Monte Carlo Depletion with Critical Spectrum for Assembly Group Constant Generation

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1. Introduction

The conventional two-step procedure [1] has been used in practical nuclear reactor analysis. In this procedure, a deterministic assembly transport code such as HELIOS and CASMO is normally to generate multigroup flux distribution to be used in few-group cross section generation. Recently there are accuracy issues related with the resonance treatment or the double heterogeneity (DH) treatment for VHTR fuel blocks. In order to mitigate the accuracy issues, Monte Carlo (MC) methods can be used as an alternative way to generate few-group cross sections because the accuracy of the MC calculations benefits from its ability to use continuous energy nuclear data and detailed geometric information. In an earlier work [2], the conventional methods of obtaining multigroup cross sections and the critical spectrum are implemented into the McCARD Monte Carlo code [3]. However, it was not complete in that the critical spectrum is not reflected in the depletion calculation.

The purpose of this study is to develop a method to apply the critical spectrum to MC depletion calculations to correct for the leakage effect in the depletion calculation and then to examine the MC based group constants within the two-step procedure by comparing the two-step solution with the direct whole core MC depletion result. .

2. MC Depletion with Critical Spectrum

In the depletion calculation, the following Bateman equation is to be solved in each region at each depletion time step (DTS):

$$\frac{dN_{mi}(t)}{dt}=\sum_j l_{ij}\lambda_j N_{mj}(t)+\sum_j \gamma^n_{mij} N_{mj}(t)-(\lambda_i+\gamma^n_{mi})N_{mi}(t);\ t\in[t_n,t_{n+1}] \quad (1)$$

where $\gamma^n_{m,i}$ is the microscopic absorption rate of nuclide i in cell m and other notations are standard. If the spectrum is to be changed to reflect the leakage inevitable in the actual core depletion, the reaction rate given by Eq. (1) should be changed as well. $\gamma^n_{m,i}$ thus need be reevaluated before the depletion calculation. Let $\gamma^B_{m,i}$ be the new microscopic absorption reaction rate obtained with critical spectrum. In order to determine $\gamma^B_{m,i}$, the fine-groupwise reaction rates $\gamma^g_{m,i}$ need to be stored for each depletion region m and nuclide i while only one reaction rate for the entire energy is needed in the normal MC depletion calculation.

The correction to incorporate the critical spectrum can be done quite easily once $\gamma^g_{m,i}$ and the groupwise critical and infinite medium spectra are known. Namely, the groupwise ratio of the assemblywise critical spectrum (ϕ^B_g) to the infinite medium spectrum ($\bar{\phi}_g$), $\phi^B_g/\bar{\phi}_g$, is to be applied uniformly across the entire region as shown in Eq. (2).

$$\gamma^B_{m,i}=\sum_g \frac{\phi^B_g}{\bar{\phi}_g}\gamma^g_{m,i} \quad (2)$$

The MC depletion calculation using the critical spectrum can be performed following the flow chart shown in Figure 1.

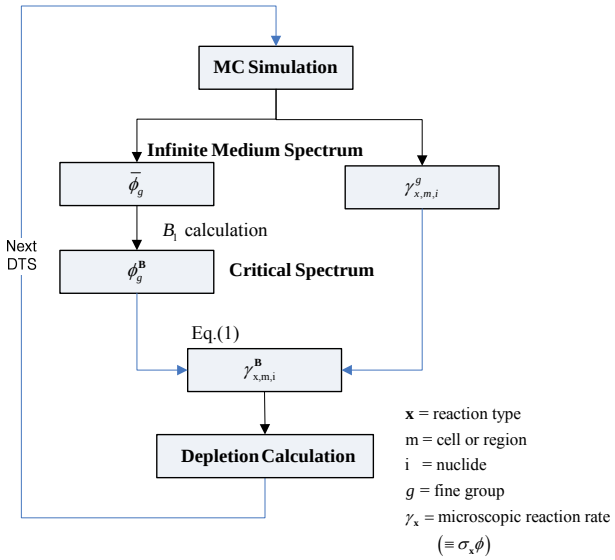

Fig. 1. Flow chart of Critical MC Depletion analysis

3. The McCARD/MASTER Code system

The McCARD/MASTER code system is a two-step code system developed to use the McCARD MC code for the group constant generation needed in the MASTER [4] 3-D core calculation. The assembly few-group constants including diffusion coefficients and form functions are generated by McCARD and tabularized as a function of temperature, boron concentration, and burnups by after a set of branch calculations via two special utility codes MIG (McCARD Input Generator) and MOCHA(McCARD Output Convertor into HOPE Ascii table). Figure 2 shows the McCARD/MASTER code system

