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Neutron nuclear data evaluation of actinide nuclei for CENDL-3.1

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Abstract: New evaluations for several actinide nuclei of the third version of Chinese Evaluated Nuclear Data Library for Neutron Reaction Data (CENDL-3.1) have been completed and released. The evaluation is for all neutron induced reactions with uranium, neptunium, plutonium and americium in the mass range A=232–241, 236–239, 236–246 and 240–244, respectively, and cover the incident neutron energy up to 20 MeV. In the present evaluation, much more effort was devoted to improving the reliability of the evaluated nuclear data for available new measured data, especially scarce or absent experimental data. A general description for the evaluation of several actinides' data is presented.

Key words: actinide, nuclear data, evaluation, CENDL, neutron

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1 Introduction

The evaluated nuclear data are needed for the design of fission and fusion reactors and for shielding calculations. The new generation Chinese Evaluated Nuclear Data Library for Neutron Reaction Data, CENDL-3.1 [1], was released by the China Nuclear Data Center in 2009. The evaluated nuclear data of actinide nuclei in CENDL-2.1 [2] were re-evaluated taking account of new experimental data, ENDF/B-Ⅵ [3] neutron cross section standards and using a new theoretical model code. In addition to those nuclides, the data of the 25 new nuclides was evaluated also during the period between 2000 and 2005. The evaluation is for all neutron induced reactions with uranium, neptunium, plutonium and americium in the mass range A=232–241, 236–239, 236–246 and 240–244, respectively, and cover the incident neutron energy up to 20 MeV. More detailed actinide nuclides in CENDL-3.1 [1] are listed in Table 1. Compared with CENDL-2.1 [2], the last column "New" in Table 1, gives the mass range of the newly evaluated nuclides.

Table 1. Actinide nuclides in CENDL-3.1 database.

	CENDL-2.1	CENDL-3.1	new
U	235,238	232–241(10)	232–234,236,237,239–241
Np	237	236–239(4)	236,238,239
Pu	239,240	236–246(11)	236–238,241–246
Am	241	240–244(6)	240,242,242m,243,244

In the CENDL-3.1 [1] evaluation, much more effort was devoted to improving the reliability of the evaluated nuclear data for available new measured data, especially scarce or absent experimental data. Major aspects of the present evaluation include systematic accumulation, correction and evaluation of all relevant experimental data; re-normalization of the neutron data to ENDF/B-Ⅵ [3] neutron cross section standards; assessment of the applicability of several optical model potentials obtained before 2000 for theoretical calculation; interpretation of the experimental results in terms of nuclear theory to allow interpolation and extrapolation of the data into unmeasured energy regions; and finally, assembly of the

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experimental and theoretical results into formal evaluated nuclear data files that can be processed for use in applied nuclear programs. This report presents a general description for the evaluation of several actinides' data.

In the following sections, an overview of actinide nuclear data of CENDL-3.1[1] in comparison with measurements and other database is presented.

2 Resonance parameters

Thermal fission and capture cross sections for actinide nuclides were corrected and estimated by averaging the measurements with suitable weights, according to the method, neutron source, sample purity and so on. The negative and low-lying resonance parameters were modified to reproduce the thermal cross sections. The results of thermal fission and capture cross sections for some important nuclides are shown in Table 2. The resonance parameters were adopted from JENDL-3.3 [4] and ENDF/B-Ⅵ [3] databases, except the resolved resonance parameters of ^{236}Np and ^{238}Np were taken from the evaluation results of G.B.Morogovskij [5] and the unresolved resonance parameters of ^{238}Np were evaluated according to the available resolved resonance parameters. According to the experimental data and benchmark results, some resolved resonance parameters have been modified and the unresolved resonance parameters were determined so as to smoothly connect with the evaluated cross sections above the resonance region.

Table 2. Fission and capture thermal cross sections.

nuclide	cross sections/b	
	(n, f)	(n, γ)
^{233}U	7.67654E+01	7.52080E+01
^{234}U	2.98537E−01	9.97503E+01
^{237}Np	2.02034E−02	1.60369E+02
^{238}Pu	1.70116E+01	5.61082E+02
^{240}Pu	6.40123E-02	2.87387E+02
^{241}Pu	1.01199E+03	3.61525E+02
^{242}Pu	1.04233E−03	1.91577E+01
^{241}Am	3.14232E+00	6.39448E+02
^{242}Am	2.09322E+03	2.18831E+02
^{242m}Am	6.39017E+03	1.22922E+03
^{243}Am	6.43805E−02	7.67044E+01

3 Evaluation procedure

There are a significant amount of measurements with different methods, facilities and neutron sources available for neutron reactions on several of the actinides in the present study. Most of the experimental data were adopted from the EXFOR/CINDA database at the Nuclear Data Section of IAEA, the Data Bank of the Nuclear Energy Agency in Paris, INIS database and relevant periodical literatures. There exists varying degrees of discrepancy in those experimental data for the same neutron reaction. For cross section evaluation, a special effort was made in the experimental data analysis and evaluation, which include systematic accumulation, correction and evaluation of all relevant experimental data, and renormalization of the neutron data to ENDF/B-Ⅵ [3] neutron cross section standards, etc.

