CCP Sensitivity Analysis by Variation of Thermal-Hydraulic Parameters of Wolsong-3, 4

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1. Introduction

The PHWRs are tendency that ROPT(Regional Overpower Protection Trip) setpoint is decreased with reduction of CCP(Critical Channel Power) due to aging effects. For this reason, Wolsong unit 3 & 4 has been operated less than 100% power due to the result of ROPT setpoint evaluation[1][2][3]. Typically CCP for ROPT evaluation is derived at 100% PHTS(Primary Heat Transport System) boundary conditions - inlet header temperature, header to header different pressure and outlet header pressure. Therefore boundary conditions at 100% power were estimated to calculate the thermal-hydraulic model at 100% power condition .

For this reason, to assess the inherent uncertainty of the thermal-hydraulic model, the sensitivity studies by varying the thermal-hydraulic parameters for CCP calculation were evaluated for Wolsong unit 3 & 4.

2. Modeling and Results

In this section computational tools and model will be introduced and the results is described for sensitivity analysis for CANDU 6 reactor PHTS.

2.1 Analysis Tools

The NUCIRC[4][6]/NUPREP[5] 2.3.1.2 code systems were used for most of sensitivity analyses.

The computer program, NUPREP 2.3.1.2[5], is a data pre-processor which is used to prepare the input data into the sequence required by the input stream of NUCIRC 2.3.1.2. NUPREP reads the specific input data(e.g., inlet/outlet feeder geometries, orifice data, bundle/channel power) for all the channels from permanent files and other common channel data prepared by the user, then sorts the data into the input stream required by NUCIRC for each channel.

NUCIRC[4] is a steady-state thermal-hydraulic code used by designers and analysts to examine the behavior of the heat transfer system(HTS) of a CANDU® nuclear reactor over a wide range of single-phase and two-phase operating conditions. This code can predict pressure, channel flow, temperature and quality at any location of primary heat transport system, and determine critical channel power ratios for both dryout and melting during overpower for any required number of channels, etc.

2.2 Modeling Conditions

Wolsong-3(2014) PHTS data were acquired at 80% and 93.8% power condition, and Wolsong-4(2015) data were acquired at 80% and 94% power condition. These data were used to make each thermal-hydraulic models to determine thermal-hydraulic parameters. And thermal-hydraulic boundary conditions of 100% power to calculate CCP were estimated. Hence the major parameters of thermal-hydraulic model to impact to CCP are pressure tube roughness, orifice degradation factor and SG fouling factor, etc.

For sensitivity analyses, thermal-hydraulic parameters such as pressure tube roughness, orifice degradation factor and SG tube roughness were varied by 10% and 30%, respectively. And SG fouling factor was varied by 5% and 20%.

2.3 Results of Sensitivity Calculation(Wolsong-3)

Table I shows the results of sensitivity calculation for Wolsong-3. In spite of excessive thermal-hydraulic parameter variation, the %CCP sensitivities for T_{RIH} and DP_{HH} were maintained constant and linearity of sensitivities was also valid as shown in Fig 1 to 4. Moreover the difference of ROPT penalty for changing sensitivity is only ~0.00% for T_{RIH} and ~0.03% for DP_{HH}. These differences are much more than the error which may be occurred by designer change.

Therefore the uncertainty in the PHTS thermal-hydraulic model at 100% power is negligible considering the plant procedure of thermal-hydraulic boundary conditions penalty.

