Results of the January 1977 Augmented Startup Program Tests Conducted at Indian Point Unit 3

N. G. Demas
J. Somerville

WESTINGHOUSE ELECTRIC CORPORATION
Water Reactor Divisions
P. O. Box 355
Pittsburgh, Pennsylvania 15230

FOREWORD

Material that is proprietary to the Westinghouse Electric Corporation has been deleted from this document. Such deletions are marked by brackets. The basis for marking the material proprietary is identified by marginal notes referring to the standards in Section 8 of the affidavit of R. A. Wiesemann of record "In the Matter of Acceptance Criteria for Emergency Core Cooling Systems for Light Water Cooled Nuclear Power Reactors (Docket No. RM-50-1)" at transcript pages 3706 through 3710 (February 24, 1972).

1.0 SUMMARY

The Indian Point Unit 3 (INT) January 1977 Augmented Startup Test[1] consisted of six load swings from ~100% power to ~50% power. The first three followed a 3-6-3-12 schedule; 3 hours to ramp from 100% power to ~50% power, 6 hours at 50% power, 3 hours to ramp up to 100% power, and 12 hours at 100% power. The last three maneuvers followed a 6-18 pattern; a ~1/2 hour ramp to ~50% power, ~50% power for ~5 hours, ~1/2 hour ramp to 100% power, and 18 hours at 100% power.

The objective of this test is to demonstrate the agreement between Westinghouse calculational models and measured core behavior for a variety of non-static operating conditions. The comparison focuses on the elevation dependent peaking factor, $F_Q(Z)$, which is the primary power distribution parameter limited in the technical specification for LOCA protection. A simulation of this test was calculated using Westinghouse models as discussed in Section 2 of Reference 2. Comparisons of the measured and calculated limiting F_Q values at every elevation during the test (the $F_Q(Z)$ envelope for the maneuver) is shown in Figure 3. This comparison shows excellent agreement between the measured $F_Q(Z)$ envelope and the corresponding calculated points. Based on these results, it is concluded that the measured core power distribution during non-static maneuvers at various power levels is accurately predicted by Westinghouse design models using 1D/2D synthesis.

The design bases FAC LOCA envelope has been found to be conservative when compared to the results of this test. The axial and radial power distributions, calculated and measured were found to be in good agreement. Finally, the calculated flux imbalance ($\Delta\phi$) from the measurements and from the simulation calculations show substantially the same behavior.

2.0 TEST DESCRIPTION

Between January 5 and January 12, 1977, the Indian Point Unit 3 Nuclear Plant performed load follow maneuvers as described in the Augmented Startup Testing Program.[1] This test included slow (3-6-3-12) and fast (6-18) load follow for three days each, interspersed with Positive and Negative Special Hot Channel Factor Surveillance testing. The cycle burnup during the test ranged between 4935 and 5135 MWT/MTU. The 60 hour power history of the plant just prior to the testing is plotted in Figure 1a and 1b. The history during the test is given in Figure 2a, 2b, 2c, 2d and 2e.

Overall, the test profiles show excellent agreement between excore and INCORE measurements of the axial flux difference, $\Delta\phi$. Portions of the tests can be characterized as intentionally stressing the $\Delta\phi$ band (±5% around the target value) on both the positive and negative sides. Constant axial offset control is shown to be very effective in controlling any induced xenon transients in that the axial flux difference returned to a near target value with D bank close to its original position.

The test data was interrupted by a reactor shutdown and startup in the middle of the 60 hour preconditioning period and a reactor shutdown and startup during the fifth day of the load follow maneuvers. This made the calculational modeling of the test considerably more difficult. However, the final results and conclusions were not noticeably altered by these shutdowns.

3.0 ANALYSIS

A simulation was carried out using a one-dimensional axial model for the core. The 1-D simulation model is essentially that discussed in Section 2.2 of Reference 2. Power level and D bank position were used as input to the axial model on an hourly or half-hourly basis. Nominal plant parameters, such as flow rate and enthalpy rise, were assumed. The results of the simulation calculations are shown on Figures 2a through 2e. The quality of the simulation can be judged by the agreement in axial flux difference between measured and calculated values. Good agreement would be found if the two values are within [ ]^{a,c} of each other. In general, the results of the INT simulation are within the criterion. However, the calculated flux difference was generally more negative than the measured values.

The measured $F_Q(Z)$ times relative power envelope for the test period is shown on Figure 3. It is well below the generic LOCA envelope and the FAC cases envelope. The envelope for the simulation calculation of the ~7 days of load follow shows good agreement with the measured envelope. The uneven distribution of margin (greater at the bottom of the core) between the calculated and measured envelopes is due to the fact that the calculated $\Delta\phi$ was consistently biased in the negative direction compared to the measured flux imbalance.

