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NORTH ANNA UNIT 1, CYCLE 2
CORE PERFORMANCE REPORT

BY

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Section 1

INTRODUCTION AND SUMMARY

On December 28, 1980 after more than eleven months of operation, North Anna Unit 1 completed Cycle 2. Since the initial criticality of Cycle 2 on January 15, 1980, the reactor core produced approximately 64 x 10^6 MBTU (10,711 Megawatt days per metric ton of contained uranium) which has resulted in the generation of approximately 6.0 x 10^9 kwhr gross (5.6 x 10^9 kwhr net) of electrical energy. North Anna 1, Cycle 2 reached the end of full power reactivity at a core burnup of approximately 9,150 MWD/MTU at which point power operation was continued through a power coastdown. The unit was operated in the power coastdown mode, achieving an additional burnup of approximately 1561 MWD/MTU prior to shutting down for refueling. The purpose of this report is to present an analysis of the core performance for routine operation during Cycle 2. The physics tests that were performed during the startup of this cycle were covered in the North Anna 1, Cycle 2 Startup Physics Test Report[1] and, therefore, will not be included here.

The second cycle core consisted of four batches of fuel. Three once burned batches were brought from Cycle 1 (Batches 1A2, 2 and 3). One fresh batch was added to the Cycle 2 core. The North Anna 1, Cycle 2 core loading map specifying the fuel batch identification, fuel assembly locations, burnable poison locations and source assembly locations is shown in Figure 1.1. Movable detector locations and thermocouple locations are identified in Figure 1.2. Control rod locations are shown in Figure 1.3.

Routine core follow involves the analysis of four principal performance indicators. These are burnup distribution, reactivity depletion, power distribution, and primary coolant activity. The core burnup distribution is followed to verify both burnup symmetry and proper batch burnup sharing, thereby, ensuring that the fuel held over for the next cycle will be compatible with the new fuel that is inserted. Reactivity depletion is monitored to detect the existence of any abnormal reactivity behavior, to

determine if the core is depleting as designed, and to indicate at what burnup level refueling will be required. Core power distribution follow includes the monitoring of nuclear hot channel factors to verify that they are within the Technical Specifications[2] limits, thereby ensuring that adequate margins to linear power density and critical heat flux thermal limits are maintained. Lastly, as part of normal core follow, the primary coolant activity is monitored to verify that the dose equivalent iodine-131 concentration is within the limits specified by the North Anna Unit 1 Technical Specifications, and to assess the integrity of the fuel.

Each of the four performance indicators is discussed in detail for the North Anna 1, Cycle 2 core in the body of this report. The results are summarized below:

1. Burnup Follow - The burnup tilt (deviation from quadrant symmetry) on the core was no greater than $\pm$0.5% with the burnup accumulation in each batch deviating from design prediction by less than 2.1%.

2. Reactivity Depletion Follow - The critical boron concentration, used to monitor reactivity depletion, was consistently within $\pm$0.25% $\Delta K/K$ of the design prediction which is well within the $\pm$1% $\Delta K/K$ margin allowed by Section 4.1.1.1 of the Technical Specifications.

3. Power Distribution Follow - Incore flux maps taken each month indicated that the measured relative assembly power values were within 4% of the predicted values. All hot channel factors met their respective Technical Specifications limits.

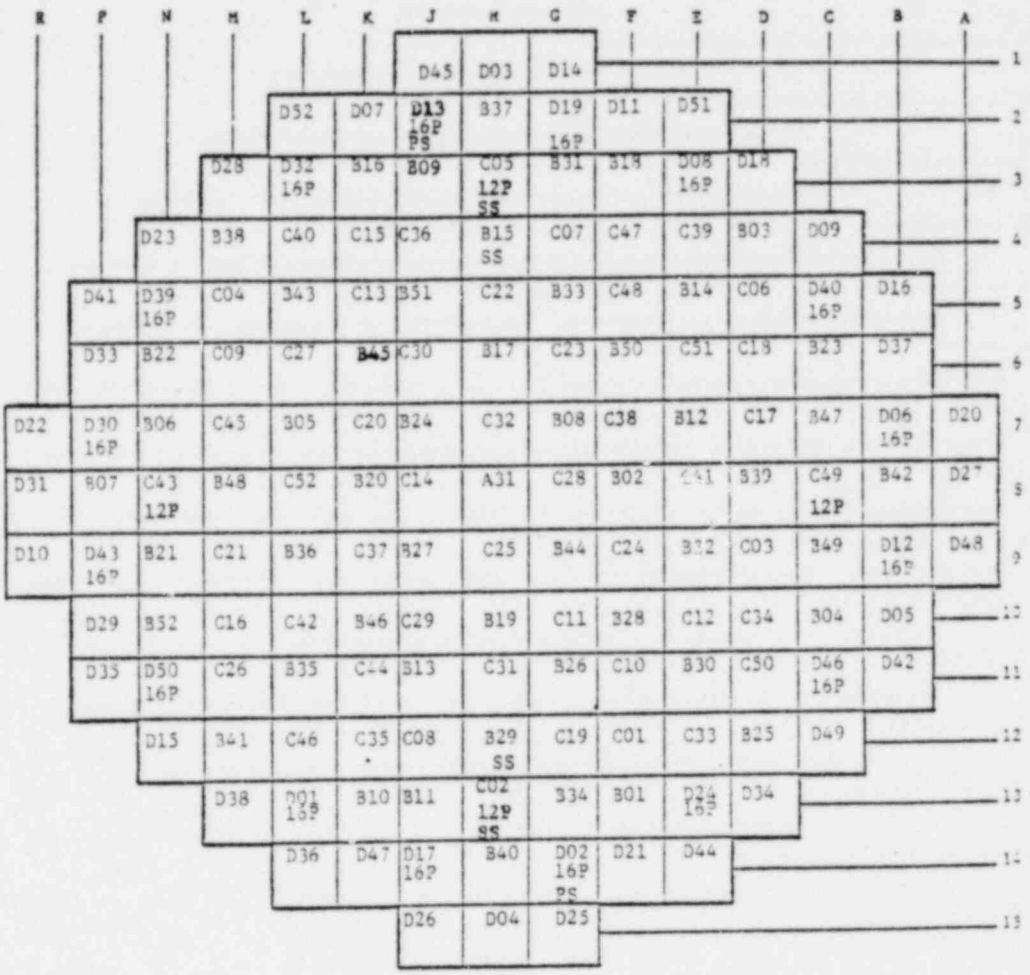
4. Primary Coolant Activity Follow - The dose equivalent iodine-131 activity level in the primary coolant at the end of Cycle 2 was approximately 1.1×10^{-2} μCi/gm. The average dose equivalent iodine -131 value during Cycle 2 was 8.9×10^{-3} μCi/gm. This corresponds to less than 1% of the operating limit for the concentration of radioiodine in the primary coolant.

In addition, the effects of fuel densification were monitored throughout the cycle. No densification effects were observed.

FIGURE 1.1

NORTH ANNA 1 - CYCLE 2

CORE LOADING



FUEL ASSEMBLY DESIGN PARAMETERS

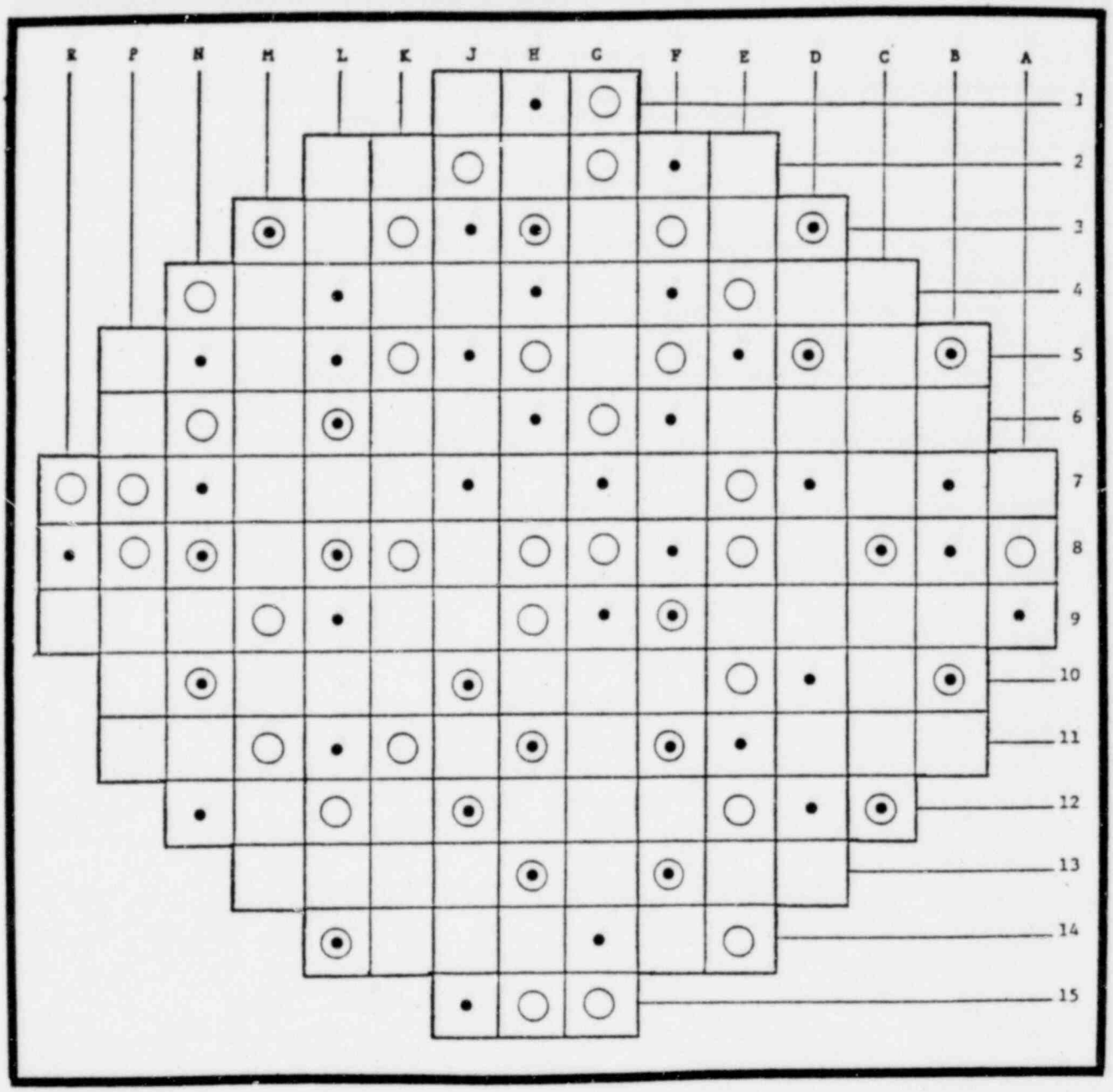
	A-Batch 1A2	B-Batch 2	C-Batch 3	D-Batch 4
Initial Enrichment (w/o U235)	2.10	2.60	3.10	3.20
Assembly Type	17x17	17x17	17x17	17x17
No. Of Assemblies	1	52	52	52
Fuel Rods per Assembly	264	264	264	264

- Assembly Identification
- One or more of the following:
  a. PS - Primary Source Assembly
  b. SS - Secondary Source Assembly
  c. xxP- Burnable Poison Assembly (xx - number of rods)

NORTH ANNA UNIT 1-CYCLE 2

MOVABLE DETECTOR AND

THERMOCOUPLE LOCATIONS



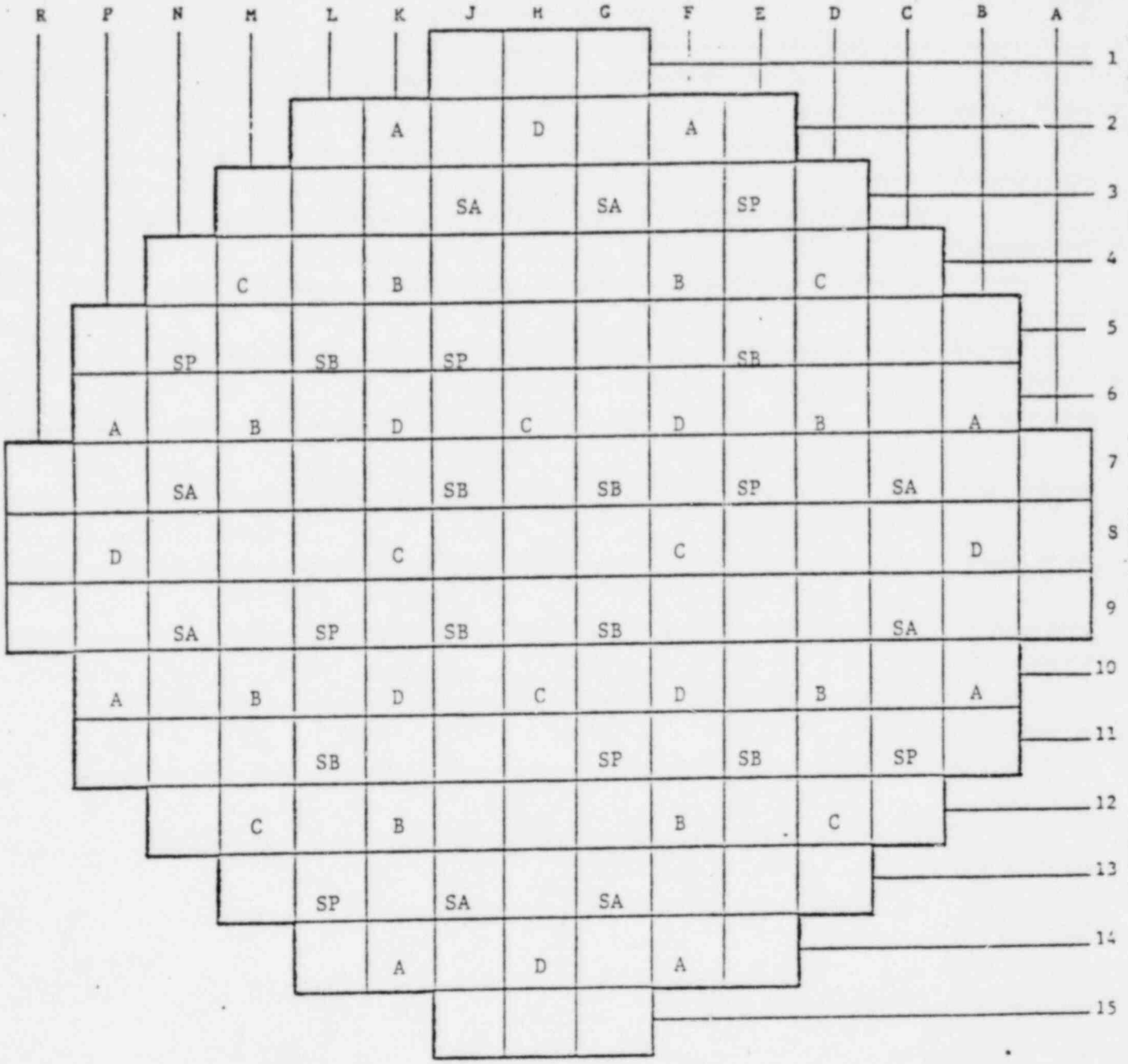
● - Movable Detector Location

◯ - Thermocouple Location

NORTH ANNA 1 - CYCLE 2

CONTROL ROD LOCATIONS

FIGURE 1.3



Absorber Material:
Ag-In-Cd

Function	Number of Clusters
Control Bank D	8
Control Bank C	8
Control Bank B	8
Control Bank A	8
Shutdown Bank S_B	8
Shutdown Bank S_A	8
SP (Spare Rod Locations)	8

Section 2

BURNUP FOLLOW

The burnup history for the North Anna Unit 1, Cycle 2 core is graphically depicted in Figure 2.1. The North Anna 1, Cycle 2 core achieved a burnup of 10711 MWD/MTU. As shown in Figure 2.2, the average load factor for Cycle 2 was 80% when referenced to rated thermal power (2775 MW(t)).

