STUDY ON EVALUATING THE REACTIVITY WORTH OF THE CONTROL RODS OF THE PWR 900 MWE

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ABSTRACT: Control rods of a nuclear reactor are divided into two groups: shut down and power control. Reactivity worth of the control rods depends nonlinearly on the rods' compositions and positions where the rods are inserted into the core. Therefore, calculation of control rod worth is of high important. In this study, we calculated the reactivity worth of the power control rod bank of the Mitsubishi PWR 900MWe. The results are integral and differential worth calibration of the control rods.

Keywords: *Control rod worth, PWR, integral and differential worth calibration*.

I. INTRODUCTION

Control rods play an important role in controlling power and assuring safety of Nuclear Power Plant (NPP). Determining integral and differential characteristics of control rod is important in design and operation of both NPP and research reactor. The control rod worth can be determined by using some direct measurement methods or using neutronics codes. In this study, we used a comprehensive neutronics calculation code system SRAC [1] that is developed by JAEA for investigating the control rod worth.

The control system is responsible for keeping the stability and safe operation of reactor. This system consists of the measurement system and main control room used for making command [2]. The control system will ensure the implementation of the reactor start up process, adjust power and normally shut down the reactor or in case of emergency situation. In PWR, the reactivity control is implemented by means of rod cluster control assembly (RCCA) together with the concentration change of boric-acid in the reactor coolant. RCCAs are divided into six groups for implementing their differential missions. Control rods are made of strong neutron absorbers and

Table 1 : Composition of control rods.

Isotopes	Atomic density (atom/barn.cm2)	Temperature (K)
Ag-107	2.3538E-02	580
Ag-109	2.1884E-02	
In-113	3.4244E-04	
In-115	7.6586E-03	
Cd-106	3.2966E-05	
Cd-108	2.3975E-05	
Cd-110	3.3756E-04	
Cd-111	3.4736E-04	
Cd-112	6.5577E-04	
Cd-113	3.3402E-04	
Cd-114	7.8627E-04	
Cd-116	2.0651E-04	

they can move in the reactor to compensate the small reactivity change due to random causes or scram when accident occurs. Reactivity depends non-linearly on composition and position of control rod in reactor. Therefore, it is necessary to determine the control rod worth.

In the reactor PWR, Control rods are arranged into some groups called rod cluster control group in each fuel assembly. One RCCA has twenty-four control rods as shown in Fig-1. RCCAs are moved by the rod cluster control (RCC) system. There are forty-eight RCCAs divided into six banks that are two shutdown banks -SA, SB and four control power banks -A, B, C, D [HYPERLINK \l "HUS11" 3]. Each bank has eight RCCA as shown in Fig-2. Control rods of Pressured water reactor (PWR) 900MWe are made of cadmium, silver and indium with the density shown in Table 1. When the reactor is started up, each bank is withdrawn in this order. The reactivity added to reactor is controlled by the concentration of boric-acid and by the position of RCCAs. A reactor is planed so that the reactor approaches to criticality when the bank SA, SB, A, B and C are fully withdrawn and the bank D is partially withdrawn. Then, the bank D will be gradually withdrawn in order to increase the reactor power to designed power while one part of bank D is still inserted in the core. The partial insertion of bank D can allow the reactor to adjust the reactor power.

