Present Status of JENDL FP Decay Data File

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JENDL FP Decay Data File is now being prepared for the use of such application fields as decay heat analysis of nuclear reactor, inventory analysis, radiation source estimation of nuclear fuel and so on. The primary file of the file has been compiled and is under quality test. After the test the file will be released until the end of next March. In the present report the present status of the JENDL Decay Data File is presented.

1 Introduction

The JENDL FP Decay Data File was planed to be compiled as a special purpose file of JENDL (Japanese Evaluated Nuclear Data Library) libraries. The libraries are expected to be used for application fields in nuclear technology. As for the decay data file for application use JNDC library [1] has been compiled in Japan for decay heat analysis. The file has been successfully applied to decay heat estimation of nuclear reactor. The file, however, has not JENDL (ENDF) format [2] and is not a JENDL library. This situation sometimes cause confusion among nuclear data community. In order to remove such confusion, the compilation of JENDL FP Decay Data File has been started. The decay data included in the JNDC library are those collected almost 10 years ago. The new measured data are reported after the compilation of JNDC library. These newly measured data are also included in JENDL FP Decay Data File. The spectrum data which are not included in the JNDC library are also included in the new file. In this report the outline of the JENDL FP Decay Data File and the some tests performed by now are presented.

2 Outline of Proposed FP Decay Data File

The FP Decay Data File is one of the JENDL Special Purpose Files; that means the file has JENDL format which is the same as ENDF one. The file is expected to include such data as half-life, decay modes, branching ratios, Q values, average decay energy values of emitted radiations (gamma rays, beta rays, alpha particles, internal conversion electrons, X rays), and their spectrum data of all fission product nuclides. The primary source of these data are measured ones. The measured data are taken from the compilation of ENSDF (Evaluated Nuclear Structure Data File) [3] which is compiled with international cooperation and is revised continuously. The primary purpose of the file is to be used for such application fields as decay heat evaluation, nuclear waste management, radiation shielding, nuclide concentration in a reactor and so on. The data contained in the file, therefore, should be “complete” and “consistent”. The measured data, however, are often “incomplete”, that is missing of gamma rays or beta rays are occurred. In such a case the average gamma energy values are underestimated and the average beta energy values are overestimated. The theoretical model calculation is needed to compensate the missing radiations. The model calculation is applied to the nuclides with no measured data and “incomplete” ones of beta and/or gamma rays. The number of nuclides to be contained is summarized in Table 1.

As shown in Table 1, the nuclides with spectrum data are 1085 out of total 1229 fission product nuclides. However, all of the nuclides do not always have complete measured spectrum data of beta and gamma rays. Most of the short-lived nuclides often lack complete measured spectrum. For these nuclides model calculation is also needed for beta and gamma ray spectrum for compensating the incomplete spectrum. The present primary file of the JENDL FP Decay Data includes the model calculated spectrum for beta and gamma rays.

Table 1: Number of nuclides contained in JENDL FP Decay Data File

• Total Nuclides :	1229	• γ ray spectrum	
∘ Stable :	142	∘ Measured :	629
∘ Isomer :	179	∘ Calculated :	543
∘ Second Isomer :	8	∘ Both :	121
• With Spectrum :	1085	• β ray spectrum	
∘ γ ray :	1051	∘ Measured :	472
∘ β ray :	896	∘ Calculated :	521
∘ α ray :	5	∘ Both :	97
∘ X ray :	507		
∘ ICE :	454		

There are about 100 nuclides which have both measured and calculated spectra of beta and gamma rays. The measured data of these nuclides are "incomplete" and are compensated by the theoretical model calculation. The adoption of the model calculated spectrum are first performed for ENDF/B-VI FP Decay Data File [4]. Using the model calculated spectrum the ENDF file can reproduce the measured aggregate spectra of beta and gamma rays after fission of variety of fissioning nuclides. The JENDL FP Decay Data File is also expected to be good agreement with the measured spectra.

