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Validation of New Covariance Data of ^{240}Pu via k_{eff} Uncertainty Estimates

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1. Introduction

Recent collaboration between KAERI and ORNL has resulted in improving neutron cross section data with covariance data of the nuclides important for the advanced fuel cycle (AFC) and safeguards applications. Preliminary evaluated nuclear data have been generated for ^{237}Np, ^{240}Pu, and Cm-isotopes selected as priority nuclides under this collaboration.

In this study, the new covariance data of ^{240}Pu have been validated through the DANTSYS/SUSD3D-based nuclear data sensitivity and uncertainty analysis of k_{eff} for criticality benchmark problems taken from the International Handbook of Evaluated Criticality Safety Benchmark Experiments (ICSBEP) specification [1]. The k_{eff} uncertainty estimates by the new covariance data of KAERI/ORNL has been compared with those by JENDL-3.3 and Low-Fidelity covariance data [2].

2. Covariance Data Files

The covariance data of actinides are necessary for an accurate estimation of the nuclear data uncertainties in the nuclear integral parameters of interest such as the k_{eff}. However such covariance data are rarely found in the ENDF/B-VII.0 and JEFF-3.1 evaluations, while the JENDL-3.3 has been providing the covariance data of 13 actinides including 7 minor actinides. Moreover, the JENDL-4.0, which has been released in May 2010, contains covariance data of all 79 actinides.

Since 2008, a set of covariance data estimates for almost all ENDF/B-VII.0 isotopes (387 out of 393 nuclides) has been developed under the Low-Fidelity Covariance Project, which was collaboration among Argonne, Brookhaven, Los Alamos, and Oak Ridge National Laboratories. Although the covariance data are not approved by Cross Section Evaluation Working Group and are not parts of the ENDF/B-VII.0 yet, they are of great worth because they can provide a complete set of covariance data including many minor actinides of interest for the AFC and safeguards applications.

In this study, the covariance data of ^{240}Pu from the JENDL-3.3 and Low-Fidelity data are considered for comparative studies with the new covariance data of KAERI/ORNL.

3. Sensitivity and Uncertainty Analysis

The DANTSYS/SUSD3D code system has been used to estimate the k_{eff} uncertainties in the nuclear data. The uncertainties originating from the covariance data of JENDL-3.3 were estimated, and then the impacts of the use of ^{240}Pu covariance data from the KAERI/ORNL data or Low-Fidelity data were analyzed for comparison.

3.1 Sensitivity and Uncertainty Analysis Code System

The overall nuclear data sensitivity and uncertainty analysis code system based on the NJOY/TRANSX and DANTSYS/SUSD3D codes are shown in Fig. 1. An ISOTXS-format 44-group cross section library was generated by using NJOY/TRANSX codes based on the JENDL-3.3 as reference cross section data. A COVFIL-format 44-group covariance matrix data was generated by using the ERRORR module of NJOY99 code based on the JENDL-3.3, KAERI/ORNL, and Low-Fidelity covariance data. The forward and adjoint flux distributions required for the sensitivity coefficients generation were then obtained from the DANTSYS calculations with the P_3-S_{16} approximations. Finally, the SUSD3D code was used for the sensitivity and uncertainty analysis of k_{eff}.

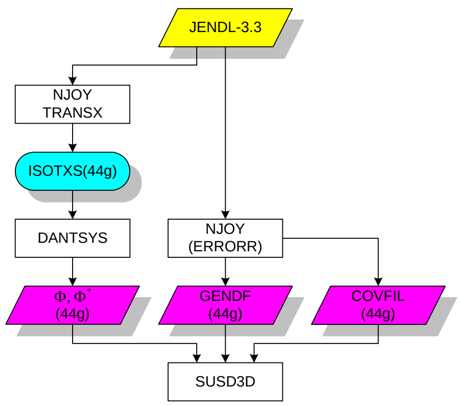

Fig. 1. Calculation system for nuclear data sensitivity and uncertainty analysis of k_{eff}.

3.2 Reference Result Based on JENDL-3.3

To validate the covariance data of ^{240}Pu, two criticality safety benchmark problems such as Pu239-JEZEBEL and Pu240-JEZEBEL, which contain relatively large amount of ^{240}Pu, were selected from the ICSBEP benchmark specification. The total k_{eff} uncertainties due to the cross sections and their covariance data of JENDL-3.3 were estimated to be 0.467% and 0.511% for Pu239-JEZEBEL and Pu240-JEZEBEL, respectively. For an accurate estimation, covariance data of the main constituents (^{239}Pu, ^{240}Pu, and ^{241}Pu) of the benchmark problems were taken into account in the sensitivity and uncertainty analysis.

