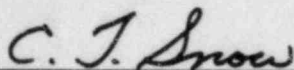


NORTH ANNA UNIT 2, CYCLE 3
CORE PERFORMANCE REPORT

by

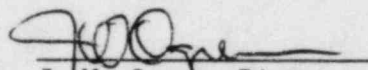
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August, 1984

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ACKNOWLEDGEMENTS

The author would like to acknowledge the cooperation of the North Anna Power Station personnel in supplying the basic data for this report. Also, the author would like to express his gratitude to Mr. C. T. Snow for his aid and guidance in preparing this report.

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Section 1

INTRODUCTION AND SUMMARY

On August 2, 1984, North Anna Unit 2 completed Cycle 3. Since the initial criticality of Cycle 3 on May 27, 1983, the reactor core produced approximately 87×10^6 MBTU (14717.3 Megawatt days per metric ton of contained uranium) which has resulted in the generation of approximately 8.4×10^9 KWHr gross (7.9×10^9 KWHr net) of electrical energy. The purpose of this report is to present an analysis of the core performance for routine operation during Cycle 3. The physics tests that were performed during the startup of this cycle were covered in the North Anna Unit 2, Cycle 3 Startup Physics Test Report¹ and, therefore, will not be included here.

The second cycle core consisted of three batches of fuel: a twice burned sub-batch from cycles 1 and 2 (3A2), a once-burned batch from cycle 2 (Batch 4A), and one fresh batch (Batch 5A). The North Anna 2, Cycle 3 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 Specifications² 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 2 Technical Specifications, and to assess the integrity of the fuel.

Each of the four performance indicators is discussed in detail for the North Anna 2, Cycle 3 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 $\pm 0.33\%$ with the burnup accumulation in each batch deviating from design prediction by less than 0.5%.

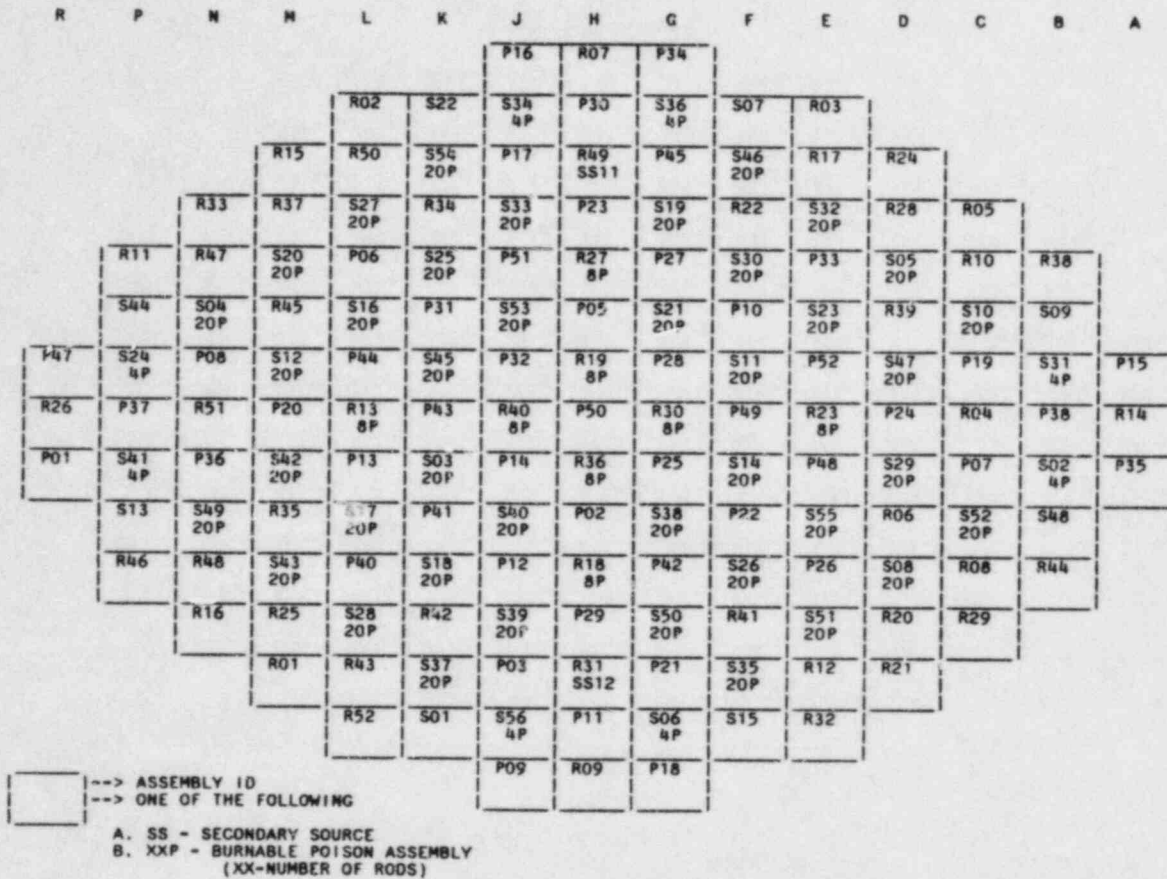
2. Reactivity Depletion Follow - The critical boron concentration, used to monitor reactivity depletion, was consistently within $\pm 0.33\% \Delta K/K$ of the design prediction which is well within the $\pm 1\% \Delta K/K$ margin allowed by Section 4.1.1.1.2 of the Technical Specifications.

3. Power Distribution Follow - Incore flux maps taken each month indicated that the assemblywise radial power distributions deviated from the design predictions by an average difference of less than 2%. All hot channel factors met their respective Technical Specifications limits.

4. Primary Coolant Activity Follow - The average dose equivalent iodine-131 activity level in the primary coolant during Cycle 3 was approximately 4.05×10^{-2} $\mu\text{Ci/gm}$. This corresponds to 4% 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 UNIT 2 - CYCLE 3
CORE LOADING MAP



FUEL ASSEMBLY DESIGN PARAMETERS

	SUB-BATCH		
	3A2	4A	5A
Initial Enrichment-W/O U235	3.10	3.41	3.59
Assembly Type	17X17	17X17	17X17
Number of Assemblies	49	52	56
Fuel Rods per Assembly	264	264	264
Assembly Identification	P01-P03 P05-P38 P40-P45 P47-P52	R01-R52	S01-S56

Figure 1.2
NORTH ANNA UNIT 2 - CYCLE 3
MOVABLE DETECTOR AND
THERMOCOUPLE LOCATIONS

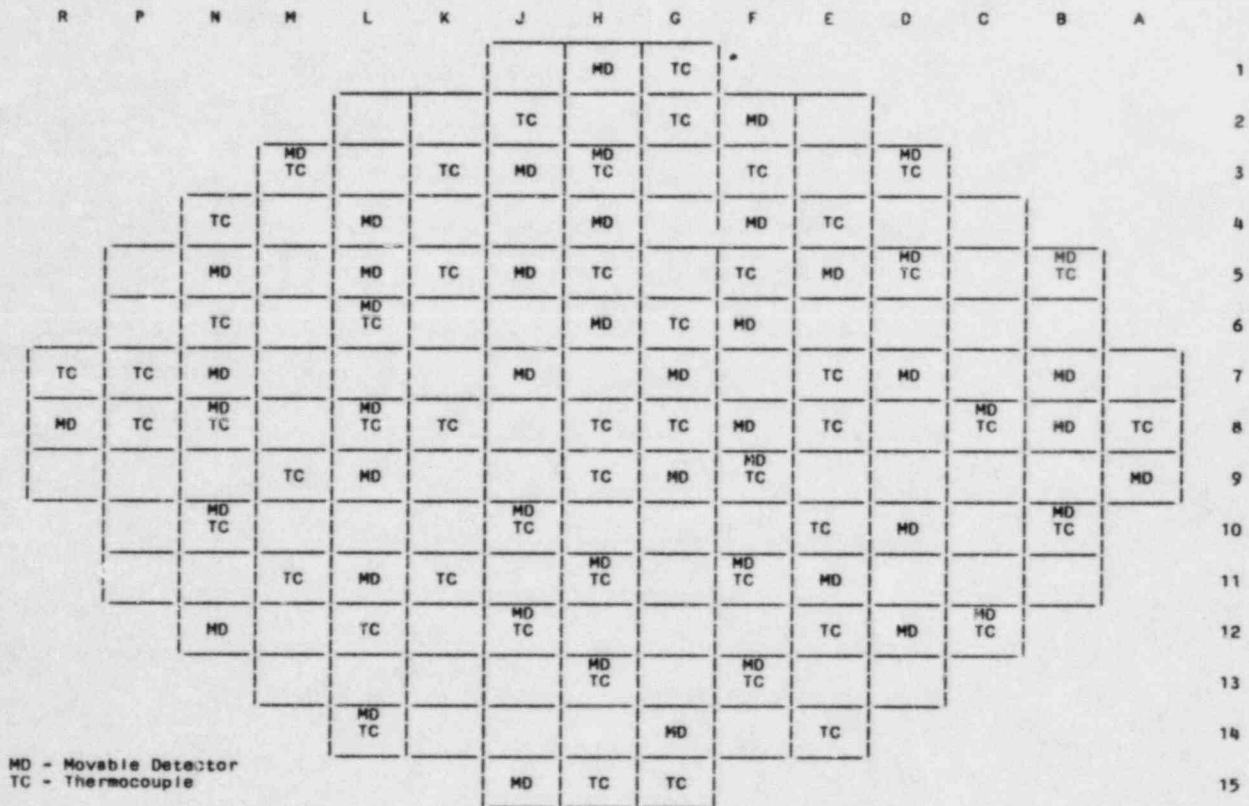
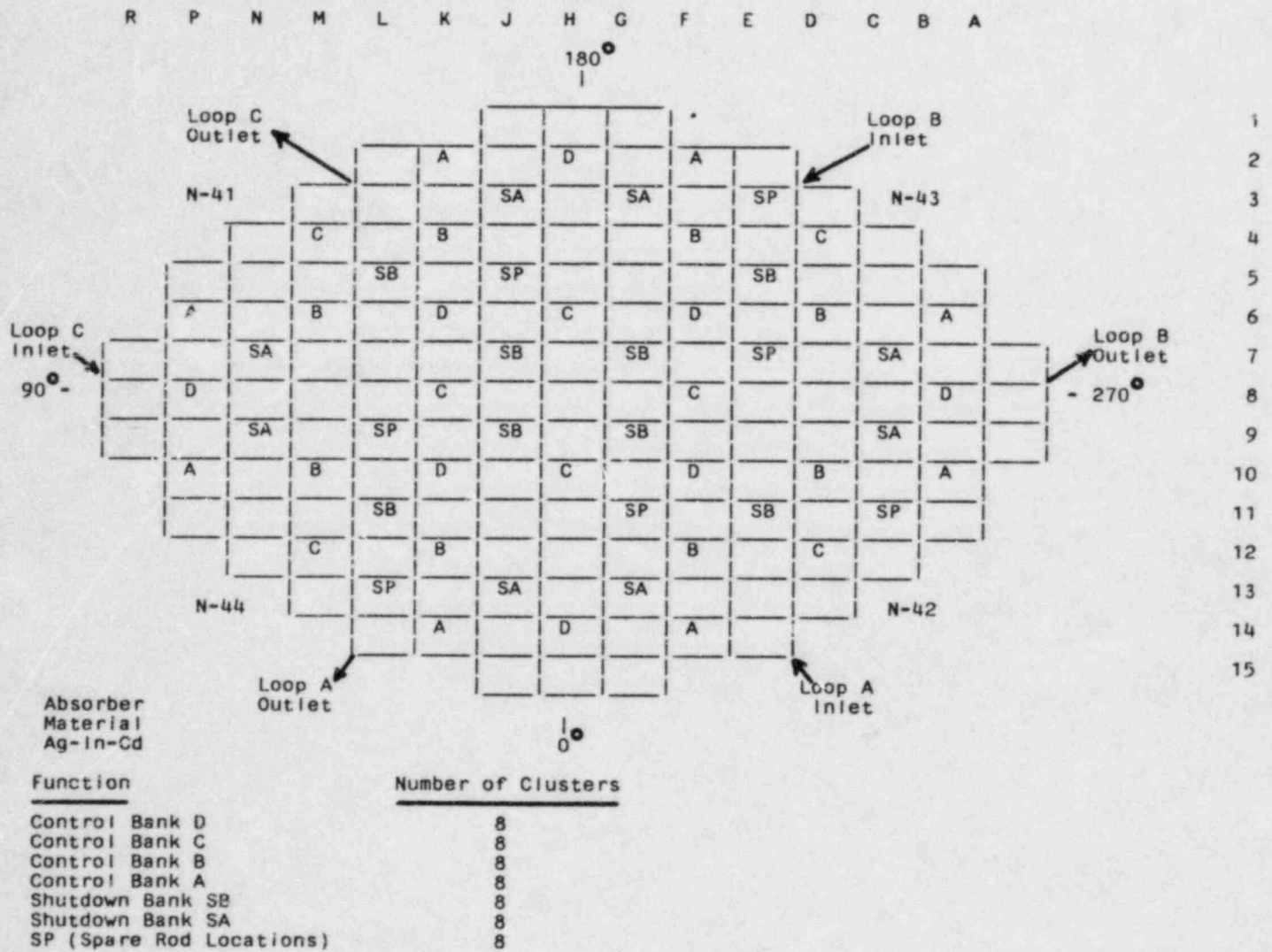


Figure 1.3
NORTH ANNA UNIT 2 - CYCLE 3
CONTROL ROD LOCATIONS



Section 2

BURNUP FOLLOW

The burnup history for the North Anna Unit 2, Cycle 3 core is graphically depicted in Figure 2.1. The North Anna 2, Cycle 3 core achieved a burnup of 14,717.3 MWD/MTU. As shown in Figure 2.2, the average load factor for Cycle 3 was 88.5% when referenced to rated thermal power (2775 MW(t)).

