 Cross-section for (n,2n) reaction at neutron energies up to 200 MeV.

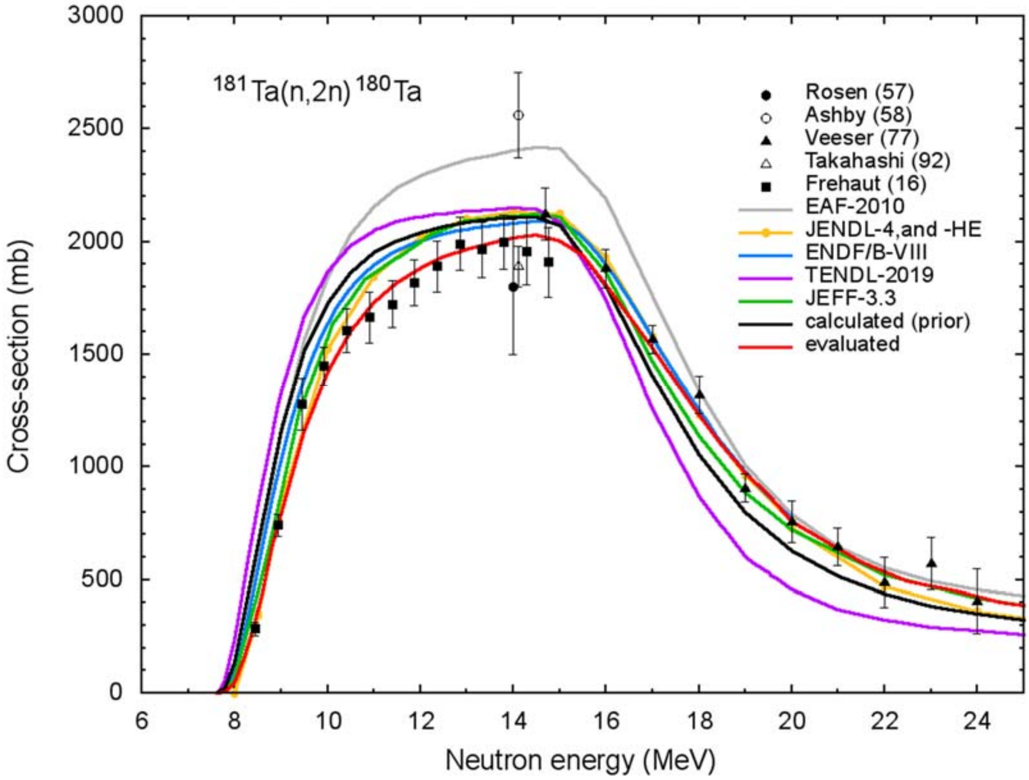


Fig.A29 Cross-section for $^{181}Ta(n,2n)^{180g}Ta$ reaction at neutron energies up to 24 MeV.

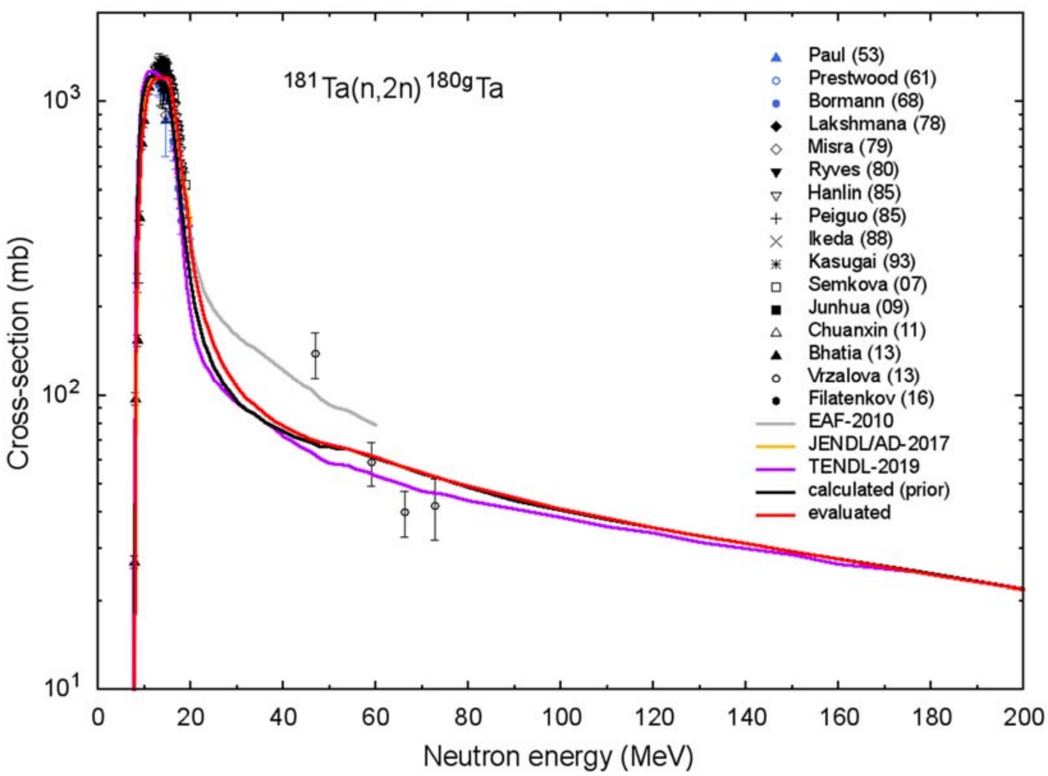


Fig.A30 Cross-section for $^{181}Ta(n,2n)^{180g}Ta$ reaction at neutron energies up to 200 MeV.

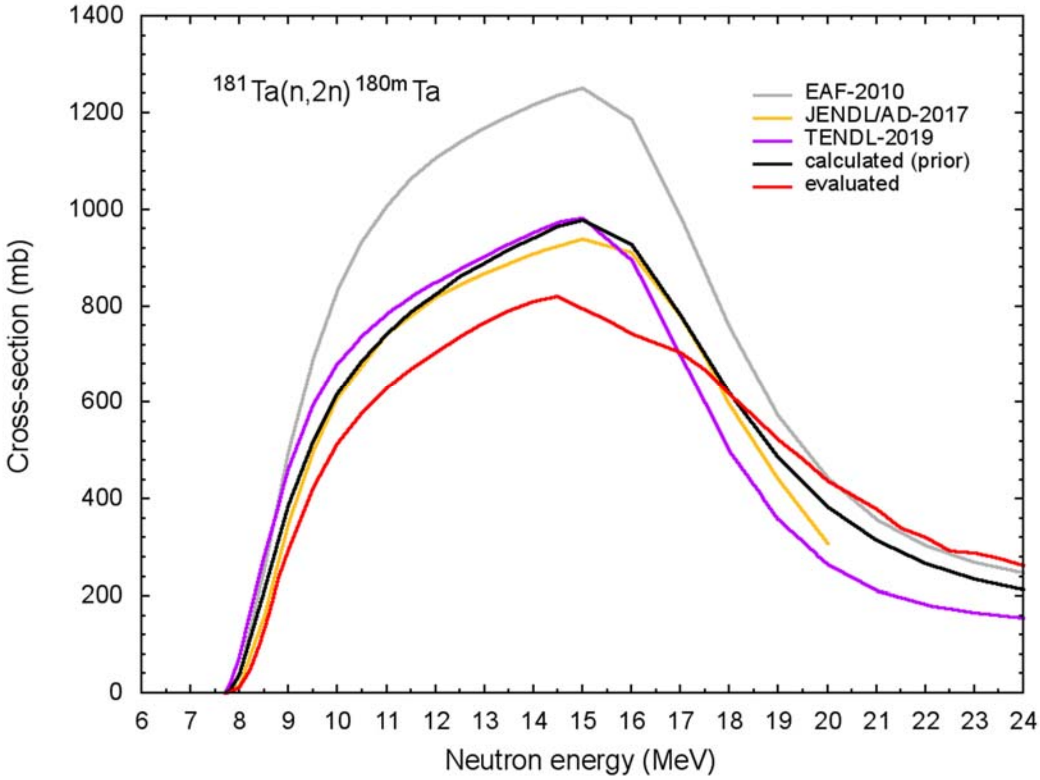


Fig.A31 Cross-section for $^{181}$Ta(n,2n)$^{180m}$Ta reaction at neutron energies up to 24 MeV.

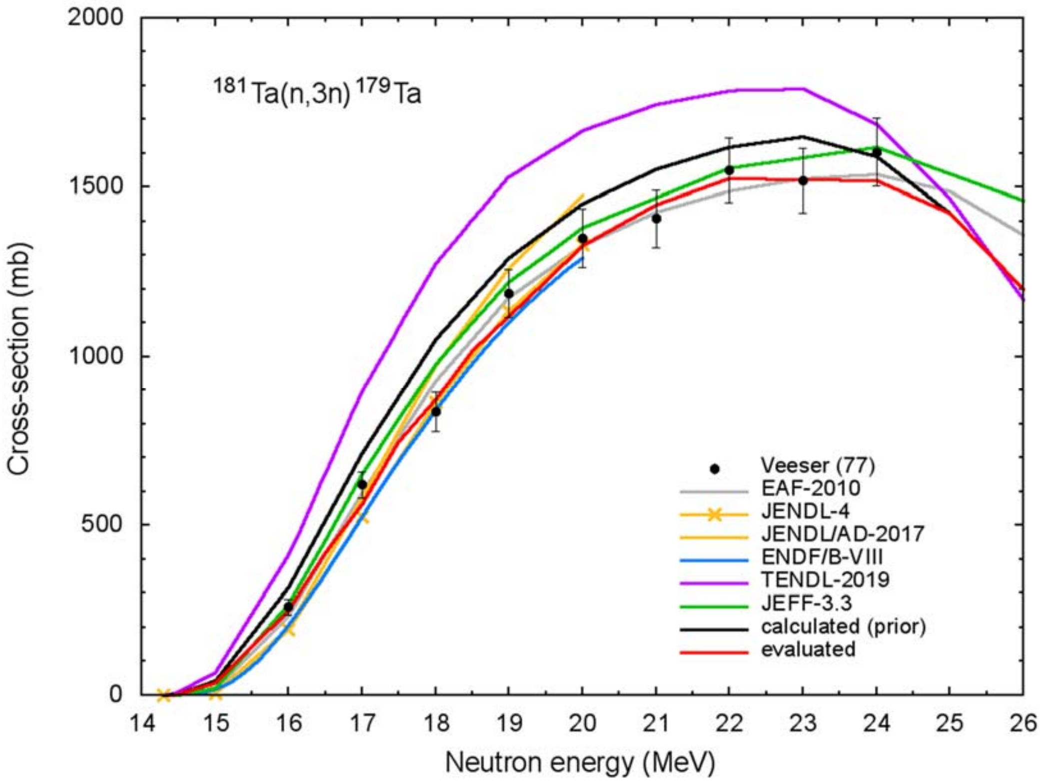


Fig.A32 Cross-section for (n,3n) reaction.

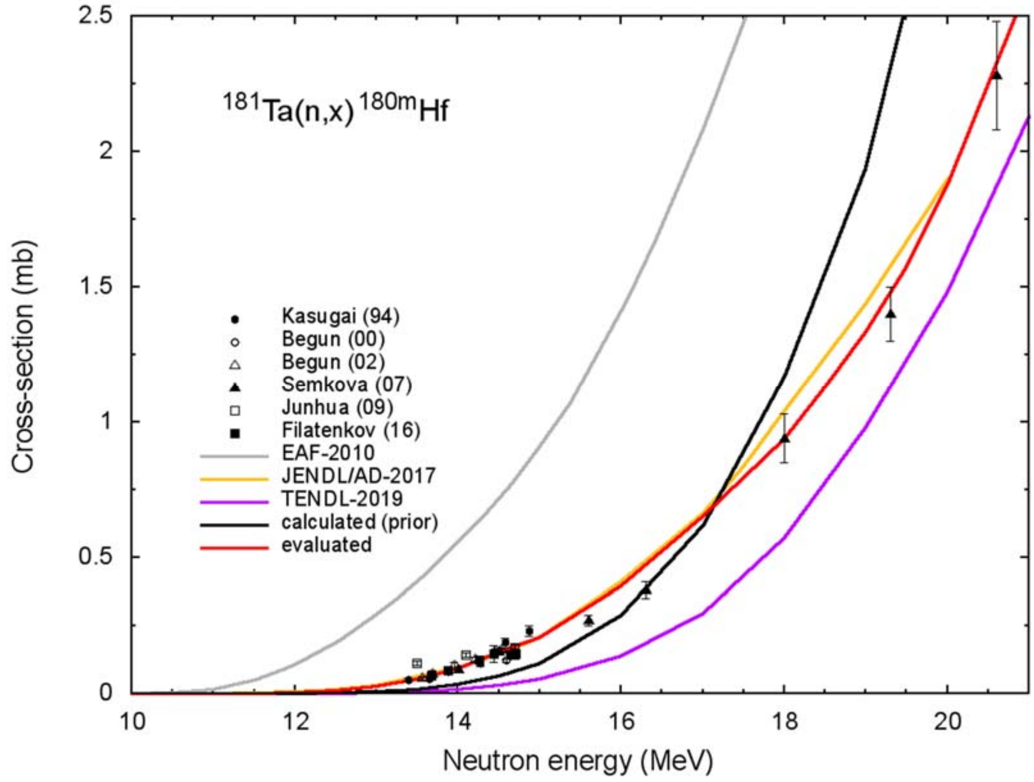


Fig.A33 Cross-section for production of $^{180m}$Hf in reactions (n,d) and (n,np).

