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Sensitivity Analysis of JENDL-3T

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Abstract: Benchmark test of JENDL-3T has been performed using many 1-D and a few 2-D benchmark models of fast critical assemblies. The change in core parameters such as k_{eff}, reaction rate ratio, sodium void worth, Doppler reactivity worth calculated by JENDL-3T from those by JENDL-2 is investigated. We have analyzed the change using sensitivity coefficients calculated from two-dimensional generalized perturbation calculations based on diffusion theory, and investigated the effect of main heavy nuclides. When considering the ^{238}U inelastic scattering, we take into account individual rotation levels.

(benchmark test, JENDL-2, JENDL-3T, change in core parameters, sensitivity coefficients, main heavy nuclides, ^{238}U inelastic scattering, rotation levels)

Introduction

The cross sections of main heavy nuclides of JENDL-3T[1)] differ remarkably from JENDL-2. Thus, it is important to evaluate the effect of the cross section changes on core parameters. To evaluate the effect we choose the many 1-D benchmarks of fast critical assemblies and a few 2-D benchmarks.

We investigate the effect of the cross section change to see what nuclides have significant contributions to the core parameter changes. Furthermore, using the cross section sensitivity coefficients calculated by the SAGEP code[2)], which is based on the two-dimensional generalized perturbation theory, we investigate the effect of the energy dependence of the cross section change on the core parameter changes. As the main nuclides with significant influence on fast reactor core parameters, we consider ^{235}U, ^{238}U and ^{239}Pu. When we consider ^{238}U, we take into account the individual rotation levels of inelastic scattering.

Benchmark Test

The JENDL-3T has been applied to the 1-D benchmark cores of fast critical assemblies with Pu or U fuel using diffusion theory. For the Pu fueled cores the JENDL-3T reduces k_{eff} by 2.0~0.3%dk/k depending on core size compared with JENDL-2. The k_{eff} values of the U fueled cores are increased by the use of JENDL-3T by about 0.8%dk/k.

The reaction rate ratio of the ^{238}U capture to ^{239}Pu fission, 28C/49F, which is an important parameter for the estimation of breeding ratio, is increased by 4% by the use of JENDL-3T for the Pu cores. The calculated to experimental values(C/E) of 28C/49F are overestimated by about 6% for large Pu fueled fast critical assemblies. Therefore, the 28C/49F is overestimated by about 10% when one uses JENDL-3T. The ratios of the threshold reaction to ^{235}U fission such as 28F/25F and 40F/25F are also increased by 6% by the use of JENDL-3T.

The two-dimensional benchmark test was performed using the fast critical assemblies FCA IV-2 and ZPPR-9. The UO_2 Doppler worth is increased by 6% for

Table 1 Percent Difference between Calculation with JENDL-3T and Experiment for 1-D and 2-D Benchmarks

1. 1-D Benchmark Core (%)

Integral Parameter	Pu-core	U-core
K_{eff}	-0.7% (-0.1%)**	1.1% (0.3%)
49F/25F	-1.5 (3)	-1.3 (-1.5)
28C/25F	5	1 (-4)
28C/49F	5 (1)	5 (-5)
28F/25F	13 (6)	11 (4)
40F/25F	13 (8)	10 (4)

2. 2-D Benchmark Core (%)

Integral Parameter	ZPPR-9	FCA-6-2	ZPPR-6-6A
K_{eff}	-0.6% (-0.1%)	0.8% (0.7%)	0.7% (0.2%)
Doppler NUO_2	-7 (-13)	-10 (-12)	-18 (-18)
Doppler Iron		15	
Doppler SUS		good (good)	
Na-void	-15~6 (4~43)	-8~5 (20~30)	

* Deviation from experiments in unit of %
** Results for JENDL-2

Table 2 Nuclide-wise change of k_{eff} and 28C/49F from JENDL-2 to JENDL-3T

	ZPPR-9	FCA 6-2	28C/49F (ZPPR-9)
^{239}Pu			
fission	-1.8(%)	0.0(%)	3.1(%)
capture	0.2	0.0	0.1
ν	0.3	0.0	0.0
χ	0.7	0.0	-0.7
Total	-0.6	0.0	2.5
^{238}U			
fission	-0.2(%)	-0.3(%)	0.0(%)
capture	-0.3	-0.4	1.4
inelastic	0.2	——	——
Total	-0.3	-0.7	1.4
^{235}U			
fission	0.0(%)	-1.5(%)	0.1(%)
capture	0.0	0.1	0.0
ν	0.0	2.5	0.0
χ	0.0	0.3	-0.1
Total	0.0	1.4	0.0