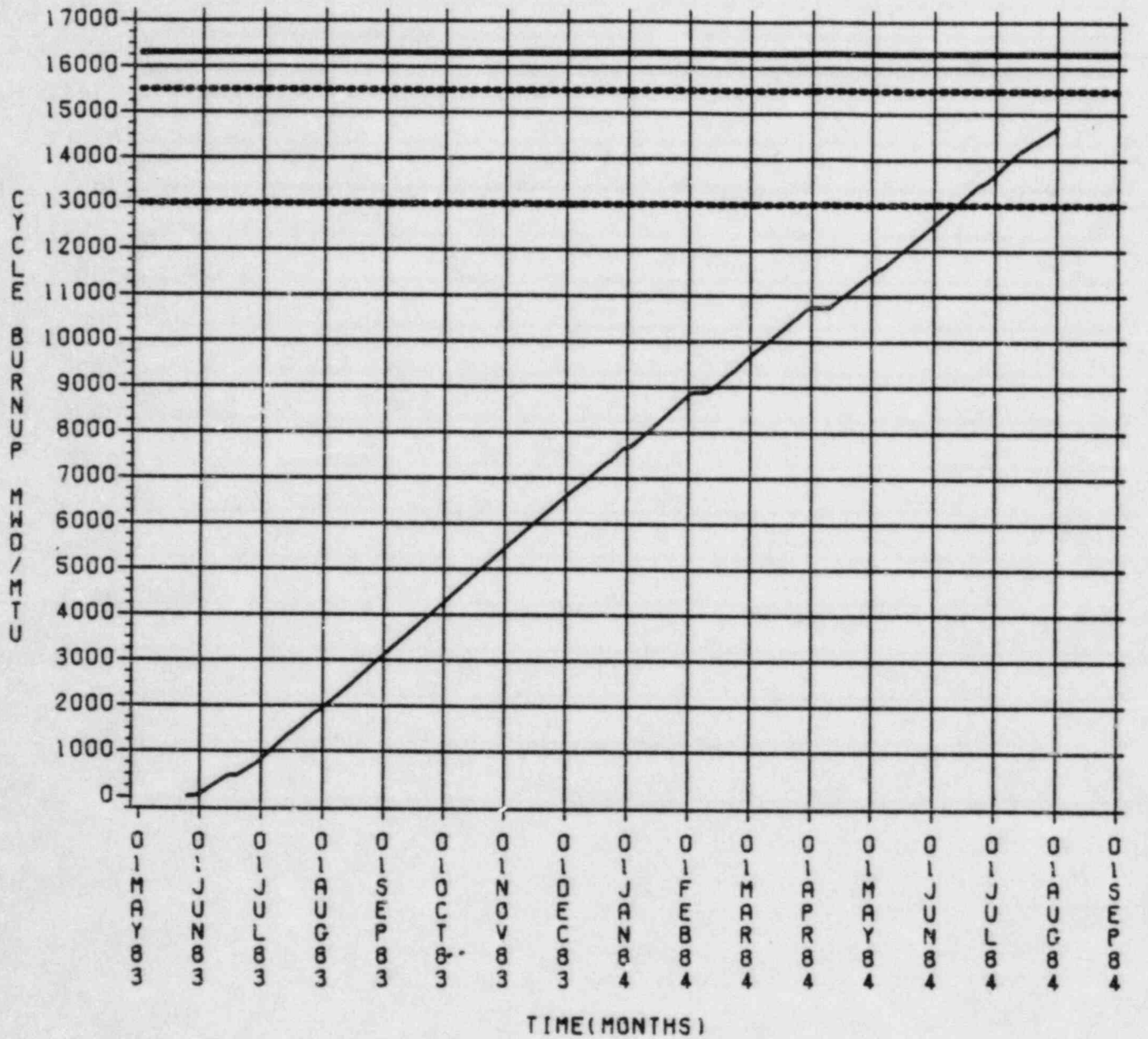
Radial (X-Y) burnup distribution maps show how the core burnup is shared among the various fuel assemblies, and thereby allow a detailed burnup distribution analysis. The NEWTOTE³ computer code is used to calculate these assemblywise burnups. Figure 2.3 is a radial burnup distribution map in which the assemblywise burnup accumulation of the core at the end of Cycle 3 operation is given. For comparison purposes, the design values are also given. Figure 2.4 is a radial burnup distribution map in which the percentage difference comparison of measured and predicted assemblywise burnup accumulation at the end of Cycle 3 operation is also given. As can be seen from this figure, the accumulated assembly burnups were generally within $\pm 4\%$ of the predicted values. In addition, deviation from quadrant symmetry in the core, as indicated by the burnup tilt factors, was no greater than $\pm 0.33\%$.

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 2.5, the batch burnup sharing for North Anna Unit 2, Cycle 3 followed design predictions closely with each batch deviating less than 0.5% from design.

Symmetric burnup in conjunction with agreement between actual and predicted assemblywise burnups and batch burnup sharing indicate that the Cycle 3 core did deplete as designed.

Figure 2.1

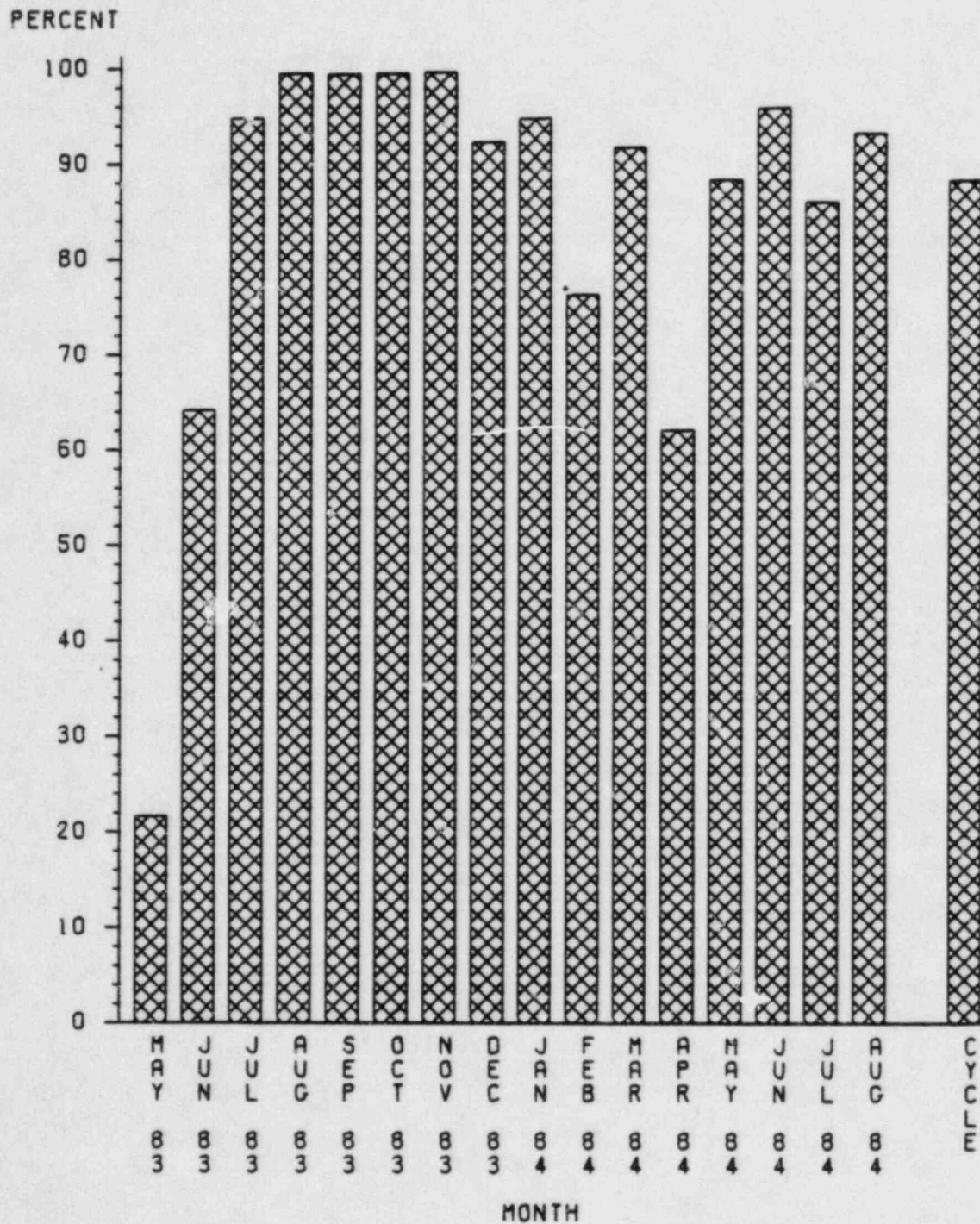
NORTH ANNA 2 - CYCLE 3
CORE BURNUP HISTORY



—— CYCLE 3 MAXIMUM DESIGN BURNUP - 16300 MWD/MTU
 ---- BURNUP WINDOW FOR CYCLE 4 DESIGN - 13000 TO 15500 MWD/MTU

Figure 2.2

NORTH ANNA 2 - CYCLE 3
MONTHLY AVERAGE LOAD FACTOR



$$\text{LOAD FACTOR} = \frac{\text{THERMAL ENERGY GENERATION IN MONTH (MWH)}}{\text{AUTHORIZED POWER LEVEL (MW) X HOURS IN MONTH (EXCLUDES REFUELING OUTAGES)}}$$

NORTH ANNA 2 - CYCLE 3
ASSEMBLYWISE ACCUMULATED BURNUP
MEASURED AND PREDICTED
(1000 MWD/MTU)

11

Figure 2.4

NORTH ANNA 2 - CYCLE 3
ASSEMBLYWISE ACCUMULATED BURNUP
COMPARISON OF MEASURED AND PREDICTED
(1000 MWD/MTU)

	R	P	N	M	L	K	J	H	G	F	E	D	C	B	A	
1																
2																
3																
4																
5																
6																
7																
8																
9																
10																
11																
12																
13																
14																
15																

BURNUP SHARING
(MWD/MTU)

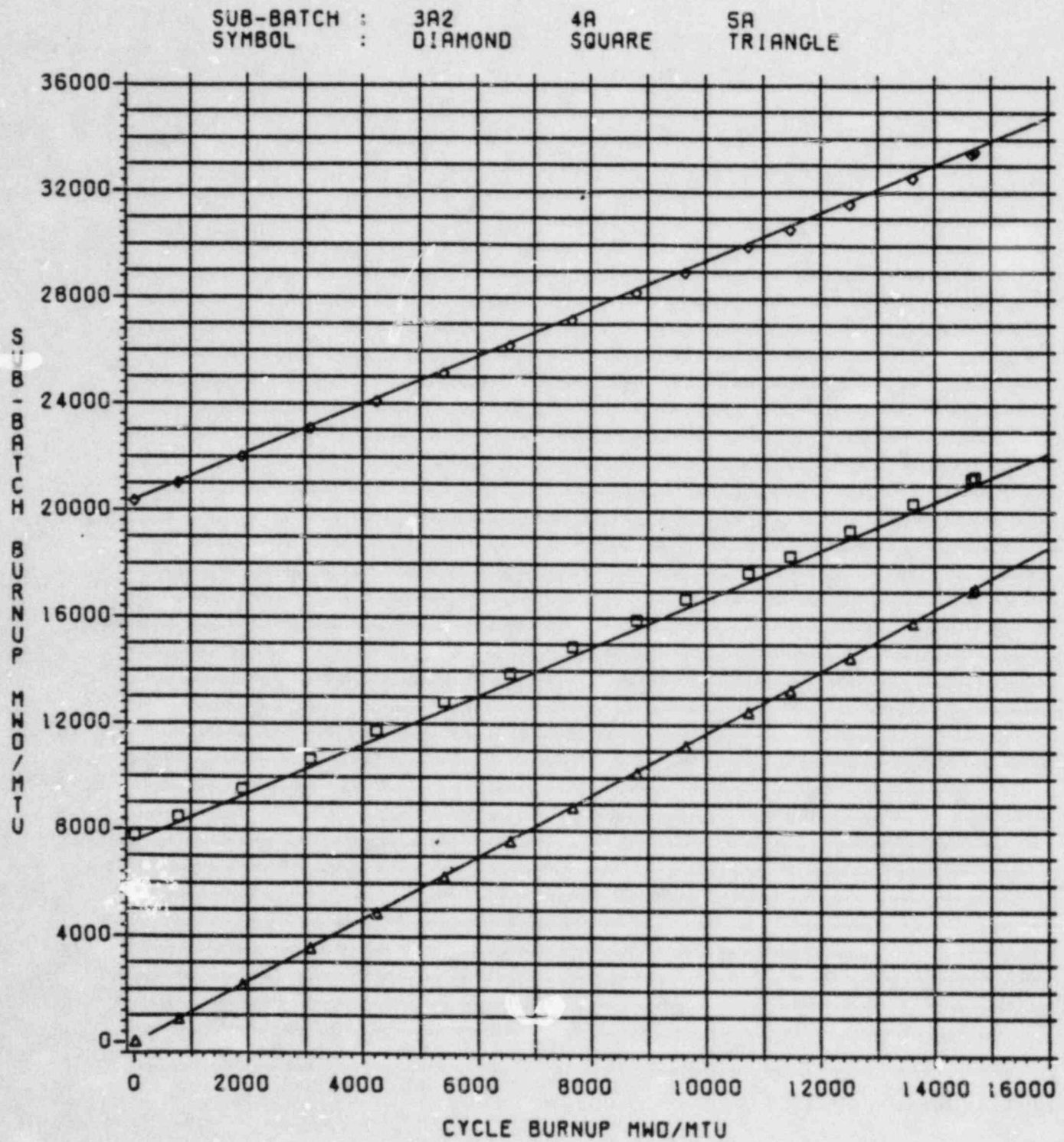
Batch	Cycle 1	Cycle 2	Cycle 3	Total
3A2	10869	9450	13194	33513
4A	---	7763	13555	21318
5A	---	---	17121	17121
Core Average			14717	

BURNUP TILT

NW = -0.18
NE = -0.01
SW = 0.32
SE = -0.12

Figure 2.5

NORTH ANNA 2 - CYCLE 3
SUB-BATCH BURNUP SHARING



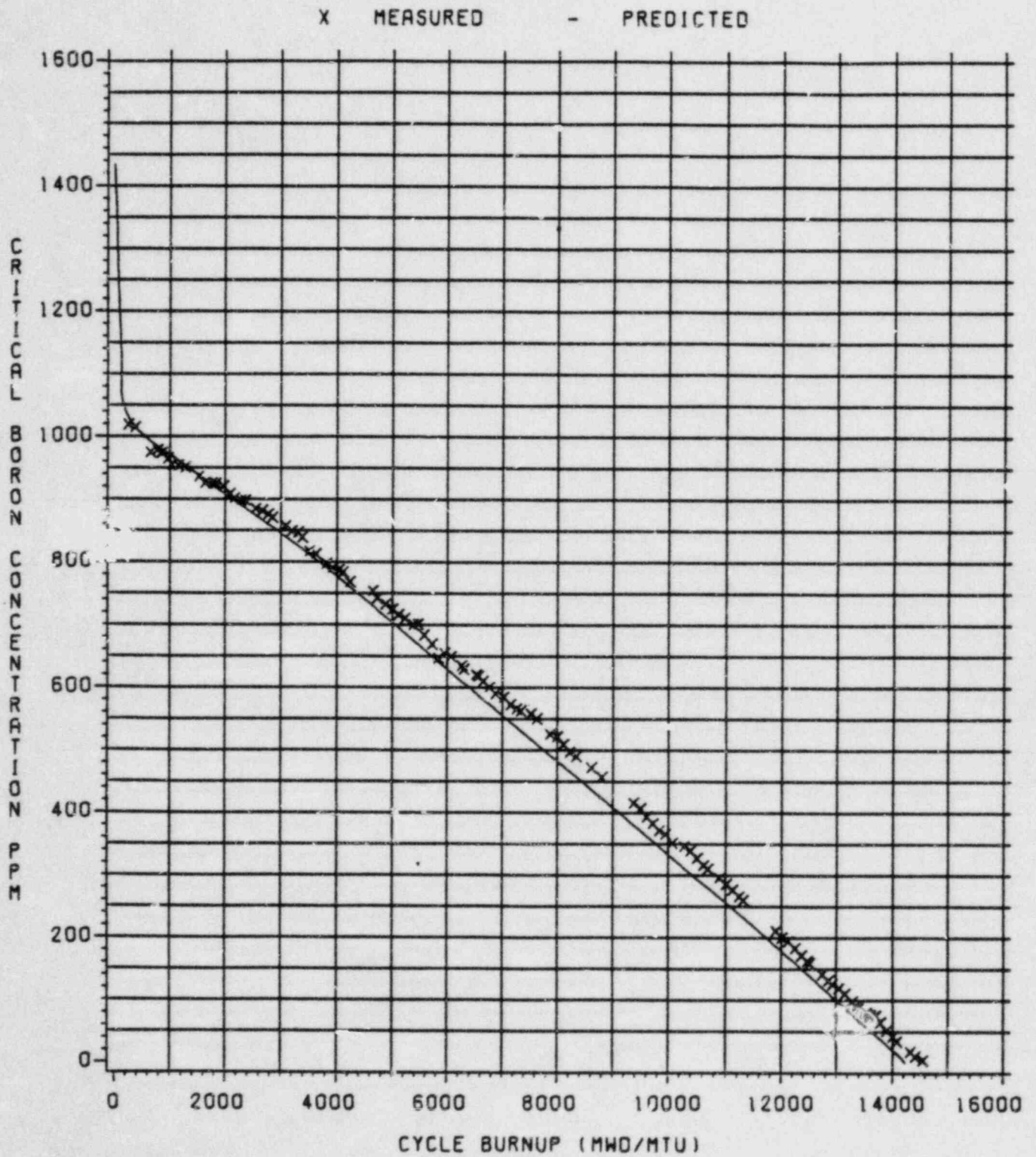
Section 3

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[®] 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 2, Cycle 3 core is shown in Figure 3.1. It can be seen that the measured data typically compare to within 42 ppm of the design prediction. This corresponds to less than $\pm 0.34\%$ $\Delta K/K$ which is well within the $\pm 1\%$ $\Delta K/K$ criterion for reactivity anomalies set forth in Section 4.1.1.1.2 of the Technical Specifications. In conclusion, the trend indicated by the critical boron concentration verifies that the Cycle 3 core depleted as expected without any reactivity anomalies.