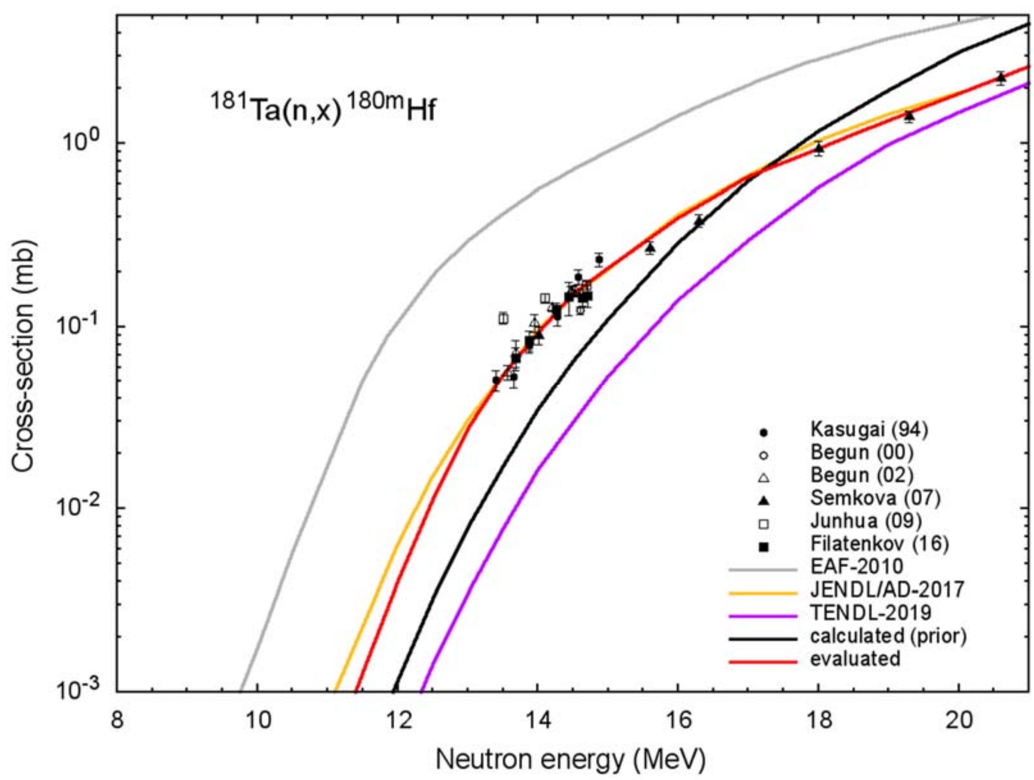


Fig.A34 Cross-section for production of $^{180m}$Hf in reactions (n,d) and (n,np).

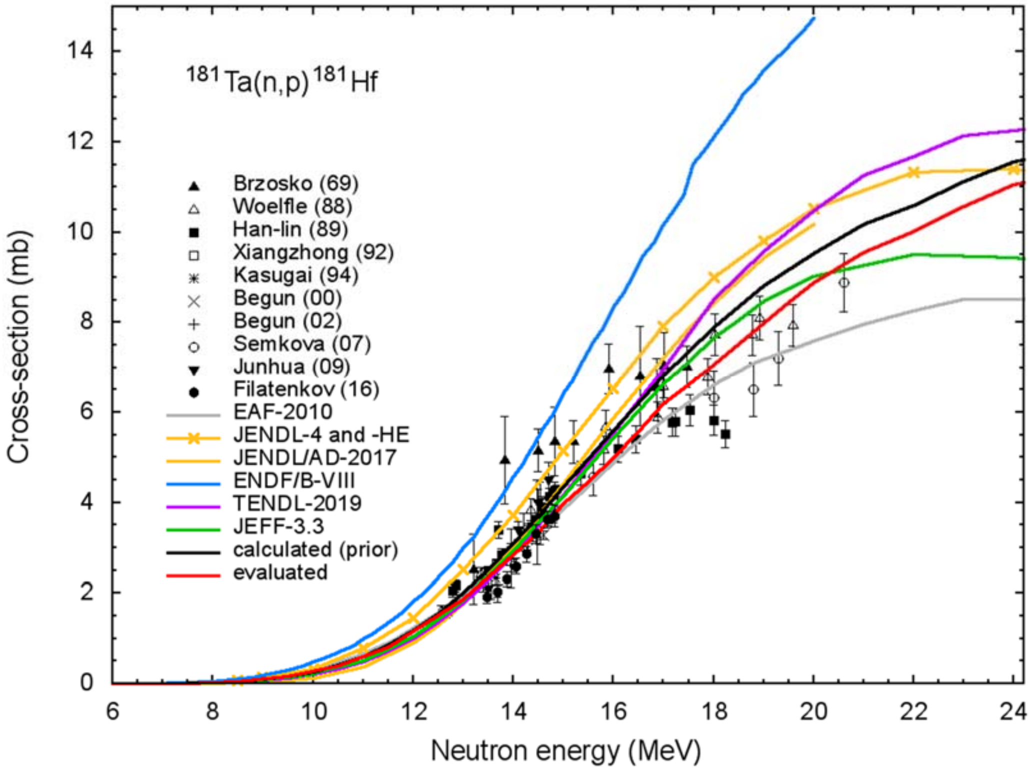


Fig.A35 Cross-section for (n,p) reaction.

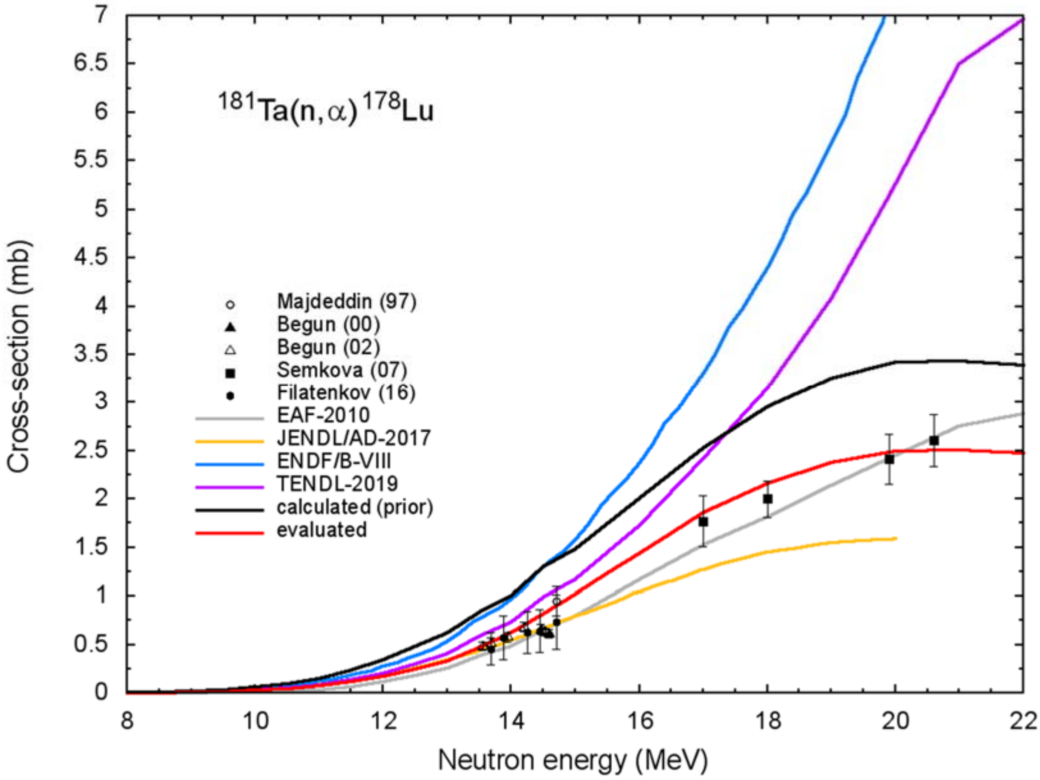


Fig.A36 Cross-section for (n,α) reaction.

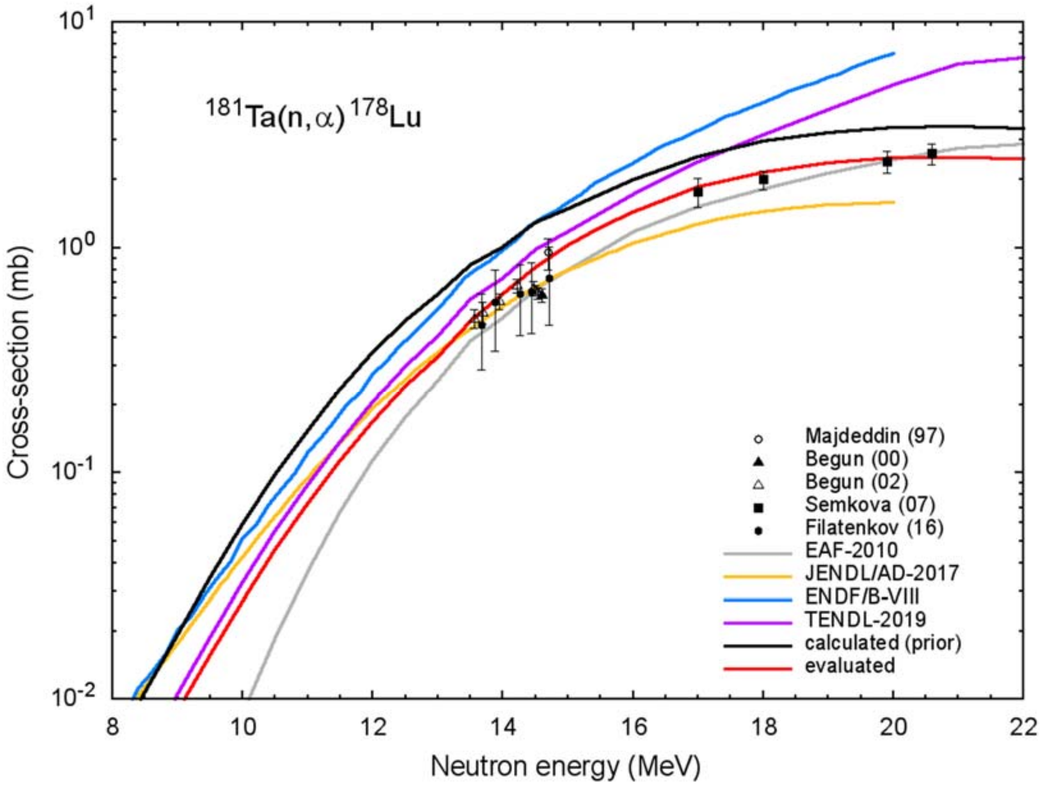


Fig.A37 Cross-section for (n,α) reaction.