3.3 Assessment of ^{240}Pu Covariance Data

To assess the impact of ^{240}Pu covariance data on the k_{eff} uncertainty estimation, the uncertainty result calculated by the JENDL-3.3-based reference analysis has been compared with those calculated for the comparative analysis by replacing the ^{240}Pu covariance data of JENDL-3.3 with those of KAERI/ORNL data or Low-Fidelity data.

For the Pu239-JEZEBEL, the total k_{eff} uncertainty for the use of Low-Fidelity ^{240}Pu covariance data was evaluated to be 0.473%. When compared with the total uncertainty of 0.467% for the use of JENDL-3.3 or KAERI/ORNL covariance data, the impact of the use of different ^{240}Pu covariance data was insignificant. For the Pu240-JEZEBEL with relatively high ^{240}Pu content, however, the total k_{eff} uncertainties were evaluated to be 0.511%, 0.526%, and 0.619% for the use of JENDL-3.3, KAERI/ORNL, and Low-Fidelity covariance data, respectively. The impact of Low-Fidelity ^{240}Pu covariance data on the Pu240-JEZEBEL increased up to 108 pcm against the JENDL-3.3.

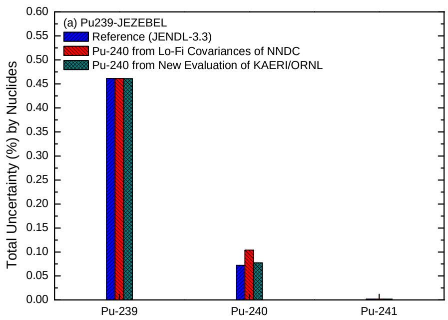

Fig. 2. Total k_{eff} uncertainty variations by nuclides for Pu239-JEZEBEL.

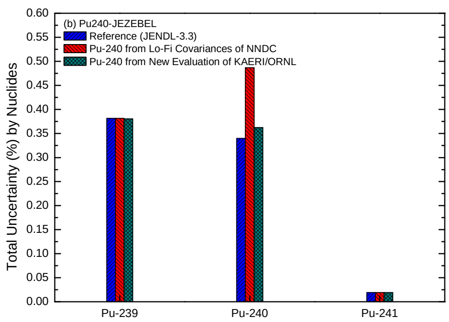

Fig. 3. Total k_{eff} uncertainty variations by nuclides for Pu240-JEZEBEL.

Figures 2 and 3 show the k_{eff} uncertainty variations by nuclides for the Pu239-JEZEBEL and Pu240-JEZEBEL, respectively. For the Pu240-JEZEBEL with the ^{240}Pu covariance data from the Low-Fidelity data, the contribution of the ^{240}Pu covariance data to the k_{eff} uncertainty estimation became larger than those of the ^{239}Pu covariance data as shown in Fig. 3.

Figure 4 shows the k_{eff} uncertainties by ^{240}Pu nuclear reactions for the Pu240-JEZEBEL benchmark problem. The uncertainties caused by the fission covariance data of ^{240}Pu from the Low-Fidelity data increased to over 4 times higher than the others. This increase had influence on the overestimation of the total k_{eff} uncertainty in the Pu240-JEZEBEL.

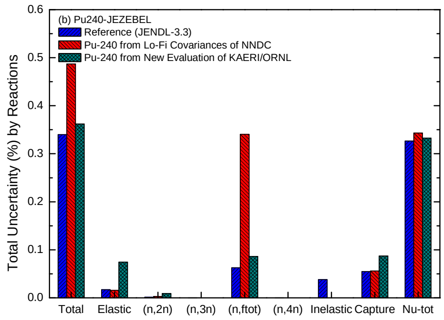

Fig. 4. Total k_{eff} uncertainty variations by ^{240}Pu reactions for Pu240-JEZEBEL.

4. Summary

For validating new KAERI/ORNL evaluations of ^{240}Pu, the DANTSYS/SUSD3D-based nuclear data sensitivity and uncertainty analysis of k_{eff} has been carried out for the Pu239-JEZEBEL and Pu240-JEZEBEL. In addition, the covariance data from JENDL-3.3 and Low-Fidelity data were taken into consideration for the comparative analysis. The k_{eff} uncertainties by the total fission covariance data of Low-Fidelity ^{240}Pu increased up to about 4 times when compared with the others. In terms of covariance data, new KAERI/ORNL evaluation of ^{240}Pu was comparable to JENDL-3.3 data for the most part.

Acknowledgments

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[2] R. C. Little et al., "Low-Fidelity Covariance Project," *Nuclear Data Sheets*, Vol. 109, p. 2828 (2008).