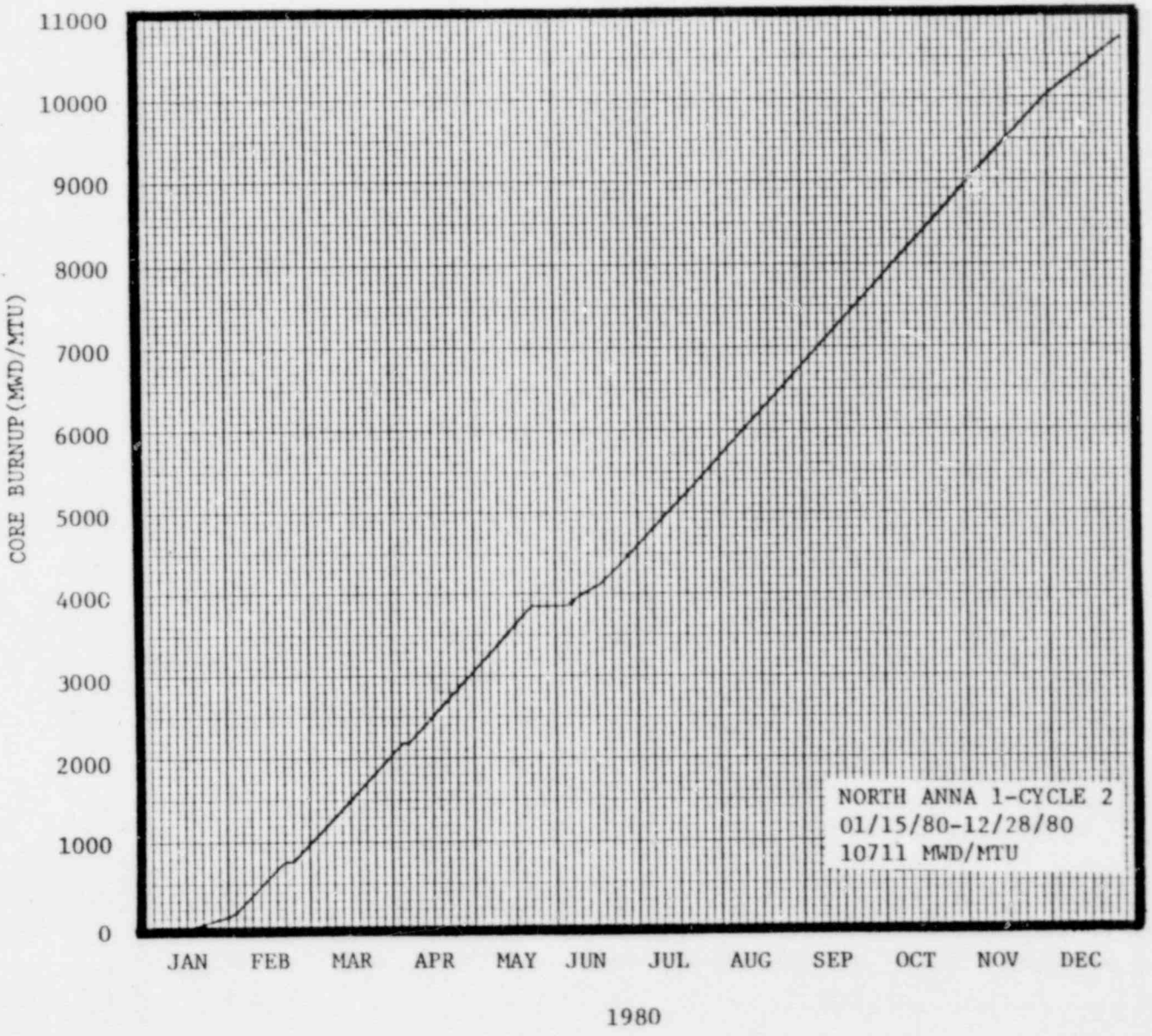
Radial (X-Y) burnup distribution maps show how the core burnup is shared among the various fuel assemblies, and thereby allow a detailed burnup distribution analysis. The NEWTOTE[3] computer code is used to calculate these assemblywise burnups. Figure 2.3 is a radial burnup distribution map in which the assemblywise burnup accumulation of the core at the end of Cycle 2 operation is given. For comparison purposes, the design values are also given. As can be seen from this figure, the accumulated assembly burnups were generally within 3.0% of the predicted values. In addition, deviation from quadrant symmetry in the core, as indicated by the burnup tilt factors, was less than $\pm$0.5%. The initial burnup tilt (0.75%) in the northeast quadrant for Cycle 2 resulted from the asymmetry caused by the power tilt that occurred during Cycle 1. As Cycle 2 proceeded, a reduction of the burnup tilt in the northeast quadrant was observed until the power tilt shifted from the southwest quadrant to the northeast quadrant. This shift of power tilt reinforced the existing burnup tilt and caused it to increase slightly in the northeast quadrant.

The burnup sharing on a batch basis is monitored to verify that the core is operating as designed and to enable accurate end-of-cycle batch burnup predictions to be made for use in reload fuel design studies. Batch definitions are given in Figure 1.1. As seen in Figure 2.4, the batch burnup sharing for North Anna Unit 1, Cycle 2 followed design predictions very closely with each batch deviating less than 2.1% from design; this is considered excellent agreement. The good agreement between actual and predicted assemblywise burnups and batch burnup sharing indicate that the Cycle 2 core did deplete essentially as designed.

NORTH ANNA 1 - CYCLE 2

CORE BURNUP HISTORY

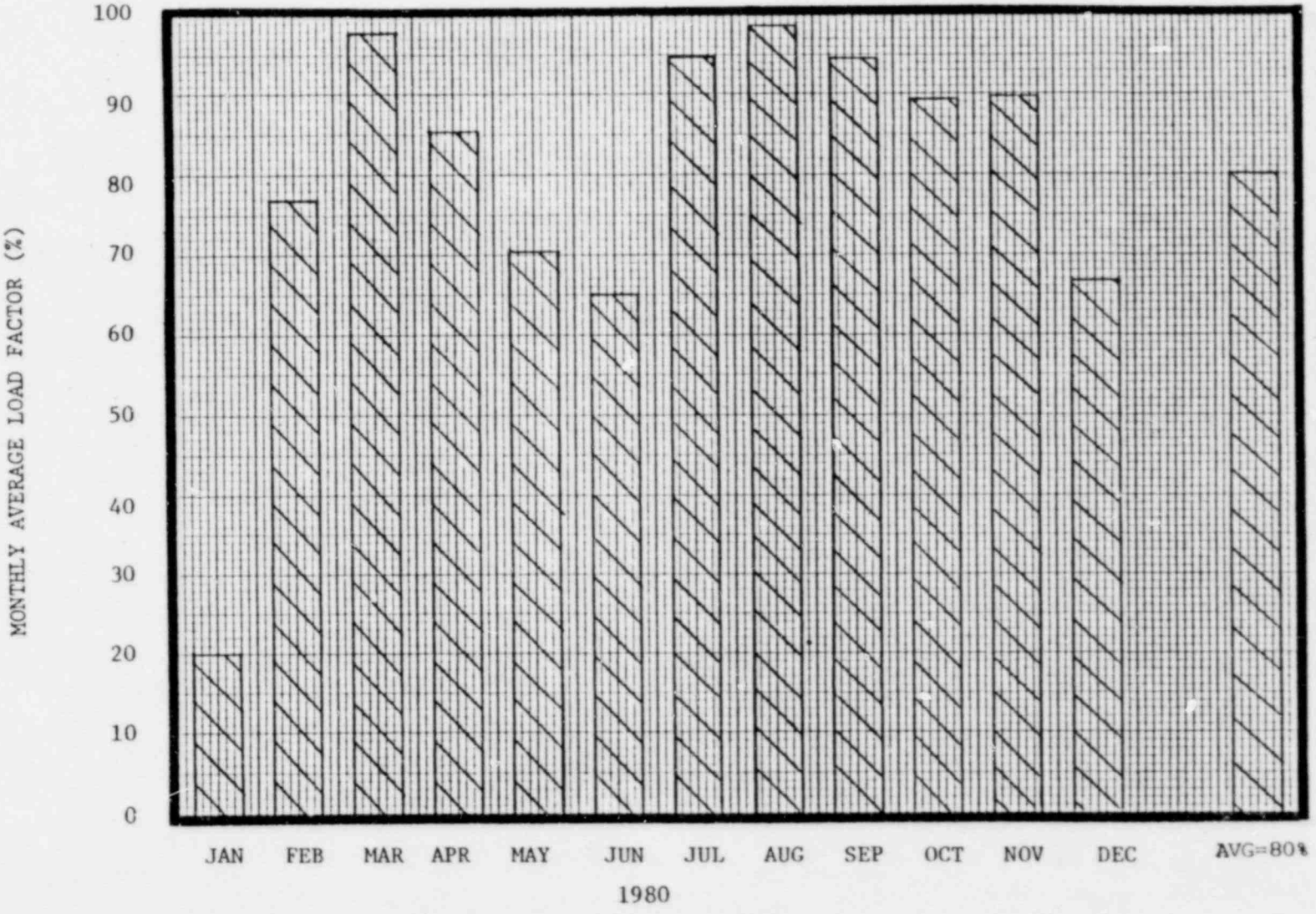
FIGURE 2.1



NORTH ANNA 1 - CYCLE 2

MONTHLY AVERAGE LOAD FACTORS

FIGURE 2.2



$$\text{Load Factor} = \frac{\text{Thermal Energy Generation in Reporting Period (MWHt)}}{\text{Authorized Power Level (MWt) x Hours in Reporting Period (excludes refueling outages)}}$$

Figure 2.3

NORTH ANNA UNIT 1 - CYCLE 2

ASSEMBLYWISE ACCUMULATED BURNUP: COMPARISON OF MEASURED WITH PREDICTED

(10^3 MWD/MTU)

R	P	N	M	L	K	J	H	G	F	E	D	C	B	A	
						7.93 7.63 3.9	9.64 9.37 2.9	7.94 7.63 4.1							1
				8.01 7.64 4.8	10.70 10.71 -0.1	12.51 12.67 -1.3	27.17 26.94 0.9	12.67 12.67 0.0	11.06 10.71 3.3	8.05 7.64 5.4					2
			8.02 7.78 3.1	12.41 12.20 1.7	28.68 28.72 -0.1	29.08 29.40 -1.1	20.74 20.84 -0.5	29.20 29.40 -0.7	29.07 28.72 1.2	12.52 12.20 2.6	8.34 7.78 7.2				3
		7.99 7.78 2.7	27.31 27.14 0.6	26.68 26.31 1.4	26.78 26.59 0.7	24.82 24.81 0.0	27.01 27.01 0.0	24.63 24.81 -0.7	26.98 26.59 1.5	26.67 26.31 1.4	27.19 27.14 0.2	8.22 7.78 5.7			4
	7.63 7.64 -0.1	12.11 12.20 -0.7	26.31 26.31 0.0	29.11 29.12 0.0	21.82 21.73 0.4	28.64 28.92 -1.0	23.22 23.14 0.3	28.58 28.92 -1.2	21.84 21.73 0.5	29.02 29.12 -0.3	26.37 26.31 0.2	12.67 12.20 3.9	8.23 7.64 7.7		5
	10.75 10.71 0.4	28.77 28.72 0.2	26.46 26.59 -0.5	21.50 21.73 -1.1	27.08 27.18 -0.4	22.37 22.49 -0.5	27.03 27.02 0.0	22.47 22.49 -0.1	27.34 27.18 0.6	22.04 21.73 1.4	27.00 26.59 1.5	28.83 28.72 0.4	11.07 10.71 3.4		6
7.77 7.63 1.8	12.58 12.67 -0.7	29.07 29.40 -1.1	24.67 24.81 -0.6	28.43 28.92 -1.7	22.23 22.49 -1.2	28.27 28.62 -1.2	21.49 21.40 0.4	28.15 28.62 -1.6	22.46 22.49 -0.1	28.36 28.92 -1.9	24.77 24.81 -0.2	29.20 29.40 -0.7	12.42 12.67 -2.0	7.64 7.63 0.1	7
9.18 9.37 -2.0	26.85 26.94 -0.3	20.99 20.84 0.7	27.18 27.01 0.6	22.75 23.14 -1.7	26.77 27.02 -0.9	21.19 21.40 -1.0	24.10 23.73 1.6	21.23 21.40 -0.8	26.96 27.02 -0.2	22.99 23.14 -0.6	26.99 27.01 -0.1	20.80 20.84 -0.2	27.50 26.94 2.1	9.68 9.37 3.3	8
7.79 7.63 2.1	12.59 12.67 -0.6	28.92 29.40 -1.6	24.60 24.81 -0.8	28.45 28.92 -1.6	22.55 22.49 0.3	28.17 28.62 -1.6	21.06 21.40 -1.6	27.87 28.62 -2.6	27.53 22.49 0.2	28.49 28.92 -1.5	24.85 24.81 0.2	29.11 29.40 -1.0	12.86 12.67 1.5	8.01 7.63 5.0	9
	10.92 10.71 2.0	28.87 28.72 0.5	26.97 26.59 1.4	21.88 21.73 0.7	26.92 27.18 -1.0	22.36 22.49 -0.6	26.72 27.02 -1.1	22.52 22.49 0.1	27.06 27.18 -0.4	21.69 21.73 -0.2	27.09 26.59 1.9	28.66 28.72 -0.2	11.16 10.71 4.2		10
	7.87 7.64 3.0	12.48 12.20 2.3	26.41 26.3 0.4	29.28 29.12 0.5	21.73 21.73 0.0	28.07 28.92 -2.9	22.82 23.14 -1.4	28.15 28.92 -2.7	21.62 21.73 -0.5	28.81 29.12 -1.1	26.73 26.31 1.6	12.47 12.20 2.2	7.95 7.64 4.1		11
		8.06 7.78 3.6	27.05 27.14 -0.3	26.40 26.31 0.3	26.88 26.59 1.1	24.68 24.81 -0.5	26.92 27.01 -0.3	24.45 24.81 -1.5	27.09 26.59 1.9	26.12 26.31 -0.7	26.95 27.14 -0.7	8.21 7.78 5.5			12
			8.09 7.78 4.0	12.59 12.20 3.2	28.37 28.72 -1.2	28.34 29.40 -3.6	20.67 20.84 -0.8	28.78 29.40 -2.1	28.63 28.72 -0.3	12.41 12.20 1.7	8.21 7.78 5.5				13
				7.93 7.64 3.8	11.11 10.71 3.7	12.56 12.67 -0.9	27.11 26.94 0.6	12.38 12.67 -2.3	10.71 10.71 0.0	7.82 7.64 2.4					14
						7.98 7.63 4.6	9.50 9.37 1.4	7.53 7.63 -1.3							15

BURNUP SHARING
(10^3 MWD/MTU)

BATCH	CYCLE 1	CYCLE 2	TOTAL
1A2	17.09	7.01	24.10
2	17.73	10.32	28.05
3	11.92	11.89	23.81
4	-	9.94	9.94
CORE AVERAGE		10.71	

