North Anna Unit 2 Cycle 10 Core Performance Report

Nuclear Analysis and Fuel
Nuclear Engineering Services

May 1995

Virginia Power

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NORTH ANNA UNIT 2, CYCLE 10

CORE PERFORMANCE REPORT

NUCLEAR ANALYSIS AND FUEL
NUCLEAR ENGINEERING SERVICES
VIRGINIA POWER
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PREPARED BY: C. D. Clemens — 5/5/95 Date

REVIEWED BY: R. F. Villaflor — 5/8/95 Date

REVIEWED BY: T. A. Brookmire — 5-8-95 Date

REVIEWED BY: A. P. Main — 5-11-95 Date

APPROVED BY: D. Dziadosz — 5/12/95 Date

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Section 1

INTRODUCTION AND SUMMARY

On March 25, 1995 North Anna Unit 2 completed Cycle 10. Since the initial criticality of Cycle 10 on October 26, 1993, the reactor core produced approximately 1.1484×10^8 MBTU (19,263 Megawatt days per metric ton of contained uranium). The purpose of this report is to present an analysis of the core performance for routine operation during Cycle 10. The physics tests that were performed during the startup of this cycle were covered in the North Anna Unit 2, Cycle 10 Startup Physics Test Report[1] and therefore, will not be included here.

North Anna Unit 2 was in coastdown from January 19, 1995 at which time the burnup was approximately 17,189 MWD/MTU. The coastdown accounted for an additional core burnup of roughly 2,074 MWD/MTU from the end of reactivity.

The Cycle 10 core consisted of 10 sub-batches of fuel: three once-burned batches, two from Cycle 9 (batches 11A and 11B) and one from Cycle 7 (batch 9A); five twice-burned batches, two from Cycles 6 and 7 (batches 8A and 8B), one from Cycles 8 and 9 (batch 10B), one from North Anna 1 Cycles 7 and 8 (batch N1/9A), and one from North Anna 1 Cycles 8 and 9 (batch N1/10C); and two fresh batches (batches 12A and 12B). The North Anna 2 Cycle 10 core loading map specifying the fuel batch

identification and fuel assembly locations is shown in Figure 1.1. The burnable poison locations and source assembly locations is shown in Figure 1.2. Movable detector locations are shown in Figure 1.3. Control rod locations are shown in Figure 1.4.

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 for 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 assess the status of the fuel cladding integrity and to compare the concentration of dose equivalent I-131 in the reactor coolant with the limits specified by the North Anna Unit 2 Technical Specifications[2].

Each of these four performance indicators for the North Anna Unit 2, Cycle 10 core is discussed in detail in the body of this report. The results are summarized below:

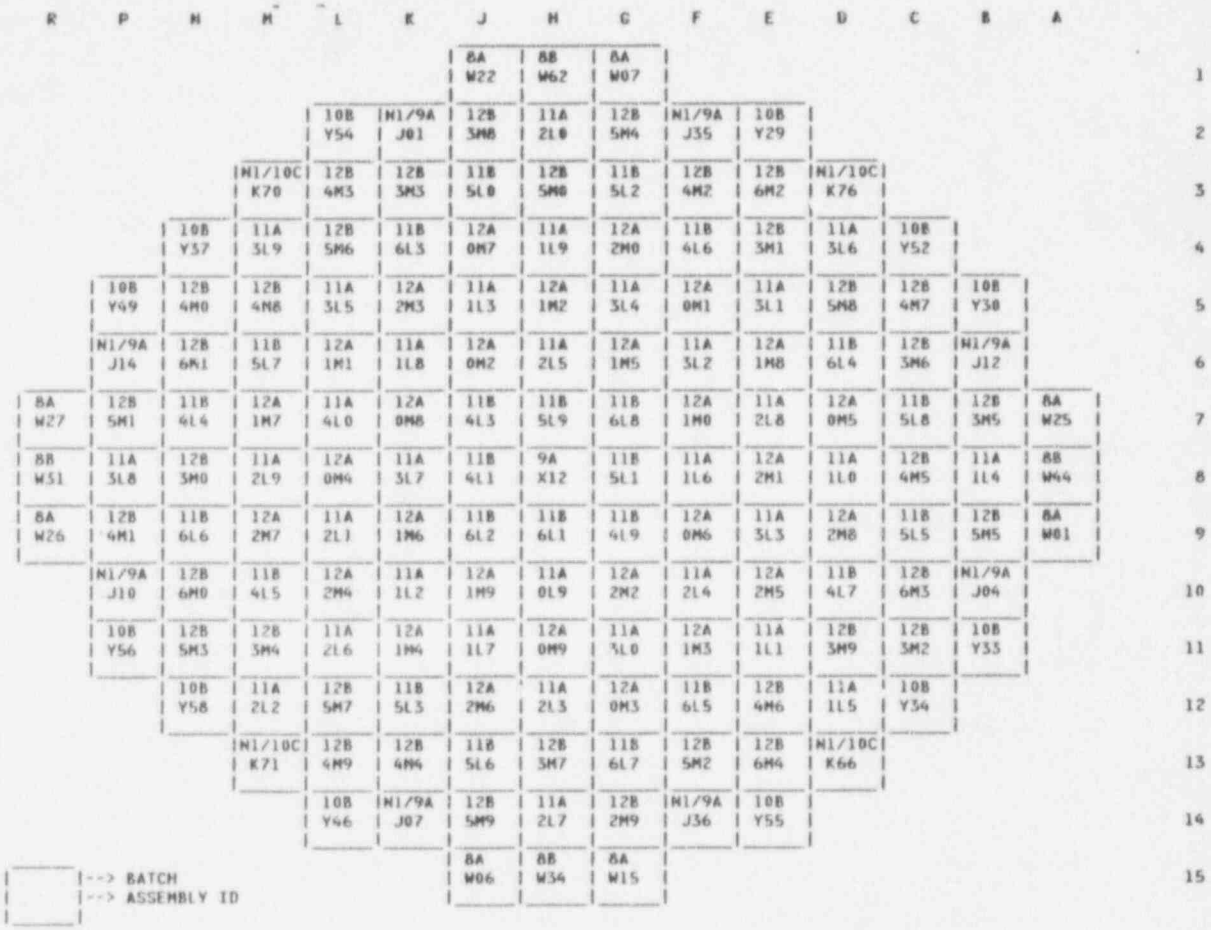
1. Burnup - The burnup tilt (deviation from quadrant symmetry) on the core was no greater than ±0.46% with the burnup accumulation in each batch deviating from design prediction by no more than 2.20%.

2. Reactivity Depletion - The critical boron concentration, used to monitor reactivity depletion, was consistently within ±0.502 ΔK/K of the design prediction which is within the ±1% ΔK/K margin allowed by Section 4.1.1.1.2 of the Technical Specifications.

3. Power Distribution - Incore flux maps taken each month indicated that the assemblywise radial power distributions deviated from the design predictions by a maximum average difference of 2.6%. All hot channel factors met their respective Technical Specifications limits.

4. Primary Coolant Activity - The average dose equivalent iodine-131 activity level in the primary coolant during Cycle 10 was approximately 0.00418 μCi/gm. This corresponds to less than 1% of the operating limit for the concentration of radioiodine in the primary coolant. An evaluation of the radioiodine and noble gas concentration in the RCS indicated at least one fuel rod was defective. Vacuum sipping inspections performed during the Cycle 10 to Cycle 11 refueling outage determined that two fuel assemblies were defective.

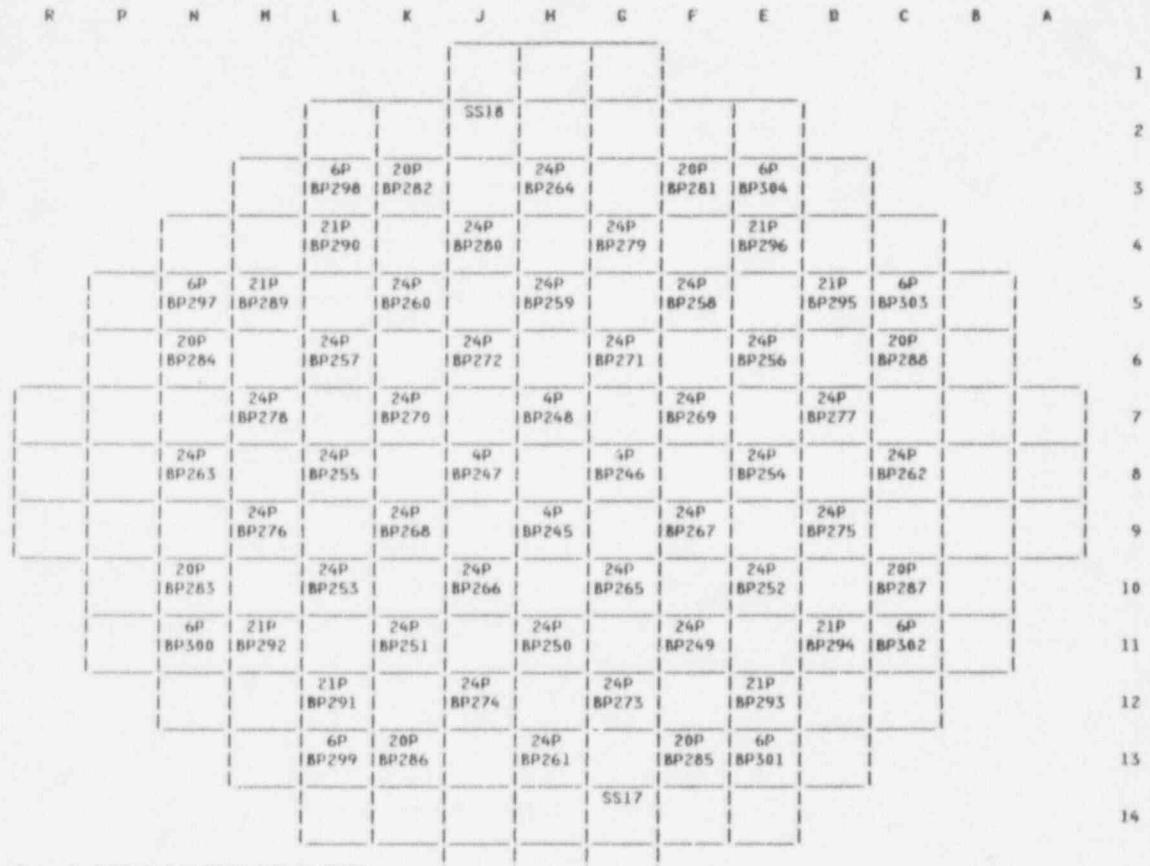
Figure 1.1
NORTH ANNA UNIT 2 - CYCLE 10
CORE LOADING MAP



FUEL ASSEMBLY DESIGN PARAMETERS

	SUB-BATCH									
	8A	8B	9A	10B	11A	11B	12A	12B	N1/9A	N1/10C
INITIAL ENRICHMENT (W/O U-235)	3.79	4.00	3.80	4.21	4.02	4.21	4.01	4.20	3.79	3.82
ASSEMBLY TYPE	17x17	17x17	17x17	17x17	17x17	17x17	17x17	17x17	17x17	17x17
NUMBER OF ASSEMBLIES	8	4	1	12	32	24	28	36	8	4
FUEL RODS PER ASSEMBLY	264	264	264	264	264	264	264	264	264	264

Figure 1.2
NORTH ANNA UNIT 2 - CYCLE 10
BURNABLE POISON AND SOURCE
ASSEMBLY LOCATIONS



4P - 4 BURNABLE POISON ROD CLUSTER
6P - 6 BURNABLE POISON ROD CLUSTER
20P - 20 BURNABLE POISON ROD CLUSTER
21P - 21 BURNABLE POISON ROD CLUSTER
24P - 24 BURNABLE POISON ROD CLUSTER
SSxx - SECONDARY SOURCE

| xxP or SSxx | - # OF BP RODS or SECONDARY SOURCE ID
| BP### | - BP ASSEMBLY ID

Figure 1.3
NORTH ANNA UNIT 2 - CYCLE 10
AVAILABLE MOVABLE DETECTOR LOCATIONS

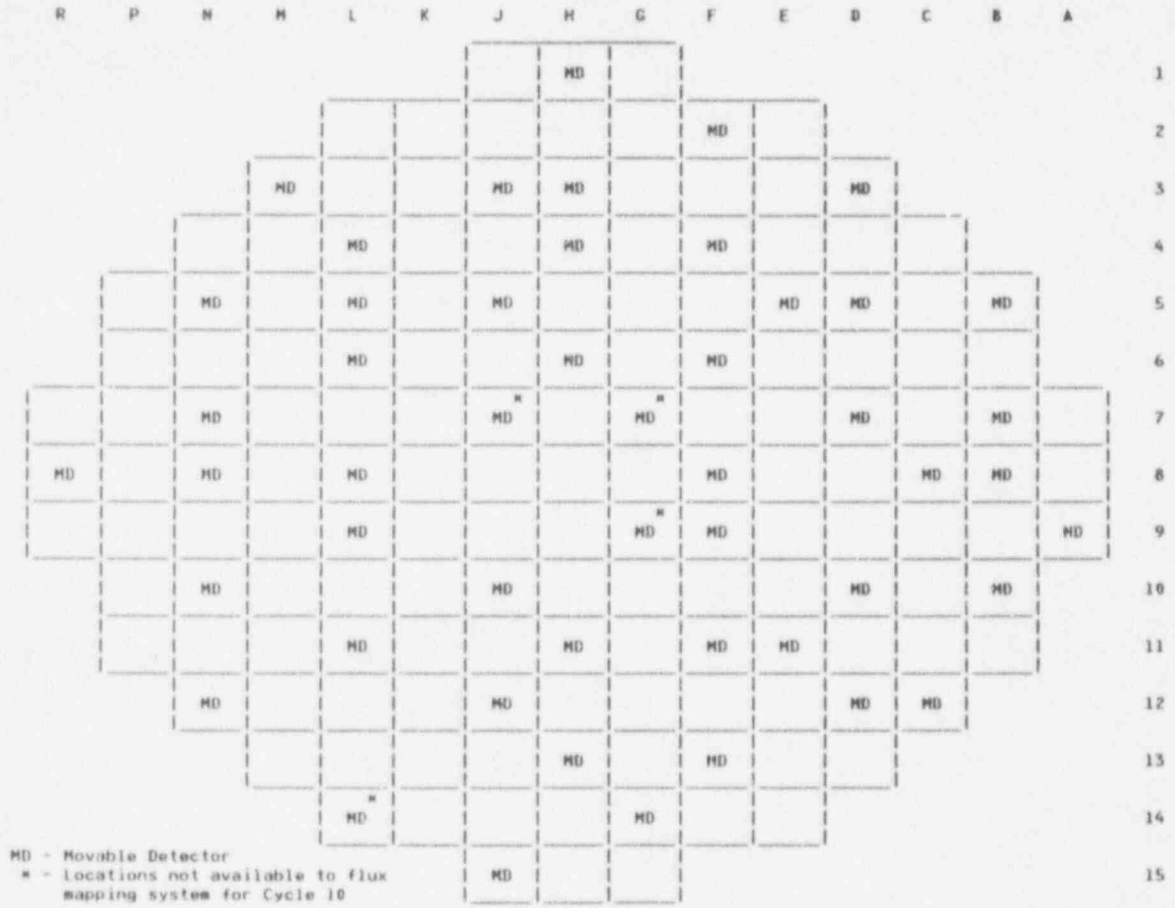
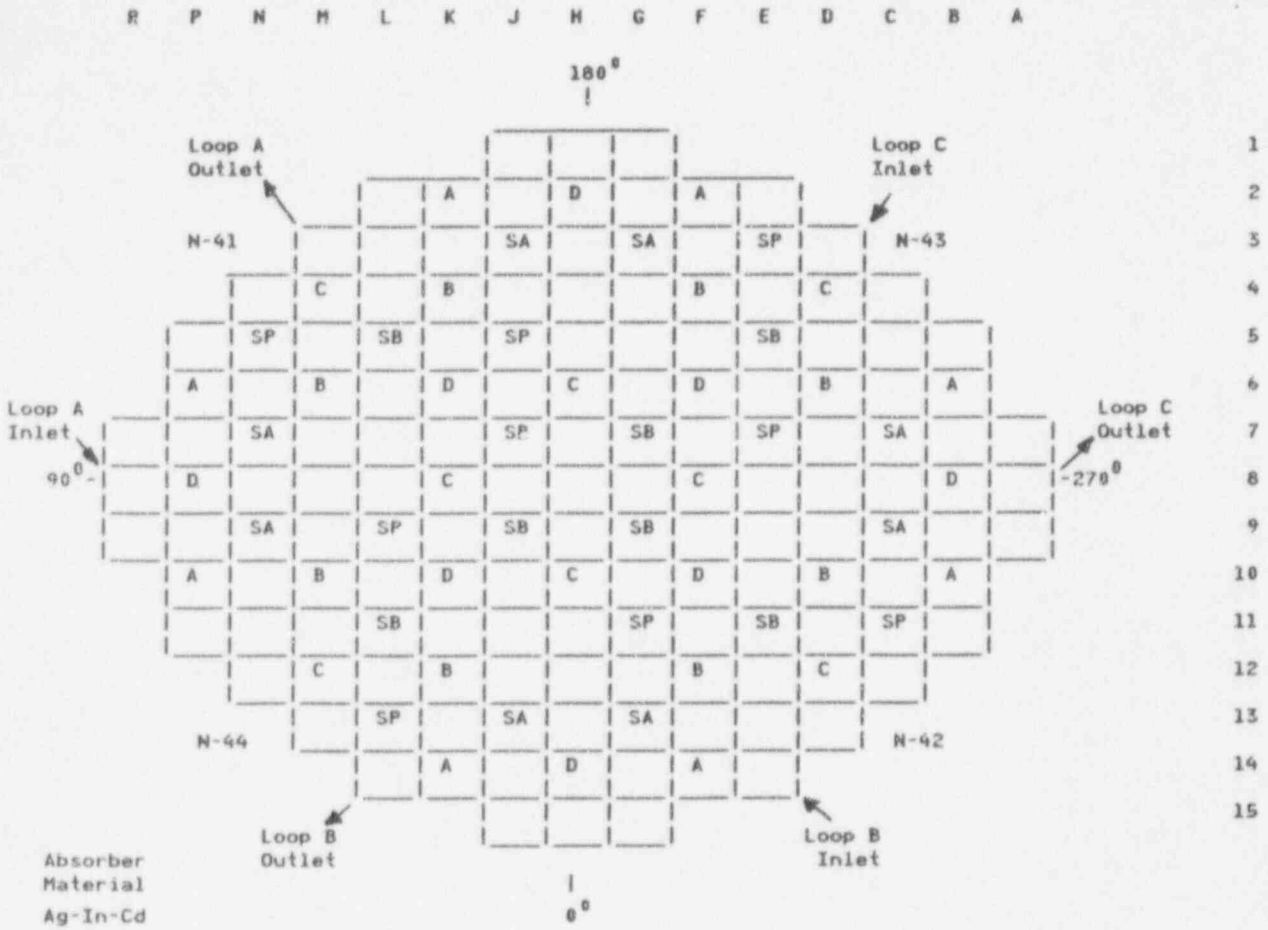


