Evaluation of 80 Group KAFAX Library for Pb-Bi Cooled Transmutation Reactor Design

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1. Introduction

A fast reactor concept, PEACER [1] was introduced as a burner of transuranic isotopes and long-lived fission products. The PEACER core was loaded with U-10%Zr-31%TRU metallic fuel and cooled with Pb-Bi coolant. Nuclear analysis was done by a series of code systems, TRANSX - DANTSYS - REBUS3 and MONTEBURNS. The data library for the TRANSX is an 80-group KAFAX-F22 developed by the Korea Atomic Energy Research Institute for the analysis of the Na-cooled break-even fast reactor, KALIMER. [2]

The purpose of this paper is to check the reliability of the modified KAFAX libraries for a transmutation reactor design.

2. Cross section data and Calculation Method

The modification of the KAFAX-F22 based on JEFF2.2 library was done in two ways. One is the addition of data for 19 M.A. isotopes, U-(234, 235, 236, 238), Np-237, Pu-(238, 239, 240, 241, 242), Am-(241, 242, 242m, 243), Cm-(242, 243, 244, 245, 246). Additional production of parallel data libraries was done based on ENDF/B-VI.8 and JENDL3.3 master libraries. There must be some differences in actinide capture cross sections among the master libraries and those need to be checked. Seconds, Fission products based on JEFF3.0 was added to original KAFAX-F22 with 11 isotopes, Se-79, Sr-90, Zr-93, Nb-94, Tc-99, Pd-107, Sn-126, I-129, Cs-135, Cs-137 and Sm-151.

Evaluation was done in two steps. One was done in the previous study [3] for limited criticality experiments as an inter-comparison of calculation results from TRANSX /DANTSYS and MCNP4c2 with experimental data from the handbook of International Criticality Safety Benchmark Evaluation Project (ICSBEP) and the experimental report of Criticality Safety Evaluation Working Group (CSEWG). The other was done in this paper for a PEACER core condition as comparison of TRANSX/DANTSYS with MCNP4c2. The depletion and transmutation rates were also checked by comparing the REBUS-3 calculation with MONTEBURNS.

3. Verification with pseudo benchmark problems

3.1. PEACER Pin Cell Model for Minor Actinide

For an inter-comparison between the R-Z model TWODANT and MCNP4c2, an unit cell of PEACER-550 was modified into an equivalent cylindrical cell. All kinds of minor actinides were added to the fuel in certain quantities, and the k-infinite values from TRANSX/ TWODANT was compared with MCNP4c2. There was a good agreement between the MCNP4c2 and TWODANT with KAFAX-2. However, there were no considerable differences among the three master libraries; JEFF3.0, ENDF/B-VI.8 and JENDL3.3. The capture ratios of Am-241 and Am-243 to U-235 and fission ratio of Cm-242 showed considerable discrepancies among three master libraries.

3.2. PEACER Pin Cell Model for Fission Products

Transmutation targets for F.P. are aimed for burning of Tc-99, I-129 and the radio-toxic isotopes. In these kinds of calculations, therefore, reliability of nuclear data for capture cross section in both the fast and epithermal regions becomes an important issue. In this study, 6 of the isotopes except Se-79, Sr-90, Nb-94, Pd-107 and Sn-126 were tested in the same way as for minor actinides. The calculated k-infinite value after adding a certain amount of a single F.P. isotope was compared with the MCNP4c2 reference model. The comparisons of k-infinite value showed 3.05 % relative error between the MCNP4c2 and TWODANT. However, this difference is occurred from the code systems. The opposite results were observed in the reaction rate ratio of Cesium isotopes of capture to total fissile fission. Cesium have 200% error in capture to total fissile fission. However, these kinds of errors seldom effect on fast reactor analysis because the overall amount of these isotopes is very small in the real world. However, the transmutation rate will be sensitive to the discrepancy found in this study.

