New Evaluation of Prompt Neutron Spectra of U-235 and Pu-239 for JENDL-3.3

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New evaluation of prompt neutron spectra for ^{235}U and ^{239}Pu was made on the basis of Madland-Nix model combined with multimodal random-neck rupture model of the fission process. The resulting spectrum for ^{235}U(n_{th}, f) was harder than the previous evaluation in JENDL-3.2 but a bit softer than the ENDF/B-VI evaluation.

1. Introduction

One of the central problems in calculating the prompt neutron spectra is *how to deal with a variety of fission fragments with a variety of excitation energies.* In order to give an approximate solution to this problem, the present author [1, 2] proposed to introduce the idea of multimodal random-neck rupture fission model [3] into the Madland-Nix model [4] of prompt neutron emission. The energy partition between the fragments is different for different fission modes, and this is fairly well described by the multimodal model. Thus we divided the the entire fission fragments into a few groups, each represented by modal average masses and total kinetic energies (TKEs), and calculated the prompt neutron spectrum for each mode independently using available empirical data. The total spectrum was obtained by synthesizing the modal spectra. Application of this methodology to prompt neutron spectra for ^{237}Np(n,f) [1] was found to give improved account of the the spectra.

This report describes results of calculation of the prompt neutron spectra for ^{235}U and ^{239}Pu performed on the basis of the method of multimodal analysis for JENDL-3.3.

2. Method

The average masses of pre-neutron-emission light and heavy fragments (LF, HF) and TKEs for each fission mode, such as Standard 1 (S1), Standard 2 (S2), Superlong (SL), were taken from multimodal analyses of experiments. The fission Q-values for each mode were calculated with TUYY mass formula [5]. The inverse cross section for fission fragments were calculated using Becchetti-Greenlees optical model potential [6].

Some modifications were made in the Madland-Nix model; *(a)* the level density parameters were calculated with the Ignatyuk model [7] taking into account the shell effects, and *(b)* difference in the number of neutrons emitted from LF and HF are allowed. The average number of neutrons $\nu_{iL(H)}$ emitted from LF and HF for each mode *i* were calculated from the prescission shapes for each mode.

The prompt-neutron spectra for each mode (modal spectra) χ_i were synthesized with respective weighting of the modal nu-values $\nu_{iL(H)}$.

$$\chi_i(E_n) = [\nu_{iL}\chi_{iL}(E_n) + \nu_{iH}\chi_{iH}(E_n)] / (\nu_{iL} + \nu_{iH}) \qquad (1)$$

The total neutron spectrum was calciulated by averaging the modal spectra with respective weighting w_i and ν_I

$$\chi_{tot}(E_n) = [\, \sum_i w_i \nu_i \chi_i(E_n)\,] / (\sum_i w_i \nu_i) \qquad (2)$$

where w_i is the mode branching ratio and ν_I the average number of neutrons emitted in a fission of type *i*. The shape parameters of the prescission nuclear shapes taken from Fan *et al.* [8] were used to calculate the neutron multiplicity $\nu_I(A)$ as a function of fragment mass *A* for mode *i*.

3. Results

3.1 U-235

Three fission modes, *i.e.*, Standard 1 (S1), Standard 2 (S2), Superlong (SL), as pointed out by Knitter *et al.* [9] , together with relevant fragment kinetic energies, were adopted in the calculation for (n_{th},f) . The modal spectra for the three modes and the synthesized total spectrum are shown in **Fig.1**. The S1-spectrum is the softest, because the total excitation energy (TXE) is the lowest for this mode. In contrast, the SL-spectrum is the hardest, as expected from the fact that total deformation energy, which in turn converts into fragment excitation energy after scission, is largest for this mode. The S2-spectrum comes in between. The total spectrum lies close to the S2-spectrum, because the branching ratio to the S2-mode accounts for 82% of the total process. **Figure 2** plots the ratio of the present and the ENDF/B-VI evaluations relative to the JENDL-3.2 evaluation. As can be seen, the present spectrum is *harder* than the previous one stored in JENDL-3.2. The calculation was then extended up to 5 MeV using the incident-energy dependence of the mode branching ratios [10].

3.2 Pu-239

Multimodal analysis of experiments by Schillebeeckx *et al.* [11] was adopted as the basis of calculation for ^{239}Pu(n_{th},f). For this nuclide, another mode, called Standard-3 (S3), was confirmed in addition to S1 and S2 modes; on the other hand, the SL-mode component was not separated due to poor statistics of the measurement. These differences however do not bring about any important consequences, because their contributions are quite small. **Figure 3** shows the modal and total spectra; main features of the spectra are similar to ^{235}U. Relative ratios of the present and ENDF/B-VI evaluations to JENDL-3.2 evaluations are shown in **Fig.4**. The result is that the ratio to JENDL-3.2 evaluation is greater than unity except the region 0.9 - 4 MeV. Thus it is difficult to summarize the features of the new spectrum in a simple word. Considering that the peak of the absolute spectrum lies around 0.8 MeV and the neutron spectrum within the FBR core lies around several hundred keV, we may say that the relative increase of 5% in the region $E_n<1$ MeV impresses like ‘softening’ of the spectrum. However, in the case of high leakage system like critical safety research facility, the increase of high energy component ($E_n>5$ MeV) will enhance leakage of fast neutrons from the core.

For higher incident energies, calculations were made using the mode branching ratios from a study on the systematics in the ratios for many nuclides [10].

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