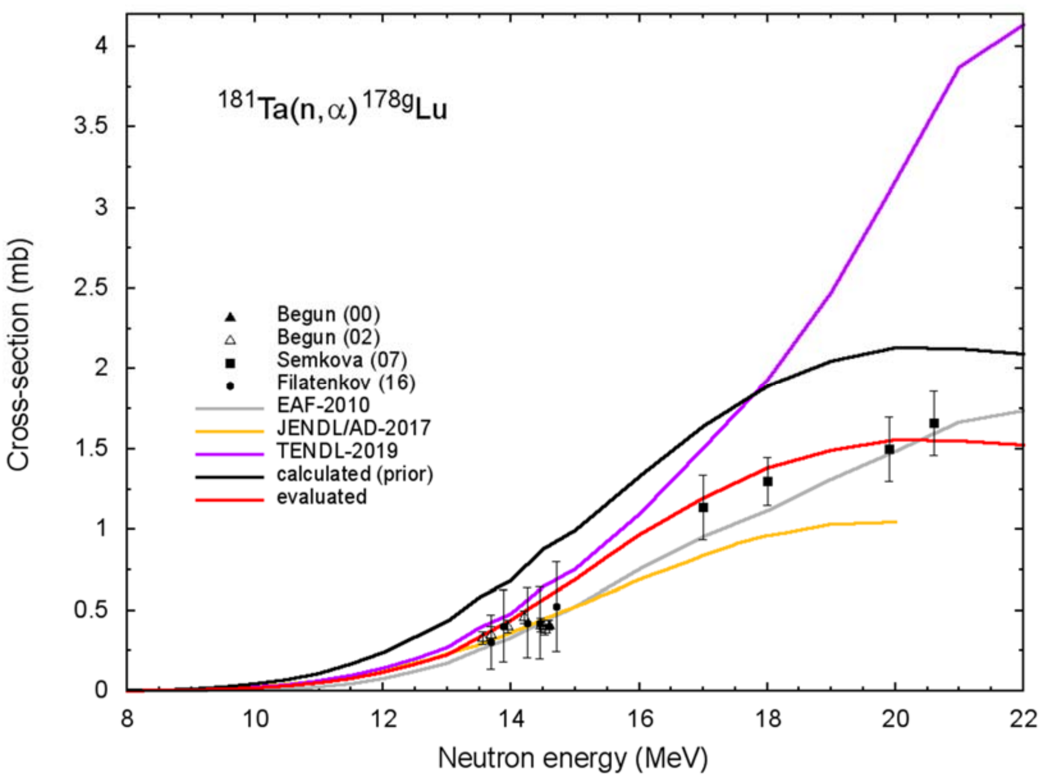


Fig.A38 Cross-section for $^{181}Ta(n,\alpha)^{178g}Lu$ reaction.

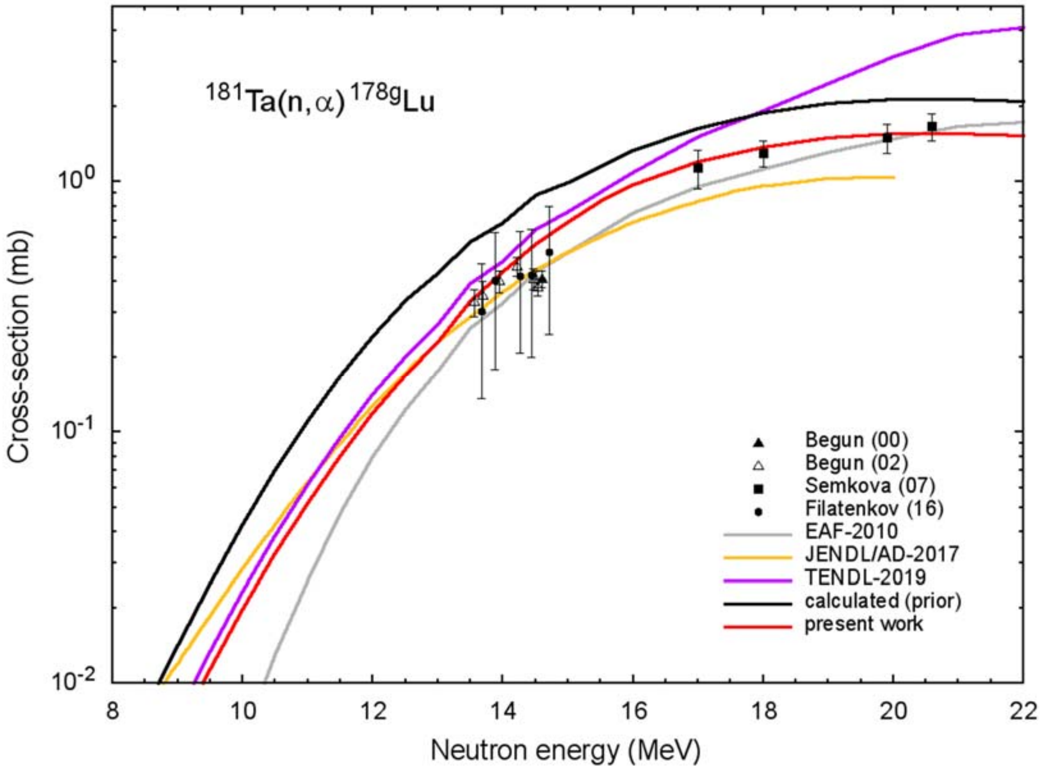


Fig.A39 Cross-section for $^{181}$Ta(n,α)$^{178g}$Lu reaction.

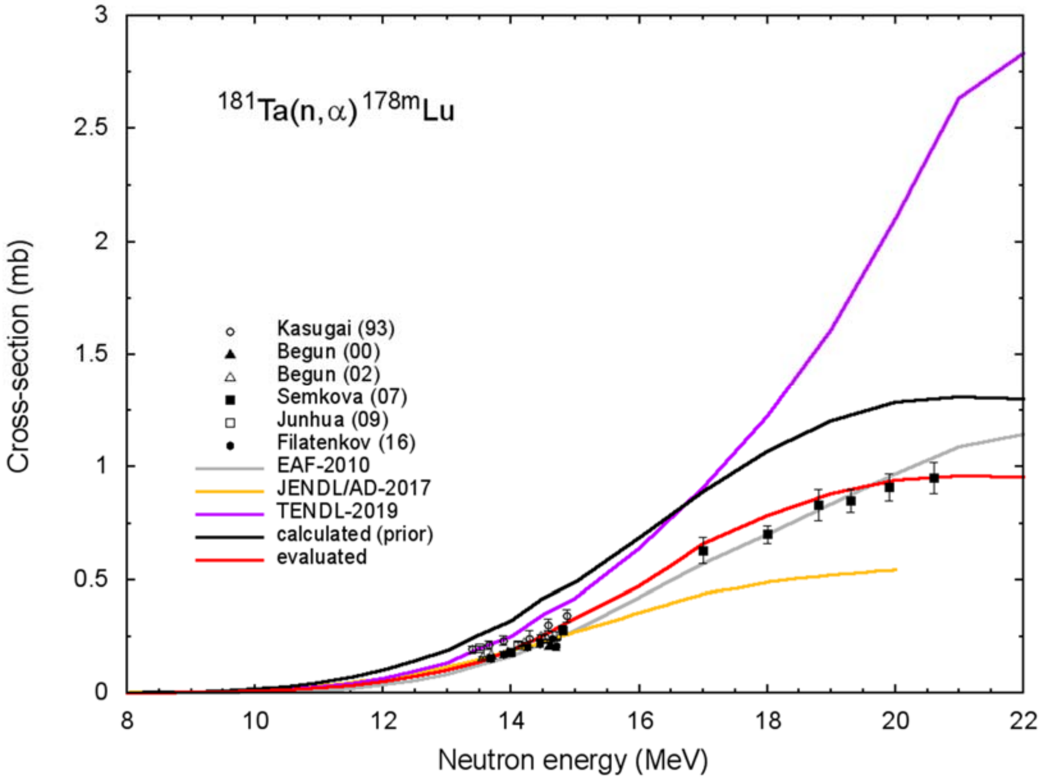


Fig.A40 Cross-section for $^{181}$Ta(n,α)$^{178m}$Lu reaction.

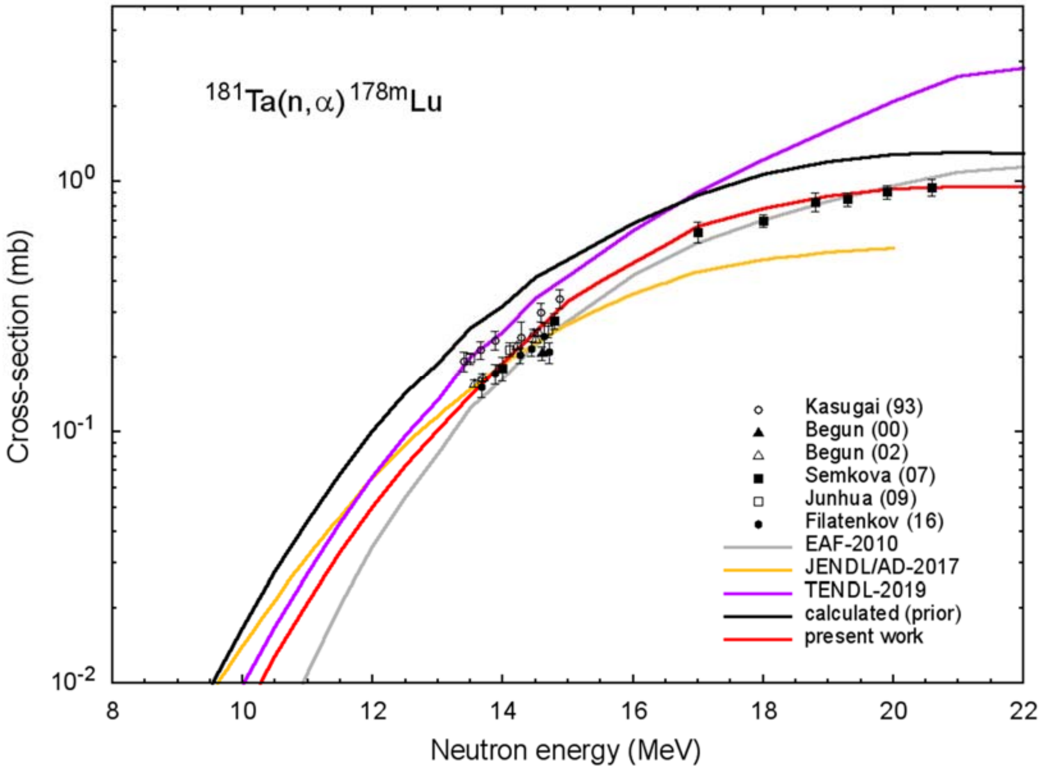


Fig.A41 Cross-section for $^{181}Ta(n,\alpha)^{178m}Lu$ reaction.

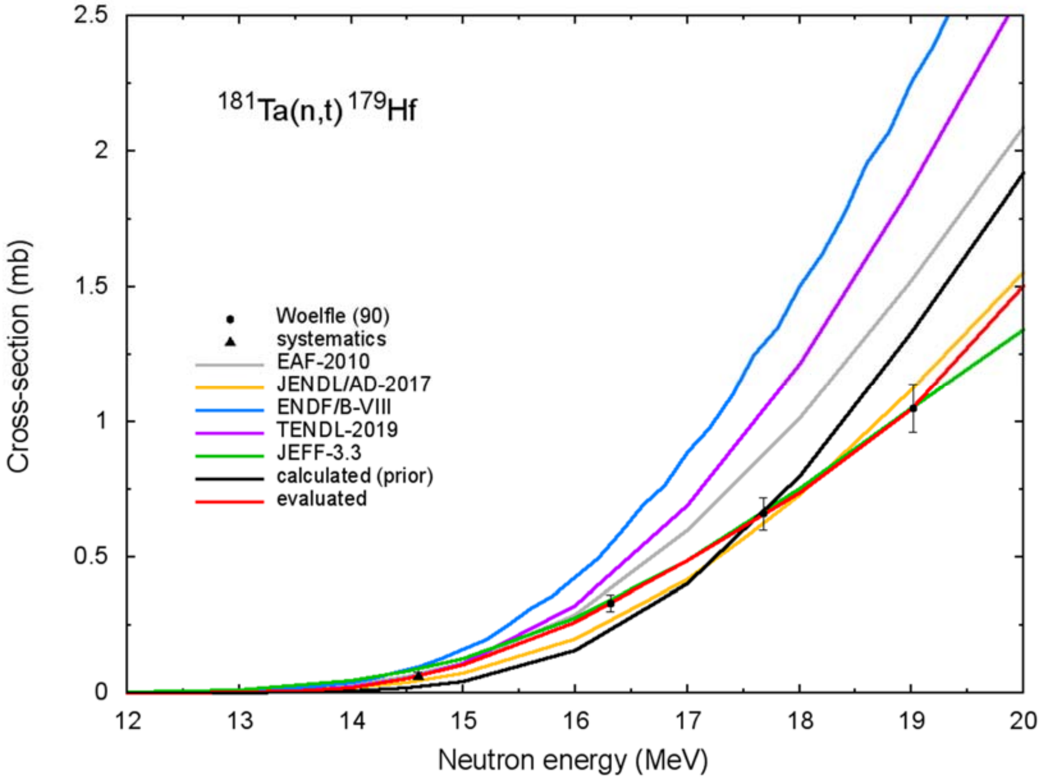


Fig.A42 Cross-section for (n,t) reaction.

