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Analysis and Evaluation of CPC / COLSS Related Test Results During YGN 3 Initial Startup

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영광 3호기 초기 시운전 동안 CPC / COLSS 관련시험 결과 분석 및 평가

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Abstract

YGN 3 is the first nuclear power plant to use the Core Protection Calculator (CPC) as the core protection system and the Core Operating Limit Supervisory System (COLSS) as the core monitoring system in Korea. The CPC is designed to provide on-line calculations of Departure from Nucleate Boiling Ratio (DNBR) and Local Power Density (LPD) and to initiate reactor trip if the core conditions exceed the DNBR or LPD design limit. The COLSS is designed to assist the operator in implementing the Limiting Conditions for Operation (LCOs) in Technical Specifications for DNBR/Linear Heat Rate (LHR) margin, azimuthal tilt, and axial shape index and to provide alarm when the LCOs are reached.

During YGN 3 initial startup testing, extensive CPC/COLSS related tests were performed to verify the CPC/COLSS performance and to obtain optimum CPC/COLSS calibration constants at various core conditions. Most of test results met their specific acceptance criteria. In the case of missing the acceptance criteria, the test results were analyzed, evaluated, and justified. Through the analysis and evaluation of each of the CPC/COLSS related test results, it can be concluded that the CPC/COLSS are successfully implemented as designed at YGN 3.

요 약

영광 3호기는 국내에서 노심보호계통으로 노심보호연산기 (CPC)를, 노심감시계통으로 노심운전제

한 감시계통 (COLSS)을 사용하는 최초의 원자력발전소이다. CPC는 핵비등 이탈율 및 국부 선출력밀도를 실시간으로 계산하여 노심 조건이 설계 제한치를 초과하면 원자로를 정지시키도록 설계되었다. COLSS는 운전원에게 핵비등 이탈율/선형열출력 여유도, 사분출력 경사비, 및 축방향 출력편차에 대한 기술지침서의 운전제한치을 적용하는데 도움을 제공하고 운전제한치를 초과하는 경우, 경보를 제공하도록 설계되었다.

영광 3호기 초기 시운전시험 동안, 다양한 노심 조건에서 CPC /COLSS의 성능을 검증하고 최적의 교정상수를 얻기 위하여 광범위한 CPC /COLSS 관련시험이 수행되었다. 대부분의 시험결과는 시험허용 범위를 만족하였고, 시험허용 범위를 불만족한 경우에는 시험결과를 분석, 평가하여 문제점을 해결하였다. 각 시험결과를 분석, 평가한 결과 영광 3호기에서 CPC /COLSS가 설계된 데로 성공적으로 설치, 운전되는 것을 확인할 수 있었다.

1. Introduction

YGN 3 is the first nuclear power plant to use the Core Protection Calculator (CPC) [1, 2] as the core protection system and the Core Operating Limit Supervisory System (COLSS) [3] as the core monitoring system in Korea. The CPC, which is a digital computer based protection system, is designed to provide on-line calculations of Departure from Nucleate Boiling Ratio (DNBR) and Local Power Density (LPD) and to initiate reactor trip if the core conditions exceed the DNBR or LPD design limit. The CPC synthesizes core power distribution from the signals provided by the three-segment excore detector system. Peak LPD and minimum DNBR values are continuously calculated from the power distributions, the reactor coolant flowrate, reactor coolant system (RCS) temperature and primary pressure. The protection function is performed by four independent CPC channels employing a two-out-of-four trip logic.

The COLSS is designed to assist the operator in implementing the Limiting Conditions for Operations (LCOs) in Technical Specifications for DNBR/Linear Heat Rate (LHR) margin, azimuthal tilt, and axial shape index (ASI) and to provide alarm when the LCOs are reached. The COLSS also provides the calculated value of plant power for comparison to the licensed power. The COLSS uses the fixed incore detector signals and relevant plant parameters in a real-time environment to construct three-dimensional power distributions and to continuously calculate LHR and DNBR margins. This information is continuously displayed to the reactor operator.

