Transactions of the Korean Nuclear Society Autumn Meeting
Pyeongchang, Korea, October 30-31, 2014

Development of Core Simulator (CoSi) for APR1400 And Analysis of LPPT Result using APR1400-CoSi

Sang-Rae Moon*, Yong-Bae Kim, Eun-Ki Lee
Nuclear Reactor Safety Lab., KHNP Central Research Institute
1312-70 Yuseongdae-ro Yuseong-gu Daejeon, 305-343 Korea
**Corresponding author: srmoon@khnp.co.kr*

1. Introduction

APR1400 nuclear power plant is FOAK (First Of A Kind) and corresponds to Shin-Kori Unit 3. Compared to existing OPR1000 nuclear power plant, Shin-Kori Unit 3 has many changes such as reactor capacity, neutron kinetics and response of ex-core detectors etc.

According to NRC guidelines, Low Power Physics Test (LPPT) is required to be performed in low temperature/low pressure (160℃/42.2 kg/cm^2) as well as NOT/NOP (291.3℃/158.2 kg/cm^2) because Shin-Kori Unit 3 is FOAK nuclear power plant. [1]

Low Power Physics Test (LPPT) is essential to verify the nuclear design and robustness of reactor safety.

LPPT consists of initial criticality, Point of Adding Heat (POAH), All Rod Out (ARO) Boron Concentration, Isothermal Temperature Coefficient (ITC), Control Rod Worth measurements and so on.

Because of no experience of FOAK's LPPT after Younggwang unit 3 (1995~), understanding of core management staff performing LPPT is very limited.

Therefore, KHNP-CRI has developed the Core Simulator for APR1400 (APR1400-CoSi) in order to improve the ability performing the LPPT. Especially, APR1400-CoSi has enhanced capability to calculate the full Core neutronic parameters by revising RAST-K that is three dimensional real time core kinetic program.

2. Core Simulator for APR1400

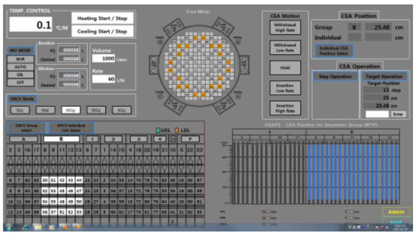
2.1 RAST-K: Three Dimensional Real Time Core Kinetic Calculation Program

In order to calculate exact core power and feedback effect as time varies, 3-D real time core kinetic calculation should be performed. For this reason, RAST-K [2] program is applied in APR1400-CoSi. RAST-K was verified through over 60 dynamic control rod measurements (DCRM) of domestic PWR. Two and three dimensional neutron diffusion equation can be solved by non-linear NEM/ANM CMFD (Nodal Expansion Method/Analytic Nodal Method) using RAST-K program. Eigenvalue and adjoint flux are obtained for steady state, and transient state can be also analyzed.

2.2 Input and Output Module of APR1400-CoSi

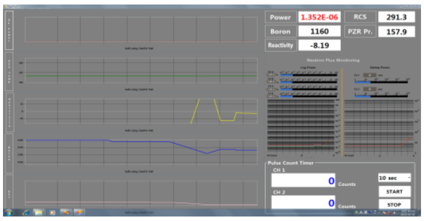
Input module has useful sub-modules which can control rod position, boron concentration, and moderator temperature. These parameters are used for input data for three dimensional core calculations and are displayed on output panel in real time.

The output module extracts useful information such as reactor power, axial shape index, reactivity, and fast/thermal flux out of the calculation results of RAST-K to provide the users with the current core status information. It also converts digital detector flux readings to analogue signal to be provided to the reactivity computer.



TEMP. CONTROL: 0.1 ℃/M
Volume: 1000 Liters
Rate: 60 L/M
CEA Position: Group B 25.48 cm
Target Position: 13 step, 25 cm, 25.48 cm

Figure 1. Input Module of APR1400-CoSi



Power: 1.352E-06
RCS: 291.3
Boron: 1160
PZR Pr.: 157.9
Reactivity: -8.19

Figure 2. Output Module of APR1400-CoSi

3. Analysis of LPPT Results using APR1400-CoSi [3]

3.1 Initial Criticality

During the criticality approach test, sub-criticality is monitored through the inverse count rate ratio (ICRR) in equation (1). Inverse count rate ratio is

$$C_0/Ci = 1/M = 1-K_{eff} \qquad (1)$$

Where, C_0 is the initial count rate and Ci is the count rate in i-th step. The test results of initial criticality are as follows;

Table 1. Test results of initial criticality

RG 5 Position(withdrawal)	Boron Concentration	Excore Power
300 cm	1157 ppm	3.0x10^{-5} %

3.2 Critical Boron Concentration (CBC)

The critical boron concentration under all rod out condition was measured using boron end point (BEP) method. The test results of critical boron concentration are as follows;