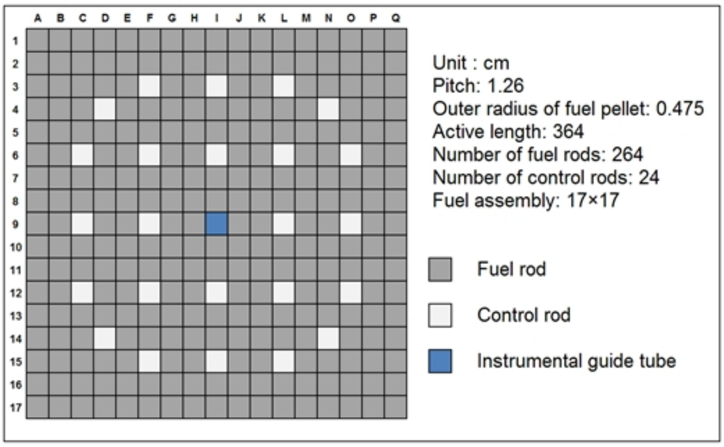
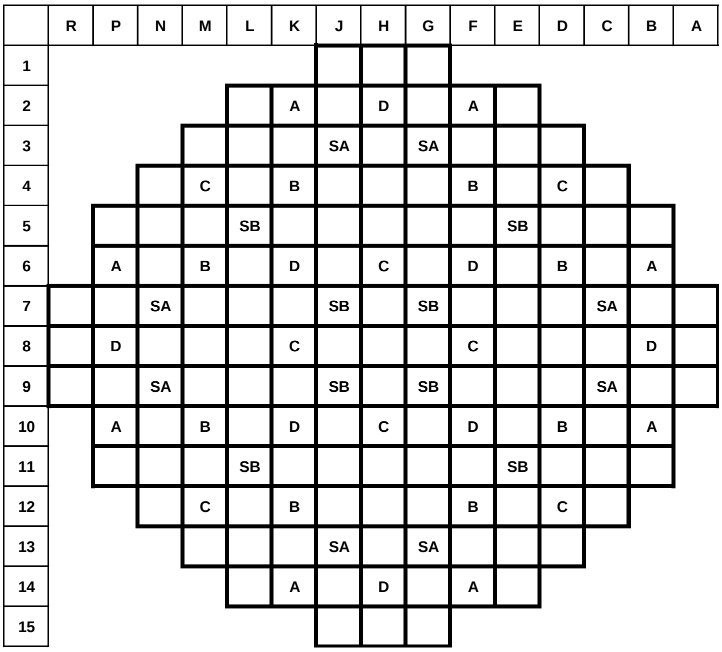


Figure 1: The position of control rods in a fuel assembly.

The reactivity worth of the control rod is a measurement of the efficiency of the control rod to absorb excess reactivity. This value mainly depends on the characteristics and the sizes of reactor core. According to the perturbation theory, if the size of the control rod is much smaller than reactor's sizes, the control rods worth will depend on the square of neutron flux 2].

$$\rho(z)=\rho_0\frac{\int_0^z \phi^2(z)dz}{\int_0^H \phi^2(z)dz} \qquad (1)$$

Where, ρ_0 is the total reactivity of control rods probabilistic collision method is used for calculating group constants of fuel rod and fuel assembly when they are fully inserted into the reactor core. Actually, the RCCAs are quite large compared to reactor's sizes so that we perform this calculation by using the comprehensive neutronics code system SRAC with nuclear library data JENDL 3.3 [HYPERLINK \l "Shi02" 4]. A quarter of reactor core is modeled for determining the control rod worth. The major results are integral and differential worth calibration of the control rods.



	R	P	N	M	L	K	J	H	G	F	E	D	C	B	A
1															
2						A		D		A					
3							SA		SA						
4				C		B				B		C			
5					SB						SB				
6		A		B		D		C		D		B		A	
7			SA				SB		SB				SA		
8		D				C				C				D	
9			SA				SB		SB				SA		
10		A		B		D		C		D		B		A	
11					SB						SB				
12				C		B				B		C			
13							SA		SA						
14						A		D		A					
15															

Figure 2: The position of RCCAs in the reactor core.

II. CALCULATION PROCEDURE

In this study, we use two modules, PIJ and CITATION, in system codes SRAC for investigating the control rods worth. SRAC is a neutronics system code based on deterministic method 1]. PIJ based on cells. CITATION based on finite difference method to solve diffusion equation. Group constants are obtained from module PIJ and used for modeling the whole core by using module CITATION. The procedures of modeling are following:

Step 1: Using module PIJ for:

- Modeling and calculating of a fuel rod.
- Modeling special cells such as instrumental guide tube and control rod in the center of a fuel matrix 3×3 to obtain accurate group constant of these cells.
- Modeling all of fuel assembly and homogenizing them into one region to prepare data for modeling the whole core.

Step 2: Using module CITATION for modeling the whole core with group constant obtained from module PIJ.

The control rods are withdrawn or inserted into the core step by step to adjust the power. In the reactor PWR 900MWe, control rod can move in the reactor with 228 steps [3] in about 4 m. In this study, using proper boundary condition, we simulate a quarter of the core instead of the whole core to reduce calculation time. The quarter core is divided into 51×51 meshes in radius direction and 100 meshes in vertical direction. In addition, there are reflectors at the bottom and top of the core and each of these regions is divided into 12 meshes. The reactor core is divided into two parts for simulating the movement of the control rods. The upper part includes the control rods and the lower part not includes control rods. The control rods are simulated to insert into the reactor by increasing the length of upper part and reducing the length of lower part. Each step is correspondingly to the length of each mesh.