MEASURED
PREDICTED
% DIFFERENCE

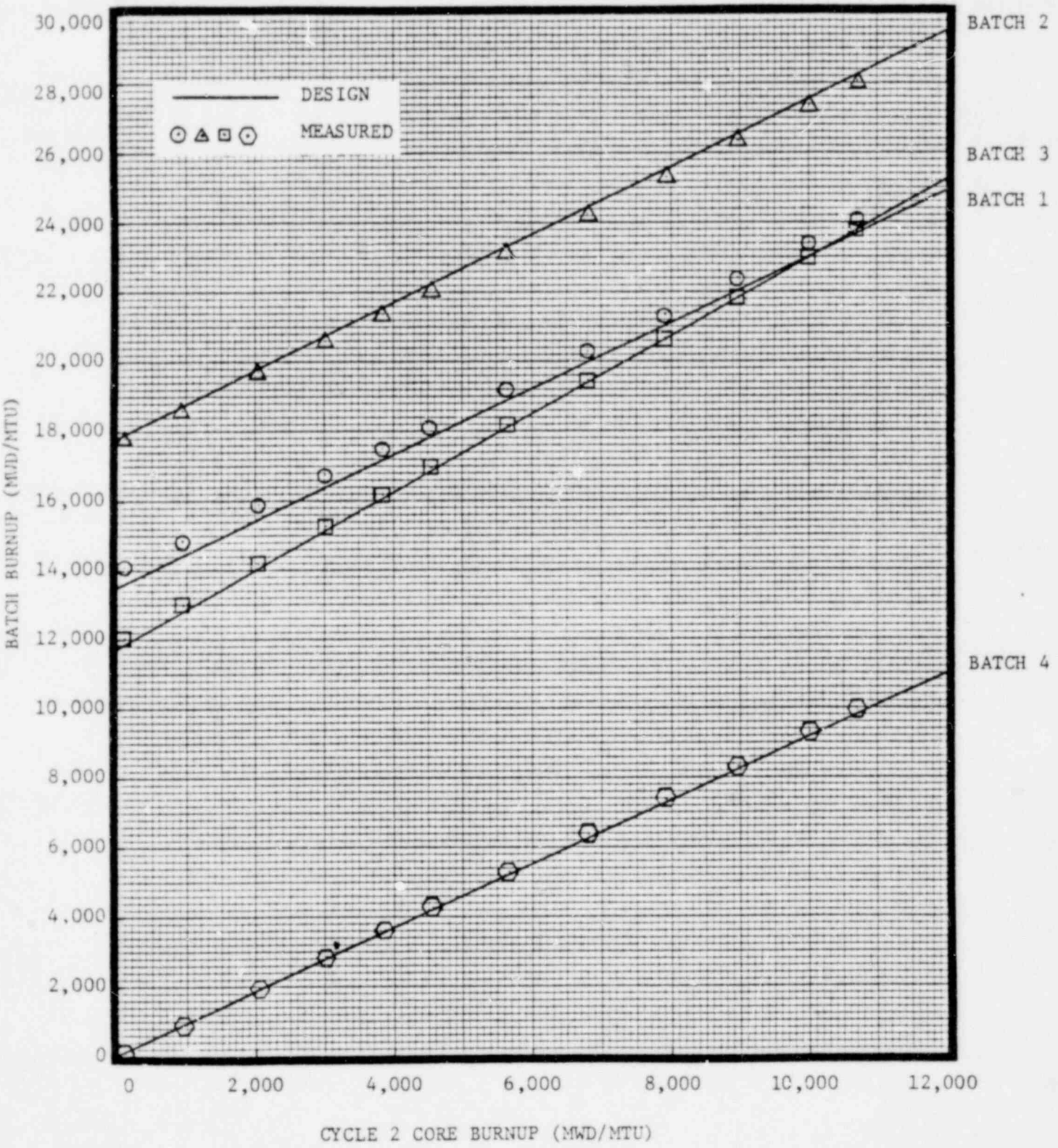
BURNUP TILT

NW- 0.9985
NE- 1.0048
SW- 0.9980
SE- 0.9988

NORTH ANNA 1 - CYCLE 2

FIGURE 2.4

BATCH BURNUP SHARING



Section 3

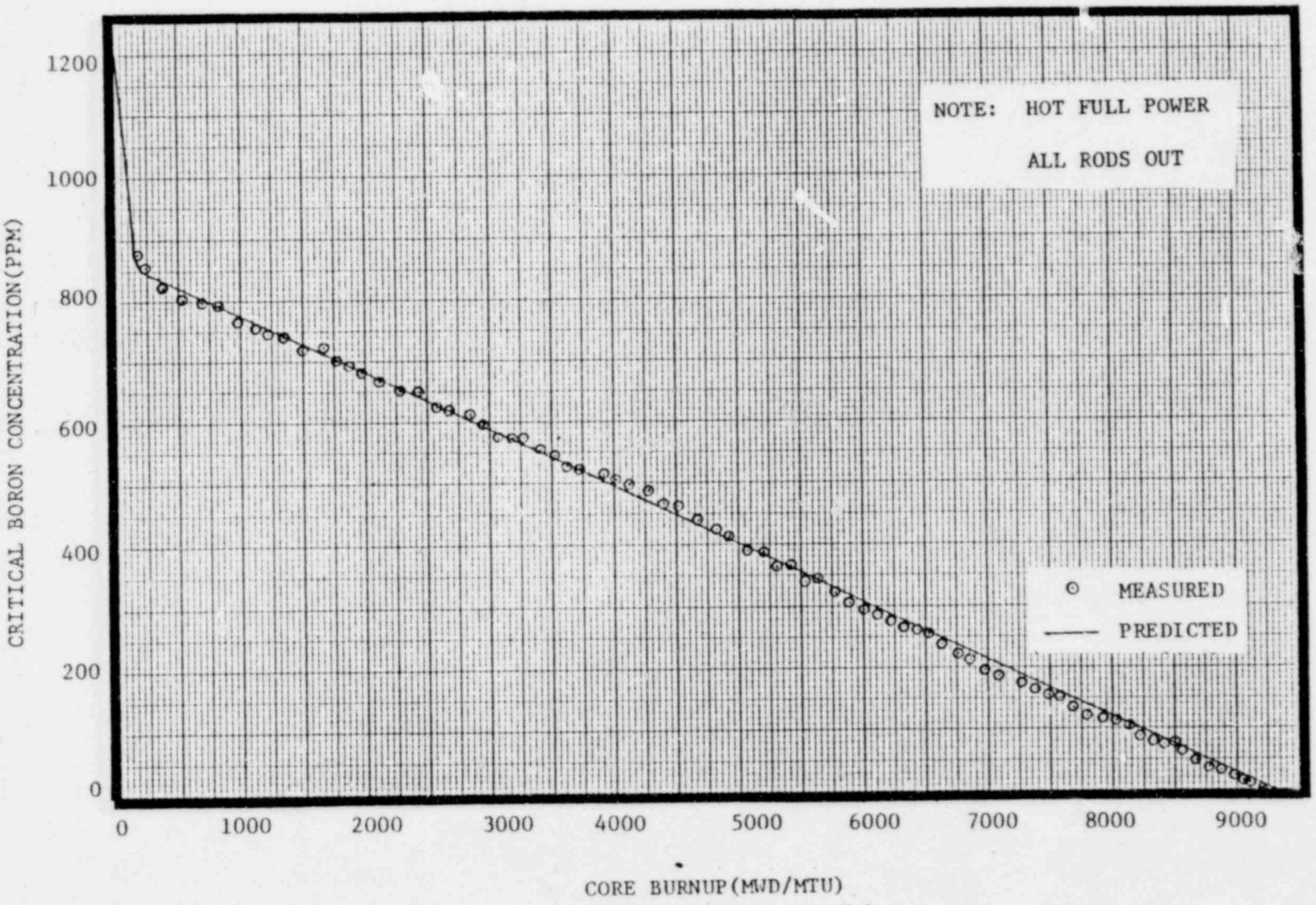
REACTIVITY DEPLETION FOLLOW

The primary coolant critical boron concentration is monitored for the purposes of following core reactivity and to identify any anomalous reactivity behavior. The FOLLOW[4] computer code was used to normalize "actual" critical boron concentration measurements to design conditions taking into consideration control rod position, xenon and samarium concentrations, moderator temperature, and power level. The normalized critical boron concentration versus burnup curve for the North Anna 1, Cycle 2 core is shown in Figure 3.1. It can be seen that the measured data compare to within 25 ppm of the design prediction. This corresponds to less than $\pm 0.25\%$ $\Delta K/K$, which is well within the $\pm 1\%$ $\Delta K/K$ criterion for reactivity anomalies set forth in Section 4.1.1.1 of the Technical Specifications. In conclusion, the trend indicated by the critical boron concentration verifies that the Cycle 2 core depleted as expected without any reactivity anomalies.

Figure 3.1

NORTH ANNA UNIT 1 - CYCLE 2

CRITICAL BORON CONCENTRATION vs. BURNUP-HFP, ARO



Section 4

POWER DISTRIBUTION FOLLOW

Analysis of core power distribution data on a routine basis is necessary to verify that the hot channel factors are within the Technical Specifications limits and to ensure that the reactor is operating without any abnormal conditions which could cause an "uneven" burnup distribution. Three-dimensional core power distributions are determined from movable detector flux map measurements using the INCORE[5] computer program. A summary of all full-core flux maps taken since the completion of startup physics testing for North Anna 1, Cycle 2 is given in Table 4.1. Power distribution maps were generally taken at monthly intervals with additional maps taken as needed.

Radial (X-Y) core power distributions for a representative series of incore flux maps are given in Figures 4.1 through 4.4. Figure 4.1 shows a power distribution map that was taken early in cycle life. Figure 4.2 shows a power distribution map that was taken near mid-cycle burnup. Figure 4.3 shows a map that was taken late in Cycle 2 life. Figure 4.4 shows a map that was taken during coastdown operation. Most of the radial power distributions were taken under equilibrium operating conditions with the unit operating at approximately full power. In each case, the measured relative assembly powers were generally within 4% of the predicted values.

The North Anna Unit 1 quadrant power tilt anomaly was described in the Cycle 1 Core Performance Report (VEP-FRD-34, December 1979) and in the Cycle 2 Startup Physics Test Report (VEP-FRD-35, June 1980). Further evaluations of the power tilt behavior during Cycle 2 indicated that the measured quadrant tilt did not exceed 1% at full-power, equilibrium conditions.

An important aspect of core power distribution follow is the monitoring of nuclear hot channel factors. Verification that these factors are within Technical Specifications limits ensures that linear power density and critical heat flux limits will not be violated, thereby providing adequate thermal margins and maintaining fuel

cladding integrity. The Cycle 2 Technical Specifications limit on the axially dependent heat flux hot channel factor, $F_Q^T(Z)$, was 2.10 x K(Z), where K(Z) is the hot channel factor normalized operating envelope. Figure 4.5 is a plot of the K(Z) curve associated with the 2.10 $F_Q(Z)$ limit. The axially dependent heat flux hot channel factors, $F_Q^T(Z)$, for a representative set of flux maps are given in Figures 4.6 through 4.9. Throughout Cycle 2, the measured values of $F_Q^T(Z)$ were within the Technical Specifications limit. A summary of the maximum values of all heat flux hot channel factors measured during Cycle 2 is given in Figure 4.10. As can be seen from this figure, there was approximately 15% margin to the limit at the beginning of the cycle, with the margin increasing substantially throughout cycle operation.

The value of the enthalpy rise hot channel factor, $F_{\Delta H}^N$, which is the ratio of the integral of the power along the rod with the highest integrated power to that of the average rod, is also routinely followed. The Technical Specifications limit for this parameter is set such that the critical heat flux (DNB) limit will not be violated. Additionally, the $F_{\Delta H}^N$ limit ensures that the value of this parameter used in the LOCA-ECCS analysis is not exceeded during normal operation. The Cycle 2 Technical Specifications limit on the enthalpy rise hot channel factor was set at 1.55 x (1+0.2(1-P)) x (1-RBP(BU)) where RBP(BU) is the thimble cell rod bow penalty and P is percentage of thermal power. The RBP(BU) values specified in the Technical Specifications are given in Figure 4.11. Because of the quadrant power tilt anomaly, revised control rod insertion limits were implemented during Cycle 2 initial operation to preclude violations of the $F_{\Delta H}^N$ Technical Specifications limit.[6] By operating in accordance with the revised insertion limits, adequate margin between the measured value and the Technical Specifications limit for $F_{\Delta H}^N$, was maintained throughout Cycle 2 as indicated by Figure 4.12.

The Technical Specifications require that target delta flux* values be determined periodically. The target delta flux is the delta flux which would occur at conditions of full power, all rods out, and equilibrium xenon. Therefore, the delta flux is measured with the core at or near these conditions and the target delta flux is established at this measured point. Since the target delta flux varies as a function of burnup, the target value is updated monthly. Operational delta flux limits are then established about this target value. By maintaining the value of delta flux relatively constant, adverse axial power shapes due to xenon redistribution are avoided. The plot of target delta flux versus burnup, given in Figure 4.13, shows the value of this parameter to have been approximately -0.5% at the beginning of Cycle 2. By the middle of the cycle, the value of delta flux had shifted to approximately -5%, and then shifted to approximately 0% by the end of Cycle 2 (excluding coastdown operation). This power shift can also be observed in the corresponding core average axial power distribution for a representative series of maps given in Figures 4.14 through 4.17. In Map N1-2-18 (Figure 4.14) taken at approximately 570 MWD/MTU, the axial power distribution had a flattened cosine shape with a peaking factor of 1.124. In Map N1-2-30 (Figure 4.15) taken at approximately 4,490 MWD/MTU, the axial power distribution was peaked slightly toward the bottom of the core with an axial peaking factor of 1.131. In Map N1-2-47 (Figure 4.16) taken at approximately 8,811 MWD/MTU, the axial power distribution was peaked toward the bottom of the core with a peaking factor of 1.132. Finally, in Map N1-2-52 (Figure 4.17) taken during coastdown operation at approximately 10,338 MWD/MTU, the axial power distribution was peaked heavily toward the top of the core with a peaking factor of 1.230. The history of $\bar{F}_z$ during the cycle can be seen more clearly in the plot of $\bar{F}_z$ versus burnup given in Figure 4.18.

*Delta Flux = $\frac{P_t - P_b}{2775} \times 100$ where P_t = power in top of core (Mw(t))
P_b = power in bottom of core (Mw(t))

In conclusion, the North Anna 1, Cycle 2 core performed satisfactorily with power distribution analyses verifying that design predictions were accurate and that the values of the hot channel factors were within the limits of the Technical Specifications.

TABLE 4.1

NORTH ANNA-UNIT 1 - CYCLE 2
SUMMARY TABLE OF INCORE FLUX MAPS
FOR ROUTINE OPERATION

MAP NUMBER	DATE	% POWER	BANK D (STEPS)	CORE $\overline{F}_Z$	F^T_Q HOT CHANNEL FACTOR				$F^N_{\Delta H}$ HOT CHANNEL FACTOR			TILT		AXIAL OFFSET %	BURNUP (MWD/MTU)	NO. OF MONITORED THIMBLES
					ASSY.	PIN	AXIAL POINT	T_{F^Q} (1)	ASSY.	PIN	$N_{F^{\Delta H}}$ (2)	MAX.	QUAD LOC.			
N1-2-15	2/7/80	99.0	228	1.113	B10	EN	45	1.762	P09	LK	1.387	1.0096	SW	0.127	300	48
N1-2-16 (3)	2/7/80	98.5	208	1.201	B10	EN	46	1.902	L13	LM	1.403	1.0138	SW	-7.267	349	46
N1-2-18	2/14/80	99.8	213	1.124	B10	EN	45	1.776	L13	LM	1.395	1.0097	SW	-0.553	570	47
N1-2-19	2/25/80	31.1	163	1.210	K14	NM	30	1.952	L13	LM	1.502	1.0185	SW	-2.960	809	43
N1-2-20	2/26/80	99.3	206	1.124	B10	EN	46	1.796	L13	LM	1.434	1.0144	SW	-1.250	824	45
N1-2-21	3/5/80	99.3	220	1.114	B10	EN	46	1.786	P09	LK	1.407	1.0108	SW	-0.659	1129	45
N1-2-22	3/5/80	98.5	213	1.156	L13	LM	46	1.823	L13	LM	1.416	1.0111	SW	-4.265	1160	41
N1-2-24 (4)	3/17/80	99.7	221	1.114	B10	EN	45	1.788	P09	ML	1.407	1.0094	SW	-1.018	1586	44
N1-2-25	4/15/80	99.3	220	1.109	B10	EN	46	1.743	B09	FK	1.397	1.0054	SW	-0.580	2511	47
N1-2-26	5/5/80	99.9	222	1.116	B10	EN	46	1.737	B09	EL	1.392	1.0030	SE	-1.498	3277	47
N1-2-27	5/9/80	99.8	221	1.128	B10	EN	46	1.742	B09	EL	1.386	1.0040	SW	-2.385	3450	47

NOTES: HOT SPOT LOCATIONS ARE SPECIFIED BY GIVING ASSEMBLY LOCATIONS (E.G. H-8 IS THE CENTER OF CORE ASSEMBLY), FOLLOWED BY THE PIN LOCATION (DENOTED BY THE "Y" COORDINATE WITH THE SEVENTEEN ROWS OF FUEL RODS LETTERED A THROUGH Q, AND THE "X" COORDINATE DESIGNATED IN A SIMILAR MANNER). IN THE "Z" DIRECTION THE CORE IS DIVIDED INTO 61 AXIAL POINTS STARTING FROM THE TOP OF THE CORE.

(1) F^T_Q INCLUDES A 1.03 ENGINEERING UNCERTAINTY AND A 1.05 MEASUREMENT UNCERTAINTY.

(2) $F^N_{\Delta H}$ INCLUDES A 1.04 MEASUREMENT UNCERTAINTY.

(3) N1-2-17 WAS A PARTIAL MAP TAKEN FOR THE POWER TILT STUDY.

(4) N1-2-23 WAS A PARTIAL MAP TAKEN FOR THE POWER TILT STUDY.

TABLE 4.1 (CONT.)

MAP NUMBER	DATE	% POWER	BANK D (STEPS)	CORE $\bar{F}_Z$	F_Q^T HOT CHANNEL FACTOR				$F_{\Delta H}^N$ HOT CHANNEL FACTOR			TILT		AXIAL OFFSET %	BURNUP (MWD/MTU)	NO. OF MONITORED THIMBLES
					ASSY.	PIN	AXIAL POINT	F_Q^T	ASSY.	PIN	$F_{\Delta H}^N$	MAX.	QUAD LOC.			
N1-2-28	5/22/80	99.8	218	1.11[illegible]	C05	EF	46	1.714	C05	EF	1.415	1.0033	NE	-1.924	3947	44
N1-2-29	6/7/80	23.5	152	1.249	B10	EN	36	2.027	L13	LM	1.504	1.0125	SW	-9.135	4049	38
N1-2-30	6/23/80	100.2	215	1.131	B10	EN	46	1.698	C05	EF	1.364	1.0035	NE	-3.096	4490	47
N1-2-31 (5)	6/24/80	99.7	207	1.196	G02	FE	47	1.820	C05	EF	1.416	1.0068	NE	-7.604	4525	39
N1-2-33 (6)	7/12/80	99.0	215	1.118	B10	EN	47	1.661	C05	EF	1.364	1.0052	NE	-2.164	5147	46
N1-2-35	7/30/80	97.9	218	1.147	L13	LM	47	1.653	C05	EF	1.351	1.0062	NE	-3.438	5762	47
N1-2-36	8/11/80	99.8	225	1.181	L13	LM	47	1.677	C05	EF	1.344	1.0052	NE	-5.194	6338	47
N1-2-37	8/28/80	99.7	216	1.178	B10	EN	47	1.651	C05	EF	1.341	1.0042	NE	-5.227	6791	46
N1-2-37Y	9/9/80	31.9	182	1.184	L13	LM	29	1.790	L13	LM	1.434	1.0152	SW	-1.120	7325	38
N1-2-38	9/11/80	99.5	217	1.143	B10	EN	47	1.602	C05	EF	1.336	1.0047	NE	-3.290	7375	47
N1-2-39	9/13/80	98.7	215	1.234	C05	EF	53	1.695	C05	EF	1.341	1.0092	NE	-8.691	7449	47
N1-2-40	9/14/80	99.3	215	1.096	L13	LM	46	1.553	C05	EF	1.333	1.0056	NE	-1.047	7453	47
N1-2-41	9/21/80	99.0	207	1.156	B10	EN	47	1.625	C05	EF	1.344	1.0065	NE	-5.241	7730	46
N1-2-42	9/27/80	100.0	199	1.251	C05	EF	53	1.713	C05	EF	1.349	1.0070	NE	-10.795	7976	47
N1-2-43	9/28/80	99.0	204	1.240	F05	MN	54	1.703	C05	EF	1.341	1.0073	NE	-9.158	8005	46

(5) N1-2-32 WAS A PARTIAL MAP TAKEN FOR AN I/E CALIBRATION.

(6) N1-2-34 DID NOT HAVE THE REQUIRED MINIMUM NUMBER OF THIMBLES.

TABLE 4.1 (CONT.)

