Intercomparison of delayed neutron summation calculations among JEF2.2, ENDF/B-VI and JNDC-V2

M.Sagisaka, K.Oyamatsu*, Y.Kukita*
Department of Nuclear Engineering, Nagoya University
*Department of Energy Engineering and Science, Nagoya University
Furo-cho, Chikusa-ku, Nagoya, 464-01, Japan.
email : sagi@luna.nucl.nagoya-u.ac.jp

We perform intercomparison of delayed neutron activities calculated with JEF2.2, ENDF/B-VI and JNDC-V2 with a simple new method. Significant differences are found at t < 20 (s) for major fissioning systems. The differences are found to stem from fission yields or decay data of several nuclides. The list of these nuclides are also given for the future experimental determination of these nuclear data.

1. INTRODUCTION

The precise evaluation of delayed neutron properties is necessary for various reactor designs. We aim to improve delayed neutron summation calculations to have enough precision as has been achieved for decay heat summation calculations. At present, it is possible to calculate delayed neutron activities in the summation method for more than 50 fissioning systems. However, the accuracy of the delayed neutron calculations are inferior to that of integral measurements because the calculations essentially require fission yields and decay data of short-lived nuclides whose properties have not been measured so far. Recently, development of RI beam facilities enables us to measure the properties of these nuclides. Based on this observation, we need to identify key nuclides whose fission yields and decay data give rise to large uncertainties in the current delayed neutron calculations. In this paper, we attempt intercomparison of delayed neutron activities calculated with major nuclear data libraries, JEF2.2, ENDF/B-VI and JNDC-V2.

2. DELAYED NEUTRON SUMMATION CALCULATIONS

In the summation method, the number of a nuclide at a cooling time is calculated by simulating decay and build up of each nuclides. The number of ith nuclide $n_i(t)$ is obtained from coupled ordinary differential equations,

$$\frac{\mathrm{d}n_i(t)}{\mathrm{d}t} = -\lambda_i n_i(t) + \sum_j b_{j\to i}\lambda_j n_j(t) \tag{1}$$

with

$$n_i(0) = y_i \,. \tag{2}$$

Here λ_i and y_i are the decay constant and the independent fission yield of nuclide i, respectively. The symbol $b_{j\to i}$ represents the production rate of nuclide i from a decay of nuclide j. Then, the delayed neutron activity from the ith nuclide is given by,

$$n_{\mathrm{d}i}(t) = P_{\mathrm{n}i}\lambda_i n_i(t) \tag{3}$$

with $P_{\mathrm{n}i}$ being the delayed neutron emission probability.

3. NEW METHOD

We start with a vector of delayed neutron activities from individual nuclides;

$$\boldsymbol{n}_{\mathrm{d}}(t) = \left(n_{\mathrm{d}1}(t)\ , n_{\mathrm{d}2}(t)\ , \cdots\ , n_{\mathrm{d}N}(t)\right). \tag{4}$$

We compare two vectors of the delayed neutron activities, $\boldsymbol{n}_{\mathrm{d}}(t)$ and $\boldsymbol{n}'_{\mathrm{d}}(t)$, which are calculated from different input nuclear libraries. First, we search for cooling times when the two vectors have marked differences. We use a quantity named 'overlap',

$$\mu(t) = \frac{\boldsymbol{n}_{\mathrm{d}}(t)\cdot\boldsymbol{n}'_{\mathrm{d}}(t)}{\left|\boldsymbol{n}_{\mathrm{d}}(t)\right|\left|\boldsymbol{n}'_{\mathrm{d}}(t)\right|} = \frac{\sum_{i=1}^{N} n_{\mathrm{d}i}(t)\cdot n'_{\mathrm{d}i}(t)}{\sqrt{\sum_{i=1}^{N}\left(n_{\mathrm{d}i}(t)\right)^2\sum_{i=1}^{N}\left(n'_{\mathrm{d}i}(t)\right)^2}}\ , \tag{5}$$

