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Validation Study on Preliminary Evaluations of U-238 for JEFF

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1. Introduction

Recently, an effort has been devoted to the update of U-238 reaction cross sections in the resonance energy region under the JEFF project targeted to further consideration in both the Collaborative International Evaluated Library Organisation (CIELO) Pilot Project organized by the OECD/NEA and the Neutron Cross-Section Standards Project by the IAEA. New versions of U-238 (denoted as "G-versions") have been evaluated by I. Sirakov and distributed to the JEFF community for an extensive validation test [1]. In this study, the validation calculations have been carried out for 94 criticality benchmark problems taken from the expanded criticality validation suite for MCNP [2]. The performances of the new evaluations have been analyzed in comparison with the reference JEFF-3.2-based MCNP calculation results.

2. Preliminary Evaluations of U-238

The improvement of the U-238 reaction cross sections in the resonance energy region is one of the key issues in the CIELO and the Neutron Cross-Section Standards projects. The G-versions of U-238 are the interim evaluations having been carried out for that purpose in the JEFF community. The G-versions consist of four separate U-238 evaluations on the basis of the treatment of the capture and inelastic scattering cross sections in the resonance energy region. Each G-version has two files named as G10 and G20, which correspond to the energy boundary between the resolved resonance (RR) and unresolved resonance (URR) regions, i.e., 10 keV and 20 keV respectively. Short descriptions of the G-versions are as follows:

Ver. 1 (G10-1 & G20-1): statistical evaluation for the compound infinitely dilute capture and inelastic scattering cross sections in terms of average resonance parameters. The inelastic cross section also includes a direct reaction component determined by a dispersive coupled-channel optical model (DCCOM).

Ver. 2 (G10-2 & G20-2): adoption of the infinitely dilute capture cross section from the GMA evaluation of Carlson et al., while the inelastic cross section is statistically calculated and with a direct component included.

Ver. 3 (G10-3 & G20-3): statistical evaluation for the infinitely dilute capture cross section while the inelastic evaluation is adopted from the recent neutron scattering study of Capote et al.

Ver. 4 (G10-4 & G20-4): simultaneous adoption of both the capture and the inelastic infinitely dilute cross sections, each one according to versions 2 and 3 respectively.

3. Criticality Benchmark Problems

The expanded criticality validation suite is widely used to validate the MCNP code along with the nuclear data libraries. The suite includes 119 criticality benchmark problems taken from the International Handbook of Evaluated Criticality Safety Benchmark Experiments (ICSBEP) [3]. The problems can be classified as five categories according to the principal fuel, i.e., highly enriched uranium (HEU), intermediate enriched uranium (IEU), low enriched uranium (LEU), Pu, and U-233 systems. In this study, 94 benchmark problems containing the U-238 isotope have been selected from the expanded suite for the validation of the G-versions of U-238. Table 1 shows the number of problems in each of these categories in the original expanded suite as well as in the selection for our validation study.

Table I: Number of Benchmark Problems in Each of Categories

Category	Number of Benchmark Problems	
	Validation of U-238	Expanded Suite
HEU	40	40
IEU	17	17
LEU	8	8
Pu	11	36
U233	18	18
Whole	94	119

4. Validation Results

The benchmark calculations were carried out by MCNP5 code and the reference calculation results were obtained with the JEFF-3.2-based ACE-format library. Figure 1 shows the difference of the reference calculation results from the benchmark k_{eff} values. The differences are generally maintained within about ±500 pcm except for several problems.

The validation calculations for the U-238 were conducted by replacing it with the G-versions of U-238 from the reference calculations. The root mean square (RMS) errors relative to the benchmark k_{eff} values were compared among the different G-versions of U-238 as shown in Fig. 2. As a whole, the RMS errors for the G-versions 3 and 4 are more comparable to the reference JEFF-3.2 than others. The obvious changes by different G-versions of U-238 come into view in the IEU systems. The comparison of the χ^2 values relative to the benchmark k_{eff} values in Fig. 3 is quite similar to the RMS errors. In contrast, the improvements in the χ^2 values for whole problems are achieved in the G20-3, G10-4, and G20-4.

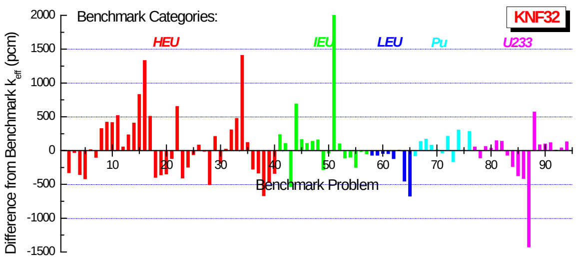

Fig. 1. Differences of JEFF-3.2-based reference calculation results from benchmark k_{eff} values.