Table 2. Test results of CBC

Predicted CBC(P)	Measured CBC(M)	Error (P-M)	Test Criteria
1195 ppm	1158 ppm	37 ppm	**±100 ppm**

3.3 Isothermal Temperature Coefficient (ITC)

The isothermal temperature coefficient under all rod out condition was measured using the endpoint method or the slope method. The test results of isothermal temperature coefficient are as follows;

Table 3. Test results of ITC

Predicted ITC(P)	Measured ITC(M)	Error (P-M)	Test Criteria
-4.0 pcm/℃	-1.5 pcm/℃	-2.5 pcm/℃	**±9 pcm/℃**

3.4 Rod Worth

The rod worth was measured using dilution method. The test results of rod worth are as follows;

Table 4. Test results of Rod Worth

	RG5 worth	RG4 worth	RG3 worth	RG2 worth	RG1 worth	A worth	B worth
Predicted (pcm)	242	425	628	925	1054	3005	7046
Measured (pcm)	229	422	640	922	1074	2968	6776
Error(%) (P-M)/P	5.4	0.7	-1.9	0..3	-1.9	1.2	3.8
Test Criteria	±15%						

3.5 CEA Symmetry Check

Individual CEA worth was measured to confirm the CEA symmetry by the dilution method. The test results of CEA symmetry check are as follows;

Table 5. Test results of CEA Symmetry Check

	R5(39) worth	R4(84) worth	R3(70) worth	R2(60) worth	R1(28) worth	A(69) worth	B(36) worth
Predicted (pcm)	38	37	43	45	66	61	66
Measured (pcm)	39	36.9	42.9	46	65.6	59.9	64
Error(%) (P-M)/P	-1.0	0.1	0.1	-1.0	0.4	1.1	2.0
Test Criteria	**±10.58 pcm**						

3.6 Analysis of Power change during the Rod SWAP Test

Large reactivity is inserted during CEA measurement test by the CEA exchange method (SWAP method). In particular, the largest reactivity is inserted when exchanging shutdown bank A with shutdown bank B when the shutdown bank B is the reference bank and the shutdown bank A has the second largest worth. In this case, the normal test range of Low Power Physics Test(LPPT) is likely to be exceed.

The maximum inserted step reactivity is about 40 pcm when shutdown B is withdrawn at core height 85~120 cm. If 40 pcm (SUR=0.16) of positive reactivity is inserted in core, then doubling time is 113 sec.

According to ANSI/ANS-19.6.1, Reactor Startup Rate should be less than 1 DPM [decade/min] during Low Power Physics Test(LPPT)

$$P = P_0 \times 10^{SUR*t} \qquad (2)$$

Where, SUR is Reactor Startup Rate and t is time[min]. If 76.9 pcm (SUR=0.33) of positive reactivity is inserted in core, then doubling time is 54.7 sec. And if 160 pcm (SUR=1) of positive reactivity is inserted in core, then doubling time is 18.1 sec.

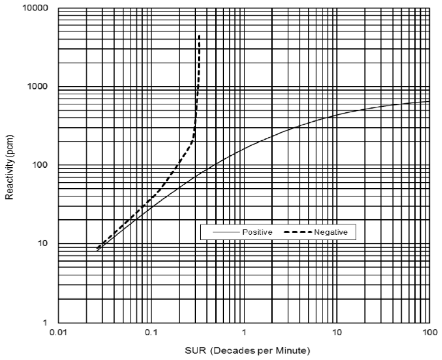


Figure 3. Reactivity vs. SUR at BOC, HZP [4]

Therefore, the test range of LPPT remains effective even though the largest incremental bank reactivity(40pcm) is inserted in core during the rod SWAP test.

4. Conclusions

APR1400-CoSi has been developed for education & training of Low Power Physics Test(LPPT). Particularly, APR1400-CoSi has an enhanced capability to calculate the full core neutronic parameters by revising RAST-K which is a three dimensional real time core kinetics program.

Low Power Physics Test (LPPT) was performed using APR1400-CoSi and the results showed very similar values with the predicted ones. In other words, the initial core model of Shin-Kori Unit 3 in APR1400-CoSi system has been verified to be appropriate enough. Also, it was confirmed that the test range of Low Power Physics Test (LPPT) remains effective even though the largest incremental bank reactivity is inserted in core by analyzing the power change during the rod SWAP test.

REFERENCES

[1] ANSI/ANS-19.6.1-2005, “Reload Startup Physics Tests for Pressurized Water Reactors.”

[2] E.K.Lee, et al., "Computer code verification report: RAST-K cod," TM.05NP01.I2005.732, KEPRI, Jan. 2006.

[3] KHNP SKN, “ Low Power Physics Test”, 3S-I-000-02, Test Procedure, 2013.

[4] The Nuclear Design Report for Shin-Kori Nuclear Power Plant Unit 3 Cycle 1, Oct 2012.