which is the directional cosine of the two vectors (see Fig. 1). The value of $1-\mu(t)$ gives a measure of the difference between the two vectors. Then, the sources of the difference can be identified using the following quantity

$$\varepsilon_i(t) = \frac{\frac{1}{2}\left(n_{\mathrm{d}i}(t) - n'_{\mathrm{d}i}(t)\right)^2}{\left|\boldsymbol{n}_{\mathrm{d}}(t)\right|\left|\boldsymbol{n}'_{\mathrm{d}}(t)\right|} = \frac{\frac{1}{2}\left(n_{\mathrm{d}i}(t) - n'_{\mathrm{d}i}(t)\right)^2}{\sqrt{\sum_{i=1}^{N}\left(n_{\mathrm{d}i}(t)\right)^2\sum_{i=1}^{N}\left(n'_{\mathrm{d}i}(t)\right)^2}}. \tag{6}$$

The value of $\varepsilon_i(t)$ represents the difference of the ith component between the two vectors. It is noted that

$$1-\mu(t) \approx \sum_{i=1}^{N}\varepsilon_i(t). \tag{7}$$

In this way, we can identify cooling times with distinct difference from the value of $1-\mu(t)$, and the sources of them from the $\varepsilon_i(t)$ values.

4. RESULTS

We make intercomparison of delayed neutron activities for ^{235}U(t), ^{235}U(f), ^{238}U(t), ^{239}Pu(t), ^{239}Pu(f). Figure 2 shows $1-\mu(t)$ for these fissioning systems after a fission burst. From this figure, we see that there are significant differences ($1-\mu(t) > 0.01$) at $t < 20$ (s) for all the fissioning systems. The value of $1-\mu(t)$ are large at short cooling times. This reflects large uncertainties in decay data and/or independent fission yields of short-lived nuclides. For example, $\boldsymbol{n}_{\mathrm{d}}(t)$ for ^{235}U(t) calculated with ENDF/B-VI is remarkably different from the others due to too large independent fission yield of ^{86}Ge in ENDF/B-VI as was reported by Miyazono et al[1].

It is interesting to see $1-\mu(t)$ in Fig. 3 and $n_d(t)$ in Fig. 4 for JEF2.2 and ENDF/B-VI. We can clearly see, from Fig. 3, significant differences in the two activity vectors between JEF2.2 and ENDF/B-VI at t < 10 (s) although the summed $n_d(t)$ values in Fig. 4 are in good agreement.

Table 1 lists nuclides (precursors) whose delayed neutron activities are significantly different ($\varepsilon_i(t)$>0.01) among the libraries. The nuclides listed in Table 1 cover more than 70 per cent of the $\sum \varepsilon_i(t)$ values at the two cooling times. We also list the yields or decay data of these nuclides, whose values are significantly different among the libraries. From this table, we see that the dependence on the input nuclear data library stems from only several yield and decay data values. Among them, as shown in Fig. 5, the discrepancy in the Pn values is remarkably large beyond the assigned uncertainty values in these libraries.

5. CONCLUSION

We make intercomparison of delayed neutron activity vectors calculated with JEF2.2, ENDF/B-VI and JNDC-V2. For major fissioning systems, the vectors are significantly different among the libraries at t < 20(s) even if the $n_d(t)$ values are in good agreement. These differences are large at short cooling times. This means that delayed neutron activities from individual precursors are different among the major libraries because fission yields and decays data of short-lived nuclides are not known well.

We also identify delayed neutron precursors, whose activities are significantly different among the libraries. The number of these precursors are limited. However, there are distinct differences in yields or decay data values of these nuclides. We note remarkable differences of the Pn values beyond the estimated uncertainty values in the libraries.

Our conclusion is summarized as follows;

(1) Delayed neutron activities from individual precursors are significantly different among the three major libraries at short cooling times, even if the aggregate activities are in good agreement.