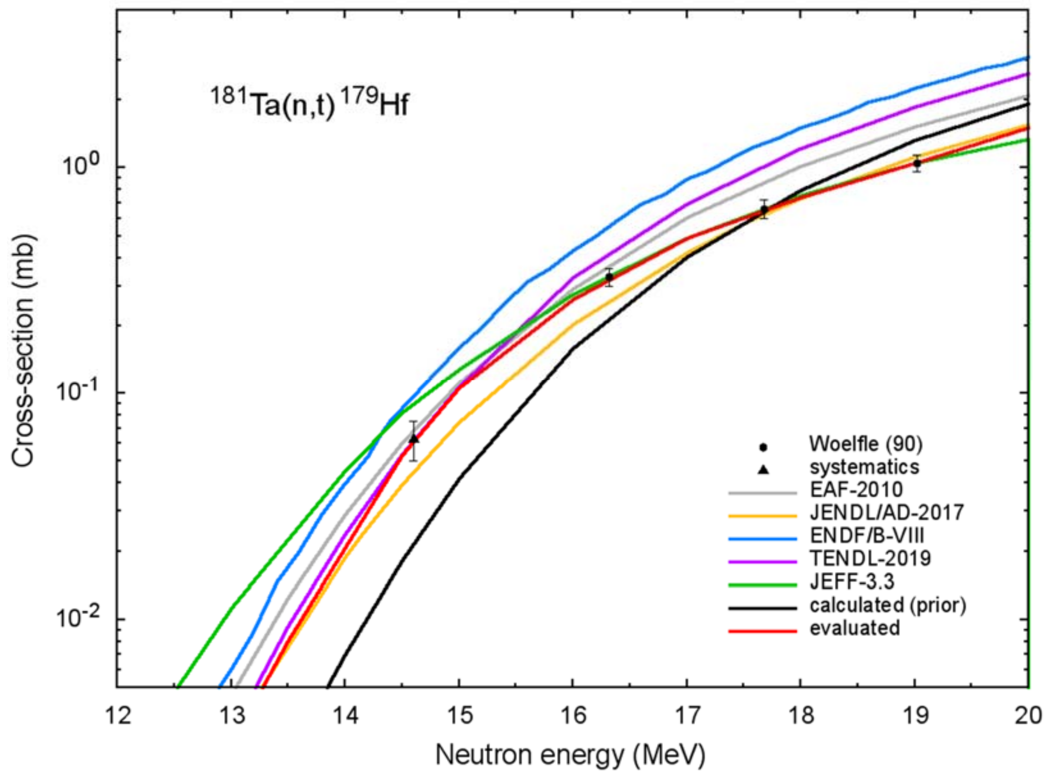


Fig.A43 Cross-section for (n,t) reaction.

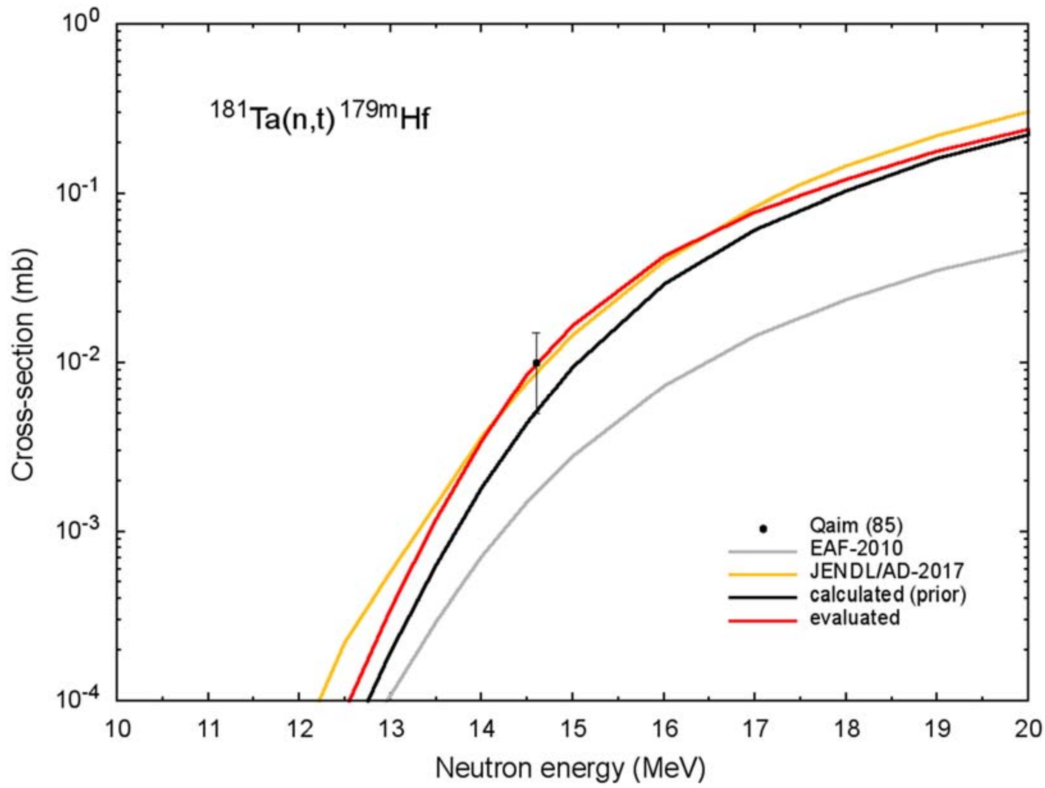


Fig.A44 Cross-section for $^{181}Ta(n,t)^{179m}Lu$ reaction.

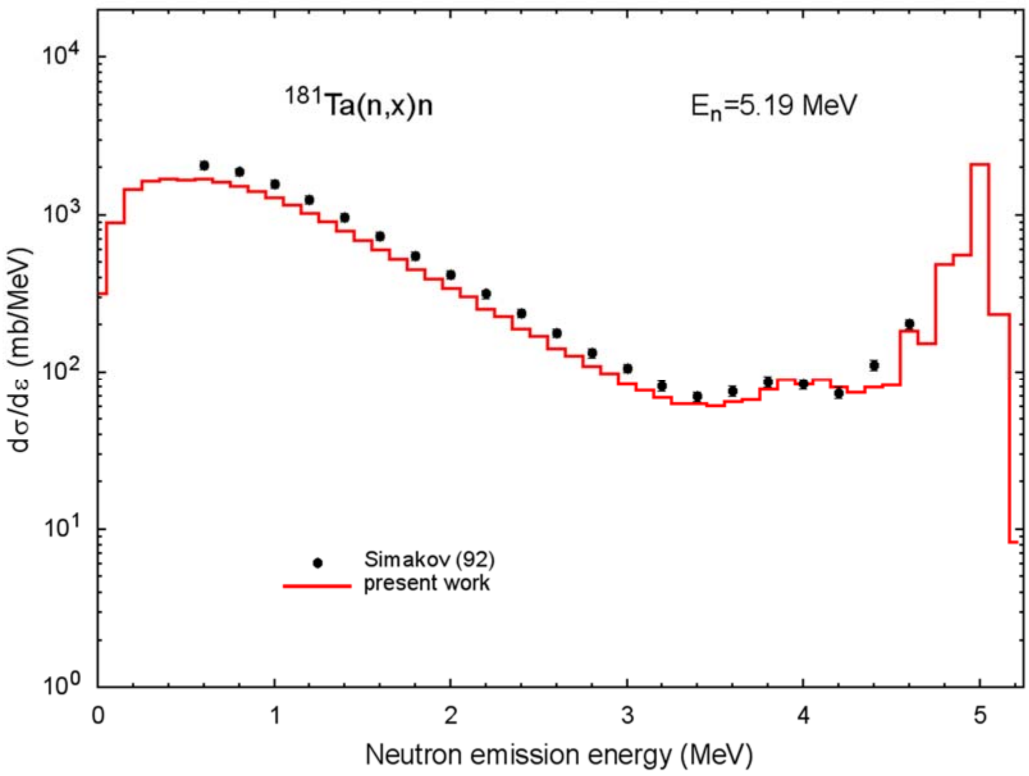


Fig.A45 Neutron energy distribution for 5.19 MeV neutrons obtained in the present work and measured data.

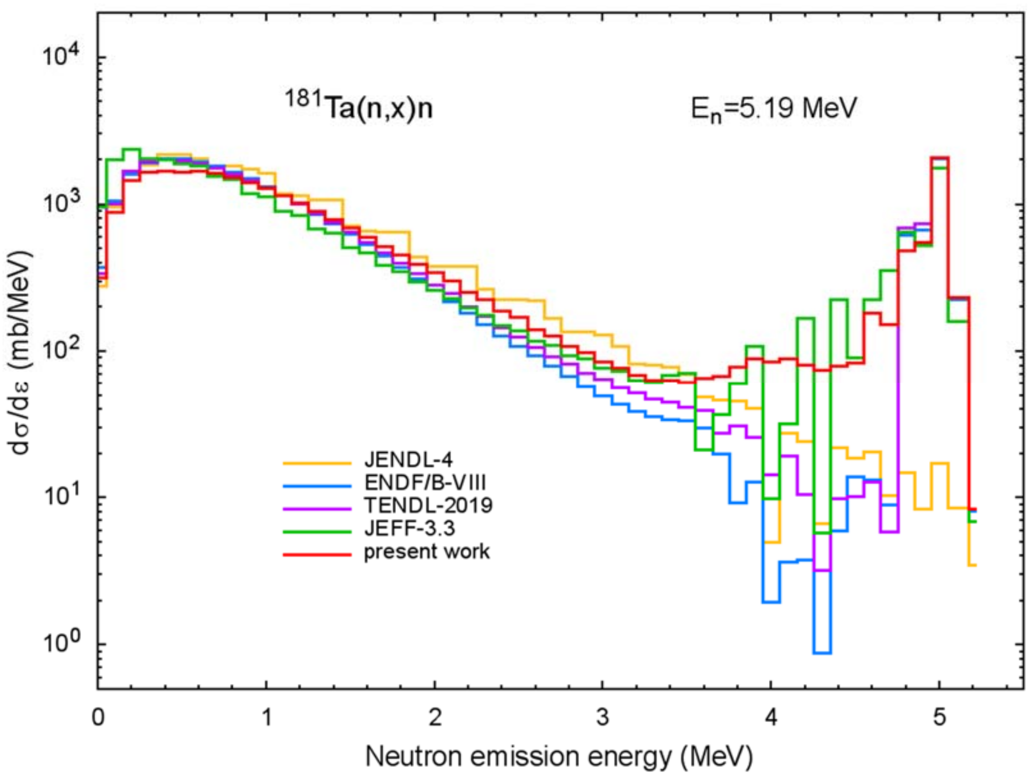


Fig.A46 Neutron energy distribution for 5.19 MeV neutrons obtained in the present work and taken from different data libraries.

