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Updated and revised neutron reaction data for ^{236,238}Np

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Abstract. Nuclear data with high accuracy for minor actinides play an important role in nuclear technology applications, including reactor design and operation, fuel cycle, estimation of the amount of minor actinides in high burn-up reactors and the minor actinides transmutation. Based on a new set of neutron optical model parameter and the reaction cross section systematics of fissile isotopes, a full set of ^{236,238}Np neutron reaction data from 10^{-5} eV $\sim$20 MeV are updated and improved through theoretical calculation. Mainly revised quantities include the total, elastic, inelastic, fission, (n, 2n) and (n, γ) reaction cross sections as well as angular distribution etc. The promising results are obtained when the renewal evaluated data of ^{236,238}Np will replace the evaluated data in CENDL-3.1 database.

1. Introduction

Nuclear data with high accuracy for minor actinides (MAs) are required to estimate the amount of minor actinides in high burn-up reactors and to research a technology to transmute the minor actinides to short half-lived nuclides or stable ones. The data of ^{236,238}Np in CENDL-3.1 [1] were evaluated in 2003, and there exist many new evaluations [2–5] on it now. In the present work the data evaluation for ^{236,238}Np in CENDL-3.1 [1] are revised. Mainly revised are (n, tot), (n, el), (n, n′), (n, 2n), (n, f) and (n, γ) reaction cross sections as well as angular distributions etc., when a new set of neutron optical model parameters (OMP) are obtained.

2. Evaluation procedure and results

2.1. Optical model parameters

Most of the experimental data are adopted from the EXFOR/CINDA [6], INIS database and relevant periodical literatures. There exist varying degrees of discrepancy in those experimental data for the same neutron reaction. For cross section evaluation, a special effort is made in the experimental data analysis and evaluation, which include systematic accumulation, correction, evaluation of all relevant experimental data, and re-normalization of the neutron data to ENDF/B-VII.1 [4] neutron cross section standards, etc. For ^{236,238}Np, there are only few measurements on fission reaction at resonance energy region. In present work, the main contribution comes from the theoretical model calculation. The theoretical models which are adopted are mainly coupled channel optical models (such as ECIS-95 [7] code) for ^{238}Np, the DWBA method for ^{236}Np and the Hauser-Feshbach statistical plus pre-equilibrium theory (as FUNF [8] code).

Based on the optical model parameters (OMP) of n+^{237}Np, and observed the reaction cross sections changing trend of (n, tot) and (n, el) for fissile isotopes according to the comparison of the available experimental data and evaluation database of $^{234-239}$Np above 100 keV, a new set of OMP of even mass of Np is obtained as shown in Table 1. The comparison of evaluated data for ^{238}Np(n, tot) reaction is shown in Fig. 1. The comparison of evaluated data for ^{238}Np(n, el) reaction is shown in Fig. 2 and compared with its of ^{237}Np also, for which exist discrepancy for different evaluated database. In general, results presented are consistent with JENDL-4.0 [3], and higher than CENDL-3.1 for (n, tot) reaction. In Fig. 1 and Fig. 2, the present result is compared with ^{237}Np data of CENDL-3.1 and JENDL-4.0 as label as C31 and J40. Because the OMP of even mass of Np is obtained from the n+^{237}Np OMP in those two databases evaluation. In the other hand, there is a significant discrepancy in the shape of (n, tot) and (n, el) reaction cross section between JEFF-3.1 [5] and other databases.

2.2. Inelastic cross sections

The direct processing contribution is very important in neutron inelastic scattering reaction calculation, which is calculated using the coupled channel model and DWBA method for ^{238}Np and ^{236}Np, respectively.

