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Improvements for Monte Carlo Burnup Calculation

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Abstract

Monte Carlo burnup calculation is development trend of reactor physics, there would be a lot of work to be done for engineering applications. Based on Monte Carlo burnup code MOI, non-fuel burnup calculation methods and critical search suggestions will be mentioned in this paper. For non-fuel burnup, mixed burnup mode will improve the accuracy of burnup calculation and efficiency. For critical search of control rod position, a new method called ABN based on ABA which used by MC21 will be proposed for the first time in this paper.

Keywords: Monte Carlo, Mixed burnup Mode, ABN

1. Introduction

During recent twenty years, Monte Carlo burnup calculation become more important in the development of reactor physics calculation, from the original coupling of MCNP and ORIGEN[1]. Monte Carlo burnup calculation has been gradually used in various fields in the reactor physics calculation, from the calculation of the assembly parameters to the core operating performance study, refer to the research reactor and commercial pressurized water reactor.

After the Fukushima accident, many countries are in pursuit of safety and economy reactor. Then analysis tools need to be more precise, and put forward new demand to Monte Carlo burnup calculation. As respond to the needs of the third generation of pressurized water reactor, the non-fuel burnable poison burnup calculation and adjustable rod critical issues in pressurized water reactor will be study in this paper, in order to improve the accuracy and efficiency of calculation.

2. MOI[2]

This research is based on MOI (Monte Carlo Optimal Integration). The main goal of MOI development is not on more advanced Monte Carlo or burnup method, but on the basic verification calculation for third generation reactor. In order to meet the requirement of safety and economy, more complex burnable poison and control rods used in the third generation reactor, such as IFBA and WABA in AP1000[3], borosilicate glass tube and Gd burnable poison in ACP1000[4], a control rod motion mechanism of MSHIM[5] in AP1000. Burnable poison fuel and control rod movement can significantly influence the reactor core power distribution, so how to calculate the burnable poison fuel burnup and predictive control rod movement quickly and accurately are challenges for Monte Carlo burnup code.

At present, MOI use the mature Monte Carlo transport calculation and burnup calculation module, the basic principle of the procedure is the same for lots of Monte Carlo burnup codes. The basic framework of MOI program contains independent sets of modular, to facilitate future maintenance and update, as shown in figure 1.

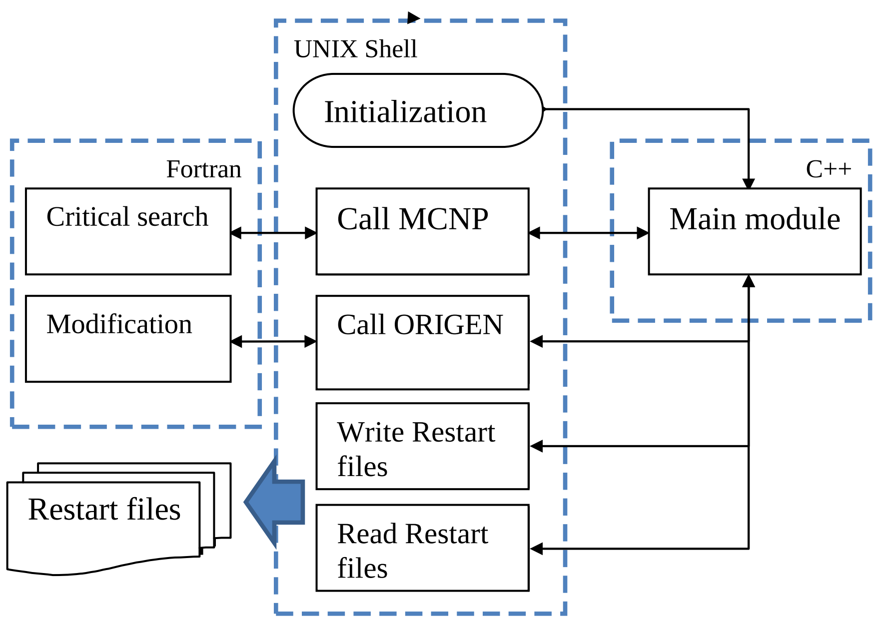

Figure 1 The basic framework of MOI

3. Non-fuel burnup problem

The third generation reactor core may adopt various kinds of burnable poison, hybrid or distributed, including gadolinium, erbium, boron and etc.. Gadolinium and erbium are usually mixed together with fuel, there are no difference between burnup of them with the common fuel. Boron is usually separation of fuel, burnup of which requires special consideration.

