North Anna Unit 2 Cycle 8 Core Performance Report

Nuclear Analysis and Fuel
Nuclear Engineering
Services

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NORTH ANNA UNIT 2, CYCLE 8

CORE PERFORMANCE REPORT

NUCLEAR ANALYSIS AND FUEL
POWER ENGINEERING SERVICES
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Section 1

INTRODUCTION AND SUMMARY

On February 26, 1992, North Anna Unit 2 completed Cycle 8. Since the initial criticality of Cycle 8 on November 1, 1990, the reactor core produced approximately 1.0862 x 10^8 MBTU (18,239 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 8. The physics tests that were performed during the startup of this cycle were covered in the North Anna Unit 2, Cycle 8 Startup Physics Test Report[1] and, therefore, will not be included here.

North Anna Unit 2 was in coastdown from January 14, 1992, at which time the burnup was approximately 16,829 MWD/MTU. The coastdown accounted for an additional core burnup of roughly 1,410 MWD/MTU from the end of full power reactivity.

The Cycle 8 core consisted of 14 sub-batches of fuel: four once-burned batches from Cycle 7 (batches 9A, 9B, N1/10A, and N1/10B); seven twice-burned batches, one from North Anna 1 Cycles 3 and 4 (batch N1/5), one from North Anna 2 Cycle 5 and North Anna 1 Cycle 4 (batch N1/6), one from North Anna 1 Cycles 5 and 6 (batch N1/7), one from North Anna 2 Cycles 2 and 3 (batch 4), one from North Anna 2 Cycles 3 and 4 (batch 5A), and two from North Anna 2 Cycles 6 and 7 (batches 8A and 8B); one thrice-burned batch from North Anna 2 Cycles 5,6, and 7 (batch 7A); and two fresh batches (batches 10A and 10B). The North Anna 2 Cycle 8 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 verify that the dose equivalent iodine-131 concentration is within the limits specified by the North Anna Unit 2 Technical Specifications[2]. A radioiodine analysis based on the iodine-131 concentration in the coolant is performed to assess the integrity of the fuel.

Each of the four performance indicators is discussed in detail for the North Anna Unit 2, Cycle 8 core 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 ±0.30% with the burnup accumulation in each batch deviating from design prediction by no more than 1.69%.

2. Reactivity Depletion - The critical boron concentration, used to monitor reactivity depletion, was consistently within ±0.39% 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 2.5%. 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 8 was approximately 0.0242 μCi/gm. This corresponds to less than 3% of the operating limit for the concentration of radioiodine in the primary coolant. Radioiodine analysis indicated several fuel rod defects, which prompted ultrasonic testing (UT) during the Cycle 8 to Cycle 9 refueling outage. During UT testing, it was confirmed that eight fuel rods in five fuel assemblies were defective.

Figure 1.1
NORTH ANNA UNIT 2 - CYCLE 8
CORE LOADING MAP

	R	P	N	M	L	K	J	H	G	F	E	D	C	B	A
1							5A S31	8B W50	5A S24						
2					8A W17	N1/10A K06	10B Y33	9B X37	10B Y56	N1/10A K01	8A W13				
3				7A V22	10B Y60	10A Y02	9B X39	10B Y39	9B X24	10A Y26	10B Y43	7A V01			
4			7A V26	9B X46	10B Y42	9A X18	10B Y48	9A X07	10B Y64	9A X08	10B Y53	9B X52	7A V35		
5		8A W14	10B Y34	10B Y51	N1/10A K11	10A Y09	9B X50	9B X33	9B X32	10A Y17	N1/10A K05	10B Y36	10B Y58	8A W11	
6		N1/10A K10	10A Y07	9A X01	10A Y20	9A X13	10A Y24	N1/5 E13	10A Y03	9A X03	10A Y27	9A X11	10A Y11	N1/10A K09	
7	5A S56	10B Y55	9B X48	10B Y63	9B X41	10A Y16	9B X40	10A Y21	9B X35	10A Y14	9B X42	10B Y61	9B X47	10B Y46	5A S06
8	8B W35	9B X25	10B Y45	9A X17	9B X45	4 R27	10A Y13	N1/7 G30	10A Y05	4 R18	9B X51	9A X06	10B Y32	9B X31	8B W64
9	5A S34	10B Y29	9B X34	10B Y38	9B X43	10A Y23	9B X22	10A Y18	N1/10B K41	10A Y28	9B X29	10B Y41	9B X49	10B Y54	5A S36
10		N1/10A K07	10A Y12	9A X05	10A Y04	9A X15	10A Y06	N1/5 E56	10A Y22	9A X02	10A Y01	9A X16	10A Y08	N1/10A K04	
11		8A W18	10B Y52	10B Y35	N1/10A K02	10A Y19	9B X30	9B X28	9B X36	10A Y15	N1/10A K08	10B Y57	10B Y37	8A W23	
12			N1/6 F57	9B X26	10B Y62	9A X20	10B Y50	9A X04	10B Y59	9A X14	10B Y31	9B X23	7A V32		
13				7A V10	10B Y44	10A Y10	9B X38	10B Y40	9B X21	10A Y25	10B Y47	7A V36			
14					8A W16	N1/10A K03	10B Y30	9B X27	10B Y49	N1/10A K12	8A W04				
15							5A S02	8B W43	5A S41						