MAP NUMBER	DATE	% POWER	BANK D (STEPS)	CORE F_Z	F_Q^T HOT CHANNEL FACTOR				$F_{\Delta H}^N$ HOT CHANNEL FACTOR			TILT		AXIAL OFFSET %	BURNUP (MWD/MTU)	NO. OF MONITORED THIMBLES
					ASSY.	PIN	AXIAL POINT	F_Q^T	ASSY.	PIN	$F_{\Delta H}^N$	MAX.	QUAD LOC.			
N1-2-44 (7)	9/30/80	99.9	210	1.152	L13	LM	47	1.596	C05	EF	1.334	1.0074	NE	-4.159	8109	47
N1-2-46	10/17/80	49.4	162	1.173	L13	LM	37	1.711	C05	EF	1.408	1.0118	NE	-8.896	8629	41
N1-2-47	10/22/80	100.0	228	1.132	L13	LM	47	1.549	C05	EF	1.326	1.0087	NE	-2.219	8811	46
N1-2-48	10/31/80	100.1	228	1.195	L10	DE	53	1.627	C05	EF	1.323	1.0083	NE	-5.713	9117	48
N1-2-49	11/18/80	87.0	228	1.116	C05	EF	13	1.522	C05	EF	1.323	1.0072	NE	0.689	9617	47
N1-2-50	11/24/80	85.9	228	1.153	C05	EF	12	1.575	C05	EF	1.320	1.0080	NE	3.317	9820	47
N1-2-51	12/5/80	72.8	228	1.194	B09	EL	12	1.624	B09	EL	1.314	1.0052	NE	5.626	10132	47
N1-2-52	12/11/80	68.0	228	1.230	B09	EL	12	1.673	C05	EF	1.311	1.0053	NE	8.322	10338	46

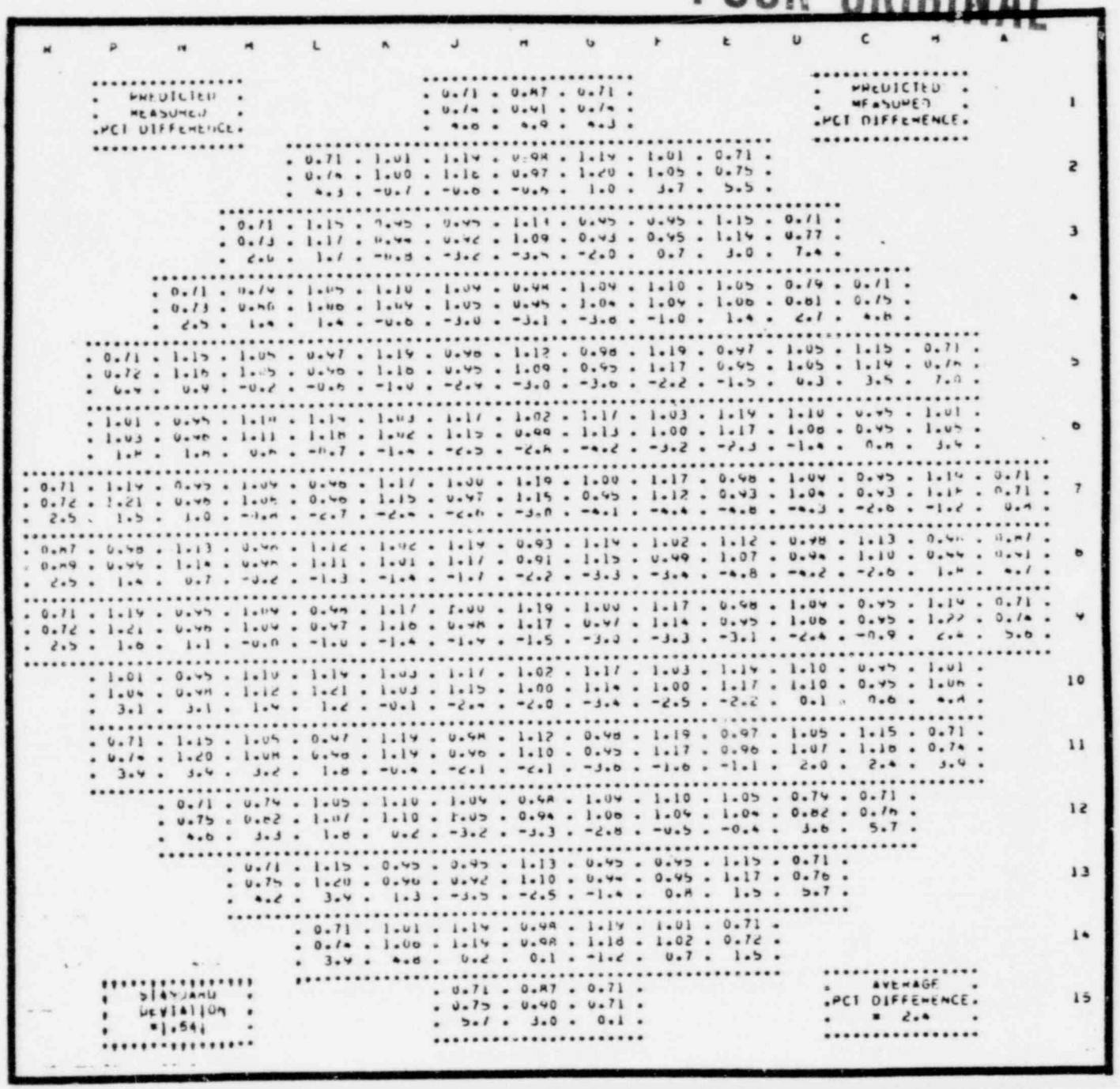
(7) N1-2-45 WAS A PARTIAL MAP TAKEN TO VERIFY THE AGREEMENT BETWEEN INCORE AXIAL OFFSETS AND EXCORE ΔI VALUES.

FIGURE 4.1

NORTH ANNA UNIT 1-CYCLE 2

ASSEMBLYWISE POWER DISTRIBUTION N1-2-18

POOR ORIGINAL



MAP NO. N1-2-18 DATE 2/14/80 POWER - 99.8%

CONTROL ROD POSITIONS $F^N_{\Delta H}$ = 1.395* AT L13-LM INCORE TILT

BANK C AT 228 STEPS F^T_Q = 1.776* AT B10-EN NW - 0.998

BANK D AT 213 STEPS $\bar{F}_Z$ = 1.124 NE - 0.996

A.O. =-0.553 SW - 1.009

*Includes uncertainties BURNUP = ~570 MWD/MTU SE - 0.997

FIGURE 4.2

NORTH ANNA UNIT 1-CYCLE 2

ASSEMBLYWISE POWER DISTRIBUTION N1-2-30

POOR ORIGINAL

R	P	N	M	L	K	J	H	G	F	E	D	C	B	A	
	PREDICTED					0.71	0.87	0.71				PREDICTED			1
	MEASURED					0.75	0.91	0.74				MEASURED			
	PCT DIFFERENCE					4.5	4.5	4.0				PCT DIFFERENCE			
				0.72	1.00	1.18	0.97	1.18	1.00	0.72					2
				0.75	1.01	1.19	0.97	1.19	1.04	0.76					
				3.9	0.4	-0.0	-0.0	1.0	3.4	5.1					
			0.73	1.14	0.95	0.96	1.13	0.96	0.95	1.14	0.73				3
			0.75	1.17	0.95	0.94	1.10	0.95	0.96	1.18	0.78				
			2.0	1.8	0.1	-2.4	-2.7	-1.5	1.2	3.1	6.8				
		0.73	0.81	1.05	1.09	1.09	0.99	1.09	1.09	1.05	0.81	0.73			4
		0.74	0.82	1.06	1.09	1.06	0.96	1.06	1.09	1.07	0.84	0.77			
		1.3	0.8	1.2	-0.2	-2.3	-2.4	-3.0	0.0	2.0	3.1	4.8			
	0.72	1.14	1.05	0.97	1.18	0.99	1.12	0.99	1.18	0.97	1.05	1.14	0.72		5
	0.71	1.13	1.04	0.97	1.17	0.96	1.09	0.96	1.17	0.97	1.06	1.19	0.77		
	-1.0	-1.0	-0.6	-0.4	-0.7	-2.4	-2.5	-2.2	-0.5	0.0	1.2	3.8	6.4		
	1.00	0.95	1.09	1.18	1.02	1.16	1.02	1.16	1.02	1.18	1.09	0.95	1.00		6
	1.01	0.96	1.09	1.17	1.01	1.14	1.00	1.14	1.01	1.17	1.09	0.96	1.04		
	0.6	0.6	0.0	-0.7	-1.1	-1.9	-1.9	-2.1	-1.1	-0.5	-0.2	1.2	3.2		
0.71	1.13	0.96	1.09	0.99	1.16	1.00	1.18	1.00	1.16	0.99	1.09	0.96	1.18	0.71	7
0.73	1.18	0.96	1.08	0.98	1.14	0.98	1.16	0.98	1.14	0.96	1.06	0.94	1.17	0.71	
2.1	-0.3	-0.2	-1.3	-2.3	-2.0	-1.9	-1.9	-2.3	-2.2	-2.5	-2.9	-2.0	-1.4	-0.1	
0.87	0.97	1.12	0.99	1.12	1.02	1.18	0.94	1.18	1.02	1.12	0.99	1.13	0.97	0.87	8
0.85	0.97	1.12	0.98	1.10	1.01	1.16	0.93	1.15	1.00	1.09	0.95	1.11	0.96	0.91	
-2.3	-0.4	-0.6	-1.0	-1.7	-1.5	-1.2	-1.4	-2.3	-2.4	-3.0	-2	-2.0	1.2	3.6	
0.71	1.18	0.96	1.09	0.99	1.16	1.00	1.18	1.00	1.16	0.99	1.09	0.96	1.18	0.71	9
0.73	1.16	0.96	1.08	0.97	1.14	0.97	1.16	0.97	1.13	0.98	1.07	0.96	1.21	0.75	
2.3	-0.3	-0.3	-0.9	-1.5	-2.0	-2.9	-2.0	-2.4	-2.6	-2.4	-1.9	-0.8	2.3	5.0	
	1.00	0.95	1.09	1.18	1.02	1.16	1.02	1.16	1.02	1.18	1.09	0.95	1.00		10
	1.03	0.97	1.10	1.18	1.01	1.13	1.00	1.13	1.01	1.16	1.10	0.96	1.05		
	2.3	2.3	1.0	0.3	-1.0	-3.0	-2.4	-2.5	-1.5	-1.2	0.3	0.7	4.4		
	0.72	1.14	1.05	0.97	1.18	0.99	1.12	0.99	1.18	0.97	1.05	1.14	0.72		11
	0.73	1.17	1.06	0.98	1.15	0.96	1.09	0.96	1.17	0.97	1.07	1.17	0.75		
	2.0	2.0	1.8	0.8	-1.5	-2.7	-2.7	-2.6	-0.4	-0.3	1.8	2.1	3.9		
		0.73	0.81	1.05	1.09	1.09	0.99	1.09	1.09	1.05	0.81	0.73			12
		0.75	0.82	1.08	1.05	0.95	1.07	1.10	1.05	0.84	0.77				
		1.7	1.3	0.8	-0.8	-3.3	-3.3	-2.2	0.3	0.3	3.3	4.7			
			0.73	1.14	0.95	0.96	1.13	0.96	0.95	1.14	0.73				13
			0.75	1.18	0.95	0.93	1.10	0.95	0.95	1.16	0.77				
			2.3	2.9	0.3	-3.5	-2.9	-1.5	0.2	1.3	4.7				
				0.72	1.00	1.18	0.97	1.18	1.00	0.72					14
				0.74	1.04	1.19	0.97	1.16	1.00	0.73					
				2.9	4.1	0.5	-0.3	-1.5	0.1	1.3					
	STANDARD					0.71	0.87	0.71				AVERAGE			15
	DEVIATION					0.75	0.89	0.71				PCT DIFFERENCE			
	=1.364					5.4	2.2	-1.1				= 1.9			

MAP NO. N1-2-30

DATE 6/23/80

POWER - 100.0%

CONTROL ROD POSITIONS

$F^N_{\Delta H}$ = 1.364* AT C5-EF

INCORE TILT

BANK C AT 228 STEPS

F^T_Q = 1.698* AT B10-EN

NW - 0.997

BANK D AT 215 STEPS

$\bar{F}_Z$ = 1.131

NE - 1.003

A.O. = -3.096

SW - 1.000

BURNUP = ~4490 MWD/MTU

SE - 1.000

*Includes uncertainties

FIGURE 4.3

NORTH ANNA UNIT 1-CYCLE 2

ASSEMBLYWISE POWER DISTRIBUTION N1-2-47

POOR ORIGINAL

R	P	N	M	L	K	J	H	G	F	E	D	C	B	A	
	PREDICTED					0.70	0.86	0.70				PREDICTED			
	MEASURED					0.74	0.90	0.73				MEASURED			1
	PCT DIFFERENCE					4.7	4.7	4.1				PCT DIFFERENCE			
				0.71	0.97	1.14	0.97	1.14	0.97	0.71					
				0.74	0.98	1.14	0.97	1.15	1.00	0.74					2
				4.2	1.0	0.4	0.4	1.3	3.5	4.8					
			0.74	1.11	0.95	0.97	1.12	0.97	0.95	1.11	0.74				
			0.75	1.13	0.95	0.95	1.10	0.95	0.96	1.14	0.78				3
			2.2	2.0	0.4	-2.0	-2.3	-1.3	1.3	3.0	5.3				
		0.74	0.83	1.05	1.09	1.10	1.01	1.10	1.09	1.05	0.83	0.74			
		0.75	0.83	1.06	1.10	1.08	0.99	1.07	1.10	1.07	0.85	0.77			4
		1.3	0.8	1.3	0.2	-1.7	-1.9	-2.8	0.1	2.0	3.1	5.3			
	0.71	1.11	1.05	0.99	1.18	1.01	1.14	1.01	1.18	0.99	1.05	1.11	0.71		
	0.70	1.09	1.04	0.98	1.17	0.99	1.12	0.99	1.18	0.99	1.06	1.16	0.76		5
	-1.4	-1.4	-0.8	-0.5	-0.5	-1.8	-1.9	-1.7	-0.1	0.4	1.5	4.8	8.0		
	0.97	0.95	1.09	1.18	1.05	1.18	1.05	1.18	1.05	1.18	1.09	0.95	0.97		
	0.97	0.95	1.09	1.17	1.05	1.16	1.03	1.16	1.05	1.18	1.10	0.97	1.01		6
	0.2	0.2	-0.3	-0.8	-0.7	-1.1	-1.1	-1.2	-0.1	0.1	0.4	2.0	4.1		
0.70	1.14	0.97	1.10	1.01	1.18	1.03	1.19	1.03	1.18	1.01	1.10	0.97	1.14	0.70	
0.72	1.13	0.96	1.08	0.98	1.15	1.01	1.18	1.01	1.16	0.99	1.08	0.95	1.13	0.70	7
1.8	-0.8	-0.6	-1.6	-2.5	-2.0	-1.4	-1.2	-1.5	-1.3	-1.6	-1.9	-1.2	-0.9	0.2	
0.86	0.97	1.12	1.01	1.14	1.05	1.19	0.98	1.19	1.05	1.14	1.01	1.12	0.97	0.86	
0.83	0.96	1.11	0.99	1.12	1.03	1.18	0.98	1.18	1.03	1.11	0.99	1.11	0.98	0.89	8
-3.5	-0.9	-1.0	-1.5	-2.1	-1.7	-0.9	-0.6	-1.5	-1.6	-2.3	-2.0	-1.3	1.4	3.5	
0.70	1.14	0.97	1.10	1.01	1.18	1.03	1.19	1.03	1.18	1.01	1.10	0.97	1.14	0.70	
0.72	1.13	0.96	1.08	0.99	1.15	0.99	1.17	1.01	1.16	0.99	1.09	0.97	1.17	0.74	9
1.9	-0.8	-0.8	-1.4	-2.0	-2.6	-3.7	-2.0	-1.8	-1.9	-1.8	-1.2	-0.0	2.4	4.7	
	0.97	0.95	1.09	1.18	1.05	1.18	1.05	1.18	1.05	1.18	1.09	0.95	0.97		
	0.99	0.97	1.10	1.18	1.04	1.14	1.02	1.15	1.04	1.17	1.10	0.96	1.01		10
	1.9	1.9	0.5	-0.3	-1.5	-3.6	-2.5	-2.3	-1.0	-0.9	0.7	1.1	4.3		
	0.71	1.11	1.05	0.99	1.18	1.01	1.14	1.01	1.18	0.99	1.05	1.11	0.71		
	0.72	1.13	1.06	0.99	1.16	0.97	1.10	0.98	1.17	0.99	1.06	1.12	0.73		11
	1.9	1.9	1.3	0.4	-1.9	-3.2	-3.3	-3.1	-0.6	-0.2	0.8	1.1	2.5		
		0.74	0.83	1.05	1.09	1.10	1.01	1.10	1.09	1.05	0.83	0.74			
		0.75	0.84	1.05	1.08	1.06	0.97	1.07	1.10	1.05	0.84	0.75			12
		1.8	1.1	0.4	-1.2	-3.7	-3.8	-2.4	0.3	0.4	2.0	2.0			
			0.74	1.11	0.95	0.97	1.12	0.97	0.95	1.11	0.74				
			0.75	1.14	0.95	0.93	1.08	0.95	0.95	1.13	0.75				13
			2.4	3.1	0.2	-3.9	-3.4	-1.7	0.2	1.9	1.9				
				0.71	0.97	1.14	0.97	1.14	0.97	0.71					
				0.73	1.00	1.13	0.95	1.12	0.97	0.72					14
				3.1	3.4	0.6	-1.2	-1.7	0.0	1.9					
	STANDARD					0.70	0.86	0.70				AVERAGE			
	DEVIATION					0.73	0.87	0.69				PCT DIFFERENCE			15
	=1.344					3.7	1.0	-1.8				= 1.8			

