Development of the Real-time Core & Thermal-Hydraulic Models for Kori-1 Simulator

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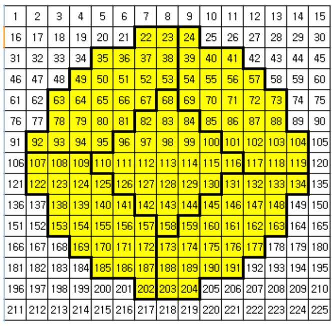
1. Introduction

The operation of the Kori-Unit 1 (1723.5MWt) is expanded to additional 10 years with upgrades of the Main Control Room (MCR). Therefore, the revision of the procedures, performance tests and works related with the exchange of the Main Control Board (MCB) are currently carried out. And as a part of it, the full-scope simulator for the Kori-1 is being developed for the purpose of the pre-operation and emergence response capability for the operators. The purpose of this paper is to report on the performance of the developed neutronics and thermal-hydraulic (TH) models of Kori Unit 1 simulator. The neutronics model is based on the NESTLE code and TH model based on the RELAP5/MOD3 thermal-hydraulics analysis code [1] which was funded as FY-93 LDRD Project 7201 and is running on the commercial simulator environment tool (the 3KeyMaster^{TM} of the WSC). As some examples for the verification of the developed neutronics and TH models, some figures are provided. The outputs of the developed neutronics and TH models are in accord with the Nuclear Design Report (NDR) [2] and Final Safety Analysis Report (FSAR) [3] of the reference plant.

1. Real-time Core Model

1.1 Nodalization of Core Model

The developed core model for the Kori Unit 1 simulator divided the total core into 12 axial slices and 121 radial meshes based on fuel assemblies, and 5 thermal-hydraulic volumes. (Fig.2)

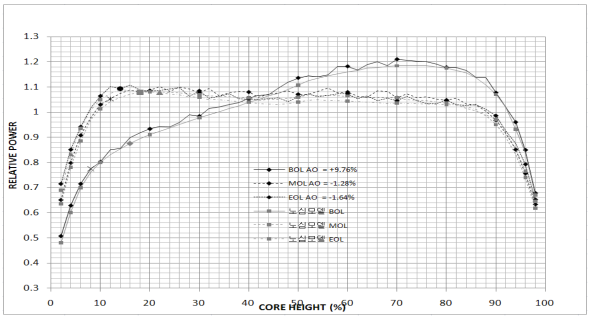


[Fig.1] Nodalization diagram of the Core Model

1.2 NIST (Non-Integrated System Test) for Core Model

1.2.1 Axial Power Distribution

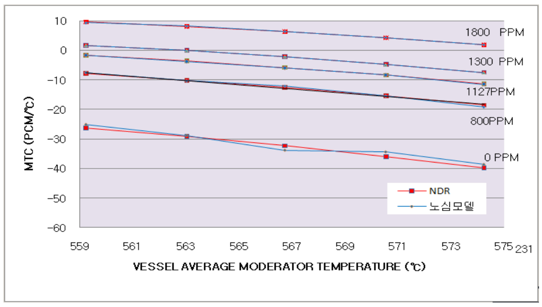
Core average axial power distributions of the NDR [2] and the core model are compared.



[Fig.2] Relative Axial Power Distribution

1.2.2 Moderator Temperature Coefficient (MTC)

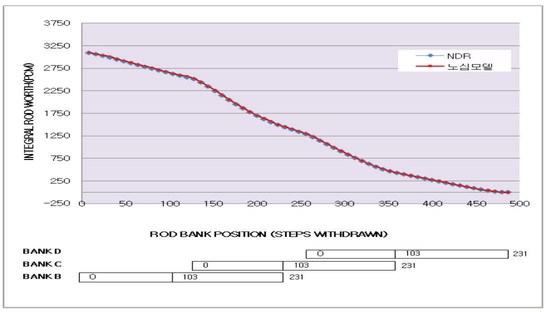
The MTC is defined as the change in reactivity per degree change in the moderator temperature. The different effects can be readily observed in Fig.3 where moderator coefficients are compared between the NDR and the core model.



[Fig.3] MTC versus Average Moderator Temperature

1.2.3 Integral Rod Worth

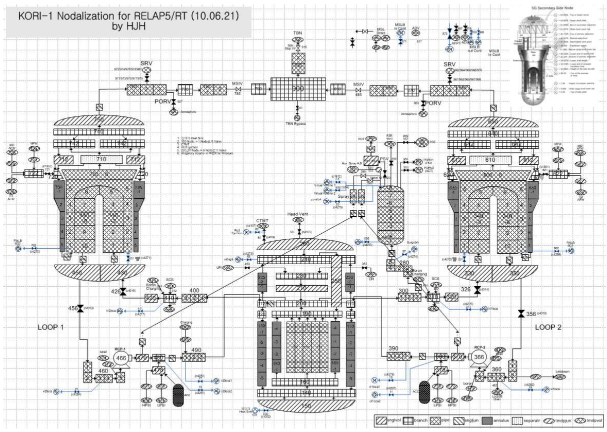
Fig.4 shows the integral rod worths versus rod position for Hot Full Power (HFP) equilibrium xenon conditions. The figure represents core conditions with a 103 steps overlap between control banks D, C and B.