--> BATCH
<-- ASSEMBLY ID

FUEL ASSEMBLY DESIGN PARAMETERS

	SUB-BATCH													
	N1/5	N1/6	N1/7	N1/10A	N1/10B	4	5A	7A	8A	8B	9A	9B	10A	1
INITIAL ENRICHMENT (W/O U-235)	3.40	3.59	3.60	3.80	4.00	3.41	3.59	3.60	3.79	4.00	3.80	4.01	3.99	4
ASSEMBLY TYPE	17x17	17x17	17x17	17x17	17x17	17x17	17x17	17x17	17x17	17x17	17x17	17x17	17x17	17
NUMBER OF ASSEMBLIES	2	1	1	12	1	2	8	7	8	4	16	31	28	
FUEL RODS PER ASSEMBLY	264	264	264	264	264	264	264	264	264	264	264	264	264	

Figure 1.2
NORTH ANNA UNIT 2 - CYCLE 8
BURNABLE POISON AND SOURCE
ASSEMBLY LOCATIONS

	R	P	N	M	L	K	J	H	G	F	E	D	C	B	A
1															
2							4P BP008		4P BP007						
3					7P BP014	12P BP024		20P BP064		12P BP023	7P BP016				
4					16P BP044		20P BP060		20P BP059		16P BP043				
5			7P BP013	16P BP042		20P BP058				20P BP057		16P BP041	7P BP015		
6			12P BP022		20P BP056		16P BP032		16P BP031		20P BP055		12P BP021		
7		4P BP006		20P BP054		16P BP030		16P BP036		16P BP029		20P BP053		4P BP005	
8			20P BP063		SS17		16P BP035		16P BP034		SS18		20P BP062		
9		4P BP004		20P BP052		16P BP028		16P BP033		16P BP027		20P BP051		4P BP003	
10			12P BP020		20P BP050		16P BP026		16P BP025		20P BP049		12P BP019		
11			7P BP012	16P BP040		20P BP048				20P BP047		16P BP039	7P BP010		
12					16P BP038		20P BP046		20P BP045		16P BP037				
13					7P BP011	12P BP018		20P BP061		12P BP017	7P BP009				
14							4P BP002		4P BP001						
15															