For ^{236}Np, the discrete levels information is listed Table 2. The parity and spin of the ground state is 6^- and the coupled channel model is not fit to calculate the directly contribution for inelastic scattering, and the 1st excited state parity is not available in ENSDF database [10]. Based on DWBA analysis, the result is about 10^{-33} barn and dozens of barn using parity as “+” and “–” for the 1st excited state, respectively. So the 1st excited state parity is probably as “+” and the directly inelastic contribution could be neglected in present work. For discrete levels information of ^{236}Np, ENSDF database [10] are adopted in present work, however, its totally different from the ENSDF data used in JENDL-4.0. The comparison of the evaluated data for ^{236}Np(n, n′) is shown in Fig. 3 and

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Table 1. Optical potential parameters of even mass Np.

par.	Particles				
	N	P	α	D	T
AR	0.595	0.50	0.52	0.81	0.75
AS	0.592	0.51	0.49	0.68	0.75
AVV	0.591	0.51	0.49	0.68	0.75
ASO	0.565	0.50	0.51	0.81	0.75
XR	1.279	1.25	1.35	1.15	1.20
XS	1.022	1.25	1.35	1.34	1.20
XV	1.221	1.25	1.35	1.34	1.20
XSO	1.279	1.25	1.35	1.15	1.20
XC	1.250	1.25	1.35	1.15	1.30
UO	0.135	−2.70	0.00	0.00	0.00
U1	0.293	0.22	0.00	0.00	0.00
U2	−0.009	0.00	0.00	0.00	0.00
VO	49.145	54.00	151.90	81.00	165.00
V1	−0.040	−0.32	−0.17	−0.22	−0.17
V2	−0.015	0.00	0.00	0.00	0.00
V3	−24.00	24.00	50.0	0.00	−6.40
V4	0.000	0.40	0.00	2.00	0.00
VSO	6.200	6.20	2.50	7.00	2.50
WO	9.206	11.80	41.70	14.40	46.00
W1	0.037	−0.25	−0.33	0.24	−0.33
W2	−12.00	12.00	44.00	0.00	0.00
A2S	0.7				
A2V	0.7				

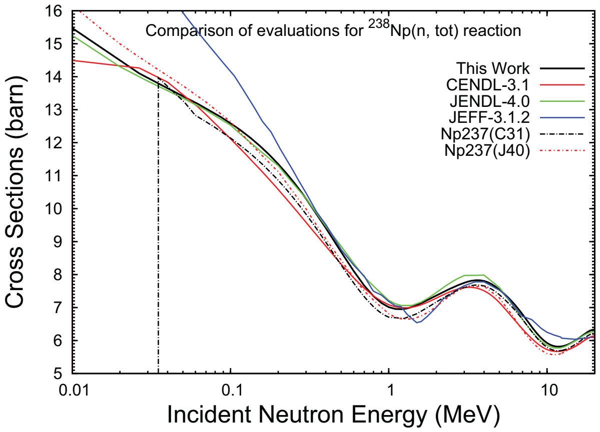

Figure 1. Comparison of evaluated data for ^{238}Np(n, tot) reaction.

compared with ^{238}Np(n, n′) to confirm the (n, n′) reaction cross sections change with the nuclei mass increasing. There exist discrepancy for different evaluations. Present result is higher than its of CENDL-3.1. The shape of (n, n′) reaction cross section in JEFF-3.1 exist big discrepancy with other databases above 8 MeV, which is possible miss the contribution of continuum or directly inelastic contribution.

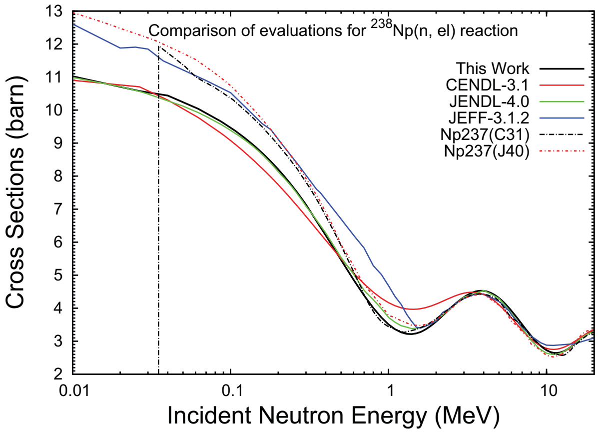

Figure 2. Comparison of evaluated data for ^{238}Np(n, el) reaction.

Table 2. Discrete levels information of ^{236}Np.