(2) These differences stem from yields or decay data of several precursors.

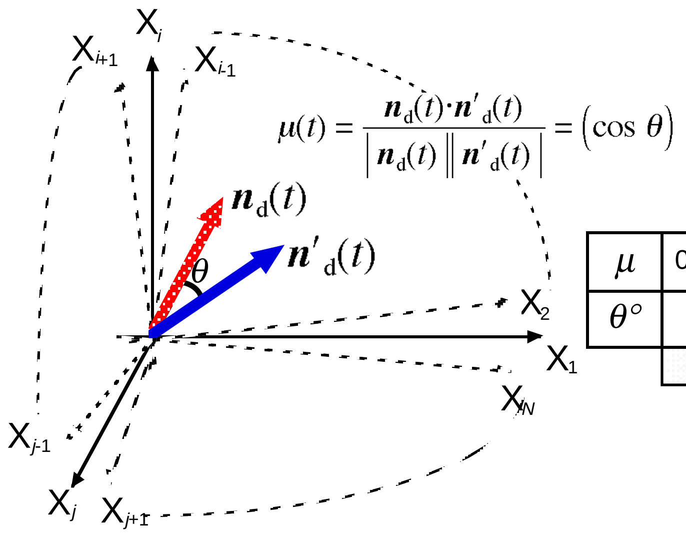
(3) Values of Pn of several key precursors are remarkably different among the libraries beyond the estimated uncertainty values.

From this study, we expect that precise experimental determination of several key decay data will greatly improve the aggregate delayed neutron calculations at short cooling times. Together with results from uncertainty analyses using ENDF/B-VI[1], we are preparing the priority list for measurements.

REFERENCES

[1] T.Miyazono et al., JAERI-Conf 97-005 (1997)

[2] K.Oyamatsu et al., Proc. Nucl. Data for Sci. and Thechnol., Trieste, Italy 1997 to be published.



The relation between μ and θ

μ	0.00	...	0.70	0.80	0.90	0.95	0.99	1.00
θ°	90	...	46	37	26	18	8	0

Better agreement →

Fig. 1. Definition of ‘overlap’ μ.