Figure 1.4
NORTH ANNA UNIT 2 - CYCLE 10
CONTROL ROD LOCATIONS



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

CALLED NORTH

Section 2

BURNUP

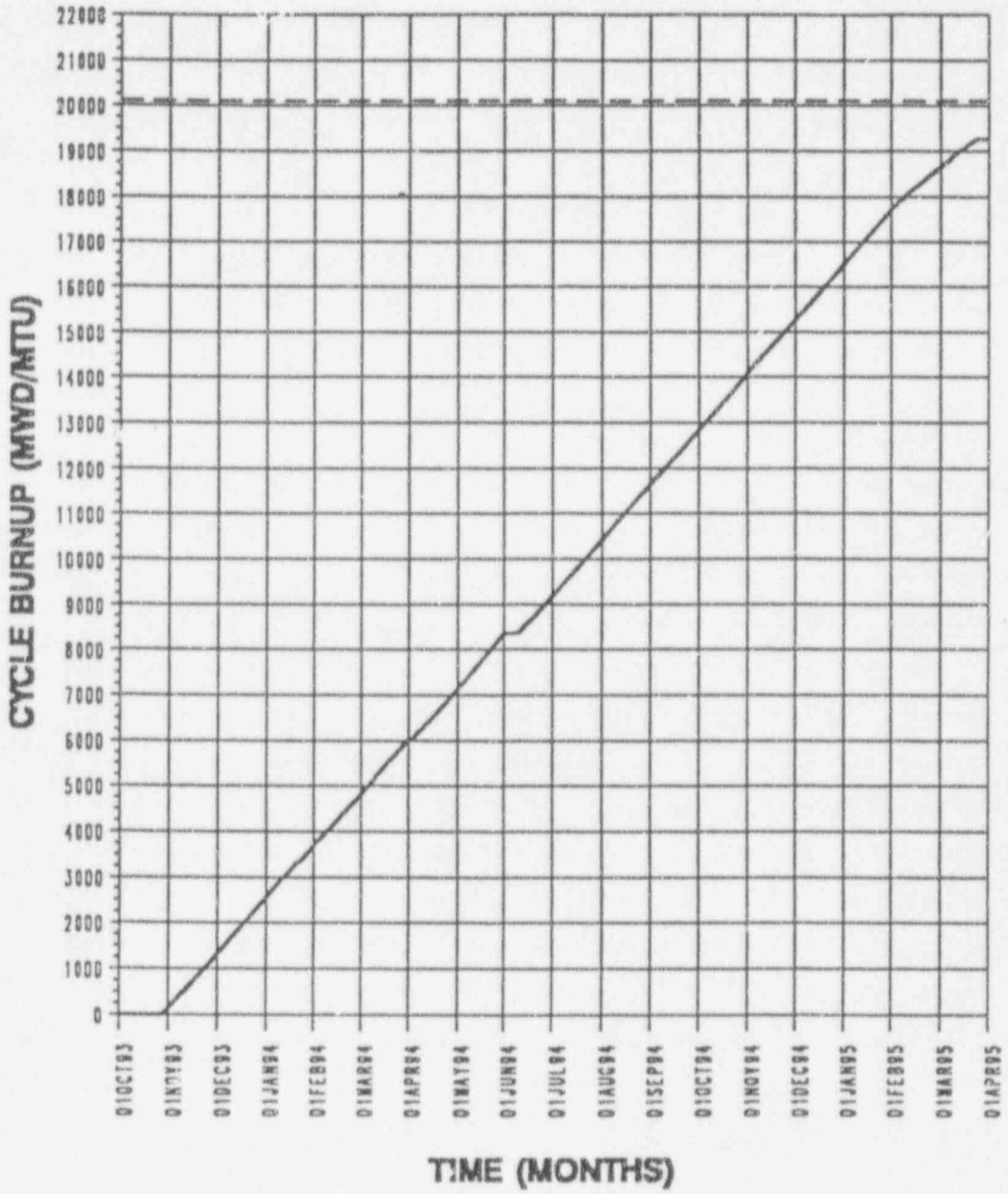
The burnup history for the North Anna Unit 2, Cycle 10 core is graphically depicted in Figure 2.1. The North Anna 2, Cycle 10 core achieved a burnup of 19,263 MWD/MTU. As shown in Figure 2.2, the average load factor for Cycle 10 was 94.4% when referenced to rated thermal power (2893 MW(t)). Unit 2 performed a power coastdown starting on January 19, 1995 until shutdown for refueling on March 25, 1995.

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 TOTE[3] computer code is used to calculate these assemblywise burnups. Figure 2.3 is a radial burnup distribution map in which the core assemblywise burnup accumulation at the end of Cycle 10 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 10 operation is also given. As can be seen from this figure, the accumulated assembly burnups were generally within ±1.20% of the predicted values. In addition, deviation from quadrant symmetry in the core throughout the cycle was no greater than ±0.44%.

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 Figures 2.5A, 2.5B, 2.5C, and 2.5D, the batch burnup sharing for North Anna 2, Cycle 10 followed design predictions closely. The burnups for all other batches did not deviate from predictions by more than 2.2%. Symmetric burnup in conjunction with agreement between actual and predicted assemblywise burnups and batch burnup sharing indicate that the Cycle 10 core did deplete as designed.

Figure 2.1
NORTH ANNA UNIT 2 - CYCLE 10
CORE BURNUP HISTORY



----- MAXIMUM DESIGN BURNUP - 20100 MWD/MTU

Figure 2.2
NORTH ANNA UNIT 2 - CYCLE 10
MONTHLY AVERAGE LOAD FACTORS

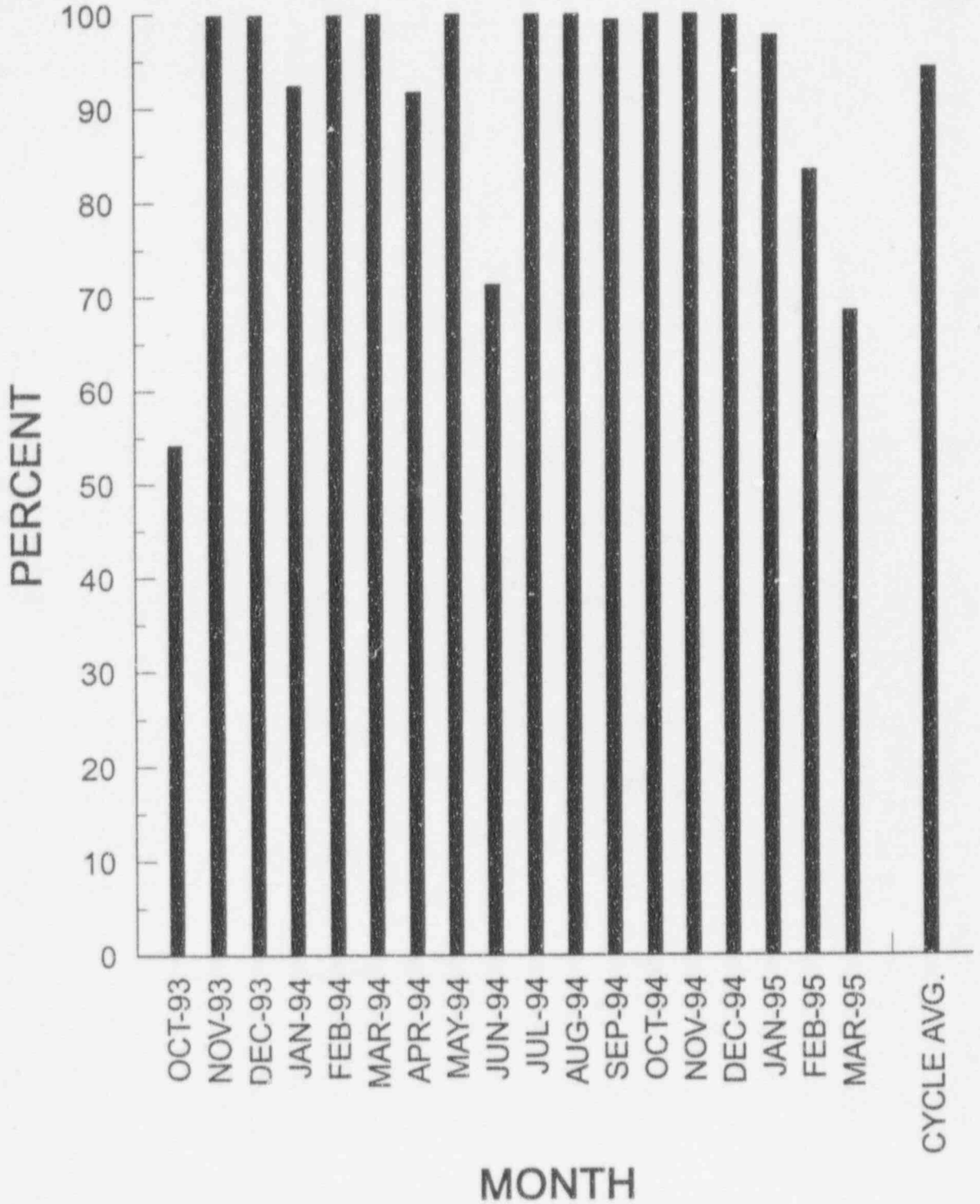


Figure 2.3
NORTH ANNA UNIT 2 - CYCLE 10
ASSEMBLYWISE ACCUMULATED BURNUP
MEASURED AND PREDICTED
(GWD/MTU)

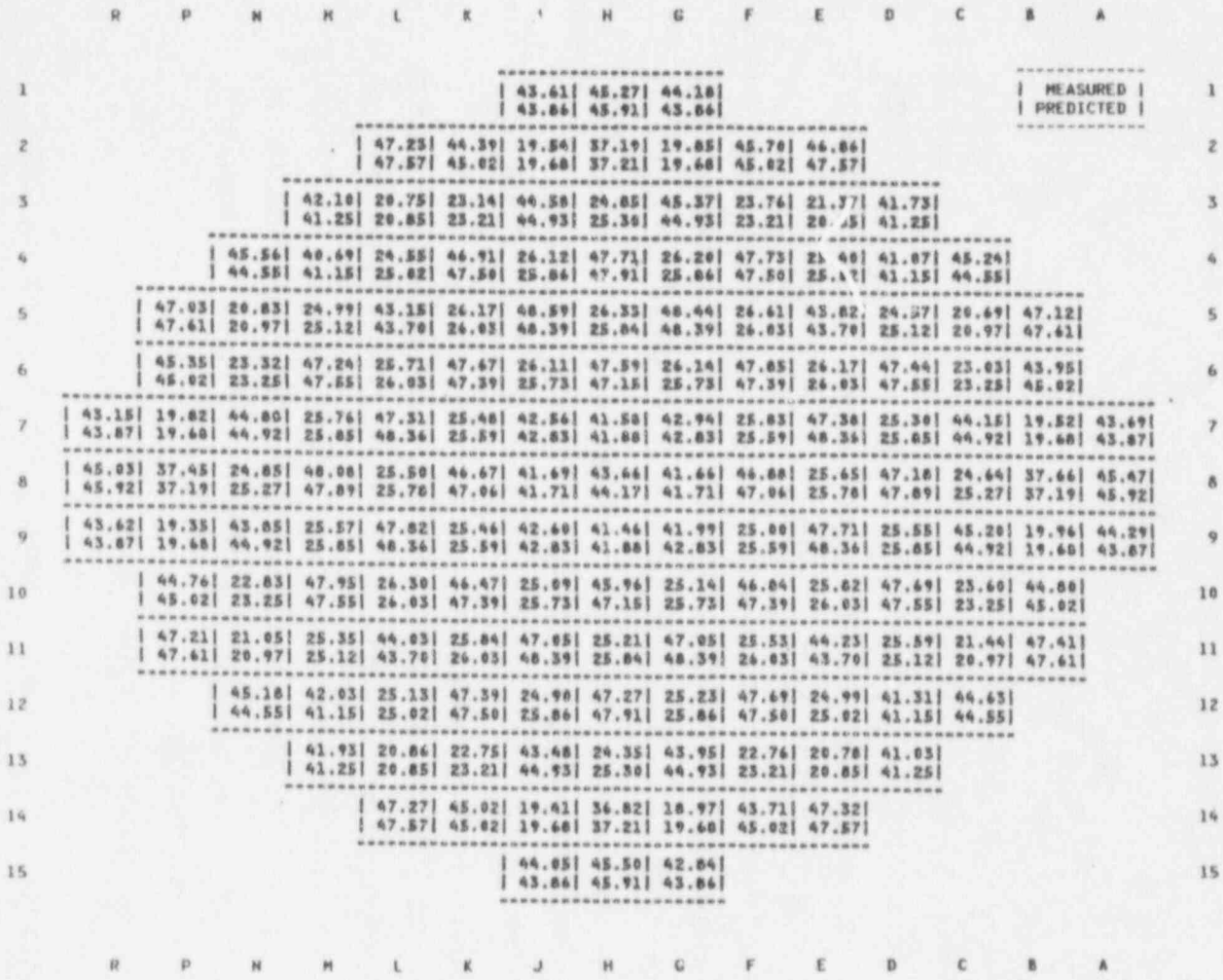
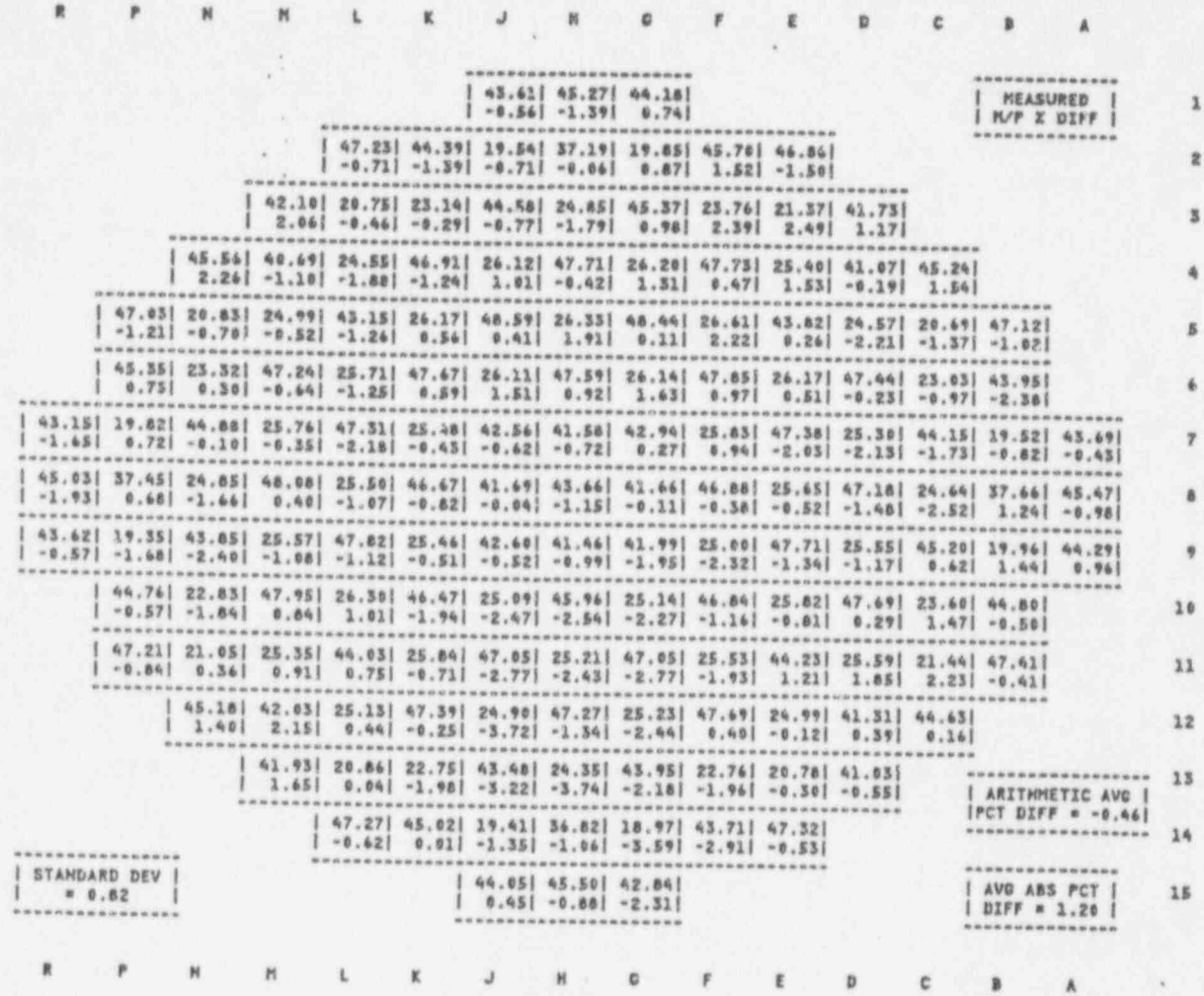


Figure 2.4
NORTH ANNA UNIT 2 - CYCLE 10
ASSEMBLYWISE ACCUMULATED BURNUP
COMPARISON OF MEASURED AND PREDICTED
(GWD/MTU)



BATCH SHARING
(MWD/MTU)

BATCH	NO. OF ASSEMBLIES	BOC BATCH BURNUP	EOC BATCH BURNUP	CYCLE BURNUP
N1/9A	8	34,477	44,710	10,233
N1/10C	4	33,624	41,700	8,076
8A	8	38,739	43,680	4,941
8B	4	39,349	45,316	5,967
9A	1	23,713	43,662	19,949
10B	12	39,610	46,504	6,894
11A	32	23,646	44,905	21,259
11B	24	22,309	44,666	22,357
12A	28	0	25,704	25,704
12B	36	0	22,461	22,461
CYCLE AVERAGE ACCUMULATED BURNUP = 19,263				

