Results of the October 1976 Augmented Startup Program Test Conducted at Indian Point Unit 3

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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) October 1976 Augmented Startup Test[1] was a 10% load swing test 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 the 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 that maneuver) are shown in Figure 1.1. 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.

2.0 TEST DESCRIPTION

Indian Point Unit 3 began operation April 25, 1976. After the startup testing interval, the core was depleted to about 1000 MWD/MTU burnup at 75% power with an average D bank position of 185 steps. The first Augmented Startup Test was begun on June 6, 1976. The core was operated from June to September, 1976 at an average power level of 80% with D bank at 190 steps. The core was shutdown at 2400 MWD/MTU for about 21 days. INT resumed operation on October 3 and after several days the plant returned to full power operation. A true equilibrium xenon condition was not established prior to 10% load swing test; therefore, a careful power history record was kept for 3 days before the start of the test. A concise pre-test history and load swing test profile are shown in Figures 2.1 and 2.2, respectively. The test profile shows both measured and calculated results as a function of real time. The top frame displays core power level and the axial peaking factor, F_Z. The middle frame gives the axial flux difference, $\Delta\phi$. The bottom frame shows the D bank position in steps withdrawn. Along the time axis, the various INCORE maps taken during the test are identified.

Overall, the test profile shows excellent agreement between excore and INCORE measurements of the axial flux difference, $\Delta\phi$. 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.

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 calculation are shown in Figure 2.2. 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 simulation are well within the criterion.

The calculated results for F_Z during the tests are also given in Figure 2.2. The guideline for good agreement in F_Z between INCORE and 1-D model results is [.][a,c] Again, the comparison is within this guideline. The calculated values for F_Z 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 2500 MWD/MTU cycle burnup at core power levels between 50% and 100%. A D bank calculation was performed at the test burnup. Power sharings calculated in the 1-D simulation of test were used to weight unrodded and rodded 2-D X-Y calculated power distributions to synthesize the assembly power distribution and $F_{\Delta H}$ 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 3.1 presents a representative comparison of INCORE and 1D/2D synthesis results for the core average axial peaking factor, F_Z, the epthalpy hot channel factor, $F_{\Delta H}$, and the power density hot channel factor, F_Q. Calculated $F_{\Delta H}$ results all fall within [ ]^{a,c} of the corresponding measurements; this is considered to be good agreement. A similar comparison for F_Z, shown in Figure 3.1, indicates measurement and calculation are within [ ]^{a,c} of each other.

The bottom frame of Figure 3.1 compares F_Q values. The calculated F_Q value was synthesized with the following expression:

$$F_Q = F_Z \times F_{XY} \times 1.03$$

where F_{XY} = the unrodded 2-D $F_{\Delta H}$ (1.34); D Bank $F_{\Delta H}$ (1.55)

1.03 = the transient xenon effect of F_{XY}.

The above expression assumes F_{XY} equals $F_{\Delta H}$ which is approximately correct for a first core. (Figure 3.1 shows that F_Q predicted by the calculational models agrees well with measurements.)

The expression for F_Q is extended to calculate the elevation-dependent peaking factor, $F_Q(Z)$, 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

Figure 1.1 compares the measured and calculated results for $F_Q(Z)$ for the test. The measured values include a 3% engineering factor and a 5% allowance for measurement uncertainty. Thus, INCORE and synthesized values for $F_Q(Z)$ are equivalent for comparison purposes. All the $F_Q(Z)$ comparisons show good agreement between calculation and measurement. The 1D/2D synthesis results tend to be slightly conservative at most elevations. It is concluded that the 1D/2D synthesis method using Westinghouse nuclear design models gave a very good prediction of the limiting values of $F_Q(Z)$ at all elevations.

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 2.1. 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 primary test objective was to develop a comparison between measured core power distribution parameters and calculated 1D/2D synthesis results using Westinghouse design models and methods. Figure 1.1 summarize the excellent agreement found for $F_Q(Z)$.

A second conclusion can be made concerning the appropriateness of the Final Acceptance Criteria (FAC) Analysis to confirm the LOCA limit envelope defined in the technical specifications. Figure 4.1 shows the FAC analysis results for $F_Q(Z)$ x Core Relative Power. These points are compared with the most limiting $F_Q(Z)$ x Core Relative Power data for the Augmented Startup Test. The Augmented Startup Test maneuver is less limiting than the FAC analysis results. The margin found in the test maneuvers is due in part to the difference between best estimate F_{XY} values and the FAC analysis F_{XY} value of 1.435.

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.