During YGN 3 initial startup testing, extensive CPC/COLSS related tests were performed to verify the CPC/COLSS performance and to obtain the optimum CPC/COLSS calibration constants at various core conditions. The CPC/COLSS related tests performed at YGN 3 are provided in Table 1, which includes the power related tests, power distribution related tests, DNBR/LPD related test, and flowrate related test. The appropriate addressable constants

Table 1. Lists of CPC/COLSS Related Tests

1. Power Related Tests
• Adjustment of COLSS Secondary Pressure Loss Term • NSSS Calorimetric Power Determination • RCS Delta T Power Determination • COLSS Turbine Power Calculation • CPC/PPS Power Adjustment • CPC Static Thermal Power Decalibration • Linear Power Subchannel Calibration Test
2. Power Distribution Related Tests
• Temperature Shadowing Factor Determination • Rod Shadowing Factor/Radial Peaking Factor Determination • Shape Annealing Matrix/Boundary Point Power Correlation Coefficient Determination
3. DNBR/LPD Related Test
• CPC/COLSS Operability
4. RCS Flowrate Related Test
• RCS Flow Measurement Test

were successfully determined and installed in CPC and COLSS.

In this report, the CPC/COLSS related tests performed during YGN 3 initial startup testing are analyzed and evaluated with detail test results and several difficulties encountered during testing are explained with the solutions to them [4].

2. Power Related Tests

The COLSS determines the plant power (PP) from the COLSS secondary calorimetric power (BSCAL), COLSS primary calorimetric power (BDELT), and COLSS turbine power (BTFSP). The plant power is used for comparison to the licensed power or DNBR/LHR Power Operating Limit (POL). The CPC calculates the neutron flux power (PHICAL) and thermal power (BDT), which are calibrated by BSCAL or BDELT during the power ascension testing (PAT). In addition, the CPC thermal power decalibration effects for rod insertion and power change are determined and the PPS linear subchannel gains of excore safety channels are adjusted for an accurate CPC power calculation.

2.1. Adjustment of COLSS Secondary Pressure Loss Terms

The objective of this test is to adjust the constants in the COLSS secondary calorimetric power algorithm to accurately calculate steam generator (S/G) and feedwater pressures from the measured S/G header pressure. This test was performed at all major power plateaus (20%, 50%, 80%, and 100%) prior to COLSS secondary calorimetric power determination. Because the feedwater and S/G pressure signals are not directly used in COLSS, the new COLSS bias and gain values for feedwater and S/G pressures should be measured by considering pressure drops between steam header and feedwater, and between steam header and S/G.

Figure 1 shows the pressure drops as a function of

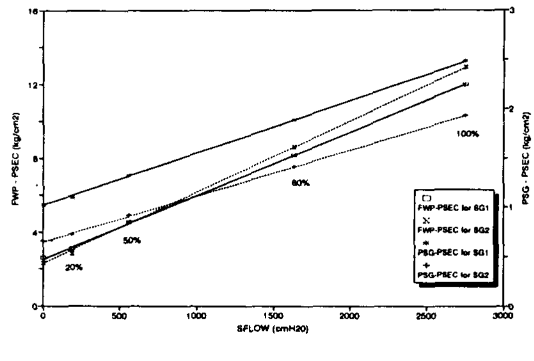


Fig. 1. Pressure Drops vs. Measured S/G Flow Signal
Note : FWP−PSEC ; Pressure drop between steam header and feedwater
PSG−PSEC ; Pressure drop between steam header and steam generator

measured steam flow signal at each power level. After installing the new COLSS bias and gain for feedwater and S/G pressures, the COLSS calculated feedwater and S/G pressures were verified to agree with the measured values within $\pm 3.52 kg/cm^2$ for feedwater pressure and $\pm 1.06 kg/cm^2$ for S/G pressure at all major power plateaus. This assures that the COLSS calculated feedwater and S/G pressures are accurate within the allowable band.

2.2. NSSS Calorimetric Power Determination

The objectives of this test are to determine the core thermal power by means of a secondary side heat balance, and to verify that the COLSS calculated secondary calorimetric power (BSCAL) agrees with the independently calculated secondary calorimetric power. The COLSS primary calorimetric power (BDELT) is also compared to the calculated secondary calorimetric power. If the difference between BSCAL and BDELT is not within $\pm 0.5\%$ for 20% power and $\pm 0.2\%$ for 50%, 80%, 100% power at equilibrium xenon condition, the COLSS $\triangle T$ power calibration constant is adjusted. This test was performed at all major power plateaus prior to the establishment of xenon equilibrium, at equilibrium xenon conditions, and before leaving the major power plateaus.