3 Adoption of Model Calculation

In the decay heat evaluation, the average energy values of nuclides with incomplete measured decay data and no measured ones were calculated by "Gross Theory of Beta Decay" [5] developed by Waseda University Group. Using these calculated energy values the decay heat values of various fissioning nuclides are well reproduced. The brief description of the model is presented here. In beta decay process, the decay constant and average beta and gamma values are described as follows:

$$\begin{aligned}
\lambda &= \sum_{i=0}^{n} \lambda^{(i)}, \\
&= \frac{1}{2\pi^3} \sum_{i=0}^{n} \sum_{\Omega} |g_\Omega|^2 \cdot |(\Psi_i, \Omega\Psi)|^2 f(E_i)|, \\
\bar{E}_\beta &= \sum_{i=0}^{n} \frac{\lambda^{(i)}}{\lambda} (Q - \epsilon_i) C^{(i)}, \\
\bar{E}_\gamma &= \sum_{i=0}^{n} \frac{\lambda^{(i)}}{\lambda} \epsilon_i,
\end{aligned}$$

where i means the $i-th$ final state of energy ϵ_i, Q the Q value of beta decay, $C^{(i)}$ the ratio of the average electron kinetic energy to the maximum electron kinetic energy $Q-\epsilon_n$, Ω the type of beta decay operator, g_Ω the coupling constant and $f(E_i)$ the Fermi function. In the "Gross Theory" the discrete levels of the daughter nuclide are treated as continuous ones. The decay constant is, therefore, represented as follows:

$$\lambda = \frac{1}{2\pi^3} \int_{-Q}^{0} \sum_{\Omega} |g_\Omega|^2 \cdot |M_\Omega(E_g)|^2 f(-E_g + 1) dE_g$$

The matrix element $|M_\Omega(E)|^2$ is given by the following equation.

$$|M_\Omega(E)|^2 = \int_{\epsilon_m in}^{\epsilon_m ax} D_\Omega(E, \epsilon) W(E, \epsilon) \frac{dn_1}{d\epsilon} d\epsilon$$

where

$D_\Omega(E, \varepsilon)$: one-particle strength function inferred from sum rules,

E : energy of final nuclear state measured from initial state,

ε : one-particle energy of decaying nucleon,

$\frac{dn_1}{d\varepsilon}$: energy distribution of one particle,

$W(E, \varepsilon)$: weight function to take into account the Pauli exclusion principle.

The beta and gamma ray spectrum are calculated using the matrix elements and the level density formula. When the calculated spectrum is incorporated into the file, the measured spectrum, if exits, is kept in the original data but the normalization factor is changed in order to keep consistency between the average energy values and the spectrum data.

4 Test of the File

The file is now being tested through comparison with decay heat measurements and aggregate fission products spectrum of beta and gamma rays. The examples of the results are shown in Figs. 1 through 3 for the decay heat after ^{235}U thermal neutron fission.

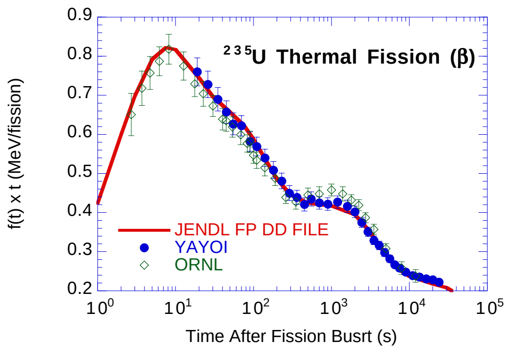

Fig. 1 Beta ray component of the decay heat after ^{235}U thermal neutron fission

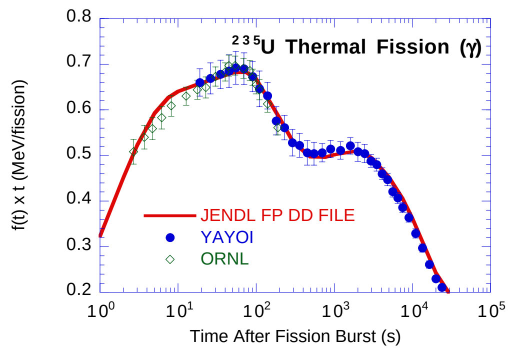

Fig. 2 Gamma ray component of the decay heat after ^{235}U thermal neutron fission

