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Isotopic Fission-yield Calculation of U-233, U-238 and Th-232 for Fast Energy Spectrum

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Abstract

An isotopic fission yield calculation method for fast energy spectrum of neutron has been proposed. This method was derived from a systematic of fission mass yield and a nuclei decay probability. The decay probability was calculated from the level density parameters that derived from a new potential function in combining with the shell correction. The potential function is a modified Wood-Saxon potential that we have called as an extended-Wood-Saxon potential. We have employed the data from RIPL-2 (Reference Input Parameter Library-2) in calculating the level density parameter. The calculation shows similar results compared to the isotopic mass yields of JENDL 3.2 for ^{233}U and ^{232}Th.

Keywords*: Systematic mass yield, Decay probability, Fast spectrum, Extended Wood-Saxon potential*.

1. Introduction

Since the time of its discovery, a nuclear fission process has fascinated scientist and engineer interests. In the beginning, the development of the fission knowledge at low energies has received most of the efforts. To some extent, fission reactions induced by neutrons and charged particles at intermediate incident energies, i.e., between 10 and 200 MeV, have been investigated[1)].

The new dawn of researches in the intermediate-energy fission is currently stimulated by the concept of hybrid nuclear energy system that is an accelerator driven systems (ADS) for energy production and to transmute the nuclear high level waste (HLW)[1)].

While in the reactor application, the fission reaction is induced by particle that is neutron with the maximum energy is below 20 MeV, in the accelerator driven system, however, the primary neutrons are produced by spallation reaction induced by protons of energy of a few GeV[1,2)].

Fission of actinides especially minor actinides is not yet understood sufficiently for incoming energies above a few MeV. One of the important data regarding the fission reaction is fission yield. Most of studies on the fission yield are terminated at the mass fission yield so that the results can not be directly employed in the analysis of the nuclear reactors or the hybrid system like ADS. In order to be used directly in the reactor application, the information gathering from the mass fission yield should be extracted further to obtain an isotopic mass yield.

In this paper the isotopic fission yield calculation method for fast energy spectrum of neutron (14 MeV) is proposed. We have chosen the fast energy spectrum in order to be able to compare with available data from JENDL 3.2 nuclear data library[3)].

2. Methodology

The distribution of fission mass yield systematically can be approximated by using five Gaussian functions which consists of one symmetric component and four asymmetric components as written in the following equation[4)].

$$\psi(A,E^*) = N_s\psi_s(A,E^*) + N_a\psi_a(A,E^*)$$

$$\begin{aligned}\psi_a(A,E^*) &= [\psi_{h1}(A,E^*) + \psi_{l1}(A,E^*) \\ &\quad ++F\{\psi_{h2}(A,E^*) + \psi_{l2}(A,E^*)\}]\end{aligned} \qquad (1)$$

where N_s, N_a and F are the normalization factors. The symmetric component of Equation (1) can be expressed as follows.

$$\psi_s(A,E^*) = \frac{1}{\sqrt{2\pi}\sigma_s}\exp\left(-\frac{(A-A_s)^2}{2\sigma_s^2}\right) \qquad (2)$$

The asymmetric components are presented in the following two equations for heavy fission products.

$$\psi_{h1}(A,E^*) = \frac{1}{\sqrt{2\pi}\sigma_{h1}}\exp\left(-\frac{(A-A_{h1})^2}{2\sigma_{h1}^{\ 2}}\right) \qquad (3)$$

$$\psi_{h2}(A,E^*) = \frac{1}{\sqrt{2\pi}\sigma_{h2}}\exp\left(-\frac{(A-A_{h2})^2}{2\sigma_{h2}^{\ 2}}\right) \qquad (4)$$

While for light fission products $\psi_{l1}(A,E^*)$ and $\psi_{l2}(A,E^*)$ are obtained from reflection of $\psi_{h1}(A,E^*)$ and $\psi_{h2}(A,E^*)$ about symmetric axis[4].