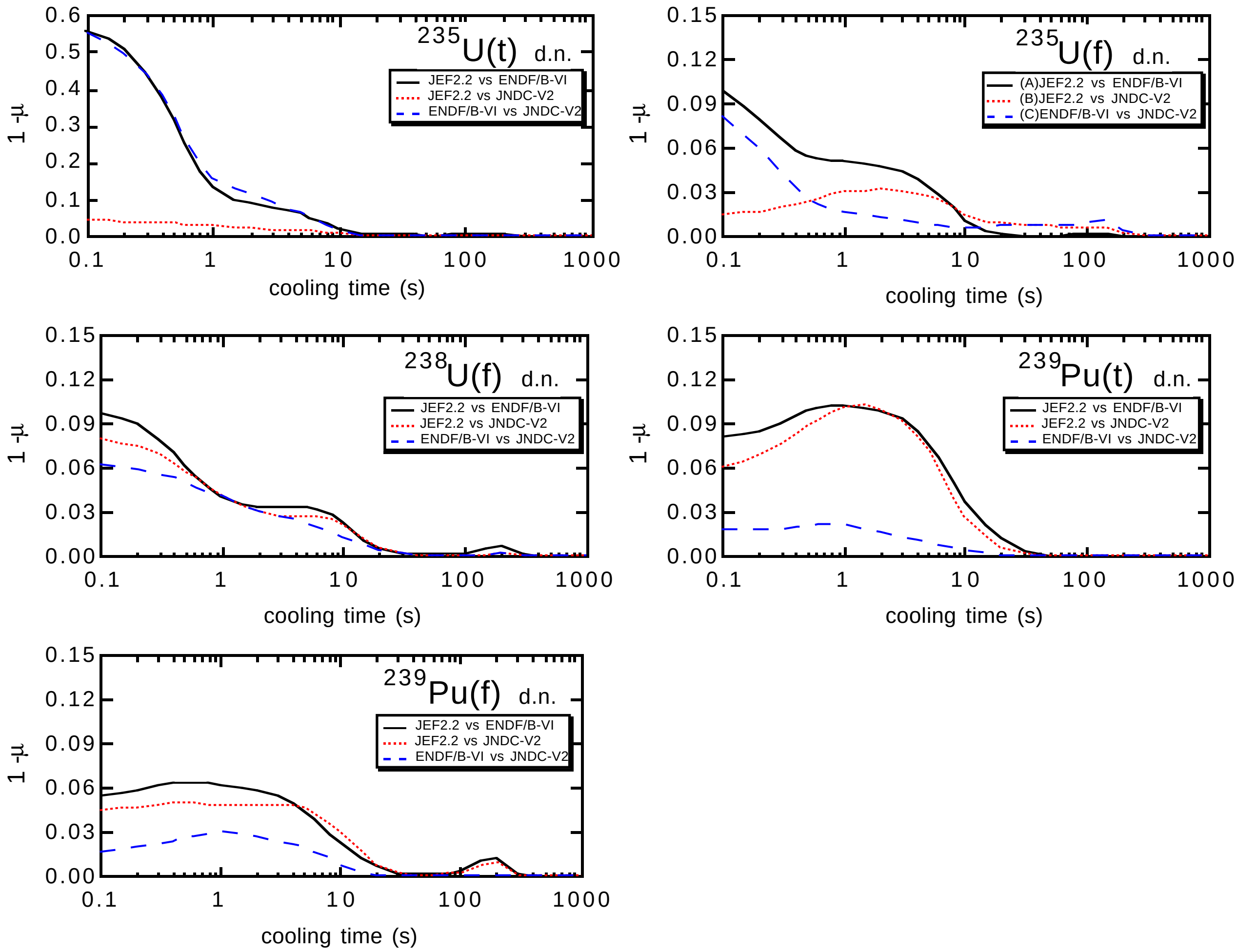


Fig. 2. Overlap between summation calculations with the three libraries for major fissioning systems.