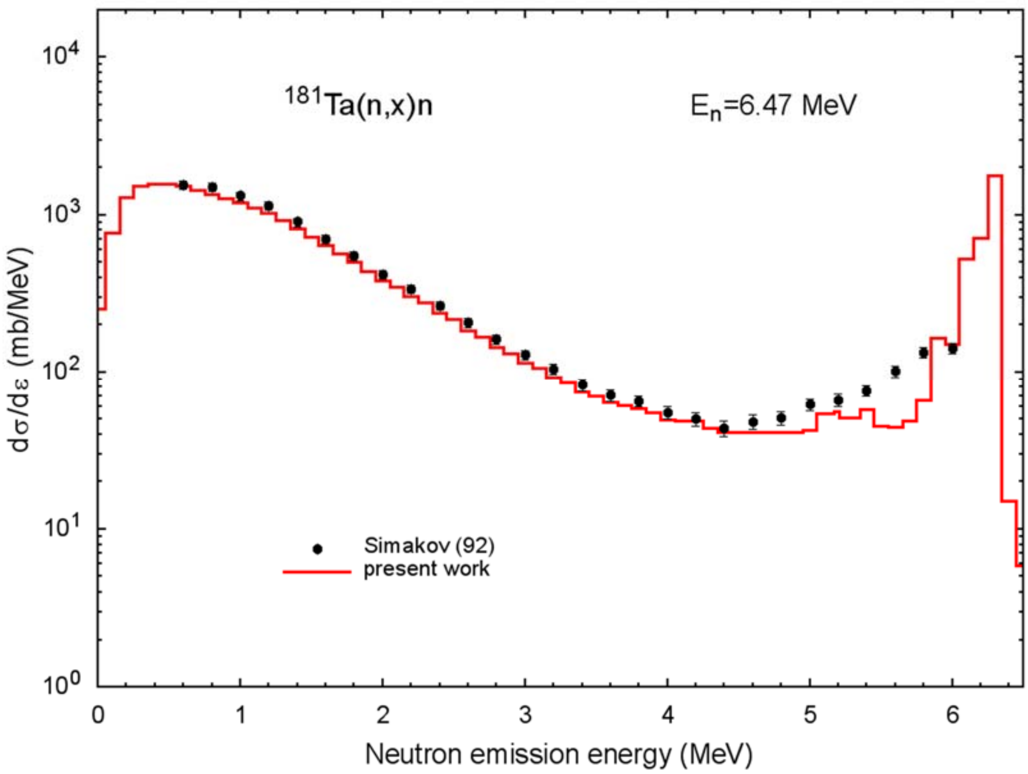


Fig.A47 Neutron energy distribution for 6.47 MeV neutrons obtained in the present work and measured data.

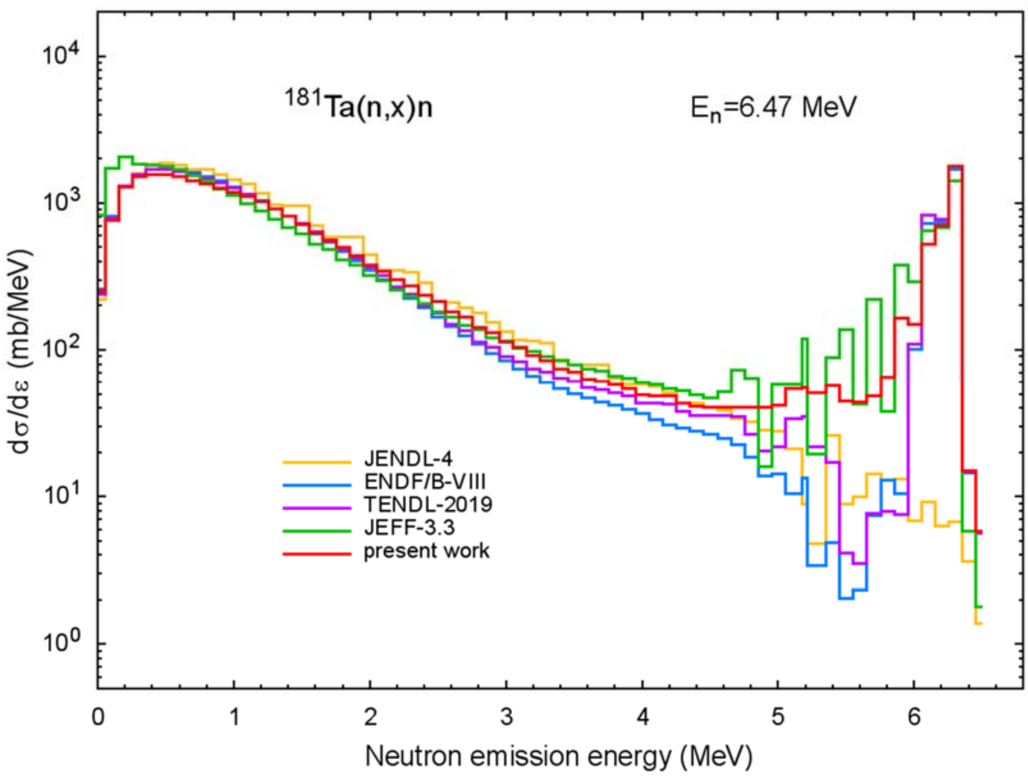


Fig.A48 Neutron energy distribution for 6.47 MeV neutrons obtained in the present work and taken from different data libraries.

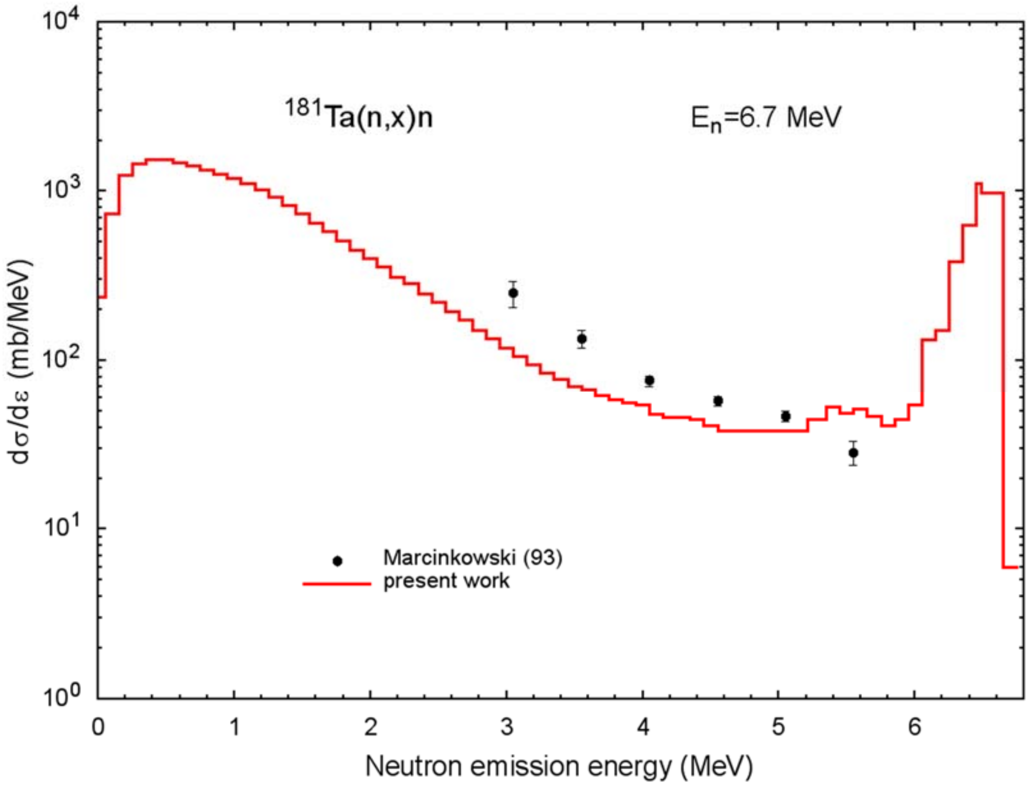


Fig.A49 Neutron energy distribution for 6.7 MeV neutrons obtained in the present work and measured data.

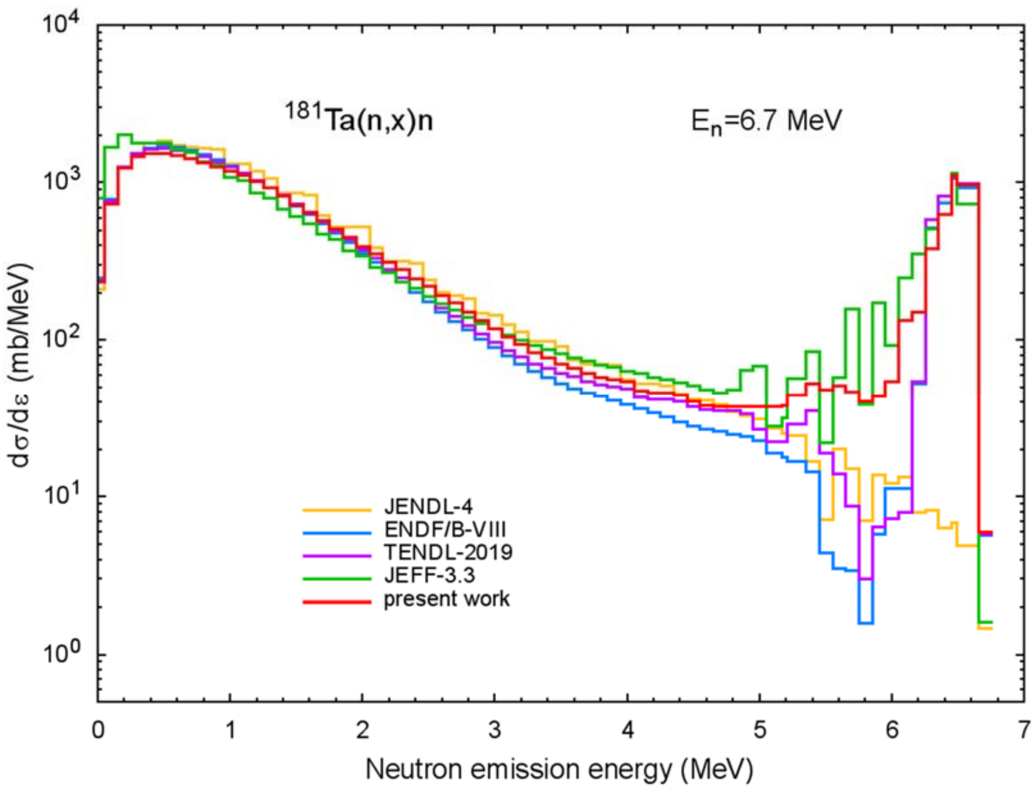


Fig.A50 Neutron energy distribution for 6.7 MeV neutrons obtained in the present work and taken from different data libraries.

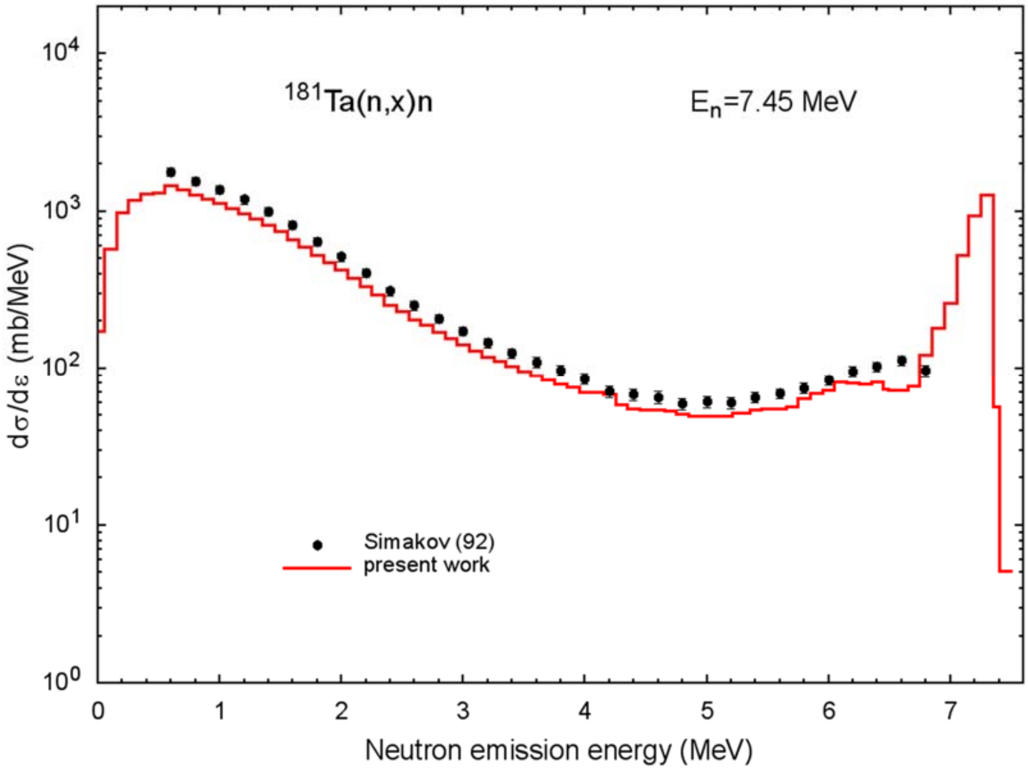


Fig.A51 Neutron energy distribution for 7.45 MeV neutrons obtained in the present work and measured data.