MAP NO. N1-2-47

DATE 10/22/80

POWER - 100.0%

CONTROL ROD POSITIONS

$F^N_{\Delta H}$ = 1.326* AT C5-EF

INCORE TILT

BANK C AT 228 STEPS

F^T_Q = 1.549* AT L13-LM

NW - 0.997

BANK D AT 228 STEPS

$\bar{F}_Z$ = 1.132

NE - 1.008

A.O. = -2.219

SW - 0.996

BURNUP ~8811 MWD/MTU

SE - 0.999

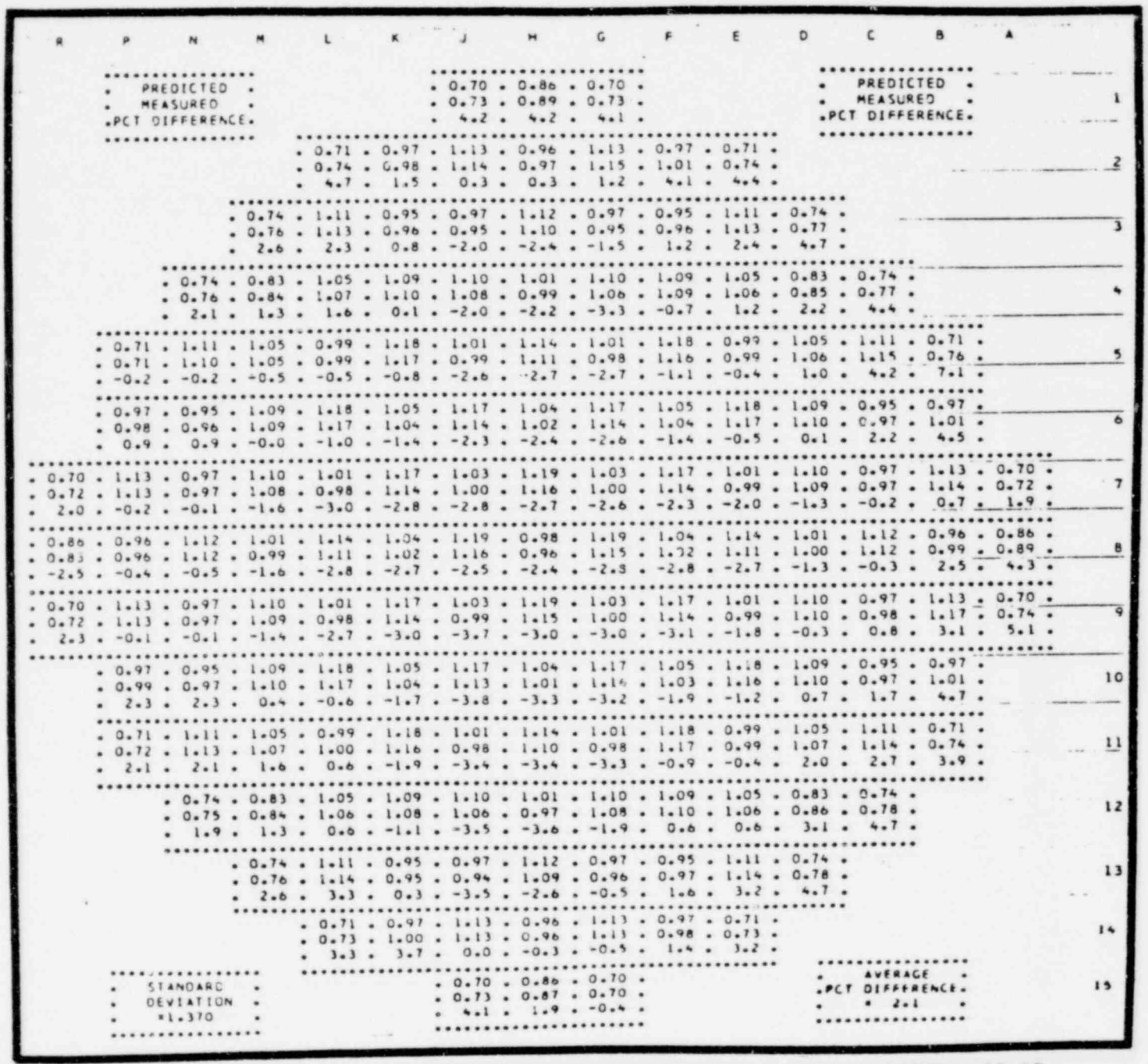
*Includes uncertainties

NORTH ANNA UNIT 1-CYCLE 2

FIGURE 4.4

ASSEMBLYWISE POWER DISTRIBUTION N1-2-52

POOR ORIGINAL



MAP NO. N1-2-52

DATE 12/11/80

POWER - 68.0%

CONTROL ROD POSITIONS

$F^N_{\Delta H}$ = 1.311* AT C5-EF

INCORE TILT

BANK C AT 228 STEPS

F^T_Q = 1.673* AT B9-EL

NW - 0.997

BANK D AT 228 STEPS

$\bar{F}_Z$ = 1.230

NE - 1.004

A.O. = +8.332

SW - 0.996

BURNUP = ∿10338 MWD/MTU

SE - 1.003

*Includes uncertainties

HOT CHANNEL FACTOR NORMALIZED
OPERATING ENVELOPE

FIGURE 4.5

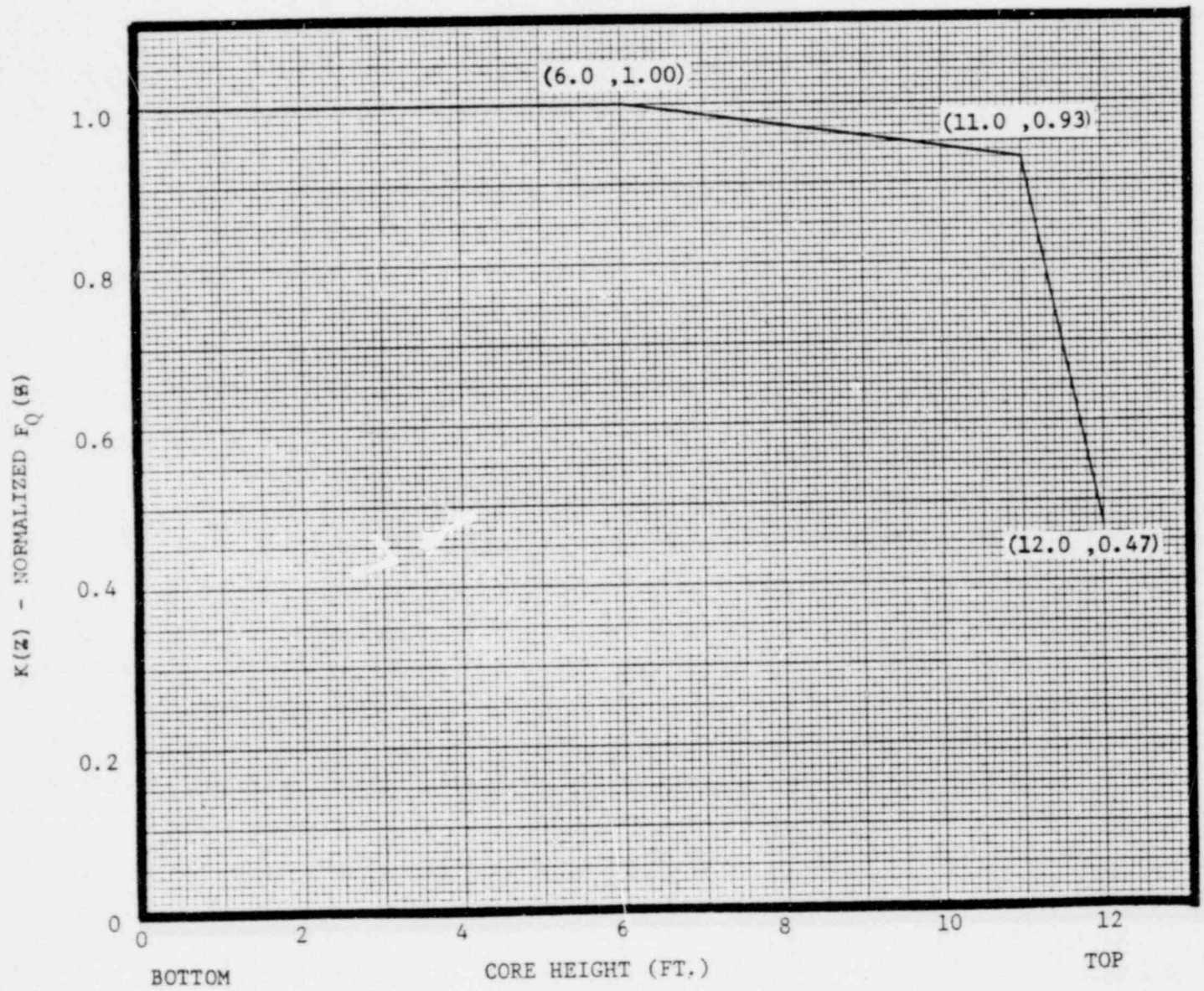
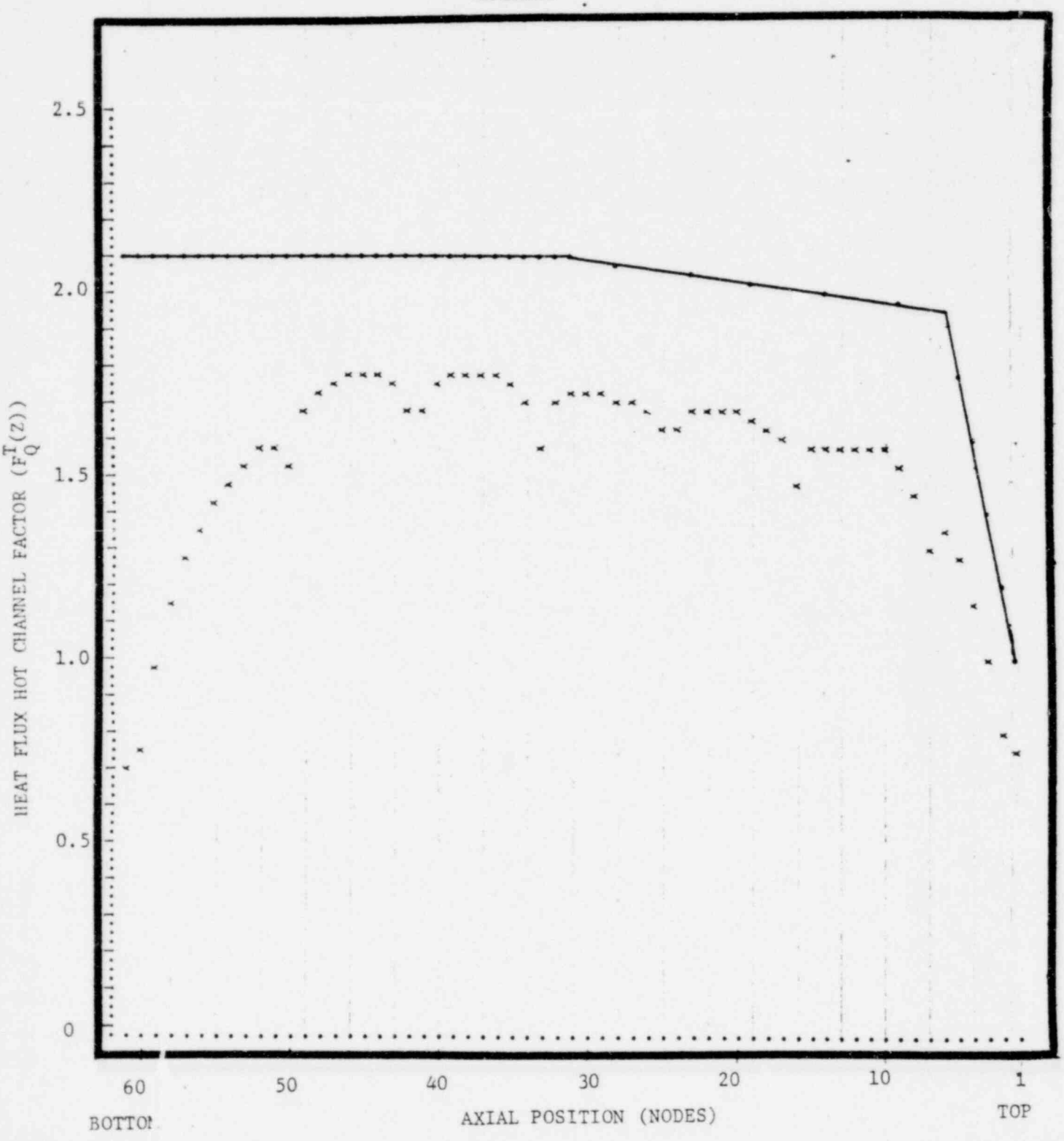