Figure 3.1

NORTH ANNA 2 - CYCLE 3
CRITICAL BORON CONCENTRATION vs. BURNUP
HFP, ARO



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 INCORE⁵ computer program. A summary of all full core flux maps taken since the completion of startup physics testing for North Anna 2, Cycle 3 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 4.3. 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 at the end of Cycle 3 life. The radial power distributions were taken under equilibrium operating conditions with the unit at approximately full power. In each case, the measured relative assembly powers were generally within 6.3% of the predicted values with an average percent difference of approximately 2.0% which is considered good agreement. In addition, as indicated by the INCORE tilt factors, the power distributions were essentially symmetric for all cases.

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 Technical Specifications limit on the axially dependent heat flux hot channel factor $F_Q(Z)$ was $2.20 \times K(Z)$, where $K(Z)$ is the hot channel factor normalized operating envelope. Figure 4.4 is a plot of the $K(Z)$ curve associated with the $2.20 F_Q(Z)$ limit. The axially dependent heat flux hot channel factors, $F_Q(Z)$, for a representative set of flux maps are given in Figures 4.5 through 4.7. Throughout Cycle 3, the measured values of $F_Q(Z)$ were within the Technical Specifications limit. A summary of the maximum values of axially-dependent heat flux hot channel factors measured during Cycle 3 is given in Figure 4.8. Figure 4.9 shows the maximum values for the Heat Flux Hot Channel Factor measured during Cycle 3. As can be seen from the figure, there was a 13% margin to the limit at the beginning of the cycle, with the margin generally increasing throughout cycle operation.

The value of the enthalpy rise hot channel factor, $F\text{-}\Delta H$, 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 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 $F\text{-}\Delta H$ limit ensures that the value of this parameter used in the LOCA-ECCS analysis is not exceeded during normal operation. The Cycle 3 limit on the enthalpy rise hot channel factor was set at $1.55 \times (1+0.3(1-P)) \times (1\text{-RBP(BU)})$, where P is the fractional power level, and RBP(BU) is the rod bow penalty. A summary of the maximum values for the Enthalpy Rise Hot Channel Factor measured during Cycle 3 is given in Figure 4.10.

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 the target delta flux versus burnup, given in Figure 4.11, shows the value of this parameter to have been approximately -2.0% at the beginning of Cycle 3. After approximately one-half of the cycle, delta flux values had shifted to -4.0% and then moved to -3.5% by the end of Cycle 3.

The power shift indicated by the delta flux values and the axial peaking factor can be observed in the corresponding core average axial power distribution for a representative series of maps given in Figures 4.12 through 4.14. In Map N2-3-13 (Figure 4.12), taken at approximately 670 MWD/MTU, the axial power distribution had a cosine shape with a peaking factor of 1.24. In Map N2-3-25 (Figure 4.13), taken at approximately 7,650 MWD/MTU, the axial power distribution was a flattened cosine with an axial peaking factor of 1.16. Finally, in Map N2-3-38 (Figure 4.14), taken at approximately 13,300 MWD/MTU, the axial power distribution was double-peaked with an axial peaking factor of 1.14. The history of F-Z during the cycle can be seen more clearly in a plot of F-Z versus burnup given in Figure 4.15.

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

$$P_b = \text{power in bottom of core (MW(t))}$$

In conclusion, the North Anna 2, Cycle 3 core performed satisfactorily with power distribution analyses verifying that design predictions were accurate and that the values of the $F_Q(Z)$ and F-delta H hot channel factors were within the limits of the Technical Specifications.

TABLE 4.1

NORTH ANNA UNIT 2 - CYCLE 3

SUMMARY OF INCORE FLUX MAPS FOR ROUTINE OPERATION

MAP NO.	DATE	BURN UP MWD/ MTU	PWR (%)	BANK D STEPS	1 F-Q (T) HOT CHANNEL FACTOR				2 F-DH(N) HOT CHNL. FACTOR			CORE F(Z) MAX		3 F(XY) MAX	4 QPTR		AXIAL OFF SET (%)	NO. OF THIM BLES
					ASSY	PIN	AXIAL POINT	F-Q(T)	ASSY	PIN	F-DH(N)	AXIAL POINT	F(Z)		MAX	LOC		
10	6-10-83	215	100	228	K14	MN	29	1.906	K14	MN	1.473	37	1.229	1.558	1.009	SW	-2.10	49
13(5)	6-30-83	671	100	228	K14	MN	38	1.893	K14	MN	1.458	37	1.242	1.538	1.014	SW	-4.79	42
14	7-22-83	1566	100	212	M10	NE	38	1.847	K14	MN	1.429	37	1.237	1.505	1.010	SW	-4.63	48
15	8- 4-83	1998	100	219	M10	NE	37	1.826	K14	MN	1.413	37	1.224	1.493	1.009	SW	-4.13	50
18(6)	9- 7-83	3315	100	210	M10	NE	37	1.804	M10	NE	1.407	38	1.216	1.484	1.008	SW	-5.33	48
19	10- 6-83	4430	100	212	L10	HI	37	1.779	L10	HI	1.402	38	1.194	1.492	1.008	SW	-4.92	49
20	11- 2-83	5471	100	217	L10	HI	38	1.771	L10	HI	1.419	38	1.173	1.510	1.006	SW	-4.21	50

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 R 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-Q(T) INCLUDES A TOTAL UNCERTAINTY OF 1.05 X 1.03.
- (2). F-DH(N) INCLUDES A MEASUREMENT UNCERTAINTY OF 1.04.
- (3). F(XY) INCLUDES A TOTAL UNCERTAINTY OF 1.05 X 1.03.
- (4). QPTR - QUADRANT POWER TILT RATIO.
- (5). MAPS 11 AND 12 WERE TAKEN FOR INCORE/EXCORE CALIBRATION.
- (6). MAPS 16 AND 17 WERE TAKEN FOR INCORE/EXCORE CALIBRATION.

TABLE 4.1 (CONT.)

MAP NO.	DATE	BURN UP MWD/MTU	PWR (%)	BANK D STEPS	F-Q (T) HOT CHANNEL FACTOR				F-DH(N) HOT CHNL. FACTOR				CORE F(Z) MAX		3 F(XY) MAX	4 QPTR		AXIAL OFF SET (%)	NO. OF THIM BLES
					ASSY	PIN	AXIAL POINT	F-Q(T)	ASSY	PIN	F-DH(N)	AXIAL POINT	F(Z)	MAX		LOC			
24(7)	12- 1-83	6577	100	216	F05	IJ	46	1.779	L10	HI	1.433	46	1.177	1.525	1.007	SW	-5.15	50	
25	12-30-83	7647	100	217	L06	HI	47	1.754	L10	HI	1.434	46	1.161	1.528	1.008	SW	-3.95	43	
26	1- 6-84	7668	100	218	F05	IJ	46	1.773	F05	IJ	1.443	46	1.164	1.540	1.007	SW	-4.37	47	
27	1- 9-84	7938	100	218	F05	IJ	47	1.762	F05	IJ	1.446	46	1.158	1.540	1.005	SW	-4.04	50	
30(8)	2-17-84	9173	100	218	D09	FE	47	1.765	D09	FE	1.445	47	1.154	1.535	1.007	SW	-3.79	39	
32(9)	3-21-84	10379	100	218	F05	IJ	48	1.765	F05	IJ	1.456	47	1.152	1.551	1.007	SW	-4.10	49	
33	4-27-84	11335	100	217	L10	HI	53	1.784	L10	HI	1.485	48	1.145	1.577	1.014	SW	-3.91	48	
34	5-16-84	11913	100	214	L10	HI	53	1.767	L10	HI	1.450	53	1.156	1.542	1.003	SW	-4.35	50	
37(10)	6-14-84	13040	100	221	L10	HI	53	1.740	L10	HI	1.443	53	1.144	1.536	1.005	SE	-2.71	46	
38	6-21-84	13299	100	221	L10	HI	53	1.760	L10	HI	1.453	53	1.144	1.546	1.006	SW	-2.60	46	
39	7-18-84	14267	75	180	L10	HI	53	1.715	L10	HI	1.433	53	1.125	1.528	1.003	SW	-3.37	46	
40	7-23-84	14445	76	180	L10	HI	53	1.716	F05	IJ	1.422	53	1.136	1.517	1.002	SW	-3.98	50	
41	7-24-84	14465	75	184	F05	IJ	19	1.698	L10	HI	1.434	20	1.139	1.526	1.002	NW	-0.48	45	
43(11)	8- 1-84	14660	99	228	L10	HI	12	1.686	F05	IJ	1.435	12	1.118	1.52M	1.005	SW	0.03	46	

(7). MAPS 21, 22, AND 23 WERE TAKEN FOR INCORE/EXCORE CALIBRATION.

(8). MAPS 28 AND 29 WERE TAKEN FOR INCORE/EXCORE CALIBRATION.

(9). MAP 31 WAS NOT ANALYZED DUE TO A LACK OF DETECTOR CALIBRATION DATA.

(10). MAPS 35 AND 36 WERE TAKEN FOR INCORE/EXCORE CALIBRATION.

(11). MAP 42 WAS TAKEN FOR INCORE/EXCORE CALIBRATION.

Figure 4.1

NORTH ANNA UNIT 2 - CYCLE 3
ASSEMBLYWISE POWER DISTRIBUTION N2-3-13

R	P	N	M	L	K	J	H	G	F	E	D	C	B	A	
<div> <div> PREDICTED MEASURED PCT DIFFERENCE </div> <div> 0.34 0.52 0.34 0.35 0.50 0.35 2.5 -4.8 3.3 </div> <div> PREDICTED MEASURED PCT DIFFERENCE </div> </div>															1
<div> <div> 0.55 0.97 1.09 0.85 1.09 0.97 0.55 0.58 1.00 1.08 0.84 1.08 1.00 0.58 5.8 2.5 -1.0 -1.3 -0.6 3.3 4.7 </div> <div> 0.63 1.02 1.17 0.99 1.23 0.99 1.17 1.02 0.63 0.65 1.06 1.19 0.99 1.21 0.98 1.18 1.05 0.66 3.7 3.5 1.8 -0.9 -1.4 -1.1 0.8 2.7 6.1 </div> </div>															2
<div> <div> 0.63 1.08 1.19 1.28 1.23 1.08 1.23 1.28 1.19 1.08 0.63 0.65 1.11 1.22 1.30 1.22 1.07 1.19 1.28 1.21 1.11 0.65 4.3 2.8 2.6 1.7 -1.0 -1.3 -3.2 -0.4 1.6 2.7 4.4 </div> </div>															3
<div> <div> 0.55 1.02 1.19 0.99 1.21 1.06 1.21 0.99 1.19 1.02 0.55 0.57 1.05 1.20 1.00 1.21 1.02 1.16 1.04 1.21 1.00 1.20 1.06 0.59 2.9 2.9 0.9 0.2 0.2 -3.8 -3.8 -1.5 0.1 0.4 1.0 3.5 6.2 </div> </div>															4
<div> <div> 0.97 1.16 1.28 1.21 1.00 1.17 1.03 1.17 1.00 1.21 1.28 1.16 0.97 1.00 1.20 1.29 1.20 0.98 1.12 0.99 1.15 1.00 1.20 1.27 1.18 1.01 2.9 2.9 0.7 -0.5 -1.8 -4.3 -3.8 -1.9 -0.2 -0.2 -0.6 1.0 3.4 </div> </div>															5
<div> <div> 0.34 1.09 0.99 1.23 1.06 1.17 1.05 1.16 1.05 1.17 1.06 1.23 0.99 1.09 0.34 0.36 1.11 0.97 1.20 1.03 1.13 1.00 1.11 1.02 1.15 1.04 1.18 0.97 1.08 0.35 4.8 1.4 -2.0 -2.9 -3.3 -3.8 -4.3 -3.8 -2.2 -1.6 -2.0 -3.8 -2.3 -1.3 0.7 </div> </div>															6
<div> <div> 0.52 0.85 1.23 1.08 1.21 1.03 1.16 0.97 1.16 1.03 1.21 1.08 1.23 0.85 0.52 0.55 0.86 1.20 1.06 1.17 1.00 1.10 0.93 1.12 1.00 1.16 1.04 1.20 0.84 0.53 4.8 1.4 -2.0 -2.6 -3.1 -3.6 -4.7 -3.7 -3.4 -3.5 -3.7 -3.8 -2.4 -1.5 0.7 </div> </div>															7
<div> <div> 0.34 1.09 0.99 1.23 1.06 1.17 1.05 1.16 1.05 1.17 1.06 1.23 0.99 1.09 0.34 0.36 1.11 0.97 1.20 1.03 1.13 1.00 1.11 1.02 1.15 1.04 1.18 0.97 1.08 0.35 4.8 1.4 -2.0 -2.9 -3.3 -3.8 -4.3 -3.8 -2.2 -1.6 -2.0 -3.8 -2.3 -1.3 0.7 </div> </div>															8
<div> <div> 0.27 1.16 1.28 1.21 1.00 1.17 1.03 1.17 1.00 1.21 1.28 1.16 0.97 0.99 1.19 1.29 1.21 0.99 1.13 1.00 1.13 0.97 1.17 1.28 1.20 1.00 2.2 2.2 0.9 0.2 -1.0 -3.2 -3.4 -3.8 -2.8 -2.5 0.3 2.9 2.9 </div> </div>															9
<div> <div> 0.55 1.02 1.19 0.99 1.21 1.06 1.21 1.06 1.21 0.99 1.19 1.02 0.55 0.58 1.07 1.23 1.01 1.19 1.03 1.18 1.02 1.18 0.99 1.21 1.05 0.57 4.6 4.6 3.6 1.7 -1.0 -2.3 -2.3 -3.5 -1.7 -0.7 1.7 2.6 3.4 </div> </div>															10
<div> <div> 0.63 1.08 1.19 1.28 1.23 1.08 1.23 1.28 1.19 1.08 0.63 0.67 1.13 1.21 1.28 1.20 1.05 1.20 1.27 1.19 1.10 0.64 6.9 4.4 1.7 0.1 -2.7 -2.8 -2.4 -0.9 -0.4 1.7 2.5 </div> </div>															11
<div> <div> 0.63 1.02 1.17 0.99 1.23 0.99 1.17 1.02 0.63 0.67 1.10 1.21 0.97 1.20 0.98 1.17 1.03 0.64 7.6 8.2 3.4 -2.3 -1.8 -1.0 0.6 0.7 2.4 </div> </div>															12
<div> <div> 0.55 0.97 1.09 0.85 1.09 0.97 0.55 0.60 1.06 1.13 0.87 1.08 0.98 0.55 8.2 9.2 3.2 2.1 -0.8 0.6 0.5 </div> </div>															13
<div> <div> STANDARD DEVIATION = 1.836 </div> <div> 0.34 0.52 0.34 0.36 0.55 0.35 10.2 5.6 0.8 </div> <div> AVERAGE PCT DIFFERENCE = 2.6 </div> </div>															14