Database	No.	E_x(MeV)	J	π
ENSDF [10]	0	0.000	6	−
	1	0.060	1	?
	2	0.231	3	−
	3	0.273	4	−
	4	0.324	5	−
JENDL-4.0 [3]	0	0.000	6	−
	1	0.056	7	−
	2	0.060	1	+
	3	0.076	2	+
	4	0.100	3	+
	5	0.120	8	−
	6	0.132	4	+

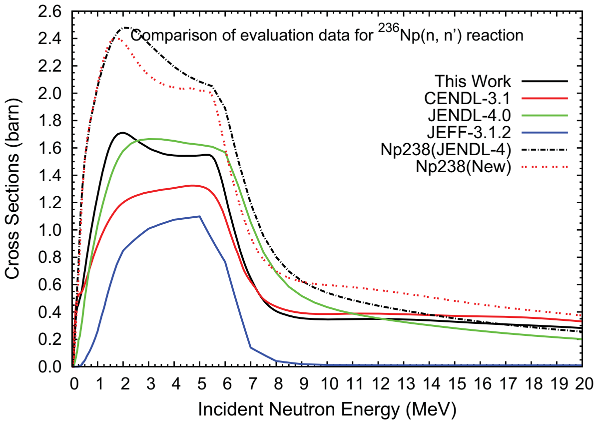

Figure 3. Comparison of evaluated data for ^{236}Np(n, n′) reaction.

2.3. Other reaction cross sections

Through evaluating the available experimental data for U, Np, Pu and Am isotopes, the changing trend of the cross sections for some important reactions, such as (n, f), (n, 2n), (n, 3n) etc. is investigated. It is 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, 2n), (n, 3n) reactions is employed for interpolation and/or extrapolation of suitable scarce experimental data, as shown in Fig. 4 for the measurements comparison of (n, f) reaction cross sections between odd mass U isotopes. To obtain the reasonable evaluated data of Np isotopes for scarce or absent measurements, the evaluated method is taken into account as mentioned above. More detailed information on neutron nuclear data evaluation of actinide nuclei is described in Ref. [9].

The systematic method mentioned above and model calculation are used to obtain reaction cross sections such as (n, 2n) and (n, f). The comparison of ^{238}Np fission cross sections is shown in Fig. 5, and compared with the result of H.C.Britt's work [11] which was based on the available measured information to simulate (n, f) cross

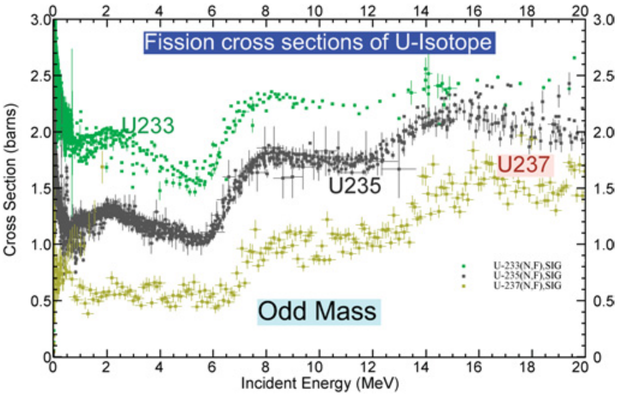

Figure 4. Comparison of (n, f) reaction for odd mass U isotopes.

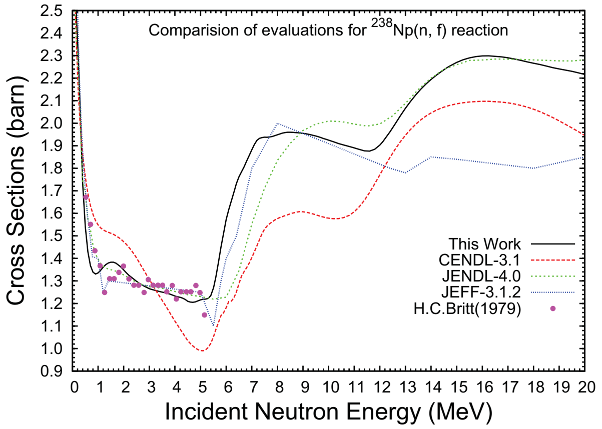

Figure 5. Comparison of the evaluated data for ^{238}Np(n, f) reaction.

sections for exotic actinide nuclei. The evaluated results for different databases are agree well with the simulated result of H.C.Britt [11] as pink points at the 1st fission process, and there are discrepancy between different evaluations above 5 MeV. The shape of (n, f) reaction cross section in JEFF-3.1 exist big discrepancy with other databases in general, especially at 0.5 ∼ 2.0 MeV and above 5 MeV. And CENDL-3.1 data is lower than other evaluated data above 5 MeV, except JEFF-3.1.