3.1 Constant power or constant flux

Burnup model of ORIGEN include constant power and constant flux, similar codes (such as MCBurn[6]) usually use constant power mode for burnup calculation. However, the separated burnable poison areas have little power, so the constant power mode to fuel burnable poison hardly get the right result for poison burnup. Some codes (such as MCODE[7]) provide a constant flux fuel option, but for the fuel cell, it will lead the burnup error. So MOI uses mixed burnup model, constant power mode for the fuel burnup and constant flux mode for non-fuel (include separate burnable poison) burnup.

3.2 Mixed burnup model in MOI

3.2.1 Power and flux allocation

The input for Burnup calculation is the total power (MW), so the power and the flux of burnup region need to be allocated, here is the process in detail.

a) First calculate the average fission energy in each burnup region produced by a neutron.

b) Calculate flux normalization coefficient and dimensionless constants

c) Get the flux and the power of each region *i*

Then constant power mode will be used in default, but if the ratio of the flux to the power is smaller than the set value, the constant flux mode would be used in this region.

3.2.2 The calculation results of IFBA

In order to test the mixed burnup model, IFBA cell is calculated. IFBA is developed by Westinghouse, the pure UO_2 fuel pellets coated with ZrB_2 film. IFBA includes both fuel and non-fuel burnup region (figure 2), the results shown in figure 3,4.