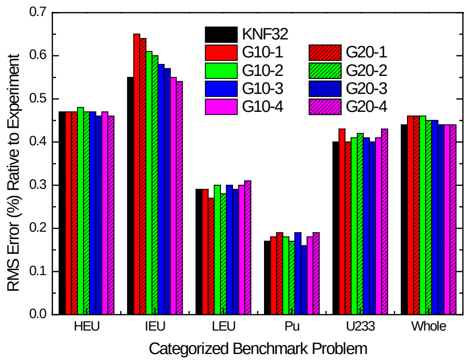

Fig. 2. Comparison of RMS errors relative to benchmark k_{eff} values among different G-versions of U-238.

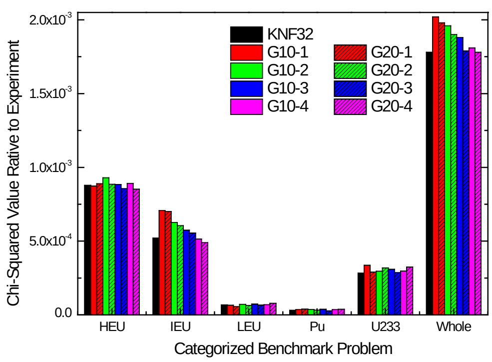

Fig. 3. Comparison of χ^2 values relative to benchmark k_{eff} values among different G-versions of U-238.

One of the important factors to be settled after validation studies is whether the extension of the energy boundary between the RR and URR regions from 10 to 20 keV is useful for the new U-238 evaluations. Table II shows the relative improvements in the χ^2 values due to the extension of the energy boundary from 10 to 20 keV. The adoption of 20 keV as the energy boundary between RR and URR is found to be efficient for all G-versions of U-238. Especially for the G-version 3, the improvements are remarkable in every benchmark categories.

Table II: Relative Improvements (%) in χ^2 values due to Extension of Energy Boundary between RR and URR from 10 to 20 keV

Category	Relative Improvements (%) in χ^2 Values			
	Ver. 1	Ver. 2	Ver. 3	Ver. 4
HEU	-1.83	4.74	3.17	4.38
IEU	0.85	3.35	3.31	4.85
LEU	14.18	9.99	10.20	-12.52
Pu	-10.89	13.94	28.46	-7.10
U233	13.69	-7.43	7.12	-9.43
Whole	1.98	3.06	4.79	1.66

The reliability of the MCNP calculation results to the benchmark k_{eff} values was verified by considering the number of problems that belonged to certain confidence intervals regarding the experimental and calculational uncertainties for the k_{eff} values. Tables III and IV show the results of the reliability checkup for the G-versions of U-238 with the energy boundary of 10 keV and 20 keV respectively. The U-238 evaluations with the energy boundary of 20 keV tend to produce more reliable MCNP calculation results below 2 standard deviations (STD) than those with the boundary of 10 keV. The enhancement is seen in the G20-4 in comparison to the reference JEFF-3.2.

Table III: Number of Problems that Belong to Certain Confidence Intervals for G-versions of U-238 with Energy Boundary of 10 keV

STD Range	KNF32	G10-1	G10-2	G10-3	G10-4
< 1	57	54	56	56	53
1 ~ 2	23	27	26	27	28
2 ~ 3	11	10	9	8	10
> 3	3	3	3	3	3

Table IV: Number of Problems that Belong to Certain Confidence Intervals for G-versions of U-238 with Energy Boundary of 20 keV

STD Range	KNF32	G20-1	G20-2	G20-3	G20-4
< 1	57	52	59	56	60
1 ~ 2	23	30	23	27	23
2 ~ 3	11	8	9	8	7
> 3	3	4	3	3	4

5. Conclusions

The preliminary G-versions of U-238 evaluations have been validated through 94 criticality benchmark problems taken from the expanded criticality validation suite for MCNP. It was found that the G-versions 3 and 4 showed better performances than others by comparing the RMS errors and χ^2 values relative to the benchmark k_{eff} values. In addition, the extension of the energy boundary between the RR and URR regions from 10 to 20 keV was considered to be efficient for all G-versions of U-238.

REFERENCES

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