The COLSS secondary calorimetric power is calculated by a secondary heat balance. The secondary heat balance is adjusted for heat losses and heat inputs to the NSSS. This test was successfully completed at all of required power plateaus without any difficulties.

2.3. RCS $\triangle$T Power Determination

The objectives of this test are to determine the core thermal power at or below 20% power by means of a primary calorimetric power calculation method, and to determine the zero power RCS temperature biases to be used in subsequent primary calorimetric power and RCS flowrate measurements. The primary calorimetric power is calculated based on the enthalpy rise across the core and the primary system flowrate measured by the CPC as follows;

$$Q = \dot{m} * \triangle h$$

where Q; Primary calorimetric power

$\dot{m}$; RCS mass flowrate

$\triangle h$; Enthalpy rise across the core

The calculated calorimetric power was used to adjust the COLSS calculated primary calorimetric power (BDELT). This test was successfully performed at 0%, 3%, 6%, 10% and 20% power level without any difficulties.

2.4. COLSS Turbine Power Calculation

The objectives of this test are to determine the COLSS turbine power calculation constants that correlate the turbine first stage pressure (TFSP) to reactor power and to verify that COLSS turbine power represents the steady-state secondary calorimetric power with acceptable accuracy. The COLSS calculates the turbine power from the measured TFSP.

The COLSS secondary calorimetric power, COLSS turbine power, and TFSP data were collected at

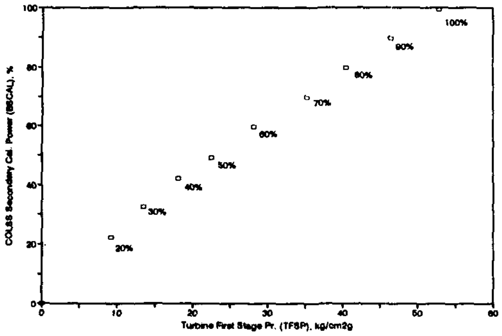


Fig. 2. COLSS Secondary Calorimetric Power vs.Turbine First Stage Pressure

20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, and 100% of rated thermal power. Upon completion of the data collection at 100% power, the measured data was used to correlate the TFSP to BSCAL with a least square fit. Figure 2 shows the BSCAL as a function of TFSP.

After obtaining the new constants, the COLSS turbine power was re-calculated using the new constants and compared to the BSCAL. After verifying that the COLSS calculated turbine power agrees with the COLSS secondary calorimetric power within the specific acceptance criteria ($\pm$3% at 20%, 30% power, $\pm$2% at 40%, 50%, 60%, 70% power, $\pm$1% at 80%, 90%, 100% power), the new constants were installed into COLSS. It ensures that COLSS turbine power agrees with the secondary calorimetric power at steady state within allowable band.

2.5. CPC/PPS Power Adjustment

The objective of this test is to calibrate each channel of the Plant Protection System (PPS) excore linear power, the CPC neutron flux power (PHICAL), and the CPC $\triangle$T power (BDT) with the COLSS calorimetric power to within $\pm$0.5% of rated thermal power. This test was performed at each power level after COLSS $\triangle$T Power Determination or COLSS Secondary Calorimetric Power Determination. The COLSS primary calorimetric power is used as the ref-

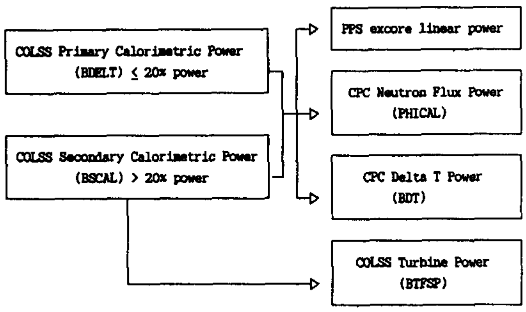


Fig. 3. CPC/COLSS Related Power Determination and Power Calibration

erence power for power calibration at less than or equal to 20% power and COLSS secondary calorimetric power at greater than 20% power. Figure 3 summarizes the CPC/COLSS related power determination and power calibration.

The PPS and CPC powers were successfully calibrated at required power plateaus without any difficulties.

