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Comparisons of S_N and Monte-Carlo methods in PWR ex-core detector response simulation

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ABSTRACT

The ex-core detector response calculation is an important part in reactor design. However, the response function cannot be measured by experiments quantitatively. Ex-core detector response simulation is therefore required. For decades, the S_N code has been used as the dedicated tool. Nowadays, more and more engineers are expressing an interest in using the Monte-Carlo method instead of the S_N method in simulations, as it is expected that the Monte-Carlo method will give higher accuracy. In this paper, the modeling and simulation of ex-core detector responses is briefly reviewed based on the Korean Kori Unit 1 reactor. Then, the differences between the S_N simulation and Monte-Carlo simulation are compared. The sensitivity of computational conditions is also discussed. It is shown that the problem dependence of cross sections and meshing dependence of spatial discretization in the ex-core detector response calculations are not as strong as expected. However, the ray effect is the main shortcoming for the S_N calculation. Based on the analysis, two benefits are shown by using MCNP for the direct 3D calculation. Firstly, the impact of ray effect is eliminated without using the S_N angular discretization. Secondly, the direct 3D calculation is easier to perform based on the powerful ability of 3D modeling and parallel computing of the Monte-Carlo code. The new DRF values are adopted in the dynamic control rod reactivity measurement of Kori Unit 1 reactor. The results show that the new DRF values improve the error of measured control rod worth by a percentage of 3.

1. Introduction

In most current designs, the reactor protection systems act by referring to the signal of ex-core detectors. The detectors are used to monitor the power level and power distribution. The robust detector response function (DRF) is essential for predicting the operational and safety problems in a power reactor (Roha et al., 2008; Viet et al., 2014; Christian et al., 2015). However, the response function cannot be quantitatively measured by experiment. In practice, it is calculated in advance by numerical methods.

Besides, the ex-core detector response is extended to be used in zero power physics to measure the control rod wroth. To improve the efficiency, the dynamic control rod reactivity measurement technique was introduced to the Korea Standard Nuclear Power Plants (Lee et al., 2005, 2014). The new technique requests better ex-core detector response modeling and simulation to improve the 3D response functions of ex-core detectors.

The ex-core detector designs are different in different reactors. In this paper, the ex-core detector function modeling and simulation in a Pressurized Water Reactor (PWR) was investigated. In a typical PWR, the upper and lower BF_3 ex-core detectors are located outside the reactor vessel. The neutron leaks from the core are moderated by the bypass and downcomer coolant, and most of it is absorbed before arriving at the ex-core detector. This makes the direct simulation difficult.

The proper methods for calculating the DRF value has been investigated for several decades (Crump and Lee, 1978; Dehart, 1992). The methods were improved from the early one- or two-dimensional approximation to the equivalent point kernel calculation for 3D model. With the developments of computing technology, the real neutron transport calculation with direct high-dimensional modeling becomes more and more popular in the past decade.

Now in practice, the DRF value is obtained by performing a multi-group adjoint neutron transport calculation. Due to the large size of the PWR core, the 2D radial and 2D axial synthesis method has been used for years to get the adjoint flux distribution. The S_N

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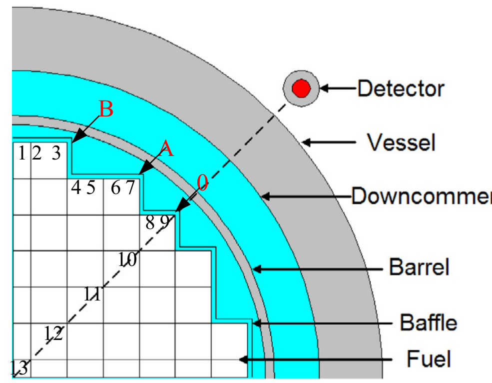
method was widely accepted as giving reasonable numerical results (Roha et al., 2008; Viet et al., 2014).

Thanks to the fast development of computer technology, the Monte-Carlo method now is becoming more and more attractive in reactor simulation. Farkas et al. (2011) tried to use the MCNP code to establish a high-fidelity model of VVER-440 PWR core and calculated the ex-core detector weighting functions. It was proved that the Monte-Carlo method had been feasible for the DRF simulation on high performance computational platforms. Since the Monte-Carlo method requires huge computational resources, it would be very helpful to know the benefit before putting it into practice.

