Revision of Heavy Nuclei Data in JENDL-3.2

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In order to deal with problems concerning the data of heavy nuclides in JENDL-3.2, a working group was organized to update the evaluated nuclear data of Uranium, Plutonium, and Thorium isotopes. The current status of the working group is reviewed, and some results about resonance parameters, secondary neutron energy spectra, fission cross sections, and direct/semidirect capture process are shown.

1. Introduction

After the release of JENDL-3.2, several problems concerning the data of heavy nuclides have been reported. The quantities with problems of great importance are as follows :

- ^{235}U resonance parameter
- Secondary neutron energy spectrum
- Fission cross sections in the smooth region
- Direct/semi-direct capture process

A working group on evaluation of nuclear data of heavy nuclides was organized in 1997 to update the evaluated nuclear data of Uranium, Plutonium, and Thorium isotopes in JENDL-3.2. The objectives of the working group are to investigate the problems and to re-evaluate the nuclear data for the next revision of JENDL — JENDL-3.3. We have investigated these problems for a couple of years, and adopted outcomes of the discussions in the new evaluations. The current status of the working group is reviewed, and some results are reported.

2. Resonance Parameters

In JENDL-3.1, resonance parameters of the single-level Breit-Wigner formula was adopted for ^{235}U in the energy range up to 100 eV. These parameters were replaced with the data of ENDF/B-VI which were based on a Reich-Moore R-matrix analysis of Leal, de Saussure, and Perez[1] at the release of JENDL-3.2. Several problems concerning cross sections in the resolved resonance region have been reported since then. The major problems are an underestimation of capture cross sections and an overestimation of k_{eff} for thermal reactors. Note that Leal

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Table 1: Fission and capture cross sections at the thermal energy calculated with the ^{235}U resonance parameters.

		Fission		Capture		Ref.
	formula	2200 m/s [b]	Res. Integ. [b]	2200 m/s [b]	Res. Integ. [b]	
JENDL-3.1	SLBW	584.0	275	96.0	152	
JENDL-3.2	R-M	584.4	279	98.81	134	[1]
JENDL-3.3	R-M	584.88	276.04	98.66	140.49	[2]

et al. gave the resonance parameters up to 2.25 keV, however the upper limit of the resolved resonance region for ^{235}U in JENDL-3.2 was 500 eV.

In 1997, Leal, Derrien, Larson, and Wright carried out a new R-matrix analysis[2] of ^{235}U resonance parameters up to 2.25 keV. We decided to adopt this resonance parameter set for JENDL-3.3. Thermal cross sections and resonance integral calculated with those parameters are shown in Table 1.

A preliminary benchmark test with the resonance parameters of Leal *et al.*[2] was carried out, and it was reported that the overestimation of k_{eff} was improved to some extent, but it is insufficient. To improve the predictivity of k_{eff}, re-evaluation of other quantities such as a prompt neutron fission spectrum is needed. The fission spectrum is under investigation by Ohsawa with a multimodal fission analysis[3].

Recently an R-matrix analysis for ^{240}Pu was also carried out[4]. The resonance parameters obtained by Bouland *et al.* will be adopted in JENDL-3.3.

3. Secondary Neutron Energy Spectrum

Secondary neutron energy spectra for the (n, n'), $(n, 2n)$, and $(n, 3n)$ reactions compiled in JENDL-3.2 have been criticized for a long time. There exists three reasons for this problem. The first one is an adoption of the evaporation formula for neutron energy spectra above a threshold energy of $(n, 2n)$ reaction. This problem arises for several minor actinodes. The second one is a special case for ^{238}U. The energy spectra of ^{238}U were calculated with the GNASH code[5], and the crude output was stored into JENDL-3.2 without any post-processing procedures. However one had to employ a processing code such as GAMFIL[6] to convert into the ENDF format. The third one is not crucial. In JENDL-3.2, energy spectra for many important nuclei were calculated with the PEGASUS code[7]. This is an evaporation model calculation code and generates an appropriate spectrum in the ENDF format, although use of the GNASH code may be preferable in view of more accurate evaluation.