The obtained result is the infinite multiplication factor corresponding to each step of the control rods moving in the reactor core. The control rod worth is obtained by using the following formula [HYPERLINK \l "Joh01" 5]:

$$\rho_w = |\rho_i| = \left|\frac{k_i - k_0}{k_i}\right| \tag{2}$$

Where: k_0 is the effective multiplication factor in case of the control rod is fully withdrawn from the core, k_i is the effective multiplication factor in case of the control rod is partly withdrawn *i-th* step from the core.

III. RESULTS AND DISCUSSION

Firstly, the influence of the number of meshes along the height of the core to the integral and differential worth calibration of the control rods is investigated. The number of meshes makes the result change but not much. Four meshing cases were investigated in which the height of the active region is divided into 10, 20, 50 and 100 meshes. The Fig.3 shows the control rod worth of bank D which plays important role in adjusting power of the reactor. Three integral characteristic curves with 10, 20 and 50 meshes are the same and they have slightly different value compared to the result with 100 meshes. These results show that increases of the number of meshes along vertical direction make very small change in result. Therefore, 51 meshes can be used in the next investigations.

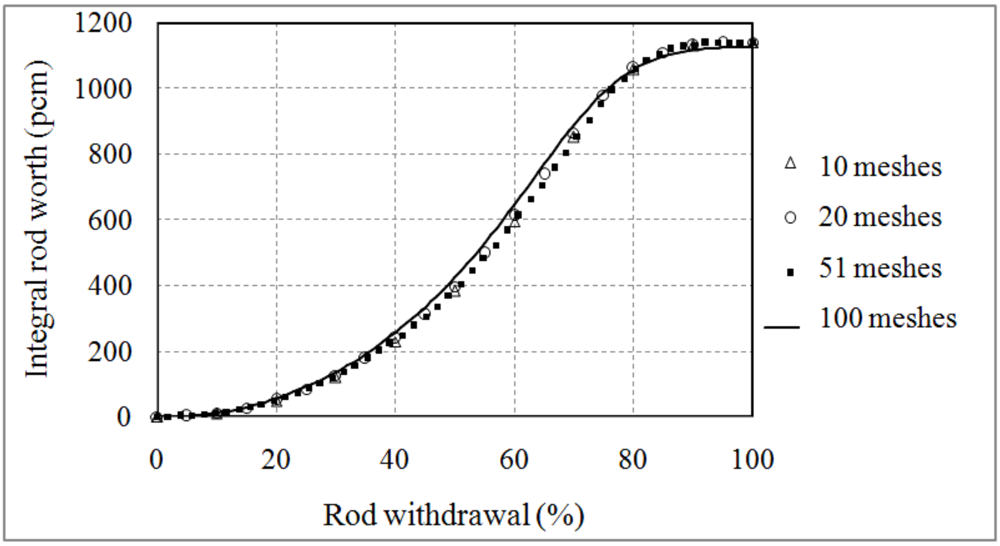


Figure 3: Integral characteristic depend on the number of meshes.

Secondly, the main important results are the integral characteristic curves of the control rod worth of power control rod banks. In Fig.4, we can see that the closer the control rod is to the bottom or the top of the reactor core, the lower of the control rod worth will be and it changes linearly near the center of the reactor core.

