Continuous-Energy Resonance Calculation Method Using Wavelets Scaling Function Expansion

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1. Introduction

The neutron flux oscillates violently within the resonance energy range because of the serious oscillation of the absorption and fission cross-section of resonance nuclides. Two existing methods were proposed to obtain the fine-structure neutron spectrum. One is the so-called hyperfine group method, which solves the neutron transport equation by dividing the energy range to thousands of energy groups [1]. The other method solves the neutron transport equation by using a combination of multi-group (MG) and thousands of point wise (PW) nuclear data [2]. This paper introduces a new method to discretize the energy variable of neutron transport equation by coupling the multi-group method and wavelet scaling function expansion method.

2. Method

In this paper, the multi-group method is used within non-resonance energy range because of the smoothness of the flux distributions in those ranges. Daubechies' wavelet scaling function is employed to expand the energy variable of neutron flux within the resonance energy range because of its excellent properties of simulating neutron spectrum with bumpy oscillation. Thus, the continuous-energy neutron transport equation within the resonant energy range is transformed to a set of equations represented by wavelets scaling function expansion moments. The continuous-energy spectrum is constructed as long as the expansion moments are obtained. Fortunately, the equations have the same form with the standard multi-group neutron equation. Therefore, the MOC can be applied as the spatial and angular solver conveniently. Due to the powerful capability of MOC, this method has capability of solving complex geometry resonance calculation problems. Thus, this method can obtain spatial dependent continuous-energy spectrum.

In this method, the continuous-energy cross-section is from the nuclear data library of MCNP [3], while the multi-group nuclear data library is jeff31 issued by IAEA. Unfortunately, in MCNP continuous-energy data library, the data are only in limited temperature situations. Therefore, interpolation is needed to obtain the continuous-energy cross-sections for other temperatures between those given temperatures. In this paper, the accuracy of the temperature interpolation is discussed.

Determining the radial power distribution for fuel pin-cell is important for fuel integrity evaluations. Recently, the spatially dependent Dancoff method (SDDM) [4] has been applied to solve this problem. Also the SDDM method is enhanced to treat the radial temperature distribution within a fuel rod [5]. In this paper, the wavelets scaling function expansion continuous-energy resonance self-shielding method is applied to consider this problem.

It is seen from the results of the tested problem that the wavelet scaling function expansion method is able to calculate accurate k-inf and neutron spectrum within resonance energy range. The advantage of this method is that the existing transport codes can be applied conveniently because the coefficients equations are similar to the multi-group neutron transport equation. Secondly, iterative calculation of the neutron transport equation will not be necessary even the fuel consists of more than one resonant nuclide. However, the neutron transport equations are transformed to a set of coefficient equations within resonance energy range in this method. Nevertheless, this method is time consuming. Because the larger of the Daubechies' order and the dilation order, the more of the coefficient equations we get. For instance, when the Daubechies' order N=5, the dilation order n=7, then there will be 136 coefficient equations in one resonance group.

Applying the Sqrt-log interpolation of the continuous-energy nuclear data, the wavelets scaling function expansion resonance self-shielding method is enhanced to calculation the problems with temperature. The precision of the interpolation of the continuous-energy nuclear data is discussed. In this paper, the PWR pin-cell problem is calculated to validate the enhanced wavelets scaling function expansion resonance self-shielding method. Comparison with the results calculated by MCNP, good results of the k-inf, continuous-energy spectrum, 238U total reaction and the power distribution results of volume average model and temperature profile model are obtained. This consistency with the Monte Carlo code MCNP makes this resonance self-shielding calculation model useful to accurately perform fuel integrity evaluations for various core designs.

3. Numerical results

A PWR fuel cell problem is calculated. The results in table 1 show wavelets scaling function expansion method can get satisfactory results of k-inf in different enrichment for PWR fuel cell problem.

Table I: Result of PWR Fuel Cell

Enrichment/**%**	k_∞		Error/%
	MCNP	WAVERESON	
3	1.38497	1.387285	-0.167
7	1.53626	1.540399	-0.269
10	1.57835	1.583838	-0.348
15	1.61687	1.624622	-0.479

The PWR pin-cell with temperature distribution is also calculated. Temperature distribution includes 2 cases. Case 1 is the temperature distribution model. Case 2 is the volume average temperature model. The pellet region is divided into 10 equal ring regions for both cases.

The bias of $\Delta k / k$ calculated by WAVERESON is 0.053%, which is larger than the value of MCNP results 0.040% calculated by the results shown in Table 2. In the work of Mastsumoto, the bias of $\Delta k / k$ calculated by MCNP4C also is 0.053%.

Table II: The k-inf results of the PWR pin-cell problem

	MCNP k-inf	WAVERESON	Error (%)
1	1.46102±0.00009	1.463022	0.137
2	1.46043±0.00009	1.462246	0.124

4. Conclusion

It is seen from the results of the tested problem that the wavelet scaling function expansion method is able to calculate accurate k-inf and neutron spectrum within resonance energy range. The advantage of this method is that the existing transport codes can be applied conveniently because the coefficients equations are similar to the multi-group neutron transport equation. Secondly, iterative calculation of the neutron transport equation will not be necessary even the fuel consists of more than one resonant nuclide. However, the neutron transport equations are transformed to a set of coefficient equations within resonance energy range in this method. Nevertheless, this method is time consuming. Because the larger of the Daubechies' order and the dilation order, the more of the coefficient equations we get. For instance, when the Daubechies' order N=5, the dilation order n=7, then there will be 136 coefficient equations in one resonance group.

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