CYCLE 14 LOW POWER PHYSICS AND POWER ASCENSION TEST PROGRAM

1.0 LOW POWER PHYSICS TESTS

1.1 Purpose

The purpose of the Cycle 14 Low Power Physics Tests (LPPT) was to obtain and confirm selected Cycle 14 core physics parameters. The physics parameters measured in the test included:

- All rods out critical boron concentration,
- Isothermal temperature coefficient of reactivity,
- CEA shutdown and regulating group worths using the Rod Group Exchange Technique,
- Verification of the absence of gross power tilts using Group 4 pseudo-ejection symmetry checks.

1.2 Summary of Principal Results

Cycle 14 criticality was achieved at 1035 on May 1, 1992. Following criticality, zero-power physics testing was initiated to measure core physics parameters and validate the core design through comparison to predicted values. A summary of the primary results is described below:

Critical Boron Concentration (All Rods Out)	1182 ppm
Total Regulating and Shutdown Group Worth	6.00 %$\Delta\rho$
Isothermal Temperature Coefficient of Reactivity	-0.09×10^{-4} $\Delta\rho$/°F

1.3 Discussion Of Measurements and Results

1.3.1 Approach to Criticality

Following the hot functional testing in which CEA drop times were measured, the Cycle 14 approach to criticality was initiated. Wide Range Channels B and C were used to determine the subcritical neutron multiplication. The approach to criticality began by withdrawing Rod Groups N, A, B, 1, 2 and 3 to the upper electrical limit and withdrawing Group 4 to approximately 100 inches.

Continuous dilution of the Reactor Coolant System began at 0545 on May 1, 1992, at an average rate of approximately 2.0 ppm boron

1.0 LOW POWER PHYSICS TESTS (Continued)

1.3 Discussion Of Measurements and Results (Continued)

1.3.1 Approach to Criticality (Continued)

per minute. Throughout the dilution RCS samples were analyzed at twenty minute intervals for boron concentration, and extrapolations of 1/M versus dilution time graphs were used to provide an estimated time of criticality. Initial criticality was achieved at 1 x 10^{-4} % power at .035 on May 1, 1992. CEA Regulating Group 4 was adjusted to 115 inches withdrawn to maintain the reactor critical during stabilization and to promote boron equalization between the pressurizer and the loop. The critical boron concentration at the above rod position was 1177 ppm and was equivalent to an all-rods-out critical boron concentration of 1182 ppm.

1.3.2 Zero Power Tests

Following Cycle 14 initial criticality, the reactivity computer was installed and checked for correct operation. The following values of β_i and λ_i were set into the reactivity computer:

Group	β_{eff}	$\lambda(sec^{-1})$
1	0.0002025	0.012751
2	0.0012661	0.031628
3	0.0011450	0.11985
4	0.0024650	0.32055
5	0.0009009	1.4021
6	0.0002178	3.8662

β_{total} = 0.0061973

1.3.2.1 CEA Coupling Checks

Coupling checks were performed for all CEAs. This was accomplished by inserting individual rods to achieve approximately a -4¢ reactivity change. This change corresponded to approximately 20 to 40 inches of insertion. Rods within each group were checked to show similar insertion that approximated a symmetry check. No abnormalities were observed during the coupling checks, and it was concluded that all control rods were properly coupled.

1.0 LOW POWER PHYSICS TESTS (Continued)

1.3 Discussion Of Measurements and Results (Continued)

1.3.2 Zero Power Tests (Continued)

1.3.2.2 Isothermal Temperature Coefficient of Reactivity (ITC) Measurement

The ITC was measured by first decreasing and then increasing the RCS temperature by approximately 20°F and compensating for the reactivity changes with CEA Group 4 motion. The temperature was decreased by manually discharging steam through the atmospheric dump valve (HCV-1040). Initial and final Group 4 positions were recorded. The worth of Group 4 used as compensation was measured from the reactivity computer trace to determine the ITC. Table 1 contains the measured and predicted ITC values along with other measured and predicted parameters. The reported value is the average of the two measurements taken from one temperature swing. The Moderator Temperature Coefficient of Reactivity (MTC), which is equal to the ITC minus the Fuel Temperature Coefficient of Reactivity (FTC), was verified to be less than the +0.5 x 10^{-4} $\Delta\rho$/°F Technical Specification limit. The most positive MTC, including uncertainties, was calculated to be +0.03 x 10^{-4} $\Delta\rho$/°F.

1.3.2.3 Shutdown and Regulating CEA Group Worths

The CEA group worths were measured in accordance with References 1 and 2 using the rod group exchange technique, where individual rod groups, called test groups, were measured by swapping them with reference groups whose worths were determined by the boration-dilution method. The reference group was determined from predictions to be the CEA group with the highest rod worth. Therefore, the worth of the test groups is a function of the measured worth of the reference group.