In these figures the decay heat is represented by those of energy release rate multiplied by time. The measured data are taken from those at Oak Ridge National Laboratory (ORNL in figures) [6] and Tokyo University (YAYOI in figures) [7]. The decay heat calculations are in good agreement with the measured data for beta, gamma and total decay heat. These figures show that the FP Decay Data File seems to be applicable to decay heat estimation of fission products. It is also interesting to compare the calculated decay heat values between those calculated with the present file and the JNDC file. The JNDC file is the basis of the calculation to produce the recommendation of reactor decay heat by Atomic Energy Society of Japan because of its success to reproduce the measured decay heat values of various fissioning nuclides. The comparison was made for ^{235}U thermal neutron fission. The differences of the decay heat values between them are shown Figs. 4 through 6. The calculations are made for ^{235}U thermal neutron fission. The differences are represented by percentage from the calculated values using the JNDC file. The comparisons were made for the cooling time region upto 10^{13} seconds after fission burst. As seen in these figures the gamma component shows about 12 % differences at about 10^{10} seconds after fission. The differences of the beta component, however, are 5 % at most. For the total decay heat the differences

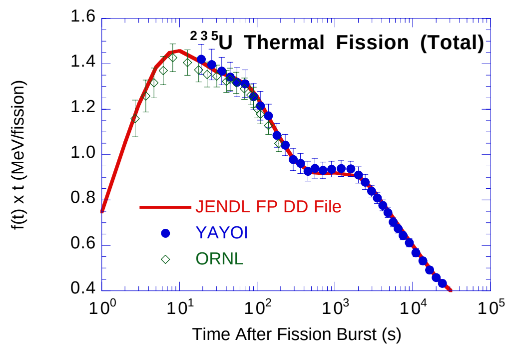

Fig. 3 Total decay heat after ^{235}U thermal neutron fission

are within 4 %. The main source of the difference seen in the gamma component at about 10^{10} seconds is the decay energy values of ^{126m}Sb. The average gamma energy value of the JNDC file is 1.7995 MeV, but it is 1.550 MeV in the new file. As there are a few nuclides which contribute to the decay heat at this cooling time region, the the data of one nuclide cause large effect on the calculation. The data in the JNDC file are based on old measured data. We should adopt new measured data for the JENDL FP DD File even if the differences are more than 10 %.

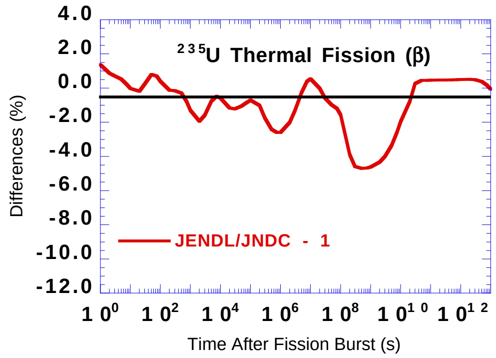

Fig. 4 Differences of beta ray component between the decay heat calculations with the JNDC file and the present JENDL DD file

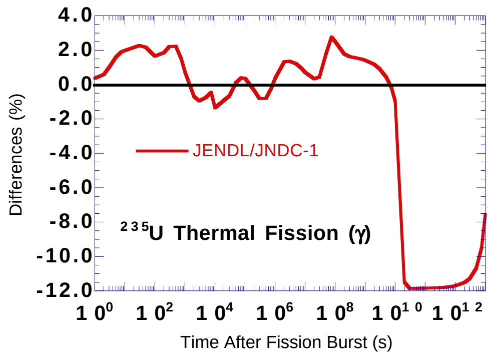

Fig. 5 Differences of gamma ray component between the decay heat calculations with the JNDC file and the present JENDL DD file

We also made comparison with the AESJ recommendation [8] of decay heat values. The Atomic Energy Safety Committee in Japan approved the usage of the AESJ recommendation as decay heat source in ECCS (Emergency Core Cooling System) analysis when the uncertainties of the recommendation are suitably taken into account. So the recommended values added three times of the uncertainties are used for the ECCS analysis. It is interesting to compare the decay heat values using new file with the recommended values. In Fig. 7 the comparison is shown. In this figure the AESJ recommendation is represented as that added three times of the uncertainties. If the new decay heat values happened to exceed the recommendation with three times of the uncertainties, it would be needed to reconsider the recommendation. The new decay heat values, however, don't exceed the AESJ recommendation at any cooling time regions and it would not need revise the recommendation.