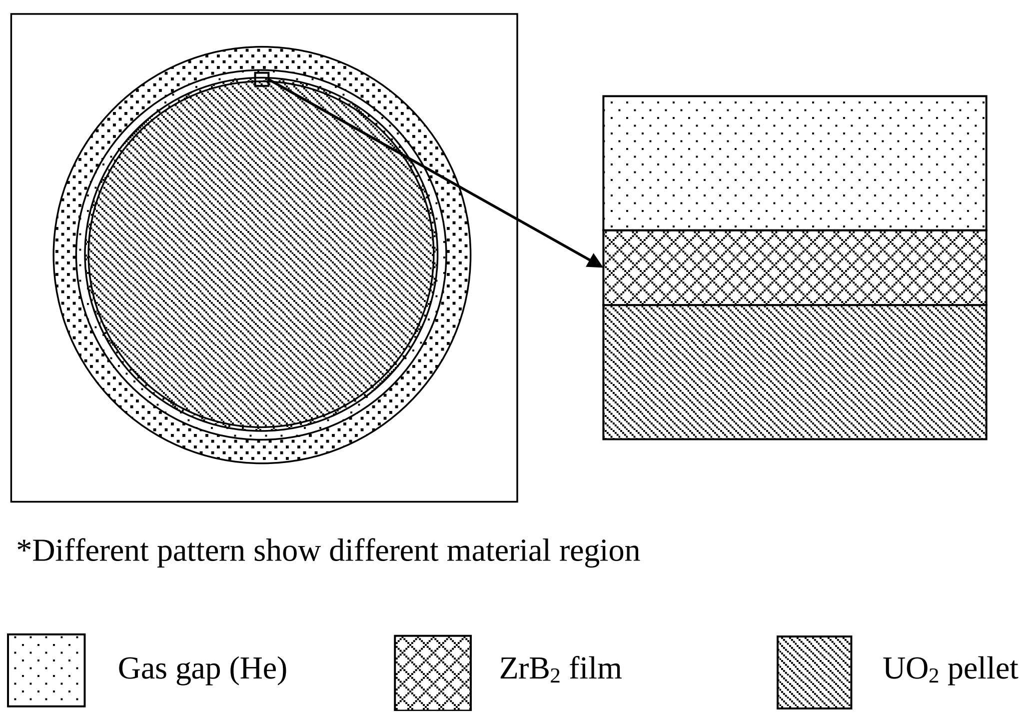

Figure 2 IFBA model

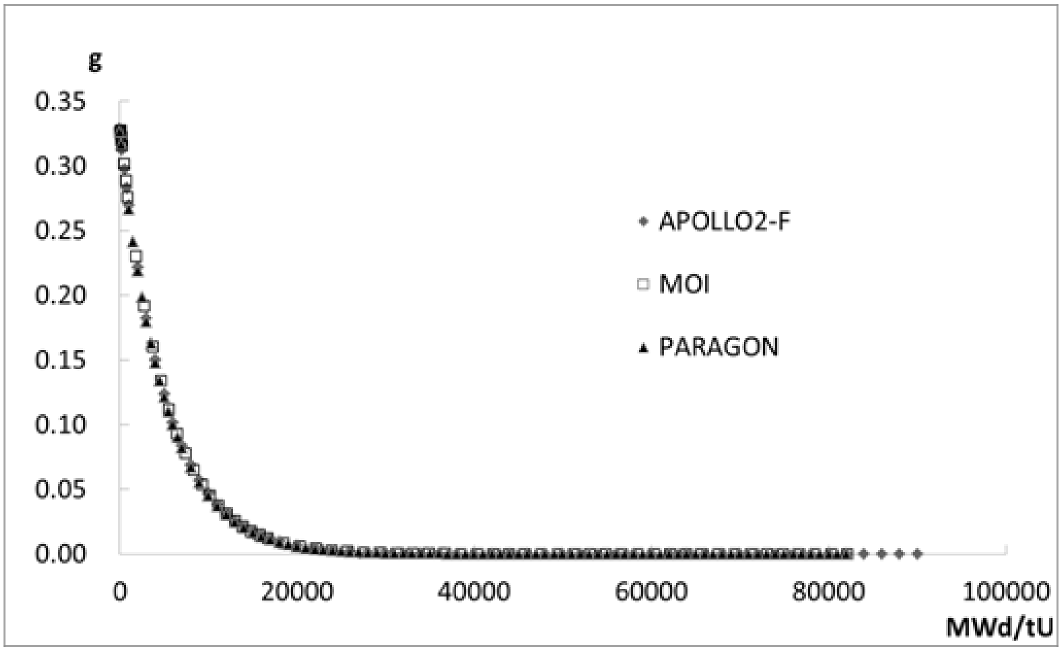

Figure 3 Mass of ^{10}B change vs burnup in IFBA

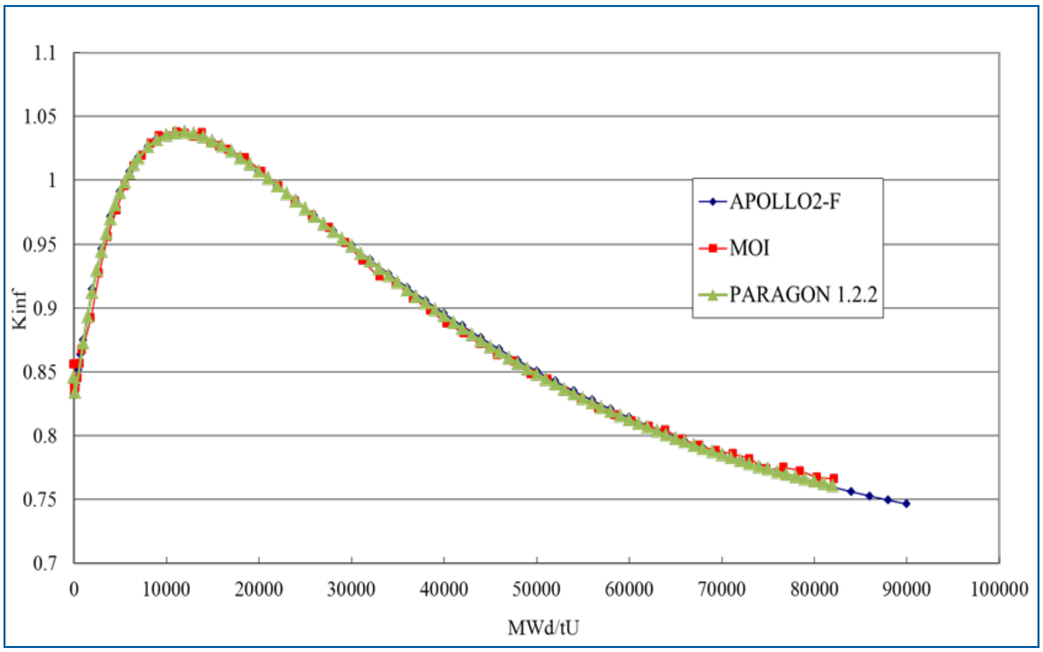

Figure 4 K_{inf} change vs burnup in IFBA

The calculation results show, MOI program can calculate the non-fuel burnup, especially the Mass of ^{10}B and K_{inf}, which is close to the results calculated by the Westinghouse PARAGON[8], and Framatome APOLLO2[9].

4. ABN method

4.1 The critical rod position search function in MOI

Critical search is a basic requirement for burnup calculation in engineering, including critical rod position search and critical boron concentration search. The third generation reactor usually emphasize the load following capability, which need more complex control rods in the reactor to adjust core power.

Due to the big effect to core power distribution and convergence of flux, adjusting rod function have been developed in the MOI. Before the burnup calculation, multiple transport calculation have been done to obtain critical rod position, such as figure 5.

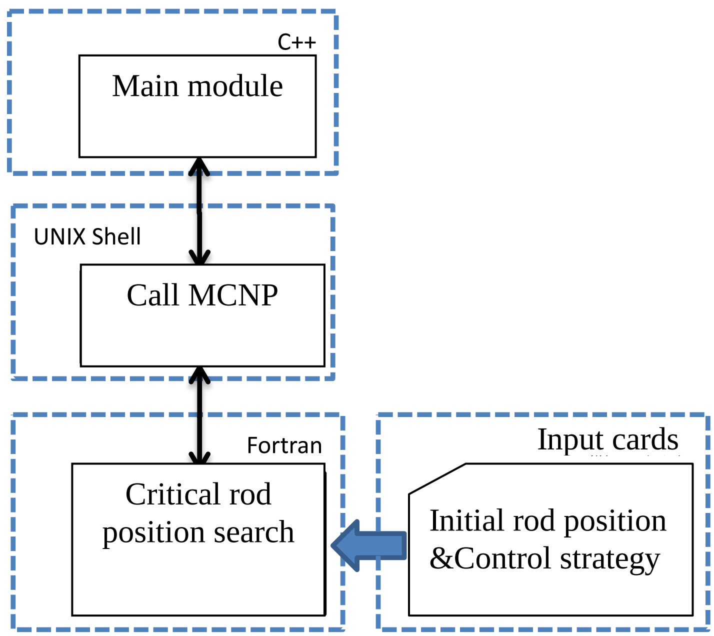

Figure 5　Regulating rod critical flow in MOI

4.2 ABA and ABN

4.2.1 ABA in MC21[10]

A literature about MC21 mentions the ABA method to get critical rod position. The Adaptive Batching Algorithm (ABA) concept is intended to reduce the time spent in converging on a control device position that corresponds to a desired reactivity condition. The premise is that it is unnecessary to converge the eigenvalue to high precision if the current control device position is far from the final position.Though the ABA method take less time than the traditional linear interpolation(shown in figure 6), we find that the variance of KEFF in ABA search is higher, it may reduce the effect of ABA with the same variance.At the same time

KEFF fluctuate before the crirtical rod positon by ABA method in figure 6. If you can avoid the wave, the calculation time would effectively reduce.

4.2.2 ABA and ABN in MOI

ABA predict the next critical rod position by the two previous results, if they are very close, the statistical error will be enlarged, resulting in KEFF wave. In order to avoid it, we propose the ABN method, which predict the critical rod position by the there previous results through the numerical algorithm of Newton interpolation to reduces the risk.

We used a linear interpolation, ABA method and ABN method in MOI. In figure 7, a typical pressurized water reactor critical rod position search results by MOI show that, in the same variance, the ABA method reduces half the computation of the linear interpolation's, and ABN method take only 1/4 time because of less wave.

5. Conclusion

According to the engineering needs of the third generation reactor, improvement on Monte Carlo burnup calculation such as mixed burnup mode and ABN method have been done based on the MOI program. After the effort for engineering application, the performance of MOI is better in efficiency and precision.