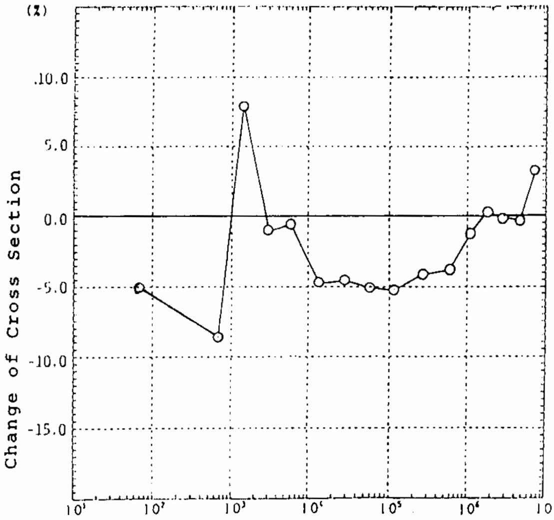

Fig. 1 Pu-239 Fission Cross Section Change from JENDL-2 to JENDL-3T (%)

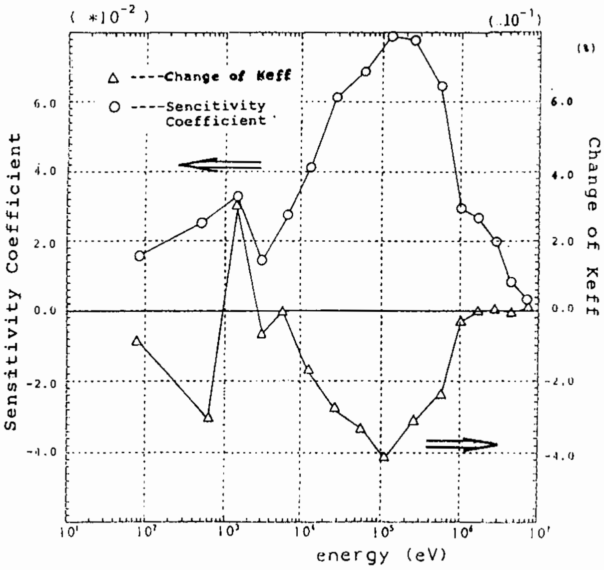

Fig.2 Sensitivity Coefficient and Change of Keff by Pu-239 Fission Cross Section in ZPPR-9

JENDL-3T and the C/E value approaches unity. The overestimation of sodium void worth by JENDL-2 is remarkably improved by JENDL-3T. The overestimation of the ^{239}Pu fission rate distribution in the outer core is improved by about 1%. These results of benchmark test are summarized in Table1.

Sensitivity Analysis

To investigate the effect of main heavy nuclides we calculate the change in FBR core parameters due to the change in each of the fission, capture, scattering cross sections and the ν value and the fission spectrum χ of the nuclides. Table 2 lists the percentage difference of k_{eff} and 28C/49F due to each cross section change from JENDL-2 to JENDL-3T for ZPPR-9(Pu-core) and FCA-6-2(U-core) cores. The k_{eff} of ZPPR-9 is decreased by 0.6% by the change of ^{239}Pu from JENDL-2 to JENDL-3T. For the reduction, the ^{239}Pu fission cross section has the largest contribution. To study the contribution we show in Figs.1 and 2 the ^{239}Pu cross section change , and the sensitivity coefficient of k_{eff}, and the product of the two quantities which corresponds to the energy-dependent contribution to k_{eff} change. The ^{239}Pu fission cross section sensitivity is large in the energy range 10^4~10^6eV,and the sum of sensitivity coefficient is 0.38. The JENDL-3T data is decreased by about 4.8% in this energy range compared to JENDL-2 (see Fig.1). Therefore the ^{239}Pu fission cross section has an effect of -1.8% (=-4.8×0.38) on k_{eff} in the energy range. The effect of the cross section increase just above 1keV is canceled out by the cross section decrease just below 1keV. But those contributions are about 0.3% and large. Therefore, the ^{239}Pu