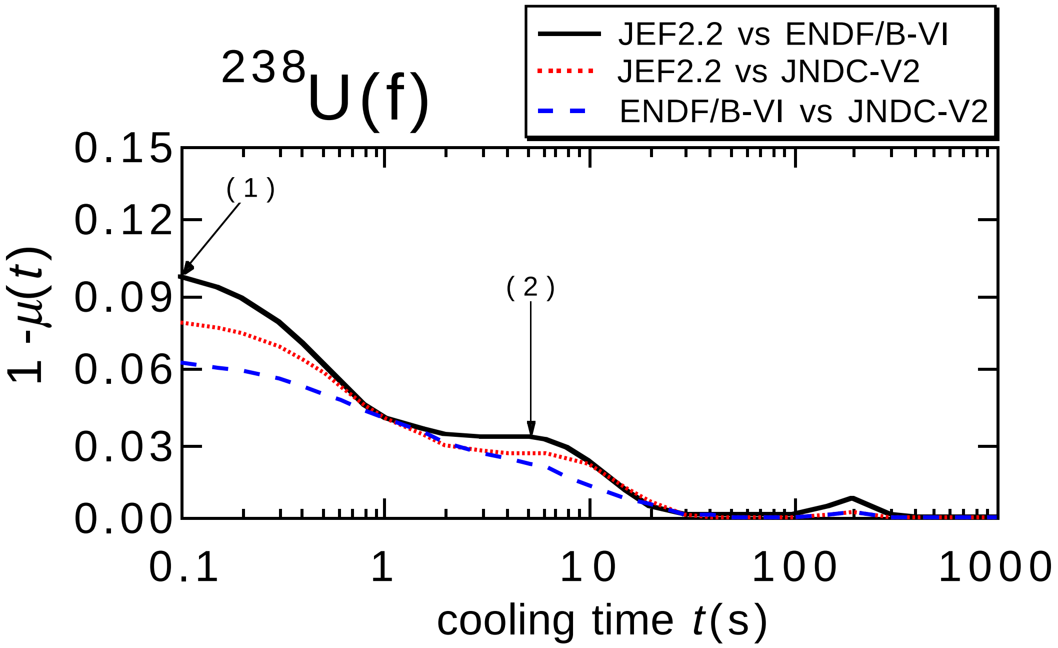


Fig. 3. Overlap of delayed neutron activities with three libraries for ^{238}U(f).

Table 1. Nuclides with large $\varepsilon_i(t)$ values for ^{238}U(f).

No.	t[s]	FP	ε_i(A)	ε_i(B)	ε_i(C)	main cause	JEF2.2	ENDF/B-	JNDC-V2
(1)	0.1	^{96}Rb	0.030	0.010	0.090	*number*	5.48e-3	8.31e-3	3.98e-3
		^{137}Sb	0.010	0.028	----------	P_n	0.996	0.200	0.200
						λ	1.925	1.451	0.571
		^{142}I	0.009	0.016	----------	P_n	0.545	0.160	0.130
						number	4.60e-4	2.96e-4	1.98e-4
		^{97}Rb	0.010	0.015	----------	*number*	1.34e-3	5.95e-4	5.67e-4
		^{141}I	----------	0.006	0.013	P_n	0.220	0.390	0.217
						number	3.16e-3	2.17e-3	1.53e-3
		^{145}Cs	0.004	0.010	----------	*number*	7.77e-3	4.95e-3	4.28e-3
(2)	5	^{85}As	0.010			*number*	5.49e-4	7.33e-4	5.56e-4
				----------	0.019	P_n	0.594	0.710	0.500
		^{90}Br	0.003	----------	0.011	*number*	1.62e-3	2.41e-3	1.52e-3
		^{139}I	0.005	0.009	----------	*number*	6.19e-3	4.32e-3	4.90e-3
		^{105}Nb	----------	0.009	----------	P_n	0.0001	0.022	0.045