BURNUP TILT

NW = 0.11 | NE = 0.44
SW = -0.22 | SE = -0.33

Figure 2.5A
NORTH ANNA UNIT 2 - CYCLE 10
SUB-BATCH BURNUP SHARING

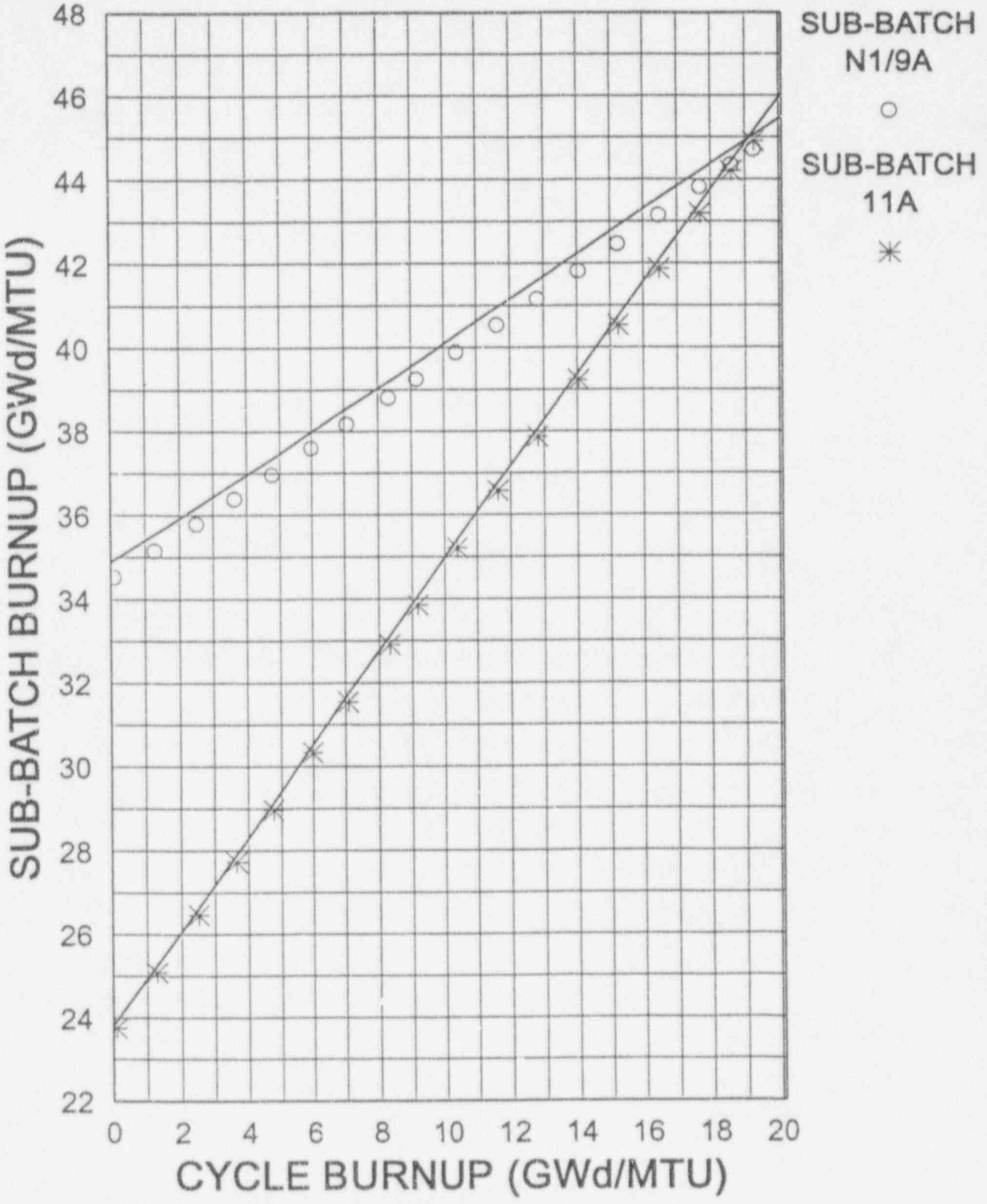


Figure 2.5B
NORTH ANNA UNIT 2 - CYCLE 10
SUB-BATCH BURNUP SHARING

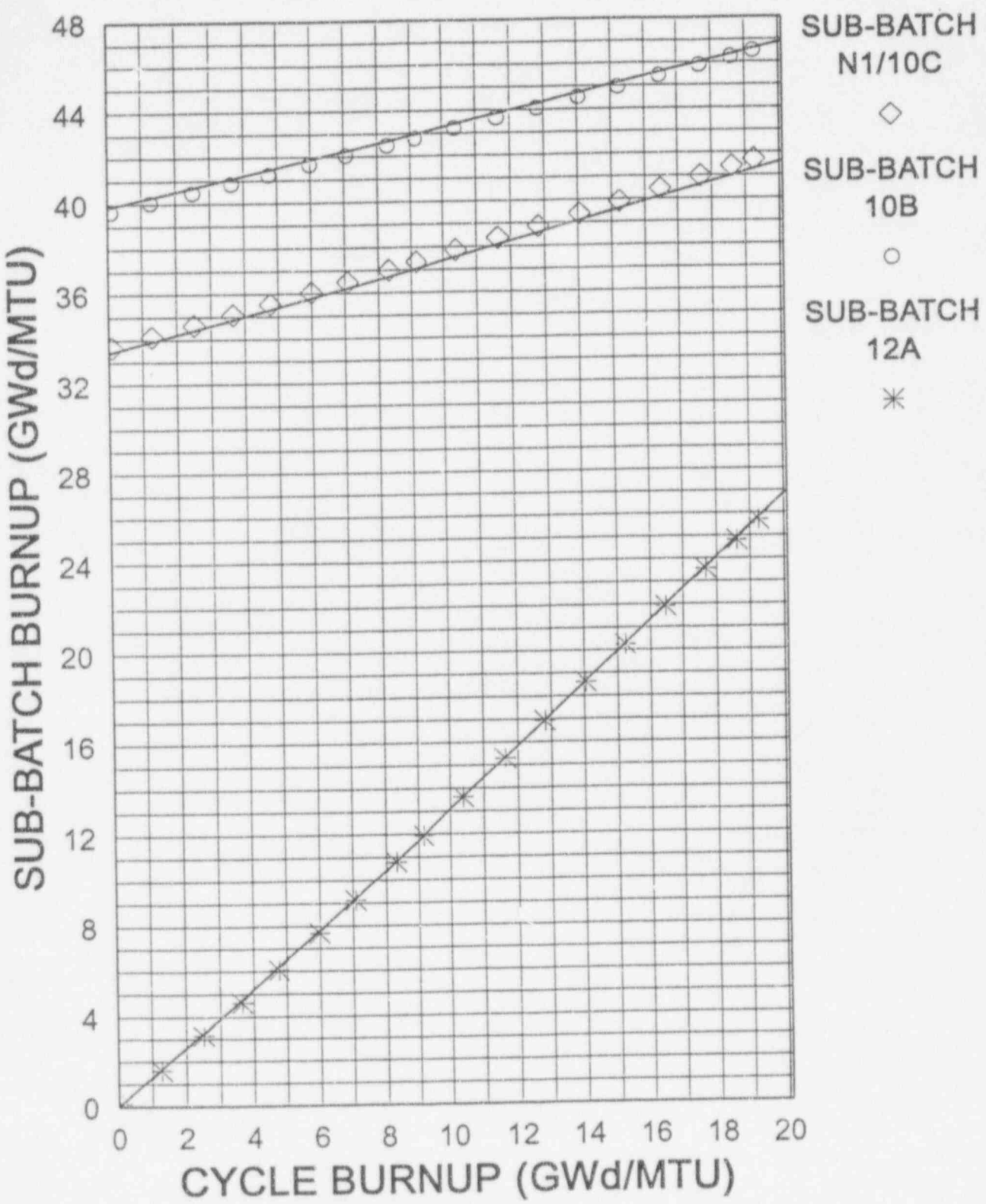


Figure 2.5C
NORTH ANNA UNIT 2 - CYCLE 10
SUB-BATCH BURNUP SHARING

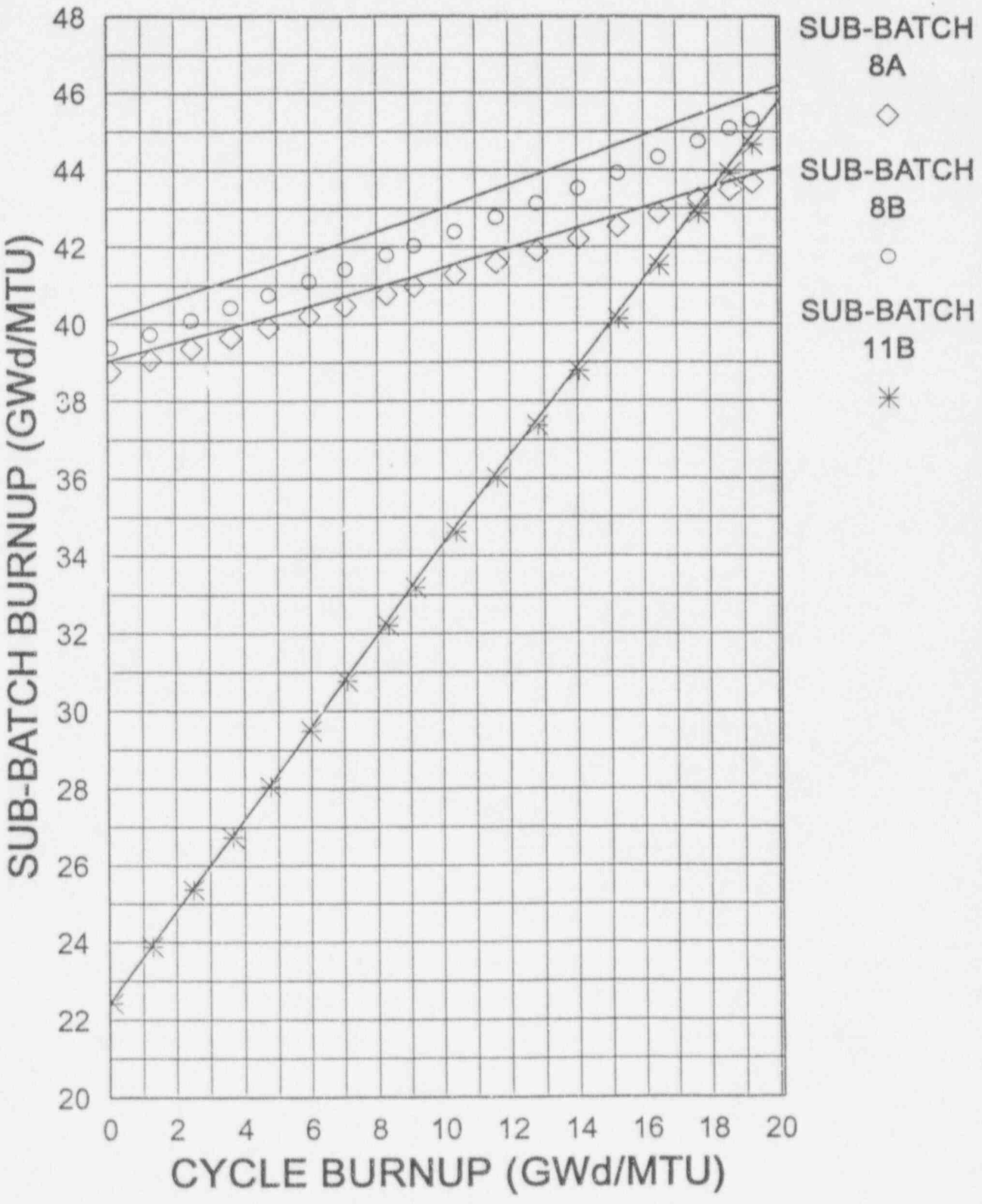
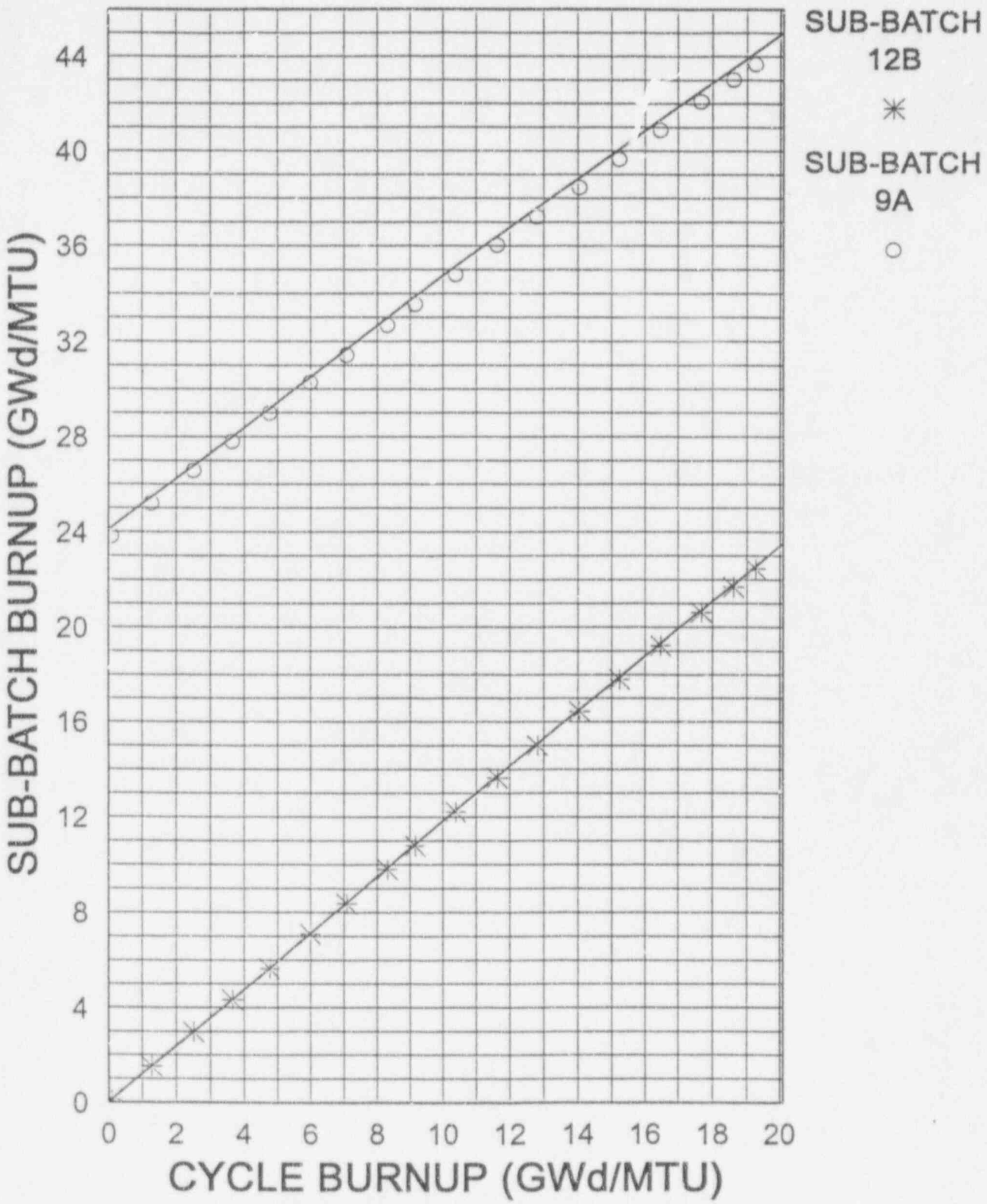


Figure 2.5D
NORTH ANNA UNIT 2 - CYCLE 10
SUB-BATCH BURNUP SHARING

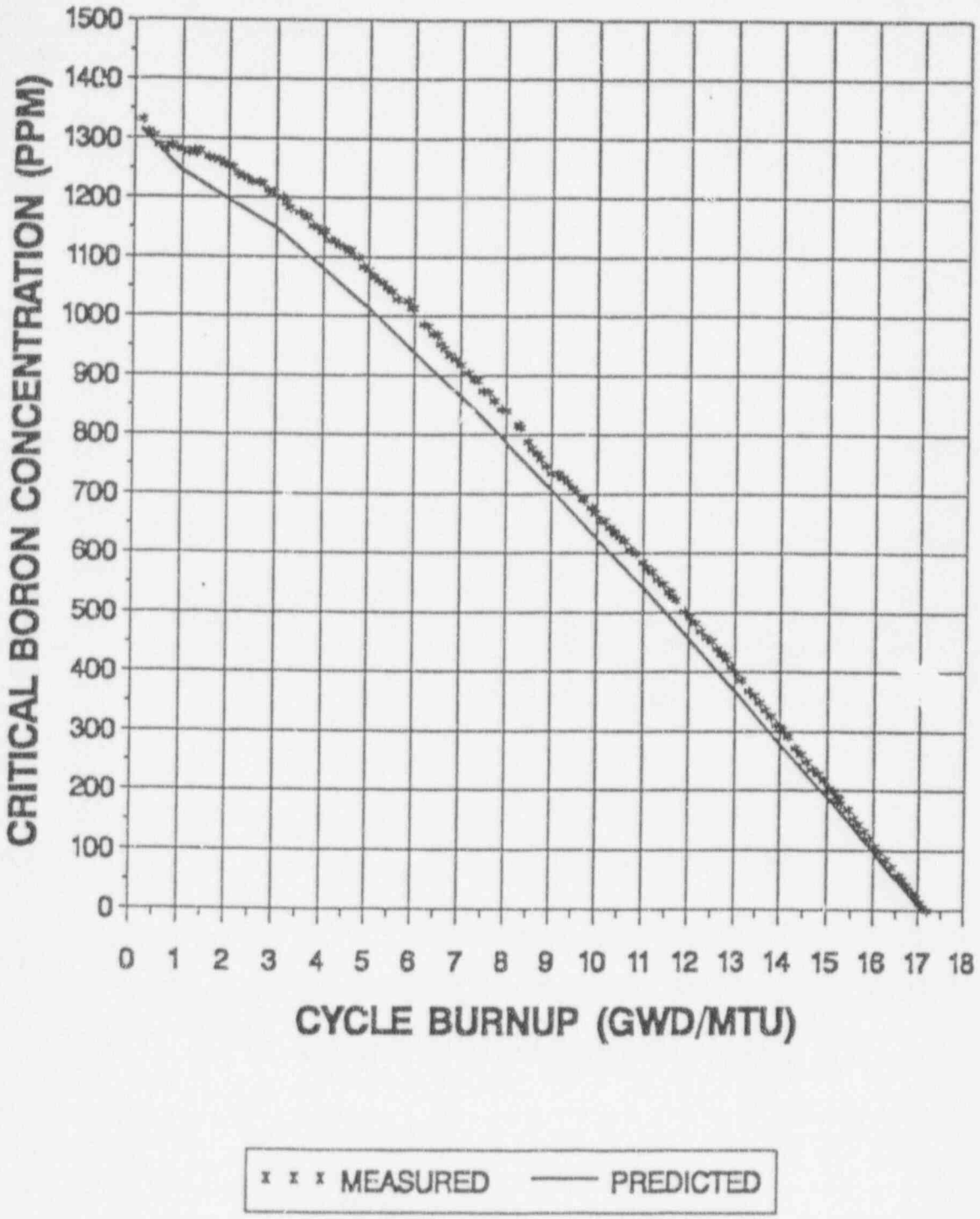


Section 3

REACTIVITY DEPLETION

The primary coolant critical boron concentration is monitored for the purposes of following core reactivity and to identify any anomalous reactivity behavior. The FOLOW[4] computer code was used to normalize "actual" critical boron concentration measurements to design conditions taking into consideration control rod position, xenon concentration, moderator temperature, and power level. The normalized critical boron concentration versus burnup curve for the North Anna 2, Cycle 10 core is shown in Figure 3.1. It can be seen that the measured data typically compared to within 76 ppm of the design prediction. This corresponds to ±0.502% ΔK/K which is within the ±1% ΔK/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 10 core depleted as expected without any reactivity anomalies.