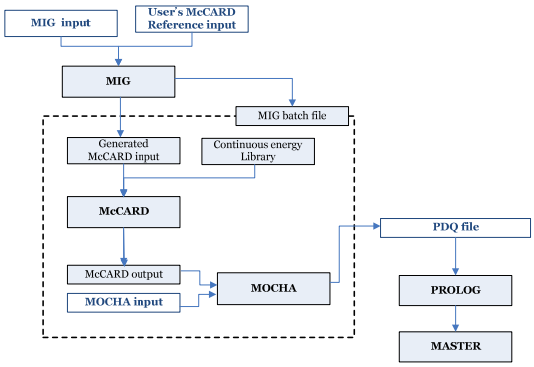

Fig. 2. Flow chart of McCARD/MASTER code system

4. Verification

To examine the McCARD generated group constants using the McCARD/MASTER system, a PWR fuel assembly (FA) and mini-core depletion analysis are performed. The reference solution is obtained by the direct McCARD run for the whole core using 10,000 histories per a cycle with 200 active cycles. A 47 group structure was used to generate the critical spectra.

4.1 Fuel Assembly Depletion

Figure 3 shows the k-infinity behaviors of the McCARD and MASTER calculations for a 4.3% enriched 17x17 PWR FA. The results of McCARD/MASTER agree well with reference within 165 pcm and the RMS error between the k-infinities is 68 pcm.

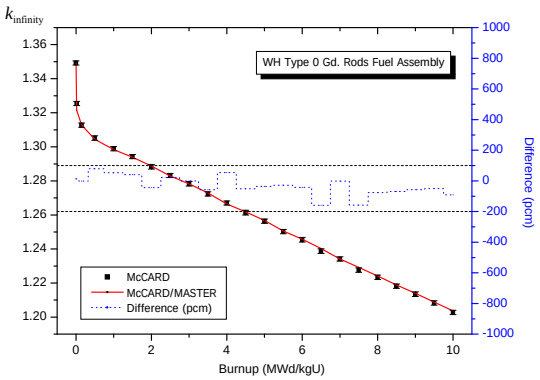

Fig. 3. The k-infinity for a PWR Fuel Assembly

4.2 Mini-core Depletion

Figure 4 shows the configuration of the mini-core consisting of three types of 17x17 PWR FA. The critical boron concentrations obtained with and without the critical spectrum option are compared in Figure 5. The RMS error of the critical boron concentrations with the infinite medium spectrum case is 49 ppm while that with critical spectrum is 29 ppm. Although the RMS error is not much improved, the boron letdown behavior is much better with the critical spectrum.

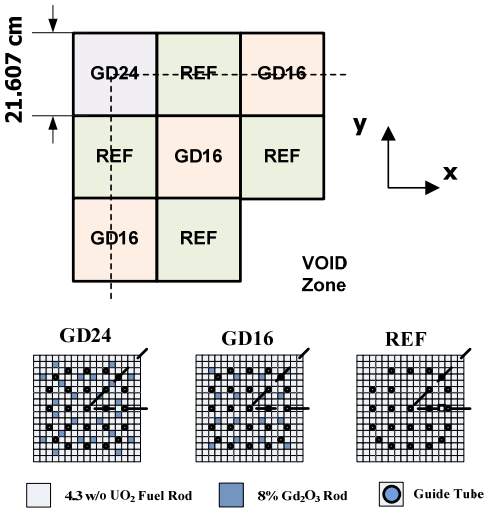

Fig. 4. Configuration of PWR mini-core problem

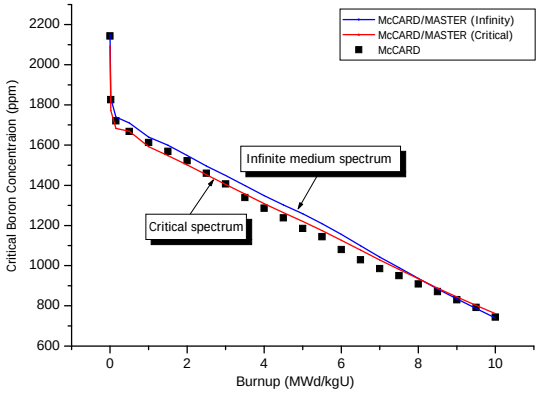

Fig. 5. Critical boron concentration for PWR Mini Core

4. Conclusions

For MC based assembly group constant generation, the capability of MC depletion with critical spectra was implemented into the McCARD MC code and the McCARD/MASTER two-step core analysis system has been established. It is confirmed that McCARD/MASTER depletion agrees well with the McCARD standalone reference for the mini-core as well as the single assembly case. The error in the critical boron concentration is much less with the critical spectrum.

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