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Comparison of Decay Heat after Thermal-Neutron Fission Calculated from Available Fission Product Yield Data for ^{235}U and ^{239}Pu

Do Heon Kim*, Choong-Sup Gil, Jounghwa Lee
Korea Atomic Energy Research Institute, 989-111 Daedeok-daero, Yuseong-gu, Daejeon 305-353, Korea
**Corresponding author: kimdh@kaeri.re.kr*

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1. Introduction

Since 2021, the United States and Japan have been producing and distributing new evaluated nuclear data files, ENDF/B-VIII.1[1] and JENDL-5[2], respectively, and Europe is producing JEFF-4[3], aiming for distribution in the middle of this year. Among them, the fission product yield data, which is essential for calculating the decay heat released after reactor shutdown along with the decay data, showed large changes in JENDL-5 and JEFF-4, unlike ENDF/B-VIII.1, where there were only small changes. For JEFF-4, only the yield data by thermal-neutron fission of ^{233}U, ^{235}U, ^{239}Pu, and ^{241}Pu have been updated as of the release of the fifth test file, JEFF-4T5.

In this study, the decay heats released after thermal-neutron fission of ^{235}U and ^{239}Pu were calculated using the fission product yield data of various versions of ENDF/B, JEFF, and JENDL, and the results were compared with some measured data. The SCALE-6.1.3 code[4] was used to calculate the decay heat using the yield library produced in SCALE/ORIGEN format from each evaluation file.[5] Comparisons were performed for VII.1, VIII.0, and VIII.1 of ENDF/B, 3.1.1, 3.3, and 4T5 of JEFF, and 4.0, FPY-2011, and 5 of JENDL.

2. Decay Heat Measurements

In the 1970s and 1980s, several experiments were conducted to measure decay heat during short cooling times of less than a few days after fission of 1 second to a few days. These experiments were motivated by concerns about the consequences of a loss-of-coolant accident (LOCA), coupled with the difficulty of calculating decay heat over very short timescales due to the lack of experimental decay data for short-lived fission products. Experiments were performed at Oak Ridge National Laboratory (ORNL), the YAYOI fast reactor facility at the University of Tokyo, Karlsruhe, Studsvik, and the University of Massachusetts Lowell [6,7]. Most of these experiments provide measurements of total, beta, and/or gamma energy release following thermal- and/or fast-neutron fission. Actinides used in the experiments included ^{232}Th, $^{233,235,238}U$, and $^{239,241}Pu$. In 1989, Tobias derived the decay heat benchmarks for ^{235}U and ^{239}Pu by least-squares fitting of available measurements.[8] He considered both thermal- and fast-neutron fission measured data for this analysis. In this study, the calculated decay heats due to thermal-neutron fission of ^{235}U and ^{239}Pu were compared with the data from ORNL[9,10], Studsvik[11], and Tobias.

3. Decay Heat Calculations

The decay heat can be calculated using the summation calculation method[12], which is defined as the sum of the activity of the fission products weighted by the average decay energy after reactor shutdown. The decay heat varies with the cooling time after the reactor shutdown and is expressed as the instantaneous energy release rate after one fission event (f(t), MeV/fission/sec) multiplied by the time after fission (t). The default decay data in the SCALE-6.1.3 code was used to calculate the decay heats during the very short cooling times after thermal-neutron fission of ^{235}U and ^{239}Pu according to various fission product yield data.

3.1 ^{235}U

For ^{235}U fission product yield data, ENDF/B-VII.1 and -VIII.0 are identical, and ENDF/B-VIII.1 has been slightly modified from the previous one. However, for the 1151 fission products included in the SCALE/ORIGEN library, all three files have identical values. Therefore, the total, beta, and gamma decay heats calculated from the three ENDF/B files are in perfect agreement, as shown in Fig. 1. Figure 1 also shows comparisons between the decay heat calculation results and ORNL measurement data, and it can be seen that they are in relatively good agreement.

JEFF-3.1.1 was originally taken from UKFY-3.6[13] and tends to have larger total decay heats than ORNL measurements in the range of about 5 seconds to about 200 seconds. This tendency has been greatly improved in JEFF-3.3. JEFF-4T5 is a major modification of JEFF-3.3, especially adding many nuclides with yields less than 10^{-14}. However, as shown in Fig. 2, the decay heat calculation results are very similar to JEFF-3.3.