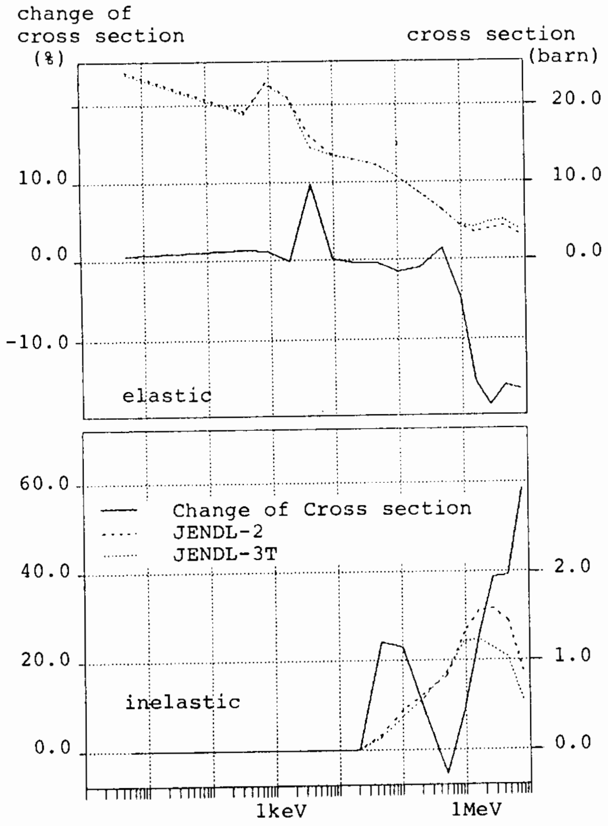

Fig.3 Change of U-238 Elastic and Inelastic Scattering Cross Sections from JENDL-2 to JENDL-3T

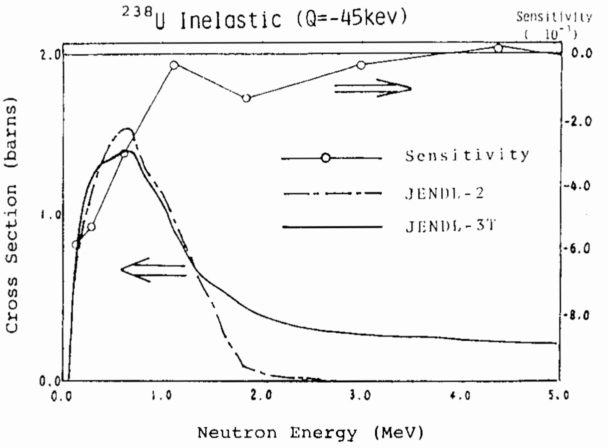

Fig. 4 The Sensitivity Coefficient of Keff and Cross Sections in the 1st Level

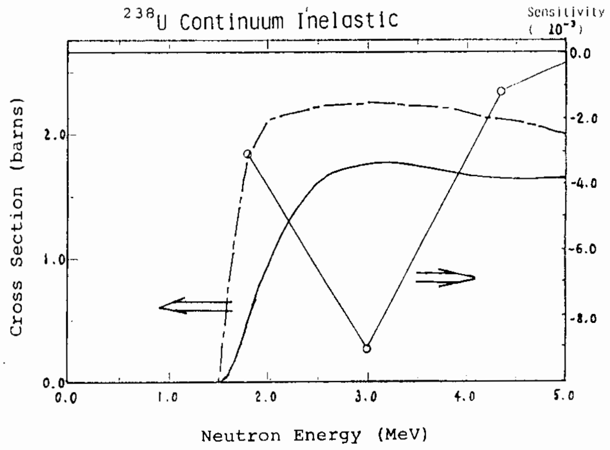

Fig. 5 The Sensitivity Cefficient of Keff and Cross Sections in the Continuum Region

fission cross section around 1keV should be evaluated carefully. This tendency also appears for the ^{239}Pu capture and ^{235}U fission cross sections. Thus the cross sections in this unresolved energy region are important. The fission spectrum change has increased k_{eff} in ZPPR-9 by 0.7% because the spectrum is hardened.

The ^{238}U cross section change from JENDL-2 to JENDL-3T reduces k_{eff} for both Pu and U fueled cores by about 0.3% and 0.7%, respectively as seen in Table2. The inelastic and the elastic cross sections largely changes from JENDL-2 to JENDL-3T as shown in Fig.3. The inelastic cross section is increased from JENDL-2 to JENDL-3T by over 20% above 1MeV. But the elastic cross section is decreased from JENDL-2 to JENDL-3T by about 20% above 1MeV. This large change, however, leads to a minor change in k_{eff} of about 0.2% as shown in Table2. If we change only the inelastic cross section not the scattering matrix, the k_{eff} is reduced by 0.8%dk/k. However, when we consider the scattering matrix change, the change becomes small.