Table I. Results of Sensitivity Calculation for Thermal-hydraulic Parameters Change (Wolsong-3)

W3		Reference model	PT Roughness 10%	PT Roughness 30%	Orifice 10%	Orifice 30%	SG Fouling 3%	SG Fouling 20%	SG Roughness 10%	SG Roughness 30%
T_{RIH}	Avg.(℃)	264.48	264.47	264.45	264.44	264.39	264.61	264.99	264.48	264.46
	Sensitivity (%CCP/℃)	-0.782	-0.782	-0.782	-0.782	-0.783	-0.782	-0.781	-0.782	-0.782
	Penalty for 2.78 °C	-2.2%	-2.2%	-2.2%	-2.2%	-2.2%	-2.2%	-2.2%	-2.2%	-2.2%
DP_{HH}	Avg.(kPa)	1230.0	1233.7	1240.3	1238.4	1253.3	1230.4	1232.0	1227.7	1223.8
	Sensitivity (%CCP/kPa)	0.0322	0.0321	0.0320	0.0320	0.0316	0.0322	0.0322	0.0323	0.0324
	Penalty for 44 kPa	1.4%	1.4%	1.4%	1.4%	1.4%	1.4%	1.4%	1.4%	1.4%
P_{ROH}	Avg.(MPa)	9.965	9.966	9.966	9.966	9.965	9.966	9.965	9.966	9.966
Difference	TRIH Penalty	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	DP_{HH} Penalty	0.00%	0.00%	-0.01%	-0.01%	-0.03%	0.00%	0.00%	0.00%	0.01%
Flow (kg/sec)	Total Flow	8866	8860	8842	8847	8802	8869	8861	8861	8846
	Diff.*	-1	**-6**	**-24******	**-19****	**-64****	3	**-5**	**-5**	**-20****

* Difference of Heat balance flow vs. changed model flow
** Unacceptable error

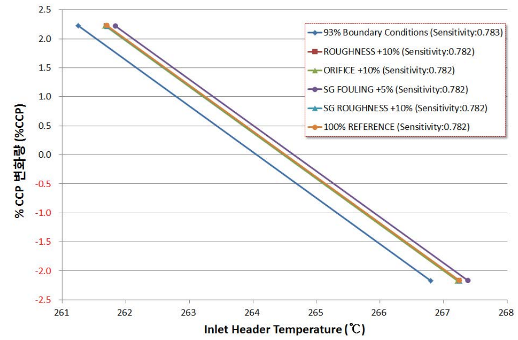

Fig. 1. Results of Wolsong-3 %CCP Sensitivity calculation of T_{RIH}(Temperature of Rx Inlet Header) for thermal-hydraulic parameters change(5%~10%)

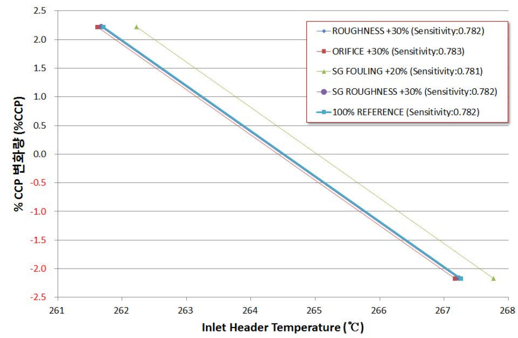

Fig. 2. Results of Wolsong-3 %CCP sensitivity calculation of T_{RIH}(Temperature of Rx Inlet Header) for thermal-hydraulic parameters change(20%~30%)

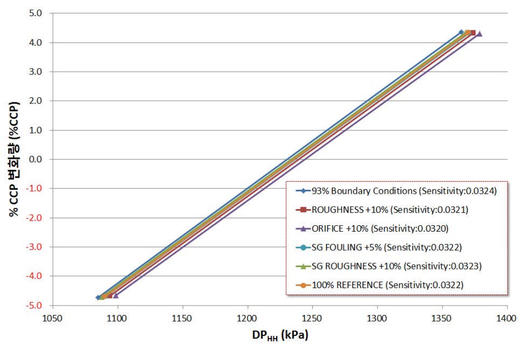

Fig. 3. Results of Wolsong-3 %CCP sensitivity calculation of DP_{HH}(Header Differential Pressure) for thermal-hydraulic parameters change(5%~10%)