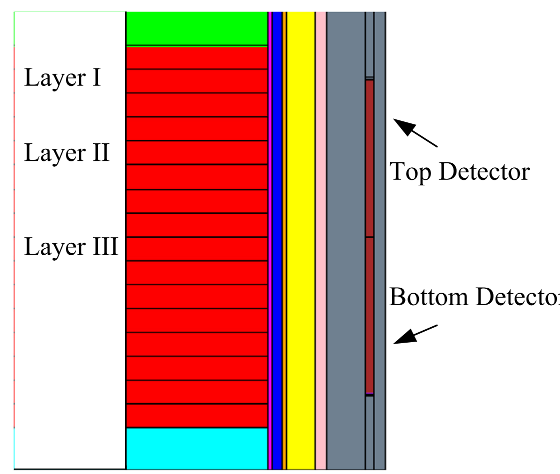
In this paper, a brief overview of the modeling and simulation of PWR ex-core detector responses is given. The PWR core in Kori Nuclear Power Plant Unit 1 (Kori-1), was modeled. Previously, the synthesis method was used in simulating this reactor. The 47 groups neutron cross section from the BUGLE96 library (White et al., 1996) was applied, and the adjoint flux distribution was calculated using the DORT code (Rhoades and Childs, 1989). The calculation was highly efficient and gave reasonable results. However, practical experiences showed that the DRF obtained in that way still has room to be improved.

In this paper, we firstly replicate previous works using the same code and computational scheme. Then, more investigations are done based on the traditional method to find out the impacts on accuracy. In addition, we describe the way of replacing DORT by MCNP (Durkee and James, 2012). Compared with the one in DORT calculation, the MCNP model is more accurate in the radial specification. Finally, a new direct 3D model is established to compare the 3D simulation with the traditional synthesis simulation. The results are compared quantitatively to show how different the two ways are. Finally, the control rod worth using the DRF value from both DORT calculations and MCNP calculations are given to show the improvement of using Monte-Carlo method for the direct 3D modeling and simulation.

To make the comparisons more consistent and convincing, the same cross section library and multi-group calculations are performed. Some new scripts are made to connect the S_N calculation and the Monte-Carlo calculation. The results prove the consistency



(a) 2D x-y model



(b) 2D r-z model

Fig. 2. Computational models in DORT and MCNP calculation.

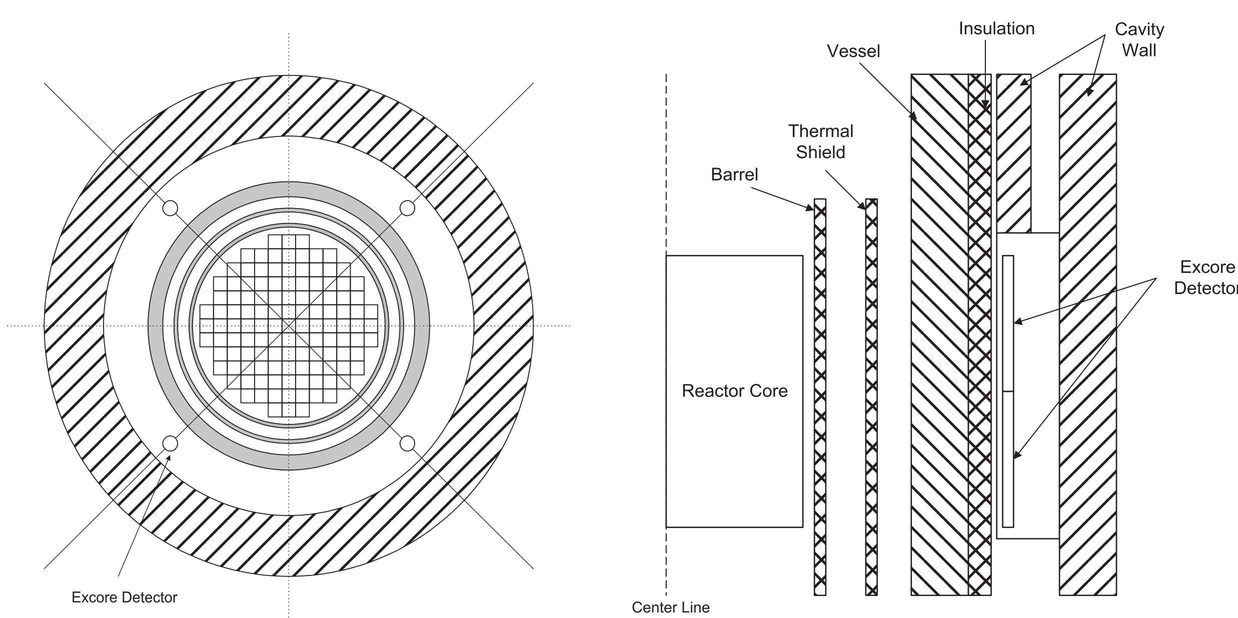


Fig. 1. Core configuration of Kori-1.