In the present revision work, we adopted the GNASH code to calculate the energy spectra. Results of the GNASH calculations were processed with the GAMFIL code. Figure 1 shows an example of the calculated spectrum, which is a spectrum of neutrons from ^{238}U at $E_n = 18$ MeV. The total neutron spectrum is compared with the experimental data[8] in Fig. 1.

4. Simultaneous Evaluation of Fission Cross Sections

A simultaneous evaluation method[9, 10] was adopted to evaluate the fission cross sections of ^{235}U, ^{238}U, ^{239}Pu, ^{240}Pu, and ^{241}Pu for JENDL-3, and the results were slightly modified and compiled into JENDL-3.2. After the release of JENDL-3.2, some new measurements of the fission cross sections of these nuclides have been published. These experimental data should be added to the database of the simultaneous evaluation in order to update the evaluated cross sections in JENDL-3.2. We investigated new experimental data which were not included in the previous evaluation, and developed a new simultaneous evaluation code SOK — Simultaneous evaluation On KALMAN — which is based on the model parameter estimation code KALMAN[11].

In the previous simultaneous evaluation, the capture cross sections of ^{238}U and ^{197}Au were incorporated into the experimental database. These reactions were, however, omitted in the present evaluation, because the evaluation of ^{238}U capture cross section was made independently[12] of the fission cross sections, and no data will be given for ^{197}Au in JENDL-3.3. Instead of these reactions we included the fission cross sections of ^{233}U in the present evaluation. A comparison of the evaluated fission cross sections of ^{233}U with the evaluated values in JENDL-3.2 and ENDF/B-VI, as well as the experimental data is shown in Fig. 2. Figure 3 shows a comparison of the fission cross section ratios of ^{233}U to ^{235}U. Since there are so many data points and they are indistinguishable, all experimental data are represented by the same symbol.

5. Direct/Semidirect Capture Process

The radiative capture process above about 5 MeV is explained by the Direct/Semidirect (DSD) radiative capture theory[13, 14]. However this process was not considered for many nuclei in JENDL-3.2. To overcome this problem, we made a computer program DSD. This code is based on the theory of Kitazawa *et al.*[15], which is the DSD theory for deformed nuclei. The maximum values of capture cross sections calculated with the DSD theory are in the order of 1 mb. Such a small cross section is not so important for practical applications. We made several approximations to make the calculation easy.

Comparisons of the calculated capture cross sections with the experimental data[16, 17] are shown in Fig. 4. The dot-dashed line is calculated with the Hauser-Feshbach theory which predicts almost negligible cross sections above 5 MeV. A summation of the Hauser-Feshbach and DSD calculations gives the final evaluated cross sections in this energy region. The dotted line in Fig. 4 shows the cross sections in JENDL-3.2, which were evaluated empirically.

6. Concluding Remarks

We briefly described some major revisions of the data of heavy nuclei — the resonance parameters of ^{235}U and ^{240}Pu, the secondary neutron energy spectra, the fission cross sections in the smooth region, and the direct/semidirect capture process. However there exists many other revisions which are not mentioned above, such as angular distributions for elastic/inelastic scattering, ν_p, ν_d, $(n, 2n)$ and $(n, 3n)$ reactions, and so forth. We have almost completed the re-evaluation of the cross sections and the other quantities described above. These nuclear data will be finalized after several benchmark tests. In addition, the working group will be active for an evaluation of covariance data.