SUMMARY

MAP NO: N2-3-13

DATE: 6/30/83

POWER: 100%

CONTROL ROD POSITIONS:

$$F-Q(T) = 1.893$$

QPTR:

D BANK AT 228 STEPS

$$F-DH(N) = 1.458$$

NW 1.000 | NE 0.998

$$F(Z) = 1.242$$

SW	1.014	SE	0.988
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$$F(XY) = 1.538$$

BURNUP = 671 MWD/MTU A.O = -4.79(%)

Figure 4.2

NORTH ANNA UNIT 2 - CYCLE 3 ASSEMBLYWISE POWER DISTRIBUTION N2-3-25

R	P	N	M	L	K	J	H	G	F	E	D	C	B	A							
PREDICTED MEASURED PCT DIFFERENCE																					
						0.33	0.50	0.33							1						
						0.33	0.50	0.34													
						0.0	-0.1	2.4													
PREDICTED MEASURED PCT DIFFERENCE																					
						0.53	0.89	0.99	0.78	0.99	0.89	0.53			2						
						0.51	0.85	0.97	0.76	0.99	0.94	0.56									
						-4.3	-4.6	-2.3	-2.4	0.2	4.9	4.6									
						0.61	0.98	1.18	0.95	1.11	0.95	1.18	0.98	0.61	3						
						0.60	0.96	1.17	0.90	1.06	0.95	1.21	1.01	0.64							
						-2.7	-2.5	-0.8	-4.6	-4.6	0.1	2.5	3.1	4.2							
						0.61	1.04	1.25	1.25	1.26	1.05	1.28	1.25	1.25	1.04	0.61	4				
						0.59	1.03	1.23	1.25	1.25	1.03	1.25	1.26	1.27	1.06	0.63					
						-4.3	-1.1	-0.9	0.4	-2.3	-2.4	-2.1	1.0	1.6	2.1	3.3					
						0.53	0.98	1.24	1.04	1.31	1.09	1.23	1.09	1.31	1.04	1.24	0.98	0.53	5		
						0.54	1.00	1.24	1.03	1.31	1.08	1.22	1.08	1.32	1.04	1.26	1.01	0.56			
						2.4	2.1	-0.3	-0.2	-0.3	-0.5	-0.6	-0.6	0.5	0.5	1.0	2.8	5.5			
						0.89	1.18	1.25	1.31	1.06	1.29	1.07	1.29	1.06	1.31	1.25	1.18	0.89	6		
						0.91	1.21	1.26	1.31	1.06	1.27	1.06	1.28	1.07	1.31	1.24	1.18	0.92			
						2.4	2.4	0.6	-0.3	-0.6	-1.0	-0.5	-0.3	0.5	-0.5	0.5	2.7				
						0.33	0.99	0.94	1.28	1.09	1.29	1.08	1.19	1.08	1.29	1.09	1.28	0.94	0.99	0.33	7
						0.33	0.99	0.94	1.26	1.06	1.26	1.07	1.19	1.08	1.29	1.06	1.24	0.93	0.98	0.33	
						0.7	-0.0	-0.3	-1.4	-2.4	-2.2	-1.4	-0.6	-0.2	0.0	-2.3	-3.0	-2.0	-1.0	-0.0	
						0.50	0.78	1.11	1.05	1.23	1.07	1.19	0.98	1.19	1.07	1.23	1.05	1.11	0.78	0.50	8
						0.50	0.77	1.10	1.05	1.22	1.06	1.17	0.98	1.19	1.06	1.19	1.02	1.09	0.79	0.52	
						0.6	-0.3	-0.7	-0.7	-0.9	-1.1	-1.7	-0.4	-0.5	-0.5	-2.9	-2.9	-2.0	1.2	3.3	
						0.33	0.98	0.93	1.27	1.08	1.28	1.06	1.19	1.07	1.27	1.08	1.26	0.94	0.99	0.33	9
						0.7	-0.7	-1.5	-1.1	-0.7	-0.7	-1.7	-0.5	-1.2	-1.3	-1.2	-1.2	-0.1	2.3	4.6	
						0.89	1.18	1.25	1.31	1.06	1.29	1.07	1.29	1.06	1.31	1.25	1.18	0.89			10
						0.90	1.18	1.26	1.33	1.07	1.25	1.05	1.26	1.06	1.31	1.27	1.19	0.93			
						0.4	0.4	0.8	1.0	1.0	-3.0	-1.8	-2.0	-0.5	-0.3	1.4	1.1	4.2			
						0.53	0.98	1.24	1.04	1.31	1.09	1.23	1.09	1.31	1.04	1.24	0.98	0.53			11
						0.55	1.01	1.27	1.05	1.31	1.06	1.20	1.06	1.32	1.04	1.26	0.99	0.54			
						2.9	2.9	2.3	1.2	-0.2	-2.3	-2.4	-2.7	0.3	0.8	1.7	1.3	2.4			
						0.61	1.04	1.25	1.25	1.28	1.05	1.28	1.25	1.25	1.04	0.61					12
						0.65	1.07	1.26	1.25	1.25	1.02	1.26	1.26	1.26	1.07	0.63					
						5.4	3.3	1.2	-0.3	-2.6	-2.7	-1.9	0.8	1.1	2.6	1.8					
						0.61	0.98	1.18	0.95	1.11	0.95	1.18	0.98	0.61							13
						0.65	1.04	1.21	0.92	1.09	0.94	1.18	1.00	0.63							
						5.5	6.3	2.3	-2.6	-2.1	-0.9	0.5	1.7	1.8							
						0.53	0.89	0.99	0.78	0.99	0.89	0.53									14
						0.57	0.96	1.01	0.78	0.98	0.90	0.54									
						6.3	7.1	2.3	1.0	-0.9	0.3	1.5									
STANDARD DEVIATION =1.543																					
						0.33	0.50	0.33													15
						0.36	0.52	0.33													
						7.7	3.6	-0.8													
AVERAGE PCT DIFFERENCE = 1.8																					

SUMMARY

MAP NO: N2-3-25

DATE: 12/30/83

POWER: 100%

CONTROL ROD POSITIONS:

F-Q(T) = 1.754

QPTR:

D BANK AT 217 STEPS

F-DH(N) = 1.434

NW 0.994 | NE 1.002

F(Z) = 1.161

SW 1.008 | SE 0.997

F(XY) = 1.528

BURNUP = 7647 MWD/MTU A.O = -3.95(%)

Figure 4.3

NORTH ANNA UNIT 2 - CYCLE 3 ASSEMBLYWISE POWER DISTRIBUTION N2-3-38

R	P	N	M	L	K	J	H	G	F	E	D	C	B	A	
<div> <div>PREDICTED</div> <div>MEASURED</div> <div>PCT DIFFERENCE</div> </div>															1
<div> <div>0.35</div> <div>0.53</div> <div>0.35</div> </div>															
<div> <div>0.36</div> <div>0.53</div> <div>0.35</div> </div>															
<div> <div>1.7</div> <div>1.6</div> <div>1.2</div> </div>															
<div> <div>0.54</div> <div>0.88</div> <div>0.98</div> <div>0.78</div> <div>0.98</div> <div>0.88</div> <div>0.54</div> </div>															2
<div> <div>0.55</div> <div>0.84</div> <div>0.97</div> <div>0.77</div> <div>0.97</div> <div>0.88</div> <div>0.55</div> </div>															
<div> <div>2.4</div> <div>-1.6</div> <div>-0.9</div> <div>-1.1</div> <div>-0.4</div> <div>0.6</div> <div>1.9</div> </div>															
<div> <div>0.62</div> <div>0.97</div> <div>1.19</div> <div>0.94</div> <div>1.06</div> <div>0.94</div> <div>1.19</div> <div>0.97</div> <div>0.62</div> </div>															3
<div> <div>0.62</div> <div>0.97</div> <div>1.16</div> <div>0.92</div> <div>1.06</div> <div>0.93</div> <div>1.19</div> <div>0.98</div> <div>0.64</div> </div>															
<div> <div>0.1</div> <div>-0.1</div> <div>-2.6</div> <div>-1.9</div> <div>-2.0</div> <div>-1.0</div> <div>0.0</div> <div>1.1</div> <div>3.2</div> </div>															
<div> <div>0.62</div> <div>1.02</div> <div>1.26</div> <div>1.22</div> <div>1.28</div> <div>1.04</div> <div>1.28</div> <div>1.22</div> <div>1.26</div> <div>1.02</div> <div>0.62</div> </div>															4
<div> <div>0.64</div> <div>1.03</div> <div>1.26</div> <div>1.21</div> <div>1.27</div> <div>1.03</div> <div>1.27</div> <div>1.21</div> <div>1.26</div> <div>1.03</div> <div>0.63</div> </div>															
<div> <div>2.4</div> <div>0.3</div> <div>0.2</div> <div>-0.5</div> <div>-1.3</div> <div>-1.3</div> <div>-1.4</div> <div>-0.5</div> <div>0.2</div> <div>0.5</div> <div>1.8</div> </div>															
<div> <div>0.54</div> <div>0.97</div> <div>1.26</div> <div>1.04</div> <div>1.33</div> <div>1.08</div> <div>1.21</div> <div>1.08</div> <div>1.33</div> <div>1.04</div> <div>1.26</div> <div>0.97</div> <div>0.54</div> </div>															5
<div> <div>0.56</div> <div>0.98</div> <div>1.23</div> <div>1.03</div> <div>1.31</div> <div>1.09</div> <div>1.21</div> <div>1.09</div> <div>1.34</div> <div>1.04</div> <div>1.23</div> <div>0.98</div> <div>0.56</div> </div>															
<div> <div>2.9</div> <div>1.2</div> <div>-1.7</div> <div>-1.6</div> <div>-1.3</div> <div>0.0</div> <div>0.0</div> <div>0.4</div> <div>0.7</div> <div>-0.3</div> <div>-2.1</div> <div>1.2</div> <div>4.5</div> </div>															
<div> <div>0.88</div> <div>1.19</div> <div>1.22</div> <div>1.33</div> <div>1.08</div> <div>1.31</div> <div>1.07</div> <div>1.31</div> <div>1.08</div> <div>1.33</div> <div>1.22</div> <div>1.19</div> <div>0.88</div> </div>															6
<div> <div>0.90</div> <div>1.22</div> <div>1.22</div> <div>1.31</div> <div>1.07</div> <div>1.31</div> <div>1.07</div> <div>1.33</div> <div>1.10</div> <div>1.31</div> <div>1.18</div> <div>1.18</div> <div>0.90</div> </div>															
<div> <div>2.9</div> <div>2.9</div> <div>0.0</div> <div>-1.5</div> <div>-0.7</div> <div>2.1</div> <div>0.6</div> <div>1.5</div> <div>1.9</div> <div>-1.7</div> <div>-3.5</div> <div>-0.4</div> <div>2.7</div> </div>															
<div> <div>0.35</div> <div>0.98</div> <div>0.94</div> <div>1.29</div> <div>1.09</div> <div>1.31</div> <div>1.08</div> <div>1.18</div> <div>1.08</div> <div>1.31</div> <div>1.09</div> <div>1.29</div> <div>0.94</div> <div>0.98</div> <div>0.35</div> </div>															7
<div> <div>0.36</div> <div>0.99</div> <div>0.95</div> <div>1.27</div> <div>1.05</div> <div>1.28</div> <div>1.08</div> <div>1.19</div> <div>1.09</div> <div>1.33</div> <div>1.07</div> <div>1.24</div> <div>0.93</div> <div>0.98</div> <div>0.36</div> </div>															
<div> <div>2.3</div> <div>1.1</div> <div>0.7</div> <div>-1.4</div> <div>-3.5</div> <div>-2.3</div> <div>0.1</div> <div>0.6</div> <div>1.5</div> <div>2.0</div> <div>-1.6</div> <div>-3.7</div> <div>-1.1</div> <div>0.4</div> <div>1.5</div> </div>															
<div> <div>0.53</div> <div>0.78</div> <div>1.08</div> <div>1.04</div> <div>1.21</div> <div>1.07</div> <div>1.18</div> <div>0.95</div> <div>1.16</div> <div>1.07</div> <div>1.21</div> <div>1.04</div> <div>1.08</div> <div>0.78</div> <div>0.53</div> </div>															8
<div> <div>0.54</div> <div>0.79</div> <div>1.08</div> <div>1.04</div> <div>1.20</div> <div>1.06</div> <div>1.18</div> <div>0.99</div> <div>1.18</div> <div>1.06</div> <div>1.16</div> <div>1.00</div> <div>1.07</div> <div>0.80</div> <div>0.55</div> </div>															
<div> <div>2.3</div> <div>1.0</div> <div>0.3</div> <div>-0.3</div> <div>-1.1</div> <div>-0.7</div> <div>-0.1</div> <div>0.9</div> <div>-0.3</div> <div>-0.4</div> <div>-4.5</div> <div>-3.6</div> <div>-1.0</div> <div>2.3</div> <div>4.1</div> </div>															
<div> <div>0.35</div> <div>0.98</div> <div>0.94</div> <div>1.29</div> <div>1.09</div> <div>1.31</div> <div>1.08</div> <div>1.18</div> <div>1.08</div> <div>1.31</div> <div>1.09</div> <div>1.29</div> <div>0.94</div> <div>0.98</div> <div>0.35</div> </div>															9
<div> <div>0.36</div> <div>0.97</div> <div>0.92</div> <div>1.27</div> <div>1.08</div> <div>1.29</div> <div>1.05</div> <div>1.18</div> <div>1.04</div> <div>1.28</div> <div>1.06</div> <div>1.26</div> <div>0.94</div> <div>1.00</div> <div>0.37</div> </div>															
<div> <div>2.3</div> <div>-0.6</div> <div>-2.1</div> <div>-1.5</div> <div>-0.8</div> <div>-1.4</div> <div>-2.3</div> <div>-0.8</div> <div>-1.4</div> <div>-1.8</div> <div>-2.6</div> <div>-1.6</div> <div>0.2</div> <div>2.8</div> <div>4.8</div> </div>															
<div> <div>0.88</div> <div>1.19</div> <div>1.22</div> <div>1.33</div> <div>1.08</div> <div>1.31</div> <div>1.07</div> <div>1.31</div> <div>1.08</div> <div>1.33</div> <div>1.22</div> <div>1.19</div> <div>0.88</div> </div>															10
<div> <div>0.86</div> <div>1.16</div> <div>1.22</div> <div>1.36</div> <div>1.08</div> <div>1.28</div> <div>1.05</div> <div>1.28</div> <div>1.06</div> <div>1.31</div> <div>1.23</div> <div>1.19</div> <div>0.92</div> </div>															
<div> <div>-2.3</div> <div>-2.3</div> <div>0.5</div> <div>1.9</div> <div>0.4</div> <div>-2.2</div> <div>-1.3</div> <div>-2.2</div> <div>-1.0</div> <div>-1.3</div> <div>0.7</div> <div>0.5</div> <div>5.2</div> </div>															
<div> <div>0.54</div> <div>0.97</div> <div>1.26</div> <div>1.04</div> <div>1.33</div> <div>1.08</div> <div>1.21</div> <div>1.08</div> <div>1.33</div> <div>1.04</div> <div>1.26</div> <div>0.97</div> <div>0.54</div> </div>															11
<div> <div>0.54</div> <div>0.98</div> <div>1.27</div> <div>1.07</div> <div>1.32</div> <div>1.06</div> <div>1.19</div> <div>1.05</div> <div>1.32</div> <div>1.04</div> <div>1.28</div> <div>0.96</div> <div>0.95</div> </div>															
<div> <div>0.9</div> <div>0.9</div> <div>1.5</div> <div>2.6</div> <div>-0.7</div> <div>-2.3</div> <div>-2.3</div> <div>-2.8</div> <div>-0.5</div> <div>0.1</div> <div>1.7</div> <div>1.5</div> <div>2.8</div> </div>															
<div> <div>0.62</div> <div>1.02</div> <div>1.26</div> <div>1.22</div> <div>1.28</div> <div>1.04</div> <div>1.28</div> <div>1.22</div> <div>1.26</div> <div>1.02</div> <div>0.62</div> </div>															12
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<div> <div>0.62</div> <div>0.97</div> <div>1.19</div> <div>0.94</div> <div>1.08</div> <div>0.94</div> <div>1.19</div> <div>0.97</div> <div>0.62</div> </div>															13
<div> <div>0.65</div> <div>1.03</div> <div>1.21</div> <div>0.92</div> <div>1.06</div> <div>0.93</div> <div>1.18</div> <div>0.97</div> <div>0.64</div> </div>															
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<div> <div>STANDARD</div> <div>DEVIATION</div> <div>=1.493</div> </div>															15
<div> <div>0.35</div> <div>0.53</div> <div>0.35</div> </div>															
<div> <div>0.38</div> <div>0.55</div> <div>0.35</div> </div>															
<div> <div>9.6</div> <div>4.8</div> <div>-0.3</div> </div>															
<div> <div>AVERAGE</div> <div>PCT DIFFERENCE</div> <div>= 1.8</div> </div>															