For Cycle 14, two variations of the rod group exchange technique were used. First, one reference group was used for Cycle 14 instead of two reference groups used in previous tests. The use of one reference group saved several hours of rod exchanges and produced less chemical waste by decreasing the number of borations of the RCS. The second variation was the use of the concept called "super groups".

1.0 LOW POWER PHYSICS TESTS (Continued)

1.3 Discussion Of Measurements and Results (Continued)

1.3.2.3 Shutdown and Regulating CEA Group Worths (Continued)

A super group is a combination of two or more test groups into a higher worth rod group. As concluded in References 1 and 2 of Section 3.0, the most accurate test group measurements occur when the test group worth is closer to the worth of the reference group. For this test Group B was used as the reference group for Groups A, 1, 2, 3 and 4. Groups 1 and 2 were combined into one super group, and Groups 3 and 4 were combined into another super group.

All group worths were well within the acceptance and review criteria for the test. The total worth for all CEA groups was also well within the 10% acceptance and review criteria of the predicted worth. The use of super groups for Cycle 14 produced the most accurate measurements of test group worths recorded for a group worth measurement test using the rod group exchange technique at both Fort Calhoun Station and other CE units.

1.3.2.4 Group 4 Pseudo-Ejection Symmetry Check for Gross Power Tilt

In order to check for ejected rod symmetry and gross power tilts at zero power, the full length worth of each of the symmetrical Group 4 CEAs was measured (i.e., each Group 4 rod except CEA 4-1 which is the center CEA). Table 1 (of this attachment) shows the worth of each rod and the deviation from the group's mean worth. The data in Table 1 indicates that no azimuthal tilt existed in the core at zero power.

1.4 Conclusions

Test personnel have concluded that the Low Power Physics Test program conducted for Cycle 14 yielded results that are as accurate as can be expected within the limitations of reasonable reactor safety, prudent use of plant equipment and accuracy of available instrumentation. The data collected during the Cycle 14 Low Power Physics Tests was analyzed by Omaha Public Power District Nuclear Engineering - Reactor Physics. The results of the Cycle 14 Low Power Physics Tests show excellent agreement with the 3-D ROCS code predicted values, thus providing confirmation of the methods used in designing the Cycle 14 core and the associated analyses.

2.0 POWER ASCENSION

2.1 Purpose

The purposes of the Cycle 14 power ascension test program was to verify that the measured at-power core parameters were within the limits of the Technical Specifications, and to compare selected measured parameters with the calculated/predicted values. The power ascension test program consisted of:

- Measurements of the following parameters at 45%, 66% and 98% power:
  - Integrated Radial Peaking Factor (F_R^T),
  - Planar Radial Peaking Factor (F_{xy}^T),
  - Azimuthal Power Tilt (T_q).
- Determination of reactivity coefficients:
  - Measurement of Isothermal Temperature Coefficient of Reactivity (ITC),
  - Measurement of Power Coefficient of Reactivity (PC),
  - Calculation of Moderator Temperature Coefficient of Reactivity (MTC).
- Comparison of measured and predicted radial power distributions and calculation of the associated root mean square deviation (σ).

2.2 Summary of Principal Results

Cycle 14 commercial operation began at 0526 on May 3, 1992, when the turbine-generator was placed on-line. Power ascension began following this event. A summary of the pertinent parameters measured during the power ascension testing program are summarized in Table 2 of this report.

2.3 Discussion Of Measurements and Results

2.3.1 Radial Peaking Factors

Measurements of F_R^T and F_{xy}^T using incore detector signals and CECOR calculations at 45%, 66% and 98% power indicate that the integrated radial peaking factor, the planar radial peaking factor, and the excore and incore azimuthal power tilts, T_{qE} and T_{qI}, were within the limits of the Technical Specifications.

2.0 POWER ASCENSION

2.3 Discussion Of Measurements and Results (Continued)

2.3.2 MTC, ITC and PC

Tests were performed on May 21, 1992, to measure the ITC and PC. The results of this test are summarized in Continuing Physics Test Report (CPTP) No. 36. The range of the 100% power MTC, including uncertainties, was $-0.76 \times 10^{-4}\ \Delta\rho/^{\circ}F$ to $-0.97 \times 10^{-4}\ \Delta\rho/^{\circ}F$, which is within the Technical Specification limits.

2.3.3 Radial Power Distribution Comparison

Comparisons between the measured (CECOR) and calculated (ROCS) radial power distributions at 45%, 66% and 98% power, respectively show that the root mean square values of σ are less than the 3% value required by the Technical Specifications.