[Fig.4] Integral Rod Worth vs. Steps Withdrawn

3. Real-time Thermal-Hydraulic Model

RELAP5 R/T input deck of Kori Unit 1 has been developed based on RELAP5 input deck for the safety analysis of the Kori-Unit 1. The differences from RELAP5 input for Kori Unit 1 are as follows. First, boron concentration is added to hydrodynamic components such as pipe, branch, pump, pressurizer and etc.. Second, a multi-dimensional nodal neutron kinetics model is used for Core modeling rather than a point kinetics model. Third, heat structures adjacent to core are changed accordingly. Fourth, the pressurizer nodes divided into 8 parts. Fifth, bypass valves, feed water and spray/aux spray lines are included. Fig.5 shows the RELAP5 R/T Nodalization for the Kori Unit 1 simulator.



[Fig.5] RELAP5 R/T Nodalization for Kori-1

To v&v the input deck for Kori-1, the calculations in the steady states at the power of 100%, 75%, 50%, 25% and no-load and at the mid-loop operation are performed.

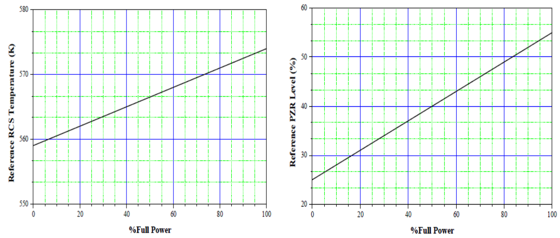
Parameters		Design Values	RELAP-RT
Reactor	Core Power (MWt)	1723.5	1725.81
	Rx Pressure Drop (bar)	2.399	2.117
	Mass Flow in Guide Tube (kg/s)	25.97	24.619
	Bypass Flow (kg/s)	281.03	257.61
	CEA ΔP (bar)	1.379	1.319
Primary System	Mass Flow in Loop 1	4265.1	4243.4
	T_{hot} (K)	592.54	592.86
	T_{cold} (K)	556.04	556.33
	ΔT (T_{hot}-T_{cold}) (K)	36.5	36.53
	PZR Level (%)	55	54.451
	PZR Pressure (bar)	155.11	155.104
	Pump Head (m)	79.86	80.27
	Pump Torque (Nm)	35.904	33.457
	Pump Speed (rpm)	1190	1190
	SG ΔP (bar)	2160	1601
2nd System	Feed Flow (kg/s)	473.75	474.14
	Steam Flow (kg/s)	57.9	57.08
	SG Level (%)	56.2	57.9
	SG Recirc Ratio	2.8	2.94

[Table.1] Calculated Outputs of TH Model at 100% Power

Table.1 shows the calculated outputs of the RELAP-RT at the 100% steady-state of the core power compared to the corresponding design values. And Table.2 shows calculated outputs of the RELAP-RT at the several core powers. The reference temperatures and pressurizer levels at several power levels are provided in Fig.6.

Parameters		RELAP3/MOD3.3	RELAP-RT
100% Power	Core Power (%)	100	100
	T_{hot} (K)	593.32	592.86
	T_{cold}(K)	556.88	556.33
	PZR Level (%)	54.89	54.45
75% Power	Core Power (%)	75	75
	T_{hot} (K)	583.07	582.47
	T_{cold}(K)	557.53	556.92
	PZR Level (%)	48.05	46.92
50% Power	Core Power (%)	50	50
	T_{hot} (K)	575.27	574.73
	T_{cold}(K)	557.97	557.42
	PZR Level (%)	41.25	38.55
25% Power	Core Power (%)	25	25
	T_{hot} (K)	567.57	567.33
	T_{cold}(K)	558.82	558.58
	PZR Level (%)	30.87	32.15
no-load Power	Core Power (%)	2	2
	T_{hot} (K)	566.49	566.49
	T_{cold}(K)	551.78	551.79
	PZR Level (%)	24.36	24.56
Mid-loop Operation	Core Power (%)	0.5	0.5
	T_{hot} (K)	334.51	333.79
	T_{cold}(K)	316.12	315.86
	PZR Level (%)	0	0

[Table.2] Calculated Outputs of TH Model at Several Powers



[Fig.6] Ref. Temp and PZR Levels at Several Powers

4. Conclusions and Furthers

The developed core and TH models show its fidelities based on the outputs of those NISTs. In following months, several transient analyses will be performed including LBLOCA and TBN trip. And the core and TH models will be integrated with other models for the primary and secondary systems for the Kori-1 simulator.

REFERENCES

[1] RELAP5-3D Code Manual, 2001. Vol. 1, Code Structure, System Models, and Solution Methods, The RELAP5-3D Code Development Team, INEEL-EXT-98-00834., Rev. 1.3a

[2] KNF, “The Nuclear Design and Core Physics Characteristics of the Kori Nuclear Power Plant Unit 1 Cycle 27”, KNF-K1C27-09039, Dec. 2009.

[3] KEPCO, 1989, Final Safety Analysis Report of Kori 1

[4] ANSI/ANS-3.5-1998, “Nuclear Power Plant Simulators for Use in Operator Training and License Examination”

[5] H.L. Choi, “Generation of the RELAP5 Base Input Data for Kori-1”, DS-SA-KR1-89153E, KAERI, 1989