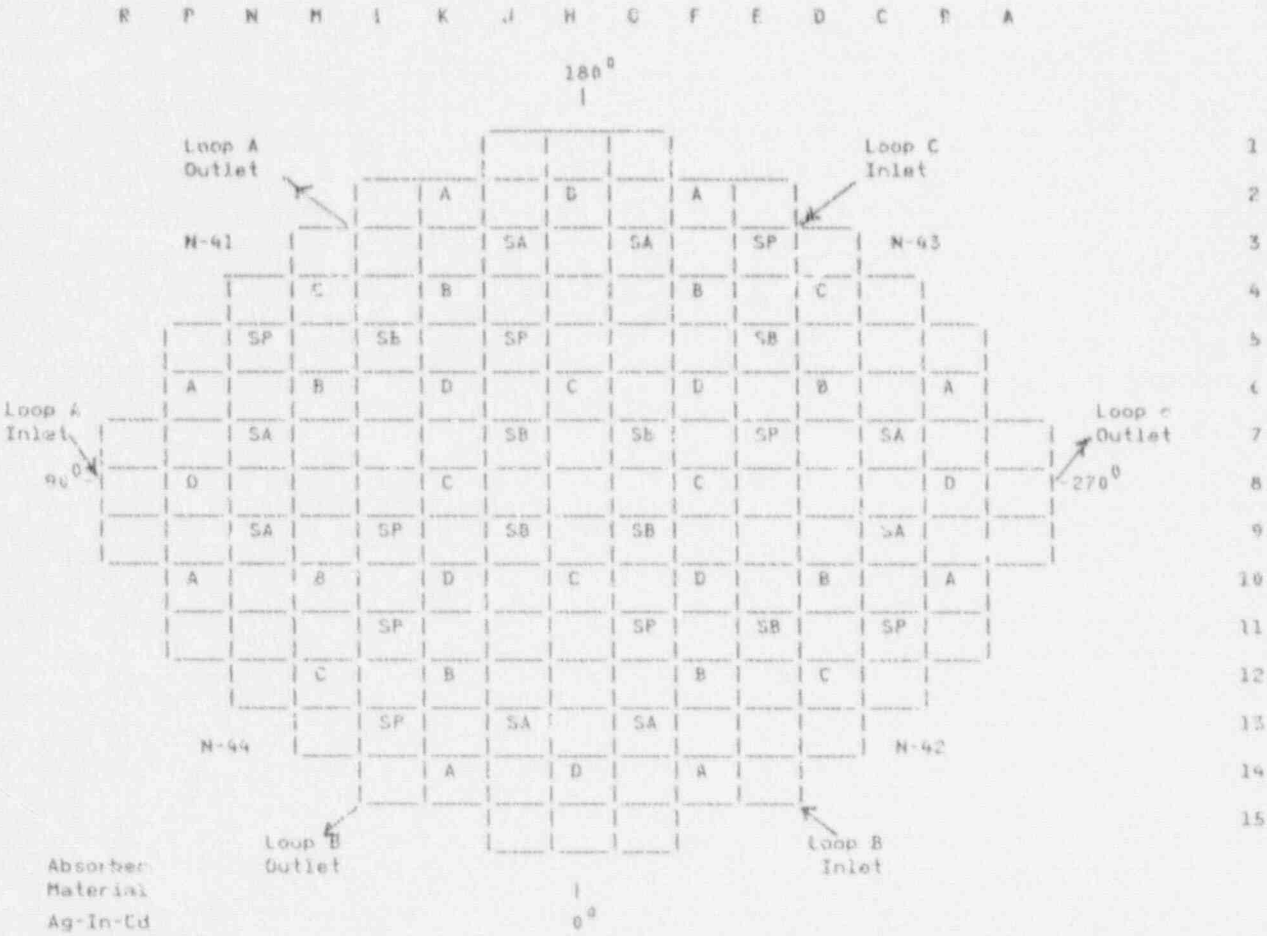
4P - 4 BURNABLE POISON ROD CLUSTER
7P - 7 BURNABLE POISON ROD CLUSTER
12P - 12 BURNABLE POISON ROD CLUSTER
16P - 16 BURNABLE POISON ROD CLUSTER
20P - 20 BURNABLE POISON ROD CLUSTER
SSxx - SECONDARY SOURCE