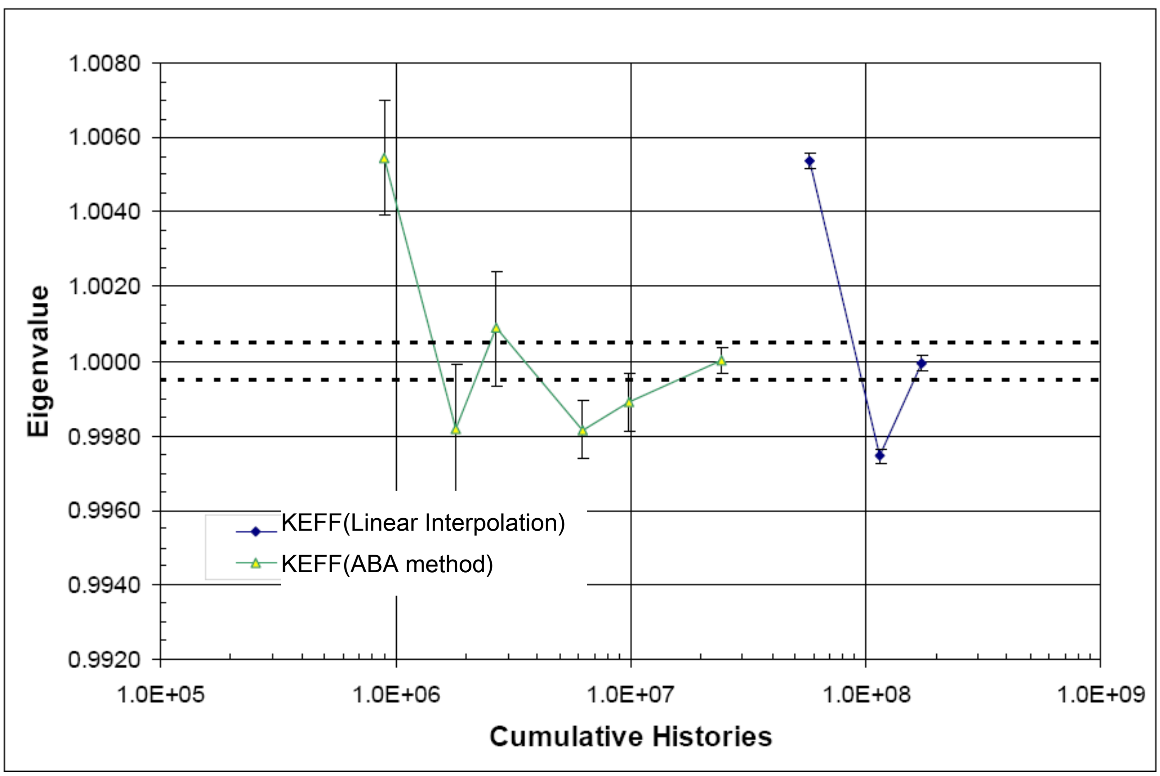

Figure 6 ABA in MC21

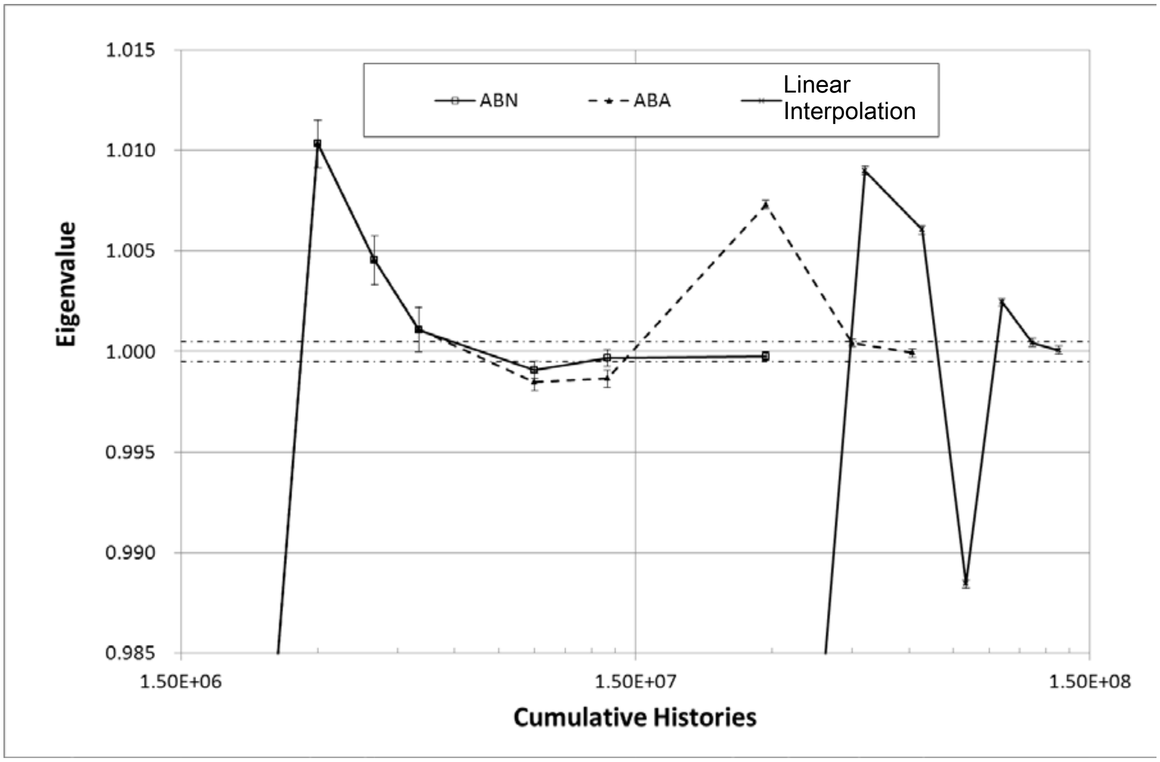

Figure 7 ABA and ABN in MOI

6. References

[1] Moore R.L., Schnitzler B.G., Wemple C.A. and etc., MOCUP: MCNP-ORIGEN2 coupled utility program[R], INEL--95/0523,1995-09-30

[2] QIANG Sheng-long, QIN Dong, CHAI Xiao-ming, YAO Dong. Research on Errors in Monte Carlo Burnup Calculations[J], Atomic Energy Science and technology, 2014, 48(12): 2321-2325

[3] CAO Bo;CHEN Yi-xue;LI Xiao-jing, Physical Characteristics Preliminary Analysis on AP1000 Fuel Assembly[J], Atomic Energy Science and technology, 2013, 47(S2): 599-602

[4] XU Min;LIU Guo-ming, Preliminary Research of MOX Fuel Assembly Management in ACP1000[J], Atomic Energy Science and technology, 2013,47 (4): 604-608

[5] Pengfei Wang, Jiashuang Wan, Zhi Chen and etc., Dynamic simulation and study of Mechanical Shim (MSHIM) core control strategy for AP1000 reactor[J], Annals of Nuclear Energy, 2014,72:49–62

[6] Ganglin Yu, Kan Wang, Development of MCBurn and its application in the analysis of SCWR physical characteristics[J], Frontiers of Energy and Power Engineering in China, 2009, 3(3): 348-352

[7] Zhiwen Xu, Pavel Hejzlar, Michael J. Driscoll, and Mujid S. Kazimi. An improved MCNP-ORIGEN depletion program MCODE and its verification for high-burnup applications[C]. PHYSOR 2002, Seoul, Korea, October 7-10, 2002

[8] M. Ouisloumen and Y. Tahara, “PARAGON: The New Westinghouse Transport Code”, Proc. Int. Conf. on the Physics of Nuclear Science and Technology, Vol. 1, 118,Long Island, New York, 1998.

[9] Santamarina, C. Chabert, A. Courcelle, O. Litaize and G. Willermoz, Qualification of the APOLLO2.5/CEA93.V6 code for UOX and MOX fueled PWRS[C]. PHYSOR 2002, Seoul, Korea, October 7-10, 2002

[10] R. E. Morrow, T. H. Trumbull, T. J. Donovan, and T. M. Sutton, A keff Search Capability in MC21，(M&C + SNA 2007)，Monterey, California, April 15-19, 2007