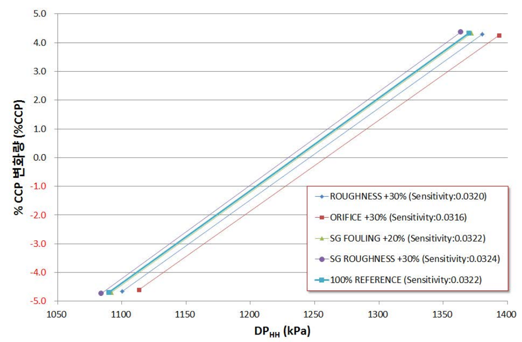

Fig. 4. Results of Wolsong-3 %CCP sensitivity calculation of DP_{HH}(Header Differential Pressure) for thermal-hydraulic parameters change(20%~30%)

2.4 Results of Sensitivity Calculation(Wolsong-4)

Table II shows the results of sensitivity calculation for Wolsong-4. In spite of excessive thermal-hydraulic parameter variation, the %CCP sensitivities for T_{RIH} and DP_{HH} were maintained constant and linearity of sensitivities was also valid as shown in Fig 5 to 8. Moreover the difference of ROPT penalty for changing sensitivity is only ~0.01% for T_{RIH} and ~0.03% for DP_{HH}. These differences for Wolsong-4 are very similar to results of Wolsong-3.

Therefore the uncertainty in the PHTS thermal-hydraulic model for Wolsong-4 at 100% power is negligible considering the plant procedure of thermal-hydraulic boundary conditions penalty.

Table II. Results of Sensitivity Calculation for Thermal-hydraulic Parameters Change (Wolsong-4)

W4		Reference model	PT Roughness 10%	PT Roughness 30%	Orifice 10%	Orifice 30%	SG Fouling 3%	SG Fouling 20%	SG Roughness 10%	SG Roughness 30%
T_{RIH}	Avg.(℃)	264.82	264.80	264.76	264.78	264.72	264.98	265.44	264.81	264.77
	Sensitivity (%CCP/℃)	-0.759	-0.761	-0.759	-0.761	-0.762	-0.760	-0.759	-0.760	-0.760
	Penalty for 2.78 ^{o}C	-2.1%	-2.1%	-2.1%	-2.1%	-2.1%	-2.1%	-2.1%	-2.1%	-2.1%
DP_{HH}	Avg.(kPa)	1235.4	1239.5	1246.4	1243.0	1258.7	1235.5	1236.3	1232.8	1228.2
	Sensitivity (%CCP/kPa)	0.0323	0.0323	0.0321	0.0322	0.0317	0.0324	0.0323	0.0324	0.0326
	Penalty for 44 kPa	1.4%	1.4%	1.4%	1.4%	1.4%	1.4%	1.4%	1.4%	1.4%
P_{ROH}	Avg.(MPa)	9.968	9.968	9.968	9.968	9.967	9.968	9.969	9.968	9.966
Difference	TRIH Penalty	0.00%	0.00%	0.00%	0.00%	-0.01%	0.00%	0.00%	0.00%	0.00%
	DP_{HH} Penalty	0.00%	0.00%	-0.01%	-0.01%	-0.03%	0.00%	0.00%	0.01%	0.01%
Flow (kg/sec)	Total Flow	8770	8744	8695	8759	8712	8780	8774	8773	8756
	Diff.*	1	**-24****	**-73****	**-10****	**-56****	**11****	**5**	**5**	**-13****