Figure 1.3
NORTH ANNA UNIT 2 - CYCLE 8
MOVABLE DETECTOR LOCATIONS

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

MD - Movable Detector

Figure 1.4
NORTH ANNA UNIT 2 - CYCLE 8
CONTROL ROD LOCATIONS



Absorber Material
Ag-In-Cd

CALLED NORTH

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

Section 2

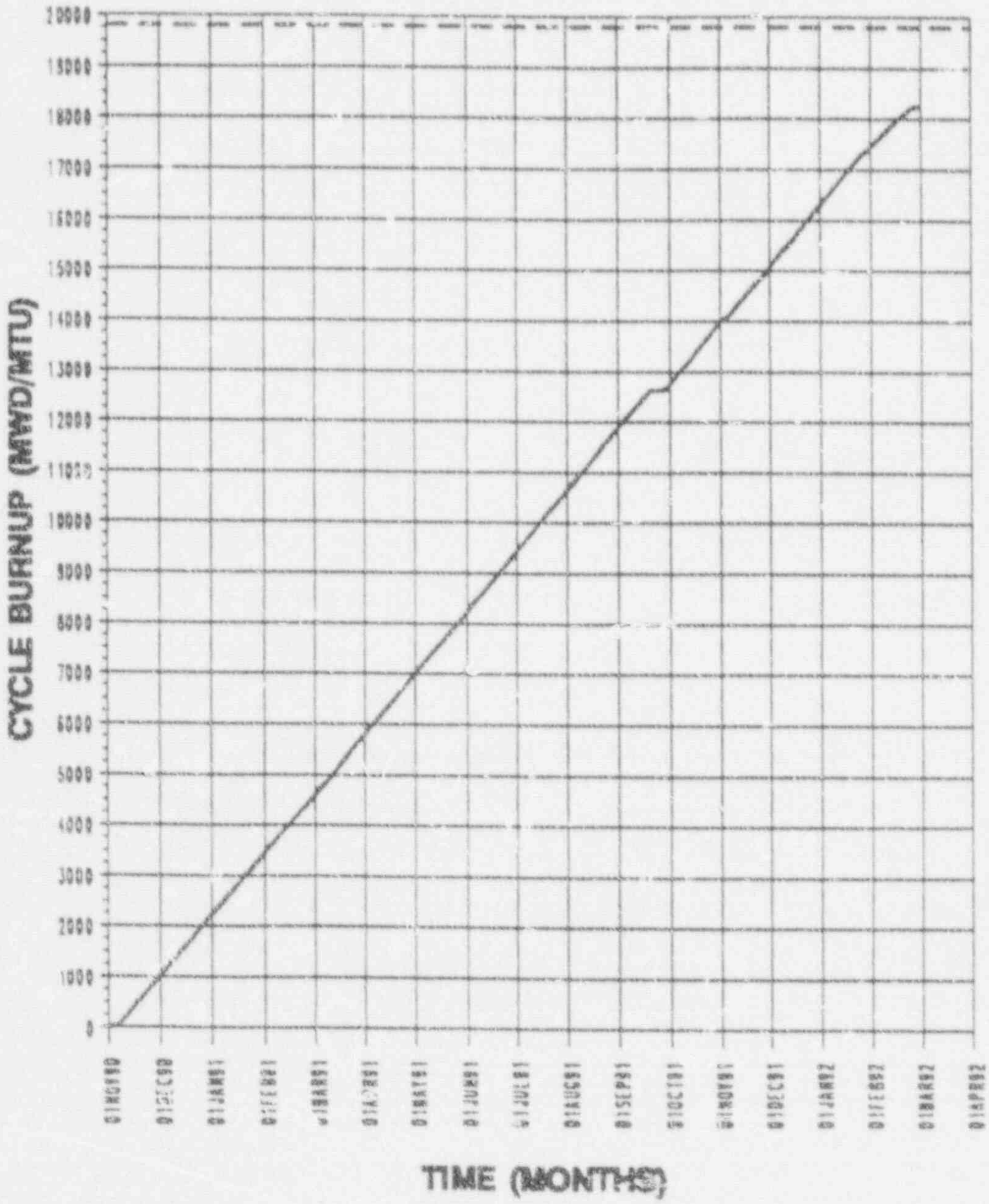
BURNUP

The burnup history for the North Anna Unit 2, Cycle 8 core is graphically depicted in Figure 2.1. The North Anna 2, Cycle 8 core achieved a burnup of 18,239 MWD/MTU. As shown in Figure 2.2, the average load factor for Cycle 8 was 95.2% when referenced to rated thermal power (2893 MW(t)). Unit 2 performed a power coastdown starting on January 14, 1992 until shutdown for refueling on February 26, 1992.

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 8 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 8 operation is also given. As can be seen from this figure, the accumulated assembly burnups were generally within ±2.98% of the predicted values. In addition, deviation from quadrant symmetry in the core throughout the cycle was no greater than ±0.30%.

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, 2.5D, and 2.5E the batch burnup sharing for North Anna 2, Cycle 8 followed design predictions closely with no batch deviating from prediction by more than 1.69%. Symmetric burnup in conjunction with agreement between actual and predicted assemblywise burnups and batch burnup sharing indicate that the Cycle 8 core did deplete as designed.

