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THE OVERVIEW OF THE JNDC FP DECAY DATA LIBRARY VERSION 2

Tadashi Yoshida
NAIG Nuclear Research Laboratory
4-1 Ukishima-cho, Kawasaki-ku, Kawasaki 210, Japan

Hitoshi Ihara, Jun-ichi Katakura, Kanji Tasaka
Japan Atomic Energy Research Institute
Tokai-mura, Ibaraki-ken 319-11, Japan

Ryuzo Nakasima
Department of Physics, Hosei University
Fujimi 2-17-1, Chiyoda-ku, Tokyo 102, Japan

Abstract: The second version of the JNDC (Japanese Nuclear Data Committee) FP Decay Data Library has been completed. The new library contains the decay and fission-yield data for 1083 unstable and 147 stable fission product (FP) nuclides and the neutron cross-sections for about 200 nuclides among these. The decay data include the gamma-ray spectrum from each nuclide as well as the half-life and the average beta- and gamma-ray energies released per decay-event, E_β and E_γ. The library, primarily for use in FP decay-heat calculations, will serve as an extensive data basis of radio nuclides pertinent to nuclear power as well. The calculated decay-heat curves agree quite well with the measured data for Th-232, U-233, -235, -238, Pu-239 and -241.

(decay heat, fission product, beta-decay, gamma-ray, summation calculation)

Introduction

The fission product (hereafter, FP) decay heat plays quite important roles in design, operation and safety of nuclear reactors. The origin of the FP decay heat is the beta- and gamma-ray energies released from unstable FPs undergoing beta-decay even after reactor shut-down. Effort toward improving the prediction accuacy of the decay heat has long been conducted on dual bases, namely, the integral measurements and the summation calculations. Summation-calculation codes sum up all the contributions from the individual FP nuclides, whose decay and yield data are contained in inclusive data libraries such as the ENDF/B, UKFPDD, CEA and JNDC libraries. The quality of the data in the library, therefore, decides the reliability of the calculated decay heat.

From Version 1 to 2

The first version of the JNDC (Japanese Nuclear Data Committee) FP decay data library was completed in 1981 [1] and applied well to reproduction of the results of the integral measurements.[2] A distinctive feature of this library lies in introduction of the thoretical values of E_β and E_γ, the average energies of the beta- and the gamma-rays released per one decay-event.[3] In revision toward the second version, the theoretical values of E_β and E_γ have been thoroughly re-examined for each nuclide, and the most reliable values have been adopted for inclusion in it.[4] The new version contains the decay and fission-yield data for 1083 unstable nuclides which are to transmute into 147 stable nuclides in the end. The fission-yield data sets have been expanded from 10 to 20 to include Pu-240, Pu-242 and several other higher-mass transuraniums. Further, the second version offers a new possibility of calculating the gamma-ray spectra from a reactor fuel at any time after shut-down, which can be used as the radiation source spectra for wide range of applications including shielding calculations.

Data Contained

Build-up and decay of FP nuclides in a nuclear reactor are described as

$$\frac{dN_i}{dt} = -(\lambda_i+\sigma_i\phi)N_i+\sum_j f_{j\to i}(\lambda_j N_j)+\sum_k g_{k\to i}(\sigma_k\phi N_k)+y_i F,$$

where

- N_i : atomic number density of the i-th nuclide
- λ_i : decay constant
- σ_i : neutron capture cross-section
- ϕ : neutron flux
- $f_{j\to i}$: production rate of nuclide i by one decay of the i-th nuclide
- $g_{k\to i}$: production rate of nuclide i by neutron capture of the k-th nuclide
- y_i : fission yield for the i-th nuclide
- F : fission rate

The FP decay heat, P(t), can be calculated as the sum of all the contributions from individual FPs as

$$P(t)=\sum_i E_i\{\lambda_i N_i(t)\},$$

where E_i is the recoverable decay energy of the i-th nuclides, which is the sum of the beta- and the gamma-ray energies, E_β and E_γ.

In order to cover all the physics data needed in the above calculation, the JNDC library contains the following items of data;

(1) Fission yield (y_i)
(2) Branching ratios ($f_{j\to i}$, $g_{k\to i}$)
(3) Half-lives ($T_{1/2}=\ln 2/\lambda_i$)

(4) Average beta-ray energy per decay (E_β)
(5) Average gamma-ray energy per decay (E_γ)
(6) Neutron reaction cross sections (σ_i)
(7) Fission energies (for power normalization)
(8) Gamma-ray spectrum for individual FPs

For the last item, (8), the data are not yet finalized at present, though they are almost complete. The data sources for the main items among the above eight entries are as follows.

Fission Yield

The yield data are principally taken from the extensive evaluation by T. R. England and B. F Rider.[5] Some modifications were needed in order to meet the length and the branching schemes of decay-chains (mass-chains) specific to the JNDC library. Especially, as the decay-chain length in the JNDC library exceeds the England's for most cases, the charge yield curves were extended both to the neutron-rich and the proton-rich sides.