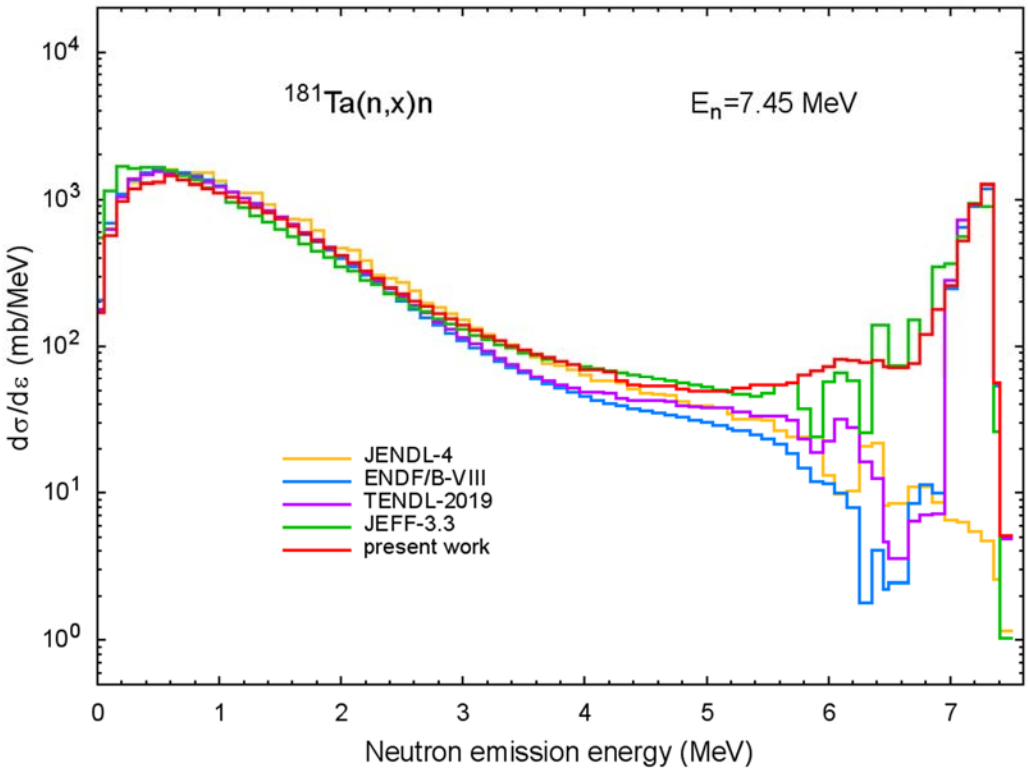


Fig.A52 Neutron energy distribution for 7.45 MeV neutrons obtained in the present work and taken from different data libraries.

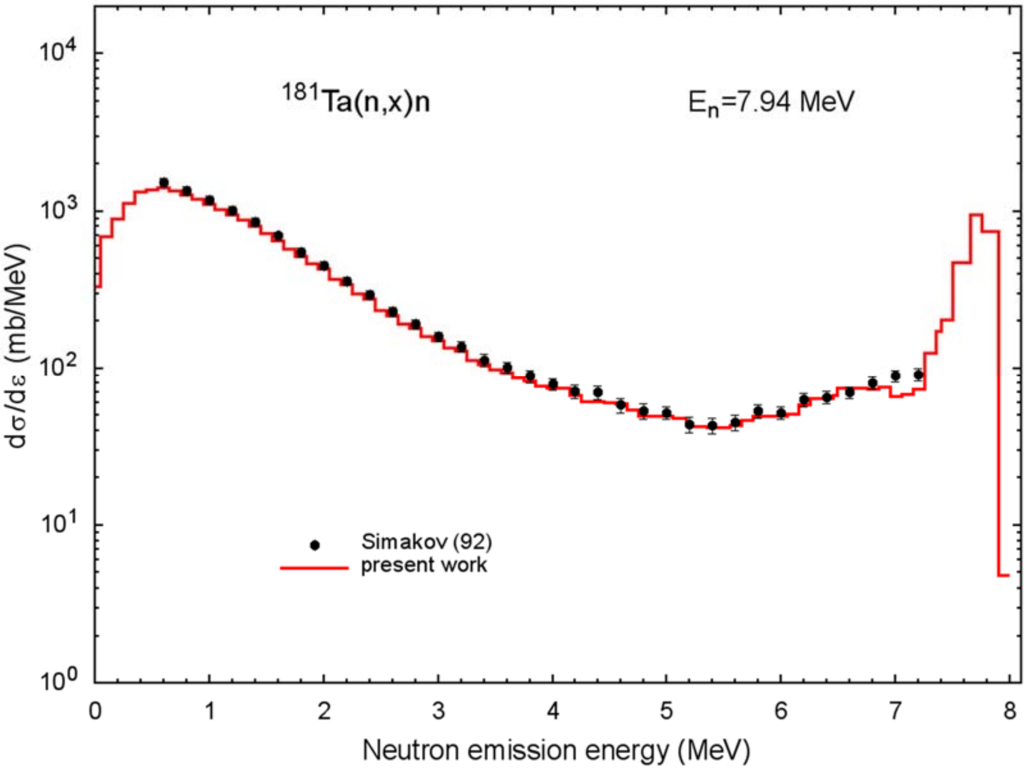


Fig.A53 Neutron energy distribution for 7.94 MeV neutrons obtained in the present work and measured data.

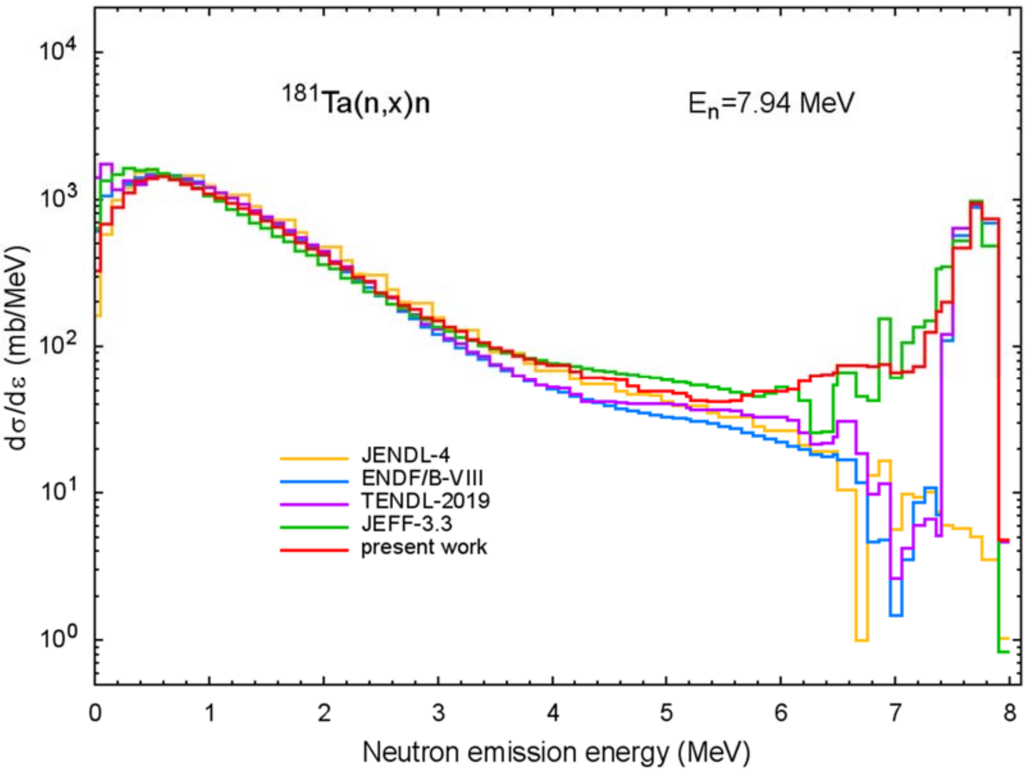


Fig.A54 Neutron energy distribution for 7.94 MeV neutrons obtained in the present work and taken from different data libraries.

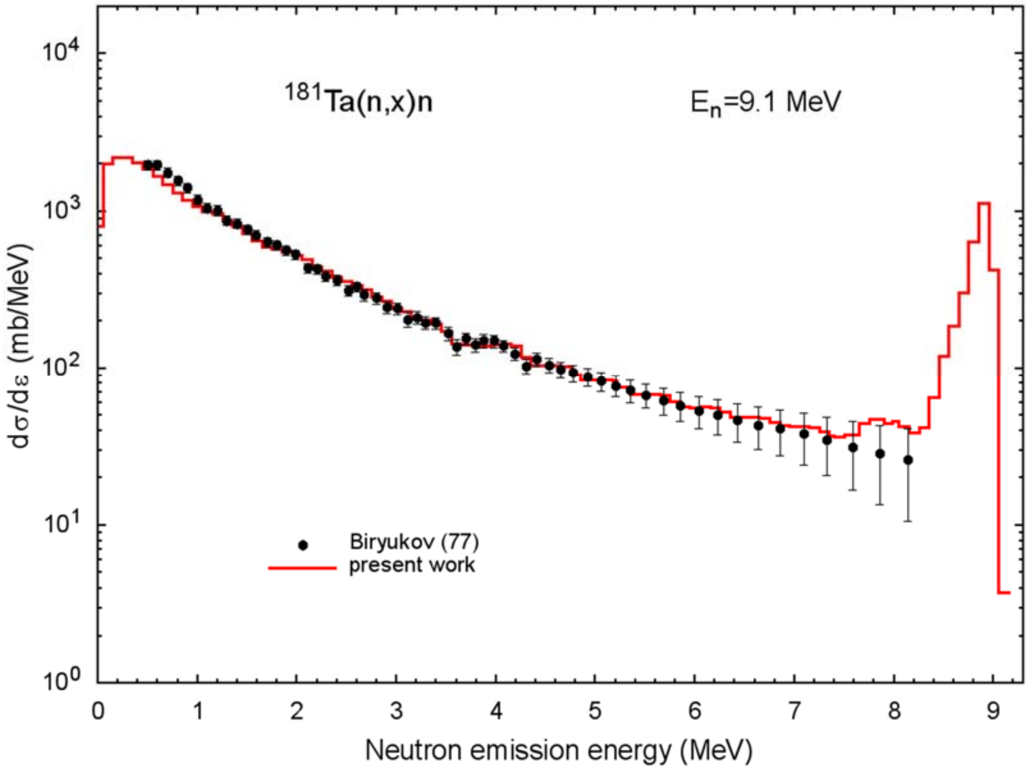


Fig.A55 Neutron energy distribution for 9.1 MeV neutrons obtained in the present work and measured data.

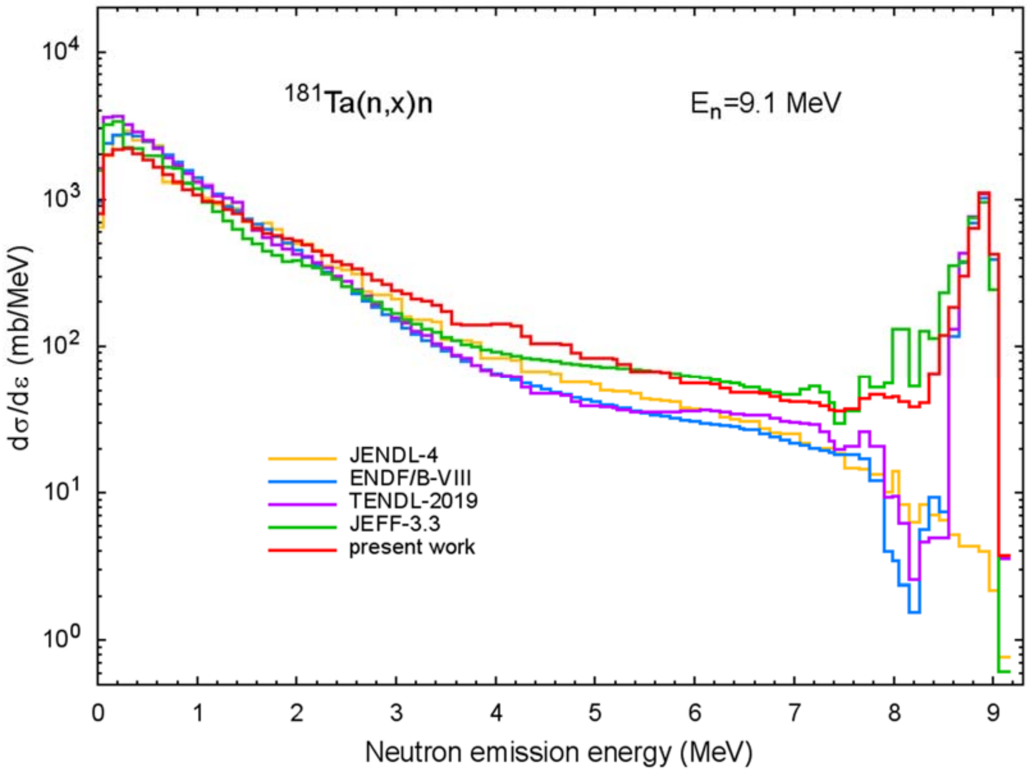


Fig.A56 Neutron energy distribution for 9.1 MeV neutrons obtained in the present work and taken from different data libraries.