2.6. CPC Static Thermal Power Decalibration

In this test, the decalibration effects of CPC static thermal power (BDT) with change in control element assembly (CEA) configuration and with change in power are determined. At 50% power plateau, the CPC static thermal power is compared with the COLSS secondary calorimetric power for various CEA configurations (i.e. All Rods Out (ARO), Group 5 at Lower Electrical Limit (LEL), Group 5+4 at LEL, Group 5+4+P at LEL, Group 5+P at LEL, Group P at LEL). For the CPC channels A and B with Group 5 fully inserted and all channels with Group P fully inserted conditions, the difference between BSCAL and BDT met the acceptance criteria of ±0.5%. Although CPC channels C and D did not pass the acceptance criteria at 50%, power ascension to 100% was permitted because normal CEA insertion is restricted by the PDIL (power dependent insertion limit). Because of this operating restriction, all channels were expected to be within the acceptance criteria. At 100% power plateau, CPC static thermal power decalibration effect with CEA insertion was determined for Group 5 at 305.0cm withdrawn position. The acceptance criteria for all CPC channels were met with the largest deviation of −0.49%.

For CPC static thermal power decalibration with power change, the adjusted CPC static thermal power between 50% and 100% was calculated and compared with COLSS secondary calorimetric power. The test results showed the error range of −3.43% to 0.97%. This error band indicates that if the BDT power is calibrated at 50% power and power is subsequently increased to 100% power without recalibration, the CPC BDT can be as much as 0.97% lower or as much as 3.4% higher than the COLSS secondary calorimetric power. The evaluation showed that the under-calculation of thermal power due to the thermal power decalibration effect could affect the safety analysis for the single 12-finger CEA drop event for which a CPC penalty factor is required. However, the CPC constants already include an allowance for this effect that is sufficient to cover the observed 0.97% under-calculation. Even if the over-calculation of CPC thermal power is not a safety concern, it can be an operational problem if it results in a high enough power to cause an unnecessary CPC alarm on DNBR. The worst case from the measurements is about a 3.5% over-estimate of power when a calibration is done at 50% power and the power is increased to 100% power without recalibration. Therefore, the potential for over-predicted thermal power should be notified and monitored relative to neutron flux power or calorimetric power during power ascension. If necessary, recalibration should be performed.

2.7. Linear Power Subchannel Calibration Test

The objective of this test is to adjust the PPS linear subchannel gains of excore safety channels so that the excore detector inputs to the CPC are of the desired magnitude in both relative and absolute val-

Table 2. KCAL Before and After Linear Subchannel Calibration

Power Plateau	CPC Channel							
	A		B		C		D	
	Before	After	Before	After	Before	After	Before	After
20%	0.5007	1.0056	0.4950	0.9825	0.5227	1.0000	0.5379	0.9930
50%	1.1640	1.0120	1.1589	1.0083	1.1698	1.0040	1.1674	1.0178

ue. These adjustments ensure that the CPC neutron flux power calibration constant (KCAL) remains close to unity (i.e. raw flux power is fairly accurate) and enhance the quality of subsequently measured shape annealing matrix (SAM). This test was performed at 20% and 50% power plateaus prior to CPC power distribution related tests.

New calibration currents were calculated using the as-found calibration current and CECOR data. As shown in Table 2, the KCAL values after linear power subchannel calibration moved to unity which was an indication that the calibration was performed successfully.

3. Power Distribution Related Tests

In this test, power distribution related CPC constants such as temperature shadowing factor (TSF), rod shadowing factor (RSF), radial peaking factor (RPF), shape annealing matrix (SAM) and boundary point power correlation coefficient (BPPCC) were verified and/or determined. At 20% power, only SAM and BPPCCs were determined. All power distribution related CPC constants were determined at 50% power. At 100% power, only RPF for the ARO configuration was determined.

For data reduction of power distribution related CPC constants, CEBASE/CECOR/CEFAST codes [5, 6, 7, 8] were used in YGN 3 initial startup testing. Approximately two hundred snapshots were taken using the CECOR snapshot function in plant monitoring system (PMS). The snapshot file includes the fixed incore detector signals, excore signals, plant parameters, and selected CPC and COLSS calculated parameters. These snapshot files were transferred to workstation directly or to workstation through PC. The snapshot files were first processed on the workstation using the CEBASE code, which translated the information contained on the snapshot into the proper form for the CECOR input. The CECOR code generated 3-D power distribution and local pin peaking factor based on the plant snapshot data and provided an input file for the CEFAST code. The input data provided to CEFAST by CECOR was reformatted as a summary file. Selected test data reduction and analysis were performed by CEFAST for TSF, RSF/RPF, and SAM/BPPCC and excore detector calibration verification. The summarized process from CECOR snapshot to CEFAST output is shown in Figure 4 [9].