Decay schemes and Half-lives

These decay data were taken from The Tables of Isotopes (7th Ed.), Nuclear Data Sheets, and journal publications. The reference covers up to the end of 1986. Half-lives were estimated by gross theory of beta-decay [6] when it is needed.

Average Beta- and Gamma-Energies

In generating the JNDC library Version 1, we adopted theoretical [6] values of E_β and E_γ for all the nuclides having Q-values larger than 5 MeV. The introduction of the theoretical values aimed at avoiding difficulty raised by missing beta and/or gamma transitions often encountered in high Q-value and complex decay schemes.[3] It should be appreciated, however, that not a few high Q-value decay schemes are essentially free from this kind of missing. In this case it seemed reasonable to use experimental decay schemes to calculate E_β and E_γ even though their Q-values are larger than 5 MeV. On the other hand there may exist some nuclides with relatively low Q-values whose decay schemes are not well confirmed by experiments. For these nuclides, it is risky to adopt the E_β and E_γ values deduced from the decay-schemes. Based on the above consideration, the decay energies, E_β and E_γ, were re-examined and the supposed 'best' values were adopted for Version 2 (see Table 1). The details of the above procedure is described in Refs. 4) and 7).

Table 1 Number of nuclides in JNDC File Version 2

Total number of nuclides	1230
Number of stable nuclides	147
Number of nuclides with accepted decay scheme	490
Number of nuclides with incomplete decay scheme	103
Number of nuclides with no experimental decay scheme	490

Neutron Cross Sections

In the present status, the library contains the neutron capture cross-sections for 80 FPs in 27 energy-group structure. The 26-th and the 27-th are the resonance integrals and the thermal cross-sections, respectively. This cross-section file is going to be extended to include almost 200 FPs. The extension will be completed by the end of 1988.

Calculationds with Version 2

Decay Heat

Figures 1 through 4 exemplify comparisons between the measured[8] and the calculated decay heat for some selected fissiles and fertiles. (According to a convention, the vertical axis implies the decay-heat multiplied by cooling time.) They agree each other almost within the error bars attached to the measured data except for Th-232 after ten-thousand second cooling. Fission yield data may be a possible source of this thorium discrepancy. Within-the-error-bar agreement is obtained not only for U-235, U-238 and Pu-239 but for U-233 and Pu-241 as far as the comparison is made with the measurement from the University of Tokyo[8] or from ORNL.[9] A few other measurements, especially that from LANL [10] (Fig. 5), are not always consistent with the Tokyo and the ORNL data, nor with the present calculation consequently. This might be the most serious problem left in the FP decay heat field waiting for solution.

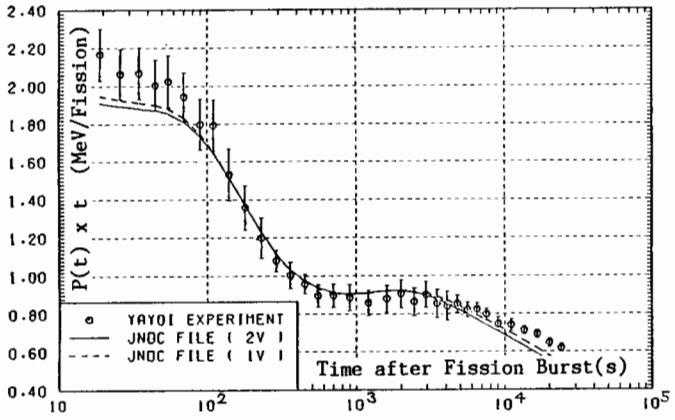

Fig.1 Decay Heat for Th-232 (Beta+Gamma)
(1V: Version 1, 2V: Version 2)

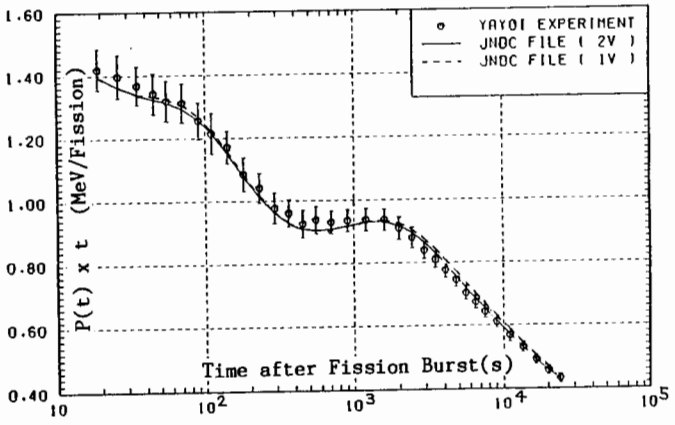

Fig.2 Decay Heat for U-235 (Beta+Gamma)