Most of the measurements for fission cross section and prompt neutron multiplicities from fission reaction (ν_p) are relevant to "standard" or other accurately measured reactions. Most of the ν_p measurements are relative to ^{252}Cf neutron multiplicities from spontaneous fission, which is very accurately known as 3.7692 ± 0.0047 [6, 7]. In the case of fission cross sections, the measurements are frequently relative to (n, f) reaction of ^{235,238}U or/and ^{239}Pu. In the present evaluation, all the ratio and cross section measured data of the fission reaction were evaluated and corrected using ENDF/B-Ⅵ [4] standards. For ν_p measurements were corrected to consist with the IAEA recommendation [6, 7].

In general, the first step of the evaluation procedure is to accumulate, assess, normalize and correct the measured data for each isotope. In order to fit the measurements for total cross section, nonelastic scattering cross section and elastic scattering angular distribution, the neutron optical model parameters were obtained with the APMN code [8], which is a program for automatically searching an optimum set of neutron optical model parameters. The theoretical models which are adopted are mainly coupled-channel optical models (such as ECIS-95 [9] code) and Hauser-Feshbach statistical plus pre-equilibrium theory (as FUNF [10] code). The sequence usually followed in the evaluation above the resonance region is to optimize the agreement of model calculated results with the evaluated experimental data for cross sections, differential cross sections and double differential cross sections, by careful model parameter adjustment. After that we assemble the experimental data after evaluation and theoretical results into formal evaluated nuclear data files with ENDF format. The final step in the evaluation is to make fine modifications in ν_p and other data (generally within experimental uncertainties) to enhance the agreement with simple fast critical benchmark measurements.

The comparison of the evaluated data with the absolute and ratio experimental data is shown in Figs. 1 and 2. In Fig. 2, the ratio measurements are converted to the absolute cross sections using ENDF/B-Ⅵ [4] standards and compared with the present evaluation. The discrepancy exists in each measurement as shown in Fig. 1. The ratio measurement is usually more reliable than the absolute one as shown in Fig. 2. However, there exist discrepancies also for the ratio measurements as shown in Fig. 3. Consequently, analysis, modification, normalization and correction are necessary and the discrepancies should be clarified before using those experimental data in our evaluation. Fig. 4 shows the ratio measurements in comparison with each other after evaluation.

Through evaluating the available experimental data for uranium, neptunium, plutonium and americium isotopes, the change trend of the cross sections

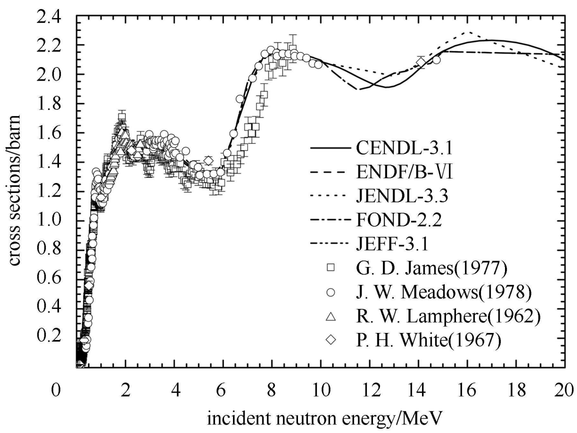

Fig. 1. Comparison of the evaluated data with the absolute measured data for ^{234}U(n, f) reaction.

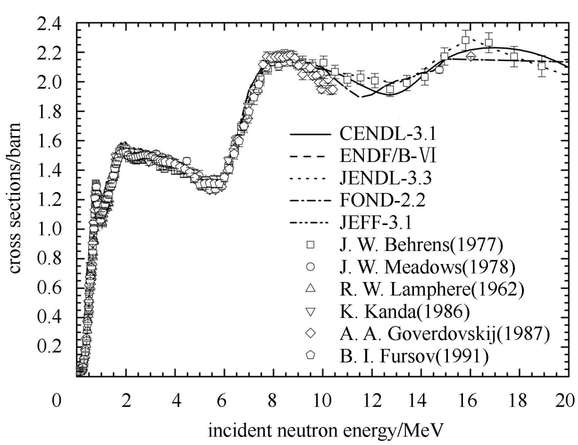

Fig. 2. Comparison of the evaluated data with the relative measured data for ^{234}U(n, f) reaction.

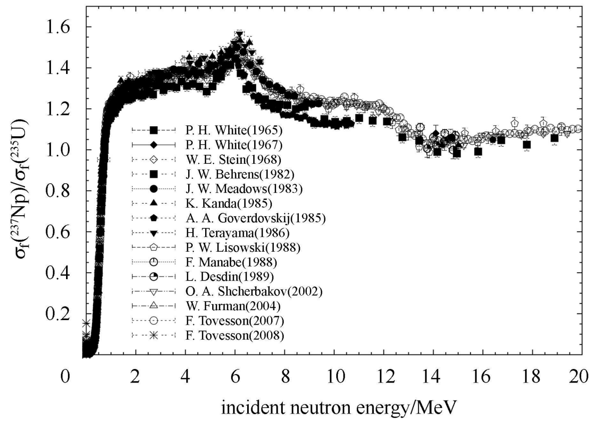

Fig. 3. Comparison of the original ratio measurements for ^{237}Np(n, f) reaction.