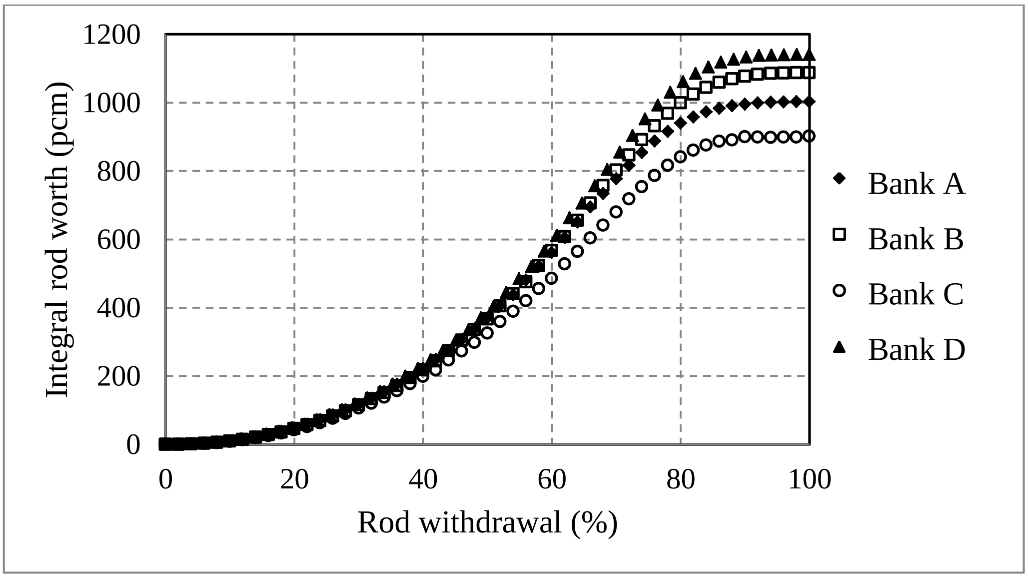


Figure 4: The integral characteristic of power control rod banks.

The average of the total worth of each control rod bank is approximate 1000pcm. Although the control rod banks have the same composition, dimensions and eight RCCAs, they are placed at different position so their worth is different. The reason is that the distribution of neutron flux is different at the position of the control rod banks [6]. Another result is the excess reactivity of the entire 48 control rod banks approximately 5.09 (% Δk/k) in accordance with specifications of PWRs designed by Mitsubishi [3]. The calculated results using the formula (1) shows that the control rod worth depends on z as a function of $(z/H)^3$ (H is the height of the reactor core). This is a symmetric function about the center of the reactor core. However, the control rod worth does not obtain the largest value at the center of the core. The peak of control rod worth shifts to the bottom of the reactor core as shown in Fig 5.

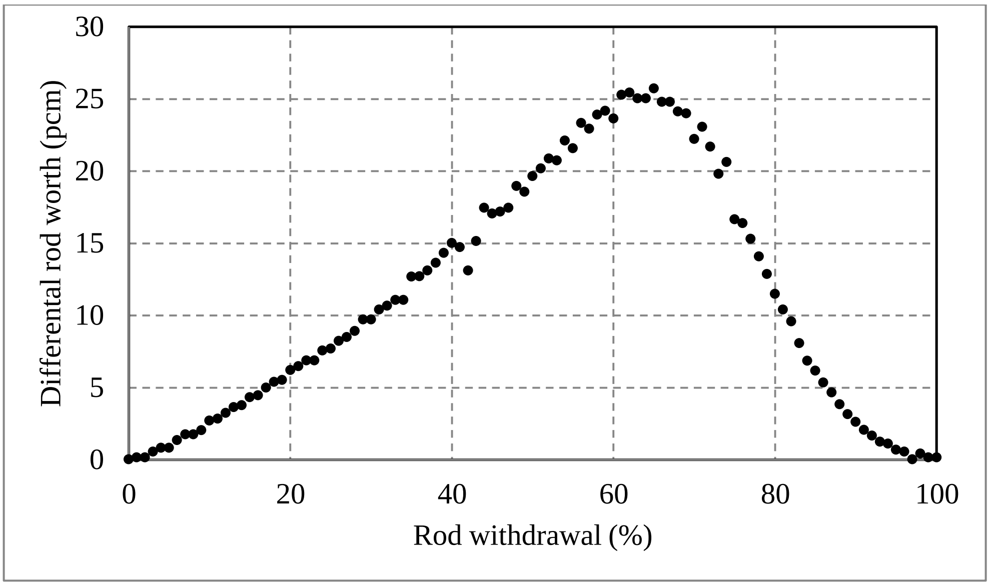


Figure 5: The differential characteristic of bank D

Fig.5 shows the differential characteristic of bank D. We can see the maximum of control rod worth at the point which is 35% far from bottom core. This result is in good agreement with experimental result of the control rod worth of the reactor PWR [3].

IV. CONCLUSION

We conducted the calculation of control rod worth of all control rod groups in the reactor PWR 900WMe that is designed by Mitsubishi company by using the comprehensive neutronic code system SRAC. Two of five modules of system code SRAC were used for modeling the fuel rods, control rods and the quarter of reactor core. The results are integral and differential characteristics of power control rods groups. The other important result that is excess reactivity of all control rods approximates 5%. These results are in good agreement with documents that was used for training at Hanoi university of Science and Technology by Mitsubishi. However we need to perform additional calculation of the control rod worth by using Monte Carlo code to verify these results.

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