SUMMARY

MAP NO: N2-3-38

DATE: 6/21/84

POWER: 100%

CONTROL ROD POSITIONS: F-Q(T) = 1.760

QPTR:

D BANK AT 221 STEPS

F-DH(N) = 1.453

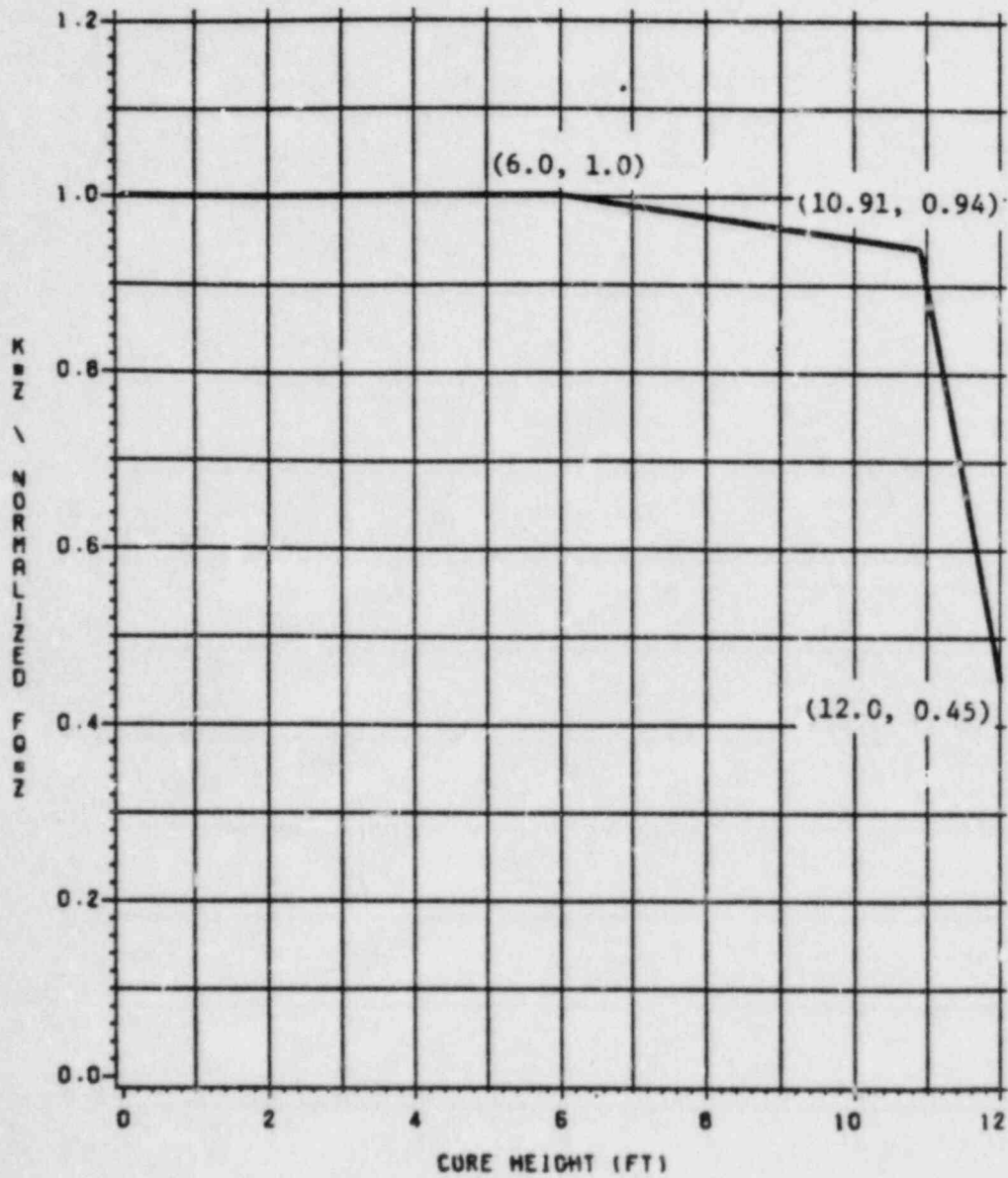
NW 0.998 | NE 1.002

F(Z) = 1.144

SW 1.006 | SE 0.994

Figure 4.4

HOT CHANNEL FACTOR NORMALIZED
OPERATING ENVELOPE



BOTTOM

TOP

Figure 4.5

NORTH ANNA UNIT 2 - CYCLE 3
HEAT FLUX HOT CHANNEL FACTOR, $F_Q^T(Z)$
N2-3-13

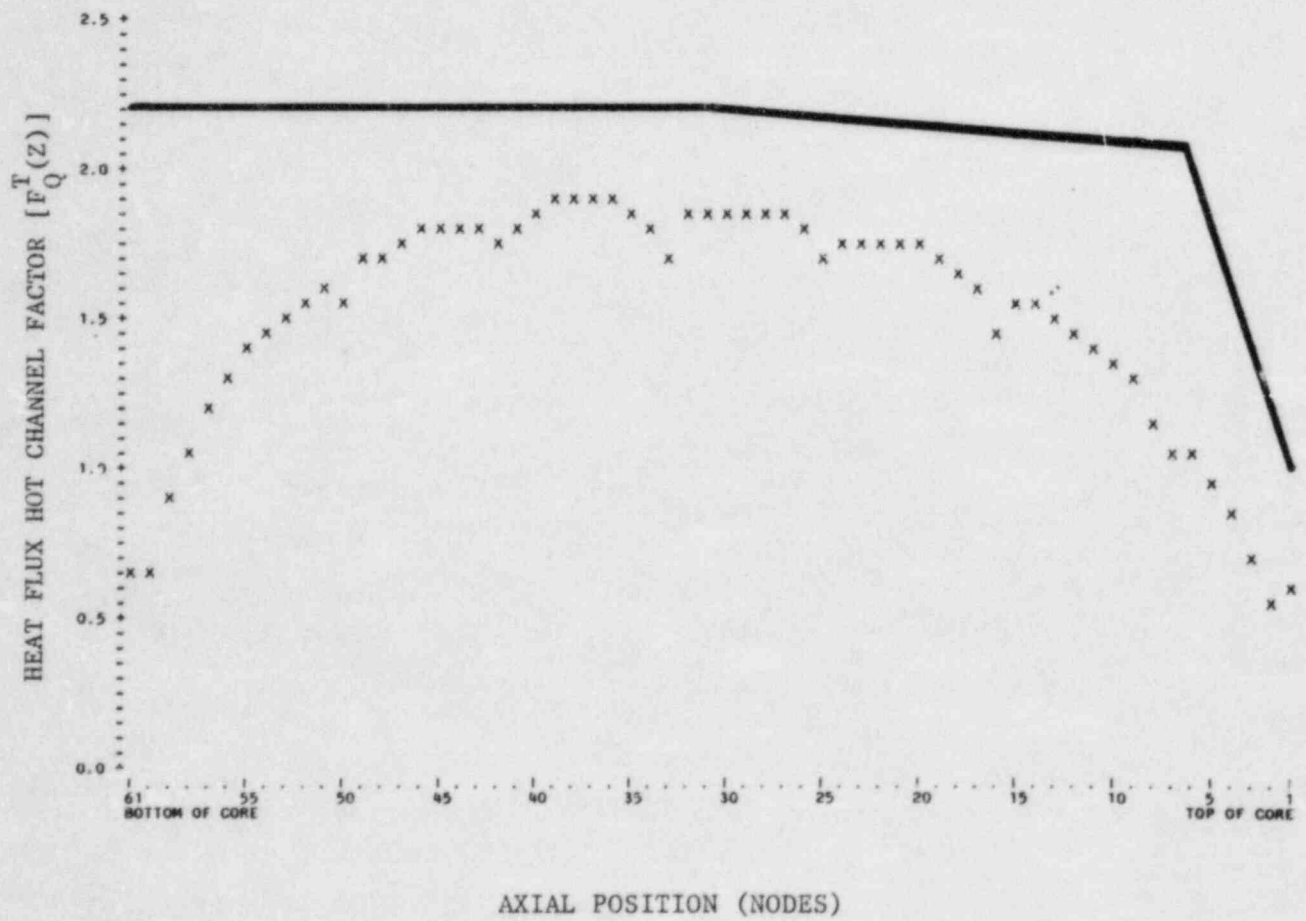


Figure 4.6

NORTH ANNA UNIT 2 - CYCLE 3
HEAT FLUX HOT CHANNEL FACTOR, $F_Q^T(Z)$
N2-3-25

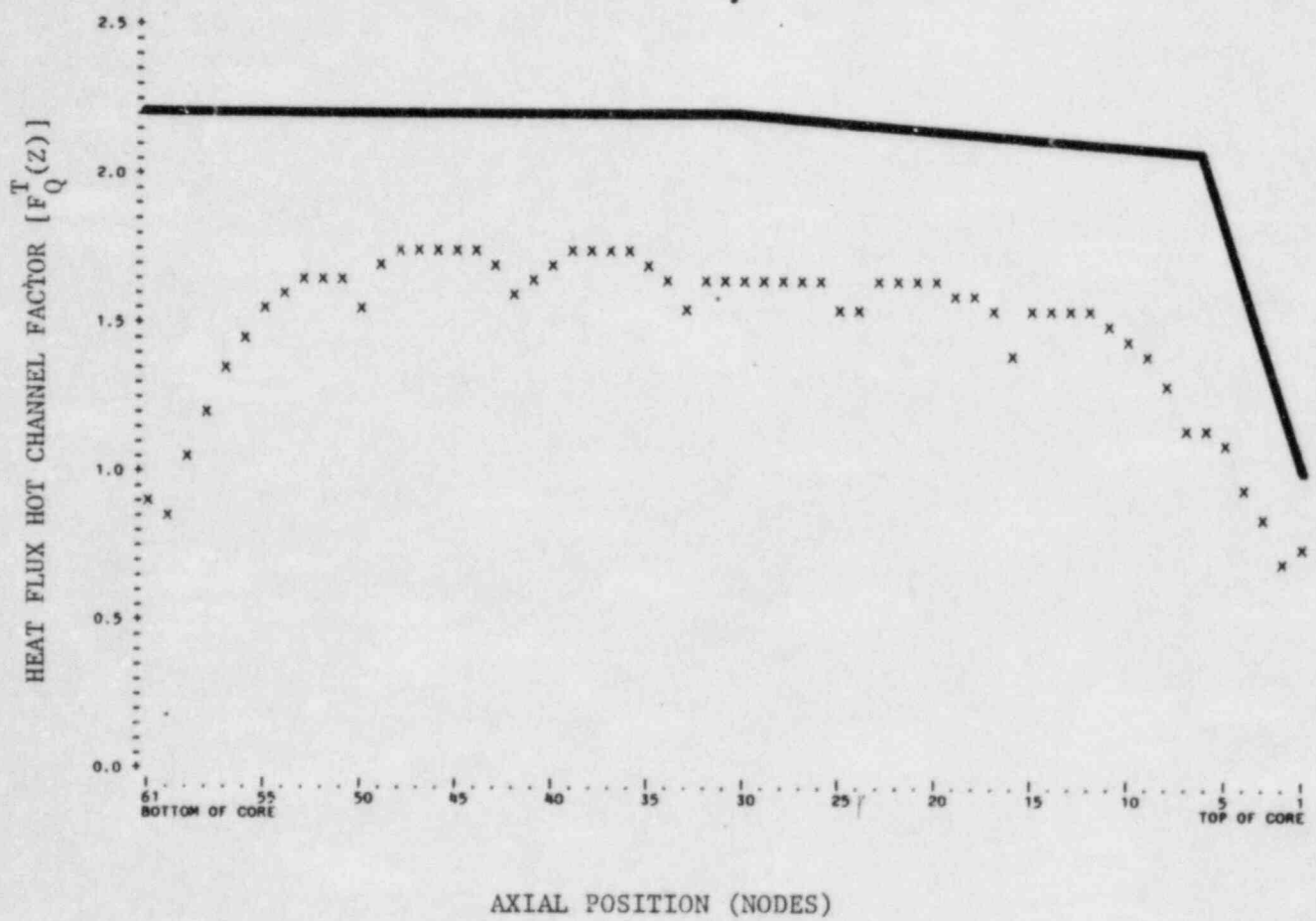


Figure 4.7

NORTH ANNA UNIT 2 - CYCLE 3
HEAT FLUX HOT CHANNEL FACTOR, $F_Q^T(Z)$
N2-3-38

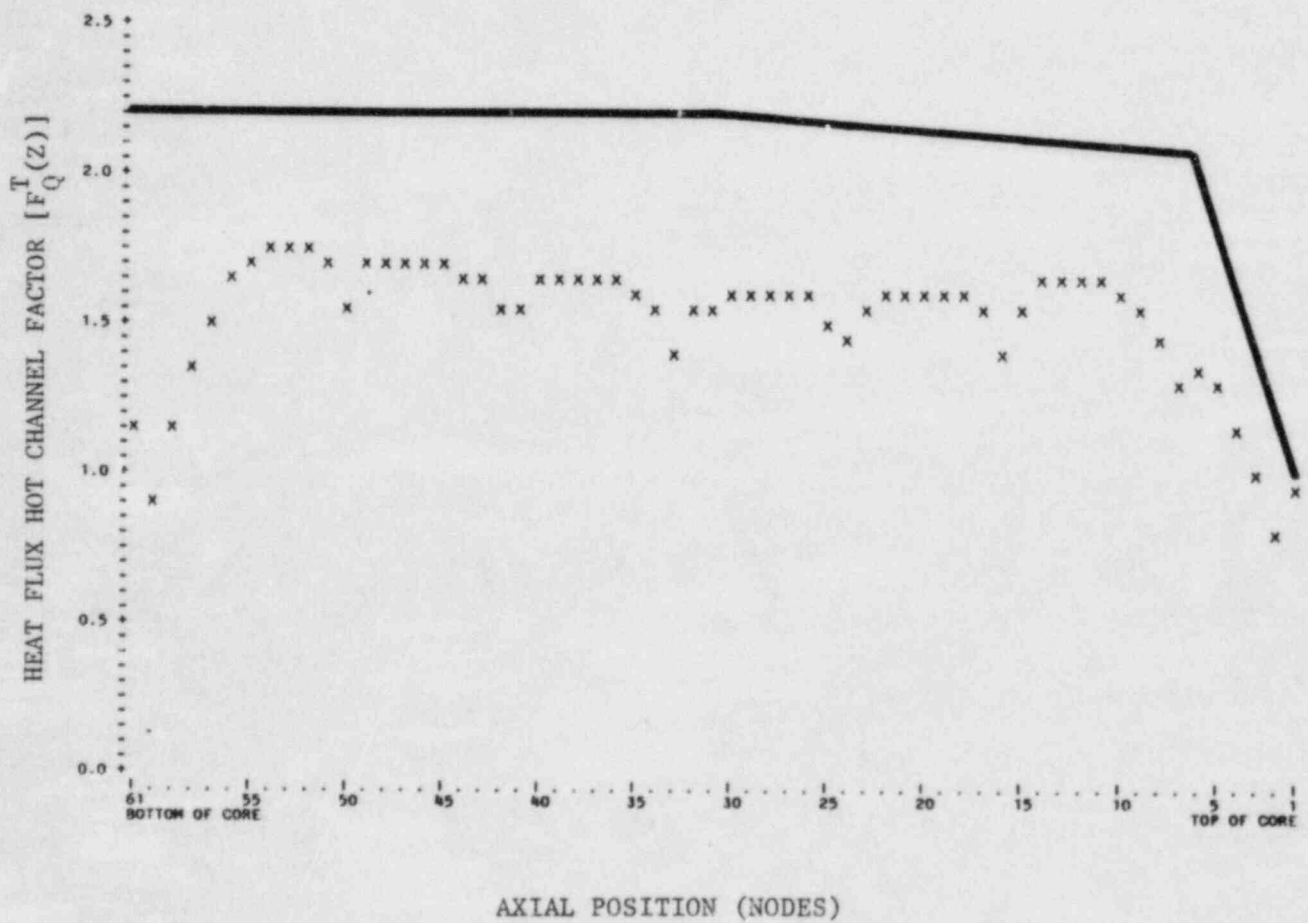


Figure 4.8

NORTH ANNA UNIT 2 - CYCLE 3

MAXIMUM HEAT FLUX HOT CHANNEL FACTOR, $F_Q \cdot P$, vs.
AXIAL POSITION

- $F_Q \cdot P$ LIMIT

* MAXIMUM $F_Q \cdot P$

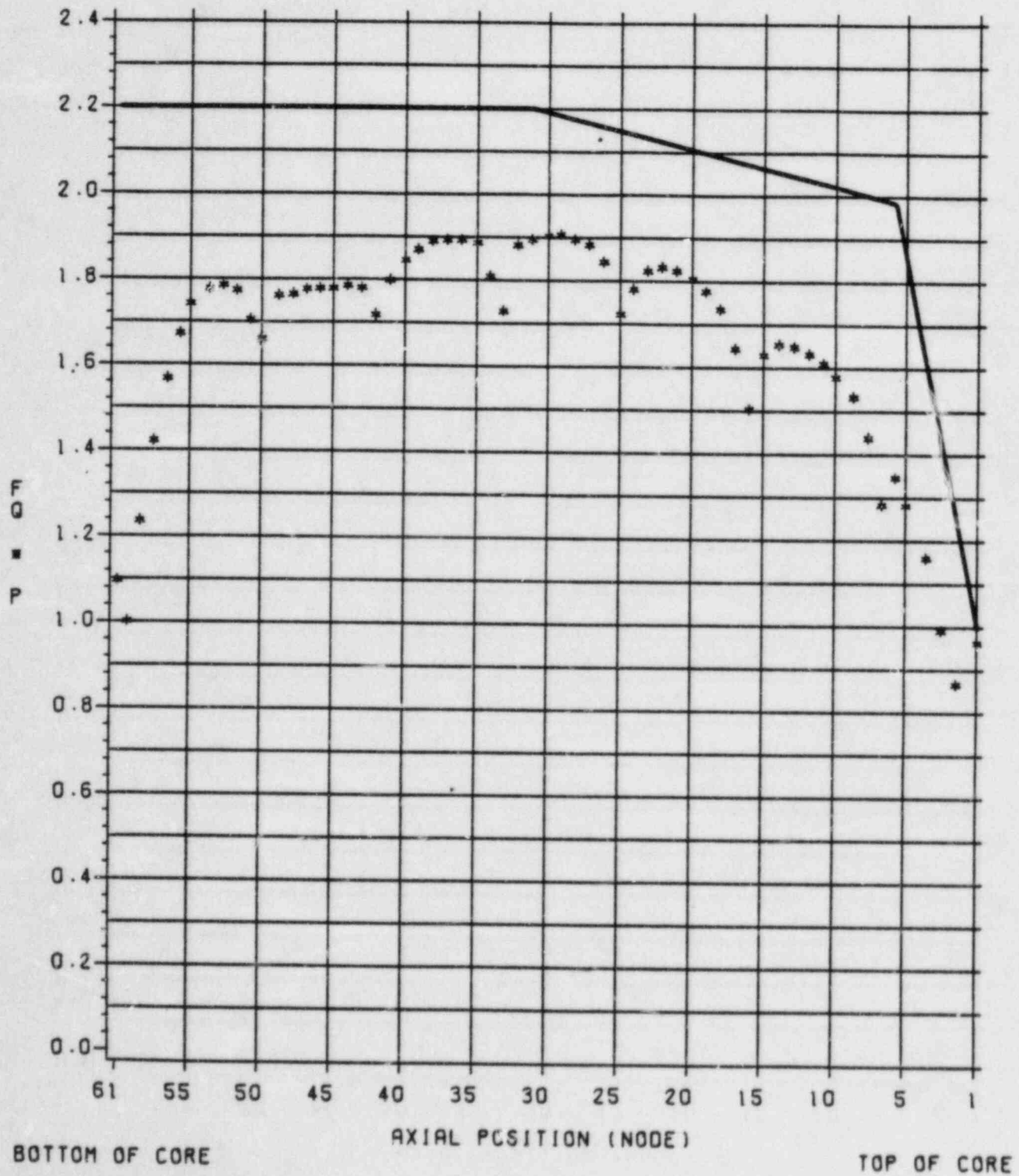


Figure 4.9

NORTH ANNA UNIT 2 - CYCLE 3
 MAXIMUM HEAT FLUX HOT CHANNEL FACTOR, $F_Q(Z)$,
 vs. BURNUP

- TECH SPEC LIMIT

X MEASURED VALUE

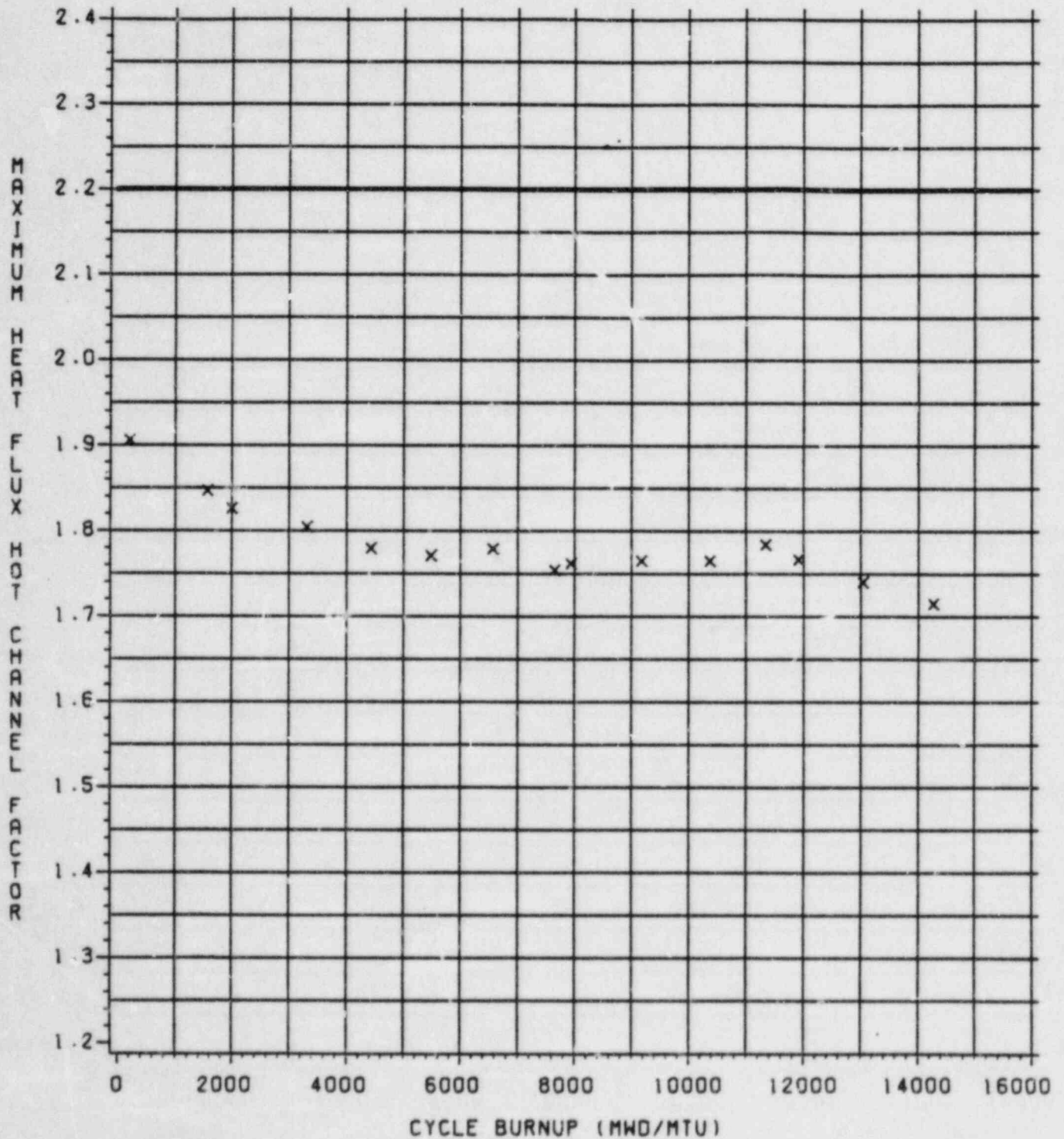


Figure 4.10

NORTH ANNA UNIT 2 - CYCLE 3

MAXIMUM ENTHALPY RISE HOT CHANNEL FACTOR, $F\text{-}\Delta H$,