FIGURE 1.1 a, c, g

±10% LOAD SWING
FROM 100%

FIGURE 2.1

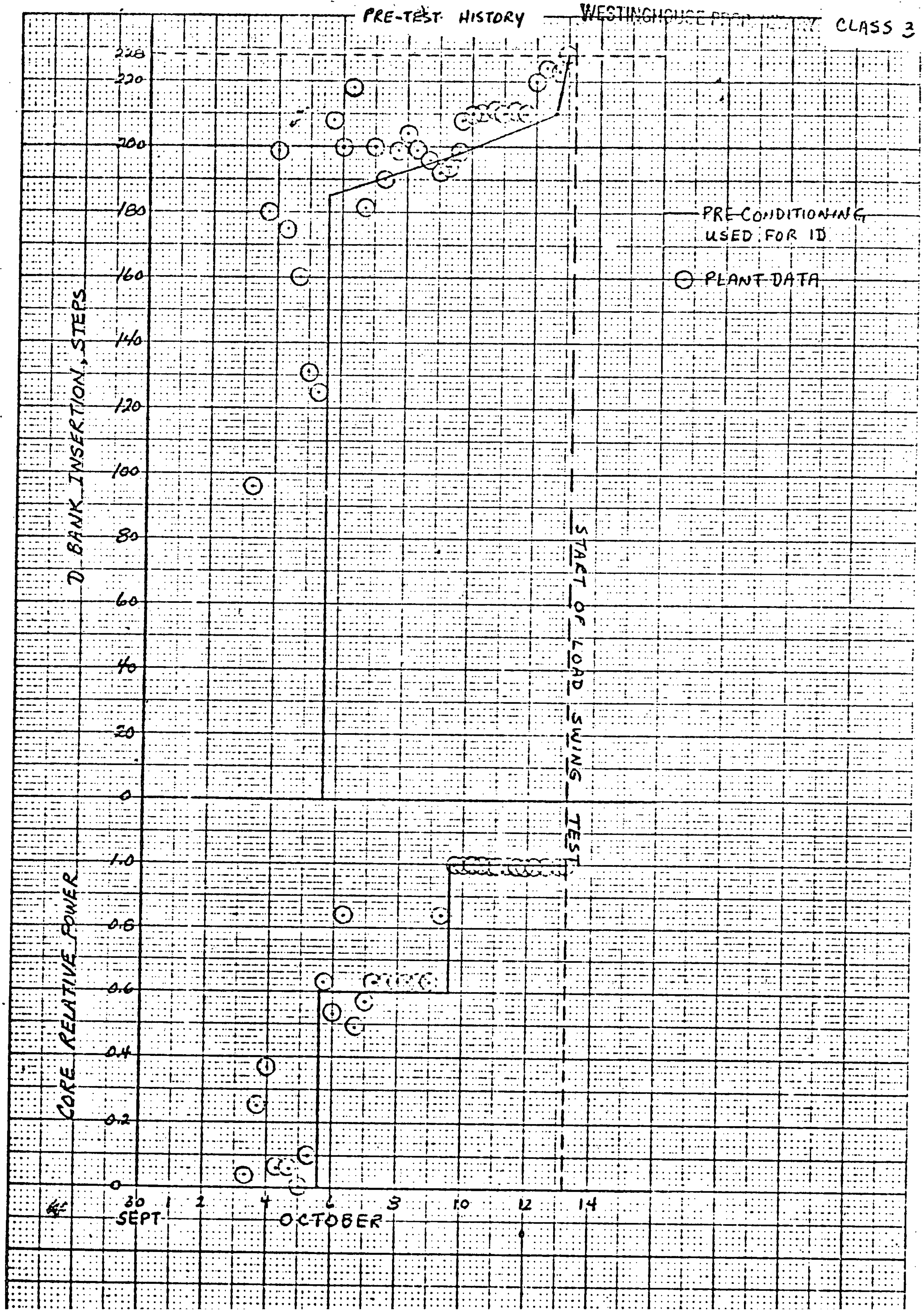
PRE-TEST HISTORY
WESTINGHOUSE PROPRIETARY CLASS 3
D BANK INSERTION, STEPS
228
220
200
180
160
140
120
100
80
60
40
20
0
CORE RELATIVE POWER
1.0
0.8
0.6
0.4
0.2
0
PRE CONDITIONING USED FOR ID
PLANT DATA
START OF LOAD SWING TEST
30
2
4
6
8
10
12
14
SEPT
OCTOBER

FIGURE 2.2

±10% LOAD SWING

PROFILE -100%

a,c,g

FIGURE 3.1

COMPARISON OF

F_Z, F_{AH}, F_Q

a,c,g

a,c,g

FIGURE 4.1
LOCA ENVELOPE

APPENDIX A

MAP COMPARISONS

±10% LOAD SWING FROM 100% POWER

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FIGURE A.1 b, c, g

±10% LOAD SWING

FIGURE 1.2 b, c, j

±10% LOAD SWING

*

FIGURE A.3

±10 % LOAD SWING

b, c, g

FIGURE A.4 b, c, g

±10% LOAD SWING

FIGURE A.5

±10% LOAD SWING

b, c, g