JENDL-4.0 and JENDL/FPY-2011 were originally taken from ENDF/B-VII.0 with some adjustments, and show very similar decay heat calculation results to ENDF/B files. On the other hand, JENDL-5 shows very large differences in yield data from the previous JENDL files, and as a result, it shows smaller total decay heats compared to the previous JENDL files in less than about 100 seconds, as shown in Fig. 3.

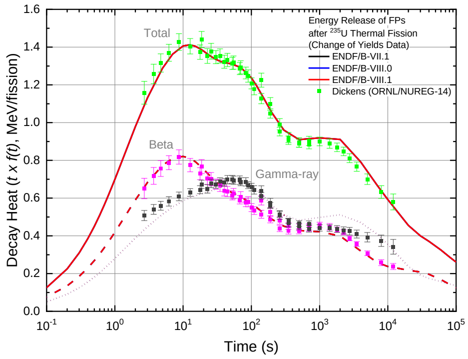

Fig. 1. Comparison of decay heat calculations for ^{235}U thermal fission with ENDF/B yield data.

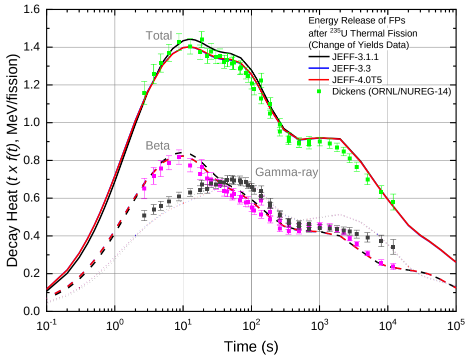

Fig. 2. Comparison of decay heat calculations for ^{235}U thermal fission with JEFF yield data.

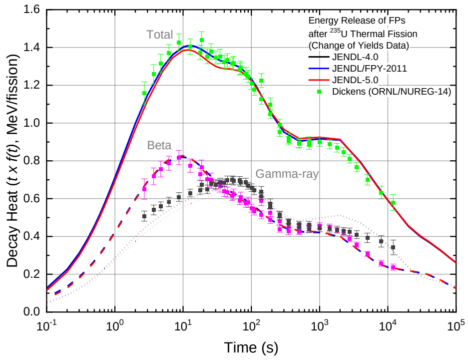

Fig. 3. Comparison of decay heat calculations for ^{235}U thermal fission with JENDL yield data.

Figure 4 compares the decay heats calculated using yield data from the latest ENDF/B-VIII.1, JEFF-4T5, and JENDL-5 with measured data from ORNL, Studsvik, and Tobias. When comparing the total decay heat, ENDF/B-VIII.1 and JEFF-4T5 show relatively similar calculation results except for the range from about 20 seconds to about 150 seconds. In contrast, JENDL-5 generally shows smaller total decay heats in the range of about 5 seconds to about 100 seconds. The ORNL measurement data have smaller values than the Studsvik and Tobias data, but the decay heat calculation results using the yield data are found to be closer to the ORNL data.

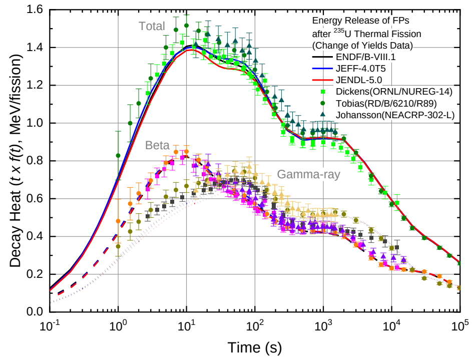

Fig. 4. Comparison of measurements and calculated decay heats using the latest yield data for ^{235}U thermal fission.

3.2 ^{239}Pu

The results of decay heat calculations using ENDF/B, JEFF, and JENDL files for ^{239}Pu fission product yield data are shown in Figs. 5 to 7, respectively.