Based on the simulation, $F_Q(Z)$ is calculated as follows:

$$F_Q(Z) = P_Z(Z) \times F_{XY} \times 1.03 \times 1.03 \times 1.05$$

where $P_Z(Z)$ = the core average axial power at elevation Z (corrected for grid effects)

1.03 = the xenon factor

1.05 = a conservatism factor

1.03 = the engineering factor

The calculated $P_Z(Z)$ values have been adjusted to account for the effect of the presence of grids which are not modeled discretely in the 1-D calculation as discussed in Section 2.2 of Reference 2.

In order to calculate the enthalpy rise hot channel factor, $F_{\Delta H}$, for comparison with the measured value, discrete fuel rod 2-D (X-Y) calculations were coupled with 1-D axial calculations. The 2-D model was depleted to approximately 5000 MWD/MTU cycle burnup. A D bank calculation was performed at the test burnup. Power sharings calculated in the 1-D simulation of tests were used to weight unrodded and rodded 2-D X-Y calculated power distributions to synthesize the $F_{\Delta H}$ corresponding to specific INCORE maps. $F_{\Delta H}$ is calculated by the expression:

$$F_{\Delta H} = \sum_{i=1}^{2} PS_i \; P_{x_o y_o i}$$

where PS_i = the axial power sharing for radial configuration i.

$P_{x_o y_o i}$ = the integrated power for radial location (x_o, y_o) for configuration i.

(x_o, y_o) = the radial location of the hot channel.

Figure 4 shows a comparison between the INCORE and simulated $F_{\Delta H}$ for a number of cases. The sample included cases spanning the relative power levels experienced during the test. Also the range of $\Delta\phi$ was spanned. For the cases selected the $\Delta\phi$ INCORE and $\Delta\phi$ simulated were no more than [ ] a,c apart. The information of Figure 4 shows that the INCORE and simulation $F_{\Delta H}$ fall within [ ] a,c of each other.

Several INCORE maps were selected for direct comparison with calculated results. These comparisons are given in Appendix A. Each comparison is identified by its INCORE map I.D. which corresponds to the map I.D.'s given in Figure 2. Pertinent map data are given at the top of each Appendix A figure. The upper frame compares INCORE and synthesized assembly power distributions. The lower frame compares the measured and 1D simulation results for $P_Z(Z)$. The grid effect correction has not been applied to calculated values of $P_Z(Z)$ in Appendix A. The measured value of $F_{XY}(Z)$ is also given in the lower frame. The "map-by-map" comparisons of Appendix A show satisfactory agreement between calculation and measurement.

4.0 CONCLUSION

The comparisons made in this report between the measured test results and the results from the calculational simulation of the test show excellent overall agreement.

The design bases FAC LOCA envelope has been found to be conservative when compared to the results of this test. The axial and radial power distributions, calculated and measured were found to be in good agreement. Finally, the calculated flux imbalance ($\Delta\phi$) from the measurements and from the simulation calculations show substantially the same behavior.

REFERENCES:

(1) K. A. Jones, C. C. Little, W. B. Henderson, "Augmented Startup and Cycle 1 Physics Program", WCAP-8575 (Westinghouse Proprietary) and WCAP-8576 (Non-proprietary), August 1975.

(2) C. R. Tuley, et.al., "Augmented Startup and Cycle 1 Physics Program--Supplement 1", WCAP-8575-Supplement 1 (Westinghouse Proprietary) and WCAP-8576-Supplement 1 (Non-proprietary), June 1976.

a, c, g

FIG. 1: INT LOAD FOLLOW TESTING: 60 HOUR POWER HISTORY PRIOR

a, c, g

FIGURE 1-B

a, c, g

FIGURE 2-A

a, c, g

FIGURE 2-8

a, c, g

FIGURE 2-C

a, c, g

FIGURE 2-D

a, c, g

FIGURE 2-E

a, c, g

FIGURE 3
LOCA ENVELOPE

a, c, g

FIGURE 4

APPENDIX A

MAP COMPARISONS
SIX-DAY OF LOAD FOLLOW

*

SIX-DAY LOAD FOLLOW 1A b,c,g

SIX-DAY LOAD FOLLOW 2A b, c, g

SIX-DAY LOAD FOLLOW 3A

b, c, g

SIX-DAY LOAD FOLLOW 4A b,c,g

*

SIX-DAY LOAD FOLLOW 5A b, c, g

SIX-DAY LOAD FOLLOW 6A ... b, c, g