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NUCIRC Single Channel Analysis for Calculating the Power Coefficients of the Wolsong Unit 1

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1. Introduction

The Wolsong Unit 1 is a CANDU(CANadian Deuterium Uranium) reactor imported from Canada, which has been generated 2061.4 MW(th) and 678.7 MWe since April 1983. Because the design lifetime of this reactor is 30 years, KHNP(Korea Hydro Nuclear Power) Co. decided to operate the Wolsong Unit 1 continuously under the confirmation of safety and economic efficiency after the refurbishment. As a part of Refurbishment Project of the Wolsong Unit 1, the nuclear design part(Chapter 4.3) of FSAR(Final Safety Analysis Report) has been revised and re-written.

This paper describes the NUCIRC single channel analysis model developed for evaluating the power coefficient of the Wolsong Unit 1.

2. Methods and Models

Most parameters determining the multiplication factor of CANDU reactors are depending on temperature. Therefore, the temperature changes cause the change of multiplication factors, which in turn affect the reactivity of a nuclear reactor system. That is, once the reactor power varies, the temperature and density changes of reactor components such as fuel, moderator, or structural materials would affect the reactivity. Additionally, the level of neutron flux depends on the density of neutron absorbers (Xenon, Samarium and Rhodium, etc.), and these nuclei would affect reactivity effects following the power level variation caused by the variation of fuel temperature and neutron spectrum. [1]

Fuel temperature changes immediately induce reactivity changes, and moderator temperature changes affect reactivity relatively slowly compared to those of fuel temperature changes. Thus, one can calculate power coefficients assuming that fuel temperature and coolant temperature are the most effective factors on the reactivity changes following the power changes in CANDU reactors.

2.1 Reactivity Power Coefficient

The temperature coefficient of reactivity is expressed with reactivity α and temperature T as follows:

$$\alpha_T = \frac{d\rho}{dT} \qquad (1)$$

Rearranging by using the definition of reactivity,

$$\alpha_T = \frac{1}{k^2}\frac{dk}{dT} \qquad \left(\because \alpha \equiv \frac{k-1}{k} = 1 - \frac{1}{k}\right) \qquad (2)$$

Because a reactor is operated under the multiplication factor of around 1,

$$\alpha_T \cong \frac{1}{k}\frac{dk}{dT} \qquad (3)$$

In the form of Eq. (3), α_{Tf}, α_{Tc}, and α_P are respectively fuel temperature coefficient, reactivity coolant temperature coefficient, and reactivity power coefficient. In the same way, the power coefficient of reactor core is defined as follows:

$$\alpha_P = \frac{d\rho}{dP} \qquad (4)$$

That is, the power coefficient is reactivity variation according to the unit change of reactor power. Evaluation of the power coefficient is vary complex, because the power P here is expressed generally as a ratio of real power to total thermal power rather than a absolute value of thermal power. But in this calculation the power coefficient can be expressed as the below, assuming that the fuel temperature T_f and the coolant temperature T_c are the most effective factors on the reactivity changes.

$$\alpha_P = \frac{\partial\rho}{\partial P} = \frac{\partial\rho}{\partial T_f}\cdot\frac{\partial T_f}{\partial P} + \frac{\partial\rho}{\partial T_c}\cdot\frac{\partial T_c}{\partial P} = \alpha_{Tf}\cdot\frac{\partial T_f}{\partial P} + \alpha_{Tc}\cdot\frac{\partial T_c}{\partial P} \qquad (5)$$

From this derivation, one can evaluate the power coefficient as a reactivity change according the power variation.

2.2 Calculation Mechanism of Power Coefficient

For the evaluation of the reactivity power coefficient, a reactor physics code RFSP[2] and a thermal-hydraulics code NUCIRC[3,4] are used. First, from the time-averaged bundle power distribution of 100% F.P.(full power) calculated by using RFSP code, the NUCIRC analysis generates the channel flow distribution of 100% F.P. Then, based on these coolant density and temperature distribution results, the RFSP analysis calculates a new bundle power distribution. The convergence criteria for this iterative calculation with RFSP and NUCIRC codes are the shape of axial power distributions and the reactivity.

After the shape of axial power distribution is converged, the reactivity of this moment becomes the reactivity of 100% F.P. With these bundle power distribution data, the channel power for 60% ~ 120% F.P. will be calculated. It is assumed that normalized axial power distributions for each power level are the same as that of 100% F.P.