vs. BURNUP

- TECH SPEC LIMIT

X MEASURED VALUE

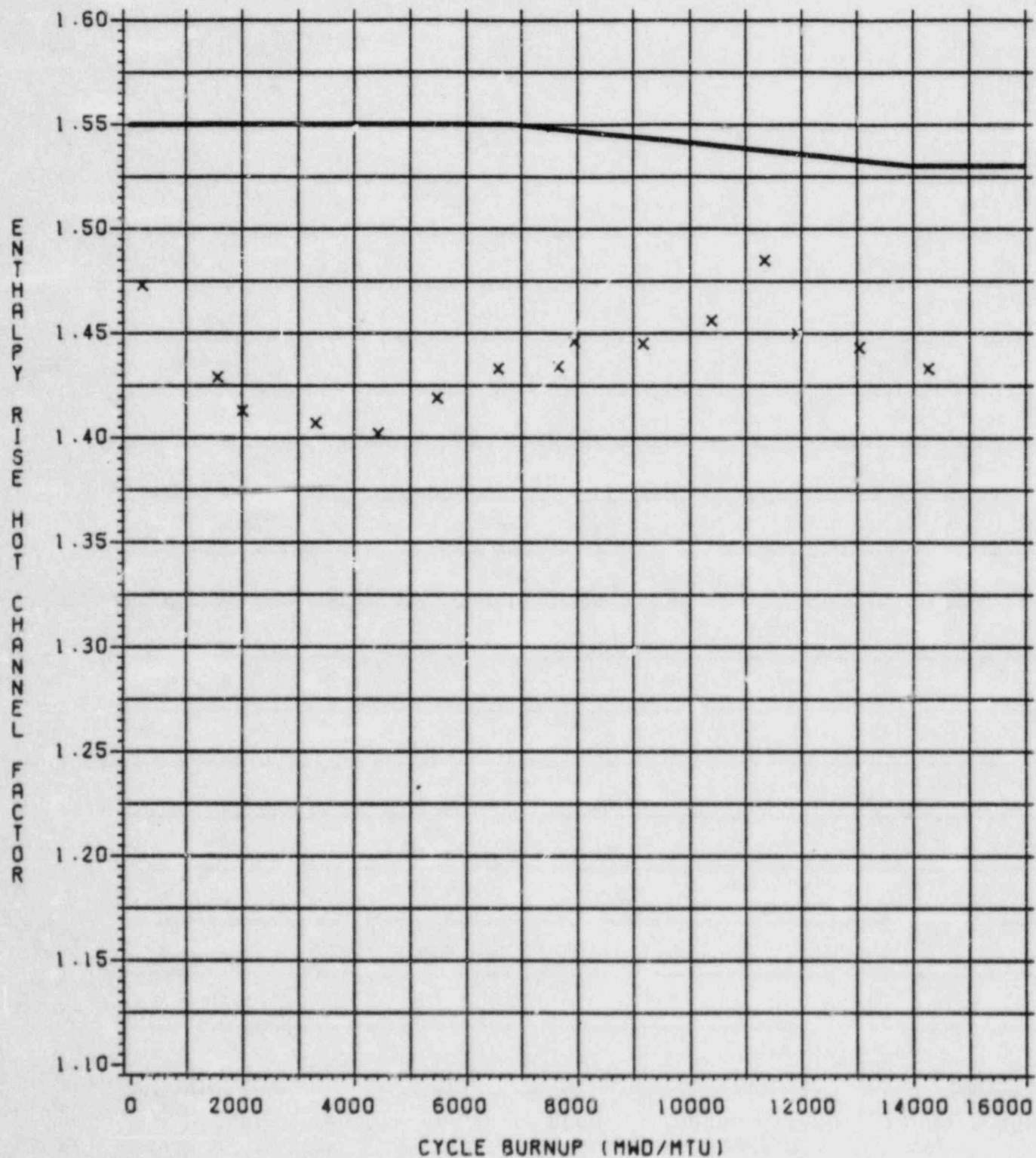


Figure 4.11

NORTH ANNA UNIT 2 - CYCLE 3
TARGET DELTA FLUX vs. BURNUP

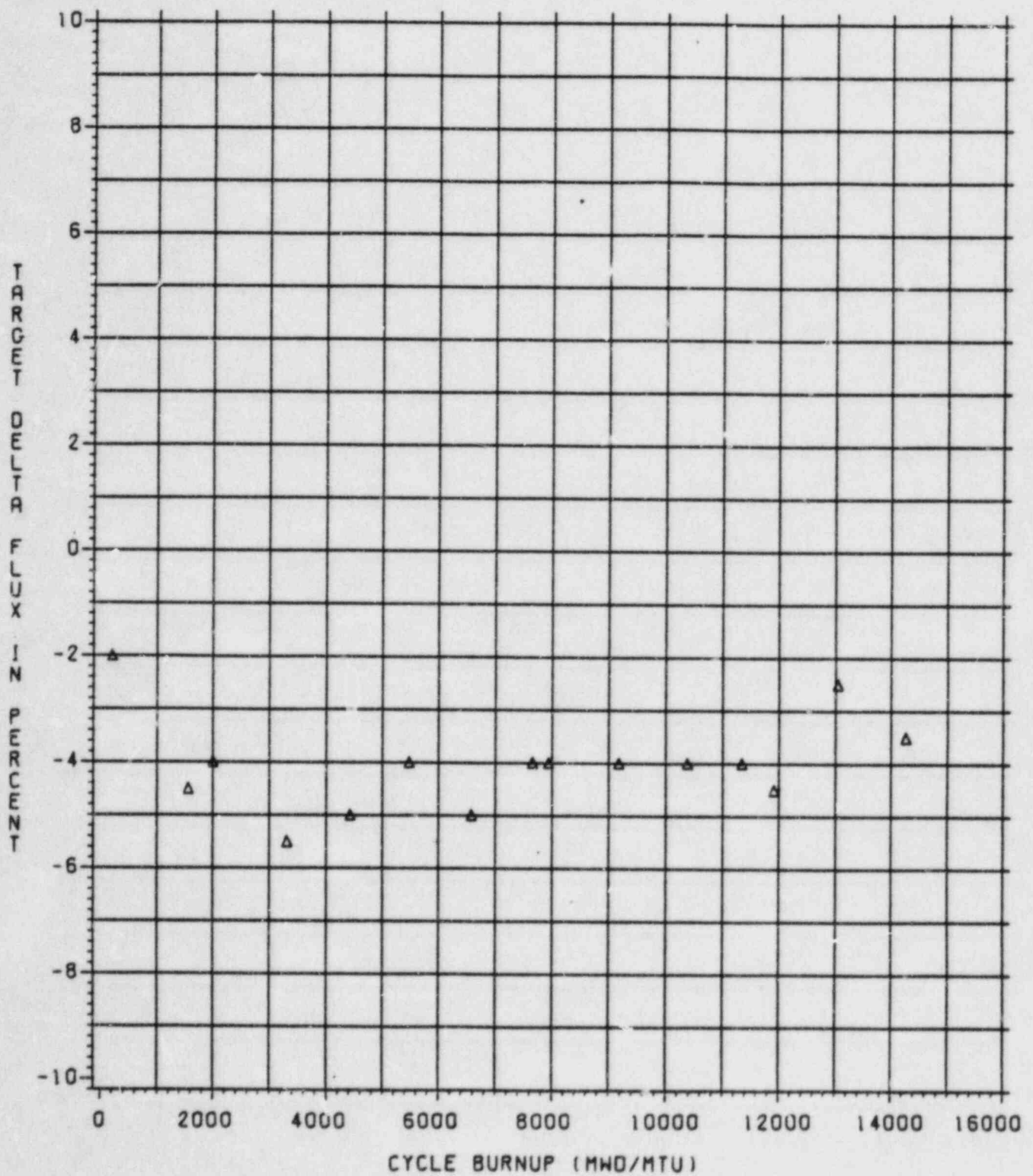


Figure 4.12

NORTH ANNA UNIT 2 - CYCLE 3
CORE AVERAGE AXIAL POWER DISTRIBUTION
N2-3-13

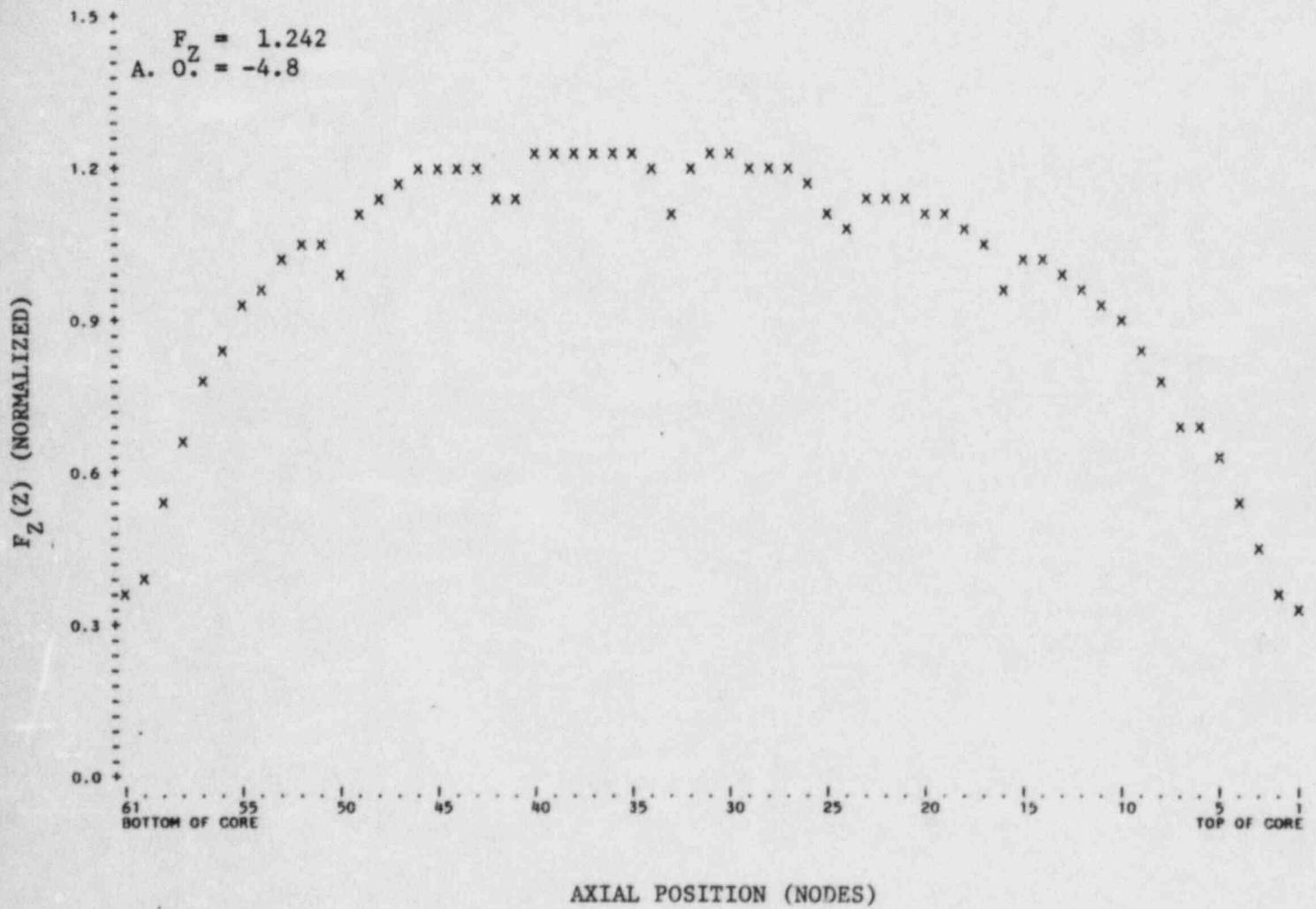


Figure 4.13

NORTH ANNA UNIT 2 - CYCLE 3
CORE AVERAGE AXIAL POWER DISTRIBUTION
N2-3-25

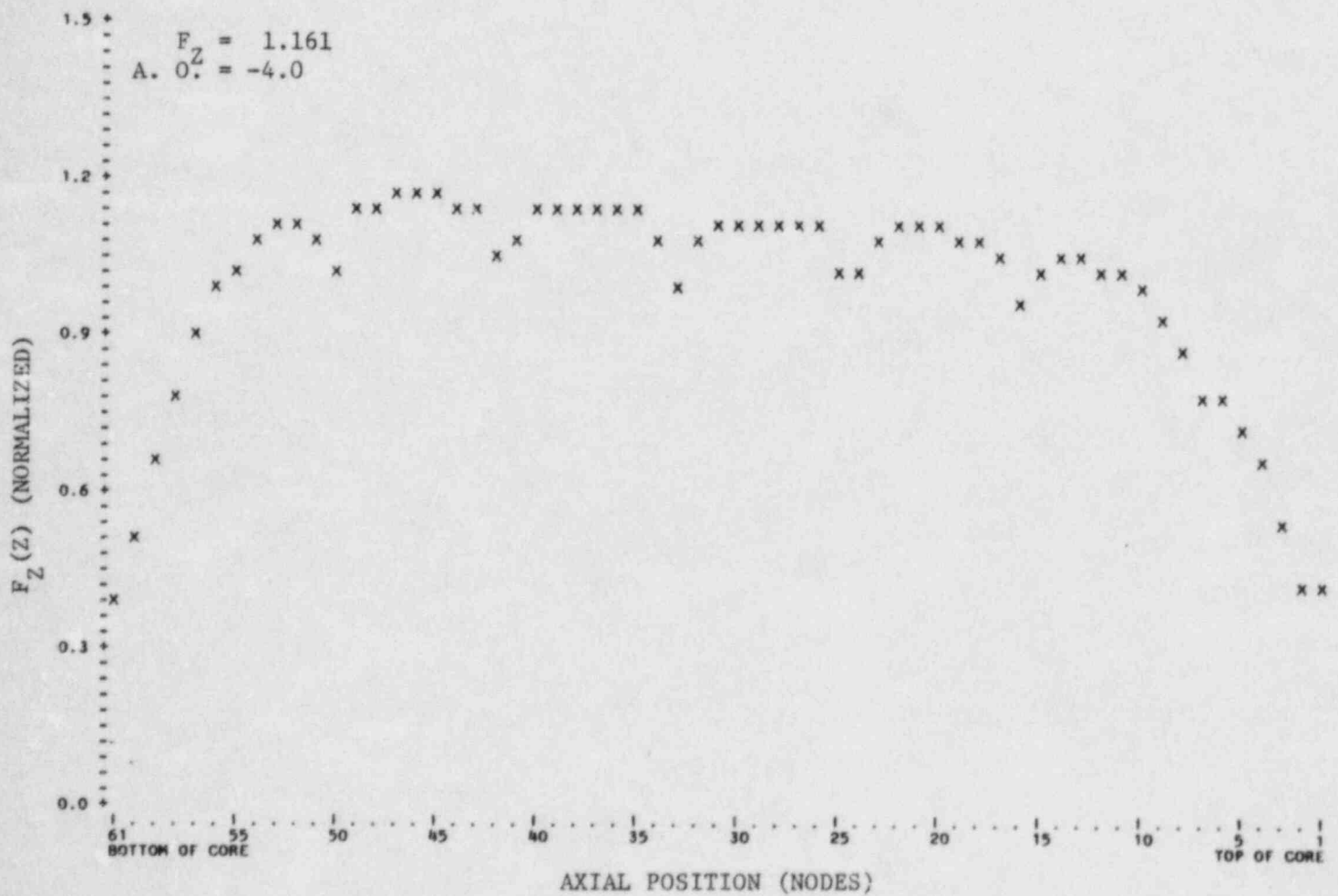


Figure 4.14

NORTH ANNA UNIT 2 - CYCLE 3
CORE AVERAGE AXIAL POWER DISTRIBUTION
N2-3-38

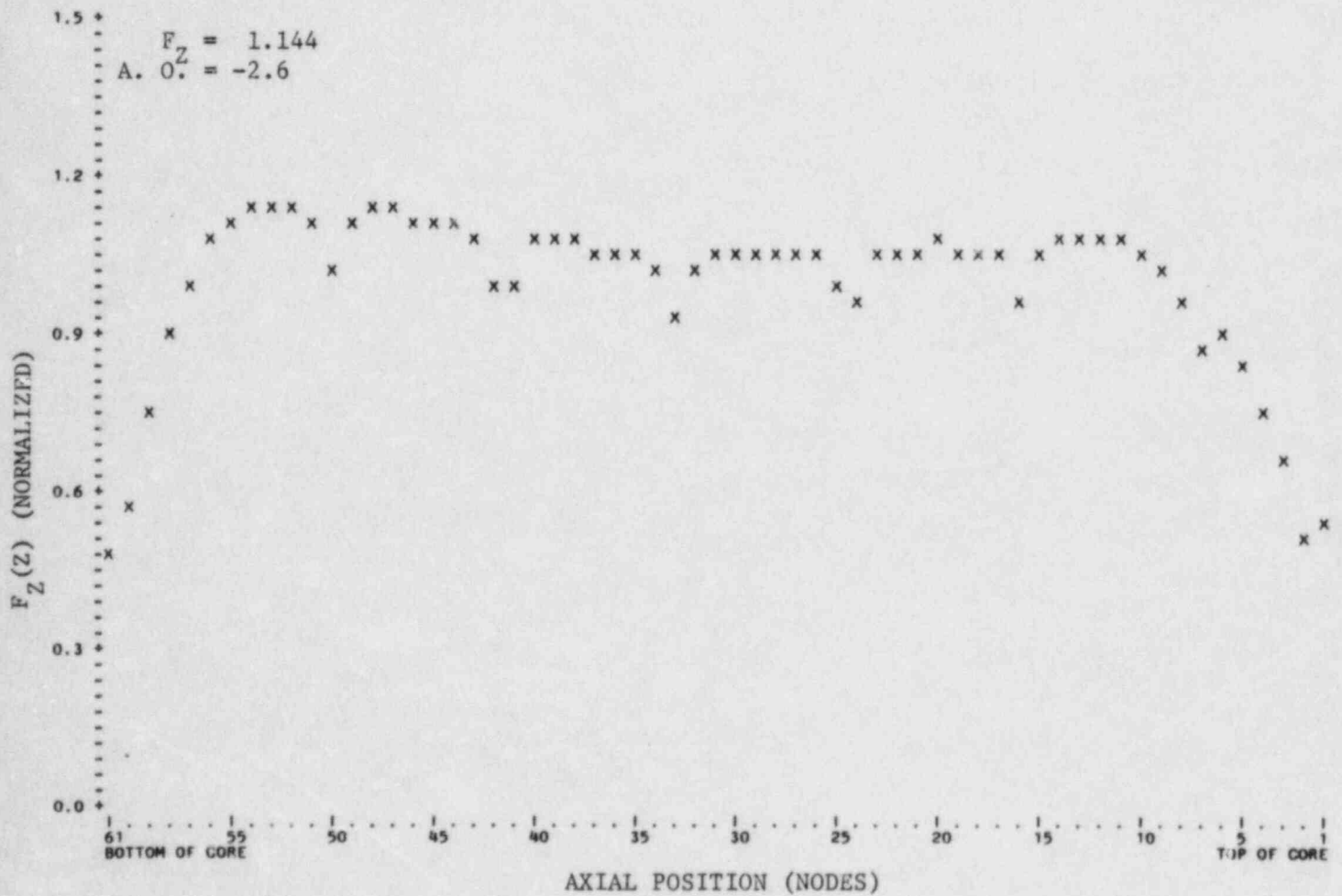
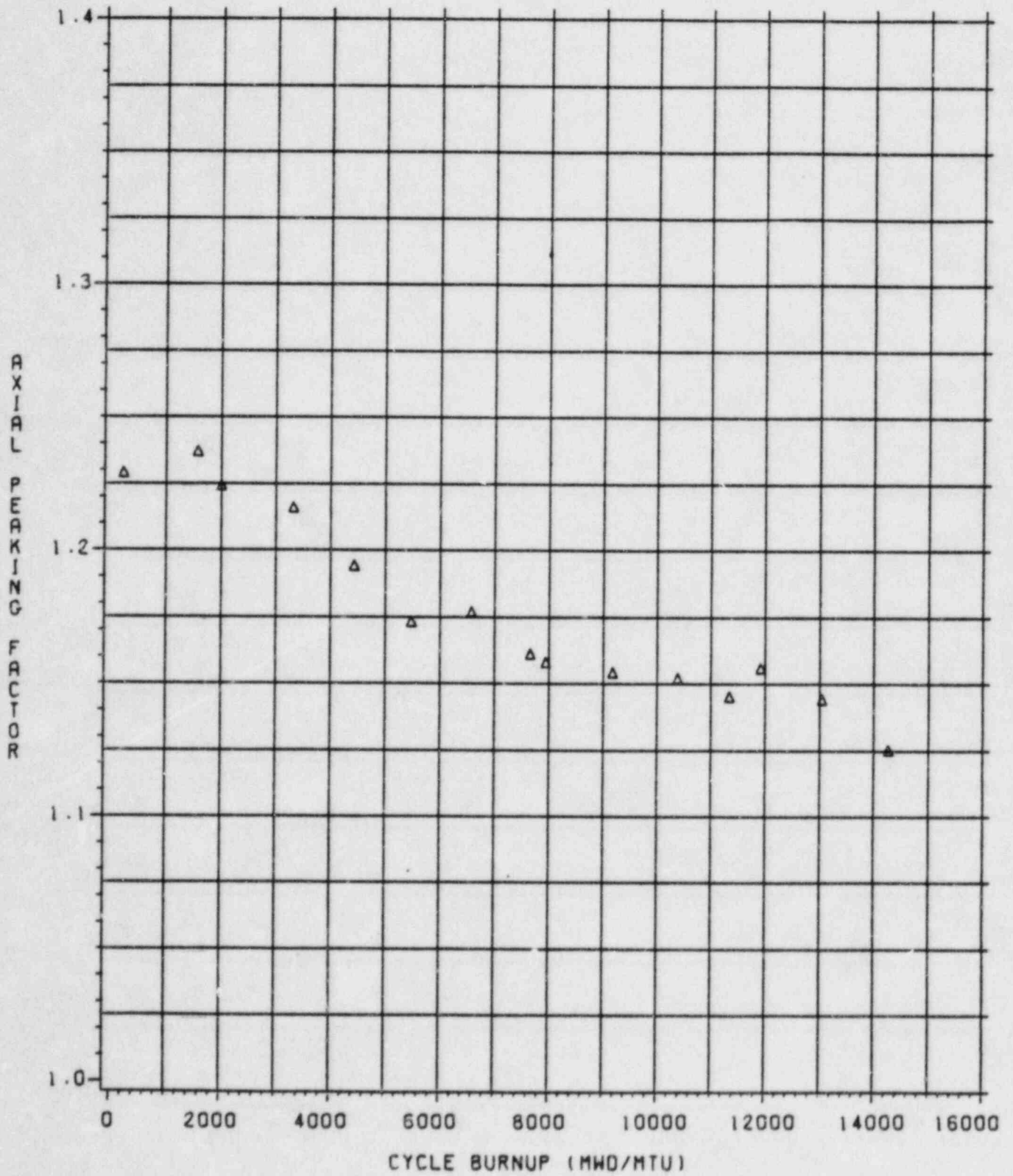


Figure 4.15

NORTH ANNA UNIT 2 - CYCLE 3
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 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 the North Anna 2 Technical Specifications, the dose equivalent I-131 concentration in the primary coolant is limited to $1.0 \mu\text{Ci/gm}$ for normal steady state operation. Figure 5.1 shows the dose equivalent I-131 activity level history for the North Anna 2, Cycle 3 core. The demineralizer flow rate averaged 76 gpm during power operation. The data shows that during Cycle 3, the