2.4 Conclusions

Radial peaking factors and azimuthal power tilts were measured at 45%, 66% and 98% power, and found to be within the Technical Specification limits. MTC measurements showed reasonable agreement with the calculated predictions using ROCS. Measurement of acceptable radial peaking factors and a MTC less than the Technical Specification limits demonstrate that the core is operating within the bounds of the safety analysis. Radial power distributions, measured at 45%, 66% and 98% power, exhibit reasonable agreement with those predicted by ROCS. These results provide confirmation of the core design methodology used and demonstrate compliance with the Technical Specifications.

3.0 REFERENCES

1. Letter, D. M. Crutchfield (NRC) to H. Berkow (NRC), "Review of Topical Report CEN-319, Entitled 'Control Rod Group Exchange Technique'" (TACS 60701), March 10, 1986.

2. Letter, D. M. Crutchfield (NRC) to R. K. Wells (CEOG), "Acceptance for Referencing of Licensing Topical Report CEN-319 'Control Rod Group Exchange Technique'", April 16, 1986.

TABLE 1

CYCLE 14 COMPARISON OF PREDICTED AND MEASURED
LOW POWER PHYSICS PARAMETERS
(Hot Zero Power, 2100 psia, 532°F)

Rod Worth by Rod Group Exchange Technique:

Group	Predicted Reactivity (%Δρ)	Measured Reactivity (%Δρ)	Predicted - Measured Reactivity (%Δρ)	Group B Position (inches withdrawn) Predicted	Group B Position (inches withdrawn) Measured	Acceptance** Criteria (%Δρ)	Review** Criteria (%Δρ)
1+2	1.51	1.53	-0.02	113	111	±0.23	±0.23
3+4	1.27	1.25	+0.02	90	78	±0.19	±0.19
A	1.59	1.60	-0.01	121	120	±0.24	±0.24
B	1.64	1.62*	+0.02	N/A	N/A	±0.16	±0.16
TOTAL	6.01	6.00	+0.01			±0.60	±0.60

* Measured via Boration-Dilution Method; Acceptance and Review Criteria are ± 10% of predicted versus ± 15% of predicted for CEA Exchange Technique.
** Criteria based upon predicted values.

Isothermal Temperature Coefficient (Δρ/°F):

Boron Conc. (ppm)	Temp. (°F)	Prediction	Measurement	Most Positive MTC	Acceptance Criteria	Review* Criteria
1178	522	-0.10×10^{-4}	-0.09×10^{-4}	$+0.03 \times 10^{-4}$	MTC Tech. Spec. Limit of $<+0.50 \times 10^{-4}$	$\pm 0.20 \times 10^{-4}$

* Difference between predicted and measured ITC.

ARO Critical Boron Concentration (ppm):

Prediction	Measurement	Predicted-Measured	Acceptance Criteria	Review Criteria
1201	1182	+19	±90 of predicted	±50 of predicted

Group 4 Pseudo-eject Symmetry Check for Gross Power Tilt:

Group-CEA #	CEA Worth (¢)	CEA Worth - Group Average (¢)
4-38	21.52	+0.44
4-39	20.95	-0.13
4-40	20.94	-0.14
4-31	20.92	-0.16

Average = 21.08

Review Criteria is ± 1.5¢ deviation from group average.

TABLE 2

PHYSICS PARAMETERS MEASURED DURING POWER ASCENSION TESTING PROGRAM

Parameter	Thermal Power (%)	Measured Value	Technical Specification Limit
F_R^T	45.8	1.64	≤ 1.9[illegible]
F_{xy}^T	45.8	1.66	≤ 2.01
T_{qI}	45.8	0.0182	≤ 0.03
T_{qE}	45.8	0.0019	≤ 0.03
F_R^T	64.9	1.63	≤ 1.93
F_{xy}^T	64.9	1.65	≤ 2.01
T_{qI}	64.9	0.0165	≤ 0.03
T_{qE}	64.9	0.0026	≤ 0.03
PC	90.3	$-1.55 \times 10^{-4}\ \Delta\rho/°F$	None
ITC	90.3	$-0.87 \times 10^{-4}\ \Delta\rho/°F$	None
MTC	90.3	$-0.74 \times 10^{-4}\ \Delta\rho/°F$	$-3.0 \times 10^{-4}\ \Delta\rho/°F \leq MTC \leq +0.2 \times 10^{-4}\ \Delta\rho/°F$
MTC (Extrapolated)	100	$-0.87 \times 10^{-4}\ \Delta\rho/°F$	$-3.0 \times 10^{-4}\ \Delta\rho/°F \leq MTC \leq +0.2 \times 10^{-4}\ \Delta\rho/°F$
F_R^T	98.0	1.61	≤ 1.79
F_{xy}^T	98.0	1.65	≤ 1.85
T_{qI}	98.0	0.014[illegible]	≤ 0.03
T_{qE}	98.0	0.0029	≤ 0.03