The comparison of ^{236}Np(n, 2n) reaction cross sections are shown in Fig. 6. The evaluated results for different databases are discrepant in shape and size above 7 MeV. In CENDL-3.1, shape of (n, 2n) exist in steps below 8 MeV, which is the primary cause of the unreasonable shape of (n, n′) and (n, f) reaction cross sections in CENDL-3.1.

2.4. Differential cross sections

Based on a new set of OMP, the FUNF theoretical calculated result are obtained for the angular distribution and energy spectra. The elastic angular distribution of ^{238}Np is shown in Fig. 7 at 14 MeV, and the comparison of the neutron emission spectra for ^{236}Np(n, f) reaction is shown in Fig. 8 with different incident neutron energy.

3. Conclusions

Based on a new set of neutron optical model parameter and the reaction cross section systematics of fissile isotopes, a full set of ^{236,238}Np neutron reaction evaluation from 10^{-5} eV ∼ 20 MeV is updated and revised. The present evaluation is compared with other available evaluation databases [1–5] and measurements. From the point of view of the microscopic evaluation, the present result is much better than the data in CENDL-3.1 [1]. The results for ^{236,238}Np will replace the evaluated data in CENDL-3.1 [1].

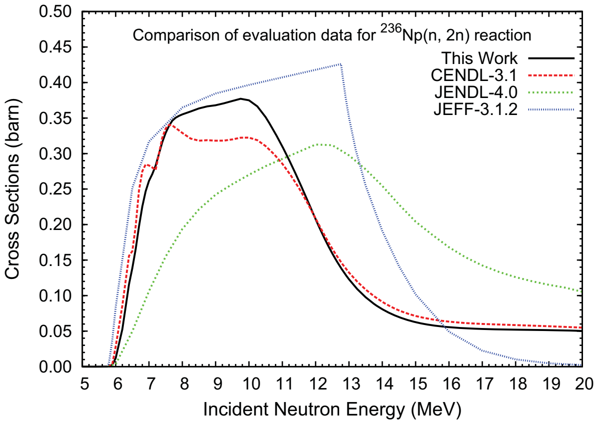

Figure 6. Comparison of the evaluated data for ^{236}Np(n, 2n) reaction.

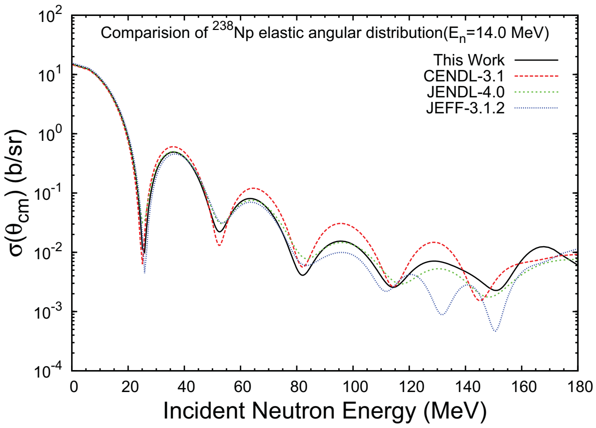

Figure 7. Comparison of ^{238}Np elastic angular distribution.

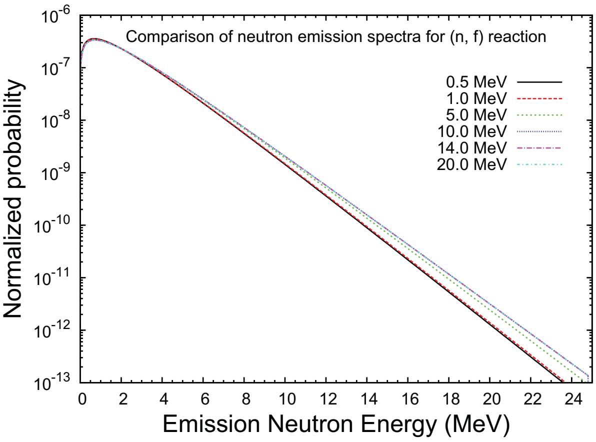

Figure 8. Comparison of neutron spectra for ^{236}Np(n, f) reaction.

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