For more detail investigation, we consider the individual rotation levels of the inelastic scattering. This reaction has 26 levels and a continuum region, which is total of the levels with the energy over 1.5MeV, in JENDL-3T. The sensitivity of the ZPPR-9 K_{eff} for the first level with the threshold energy of 45keV is shown in Fig.4 together with the cross sections for JENDL-2 and JENDL-3T, and those of continuum region are shown in Fig.5. For the first level, the cross section is larger for the JENDL-3T than for the JENDL-2, particularly in direct interaction range, which clearly appear over 1.5MeV. The increase of the cross section from JENDL-2 to JENDL-3T and the negative sensitivity make the 0.2% decrease for K_{eff}. The contribution of the cross section difference between JENDL-2 and JENDL-3T above the 2nd level is small compared to the first level. The cross section change from the 1st level to the 10th level decreases k_{eff} by 0.7%. For the levels from the 11th to the 26th level, the each level number of JENDL-3T doesn't exactly correspond to that of JENDL-2 . So it is difficult to compare the cross sections simply by taking the difference in individual levels for between the same level JENDL-2 and JENDL-3T. However, the K_{eff} increases by the levels over 1.27MeV, especially in the continuum region. Figure 5 shows that the cross section is larger for JENDL-2 than JENDL-3T in the continuum region. So this decrease of the cross section and the negative sensitivity make 0.9% increase to K_{eff}, which is opposite to the lower level effect. After all, the total change of K_{eff} is 0.2% in spite of -0.8%, which is in the case of not taking account of any effect of scattering matrix.

The ^{238}U inelastic and elastic scattering cross sections also have large influence on sodium void worth. The change of these cross sections from JENDL-2 to JENDL-3T decreases sodium void worth in ZPPR-9 by about 8%. Furthermore the ^{23}Na inelastic cross section is decreased by about 5% above 0.5MeV and the elastic scattering cross section is increased by about 5% in the energy range of 100keV~5keV. These cross section changes reduce the void worth by about 5%. Thus, the 20~30% overestimation of sodium void worth by JENDL-2 is remarkably improved by JENDL-3T.

The ^{235}U cross section alteration has increased k_{eff} of FCA VI-2 core by 1.4%. The ^{235}U fission cross section is decreased by about 3% in the energy range 10keV~1MeV and by about 7% in the energy range 1keV~10keV. Then k_{eff} is decreased by 1.0%. The ν value is tentatively largely increased from JENDL-2 to JENDL-3T by 2.5% in the energy range 100eV~1MeV. This increase has a remarkable contribution to k_{eff} of the U fueled cores.

For the 28C/49F, the change of the ^{239}Pu fission cross section has increased the ratio by about 3%, and that of the ^{238}U capture cross section has increased it by about 1.4%. Thus, the 28C/49F is increased by about 4%.

Concluding Remarks

From the 1-D and 2-D benchmark tests we have found that the core parameters estimated by JENDL-3T remarkably differ from those by JENDL-2. The k_{eff} for the Pu cores has decreased by about 0.7%dk/k in average, while that for the U cores has increased by about 0.7%dk/k. The 28C/49F has increased by about 4%, and the threshold reaction to 25F has increased by about 6%. The UO_2 Doppler reactivity worth and the sodium void worth were improved.

To investigate the contribution to the change of the core parameters, we have performed sensitivity analysis. For the k_{eff}, the ^{239}Pu fission cross section has an effect of -1.8%dk/k for the Pu cores. The ^{235}U fission cross section and the value have contributions of -1.5%, and 2.5%dk/k in the U cores. The ^{238}U inelastic cross section has complex effect on K_{eff}. High energy excitation levels over 1.27MeV give large increase about 1%dk/k to K_{eff}, while low energy rotation levels below 0.9MeV give decrease of about 0.7%dk/k to K_{eff}. For the 28C/49F, the ^{239}Pu fission and ^{238}U capture cross sections have large contributions.

Therefore, we recommend to carefully investigate the above cross sections until the final compilation of JENDL-3.

Reference

1) JENDL-3T is a temporary file for testing the evaluated data which are for JENDL-3. The data in JENDL-3T will be partly revised in JENDL-3.

2) A.Hara, T.Takeda, Y.Kikuchi
"SAGEP: Two-Dimensional Sensitivity Analysis Code Based on Generalized Perturbation Theory", JAERI-M 84-027 (1984)