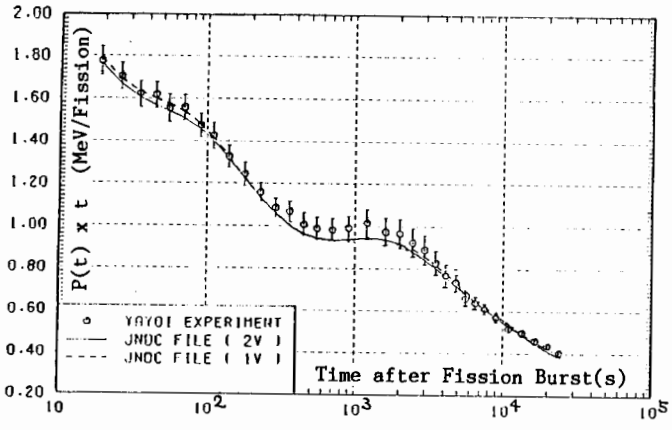

Fig.3 Decay Heat for U-238 (Beta+Gamma)

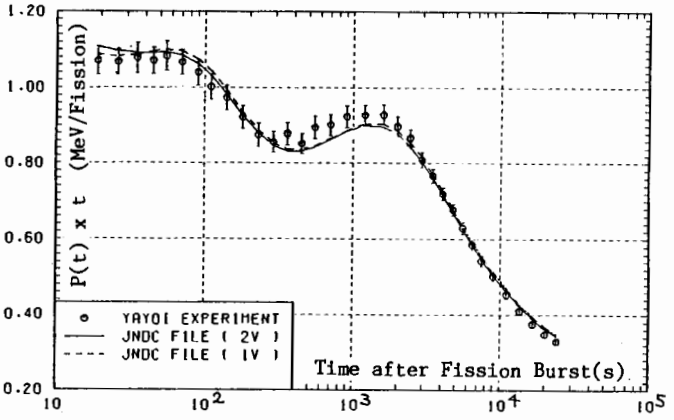

Fig.4 Decay Heat for Pu-239 (Beta+Gamma)

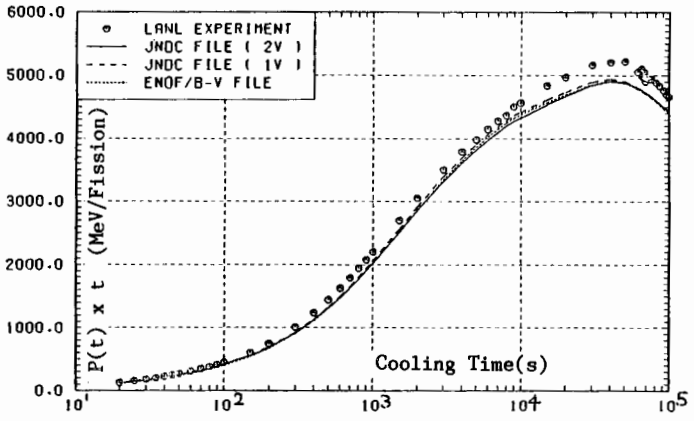

Fig.5 Decay Heat for Pu-239 (Beta+Gamma)
(5.5 hour irradiation)

Gamma-Ray Spectra

The JNDC library Version 2 offers a new possibility of calculating the gamma-ray energy spectra from aggregate FP nuclides accumulated during reactor operation. The extended DCHAIN code [11] sums all the spectrum contributions and outputs the aggregate spectrum at any time after reactor shut-down. The calculated spectra agree quite well with the measurement even just a few minutes after a fission burst (Fig. 6). This was made possible by inroduction of theoretical spectra [12] of short-lived (or high Q-valued) FPs, for which quite scarce experimental data are available.

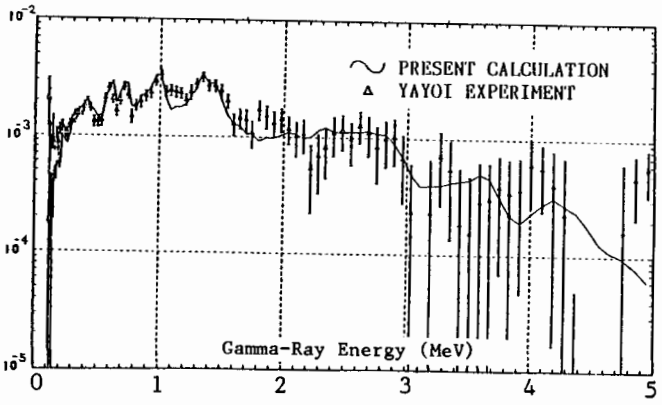

Fig.6 Delayed Gamma-Ray Spectrum from U-238
(140 sec after irradiation, see Ref.12)

Concluding Remarks

After finalizing the JNDC library Version 2, the Decay Heat Evaluation Working Group of JNDC is working toward the following three goals.

(1) Evaluation of the calculation accuracy of decay heat based on Version 2.

(2) Compact presentation of the calculated results by generating exponential fitting-formulae, both for the decay-heat and the gamma-ray spectra.

(3) Standardization of the calculated results.

The JNDC library will be released for world users from the Nuclear Data Center of the Japan Atomic Energy Research Institute.

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