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Analysis on Effective Delayed Neutron Fraction (β_{eff}) Using ENDF/B-VI.5 and VII.0

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1. Introduction

Although delayed neutrons account for a very small fraction (less than 1%) of the neutrons generated from fission, they play an important role in the control of fission chain reaction [1]. Hence, various experiments were performed to measure effective delayed neutron fraction (β_{eff}) in thermal [2] and fast systems [3] as well as a research reactor [4]. However, because of the difficulties in accurately measuring β_{eff}, this value is currently evaluated from theoretical calculations whose accuracy is depended on applied method and cross-section library.

The theoretical calculation for β_{eff} is mainly performed by Keepin Method [5] using the forward and adjoint neutron fluxes. However, it is difficult to derive a solution of the adjoint neutron transport equation using Monte Carlo codes (e.g., MCNPX) due to the treatment of continuous energy cross-section library. Currently, an alternative method is developed to simply evaluate the β_{eff}, and in this study, their accuracies are assessed by comparing existing measurement results.

2. Methods and Materials

The effective delayed neutron fraction (β_{eff}) is traditionally defined as follows;

$$\beta_{eff} = \frac{\sum_i \sum_m \int \psi \chi_{di}^m v_{di}^m \sum_f^m \phi d\Omega' dE' d\Omega dE dr}{\sum_m \int \psi \chi_t^m v_t^m \sum_f^m \phi d\Omega' dE' d\Omega dE dr} \tag{1}$$

where, m and i mean the m^{th} isotope and i^{th} delayed neutron group respectively, and ψ represents the adjoint neutron flux, ϕ represents the angular neutron flux. Also, v_t is the total number of fission neutrons (prompt+ delayed), χ_t is the normalized energy spectrum of all fission neutrons. In order to solve Eq.(1), it is necessary to exactly calculate the adjoint neutron flux, but most Monte Carlo codes are usually not applicable. However, an alternative calculation method is currently proposed to evaluate the β_{eff} without any use of the adjoint neutron flux. On the basis of Prompt Method [6], the expression of β_{eff} in Eq.(1) can be simply changed into as follows;

$$\beta_{eff} = \frac{\langle \chi_d v_d \rangle}{\langle \chi v \rangle}$$

$$= 1 - \frac{\langle \chi v - \chi_d v_d \rangle}{\langle \chi v \rangle} = 1 - \frac{\langle \chi v_p - (\chi_d - \chi) v_d \rangle}{\langle \chi v \rangle}$$

$$\approx 1 - \frac{\langle \chi_p v_p \rangle}{\langle \chi v \rangle} = 1 - \frac{k_p}{k} \tag{2}$$

where, the brackets denote the inner product, and the number of prompt fission neutrons, v_p, denotes by a v–v_d. In Eq.(2), it is approximated that the $(\chi_d-\chi)v_d$ is two order of magnitude smaller than the χv_p because v_d is two order of magnitude smaller than the v_p. For the same reason, the shape of χ is almost same with that of χ_p. By introducing an alternative calculation method, Monte Carlo codes can easily evaluate the effective delayed neutron fraction (β_{eff}) explained by the ratio of the delayed to the total multiplication factors.

For the accuracy confirmation of the β_{eff} values derived from the above-mentioned methods, benchmark calculations are performed in regard to fast critical experiments [7] at Los Alamos National Laboratory (LANL). These experiments were progressed with the compact metal assemblies designed with a sphere shape, and detailed information related with core and reflector are described in **Table 1**. In addition, these experiments measure the β_{eff} and the prompt neutron life time for various fast critical assemblies.