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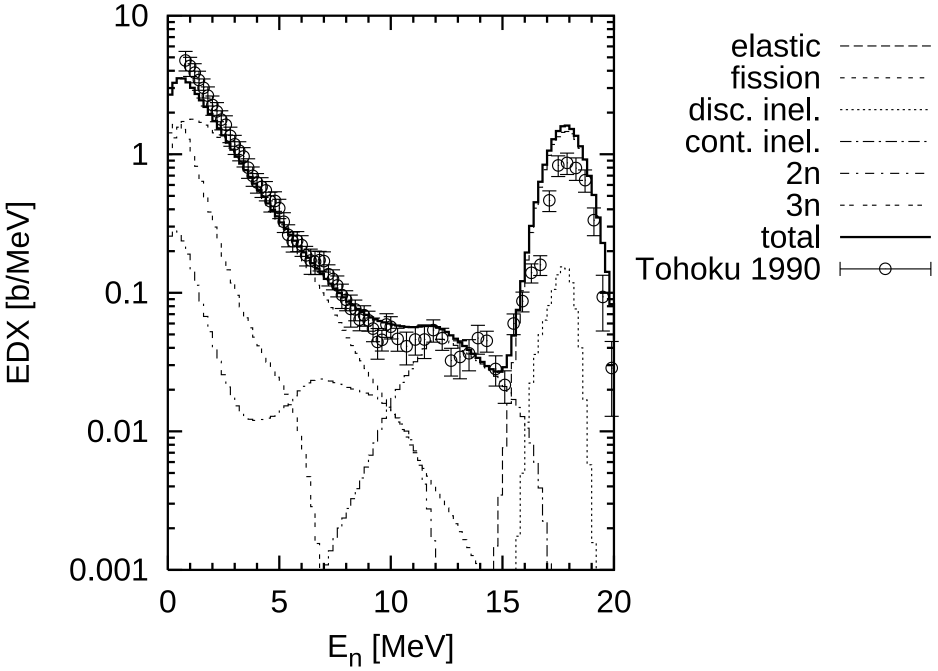

Figure 1: Secondary neutron energy spectrum of ^{238}U at the incident energy of 18 MeV. The total spectrum is decomposed into contributions of various processes.

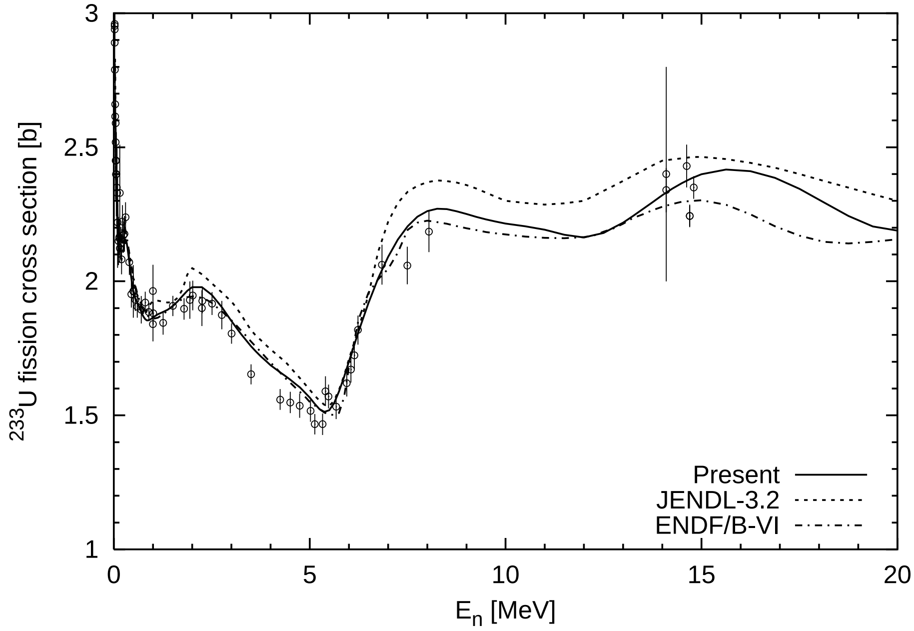

Figure 2: Comparison of the fission cross sections of ^{233}U with the experimental data and the evaluated cross sections in JENDL-3.2 and ENDF/B-VI.