The test method, data reduction method, test results and evaluation for TSFs, RSF, RPF, SAM and BPPCCs are provided as below.

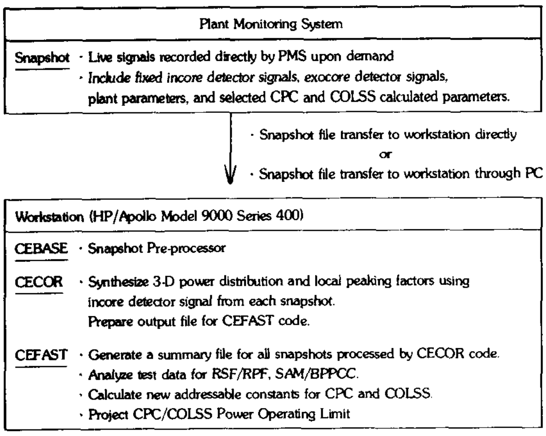


Fig. 4. Summarized Process from CECOR Snapshot to CEFAST Output

3.1. Temperature Shadowing Factor Determination

The decalibration of the excore detectors due to the change in the RCS cold leg temperature (Tcold) was determined. Temperature variation in Tcold will be accompanied by coolant density changes which will affect neutron attenuation across the downcomer of the reactor vessel and the response of the excore detector. The RCS Tcold was raised about 1.5°C and lowered about 6°C from the nominal temperature with power being held as constant as practical. The 19 data sets over temperature range of approximately 7.5°C were taken using PMS snapshot function in a reasonable amount of time.

In CEFAST code, the power indicated by the excore detector is ratioed to secondary calorimetric power for each temperature plateau. This ratio is related to the decalibration of the excore detectors due to RCS Tcold changes. The TSF correction constants are determined and compared to the values installed in the CPCs automatically. The CPC algorithm to determine TSF is as follows;

If Tcmin $\geq$ Tcref, TSF $= 1.0 + C_{t1} *$ (Tcref-Tcmin)

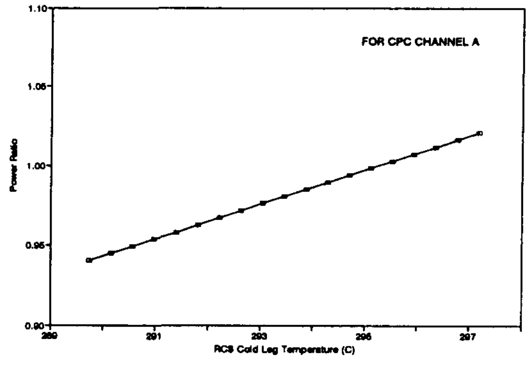
If Tcmin $<$ Tcref, TSF $= 1.0 + C_{t2} *$ (Tcref-Tcmin)

where Tcmin ; Minimum compensated Tcold

Tcref ; Reference temperature for TSF calculation

C_{t1}, C_{t2} ; TSF correction constants

The TSF correction constants measured for each CPC channel was 0.0033°C^{-1}, which was within the acceptance band of 0.0019°C^{-1} to 0.0056°C^{-1}. Figure 5 shows the decalibration effects as a function of Tcold. This assures appropriate conservatism in accommodating the effect of changes in RCS cold leg temperature on CPC neutron flux power.



$$* \text{ Power Ratio} = \frac{\text{(PHICAL/BSCAL) at temperature}}{\text{(PHICAL/BSCAL) nominal}}$$

Fig. 5. Power Ratio vs. Cold Leg Temperature

3.2. Rod Shadowing Factor/Radial Peaking Factor Determination

The RSF is used to account for the alternation in the neutron flux power seen by the excore detectors when control rods are inserted assuming no change in gross power level. The RPFs are used to account for the change in overall radial power distribution caused by CEA insertion by ensuring that most limiting radial peak for the existing CEA configuration is used in the CPC and COLSS calculations.