Figure 3.1
NORTH ANNA UNIT 2 - CYCLE 10
CRITICAL BORON CONCENTRATION vs. BURNUP
(HFP,ARO)



Section 4

POWER DISTRIBUTION

Routine analysis of core power distribution data is necessary to verify that the hot channel factors comply with their Technical Specifications limits, and ensure that the reactor is not operating with 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] and CECOR[13] computer programs. The INCORE program was used from the beginning of cycle through flux map 10. The CECOR program was used from flux map 11 to the end of cycle. A summary of all full core flux maps taken for North Anna 2, Cycle 10 is given in Table 4.1, excluding the initial power ascension flux maps. Power distribution maps were generally taken at monthly intervals with additional maps taken as needed.

Radial (X-Y) core power distribution for a representative series of incore flux maps are given in Figures 4.1, 4.2, and 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 near the end of Cycle 10. The measured relative assembly powers were generally within 7 5% and the maximum average percent difference was equal to 2.6%. In addition, as indicated by the INCORE and CECOR tilt factors, the power distributions were essentially symmetric for each case.

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 margin and maintaining fuel cladding integrity. North Anna Unit 2 Technical Specification 3.2.2 limited the axially dependent heat flux hot channel factor, $F_Q(Z)$, to 2.19 x K(Z), where K(Z) is the hot channel factor normalized operating envelope, and 2.19 is the Fq limit at rated thermal power, both as specified in the Core Operations Limit Report (COLR)[6]. Figure 4.4 is a plot of the K(Z) curves associated with the 2.19 $F_Q(Z)$ 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, 4.6, and 4.7. Throughout Cycle 10, 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 10 is given in Figure 4.8. Figure 4.9 shows the maximum values for the heat flux measured during Cycle 10. The rise in the EOC maximum FQ(Z) data is due to power coastdown, and is not a concern for possible Technical Specification violations. The minimum margin to the F_Q limit in the axial region covered by the Technical Specification 4.2.2.2 is 11.9% for all flux maps. (Technical Specification 4.2.2.2.g states that F_Q surveillence is not applicable in the lower core region from 0% to 15% inclusive, and the upper core region from 85% to 100% inclusive.)

The value of the enthalpy rise hot channel factor, F-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 departure from nucleate boiling ratio (DNBR) limit will not be violated. Additionally, the F-delta-H limit ensures that the value of this parameter used in the LOCA-ECCS analysis is not exceeded during normal operation. North Anna Technical Specification 3.2.3 limited the enthalpy rise hot channel factor to 1.49(1+0.3(1-P)) for Cycle 10, where 1.49 is the F-delta-H at rated thermal power and 0.3 is the power factor multiplier, both as specified in the COLR. A summary of the maximum values for the enthalpy rise hot channel factor measured during Cycle 10 is given in Figure 4.10. As can be seen from this figure, the minimum margin to the limit was approximately 1.3%.

The target delta flux* is the delta flux which would occur at conditions of full power, all rods out, and equilibrium xenon. 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. 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 -5.3% at the

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$$* \text{ Delta Flux} = \frac{Pt-Pb}{2893} \times 100$$ where Pt = power in top of core (MW(t))
Pb = power in bottom of core (MW(t))

beginning of Cycle 10. Delta flux values oscillated between -4.0% and -6.5% and then, at a burnup of about 17000 MWD/MTU, began an increase to -2.6% before the coastdown. At the end of Cycle 10, the target delta flux increased to 8.3% due to the coastdown. This axial power shift can also 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 N2-10-06 (Figure 4.12), taken at 1782 MWD/MTU, the axial power distribution had a shape peaked toward the middle of the core with a peaking factor of 1.221. In Map N2CAM14A (Figure 4.13), taken at 10811 MWD/MTU, the axial power distribution peaked toward the bottom of the core with an axial peaking factor of 1.166. Finally, in Map N2CAM20A (Figure 4.14), taken at 17126 MWD/MTU, the axial peaking factor was 1.144, with the axial power distribution shifted slightly toward the bottom. 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.

In conclusion, the North Anna 2, Cycle 10 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 10
SUMMARY OF FLUX MAPS FOR ROUTINE OPERATION

3 MAP NO.	DATE	BURN UP MWD/ MTU	PWR (Z)	BANK D STEPS	1 F-Q(T) HOT CHANNEL FACTOR				F-DH(M) HOT CHNL. FACTOR			CORE F(Z) MAX		2 CORE TILT		AXIAL OFF SET (Z)	NO. OF THIM BLES
					ASSY	PIN	AXIAL POINT	F-Q(T)	ASSY	PIN	F-DH(M)	AXIAL POINT	F(Z)	MAX	LOC		
5	11-15-93	671	100.03	225	P07	NE	36	1.929	P07	NE	1.451	36	1.227	1.015	NW	-4.549	46
6	12-13-93	1782	99.97	225	P07	OE	36	1.860	P07	9E	1.409	36	1.221	1.011	NW	-4.405	46
7	01-17-94	3146	100.00	225	L12	JI	36	1.826	M11	QQ	1.395	36	1.205	1.007	NW	-4.426	46
8	02-09-94	3985	99.94	225	M11	QQ	37	1.815	M11	QQ	1.401	38	1.192	1.004	NE	-4.529	46
9	03-11-94	5176	99.98	225	M11	QQ	40	1.797	D11	IJ	1.405	39	1.178	1.005	NE	-4.594	46
10	04-11-94	6315	99.95	225	F05	JI	46	1.809	F05	JI	1.413	45	1.178	1.007	NE	-4.997	46
11	05-12-94	7549	100.02	225	G04	*	46	1.820	G04	*	1.432	46	1.169	1.007	NE	-5.415	46
12	06-14-94	8516	99.99	225	F05	*	48	1.845	F05	*	1.440	48	1.177	1.008	NE	-6.063	46
13	07-13-94	9662	100.03	225	F05	*	48	1.846	F05	*	1.449	48	1.168	1.009	NE	-5.428	46
14	08-11-94	10811	100.02	225	F05	*	48	1.851	F05	*	1.456	48	1.166	1.010	NE	-5.427	46
15	09-09-94	11953	100.01	225	F05	*	52	1.844	F05	*	1.457	52	1.166	1.009	NE	-5.154	46
16	09-27-94	12673	99.95	225	F05	*	52	1.843	F05	*	1.457	52	1.168	1.009	NE	-5.009	46
17	10-27-94	13869	99.94	225	F05	*	52	1.839	F05	*	1.452	52	1.169	1.010	NE	-4.776	46
18	11-15-94	14628	99.94	225	F05	*	52	1.833	F05	*	1.449	52	1.167	1.010	NE	-4.659	46
19	12-15-94	15815	100.04	225	F05	*	52	1.814	F05	*	1.441	53	1.165	1.009	NE	-4.207	46
20	01-17-95	17126	99.97	225	F05	*	52	1.767	F05	*	1.432	53	1.144	1.009	NE	-2.632	46
21	02-14-95	18145	84.11	225	F05	*	11	1.850	F05	*	1.439	11	1.188	1.011	NE	5.459	46
22	03-17-95	19067	64.87	205	F05	*	11	1.938	F05	*	1.447	11	1.228	1.012	NE	8.284	46

* - Switched to CECOR

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. CORE TILT - DEFINED AS THE AXIAL QUADRANT POWER TILT FROM INCORE/CECOR.

Figure 4.1
NORTH ANNA UNIT 2 - CYCLE 10
ASSEMBLYWISE POWER DISTRIBUTION N2-10-06

R	P	N	M	L	K	J	H	G	F	E	D	C	B	A	
	PREDICTED					0.24	0.29	0.24				PREDICTED			
	MEASURED					0.25	0.30	0.25				MEASURED			1
	PCT DIFFERENCE					2.7	2.7	3.6				PCT DIFFERENCE			
				0.30	0.52	1.07	0.92	1.08	0.52	0.30					
				0.32	0.52	1.08	0.93	1.10	0.54	0.32					2
				3.8	1.6	0.9	0.9	2.0	4.6	4.4					
			0.39	1.10	1.18	1.17	1.32	1.18	1.18	1.10	0.39				
			0.40	1.12	1.18	1.18	1.33	1.20	1.22	1.14	0.41				3
			1.4	1.1	0.0	0.9	0.7	1.9	3.3	3.6	4.2				
		0.40	0.84	1.28	1.22	1.28	1.21	1.28	1.22	1.28	0.84	0.40			
		0.41	0.85	1.29	1.23	1.30	1.23	1.30	1.24	1.29	0.85	0.40			4
		2.0	1.2	1.2	1.1	1.3	1.3	1.1	2.0	1.2	0.8	1.2			
	0.31	1.12	1.29	1.24	1.27	1.19	1.26	1.19	1.27	1.24	1.29	1.12	0.31		
	0.31	1.12	1.29	1.24	1.28	1.21	1.28	1.21	1.29	1.24	1.27	1.11	0.32		5
	0.2	0.2	0.0	0.0	0.6	2.2	2.1	1.9	1.8	0.5	-1.1	-0.2	3.1		
	0.52	1.19	1.22	1.27	1.20	1.27	1.18	1.27	1.20	1.27	1.22	1.19	0.52		
	0.53	1.21	1.24	1.28	1.22	1.29	1.21	1.29	1.22	1.26	1.20	1.17	0.52		6
	1.6	1.6	1.1	0.6	1.2	2.0	1.9	1.5	1.6	-0.6	-1.4	-0.9	1.0		
0.24	1.09	1.18	1.29	1.19	1.26	1.27	1.24	1.26	1.26	1.18	1.28	1.17	1.07	0.24	
0.26	1.12	1.20	1.29	1.18	1.26	1.28	1.26	1.27	1.27	1.18	1.25	1.15	1.06	0.24	7
6.4	3.1	1.6	0.6	-0.4	-0.4	1.5	1.5	0.9	0.7	-0.4	-2.8	-1.5	-1.2	-0.2	
0.29	0.92	1.32	1.21	1.25	1.17	1.23	1.13	1.23	1.17	1.25	1.21	1.32	0.92	0.29	
0.31	0.95	1.34	1.22	1.27	1.19	1.22	1.12	1.20	1.15	1.23	1.17	1.30	0.92	0.29	8
6.4	3.1	1.4	1.4	1.2	1.3	-0.1	-0.2	-2.2	-2.1	-2.2	-2.9	-1.6	-0.0	1.2	
0.24	1.07	1.17	1.28	1.18	1.26	1.26	1.24	1.27	1.26	1.19	1.29	1.18	1.09	0.24	
0.25	1.09	1.17	1.29	1.20	1.26	1.23	1.22	1.24	1.23	1.16	1.26	1.17	1.09	0.25	9
6.4	2.0	-0.2	0.6	1.4	0.3	-2.0	-2.0	-2.3	-2.4	-1.9	-2.3	-0.6	0.8	2.2	
	0.52	1.19	1.22	1.27	1.20	1.27	1.18	1.27	1.20	1.27	1.22	1.19	0.52		
	0.52	1.18	1.24	1.30	1.21	1.24	1.15	1.22	1.17	1.24	1.22	1.19	0.53		10
	-0.4	-0.4	1.5	2.6	1.0	-2.5	-2.6	-3.7	-2.7	-2.2	-0.6	0.4	2.7		
	0.31	1.12	1.29	1.23	1.27	1.19	1.26	1.19	1.27	1.24	1.29	1.12	0.31		
	0.31	1.14	1.32	1.27	1.26	1.16	1.22	1.15	1.24	1.22	1.30	1.13	0.31		11
	2.5	2.5	2.5	2.5	-0.6	-2.5	-2.6	-3.4	-1.9	-0.9	0.8	1.3	2.6		
		0.40	0.84	1.28	1.22	1.28	1.21	1.28	1.22	1.28	0.84	0.40			
		0.42	0.88	1.31	1.22	1.25	1.17	1.24	1.19	1.26	0.86	0.41			12
		5.3	3.9	2.5	-0.0	-3.1	-3.1	-3.7	-2.7	-1.6	1.5	2.3			
			0.39	1.10	1.18	1.18	1.32	1.17	1.18	1.10	0.39				
			0.41	1.13	1.15	1.14	1.28	1.13	1.13	1.08	0.40				13
			5.3	2.5	-2.4	-3.1	-3.4	-4.0	-4.1	-1.7	2.1				
				0.30	0.52	1.08	0.92	1.07	0.52	0.30					
				0.32	0.54	1.09	0.91	1.03	0.49	0.29					14
				4.7	4.7	0.6	-1.1	-4.0	-4.1	-4.3					
	STANDARD					0.24	0.29	0.24				AVERAGE			
	DEVIATION					0.25	0.29	0.23				PCT DIFFERENCE			15
	=1.381					4.7	0.5	-3.9				= 2.0			

SUMMARY

MAP NO: N2-10-06 DATE: 12/13/93 POWER: 99.97%

CONTROL ROD POSITION: F-Q(T) = 1.860 QPTR:

D BANK AT 225 STEPS F-DH(M) = 1.409 NW 1.0106 | NE 1.0043

F(Z) = 1.221 SW 1.0024 | SE 0.9826

BURNUP = 1782 MWD/MTU A.O. = -4.405%

Figure 4.2
NORTH ANNA UNIT 2 - CYCLE 10
ASSEMBLYWISE POWER DISTRIBUTION N2CAM14A

R	P	N	M	L	K	J	H	G	F	E	D	C	B	A	
	PREDICTED					0.25	0.30	0.25				PREDICTED			
	MEASURED					0.25	0.31	0.25				MEASURED			1
	PCT DIFFERENCE					1.2	2.3	1.6				PCT DIFFERENCE			
				0.32	0.52	0.98	0.85	0.98	0.52	0.32					
				0.32	0.52	0.99	0.85	1.00	0.54	0.33					2
				-0.3	0.4	0.8	0.1	1.4	4.6	3.3					
				0.41	1.06	1.20	1.10	1.30	1.10	1.21	1.06	0.41			
				0.42	1.06	1.21	1.11	1.27	1.11	1.24	1.09	0.43			3
				2.9	-0.6	0.3	1.5	-2.0	0.9	2.5	2.7	4.5			
			0.41	0.83	1.30	1.19	1.37	1.18	1.37	1.19	1.30	0.83	0.41		
			0.41	0.82	1.27	1.19	1.38	1.20	1.39	1.22	1.33	0.84	0.41		4
			-0.7	-0.8	-2.6	-0.2	1.1	1.5	1.8	2.8	2.3	0.6	-0.1		
		0.32	1.07	1.31	1.21	1.39	1.19	1.38	1.19	1.39	1.21	1.31	1.07	0.32	
		0.32	1.06	1.30	1.22	1.40	1.21	1.40	1.21	1.42	1.24	1.28	1.06	0.33	5
		-0.5	-0.7	-0.2	1.0	0.5	1.4	1.6	1.8	2.3	2.4	-2.0	-0.6	4.4	
		0.52	1.21	1.19	1.39	1.21	1.37	1.16	1.36	1.21	1.39	1.19	1.21	0.52	
		0.52	1.21	1.18	1.36	1.20	1.37	1.18	1.39	1.23	1.40	1.18	1.20	0.53	6
		0.0	-0.1	-0.8	-1.9	-0.4	0.7	1.7	1.6	2.0	0.9	-0.7	-0.5	0.9	
	0.25	0.98	1.10	1.37	1.19	1.36	1.19	1.13	1.18	1.36	1.19	1.37	1.10	0.98	0.25
	0.25	0.99	1.11	1.36	1.18	1.35	1.18	1.14	1.19	1.37	1.19	1.35	1.09	0.99	0.25
	1.1	0.3	1.0	-0.7	-1.4	-0.7	-0.0	0.6	0.8	0.9	0.1	-1.5	-0.7	1.4	1.8
	0.30	0.85	1.30	1.18	1.38	1.15	1.12	1.01	1.12	1.15	1.38	1.18	1.30	0.85	0.30
	0.31	0.85	1.27	1.16	1.34	1.14	1.12	1.01	1.12	1.16	1.37	1.17	1.28	0.88	0.31
	3.6	-0.6	-2.2	-1.4	-2.3	-1.1	-0.7	-0.4	-0.0	0.8	-0.1	-0.8	-1.8	3.1	3.4
	0.25	0.98	1.10	1.37	1.19	1.36	1.18	1.13	1.19	1.36	1.19	1.37	1.10	0.98	0.25
	0.25	0.97	1.09	1.36	1.19	1.35	1.16	1.12	1.17	1.33	1.18	1.37	1.11	1.01	0.26
	0.3	-0.8	-1.2	-0.7	0.0	-0.8	-1.3	-1.3	-1.5	-2.6	-0.6	0.1	0.5	2.5	6.0
		0.52	1.21	1.19	1.39	1.21	1.36	1.16	1.37	1.21	1.39	1.19	1.21	0.52	
		0.52	1.20	1.19	1.39	1.20	1.33	1.13	1.34	1.19	1.39	1.21	1.23	0.54	10
		-0.7	-0.9	-0.1	0.2	-0.9	-2.3	-1.9	-1.7	-1.5	0.3	1.4	1.9	4.0	
		0.32	1.07	1.31	1.21	1.39	1.19	1.38	1.19	1.39	1.21	1.31	1.07	0.32	
		0.32	1.07	1.32	1.23	1.38	1.17	1.35	1.17	1.36	1.23	1.34	1.10	0.33	11
		0.2	0.6	0.8	1.8	-0.6	-2.1	-2.2	-1.9	-2.0	1.8	2.3	2.7	3.1	
			0.41	0.83	1.30	1.19	1.37	1.18	1.37	1.19	1.30	0.83	0.41		
			0.43	0.84	1.31	1.17	1.32	1.15	1.34	1.18	1.32	0.86	0.43		12
			4.7	1.0	0.2	-1.3	-3.3	-2.5	-1.8	-0.8	1.1	3.8	6.4		
				0.41	1.06	1.21	1.10	1.30	1.10	1.20	1.06	0.41			
				0.41	1.06	1.19	1.08	1.26	1.09	1.20	1.07	0.42			13
				0.2	-0.4	-1.3	-2.3	-2.9	-1.8	-0.5	0.5	1.9			
					0.32	0.52	0.98	0.85	0.98	0.52	0.32				
					0.32	0.51	0.97	0.83	0.96	0.51	0.32				14
					-0.7	-1.2	-1.3	-2.1	-2.1	-1.1	-0.8				
	STANDARD					0.25	0.30	0.25				AVERAGE			
	DEVIATION					0.26	0.30	0.24				PCT DIFFERENCE			15
	=1.198					5.3	-0.6	-1.7				= 1.5			

SUMMARY

MAP NO: N2CAM14A DATE: 08/11/94 POWER: 100.02%

CONTROL ROD POSITION: F-Q(T) = 1.851 QPTR:

D BANK AT 225 STEPS F-DH(M) = 1.456 NW 0.9990 | NE 1.0096

F(Z) = 1.166 SW 0.9919 | SE 0.9995

BURNUP = 10811 MWD/MTU A.O. = -5.427%

Figure 4.3
NORTH ANNA UNIT 2 - CYCLE 10
ASSEMBLYWISE POWER DISTRIBUTION N2CAM20A

R	P	N	M	L	K	J	H	G	F	E	D	C	B	A	
	PREDICTED					0.28	0.34	0.28				PREDICTED			
	MEASURED					0.29	0.35	0.29				MEASURED			1
	PCT DIFFERENCE					3.2	2.9	1.6				PCT DIFFERENCE			
				0.35	0.56	1.00	0.88	1.00	0.56	0.34					
				0.35	0.56	1.01	0.87	1.01	0.58	0.36					2
				-0.2	0.3	0.6	-0.4	1.1	4.7	3.4					
			0.44	1.06	1.21	1.09	1.29	1.09	1.21	1.06	0.44				
			0.45	1.05	1.21	1.10	1.25	1.09	1.23	1.08	0.46				3
			4.1	-0.4	0.2	1.3	-3.1	0.3	2.2	2.7	5.3				
		0.43	0.84	1.28	1.16	1.35	1.15	1.35	1.16	1.28	0.84	0.43			
		0.43	0.84	1.25	1.16	1.36	1.16	1.37	1.19	1.31	0.85	0.43			4
		0.1	-0.4	-2.6	-0.5	0.8	0.9	1.3	2.4	2.2	0.7	0.1			
	0.35	1.06	1.28	1.18	1.38	1.17	1.37	1.17	1.38	1.18	1.28	1.06	0.35		
	0.35	1.06	1.28	1.19	1.38	1.19	1.39	1.19	1.40	1.21	1.25	1.05	0.36		5
	0.4	0.4	0.1	1.1	0.3	1.3	1.2	1.4	1.9	2.4	-2.1	-0.4	5.2		
	0.56	1.21	1.16	1.38	1.19	1.36	1.14	1.36	1.18	1.38	1.16	1.21	0.56		
	0.56	1.21	1.15	1.34	1.18	1.37	1.16	1.38	1.20	1.39	1.15	1.20	0.56		6
	0.5	0.4	-0.7	-2.6	-0.7	0.4	1.3	1.2	1.4	0.8	-0.8	-0.3	1.5		
0.28	1.00	1.09	1.35	1.17	1.36	1.17	1.12	1.17	1.36	1.17	1.35	1.09	1.00	0.28	
0.29	1.01	1.11	1.34	1.15	1.35	1.16	1.12	1.17	1.37	1.17	1.33	1.08	1.02	0.29	7
1.5	0.7	1.5	-0.6	-1.7	-1.0	-0.3	0.3	0.6	0.8	0.0	-1.6	-0.5	2.3	2.8	
0.34	0.88	1.29	1.15	1.37	1.14	1.12	1.01	1.12	1.14	1.37	1.15	1.29	0.88	0.34	
0.36	0.87	1.26	1.14	1.34	1.12	1.10	1.01	1.11	1.16	1.37	1.15	1.26	0.91	0.36	8
6.1	-0.5	-2.3	-1.5	-2.4	-1.3	-0.9	-0.6	-0.1	1.3	0.0	-0.7	-1.8	3.9	4.3	
0.28	1.00	1.09	1.35	1.17	1.36	1.17	1.12	1.17	1.36	1.17	1.35	1.09	1.00	0.28	
0.28	0.99	1.07	1.34	1.18	1.35	1.15	1.10	1.15	1.32	1.16	1.35	1.10	1.04	0.31	9
0.5	-0.8	-1.3	-0.6	0.4	-0.9	-1.5	-1.6	-1.7	-2.8	-0.5	0.4	1.0	3.3	7.1	
	0.56	1.21	1.16	1.38	1.18	1.36	1.14	1.36	1.19	1.38	1.16	1.21	0.56		
	0.55	1.19	1.16	1.38	1.17	1.33	1.12	1.34	1.16	1.38	1.18	1.24	0.58		10
	-0.9	-1.3	-0.2	0.2	-1.1	-2.7	-2.4	-2.1	-1.8	0.3	2.0	2.5	5.1		
	0.35	1.06	1.28	1.18	1.38	1.17	1.37	1.17	1.38	1.18	1.28	1.06	0.35		
	0.35	1.07	1.29	1.20	1.36	1.14	1.33	1.14	1.34	1.20	1.32	1.09	0.36		11
	0.1	0.6	0.7	1.5	-0.9	-2.6	-3.0	-2.4	-2.7	-1.6	2.8	3.4	4.0		
		0.43	0.84	1.28	1.16	1.35	1.15	1.35	1.16	1.28	0.84	0.43			
		0.46	0.85	1.28	1.14	1.30	1.12	1.32	1.15	1.30	0.88	0.46			12
		6.0	1.1	0.1	-1.5	-3.8	-2.9	-2.0	-0.9	1.3	4.7	7.0			
			0.44	1.06	1.21	1.09	1.29	1.09	1.21	1.06	0.44				
			0.44	1.05	1.19	1.06	1.25	1.07	1.21	1.07	0.45				13
			0.2	-0.6	-1.5	-2.4	-2.8	-1.6	-0.2	0.9	2.6				
				0.34	0.56	1.00	0.88	1.00	0.56	0.35					
				0.34	0.55	0.99	0.86	0.99	0.55	0.35					14
				-0.8	-1.2	-1.1	-1.6	-1.2	-0.5	0.4					
	STANDARD					0.28	0.34	0.28				AVERAGE			
	DEVIATION					0.30	0.34	0.28				PCT DIFFERENCE			15
	=1.438					5.9	-0.8	-0.9				= 1.6			

SUMMARY

MAP NO: N2CAM20A
DATE: 01/17/95
POWER: 99.97%

CONTROL ROD POSITION:
F-Q(T) = 1.767
QPTR:

D BANK AT 225 STEPS
F-DH(M) = 1.432
NW 0.9988 | NE 1.0090
F(Z) = 1.144
SW 0.9910 | SE 1.0012

BURNUP = 17126 MWD/MTU
A.O.= -2.632%

Figure 4.4
NORTH ANNA UNIT 2 - CYCLE 10
HOT CHANNEL FACTOR NORMALIZED
OPERATING ENVELOPE

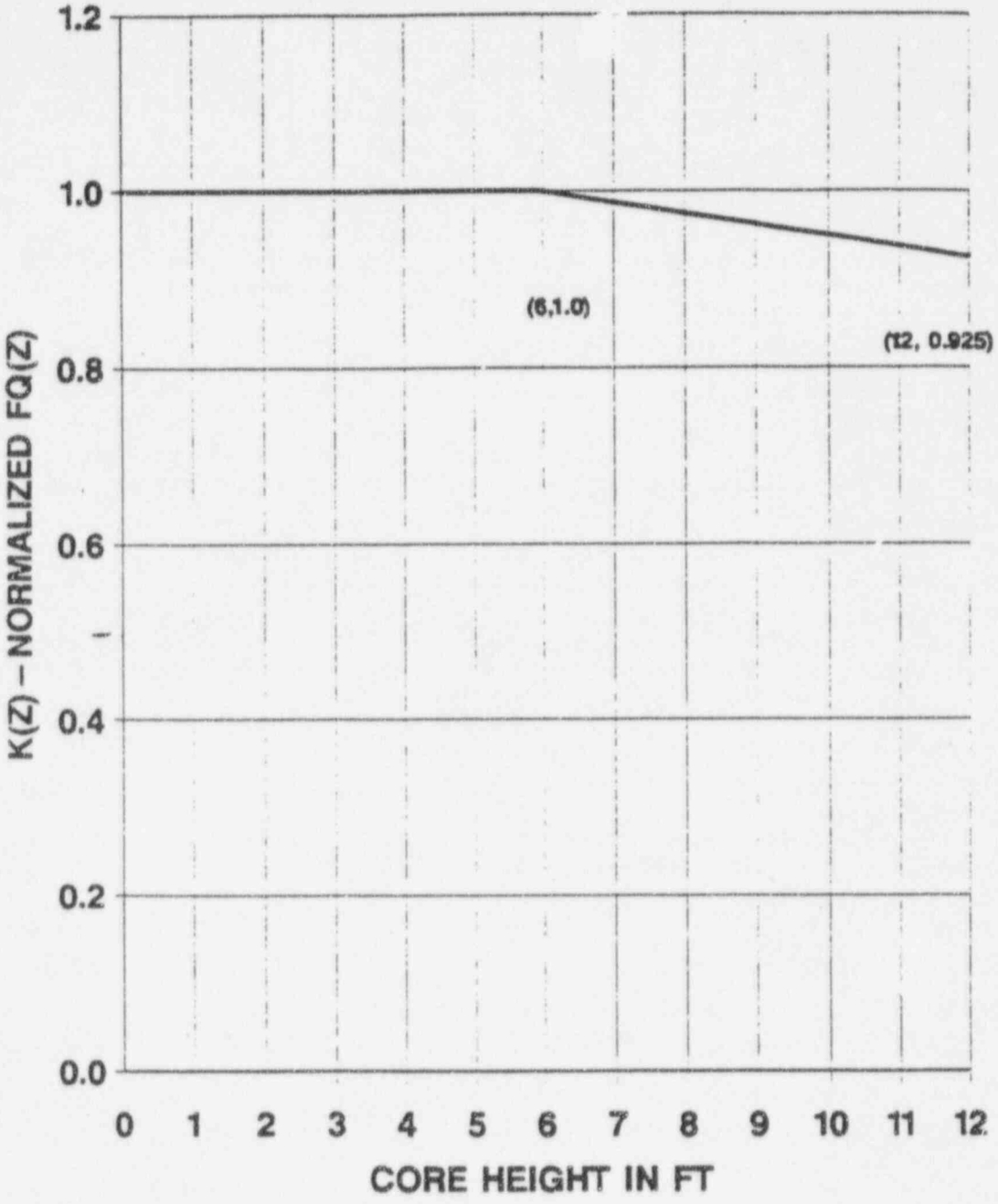


Figure 4.5
NORTH ANNA UNIT 2 - CYCLE 10
HEAT FLUX HOT CHANNEL FACTOR, $F_Q(Z)$
N2-10-06

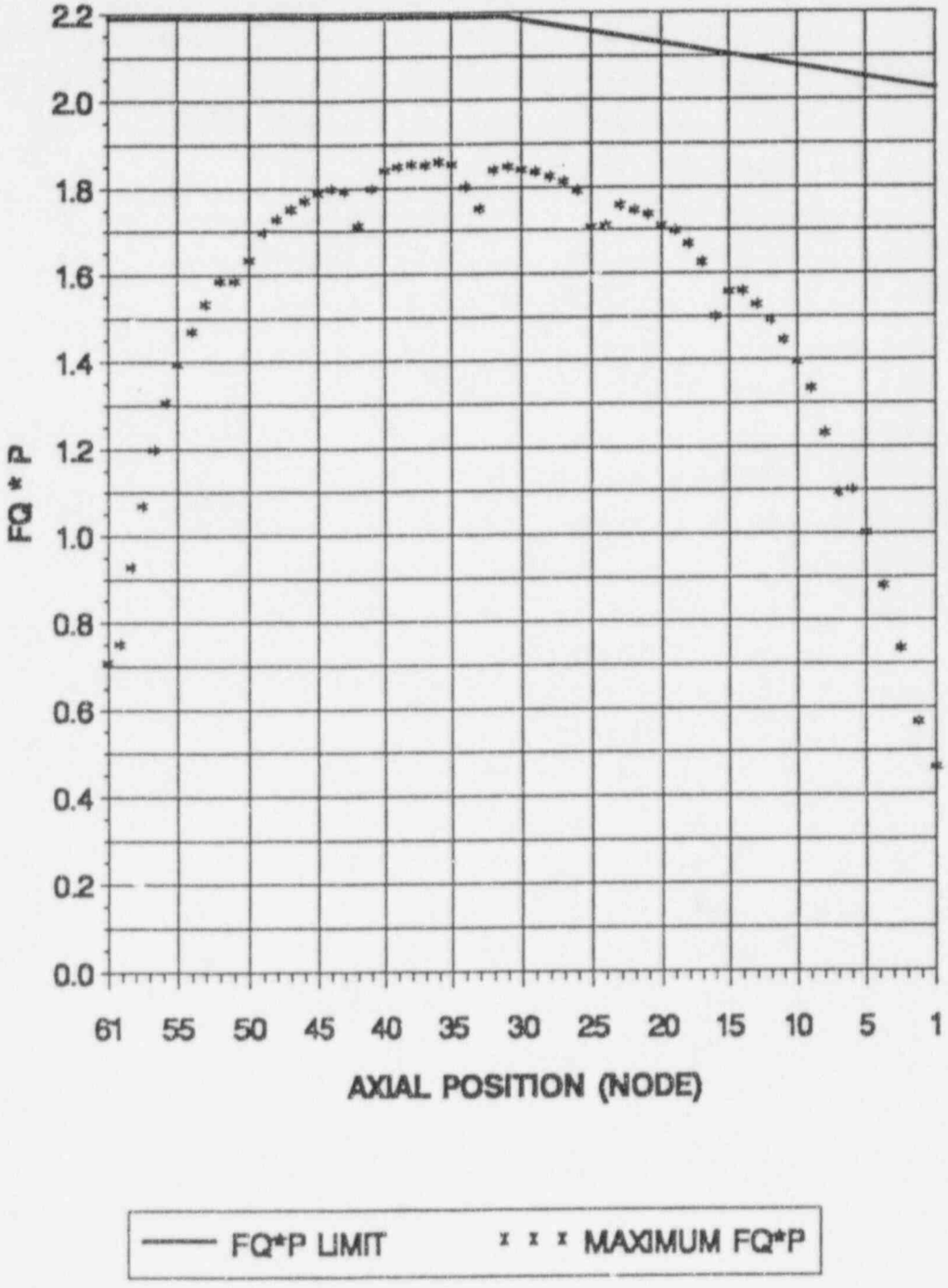
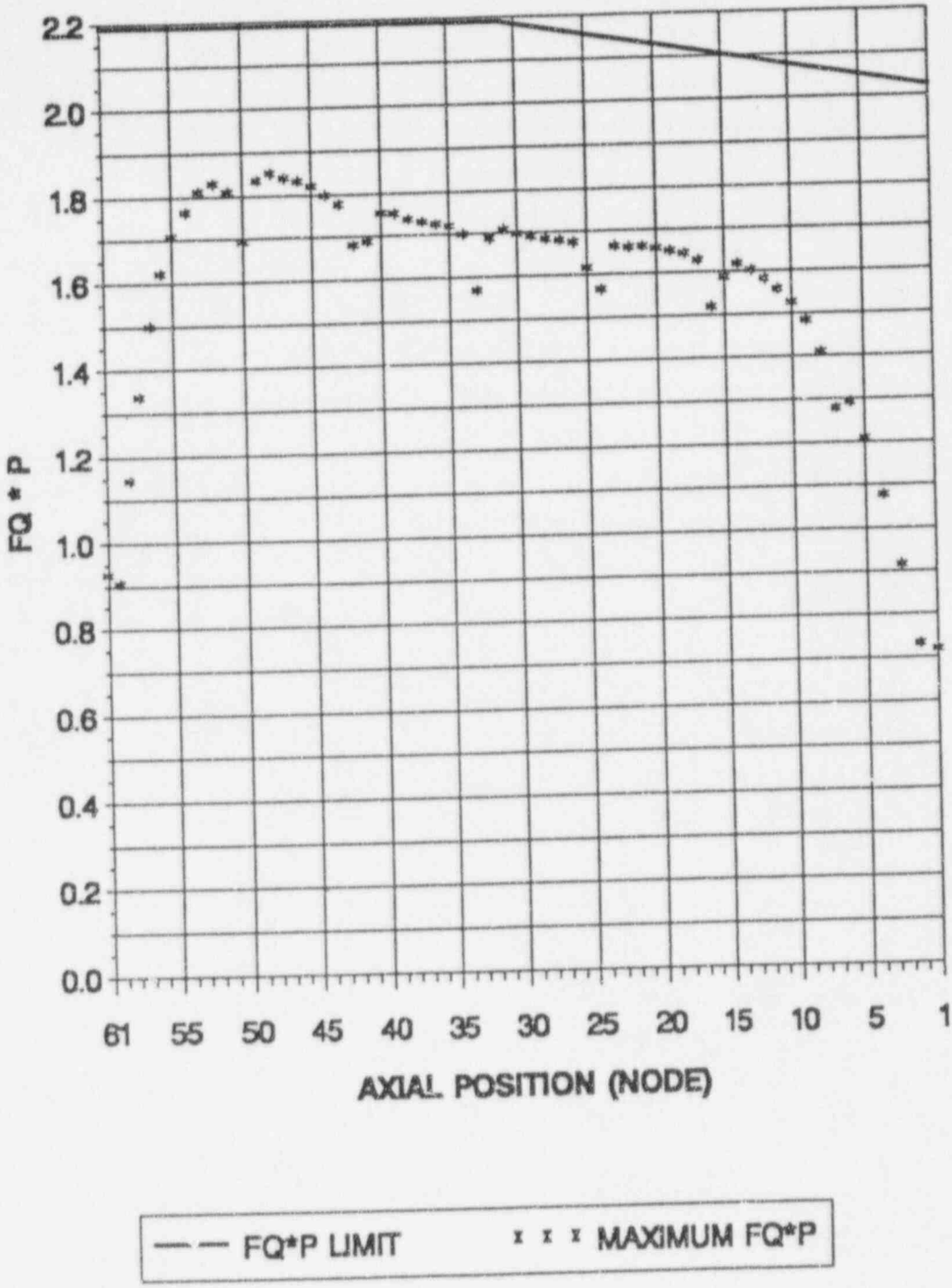