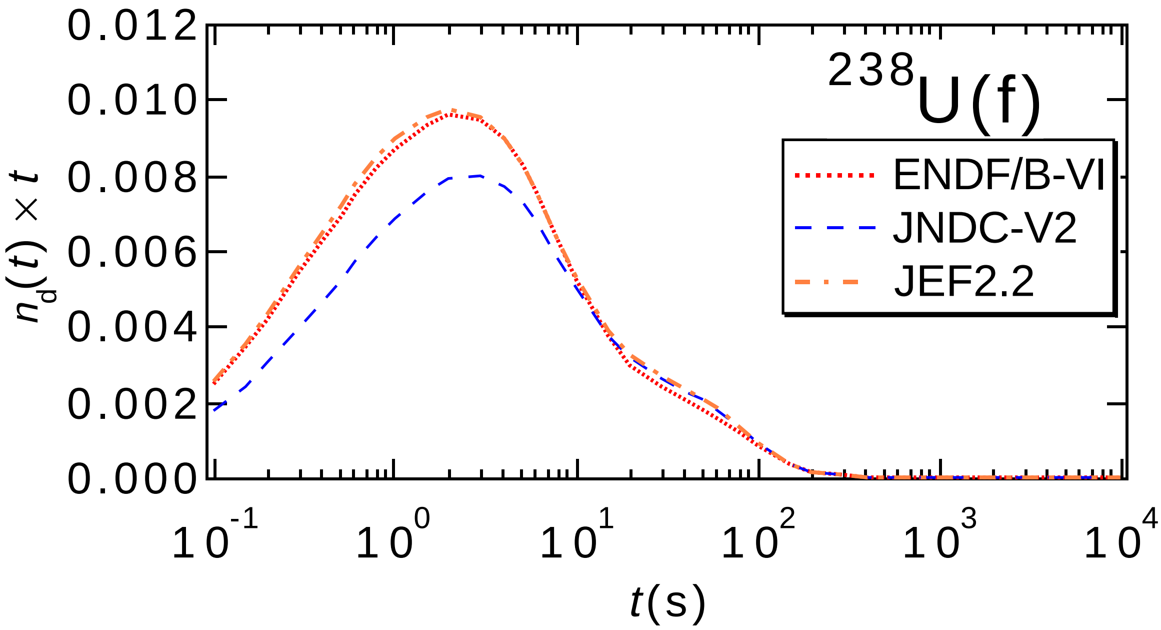


Fig. 4. Aggregate delayed neutron activities for ^{238}U(f).

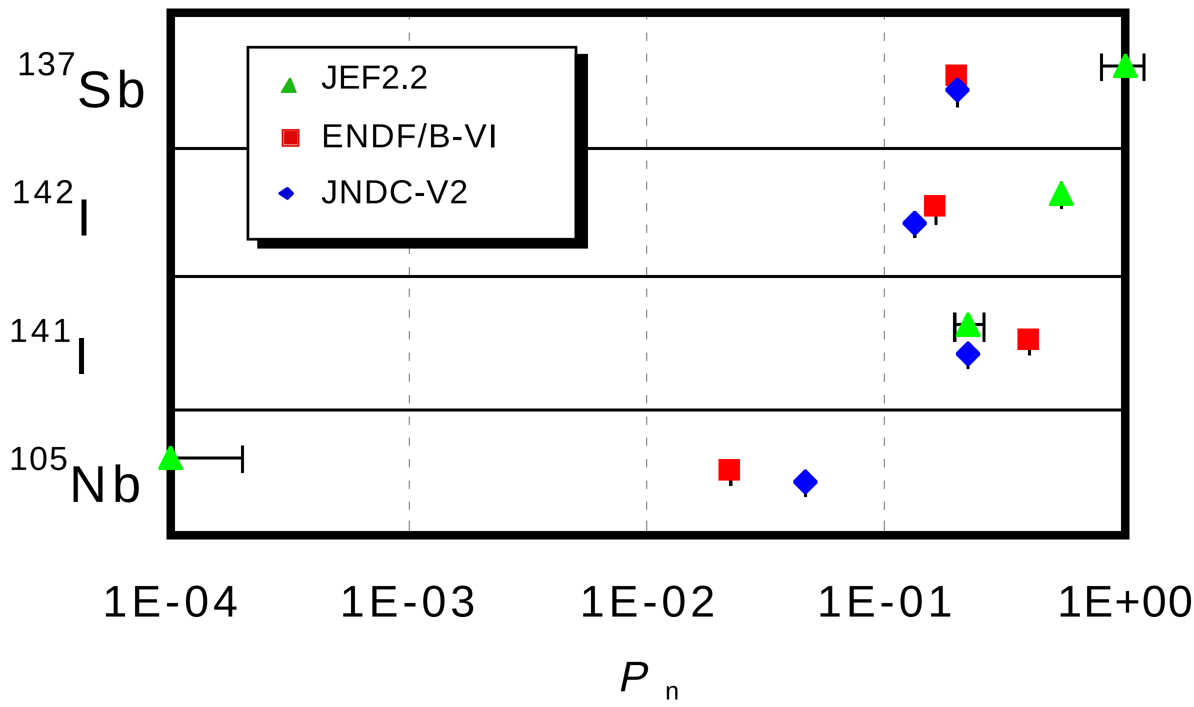


Fig. 5. Delayed neutron emission probabilities of ^{137}Sb, ^{142}I, ^{141}I and ^{105}Nb.