In the same way as the case of 100% F.P., the value of reactivity for each power level is evaluated by iterative calculation until the shape of axial-power distribution were converged. Finally, the reactivity power coefficient can be estimated from the reactivity values for each power level.

2.3 NUCIRC Single Channel Analysis Model

For our analysis, the ITYPE=2 option among 9 modules of the NUCIRC code was used to determine channel coolant flow from the given $\Delta P_{H\text{-}H}$ and feeder geometry. After retubing of the refurbishment, a new NUCIRC single channel analysis model should be re-generated considering that feeders and pressure tubes (PT) are replaced with new ones. Additionally aging effects on pump characteristic curves, steam generator geometries, and the PHT system should be considered in modeling. Since pressure tubes are replaced with new ones, diametric creep of PT would be zero. Table I summarizes the roughness values of feeders, end-fittings and pressure tubes. The boundary conditions of four passes are summarized in Table II.

Table I: Roughness of Reference T-H Model at 0 EFPD

	HD 2-3	**HD 4-1**	**HD 6-7**	**HD 8-5**
inlet feeder roughness, in (top)	0.00030	0.00030	0.00030	0.00030
(bottom)	0.00030	0.00030	0.00030	0.00030
inlet end-fitting roughness, in (top)	0.00006	0.00006	0.00006	0.00006
(bottom)	0.00006	0.00006	0.00006	0.00006
Pressure tube roughness, in	0.00002	0.00002	0.00002	0.00002
outlet end-fitting roughness	0.00006	0.00006	0.00006	0.00006
outlet feeder roughness, in, (top)	0.00030	0.00030	0.00030	0.00030
(bottom)	0.00030	0.00030	0.00030	0.00030

Table II: Roughness of Reference T-H Model at 0 EFPD

BC's	**T_{IN}**	**$\Delta P_{H\text{-}H}$**	**P_{OUT}**
Pass 23	261.92 °C	185.82 psi	9.9485 MPa
Pass 41	261.85 °C	185.39 psi	9.9560 MPa
Pass 67	260.92 °C	182.12 psi	9.9410 MPa
Pass 85	261.30 °C	184.12 psi	9.9885 MPa

3. Results

The evaluated value of the reactivity power coefficient is finally calculated in a reactor physics analysis by using the RFSP code, therefore only the thermal hydraulics results by NUCIRC analysis will be presented in this paper. As mentioned in Section 2.2, 3 ~ 5 iterative calculations between RFSP and NUCIRC codes are performed until the shape of the power distributions is converged.

The total coolant mass flow rate through the reactor core is reduced as the power increases. The relative changes of total mass flow rates are presented in Figure 1. According to the power increases, the flow rate in a high-power channel (N-17) is reduced larger than that of a low-power channel (V-17).

Figure 2 shows the coolant density distribution of N-17 channel at 0 EFPD after Retubing of Wolsong Unit 1. As the power increases, coolant density decreases gradually and decreases rapidly when the coolant boils.

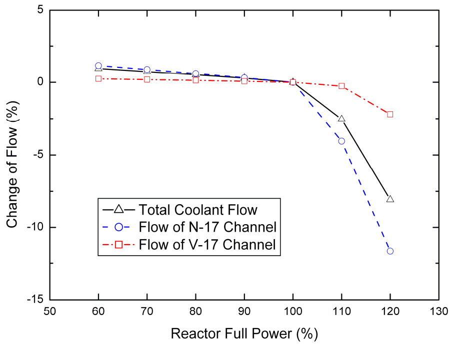

Fig. 1. Flow Change Depending on Powers at 0 EFPD after the Retubing of Wolsong Unit 1.

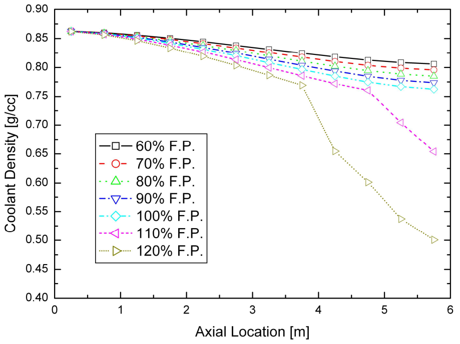

Fig. 2. Coolant Density Distribution of N-17 Channel at 0 EFPD after Retubing of Wolsong Unit 1

3. Conclusions

The NUCIRC model to calculate the power coefficient at 0 EFPD(Effective Full Power Day) after the refurbishment of the Wolsong Unit 1 has been completed, which is also a part of revising chapter 4.3 of the FSAR(Final Safety Analysis Report).

Acknowledgement

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