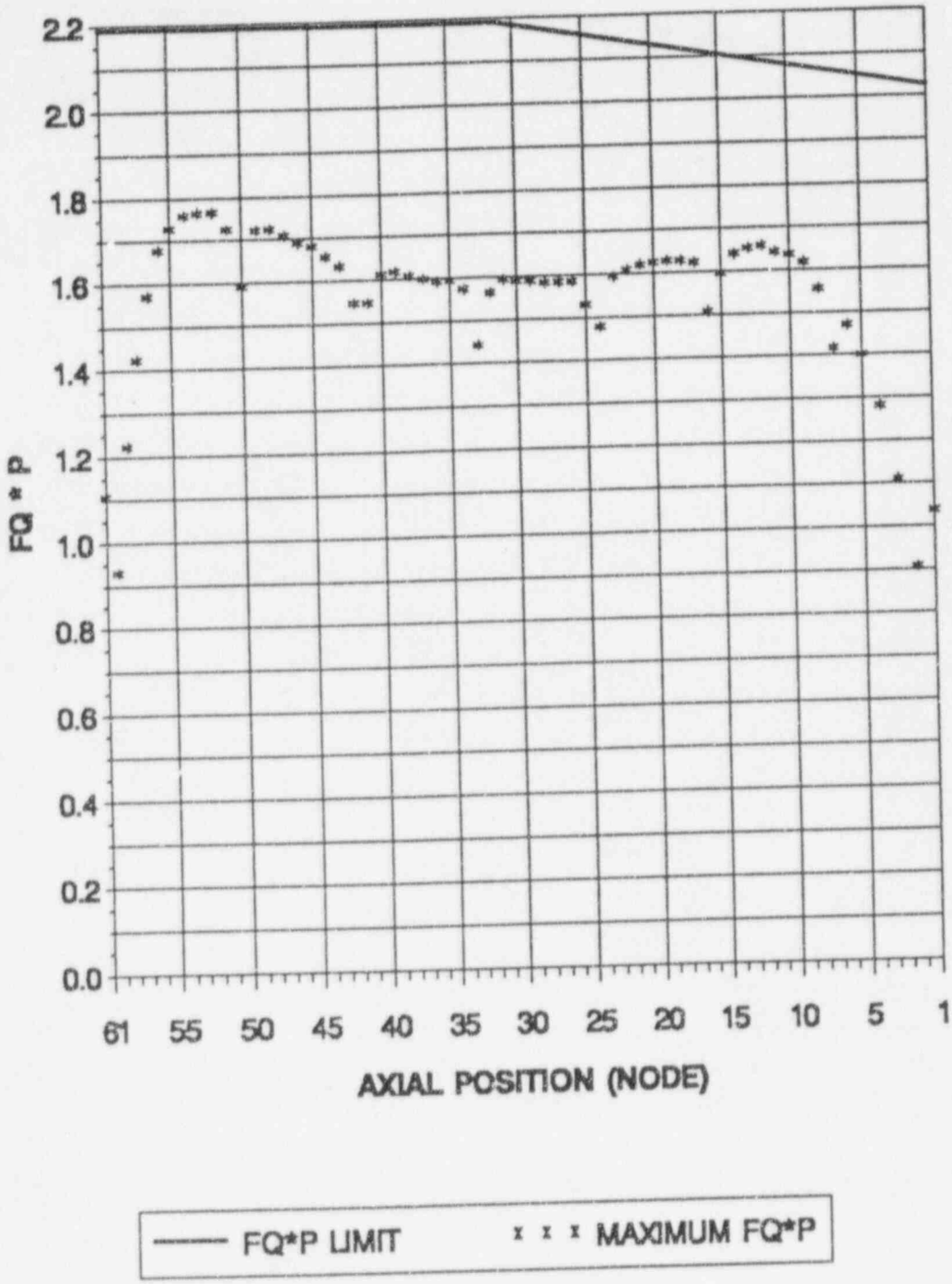
Figure 4.6
NORTH ANNA UNIT 2 - CYCLE 10
HEAT FLUX HOT CHANNEL FACTOR, $F_Q(Z)$
N2CAM14A



BOTTOM OF CORE

TOP OF CORE

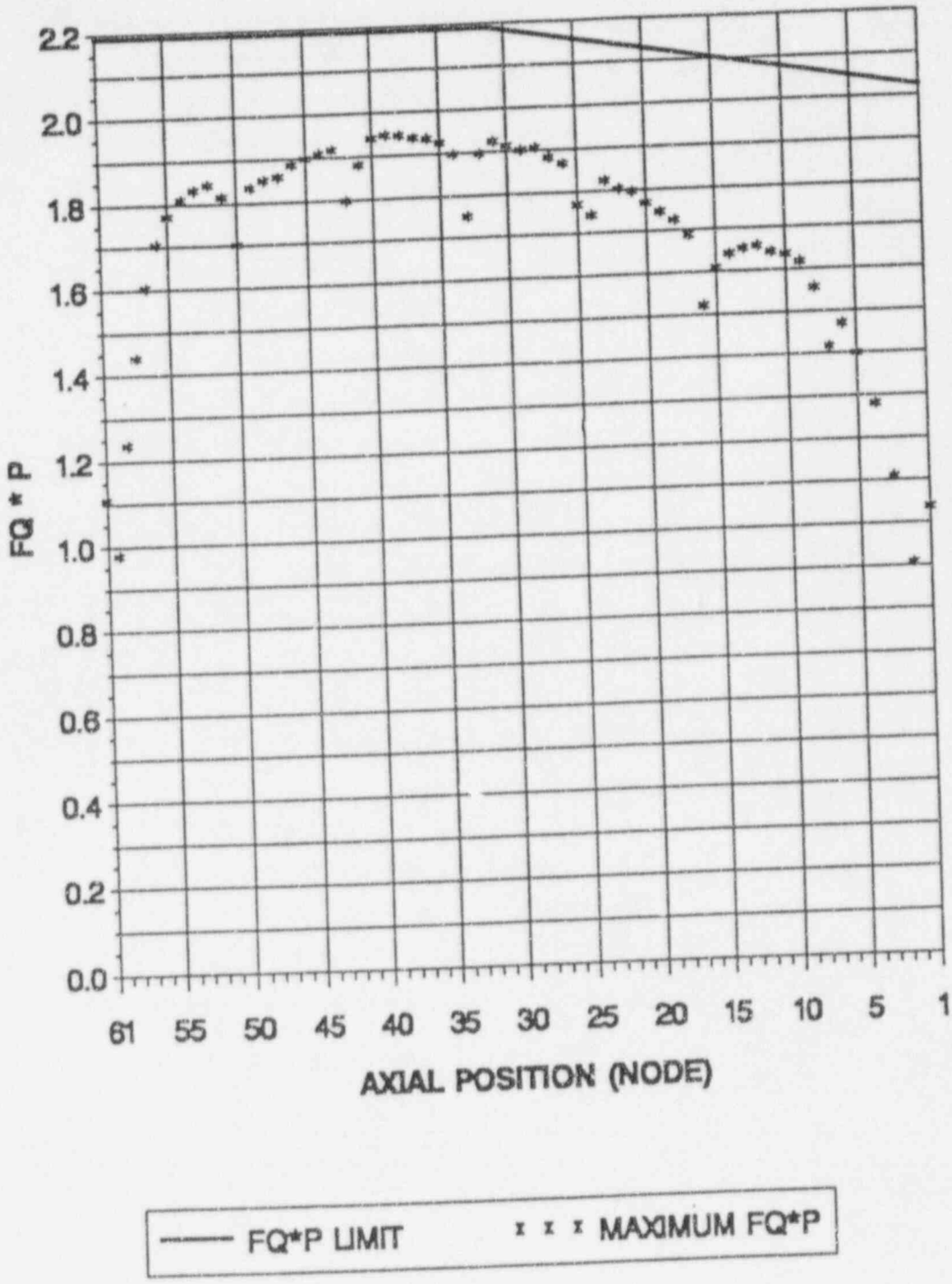
Figure 4.7
NORTH ANNA UNIT 2 - CYCLE 10
HEAT FLUX HOT CHANNEL FACTOR, $F_Q(Z)$
N2CAM20A