Table 1. Fast Critical Experiments to measure the β_{eff}

Name	Shape	Core		Reflector[b) [thickness]
		Composition [atoms/b cm]	Density [g/cm^3]	
Lady Godiva	Sphere	^{234}U: 0.00049 ^{235}U: 0.04500 ^{238}U: 0.00250	18.74	-
Flattop-U(93)	Sphere	^{234}U: 0.00049 ^{235}U: 0.04449 ^{238}U: 0.00270	18.62	U(nat) 18.01cm
Jezebel-Pu(4.5)	Sphere	^{239}Pu: 0.03705 ^{240}Pu: 0.00175 ^{241}Pu: 0.00012 ^{64}Gd: 0.00138	15.61	-
Jezebel-^{233}U	Sphere	^{233}U: 0.04671 ^{234}U: 0.00059 ^{235}U: 0.00001 ^{238}U: 0.00029	18.42	-
Flattop-^{233}U[a)	Sphere	^{233}U: 0.04671 ^{234}U: 0.00059 ^{235}U: 0.00001 ^{238}U: 0.00028	18.42	U(nat) 19.52cm

a) A 0.293cm gap between core and reflector.
b) Reflector consists of 0.00034 ^{235}U atoms/b cm and 0.04774 ^{238}U atoms/b cm.

3. Results and Discussions

This work has evaluated the effective delayed neutron fraction (β_{eff}) for some experiments on the basis of two different cross-section libraries (ENDF/B-VI.5 and VII.0) and methods. For these calculations, two calculation codes (MCNPX [8] and McCARD [9]) are used, and the results are shown in **Figure 1** and **Table 2**. In case of employing Prompt Method, although there are some differences between the calculated and measured results, the trends of expected values are reasonably matched with the other one. Especially, the β_{eff} values evaluated from ENDF/B-VII.0 library are more accurately predicted than those derived from the previous library. In the case of another one, expected β_{eff} values are precise agreement with measured results within plus or minus 7% error. From these results, it is confirmed that the effective delayed neutron fraction (β_{eff}) is sufficiently evaluated from the theoretical calculation with the latest cross-section library.

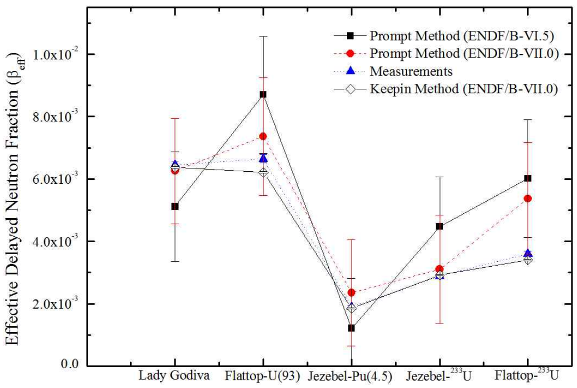

Figure 1. A Comparison of Experimental and Calculated Results for Effective Delayed Neutron Fraction (β_{eff})

Table 2. Effective Delayed Neutron Fraction (β_{eff}) Evaluated from Two Different Cross-section Libraries

Name	Effective Delayed Neutron Fraction (β_{eff})			
	Prompt Method*		Keepin Method	Experiment
	B-VI.5	B-VII.0	B-VII.0	
Lady Godiva	0.00511 (±0.00176)	0.00625 (±0.00169)	0.00637 (±0.00003)	0.00645 (±0.00013)
Flattop-U(93)	0.00871 (±0.00188)	0.00737 (±0.00189)	0.00621 (±0.00003)	0.00665 (±0.00013)
Jezebel-Pu(4.5)	0.00121 (±0.00160)	0.00235 (±0.00170)	0.00185 (±0.00002)	0.00190 (±0.00004)
Jezebel-^{233}U	0.00447 (±0.00160)	0.00310 (±0.00174)	0.00292 (±0.00002)	0.00289 (±0.00007)
Flattop-^{233}U	0.00601 (±0.00189)	0.00537 (±0.00180)	0.00340 (±0.00002)	0.00360 (±0.00009)

**The uncertainty for β_{eff} value was denoted by the sum of standard deviations for the delayed and the total multiplication factors.*

4. Conclusions

In order to evaluate the effective delayed neutron fraction (β_{eff}) from theoretical calculation, this work has introduced Prompt and Keepin Methods. The difference caused by two different cross-section libraries of ENDF/B-VI.5 and ENDF/B-VII.0 is also investigated, and the accuracies are confirmed by the benchmark calculations for fast critical experiments at LANL. As a result, although the expected results are significantly influenced by cross-section library, the β_{eff} can be sufficiently evaluated from theoretical calculation with the latest one (i.e., ENDF/B-VII.0).

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