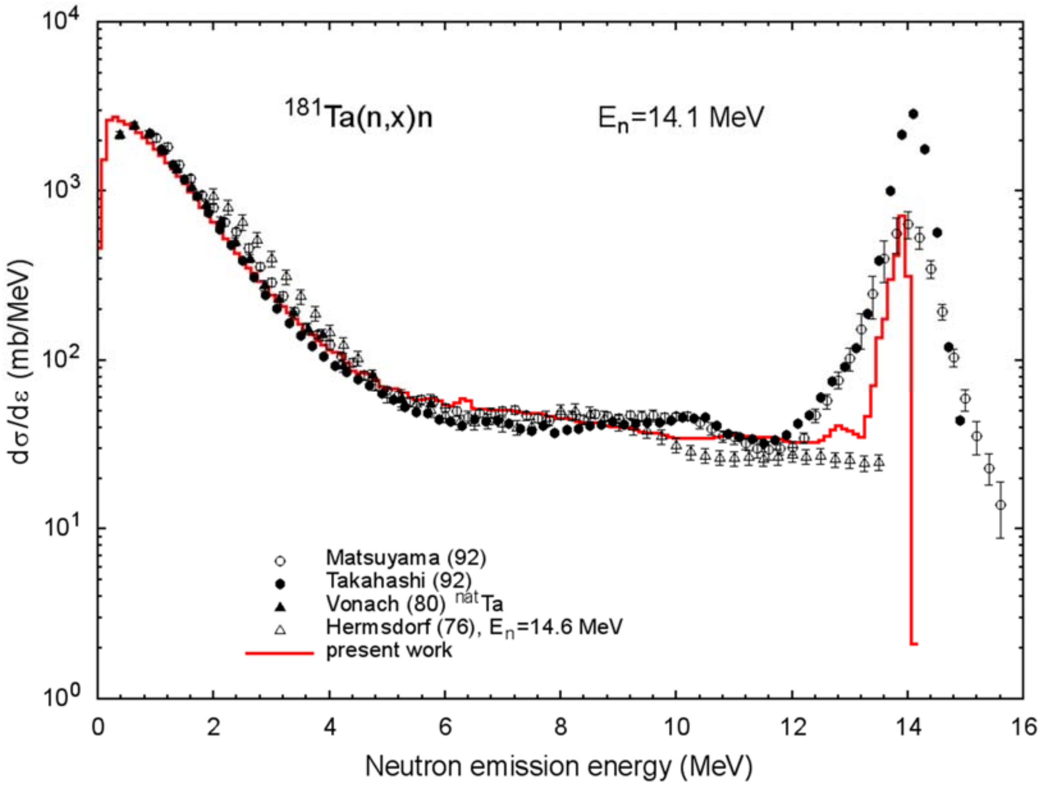


Fig.A57 Neutron energy distribution for 14.1 MeV neutrons obtained in the present work and measured data.

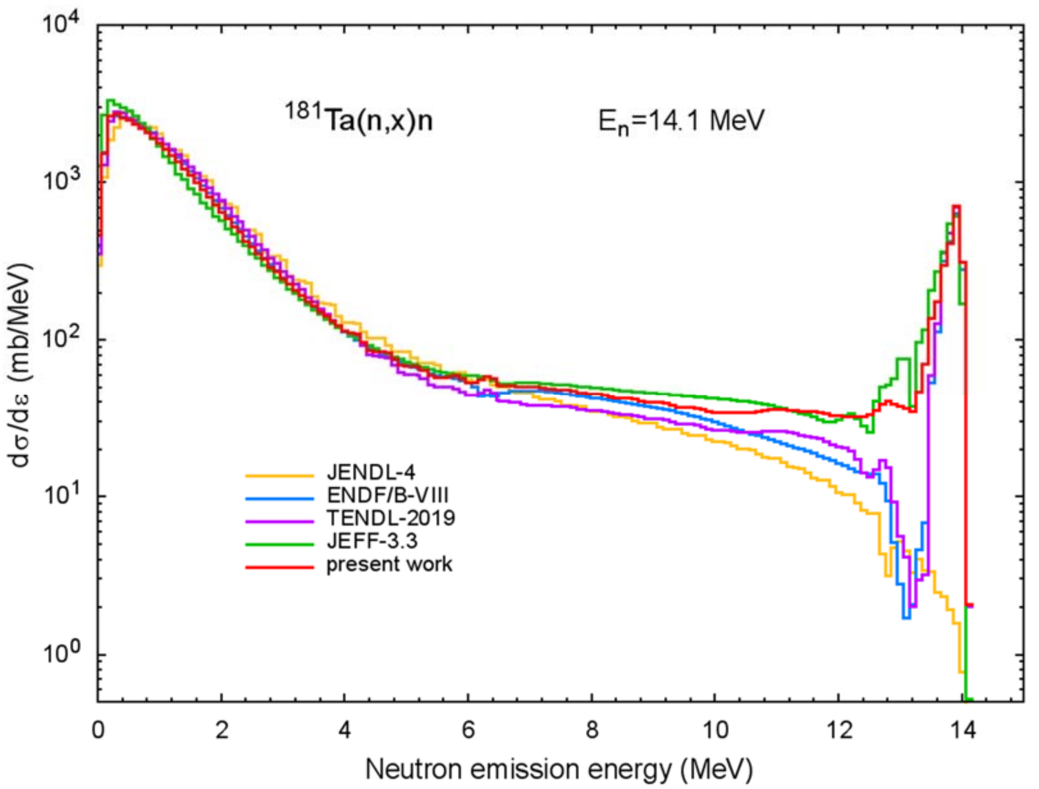


Fig.A58 Neutron energy distribution for 14.1 MeV neutrons obtained in the present work and taken from different data libraries.

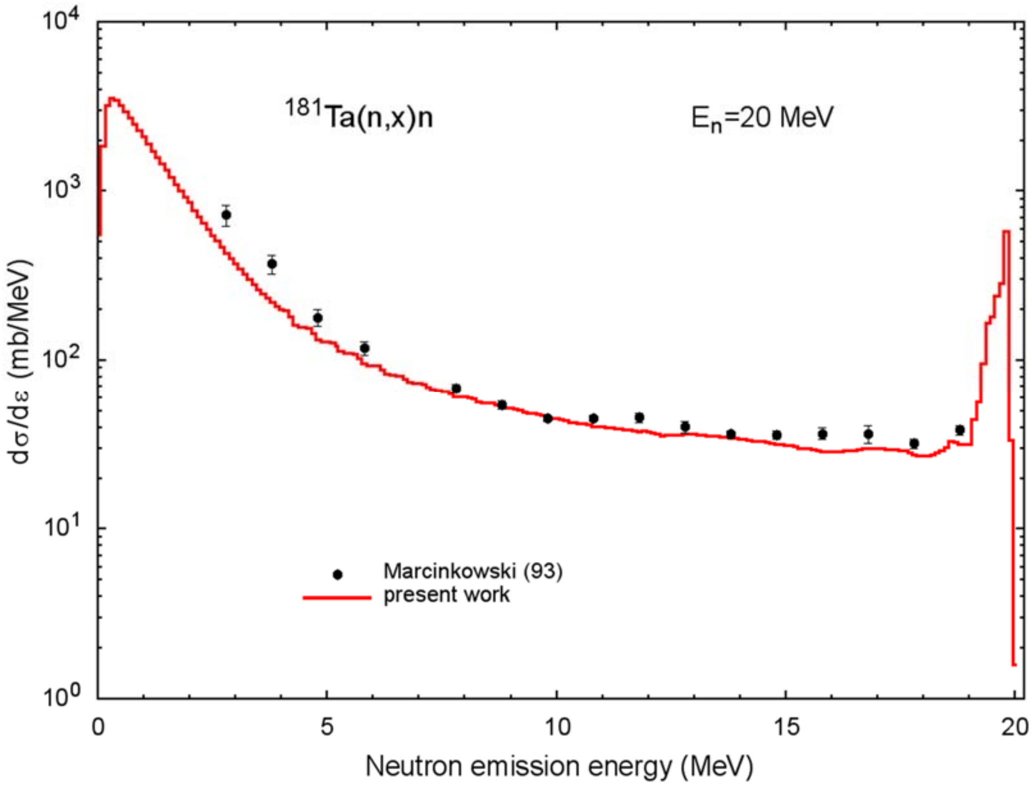


Fig.A59 Neutron energy distribution for 20 MeV neutrons obtained in the present work and measured data.

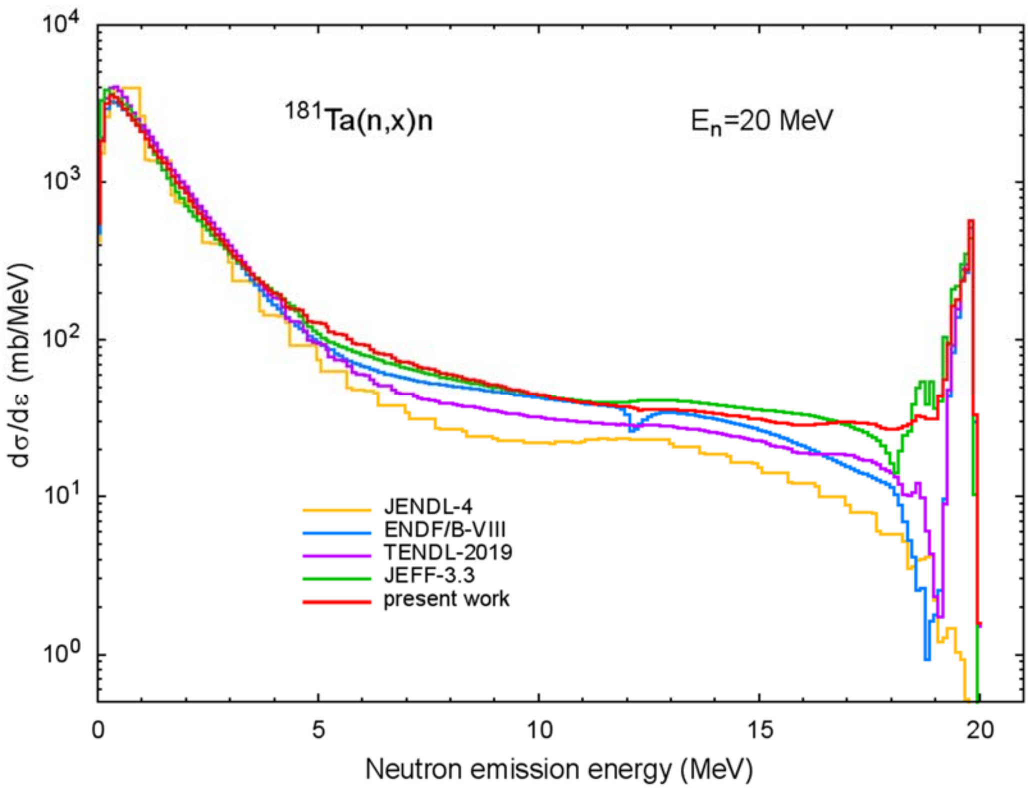


Fig.A60 Neutron energy distribution for 20 MeV neutrons obtained in the present work and taken from different data libraries.

