3.2 International β_{eff} Benchmark Experiments in FCA

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Benchmark experiments of the effective delayed neutron fraction β_{eff} were performed at FCA between 1995 and 1998 to improve prediction accuracy of the β_{eff}[1,2]. The experiments were carried out in three cores which were built to provide a systematic change in ^{235}U, ^{238}U and ^{239}Pu contributions to the β_{eff}: XIX-1 core(U fuel), XIX-2 core(Pu/U fuel) and XIX-3 core(Pu fuel). Table 3.2.1 summarizes main characteristics of these cores. Six organizations from five countries(CEA/France, IPPE/Russia, KAERI/Korea, LANL/USA, Nagoya-University/Japan and JAERI/Japan) participated in the experiments with their measurement methods and have reported their β_{eff} values so far.

The final value of experimental β_{eff} was derived by comparing the β_{eff}'s between the measurement methods to improve reliability of the final value. The analysis of experiments was made using the JENDL-3.2 nuclear data file[3] and JAERI's calculation system for fast reactor neutronics to check the prediction accuracy of β_{eff}[4].

Table 3.2.1 Main characteristics of FCA cores

Core name	XIX-1	XIX-2	XIX-3
- Fuel	Enriched uranium	Plutonium /Natural uranium	Plutonium
- Fuel enrichment	93%	23%	(92% fissile Pu)
- Core dimensions Radius x Height(cm)	33.0 x 50.8	35.7 x 61.0	35.1 x 61.0
- β_{eff} (pcm)	742	364	251
- Nuclide contributions to β_{eff}			
^{235}U	94%	10%	9%
^{238}U	6%	47%	11%
^{239}Pu	—	41%	77%
^{240}Pu, ^{241}Pu, ^{241}Am	—	2%	3%

Finalization of Experimental β_{eff}

Table 3.2.2 shows the β_{eff}'s that were measured by the individual method. The final value of β_{eff} in each core was obtained by taking the mean value of these individual β_{eff}'s. Correlations of β_{eff}'s between different methods were taken into account in this procedure because several common parameters such as fission rate were used to determine the β_{eff} in the different methods. The mean value m of the β_{eff} was determined by

$$m = (\mathbf{u} \cdot \mathbf{C}^{-1} \cdot \mathbf{u}^{T})^{-1} \cdot \mathbf{u} \cdot \mathbf{C}^{-1} \cdot \mathbf{p} \,. \qquad (3.2.1)$$

where $\mathbf{p}$ is a column vector whose elements are the β_{eff}'s by the individual method, $\mathbf{C}$ is a covariance matrix of β_{eff}'s, $\mathbf{u}$ is a row vector with all elements equal to unity and T means a transpose of vector. The internal uncertainty δ_{int} of the m was estimated by the error propagation law :

$$\delta_{int} = \sqrt{(u \cdot C^{-1} \cdot u^{T})^{-1}} . \qquad (3.2.2)$$

The external uncertainty δ_{ext} was estimated by

$$\delta_{ext} = \sqrt{\chi^2/f} \cdot \delta_{int} . \qquad (3.2.3)$$

where f is the degrees of freedom, χ^2 the statistical parameter calculated from the residuals of individual β_{eff}'s around the m. The δ_{ext} reflects the scattering of the individual data around the m. Table 3.2.3 presents the results for the m, δ_{int} and δ_{ext}. The δ_{ext} was larger than the δ_{int} in the XIX-1 and XIX-2 cores where the δ_{ext} was adopted as the uncertainty of the final value. The δ_{int} was adopted in the XIX-3 core. These results satisfied the target accuracy of 3% required for the experimental β_{eff}[5].

Table 3.2.2 β_{eff} values obtained by different experimental methods

Unit : pcm

	Core name	XIX-1	XIX-2	XIX-3
(1)	Covariance-to-mean method (JAERI)	724±13(2%)*	—	252±5(2%)
(2)	Modified Bennett method (Nagoya-University)	782±16(2%)	368±6(2%)	256±4(2%)
(3)	Noise method (CEA)	743±19(3%)	—	250±6(2%)
(4)	Rossi-α method (IPPE)	771±23(3%)	—	—
(5)	Nelson-number method (LANL)	737±20(3%)	—	—
(6)	Cf source method			
	JAERI/KAERI	735±20	358±10	249±7
	IPPE	706±30	351±10	244±7
	Mean of two participants	727±20(3%)	355±10(3%)	247±7(3%)

* Values in parentheses : relative uncertainty

Table 3.2.3 Final value and uncertainty of β_{eff}

Unit : pcm

Core name	XIX-1	XIX-2	XIX-3
Mean value of β_{eff}(m)	742	364	251
δ_{int}	±11(2%)	±7(2%)	±4(2%)
δ_{ext}	±24(3%)	±9(3%)	±4(2%)

Analysis of the measured β_{eff}

Cell calculations were made for each region in the reactor to prepare cell averaged effective cross sections in seventy energy groups. We used the SLAROM code[6] which is based on the collision probability method, a group constants set JFS3-J3.2 with a seventy energy group structure[7] and a one-dimensional infinite slab model of the cell.

Core calculations were made by a diffusion theory code POPLARS[8] in a three-dimensional X-Y-Z model. The β_{eff} was calculated by using the delayed neutron(D.N.) yields and the D.N. spectra of the JENDL-3.2. The incident neutron energy dependence of D.N. yields was taken accout of in this calculation. To see the effect of changing the D.N. spectra on the β_{eff} calculation, the D.N. spectra of ENDF/B-VI[9] were also used for the calculation with the D.N. yields of JENDL-3.2. A correction of about 1% for transport effect was applied to these results. This correction factor was estimated with a two-dimensional transport theory code TWOTRAN-II[10].

Table 3.2.4 presents the ratios of calculation to experiment(C/E's) of the β_{eff}. The effect of changing the D.N. spectra on the β_{eff} calculation was found to be small(at most 0.6%). Good agreement was found in the XIX-1 and XIX-2 cores between experiment and calculation. On the other hand, the calculation underpredicted the β_{eff} of XIX-3 core by 2~3%. The present values of β_{eff} and the C/E's will be used in future for evaluation of the D.N. yields.

Table 3.2.4 Ratios of calculation to experiment(C/E's) of β_{eff}

Core name			XIX-1	XIX-2	XIX-3
	D.N. yield	D.N. spectra			
(a)	JENDL-3.2	JENDL-3.2	1.004	1.005	0.972
(b)	JENDL-3.2	ENDF/B-VI	1.003	1.009	0.978

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