BOTTOM OF CORE

TOP OF CORE

Figure 4.8
NORTH ANNA UNIT 2 - CYCLE 10
MAXIMUM HEAT FLUX HOT CHANNEL FACTOR, $F_Q(Z)*P$, vs. AXIAL POSITION



BOTTOM OF CORE

TOP OF CORE

Figure 4.9
NORTH ANNA UNIT 2 - CYCLE 10
MAXIMUM HEAT FLUX HOT CHANNEL FACTOR, $F_Q(Z)$, vs. BURNUP

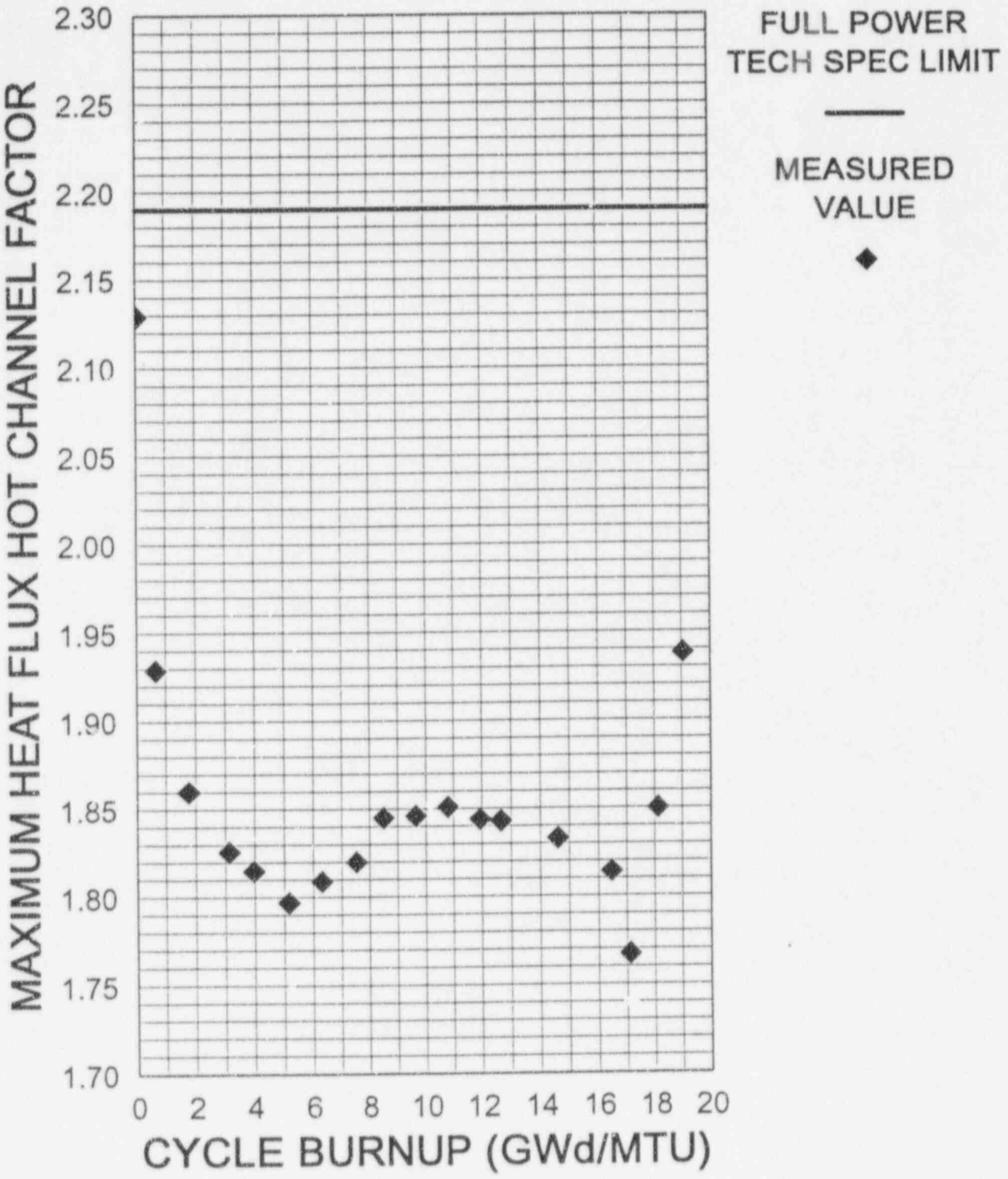


Figure 4.10
NORTH ANNA UNIT 2 - CYCLE 10
MAXIMUM ENTHALPY RISE HOT CHANNEL FACTOR, F-delta-H, vs. BURNUP

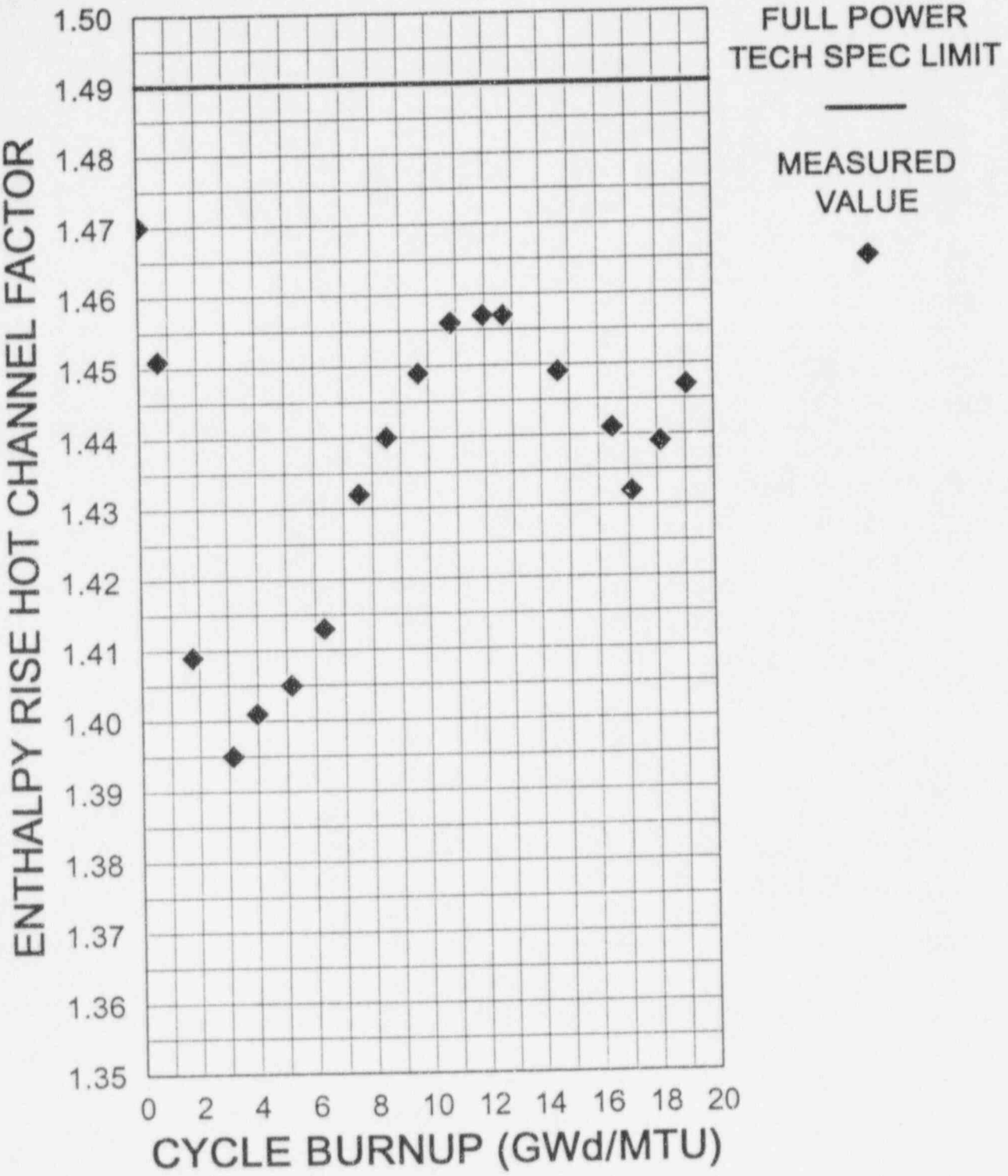


Figure 4.11
NORTH ANNA UNIT 2 - CYCLE 10
TARGET DELTA FLUX vs. BURNUP

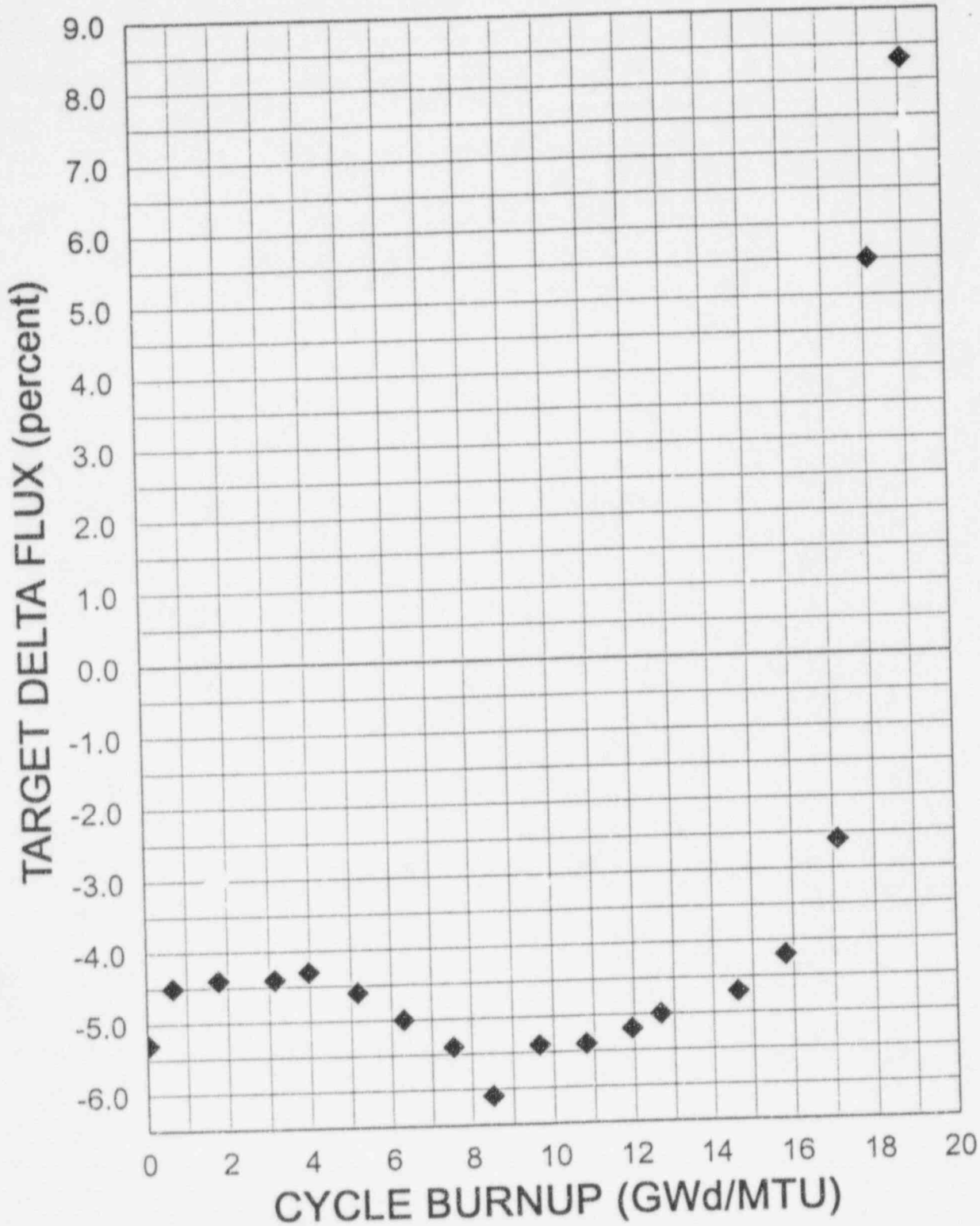


Figure 4.12
NORTH ANNA UNIT 2 - CYCLE 10
CORE AVERAGE AXIAL POWER DISTRIBUTION
N2-10-06

Fz = 1.221
AXIAL OFFSET = -4.405%

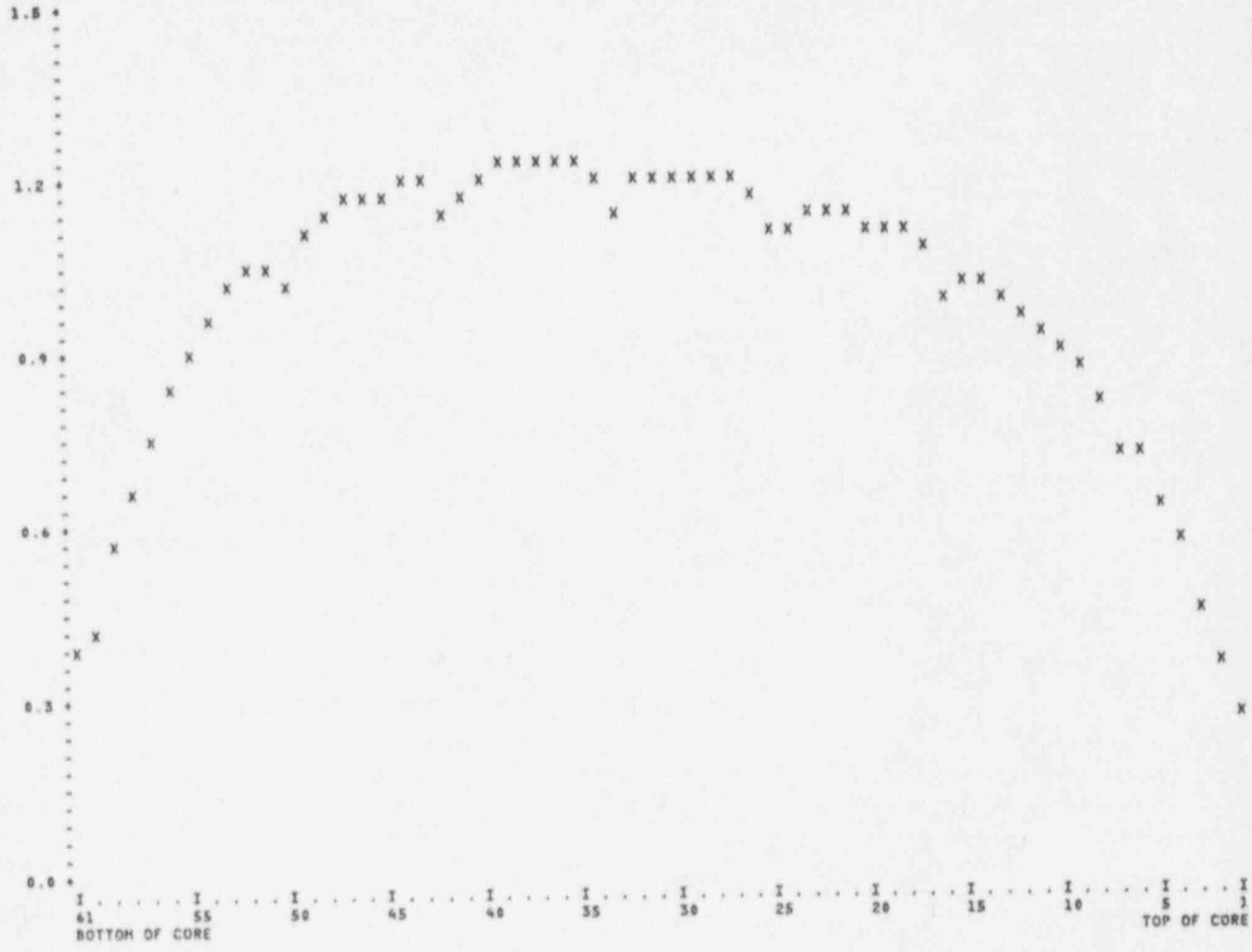


Figure 4.13
NORTH ANNA UNIT 2 - CYCLE 10
CORE AVERAGE AXIAL POWER DISTRIBUTION
N2CAM14A

Fz = 1.166
AXIAL OFFSET = -5.427%

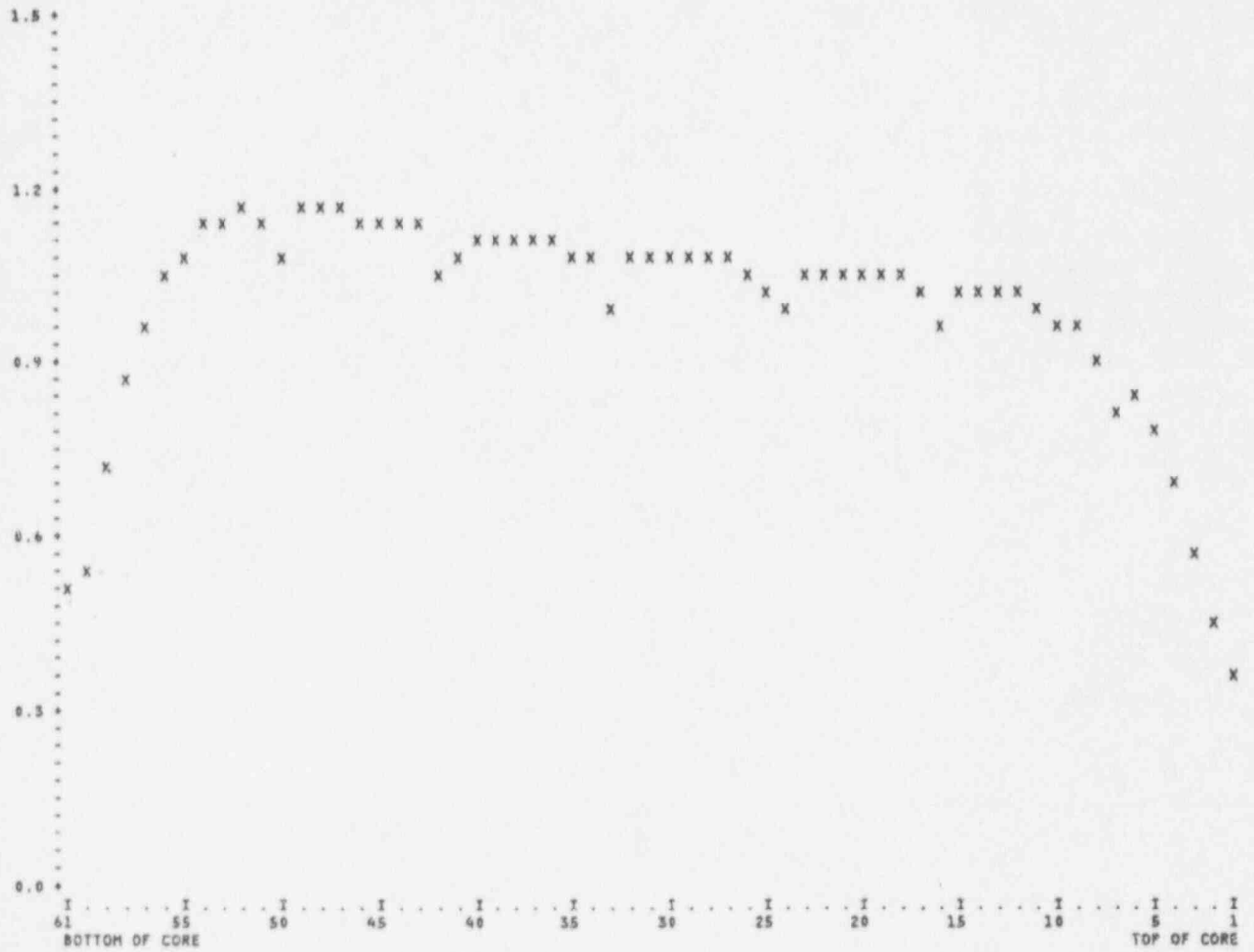


Figure 4.14
NORTH ANNA UNIT 2 - CYCLE 10
CORE AVERAGE AXIAL POWER DISTRIBUTION
N2CAM20A

Fz = 1.144
AXIAL OFFSET = -2.632%

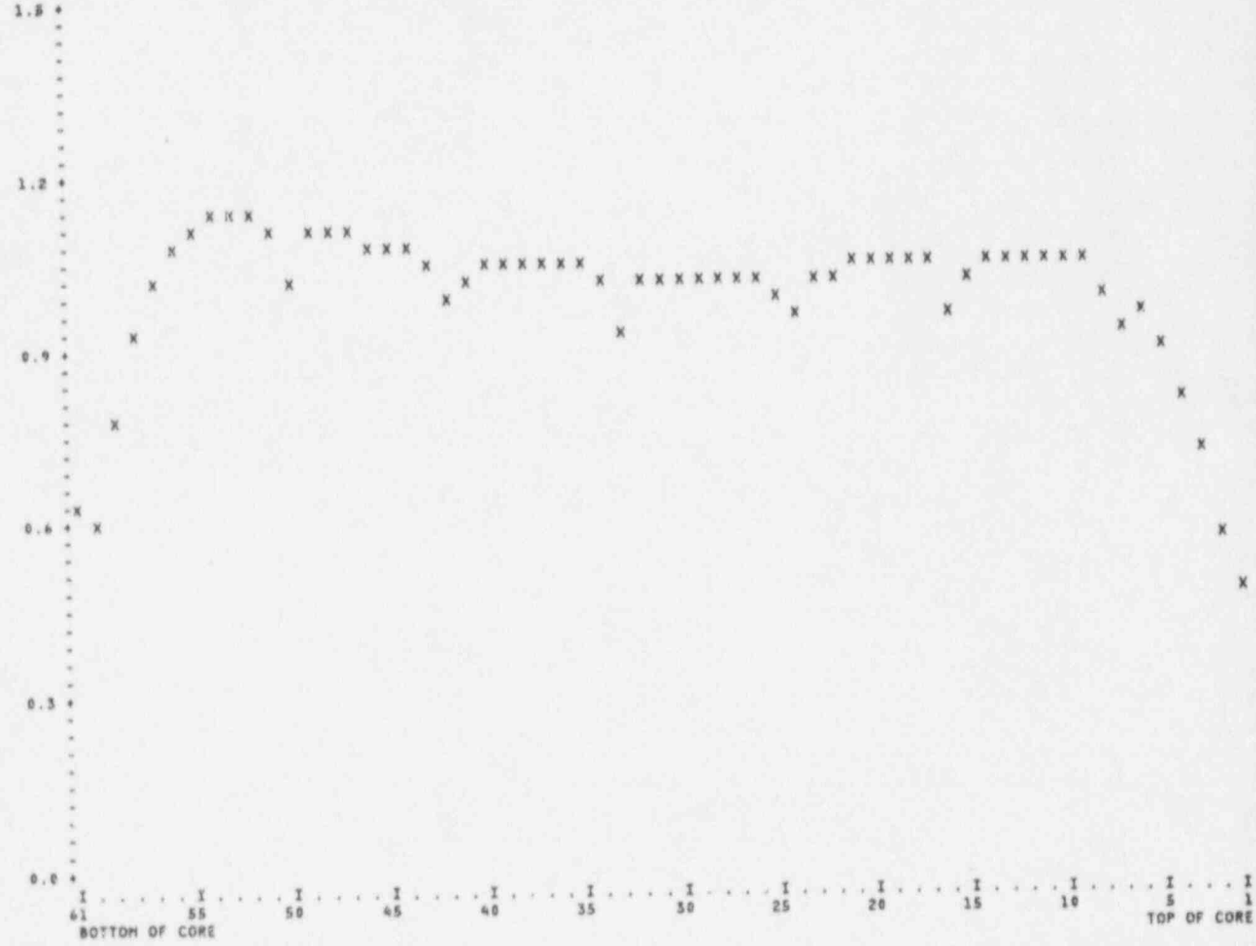
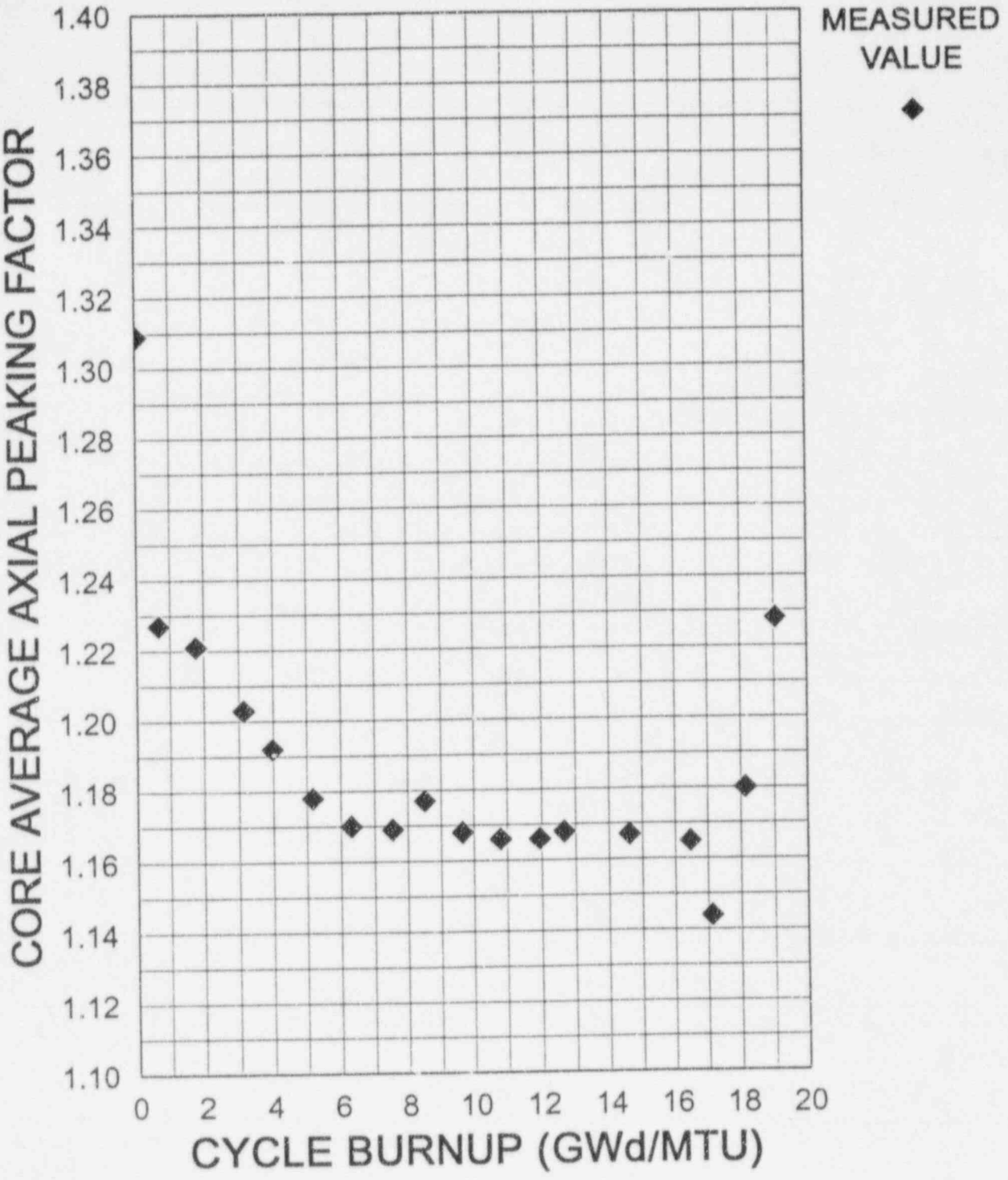


Figure 4.15
NORTH ANNA UNIT 2 - CYCLE 10
CORE AVERAGE AXIAL PEAKING FACTOR vs. BURNUP



Section 5

PRIMARY COOLANT ACTIVITY

The specific activity levels of radioiodines in the primary coolant are important to core and fuel performance as indicators of failed fuel and are important with respect to offsite dose calculations associated with accident analyses.

Two mechanisms are responsible for the presence of radioiodines in the primary coolant. Radioiodines are always present due to direct fission product recoil from trace fissile materials plated onto core components and fuel structure surfaces or trace fissile materials existing as impurities in core structural materials. This fissile material is generally referred to as "tramp" material, and the resulting iodines are referred to as tramp iodine. Fission products will also diffuse into the primary coolant if a breach in the cladding (fuel defects) exists. Fuel defects, when present, are generally the predominant source of radioiodines in the primary coolant.

North Anna 2 Technical Specification 3.4.8 limits the radioiodines in the primary coolant to a dose equivalent I-131 value of 1.0 µCi/gm for modes one through five, inclusive. Figure 5.1 shows the dose-equivalent I-131 activity history for Cycle 10. These data show that the dose equivalent I-131 activity was substantially below the 1.0 µCi/gm limit for steady state power operation. The average full power equilibrium dose

equivalent I-131 concentration for the cycle was 4.18 X 10^{-3} µCi/gm which corresponds to less than 1% of the Technical Specification limit.

Correcting the I-131 concentration for tramp iodine involves calculating the I-131 activity from tramp fissile sources and subtracting this value from the measured I-131. The resultant is an estimate of the I-131 activity resulting directly from defective fuel. The magnitude of the tramp-corrected I-131 can be used as an indication of the number of defective fuel rods.

The threshold for the tramp-corrected I-131 that would indicate the presence of a fuel defect is typically established at 5.0 X 10^{-4} µCi/gm. The cycle average tramp-corrected I-131 was 1.44 X 10^{-4} µCi/gm. The average tramp-corrected I-131 during March 1995 was 3.60 X 10^{-4} µCi/gm. Although there was evidence of a fuel defect, the tramp-corrected I-131 never reached the threshold value, and in this case, was not a reliable indicator of a fuel defect. This is unusual but possible for defects that are very small which do not permit radioiodine isotopes to readily migrate to the coolant.

However, near the end of the cycle during coastdown operation the RCS concentration of Xe-133 (a noble gas) increased dramatically. Figure 5.2 shows the RCS Xe-133 concentration trend for Cycle 10. Noble gas isotopes such as Xe-133 and Xe-135 are more difficult to mathematically account for in the RCS compared to radioiodine because of their greater sensitivity to coolant exchanges with the RCS during dilution and uncertainties resulting from degassing in CVCS components such as the

volume control tank. Like radioiodines, radioactive noble fission gases are always present in the RCS due to tramp fissile sources. However large increases in noble gas concentration such as that shown on Figure 5.2 are not due to tramp fissile sources and can only be explained by the occurrence of a fuel defect.

Figure 5.3 is the RCS I-131 (not dose equivalent) concentration trend for Cycle 10. The spike in the I-131 concentration which occurred when the unit was shutting down at the end of the cycle is a positive indication of a fuel defect. The spike in the iodine concentration is also shown on Figure 5.1.

The ratio of the specific activities of I-131 to I-133 is used to characterize the type (size) of fuel failure or failures 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 leaving the I-131 dominant in activity, thereby causing the ratio to be roughly 0.5 or more. In the case of larger leaks and tramp material, where the diffusion mechanism is negligible, the I-131/I-133 ratio will generally be less than 0.1. The use of these ratios with regard to defect size is empirically determined and generally used throughout the commercial nuclear power industry.