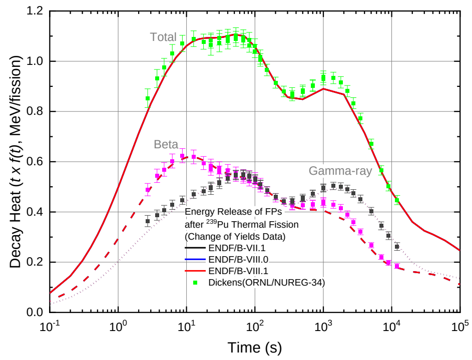

Fig. 5. Comparison of decay heat calculations for ^{239}Pu thermal fission with ENDF/B yield data.

As in ^{235}U, all ENDF/B files show identical decay heat calculations, which are in good agreement with the ORNL measurement data. In the case of JEFF, the total decay heat calculation results using JEFF-3.1.1 are significantly larger than those of other files in the range of about 10 seconds to about 400 seconds. On the other hand, the calculation results using JEFF-4T5 show slightly smaller values than those of other files in the range of about 200 seconds to about 2000 seconds. JENDL-4.0 and JENDL/FPY-2011 also produce decay heats very similar to the ENDF/B files, as does ^{235}U. In addition, the calculations using JENDL-5 appear to overestimate those of the previous files and/or the

ORNL measurement data in the range of about 7 seconds to about 400 seconds.

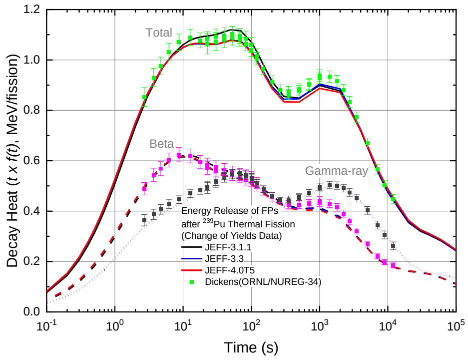

Fig. 6. Comparison of decay heat calculations for ^{239}Pu thermal fission with JEFF yield data.

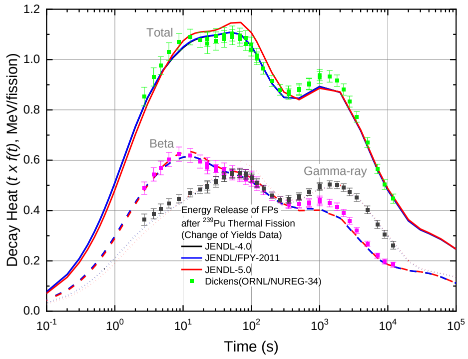

Fig. 7. Comparison of decay heat calculations for ^{239}Pu thermal fission with JENDL yield data.

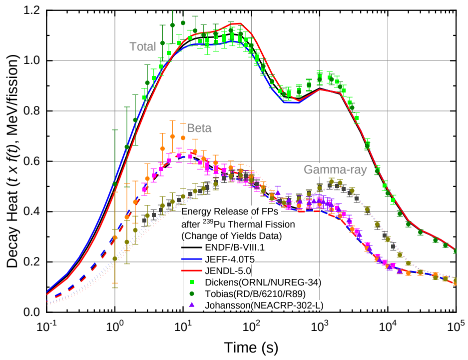

Fig. 8. Comparison of measurements and calculated decay heats using the latest yield data for ^{239}Pu thermal fission.

As shown in Fig. 8, the decay heat measurement data for ^{239}Pu thermal-neutron fission generally show similar trends within the uncertainty range, except for some relatively large differences that the Tobias data shows in less than about 10 seconds. Comparing the total decay heats, the latest ENDF/B-VIII.1 still follows the measured data relatively well, and in the range of about 10 seconds to about 500 seconds, JEFF-4T5 calculates smaller values and JENDL-5 calculates larger values.

4. Summary

Recently, with the release of new evaluated nuclear data files, validation calculations of the decay heat released after fission have been performed for the fission product yield data of ENDF/B, JEFF, and JENDL. In this study, the decay heats due to thermal fission of ^{235}U and ^{239}Pu were calculated and compared with the measured data of ORNL, Studsvik, and Tobias. The calculation results using the latest yield data of some nuclear data files show relatively large differences from the measured data or each other in some time ranges. In the future, comparisons of the yield data and decay heat calculation results for other actinides in the latest nuclear data files will be conducted.

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