Starting from an ARO configuration with equilibrium xenon (ASI = Equilibrium Shape Index (ESI) $\pm$ 0.04), CEA Group 5, 4 and PSCEA were inserted, in sequence, without overlap. Reactivity changes were compensated for by RCS boron dilution. The CECOR snapshots were taken at each endpoint, i.e., ARO, Group 5 at LEL, Group 5+4 at LEL, and Group 5+4+P at LEL. Group 4 was then withdrawn, followed by Group 5 without overlap with Group P at LEL. CECOR snapshots were taken at each endpoint, i.e., Group 5+P at LEL and Group P at LEL. Reactivity changes were compensated for by RCS boration.

In CEFAST code, RSFs are determined by comparing both the response of the excore detectors for each CPC channel and COLSS secondary calorimetric power when CEAs are inserted to the case when all CEAs are out. The measured RSFs were used to calculate new CPC RSF multipliers (ASM2 through ASM5) which were installed in CPC database. RPFs were determined from CECOR analysis of incore detector data taken with the various CEA configurations. These RPFs were compared to the values installed in the CPCs. Then, appropriate adjustments to the CPC and COLSS constants (ARM1 through ARM5 and AB1(1) through AB1(5), respectively) were made as required. The CPC algorithm to determine the RSF/RPF is as follows ;

For CPC, $RSF = ASMi * RSF_{CPC}$

$RPF = ARMi * RPF_{CPC}$

For COLSS, $PLRAD = AB1(i) * FDEN$

where ASMi ; CPC RSF multiplier, addressable constants

RSF_{CPC} ; Precalculated RSF (CPC Database)

ARMi ; CPC RPF multiplier, addressable constants

RPF_{CPC} ; Precalculated RPF (CPC Database)

PLRAD ; COLSS planar radial peaking factor

AB1(i) ; COLSS addressable constant for RPF

At 100% power, the ARO RPF was determined from CECOR analysis of incore detector data. Appropriate adjustments to the CPC and COLSS constants (ARM1 and AB1(1)) were made as required. The measured RSF/RFP and new ASM/ARM for the various CEA configuration are summarized in Table 3.

3.3. SAM/BPPCC

The SAM/BPPCC constants are used by CPC to synthesize the core axial power distribution from the three-segment excore detectors. The core axial power distributions at 20 nodes are synthesized by spline approximation using the core peripheral powers and boundary powers at core top and bottom.

The data required to calculate the SAM and BPPCCs were taken at 15 minute intervals over a period at least 9 hours at 20% power and at least 30 hours at 50% power during an induced axial xenon oscillation. The axial xenon oscillation was induced by inserting and withdrawing CEA Group 5 and PSCEA up to mid-core with RCS boron changes compensating for reactivity changes. Figure 6 shows the free xenon oscillation induced at 50% power

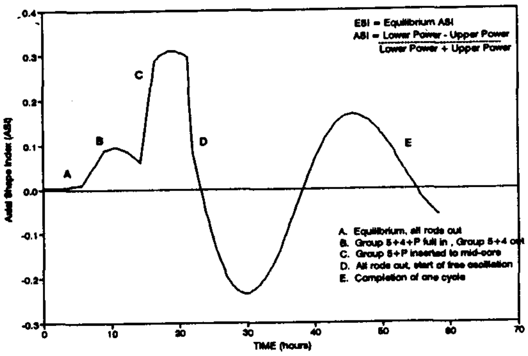


Fig. 6. Free Xenon Oscillation During SAM/BPPCC Measurement at 50% Power

Table 3. RSF/RPF Test Results

CEA Configuration	Measured* RSF	Measured RPF	New ASM*		New ARM	
ARO (50%)	N/A	1.5434	N/A		ARM1	1.016
ARO (100%)	N/A	1.4836	N/A		ARM1	0.9973
Group P at LEL	1.0216	1.5622	ASM2	1.0216	ARM2	1.0006
Group 5 at LEL	1.0722	1.6335	ASM3	1.0722	ARM3	1.0060
Group 5+P at LEL	1.1045	1.6345	ASM4	1.1045	ARM4	1.0344
Group 5+4 at LEL	1.0177	1.7440	ASM5	1.0	ARM5	1.0
Group 5+4+P at LEL	1.0230	1.8100	ASM5	1.0	ARM5	1.0

* For CPC channel A

SAM/BPPCC measurement.