In a F.P. transmutation, a special thermal spectrum zone is designed for an effective burning of fission products. In a PEACER core concept, the ZrH_2 moderator is used for F.P. transmutation in a thermal spectrum zone. Based on this thermal spectrum model, the same benchmark calculation was repeated. Also, it was showed not such a good agreement for all F.P. between the MCNP4c2 and TWODANT. It was concluded that the KAFAX library showed some considerable error by 60~200% in the capture reaction rate in both the fast and thermal spectrums. Concerning the issue of criticality, this error would be negligible because their amounts are actually small in the reactor. However, a detailed burnup calculation should be done for the accuracy of the transmutation speed.

4. Benchmark Problems for the Isotopic Depletion Calculation

4.1. Depletion Calculation Method

In a previous chapter, capture reaction rates of Am-241, Am-243, Cm-242, Cs-135, and Cs-137 showed considerable differences among master libraries. Therefore, depletion of actinides and fission product isotopes would make large errors in some isotopes as fuels burn up. Depletion calculation should be done by a REBUS-3 code. In this chapter, accuracy of this module was checked by a comparison with MONTEBURNS.

As a reference calculation, a well-benchmarked depletion problem with uranium and plutonium was modeled. Geometry model of PEACER-550 core was analyzed without minor actinides. Changes of k-infinite and number densities of U and Pu during 3 years period were calculated with both computer codes. Both change rate curves were almost linear and showed considerable differences at initial steady-state values because of model differences. Table 1 showed the change ratios of final to initial values. All three KAFAX libraries showed reasonable errors.

Table 2. Ratio of Change after 3 years in k-infinite and Isotopic Mass, Final to Initial Condition

		MONTEBURNS	REBUS-3		
		ENDF/B-VI	KAFAX-1	KAFAX-2	KAFAX-3
Reference Case	k-infinite	0.868	0.857	0.861	0.861
	U-235	0.665	0.647	0.648	0.616
	Pu-239	0.779	0.759	0.771	0.763
Isotopic Case	Am241	0.700	0.509	0.572	0.567
	Am243	0.756	0.825	0.855	0.865
	Cm242	0.022	0.007	0.008	0.006
	Cs135	1.645	1.624		
	Cs137	1.478	1.597		

4.2. Minor Actinide and Fission Product Depletion

In case of Am-241 and Am-243 transmutation, REBUS-3 module showed large discrepancies compared with MONTEBURNS. KAFAX-2 and -3 showed almost same slopes, but KAFAX-1 showed different rate of transmutation. This result was consistent with capture reaction ratio differences among three libraries in Section 3.1. Capture reaction rate ratio of Am-243 showed about 18% difference in KAFAX-1 compared with KAFAX-2 and -3.

As a result, Cm-242 showed very similar rates of change among three libraries and between two codes. This was inconsistent with results at Section 3.1 where there were large differences in capture reaction rate ratio. It was believed that the rate of change in Cm-242 was dependent on alpha decay chain faster than nuclear transmutation chain. Half-life of Cm-242 is 162.79 days.

Fission product chain was checked for Cs-135 and Cs-137. They showed large differences in capture reaction rate ratio in section 3.2. Table 1, however, showed no large differences in rate of change, about 1.28 % error in Cs-135 and about 8.05 % error in Cs-137 compared with MONTEBURNS. This level of error is not high to be considered in benchmark problems. In this calculation, it was believed that very slow rate of transmutation of Cs-135 and Cs-137 could not overcome the rate of production rates.

5. CONCLUSIONS

For an evaluation of transmutation of minor actinide and fission products in a Pb-Bi cooled fast reactor, the KAFAX nuclear data library was updated. Three kinds of updated KAFAX libraries were based on JEFF3.0, ENDF/B-VI.8 and JENDL3.3 and its reliability was tested in minor actinide transmutation calculation.

Most actinides demonstrated good agreement with the reference and the three libraries. However, the capture reaction rate ratio of Am-241, Am-243, and Cm-242 showed large discrepancies. The capture cross sections of those isotopes should be updated for a precise prediction of transmutation performance. Even though fission product isotopes are not important for reactor design, a transmutation capability prediction should be done with intensive care because the capture rate showed a large error compared with the MCNP4c2 reference.

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