FIGURE 4.6

NORTH ANNA UNIT 1-CYCLE 2

HEAT FLUX HOT CHANNEL FACTOR, $F_Q^T(Z)$

N1-2-18



NORTH ANNA UNIT 1-CYCLE 2 FIGURE 4.7

HEAT FLUX HOT CHANNEL FACTOR, $F_Q^T(Z)$

N1-2-30

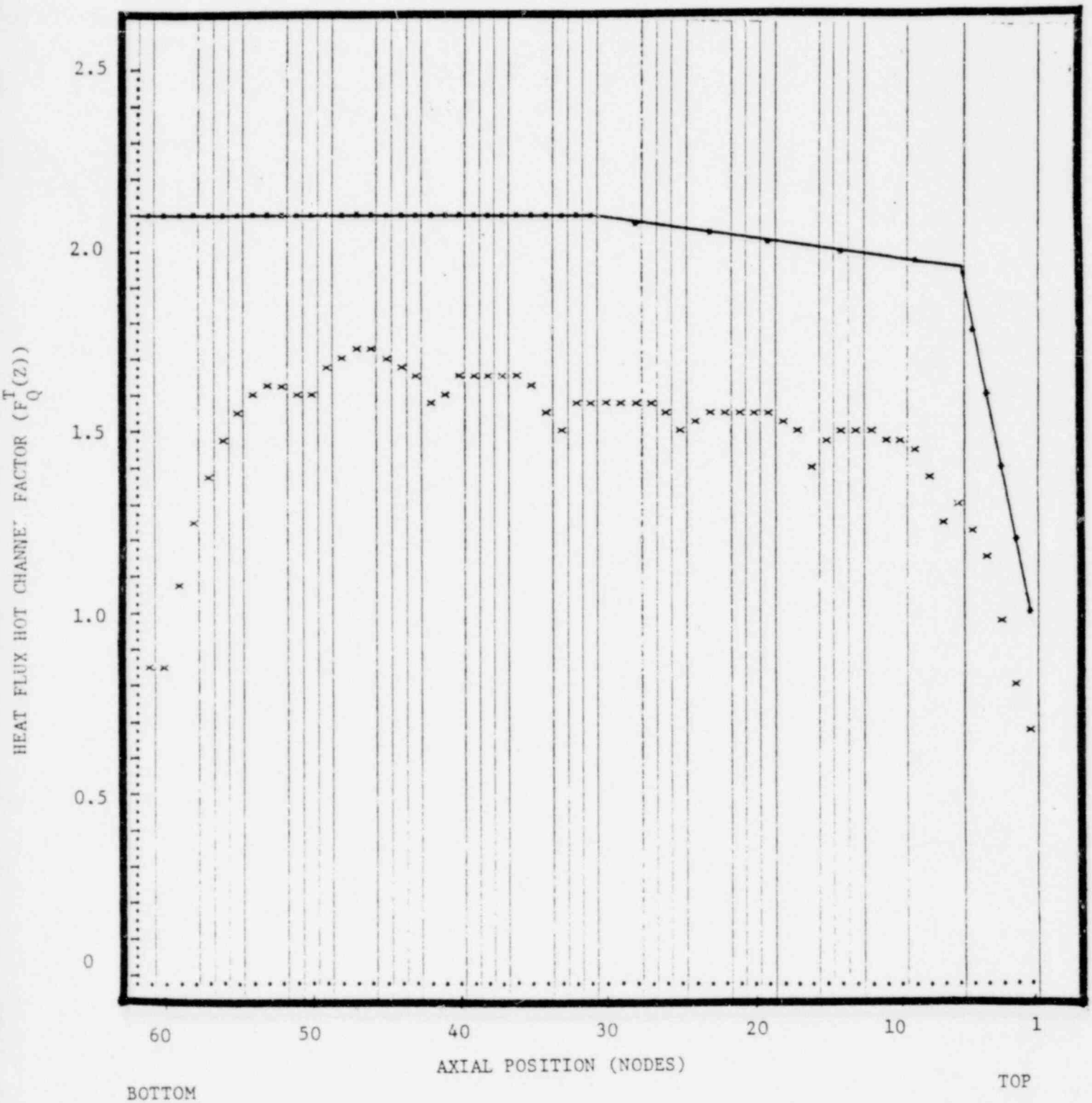


FIGURE 4.8

NORTH ANNA UNIT 1-CYCLE 2

HEAT FLUX HOT CHANNEL FACTOR, $F_Q^T(Z)$

N1-2-47

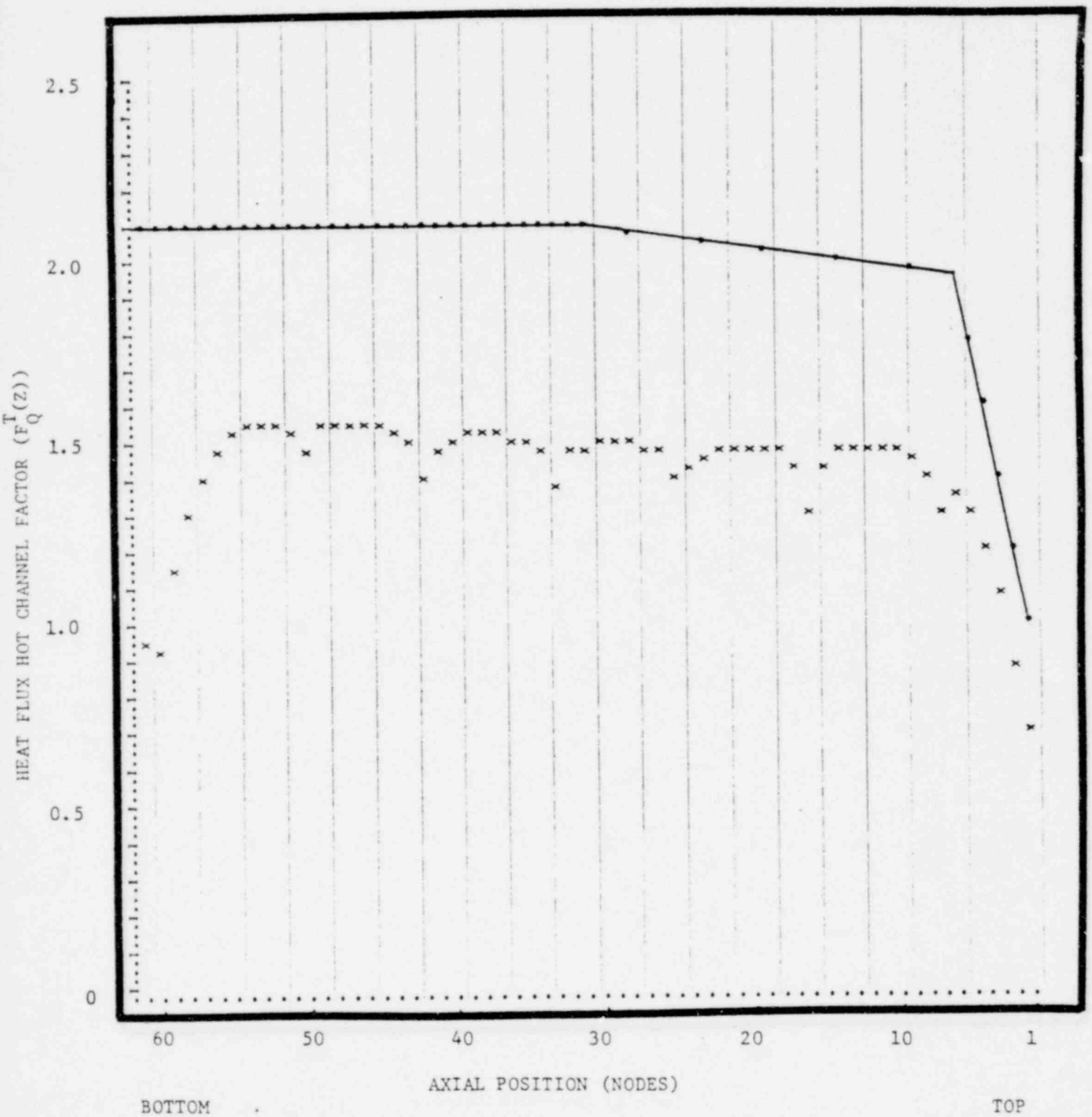
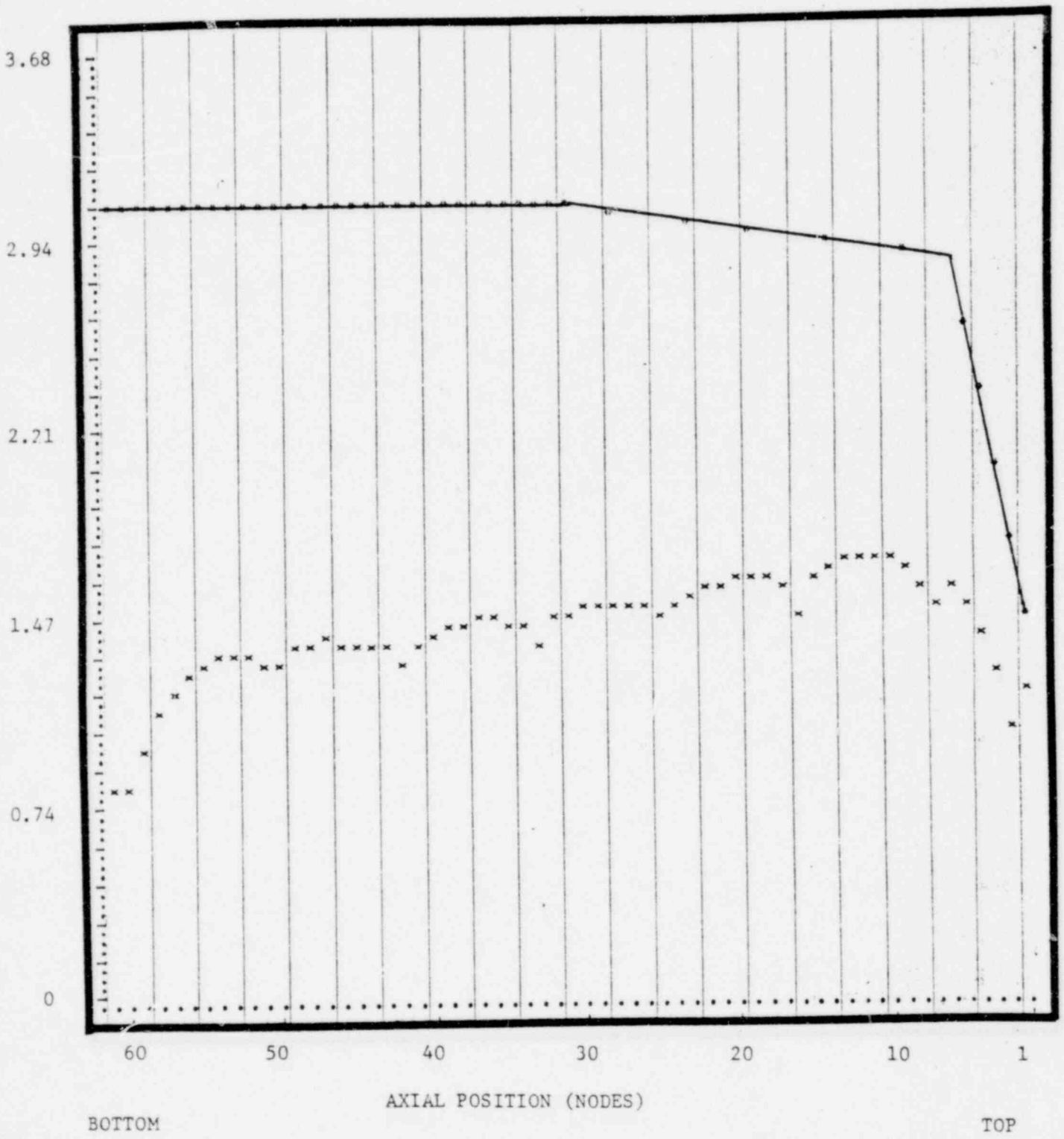


Figure 4.9

NORTH ANNA UNIT 1-CYCLE 2

HEAT FLUX HOT CHANNEL FACTOR, $F_Q^T(Z)$

N1-2-52



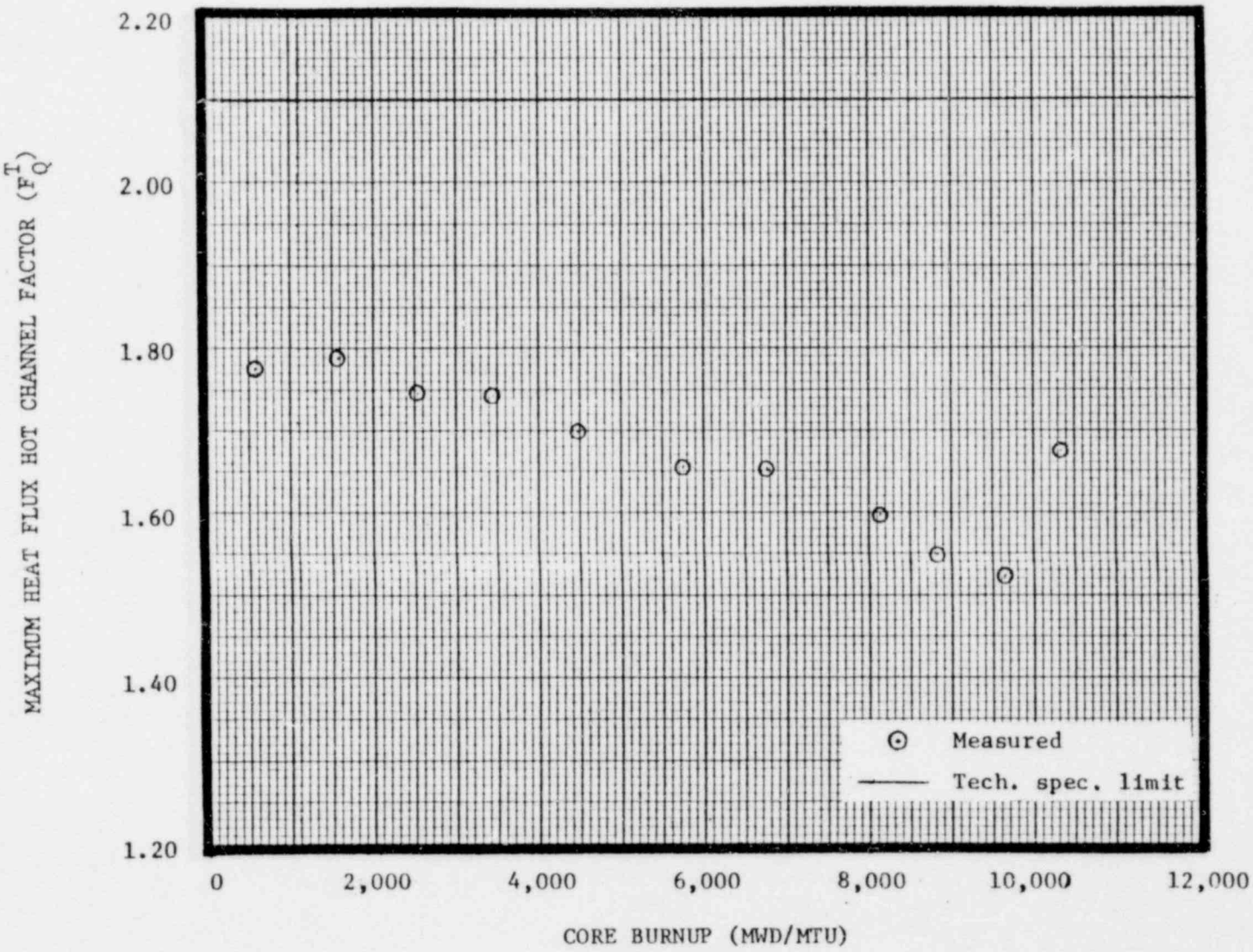
NORTH ANNA 1-CYCLE 2

FIGURE 4.10

MAXIMUM HEAT FLUX HOT CHANNEL FACTOR

vs.

BURNUP



NORTH ANNA UNIT 1-CYCLE 2

ROD BOW PENALTY ON $F^N_{\Delta H}$

FIGURE 4.11

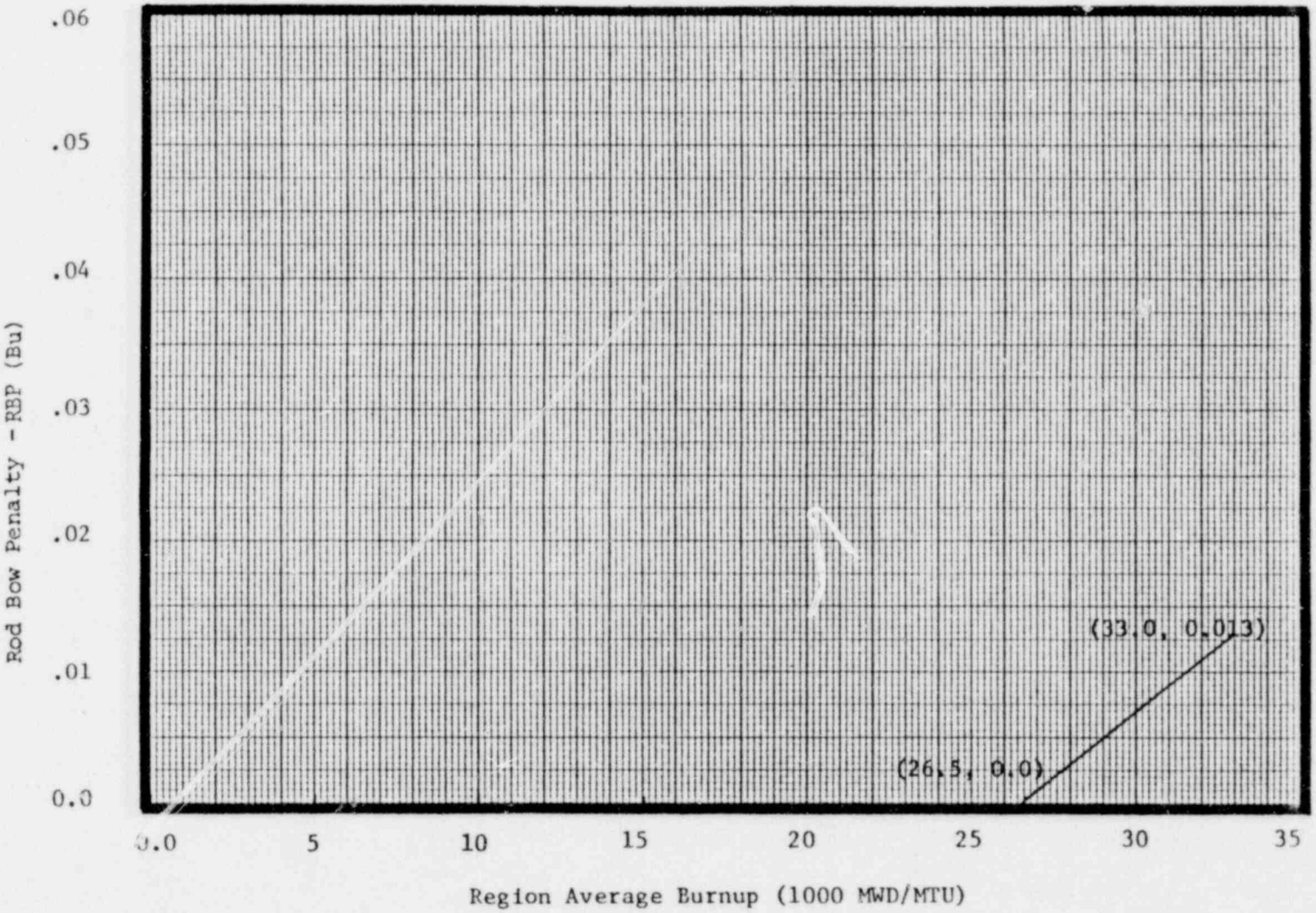
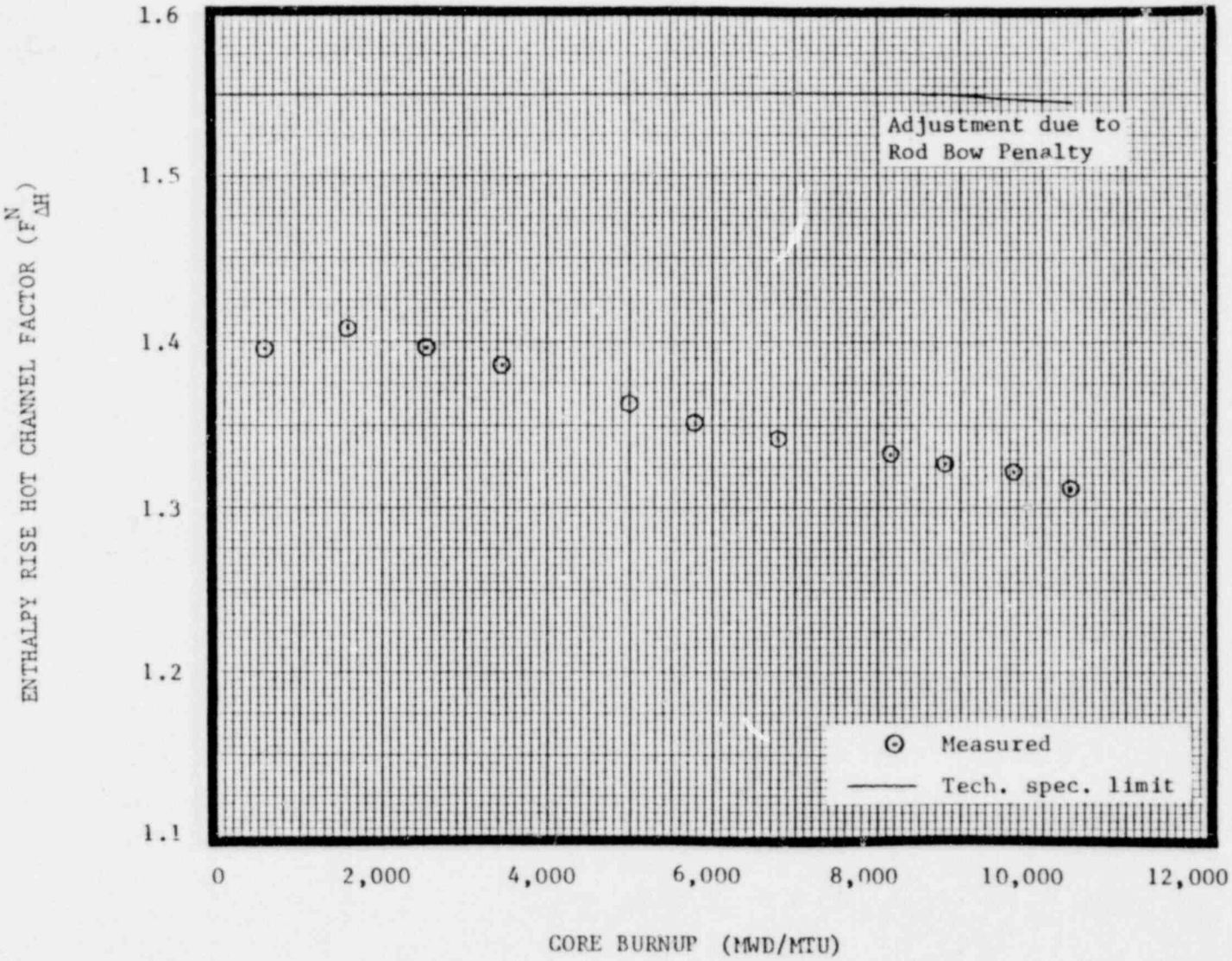