* Difference of Heat balance flow vs. changed model flow
** Unacceptable error

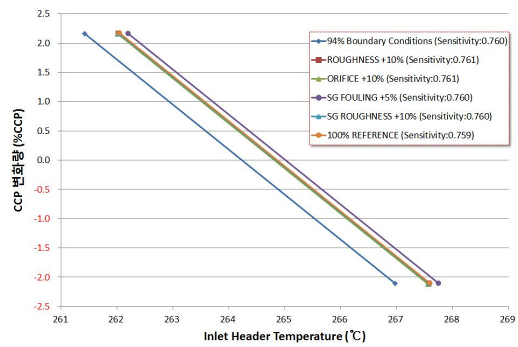

Fig. 5. Results of Wolsong-4 %CCP sensitivity calculation of T_{RIH}(Temperature of Rx Inlet Header) for thermal-hydraulic parameters change(5%~10%)

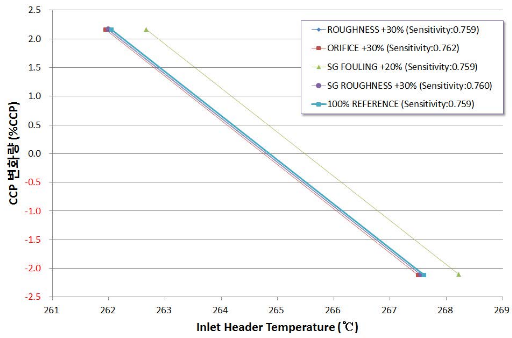

Fig. 6. Results of Wolsong-4 %CCP sensitivity calculation of T_{RIH}(Temperature of Rx Inlet Header) for thermal-hydraulic parameters change(20%~30%)

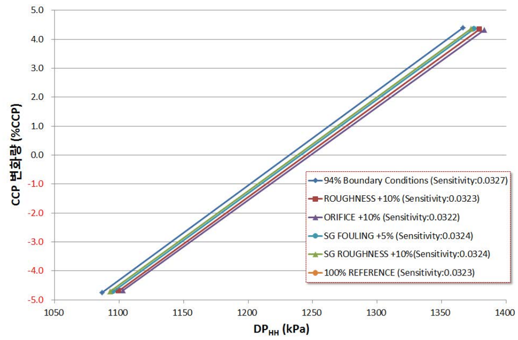

Fig. 7. Results of Wolsong-4 %CCP sensitivity calculation of DP_{HH}(Header Differential Pressure) for thermal-hydraulic parameters change(5%~10%)

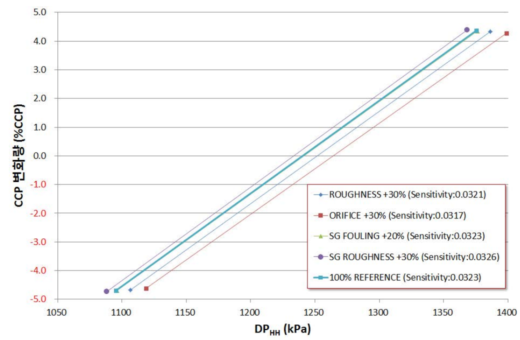

Fig. 8. Results of Wolsong-4 %CCP sensitivity calculation of DP_{HH}(Header Differential Pressure) for thermal-hydraulic parameters change(20%~30%)

3. Conclusions

Actually thermal-hydraulic boundary condition data for Wolsong-3&4 cannot be taken at 100% power condition at aged reactor condition.

Therefore, to create a single-phase thermal-hydraulic model with 80% data, the validity of the model was confirmed at 93.8%(W3), 94.2%(W4, in the two-phase). And thermal-hydraulic boundary conditions at 100% power were calculated to use this model. However this can have the inherent uncertainty that can be used for other convergence conditions of each person.

For this reason, the sensitivities by varying thermal-hydraulic parameters for CCP calculation were evaluated for Wolsong unit 3 & 4. For confirming the uncertainties by variation PHTS model, sensitivity calculations were performed by varying of pressure tube roughness, orifice degradation factor and SG fouling factor, etc.

In conclusion, sensitivity calculation results were very similar and the linearity was constant. And the inherent uncertainty in the thermal-hydraulic model can be negligible by applying plant procedure of thermal-hydraulic boundary conditions penalty.

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