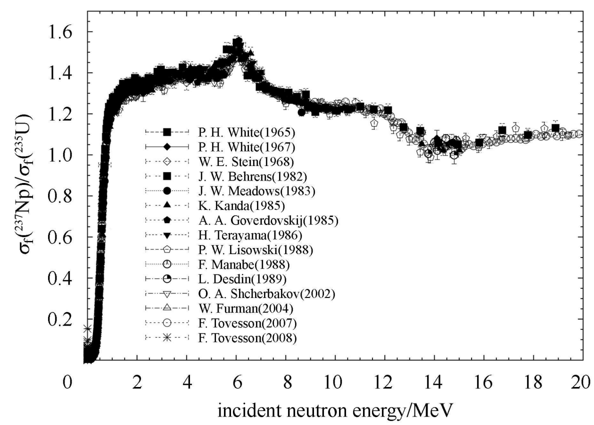

Fig. 4. Comparison of the corrected ratio measurements for ^{237}Np(n, f) reaction.

for some important reactions, such as (n, f), (n, γ), (n, 2n), (n, 3n) was investigated. It was observed that the reaction cross sections depend on the characteristic concerning even-odd for the same Z, the related fission barrier, the level density, and the pair corrections of the actinide nuclide. A systematic method to estimate the cross section for (n, f), (n, γ), (n, 2n), (n, 3n) reactions was employed for interpolation and/or extrapolation of suitable scarce experimental data, as shown in Fig. 5 for the comparison of (n, f) reaction cross sections between even mass uranium isotopes. To obtain the reasonable recommended data of actinide nuclides for scarce or absent experimental data, the evaluated method was applied as mentioned above.

As an example, the systematic method was applied to obtain the evaluated data such as ^{246}Pu(n, f) reaction, the only existing data being the experimental data at thermal energy. In order to recommend the complete neutron data for ^{246}Pu, the theoretical calculation was employed based on the change trend

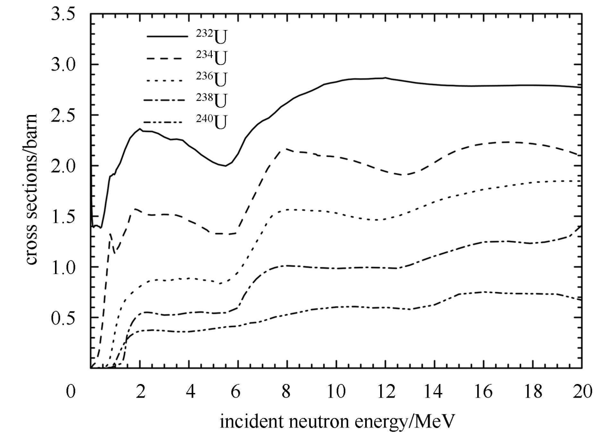

Fig. 5. Comparison of (n, f) reaction for even mass uranium isotopes.

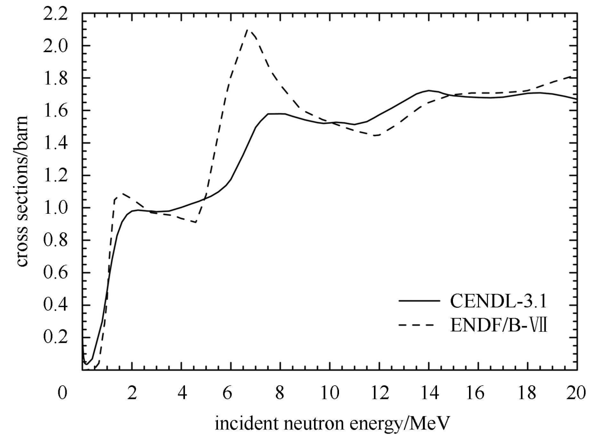

Fig. 6. Comparison of the evaluated data for ^{246}Pu(n, f) reaction.

to adjust the related fission barriers, level densities and pair corrections at saddle points for (n, f), (n, n′f) and (n, 2nf) phase of the even-even systematic of plutonium. The (n, 2n), (n, 3n) reaction cross sections and other quantities were calculated based on the adjusted theoretical parameters in the same way as the even-even systematic of plutonium. The systematic calculated fission cross section of ^{246}Pu is compared with ENDF/B-VII [11], and the plot is shown in Fig. 6.

4 Conclusion

Nuclear data of neutron induced reactions were evaluated for 31 actinide nuclides from U to Am in the neutron energy up to 20 MeV during the period between 2000 and 2005. The evaluated results as a part of CENDL-3.1 [1] were released in 2009. Actinide nuclear data in CENDL-3.1 [1] were widely revised and improved, and 25 new actinide nuclear data were added in comparison with CENDL-2.1 [2].

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