Low Power Physics Test Experience at SKN3 as Lead Unit

Yu Sun Choi*, Sun Kwan Hong , Ho Cheol Shin
KHNP-CRI, 70 Yuseongdaero 1312beon-gil, Yuseong-gu, Daejeon 34101, Korea
**Corresponding author: yschoi5577@khnp.co.kr*

1. Introduction

Shin Kori (SKN) unit 3 is the first nuclear power plant of the Advanced Power Reactor 1400(APR1400) constructed in Korea which received the operation license last year. SKN 3 as the lead unit or first-of-a-kind plant is designed to operate at rated thermal output of 4,000 MW to produce an electric power output of around 1,450 MWe. Low Power Physics Test Program is characterized by the performance test at low temperature and normal temperature of zero power physics test, including 1) Core Symmetry Test, 2) Isothermal Temperature Coefficient (ITC) Measurement, 3) Control Rod Worth Measurement, 4) Differential Boron Worth Measurement, 5) Dropped and Ejected Rod Worth Measurement and 6) Critical Boron Measurement. All measured data are in good agreement with the predicted data. The follow-on plant will not repeat zero power physics test procedures at off-normal condition, especially low temperature critical approach and N-1 control rod worth measurement.

2. Reactor Core and Fuel Design of SKN3

The reactor core consists of 241 fuel assemblies built up fuel rods containing uranium dioxide fuel with an average enrichment of 2.6% in a 16X16 array. The number of Control Element Assembly(CEA) is 93 with 8 additional CEAs. The core is designed for an operating 18 months with a discharge burnup as high as approximately 60,000 MWD/MTU. The neutron flux shape is monitored by fixed in-core instrumentation assemblies.

3. Low Power Physics Test Experience at SKN3

3.1 Core Symmetry Verification

The objective of this test is to demonstrate that no core loading or fabrication errors, which result in measurable CEA asymmetries have occurred. The worth of each CEA was measured to the worth of the other CEAs within its symmetric subgroup. All measured values of each CEA worth relative to the average worth of a CEA in that same subgroup was within test criteria(±10.58 pcm), means that there were no major fuel or CEA fabrication error or no major core misloading.

3.2 Isothermal Temperature Coefficient Measurement

The objective of the ITC measurement is to confirm the reactivity control characteristic. The test results demonstrate that the reactivity response to temperature changes in the reactor core is consistent with design predictions as shown in Table 1.

Table 1. ITC Measurement Results

Conditions	Measured ITC (pcm/℃)	Predicted ITC (pcm/℃)	Difference (M-P) (pcm/℃)	Test Criteria (pcm/℃)
EARO, Low Temp.	-1.6	-2.0	0.4	±9
EARO, HZP	-3.1	-4.1	1.0	±9

* EARO : Essentially All Rod Out, RG : Regulating Group

3.3 Control Rod Worth Measurement

The objective of this test is to confirm the capability to shut down and control reactivity. It demonstrates that the reactivity worth of the safety and regulating control rods are consistent with predictions. This test provides a level of assurance that the fuel and core components configured are consistent with design assumptions. The total safety and regulating control rod worth verifies adequate shutdown margin capability. Control rod group worths and shapes provide initial indication of an acceptable power distribution. The measured group and total worths agreed with the predicted value within test criteria as shown in Table 2.

Table 2. CEA Group Worth Measurement Results

(a) at low Temperature

CEA Group	Measured Worth (pcm)	Predicted Worth (pcm)	Difference (M-P) (pcm)	% Error (M-P)/P (%)	Test Criteria (% or pcm)
RG5	147	140	7	4.8	±15% or 100pcm
RG4	340	335	5	1.5	
RG2	742	773	-31	-4.2	

(b) at Hot Zero Power

CEA Group	Measured Worth (pcm)	Predicted Worth (pcm)	Difference (M-P) (pcm)	% Error (M-P)/P (%)	Test Criteria (% or pcm)
RG5	232	242	-10	-4.3	±15% or 100pcm
RG4	419	425	-6	-1.4	
RG2	883	925	-42	-4.8	

3.4 Differential(or Inverse) Boron Worth

The difference boron worth is defined as the change in boron concentration, which will cause 1 pcm reactivity change. The measured IBW values agreed with the predicted values within test criteria as shown in Table 3.

Table 3. Differential Boron Worth Measurement Results

Conditions	Measured IBW (ppm/pcm)	Predicted IBW (ppm/pcm)	Difference (M-P) (ppm/pcm)	Test Criteria (ppm/pcm)
HZP	-0.0932	-0.0921	+0.010	±0.015

3.5 Pseudo Dropped and Ejected Rod Worth

The objective of pseudo dropped and ejected rod worth measurement is to confirm that the rod insertion limit will be adequate to ensure a shutdown margin, which consistent with rod ejection or drop accident analyses. Pseudo dropped and ejected rod worth were measured at Hot Zero Power and low temperature core conditions, respectively. The measured ejected and dropped rod worths agreed with the predicted value within test criteria as shown in Table 4.

Table 4. Ejected and Dropped Worth Measurement Results

CEA	Measured Worth (pcm)	Predicted Worth (pcm)	Difference (M-P) (pcm)	% Error (M-P)/P (%)	Test Criteria (% or pcm)
Worst Ejected	152	201	-49	-24.4	±31% or 100 pcm
Worst dropped	75	66	9	13.6	
Worst Dropped PSCEA	14	15	-1	-6.7	

3.6 Critical Boron Measurement

The objective of this test is to confirm the reactivity balance. This test measures the overall reactivity of the reactor core and validates the accuracy of the predicted criticality. This test provides verification that soluble boron sources provide adequate negative reactivity as modeled in the accident analyses. The core conditions under which the critical boron measurements were performed are the same as those for the ITC measurements. All measured values agreed with the predicted value within test criteria.

Table 5. Critical Boron Concentration Measurement Results

Conditions	Measured CBC (ppm)	Predicted CBC (ppm)	Difference (M-P) (ppm)	Test Criteria (pcm/℃)
EARO, Low Temp.	1,188	1,218	-30	±100
EARO, HZP	1,044	1,076	-32	

4. Conclusion

Low Power Physics Test of SKN3 are performed in accordance with Initial Test Program RG1.68 to confirm that measured values are agree with the predicted values with test criteria, which program should consist of Core Symmetry Test, Isothermal Temperature Coefficient Measurement, Control Rod Worth Measurement, Differential Boron Worth Measurement, Dropped and Ejected Rod Worth Measurement and Critical Boron Measurement. All test objectives have been satisfied, which are good agreement with the predicted values.

Follow-on plant could be omitting the testing procedures at the low temperature and tests related to dropped/ejected rod worth measurements, because successful LPPT at SKN3 as the lead unit.

Reference

[1] Han-Gon Kim, "The Design Characteristics of Advanced Power Reactor 1400," IAEA-CN-164-3S09.
[2] Sung-Goo Chi et al ,"Low Power Physics Test Experience at YGN3 as the Lead Unit , " Proceedings of 10th KAIF/KNS Annual Conference, 1995.
[3] NRC, RG 1.68, "Initial Test Programs for Water-Cooled Nuclear Power Plants", Washington, DC. Rev4, June 2013.
[4] ANSI/ANS-19.6.1-2011, "Reload startup Physics Tests for Pressurized Water Reactors"