FIGURE 4.12

NORTH ANNA UNIT 1 - CYCLE 2

ENTHALPY RISE HOT CHANNEL FACTOR vs. BURNUP



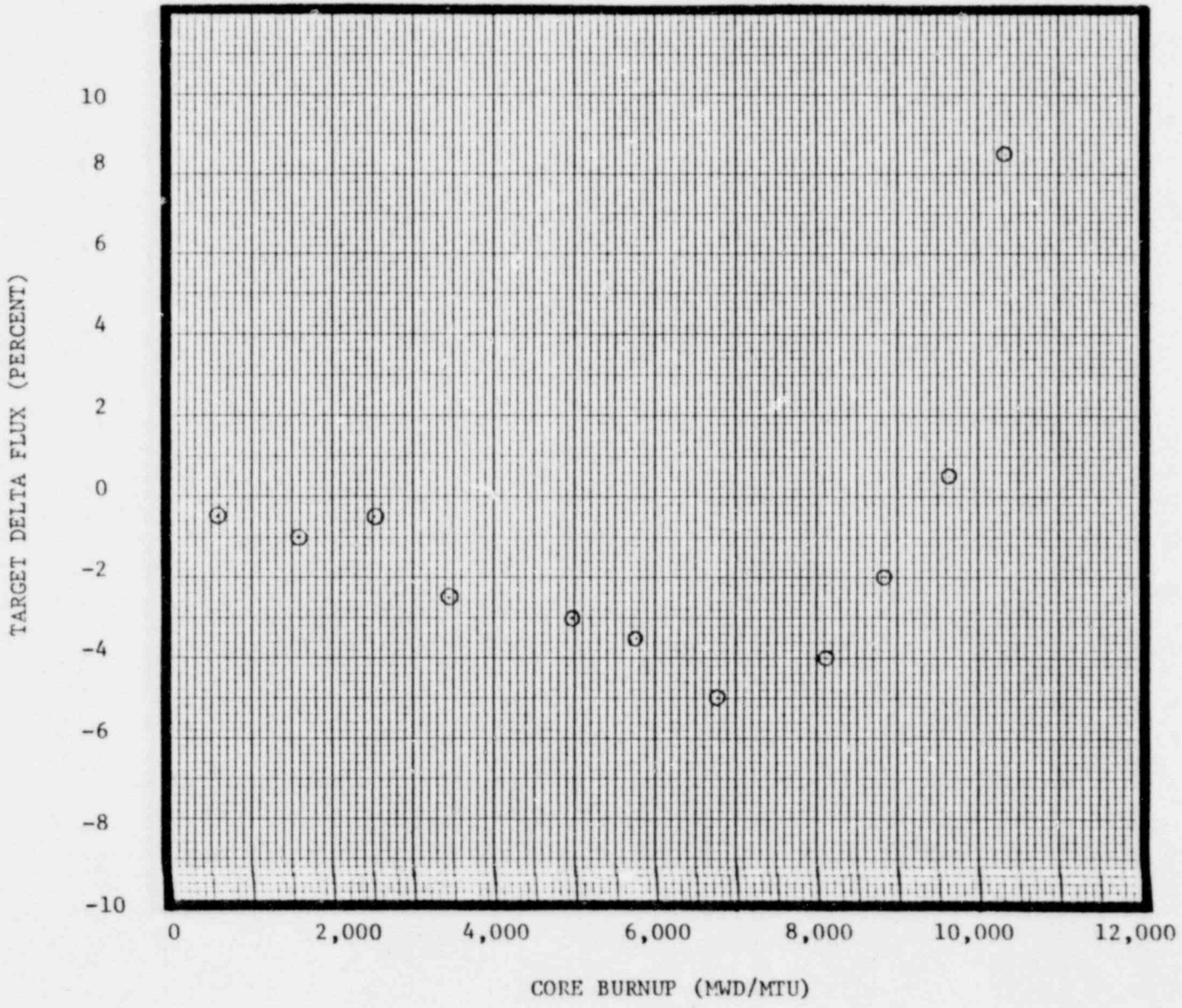
NORTH ANNA UNIT 1-CYCLE 2

TARGET DELTA FLUX

vs.