Figure 5.4 shows the I-131/I-133 ratio data for North Anna 2 Cycle 10. The I-131/I-133 ratio was between 0.05 and 0.15 throughout most of the

cycle. However, this parameter becomes somewhat meaningless with respect to fuel defects because the defect(s) was small enough to inhibit migration of radioiodines to the RCS. The I-131 to I-133 ratio maintained a value close to 0.1 throughout the cycle which indicates that the tramp fissile material is open to the coolant (seen as a large "defect"). A ratio of approximately 0.1 is typical of a core with zero defects.

Fuel vacuum sipping tests were performed on all fuel assemblies from Cycle 10. All assemblies scheduled for reuse in Cycle 11 were determined to have no fuel defects. Two assemblies scheduled to be permanently discharged were found to be defective. Assembly 2L8 operated in N2C9 and N2C10 and received an accumulated average burnup of 47,382 MWd/MtU. Assembly Y33 operated in N2C8, N2C9, and N2C10 and received an accumulated average burnup of 47,408 MWd/MtU. Possible failure mechanisms for these two assemblies are currently being investigated. These fuel assemblies will be restricted from further use in accordance with the zero defect policy[11].

Figure 5.1
NORTH ANNA UNIT 2 - CYCLE 10
DOSE EQUIVALENT I-131 vs. TIME

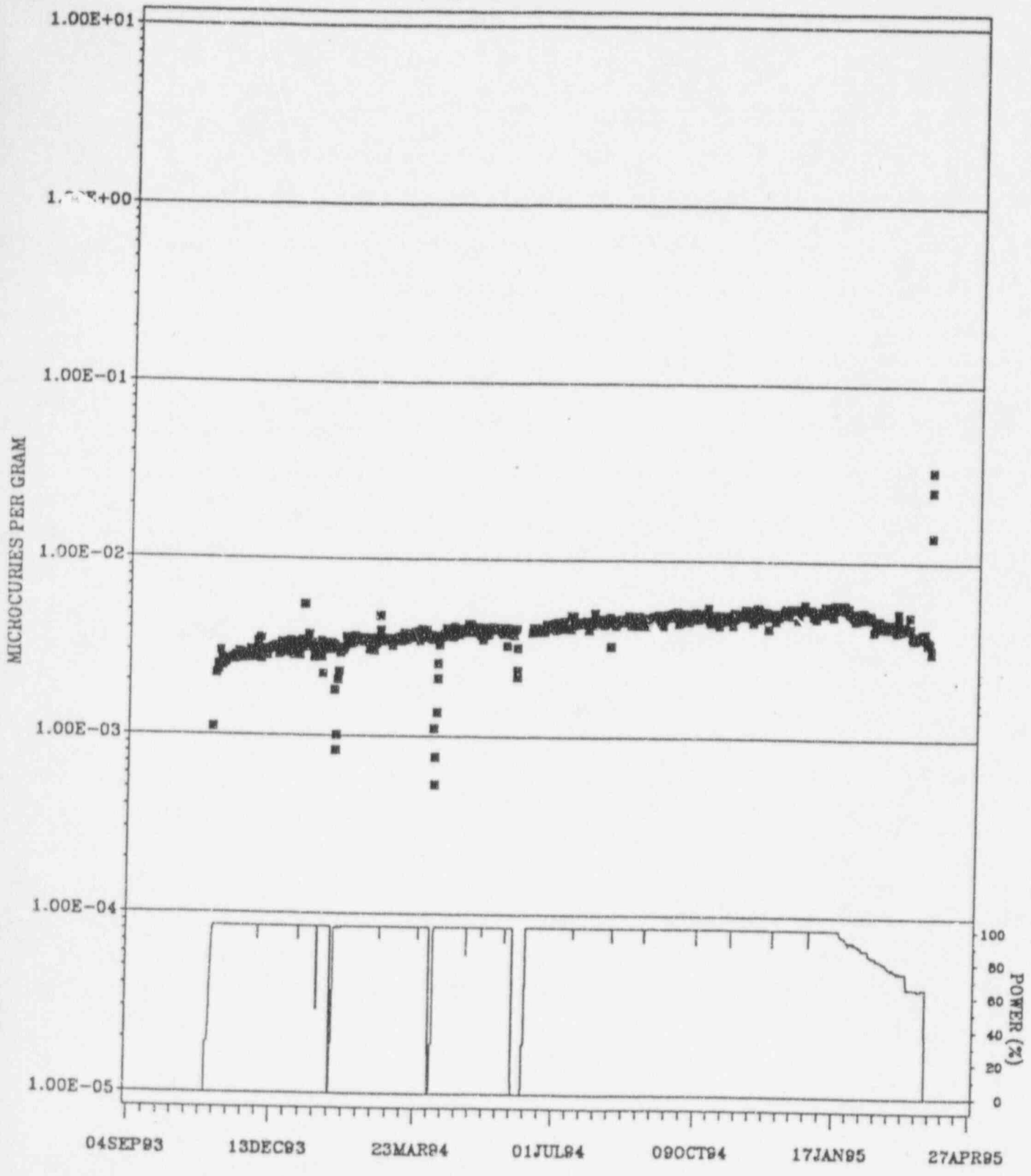


Figure 5.2
NORTH ANNA UNIT 2 - CYCLE 10
MEASURED RCS XENON-133 VS. TIME

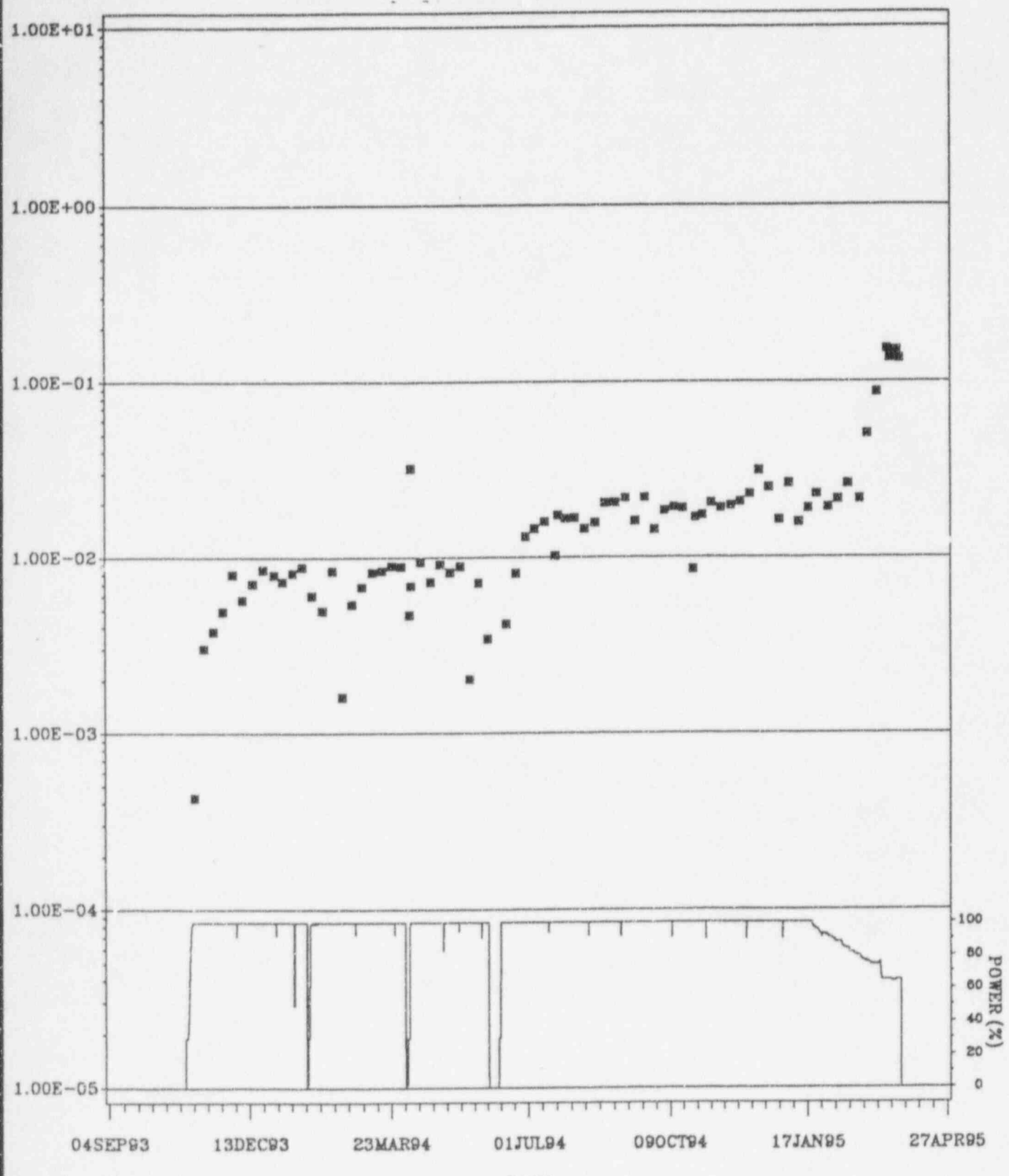


Figure 5.3
NORTH ANNA UNIT 2 - CYCLE 10
MEASURED RCS IODINE-131 VS. TIME

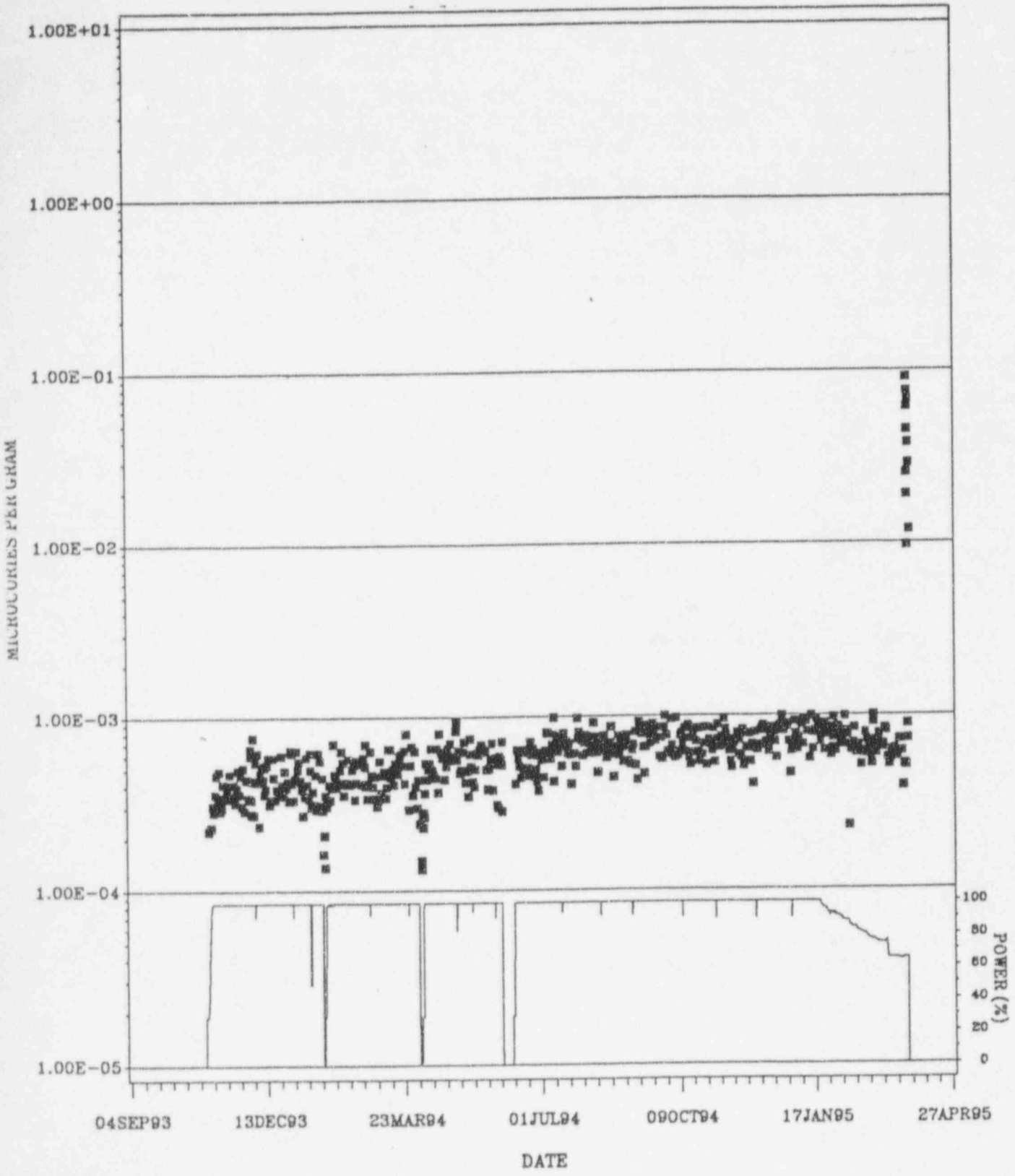
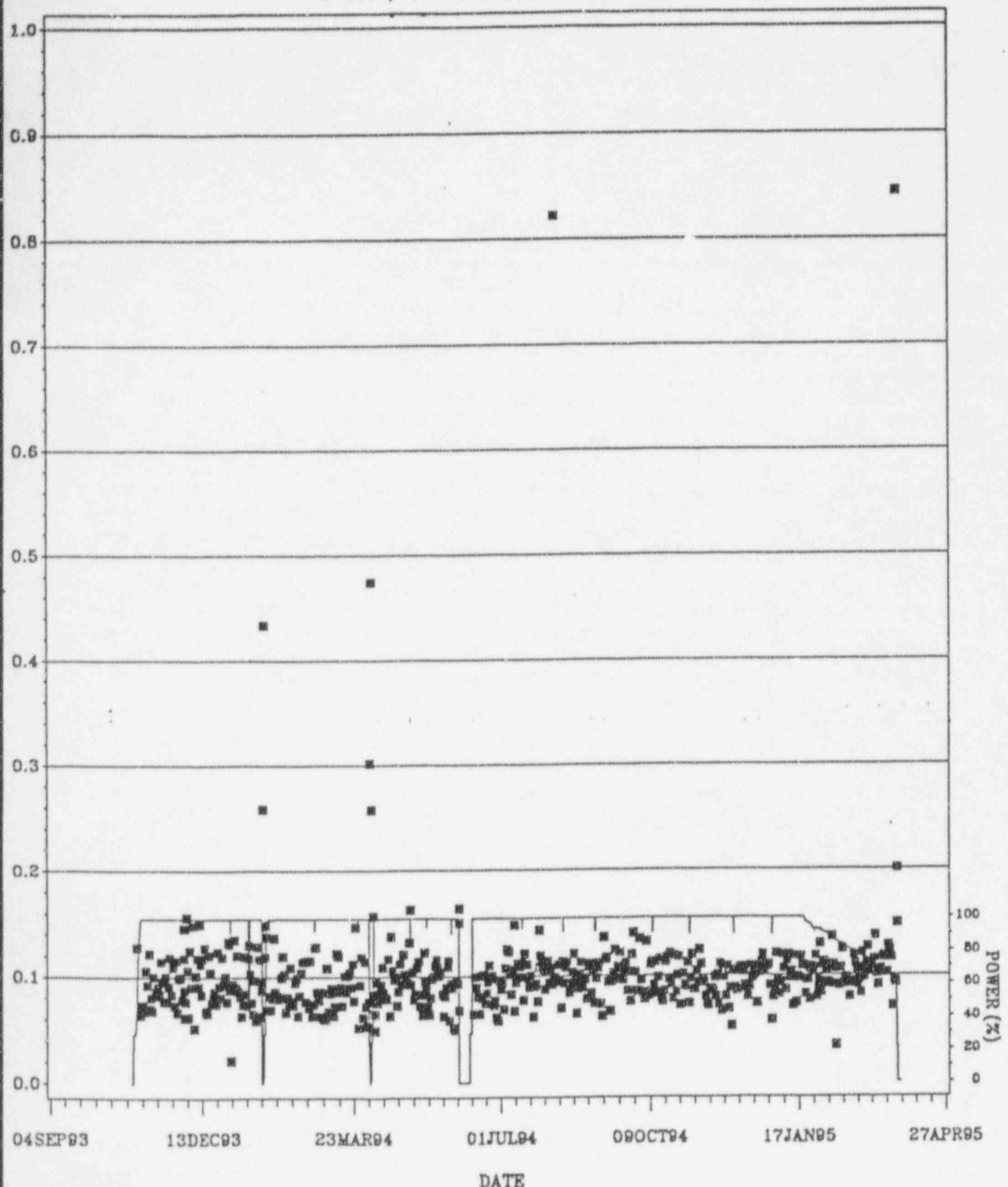


Figure 5.4
NORTH ANNA UNIT 2 - CYCLE 10
I-131 / I-133 ACTIVITY RATIO VS. TIME



Section 6

CONCLUSIONS

The North Anna 2, Cycle 10 core has completed operation. Throughout this cycle, all core performance indicators compared favorably with design predictions. Core related Technical Specifications limits were met with significant margin. No significant abnormalities in reactivity or burnup accumulation were detected. RCS noble gas and radioiodine activity indicated there was a fuel rod defect late during Cycle 10. Fuel vacuum sipping tests identified two discharged assemblies as defective. These assemblies will be restricted from further use in accordance with the zero defect policy[11].

Section 7

REFERENCES

1) E. R. Makovksy, "North Anna Unit 2, Cycle 10 Startup Physics Test Report," Technical Report NE-963 Rev. 0, December, 1993.

2) North Anna Power Station Unit 2 Technical Specifications, Sections 3/4.1, 3/4.2 and 3/4.4.8.

3) T. W. Schleicher, "The Virginia Power Fuel Assembly Burnup and Isotopics Code Manual," Technical Report NE-679, Virginia Power, February, 1990.

4) D. L. Gilliatt, "The Virginia Power Follow Code Manual," Technical Report NE-679, Rev. 1, Virginia Power, April, 1991.

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

6) Memorandum from R. G. McAndrew to J. R. Hayes, "Core Operating Limits Report (COLR) Tech Spec Amendment 146/130", July 5, 1991.

7) W. S. Miller,"North Anna 2, Cycle 10 FOLOW Input and Calculations", Calculation Note PM-507, Rev. 0, Addendum R, March 1995.

8) S. S. Kere, "Reload Safety Evaluation North Anna 2 Cycle 10 Pattern RE," Technical Report NE-955 Rev. 2, Virginia Power, October, 1993.

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9) P. D. Banning, "North Anna 2 Cycle 10 Design Report" Technical Report NE-958, Virginia Power, October, 1993.

10) W. S. Miller, "North Anna 2 Cycle 10 TOTE Calculations", Calculation Note PM-507, March, 1995.

11) Nuclear Standard ENNS-2904, "Fuel Integrity Monitoring", Rev. 0, May 26, 1992.

12) R. A. Hall, et al,"North Anna Unit 2 Cycle 10 Flux Map Analysis", Calculation Note PM-515, Rev. 0, and Addenda, October 1993 - March 1995.

13) T. W. Schleicher, "The Virginia Power CECOR Code Package", Technical Report NE-831, Rev. 2, March, 1994.