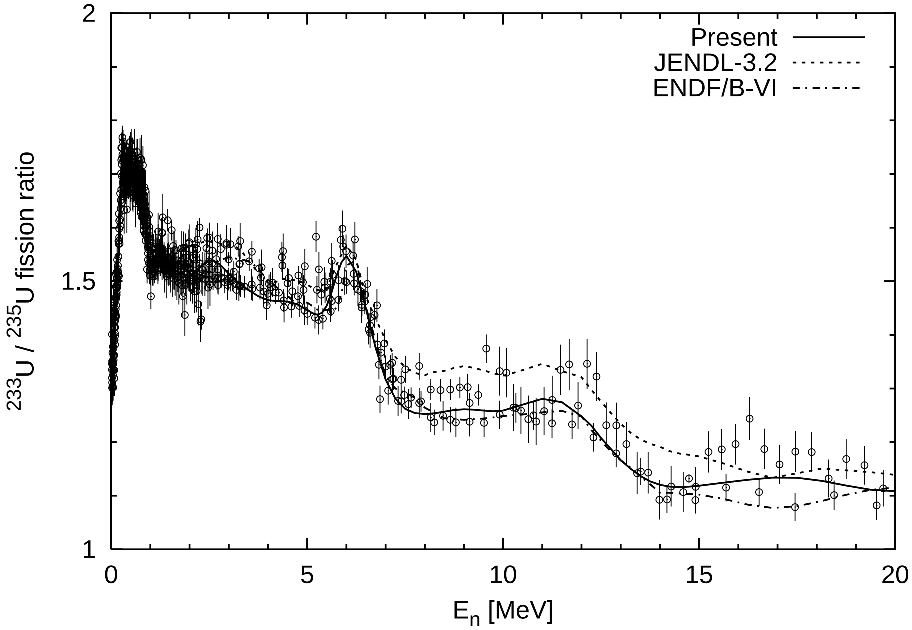

Figure 3: Comparison of the fission cross section ratios of ^{233}U to ^{235}U with the experimental data, and with the evaluated values of JENDL-3.2 and ENDF/B-VI.

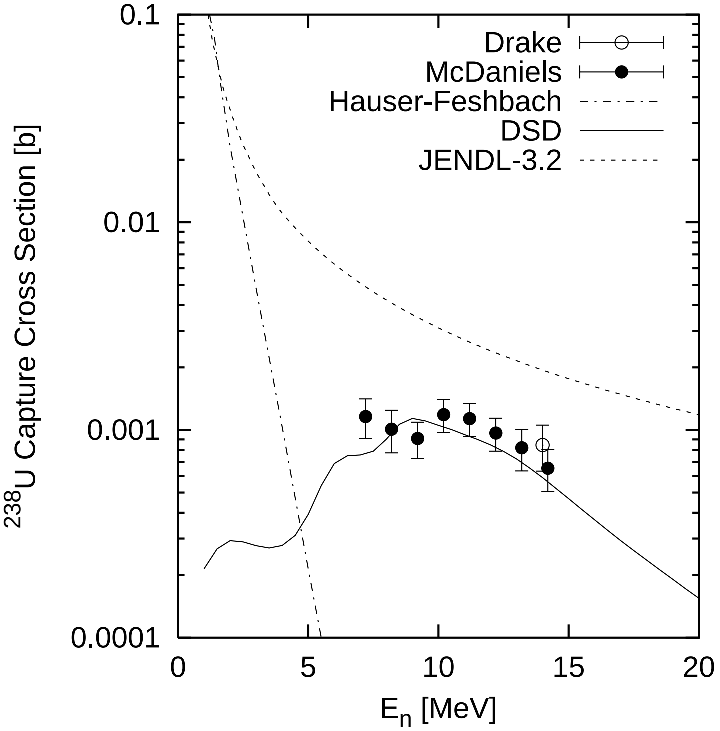

Figure 4: Comparison of the radiative capture cross sections of ^{233}U, and with the evaluated cross sections in JENDL-3.2. The solid line is calculated with the DSD code, the dot-dashed line is calculated with the Hauser-Feshbach theory.