BURNUP

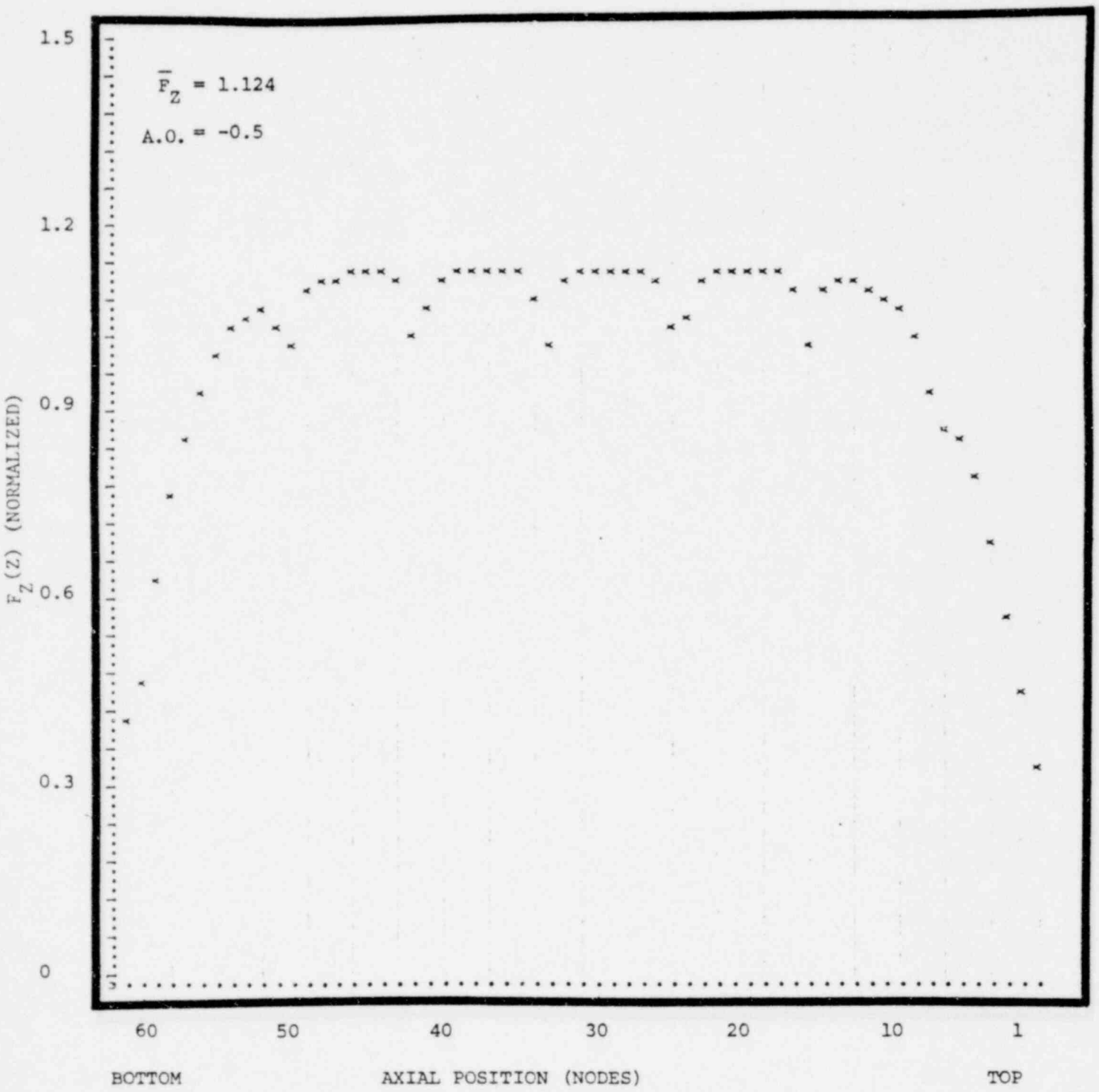
FIGURE 4.13



NORTH ANNA UNIT 1-CYCLE 2 FIGURE 4.14

CORE AVERAGE AXIAL POWER DISTRIBUTION

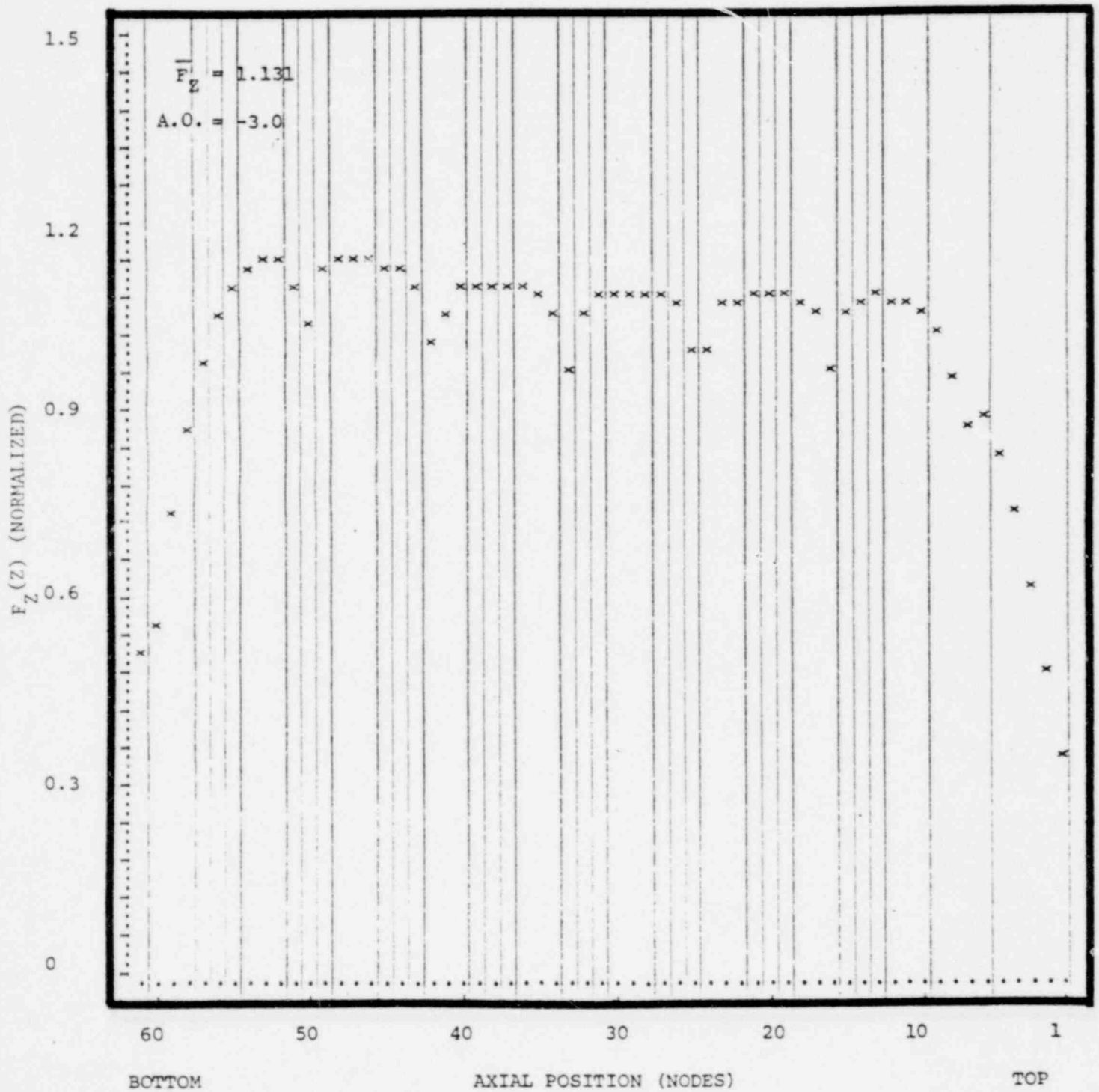
N1-2-18



NORTH ANNA UNIT 1-CYCLE 2 FIGURE 4.15

CORE AVERAGE AXIAL POWER DISTRIBUTION

N1-2-30

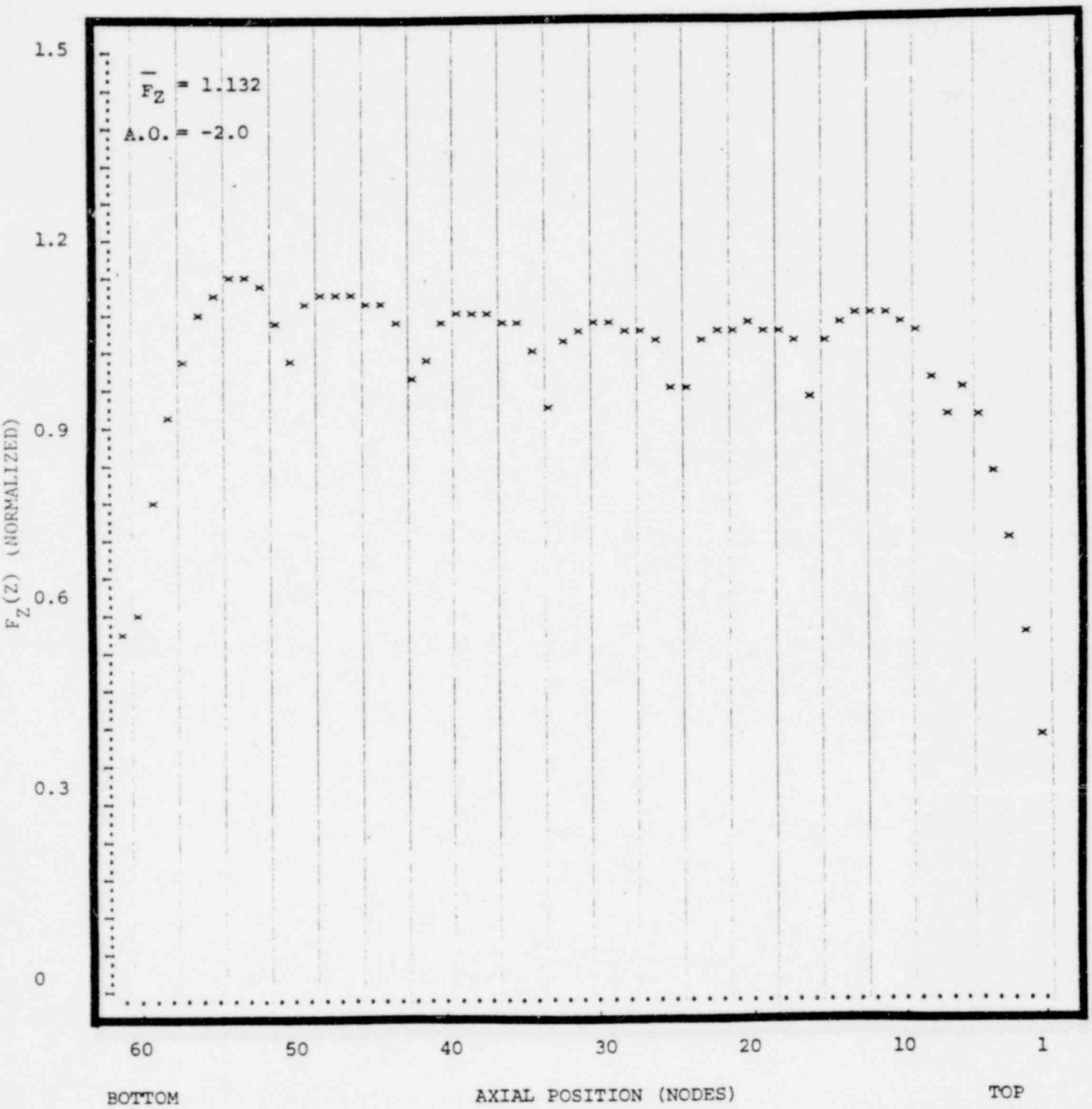


NORTH ANNA UNIT 1-CYCLE 2

FIGURE 4.16

CORE AVERAGE AXIAL POWER DISTRIBUTION

N1-2-47

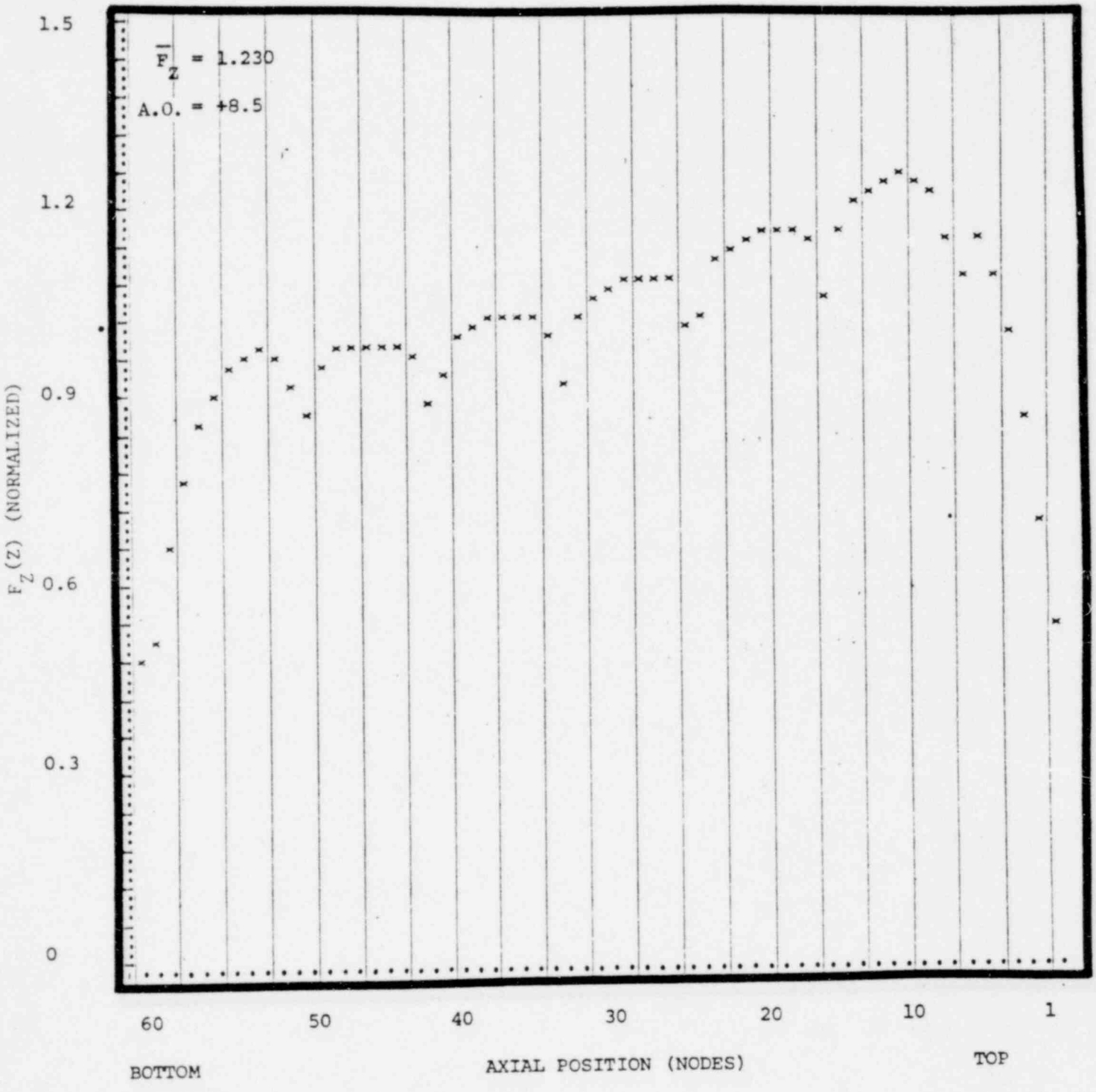


NORTH ANNA UNIT 1-CYCLE 2

FIGURE 4.17

CORE AVERAGE AXIAL POWER DISTRIBUTION

N1-2-52

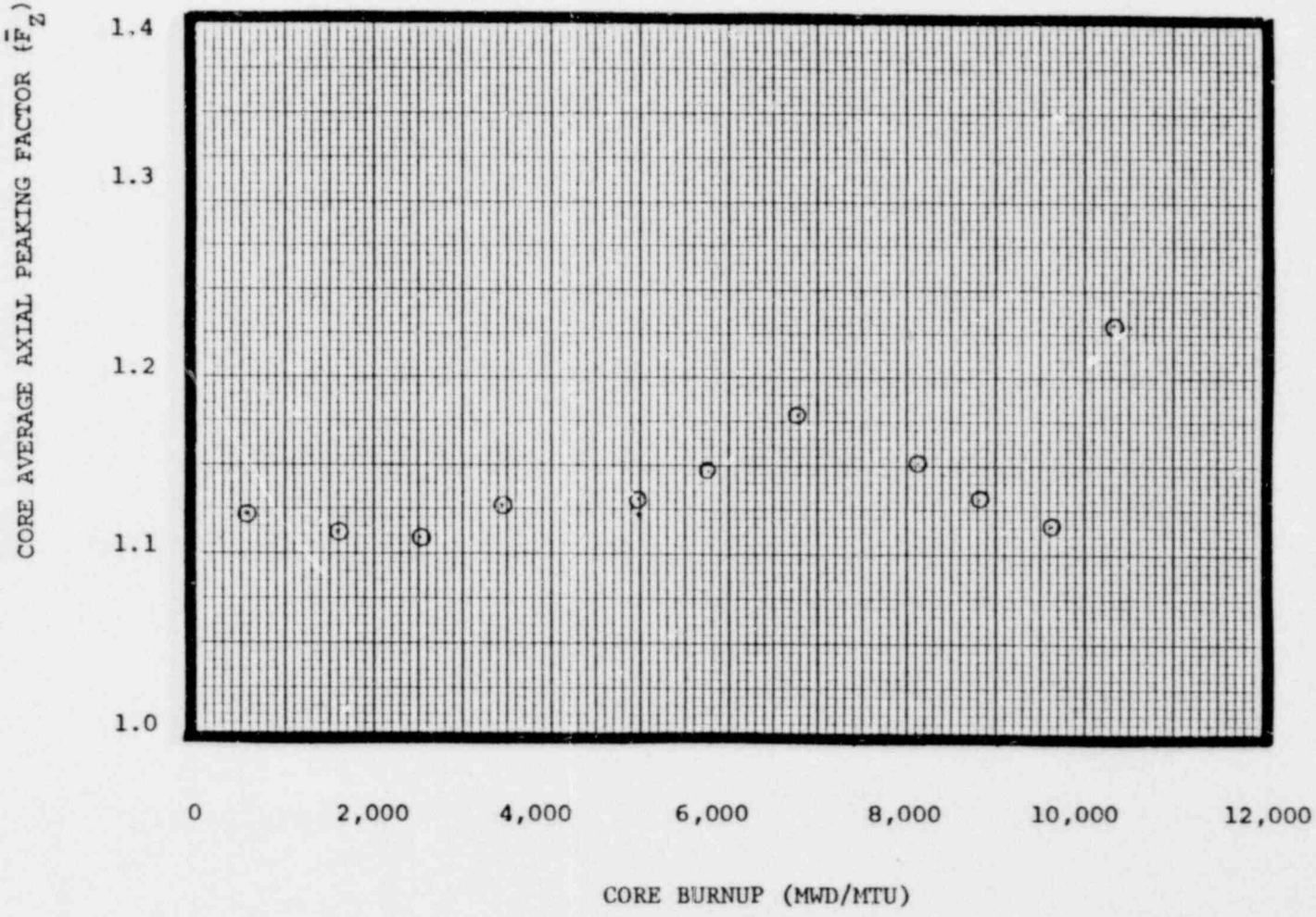


NORTH ANNA UNIT 1-CYCLE 2 FIGURE 4.18

CORE AVERAGE AXIAL PEAKING FACTOR

VS.

BURNUP



Section 5

PRIMARY COOLANT ACTIVITY FOLLOW

Activity levels of iodine-131 and 133 in the primary coolant are important in core performance follow analysis because they are used as indicators of defective fuel. Additionally, they are also important with respect to the offsite dose calculation values associated with accident analyses. Both I-131 and I-133 can leak into the primary coolant system through a breach in the cladding. As indicated in Section 3.4.8 of the North Anna Technical Specifications, the dose equivalent I-131 concentration in the primary coolant was limited to 1.0 μCi/gm for normal steady state operation. Figure 5.1 shows the dose equivalent I-131 activity level history for the North Anna 1, Cycle 2 core.

The data on Figure 5.1 shows that the core operated substantially below the 1.0 μCi/gm limit during steady state operation (the spike data is associated with power transients and/or shutdowns). The average equilibrium dose equivalent I-131 concentration during Cycle 2 was 8.9×10^{-3} μCi/gm which is less than 1% of the Technical Specifications limit. This value is considerably less than value of 3.9×10^{-2} μCi/gm that was reported in the Cycle 1 Core Performance Report (VEP-FRD-34, December 1979) The reduction of coolant activity likely results from some of the defective fuel being removed between Cycles 1 and 2.

The ratio of I-131 to I-133 is used to characterize the type of fuel failure which is present in the reactor core. Use of the ratio for this determination is feasible because I-133 has a short half-life (approximately 24 hours) compared to that of I-131 (approximately eight days) so that for pinhole defects where the diffusion time through the defect is on the order of days, the I-133 decays out leaving I-131 dominant in activity, thereby causing the ratio to be 0.5 or more. In the case of large leaks, uranium particles in the coolant, and/or "tramp" uranium*, where the diffusion

*"Tramp" uranium consists of small particles of uranium which adhere to the outside of the fuel during the manufacturing process.

mechanism is negligible, the I-131/I-133 ratio will generally be less than 0.1. As shown in Figure 5.2, the I-131/I-133 ratio data points associated with equilibrium operation are generally within the range 0.5 $\pm$0.2, indicating pinhole defects.

Finally, the data on Figures 5.1 and 5.2 indicate that both the dose equivalent I-131 concentration and the I-131/I-133 ratio showed slight increases during the cycle. It is believed that this could have been caused by the core power redistribution (both radial and axial) that occurred as described in the previous section of this report. It is also believed that these data indicate that no new defect events occurred during the cycle and that the original defect(s) did not degrade.

FIGURE 5.1

NORTH ANNA UNIT 1 - CYCLE 2

DOSE EQUIVALENT I-131 CONCENTRATION vs. TIME

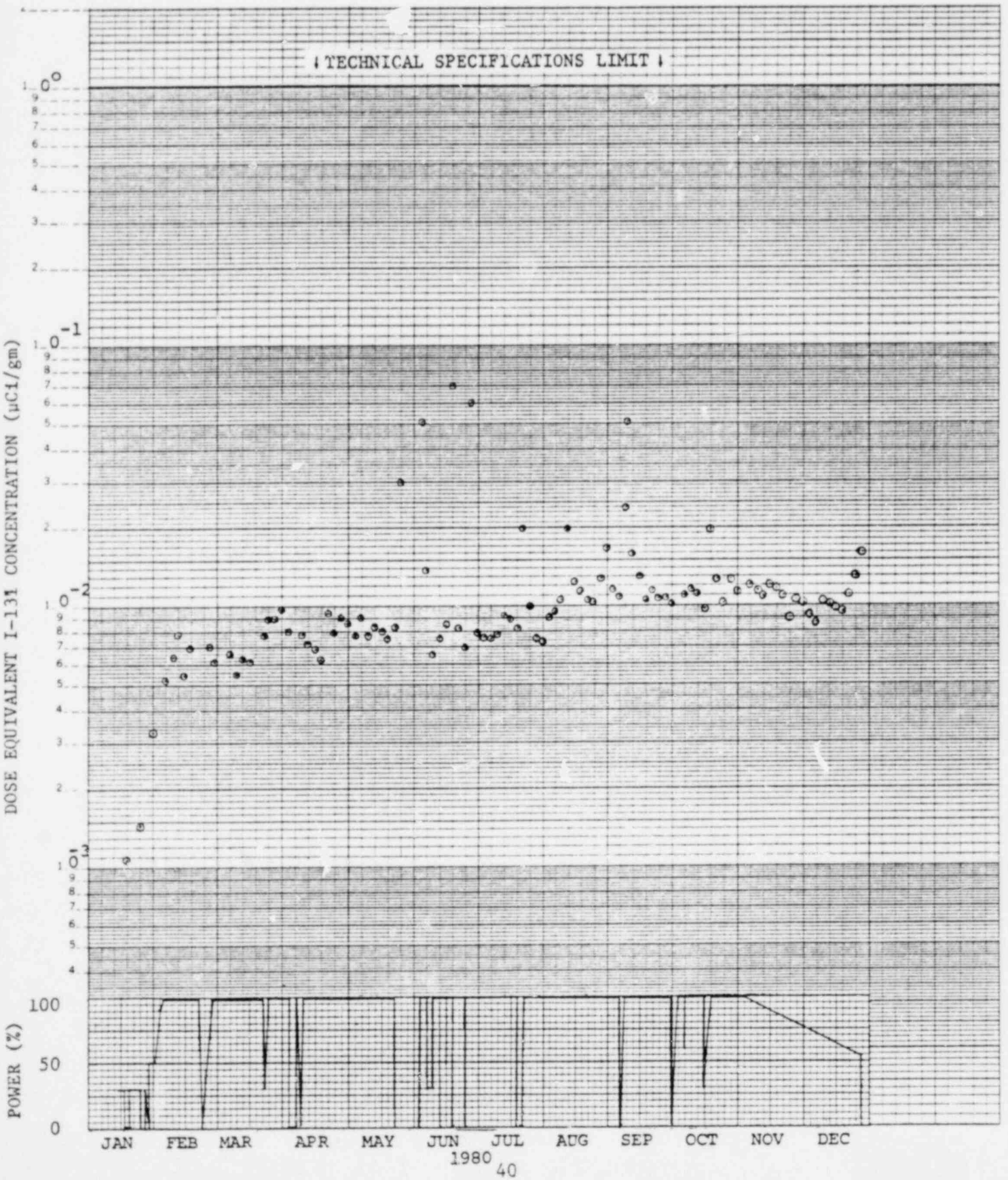
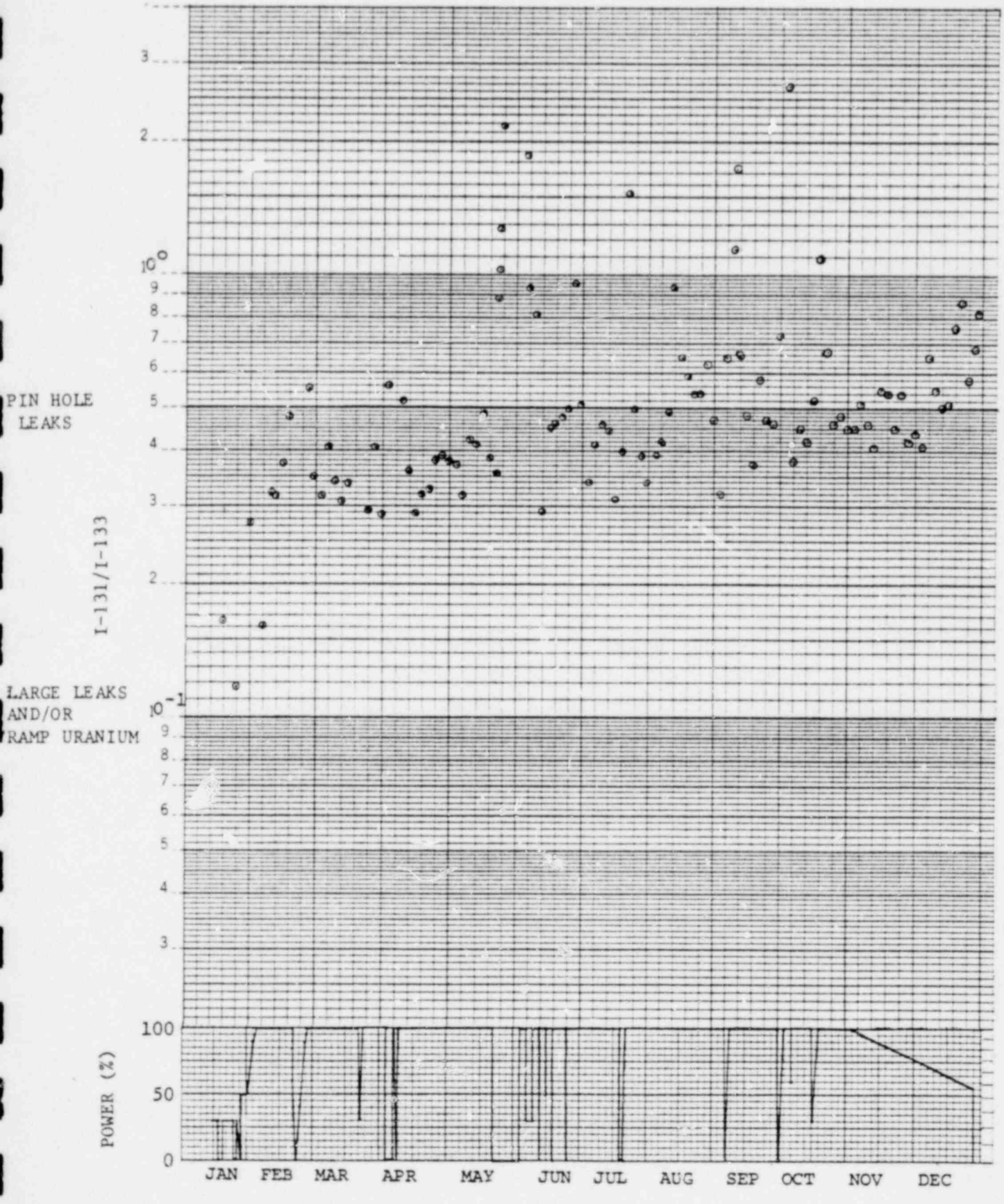


FIGURE 5.2

NORTH ANNA UNIT 1 - CYCLE 2

I-131/I-133 RATIO vs. TIME



Section 6

CONCLUSIONS

The North Anna 1 core has completed Cycle 2 operation. Throughout the cycle, all core performance indicators compared favorably with the design predictions and all core related Technical Specifications limits were met with significant margin during full power operation. No abnormalities in reactivity or batch burnup accumulation were detected. The analysis of radioiodine data for Cycle 2 indicates that there are pinhole leaks in the fuel cladding, which were probably carried over from Cycle 1. However, based on the coolant activity level and the inability to observe any fuel defects during the refueling shuffle, it is concluded that the fuel defect level was low.

REFERENCES

1) T. J. Kunsitis, T. K. Ross and J. H. Leberstien, "North Anna Unit 1, Cycle 2 Startup Physics Test Report," VEP-FRD-35, June, 1980.

2) North Anna Power Station Unit 1 Technical Specifications.

3) T. K. Ross, "NEWTOTE Code," NFO-CCR-6, August, 1978.

4) R. D. Klatt, W. D. Leggett, III, and L. D. Eisenhart, "FOLLOW Code," WCAP-7482, February, 1970.

5) W. D. Leggett, III and L. D. Eisenhart, "INCORE Code," WCAP-7149, December, 1967.

6) Letter from C. M. Stallings (Vepco) to H. R. Denton (NRC), Serial No. 116, March 11, 1980.