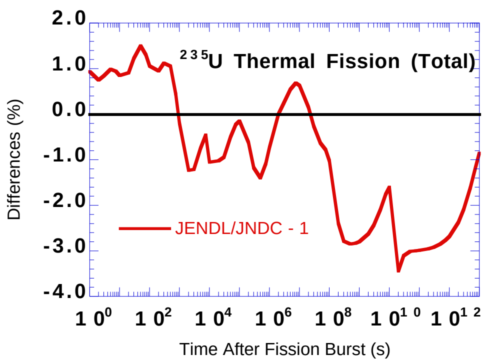

Fig. 6 Differences of total decay heat between the calculations with the JNDC file and the present JENDL DD file

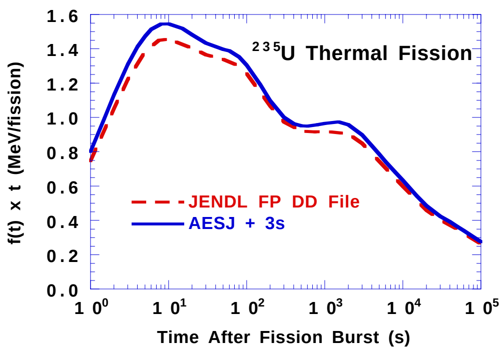

Fig. 7 Comparison of decay heat between the AESJ recommendation and the calculation with JENDL DD file

At present the decay heat comparisons with measured data are limited to some fissioning nuclides. Further comparisons for other fissioning nuclides will be needed before release of the file in order to confirm the applicability to decay heat evaluation of any fissioning nuclides. Such comparisons are now being done.

The spectrum data of the file are also tested by comparing the measured aggregate fission product spectra of beta and gamma rays. The examples of the spectrum calculation are shown in Figs. 8 and 9. Both spectra were taken at 2.2 seconds after the ^{235}U target was irradiated by thermal neutrons for

1 second. The measurements were performed at Oak Ridge National Laboratory [6]. In the figures the results of two kind of calculations are shown: one is the calculated result using the present JENDL FP Decay Data File which includes the model calculated spectra, another is that using ENDF/B-V FP Decay Data File [9] which includes only the measured spectrum data of fission products. The present version of the ENDF is 6th, which also includes the model calculated spectra but the old version is shown here in order to see the effectiveness of the model calculated spectra.

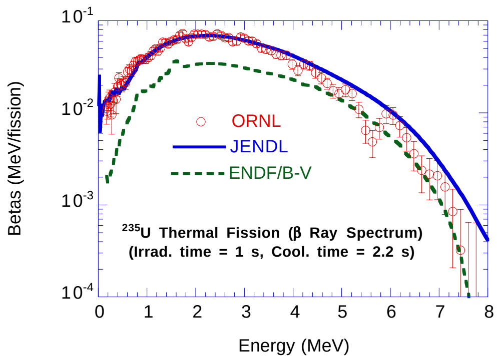

Fig. 8 Aggregate beta ray spectrum after ^{235}U thermal neutron fission

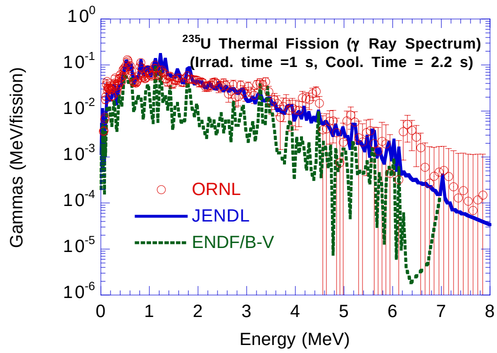

Fig. 9 Aggregate gamma ray spectrum after ^{235}U thermal neutron fission

As seen in these figures the adoption of the model calculated spectra shows good agreement with the measured spectra even in the short cooling time where the nuclides with no measured or incomplete data make major contribution to the spectra. The calculations using only the measured spectral data of fission products largely underestimate the measured spectra. This fact shows that the the model calculated spectra of individual fission product nuclides are effective to estimate the aggregate spectra of both beta and gamma rays. We will continue the comparison with the measured spectra for other fissioning nuclides before the release of the file.

5 Summary

The present status of JENDL FP Decay Data File is described. The primary file of the file has been compiled and is under the test of assessing the quality of the file. The test which has been performed by now has showed good agreement with the measured data of both decay heat values and aggregate fission products spectra of both gamma and beta rays for ^{235}U thermal neutron fission. The further test of the file will be performed for other fissioning nuclides. The file will be released after the test is finished. The release will be made until the end of next March.

References

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