core operated substantially below the $1.0 \mu\text{Ci/gm}$ limit during steady state operation (the spike data is associated with power transients and unit shutdown). Specifically, the average dose equivalent I-131 concentration of $0.0405 \mu\text{Ci/gm}$ is equal to 4% of the Technical Specifications limit.

The ratio of the specific activities of I-131 to I-133 is used to characterize the type of fuel failure which may have occurred in the reactor core. Use of the ratio for this determination is feasible because I-133 has a short half-life (approximately 21 hours) compared to that of I-131 (approximately eight days). For pinhole defects, where the diffusion time through the defect is on the order of days, the I-133 decays out leaving the I-131 dominant in activity, thereby causing the

ratio to be 0.5 or more for a demineralizer flow rate of 75 gpm. In the case of large leaks, uranium particles in the coolant, and "tramp" uranium*, where the diffusion mechanism is negligible, the I-131/I-133 ratio will generally be less than 0.1 for a demineralizer flow rate of 75 gpm. Figure 5.2 shows the I-131/I-133 ratio data for the North Anna 2, Cycle 3 core. These data generally indicate there were probably pinhole defects in the fuel used during Cycle 3.

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

Figure 5.1

NORTH ANNA 2 - CYCLE 3
DOSE EQUIVALENT I-131 vs. TIME

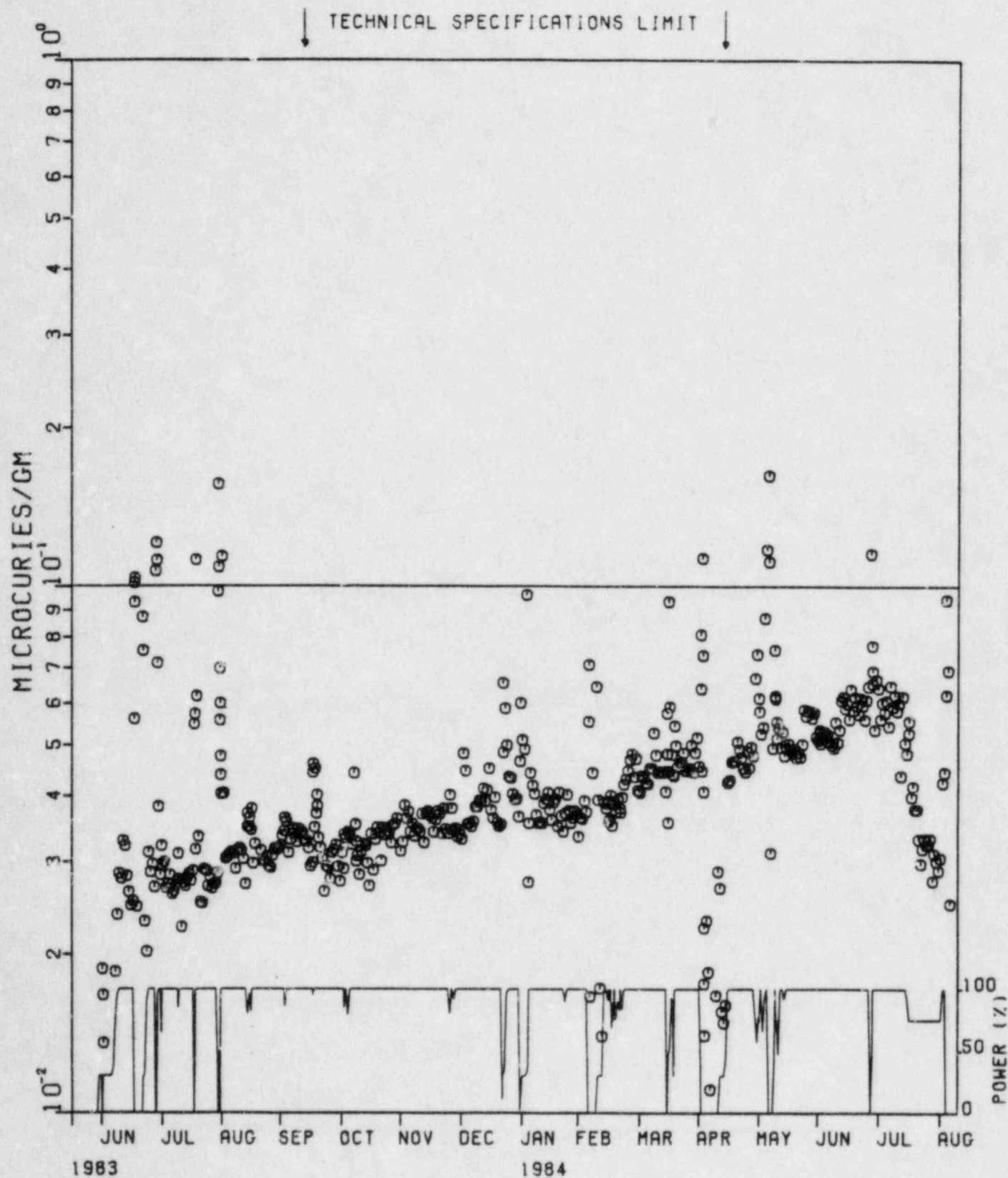
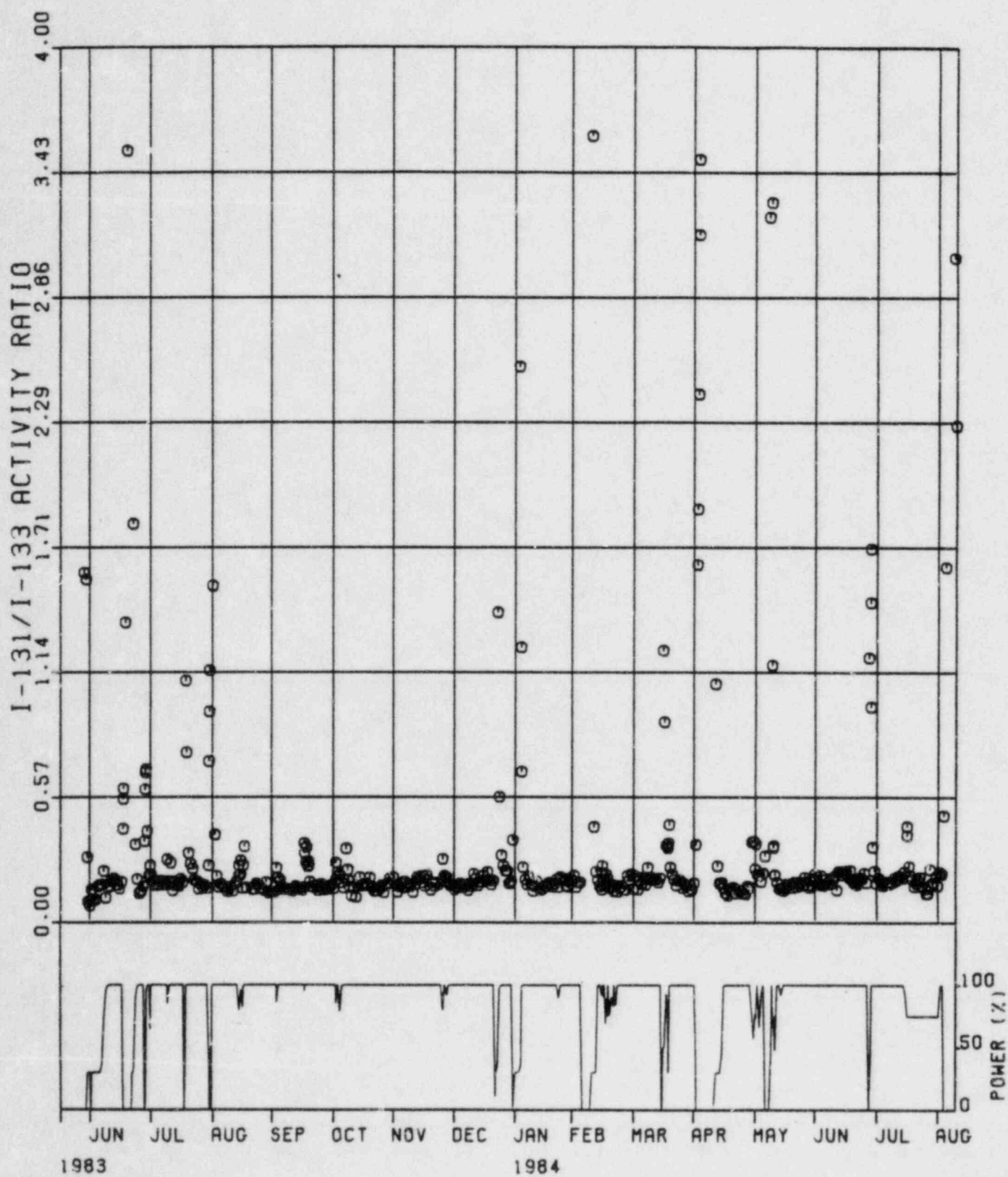


Figure 5.2

NORTH ANNA 2 - CYCLE 3
I-131 / I-133 ACTIVITY RATIO vs. TIME



CONCLUSIONS

The North Anna 2, Cycle 3 core has completed operation. Throughout this cycle, all core performance indicators compared favorably with the design predictions and all core related Technical Specifications limits were met with significant margin. No abnormalities in reactivity, power distribution, or burnup accumulation were detected. In addition, the mechanical integrity of the fuel has not changed significantly throughout Cycle 3 as indicated by the radioiodine analysis.

Section 7

REFERENCES

- 1) B. D. Mann, "North Anna Unit 2, Cycle 3 Startup Physics Test Report," VEP-NOS-4, June, 1983.
- 2) North Anna Power Station Unit 2 Technical Specifications, Sections 3/4.1 and 3/4.2.
- 3) T. K. Ross, "NEWTOTE Code", VEPCO NFO-CCR-6 Rev-8, April, 1984.
- 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.