The CEFAST code calculates the SAM and BP-PCCs from the test data taken during the xenon oscillation. Each set of incore response is processed using CECOR code to provide a set of measured peripheral axial power distribution information. A least square analysis of the measured power distribution data from the CECOR versus the corresponding excore data is performed to determine the best set of SAM/BPPCC constants.

The measured SAM/BPPCC values are provided in Table 4, which shows an acceptable performance. The measured SAM showed a strong diagonal elements which mean that a excore detector signal at certain level is largely dependent on the corresponding level's core peripheral power. It is also noted that all element in the inverse SAM had positive values as expected. The root mean square (RMS) error between CECOR calculated axial power distribution values and CPC synthesized values using the new SAM and BPPCC was within the acceptance criteria of 5.5% for all channels. After successful completion of CPC power distribution related tests, the values of addressable uncertainty multipliers (BERR1 and BERR3) were reduced from their pretest values (which were initially penalized by 10%) and installed in CPC, which increases the overall thermal margin.

4. DNBR/LPD Related Test

In this test, CPC DNBR/LPD and COLSS DNBR/LHR POL calculations were verified. For the CPC verification, the DNBR and LPD recorded from each CPC channel were compared with the values calculated by the CEDIPS code [10]. The CEDIPS code uses CPC FORTRAN simulator to determine the ranges of expected CPC responses. When provided with a known variation of data recorded from the CPC, the CEDIPS code calculates the ranges of values of DNBR and LPD that are expected to be observed on the CPC operator module. If the observed values are within the ranges of the expected values, the functioning of each CPC channel is considered to be verified.

For the COLSS verification, the COLSS calculated DNBR/LHR POLs were compared with the values

Table 4. SAM/BPPCC Test Results at 50% Power

CPC Channel	Measured SAM Values (Sij)			Measured BPPCC Values	Axial Shape RMS Error
	4.6004	−1.2969	0.1414	BPPCC1 = 0.0095	
A	−1.2132	4.7220	−1.3012	BPPCC2 = 0.0488	5.0559%
	−0.3873	−0.4251	4.1598	BPPCC3 = 0.0092	
				BPPCC4 = 0.0421	
	4.7139	−1.2552	−0.0081	BPPCC1 = 0.0095	
B	−1.4401	5.0683	−1.6089	BPPCC2 = 0.0488	4.7895%
	−0.2738	−0.8130	4.6171	BPPCC3 = 0.0092	
				BPPCC4 = 0.0421	
	4.6070	−1.2335	0.0537	BPPCC1 = 0.0095	
C	−1.2960	4.8699	−1.4171	BPPCC2 = 0.0488	4.60735%
	−0.3110	−0.6364	4.3635	BPPCC3 = 0.0092	
				BPPCC4 = 0.0421	
	4.4414	−1.1718	0.0792	BPPCC1 = 0.0095	
D	−1.1865	4.9026	−1.5772	BPPCC2 = 0.0488	5.23534%
	−0.2549	−0.7308	4.4980	BPPCC3 = 0.0092	
				BPPCC4 = 0.0421	

calculated by off-line COLSS FORTRAN simulator. In addition, a statistical analysis of difference among sensor inputs measuring "like" parameters was performed off-line to ensure that the instruments were functioning properly.

All of the CPC calculated DBNR and LPD values were bounded by the corresponding CEDIPS ranges of values with the exception of maximum DNBR values calculated by channel B at 80% and 100% power, which were slightly greater than the CEDIPS upper DNBR limits. A transcription error and error in reading the CPC operator module were thought to be the reasons for channel B failure to meet the acceptance criteria. The CPC channel B data was re-taken at 80% and 100% power plateaus. Re-test results showed that the CPC channel B values for DNBR and LPD were satisfactorily bounded by the CEDIPS calculated ranges of values.

The CPC calculated minimum and maximum DNBR/LPD values recorded at 20%, 50%, 80%, and 100% power plateau and the CEDIPS calculated ranges of expected values are shown in Table 5.

5. RCS Flowrate Related Test

The objective of this test is to measure the RCS flowrate using the Reactor Coolant Pump (RCP) $\triangle P$ method and the calorimetric power method at 20%, 50%, 80%, and 100% power plateaus. In the RCS $\triangle P$ method, the RCS mass flowrate is determined from averaged RCS $\triangle P$ values and associated calibration correction. The calibration corrected $\triangle P$ values are used with the RCS performance curve to obtain individual loop flowrate. The four loop flowrates are summed to obtain the total RCS flowrate. In the calorimetric power method, the RCS mass flowrate is calculated by dividing the COLSS secondary calorimetric power (BSCAL) by the average core enthalpy rise. As the reference measurement for comparison and calibration, the RCP $\triangle P$ method is used at 20% and 50% power plateaus and the calorimetric power method at 80% and 100% power plateaus.