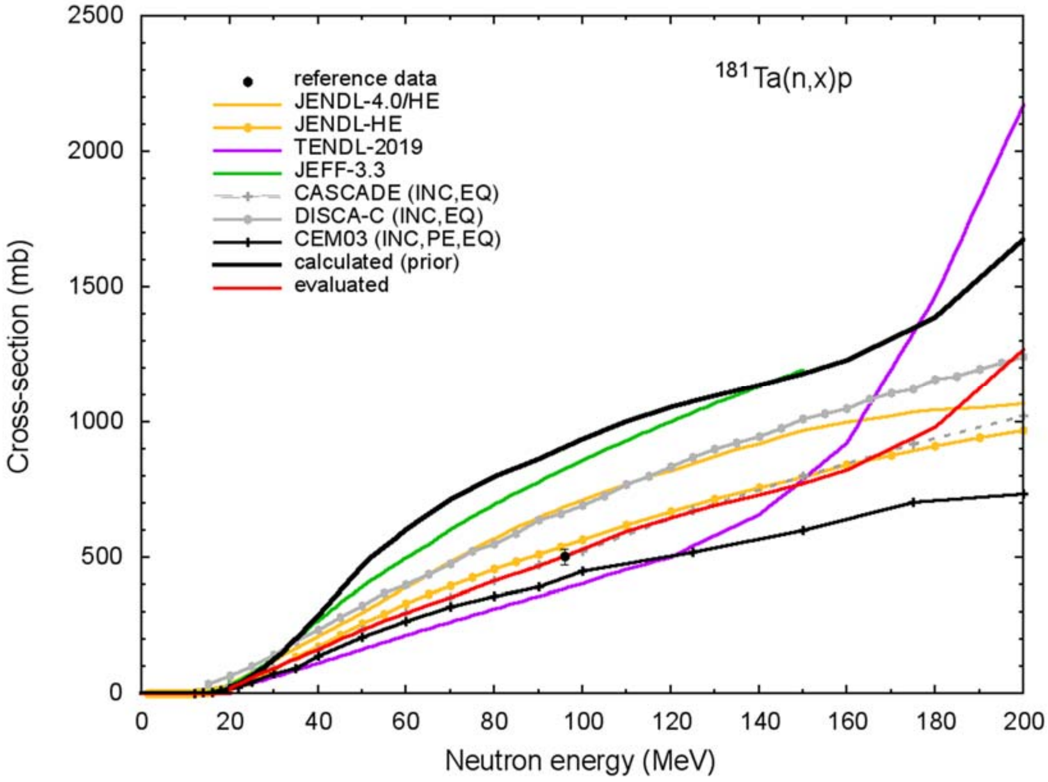


Fig.A61 Proton production cross-section.

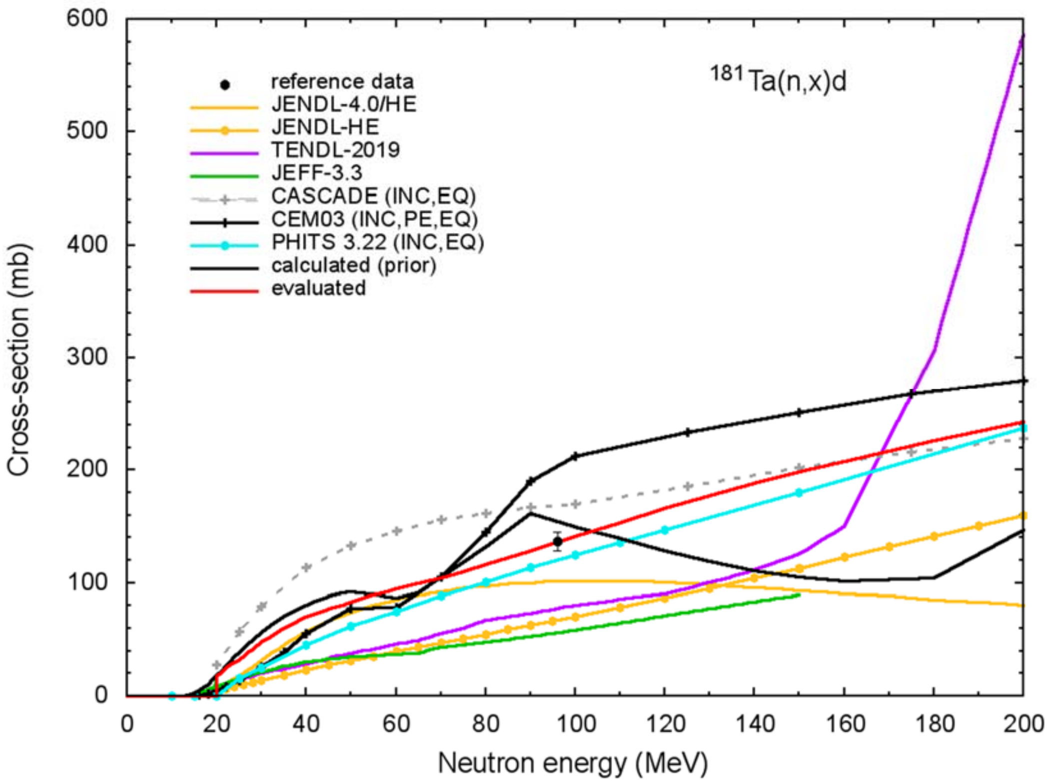


Fig.A62 Deuteron production cross-section.

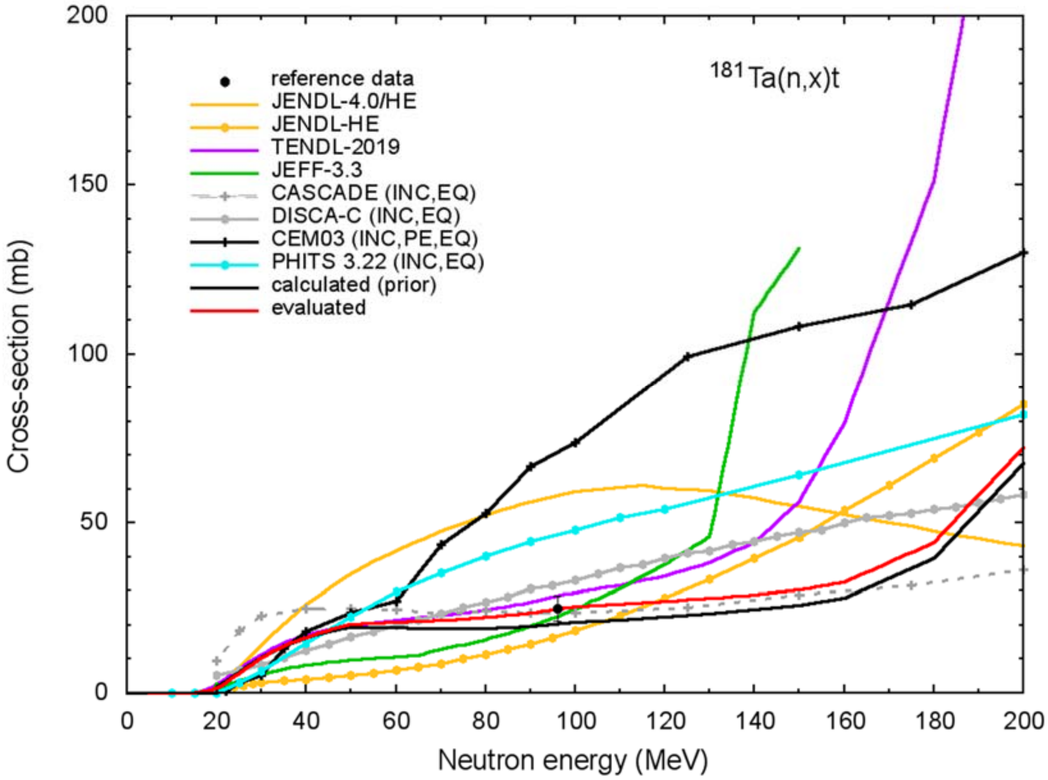


Fig.A63 Triton production cross-section.

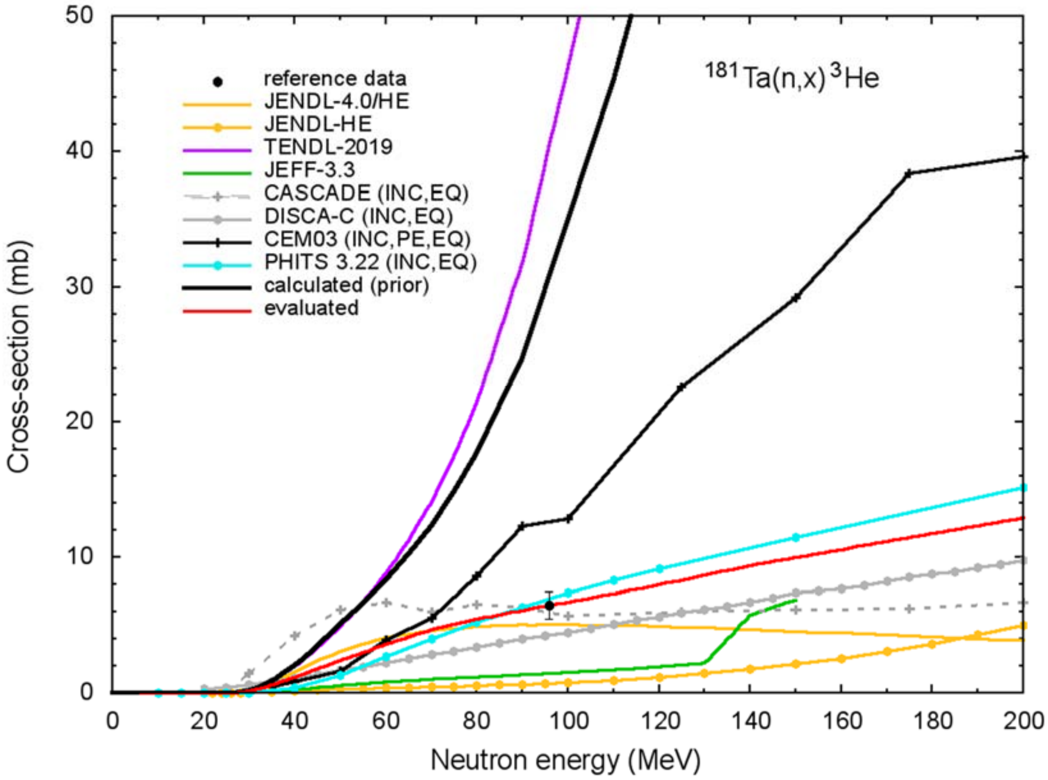


Fig.A64 $^{3}$He production cross-section.

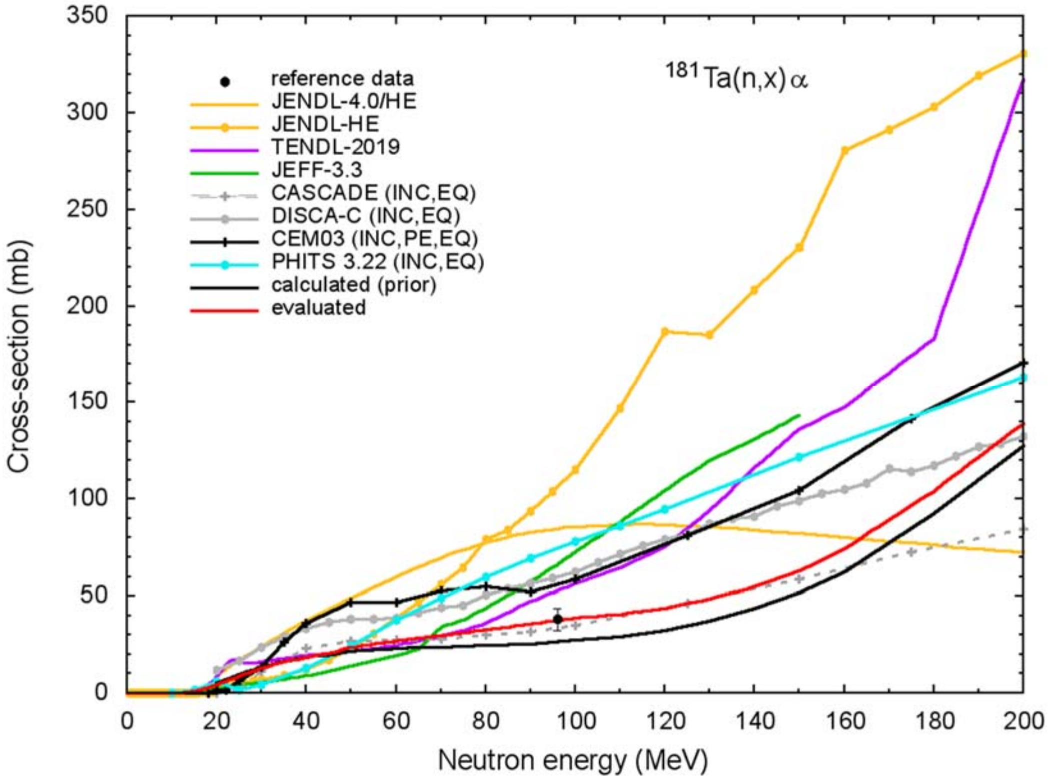


Fig.A65 α-particle production cross-section.

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