A_f is the mass number of fission nuclide, and E^* is the excitation energy which is the sum of the binding energy (*BN*) and the incident energy (*E*) of projectile particle[4]. The rest parameters can be expressed in the following equations[5]. These parameters are derived from experimental data by using the *least square* method[5].

$$\sigma_s = 12.6 \tag{5}$$

$$\sigma_{h1} = \left(-25.27 + 0.0345A_f + 0.216Z_f\right)\left(0.438 + E + 0.333BN^{0.333}\right)^{0.0864} \tag{6}$$

$$\sigma_{h2} = \left(-30.73 + 0.0394A_f + 0.285Z_f\right)\left(0.438 + E + 0.333BN^{0.333}\right)^{0.0864}$$

$$A_{h1} = 0.5393\left(A_f - \bar{\nu}\right) + 0.01542A_f\left(40.2 - \frac{Z_f^2}{A_f}\right)^{1/2} \tag{7}$$

$$A_{h2} = 0.5612\left(A_f - \bar{\nu}\right) + 0.01910A_f\left(40.2 - \frac{Z_f^2}{A_f}\right)^{1/2} \tag{8}$$

The $\bar{\nu}$ parameter, the average number of prompt neutrons emitted in each fission is calculated by using Wahl equation[6].

The isotopic fission yield can be obtained by employing the decay probability of nuclide that has been derived from the evaporation model. In this procedure the Extended Wood-Saxon potential has been employed. The detail explanation of this process can be found in the Reference[7].

The decay probability of nuclide is calculated using the following formula[1].

$$G_{C\beta}(\varepsilon) = \frac{g_\beta \mu_\beta \varepsilon \sigma_{C\beta}(\varepsilon)\rho_\beta(E)}{\sum_\nu g_\nu \mu_\nu \int_0^{\varepsilon - Q} \varepsilon' \sigma_{C\nu}(\varepsilon')\rho_\beta(E')d\varepsilon'} \tag{9}$$

The g_β is the statistical factor, and $\rho_\beta(E)$ is the level density, which can be written as below[8]:

$$\rho(E) = \exp\left(2\sqrt{aE}\right) \tag{10}$$

The parameter a in equation (10) has been called as the level density parameter that is calculated from the following equation[9]. We have employed the data from RIPL-2 (Reference Input Parameter Library-2) in calculating the level density parameter.

$$a(A,Z,U) = \tilde{a}(A)\left\{1 + \frac{\delta E}{U}\left(1 - \exp(-\gamma U)\right)\right\} \tag{11}$$

The parameter $\tilde{a}$ is asymptotic value at infinite excitation energy U. There are three-semi empirical $\tilde{a}$ formulas[10]. In this paper the Iljinov formula is chosen as asymptotic parameter.

$$\tilde{a}(A) = 0.114A + 0.098A^{\frac{2}{3}} \tag{12}$$

where δE is shell correction, which can be expressed as in equation (13).

$$\delta E = M_{\exp} - M_{Calc} \tag{13}$$

The parameter $M_{\exp}$ is obtained from table[11] while M_{Calc} is calculated by using binding energy formula[12,13].

$$B_{nucl}(A,Z) = a_v(1 - k_v I^2)A - a_S(1 - k_s I^2)A^{2/3} - \frac{3}{5}\frac{e^2 Z^2}{R_o} + E_{pair} - E_{shell} - a_k A^{1/3} - a_o - f_p \frac{Z^2}{A} - W|I| \tag{14}$$

In the equation (14), all coefficients have been compiled by Royer[13].

The isotopic fission yield can be derived from equation (1) and equation (9).

3. Results and Discussion

Figures 1. and 2 show the calculated fission mass yield of ^{233}U and ^{238}U at the neutron energy of 14 MeV, respectively. It should be noted that not all of the calculated fission mass yield are included in these figures since the total number of data are very huge. They were limited to the values of 0.01 % or above. The same data that have been taken from JENDL 3.2 nuclear data library are also given in this figure for comparison, which indicated with "dot line". These two data might become closed to each other when the whole calculated fission mass yield are taken into account.

The calculated fission products distribution for the neutron induced fission reactions of ^{233}U and ^{238}U with the neutron energy of 14 MeV are shown in Figures 3 and 4, correspondingly. As can be seen from these figures, the obtained values are quite similar compared to that of JENDL 3.2.