The measured RCS flowrate is then compared with COLSS calculated RCS flowrate. The COLSS flow is adjusted to agree with the measured flow within (+0.0% to −0.2%) of design flowrate by changing the COLSS flow addressable constant. Once an acceptable value of COLSS flow is obtained, CPC flow addressable constants are adjusted in each CPC channel such that CPC flow agrees with the COLSS flow. Because the RCS flowrates impact the primary power determination, the COLSS and CPC primary calorimetric power (BDELT and BDT) are adjusted to agree with the COLSS secondary calorimetric power (BSCAL).

The measured RCS mass flowrate at 20% using the RCP $\triangle P$ method was 108.6% of design, which met the acceptance criteria of 106.9% to 109.4%. This measured flowrate was determined using the revised RCP casing $\triangle P$ curve based on the data obtained during Post-core hot functional testing (HFT). Because the measured flowrate at 20% was greater than that measured during Post-core HFT, CPC and COLSS flow adjustments were not performed.

The measured RCS flowrate at 50% using the

Table 5. CPC/CEDIPS Comparison of DNBR and LPD (For Channel A)

Power Level	CEDIPS Minimum DNBR	CEDIPS Maximum DNBR	CPC Minimum DNBR	CPC Maximum DNBR	CEDIPS Minimum LPD(W/cm)	CEDIPS Maximum LPD(W/cm)	CPC Minimum LPD(W/cm)	CPC Maximum LPD(W/cm)
20%	5.6463	6.1905	5.9631	6.0325	221.66	239.58	225.07	225.78
50%	2.9748	3.1937	3.0552	3.0967	358.42	378.56	365.24	366.55
80%	2.4219	2.5797	2.5023	2.5355	405.10	423.47	409.42	410.25
100%	1.8857	1.9816	1.9332	1.9632	476.80	491.60	480.62	482.43

RCP △P method and the revised RCP casing △P curve was 109.25% of design. The measured RCS flowrate was slightly higher than the specified acceptance criteria of 109.1% of design. At YGN 3, the first change in system resistances was noticed approximately 10 days following the completion of Post-core RCS flowrate measurement test. The RCP △P decreased by approximately 200.0 cmH_2O, resulting in an apparent increase in flowrate of 2.3%. The second change was noticed following the outage in Nov., 1994. At this time, the RCP △P decreased by approximately 65 cmH_2O, resulting in an apparent increase in RCS flowrate of approximately 0.5%. Because the measured flowrate at 50% was greater than that at 20%, CPC and COLSS constants were not adjusted to include any of the apparent increase in RCS flowrate. CPC and COLSS addressable constants remained valid based on the Post-core flowrate test results to yield a flowrate of approximately 107.8%.

The measured RCS flowrate at 80% using the calorimetric power method was 109.4% of design. The measured RCS flowrate exceeded the RCS flowrate acceptance criteria of 106.6% to 108.8%. The effect of higher-than-expected RCS flowrate was evaluated at 110.4% of design on RCS components, reactor vessel internals, nuclear fuel, and CEA scram time. The evaluation concluded that the mechanical components had sufficient margin to permit continued operation to 100%. Because the measured flowrate at 80% was greater than that at 50%, CPC and COLSS constants were not adjusted.

At 100% power plateau, the measured RCS flowrate using the calorimetric power method was 108.1% of design, which met the acceptance criteria. The flowrate related CPC and COLSS addressable constant was adjusted at 100% power as required.

6. Conclusions

Through the analysis and evaluation of each of the CPC/COLSS related test results, it can be concluded that the CPC/COLSS are successfully implemented as designed at YGN 3. As the lead unit (First-of-a-Kind unit), extensive tests were performed in YGN 3 during initial startup testing. However, many tests can be eliminated or reduced in scope in YGN 4 and UCN 3, 4 as the follow-on units using the experiences gained during YGN 3 testing. Also, the test experiences of YGN 3 can be utilized in the CPC/COLSS related reload startup testing [11].

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