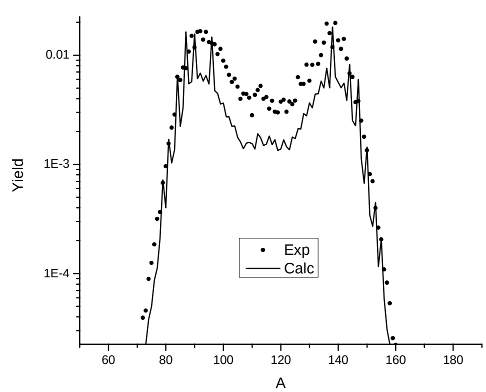

Figure 1. Calculated fission mass yield of ^{233}U at neutron energy of 14 MeV

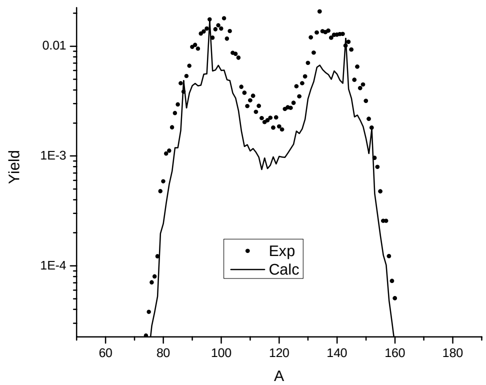

Figure 2. Calculated fission mass yield of ^{238}U at neutron energy of 14 MeV

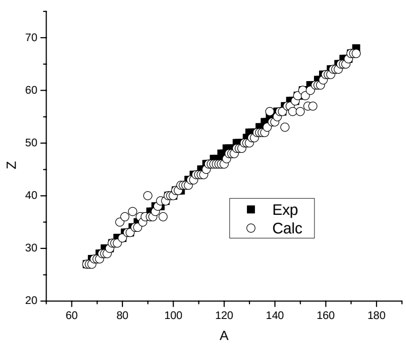

Figure 3. Comparison of JENDL 3.2 Data and calculated result of FP distribution from ^{233}U + n (14MeV) fission reaction

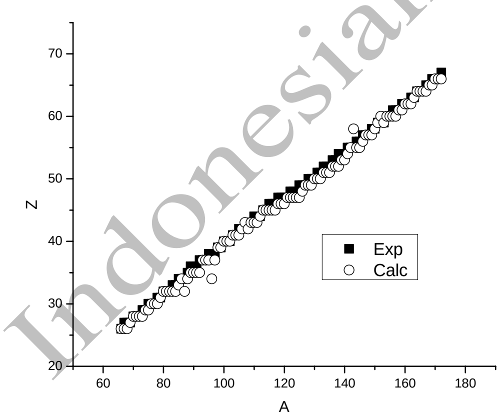

Figure 4. Comparison of JENDL 3.2 Data and calculated result of FP distribution from ^{238}U + n (14MeV) fission reaction

The similar results are also obtained for ^{232}Th. Figure 5 shows the calculated fission mass yield of ^{232}Th with the neutron energy of 14 MeV, in comparison with that of JENDL 3.2 nuclear data library. As has been mentioned above, not all of the fission mass yields are incorporated in this figure since the total numbers of data are extremely enormous. Only the fission mass yields of the values of 0.01 % or above are included.

Figure 6 shows the distribution of calculated fission products of ^{232}Th which induced by neutron with the energy of 14 MeV. Comparable to ^{233}U and ^{233}U, the obtained values for ^{232}Th are fairly similar compared to that of JENDL 3.2.

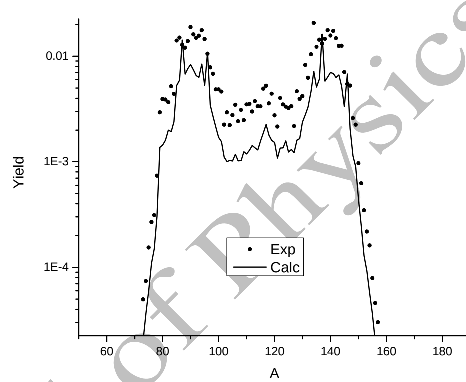

Figure 5. Calculated fission mass yield of ^{232}Th at neutron energy of 14 MeV

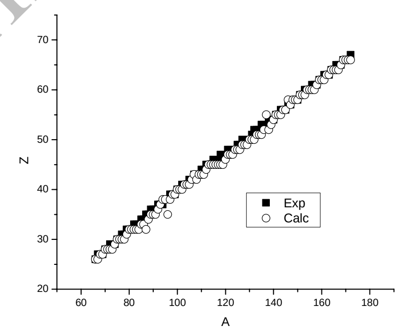

Figure 6. Comparison of JENDL 3.2 Data and calculated result of FP distribution from ^{232}Th + n (14MeV) fission reaction

4. Conclusion

The isotopic fission yield calculation method for fast energy spectrum of neutron has been proposed. This method was derived from the systematic of fission mass yield and the nuclei decay probability. The decay probability was calculated from the level density parameters with the extended-Wood-Saxon potential. The calculation results on ^{233}U, ^{238}U and ^{232}Th demonstrate a good agreement with the isotopic mass yields of JENDL 3.2.

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