Figure 2.1
NORTH ANNA UNIT 2 - CYCLE 8
CORE BURNUP HISTORY



----- MAXIMUM DESIGN BURNUP - 19800 MWD/MTU

Figure 2.2
NORTH ANNA UNIT 2 - CYCLE 8
MONTHLY AVERAGE LOAD FACTORS

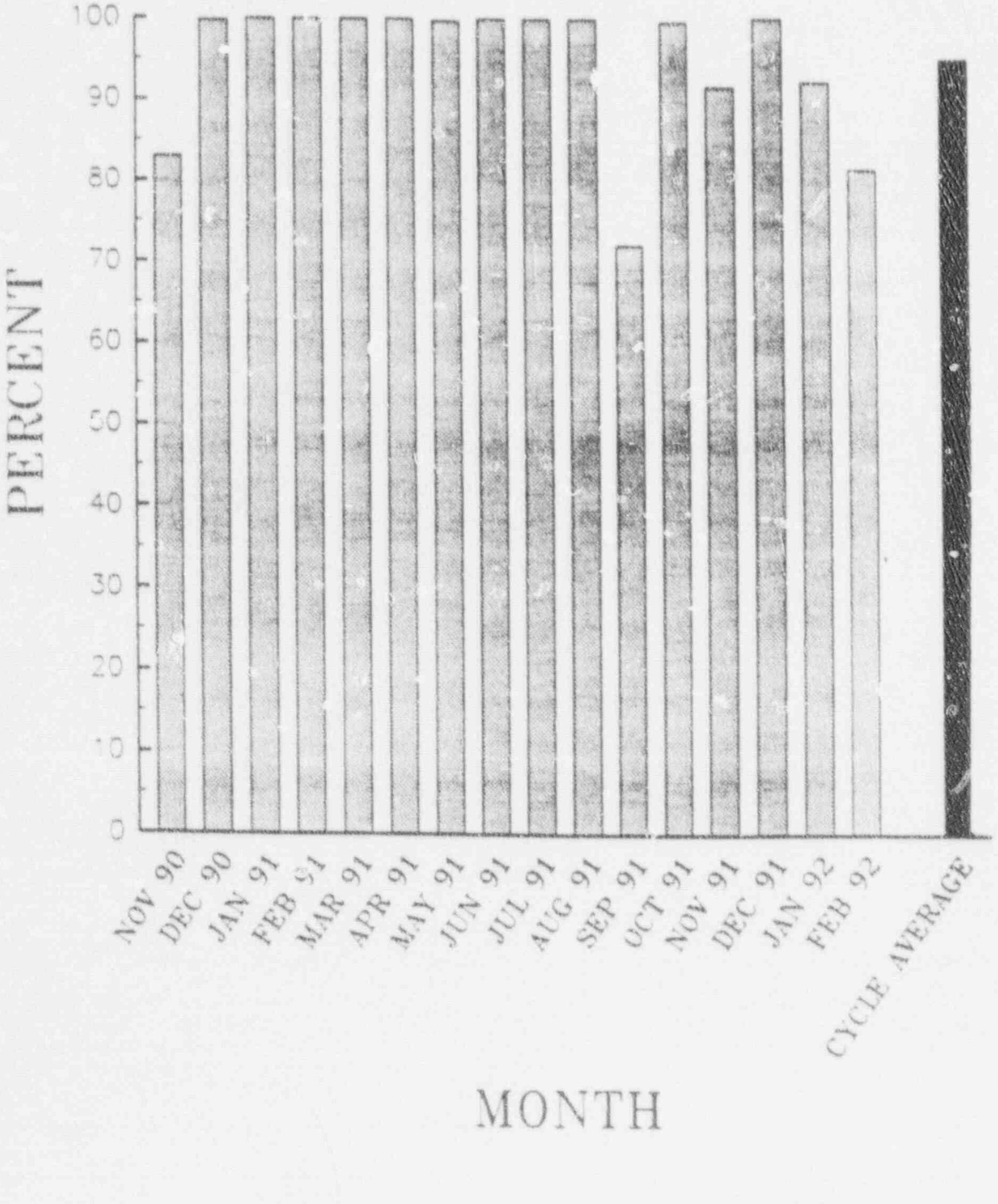


Figure 2.3
NORTH ANNA UNIT 2 - CYCLE 8
ASSEMBLYWISE ACCUMULATED BURNUP
MEASURED AND PREDICTED
(GWD/MTU)

	R	P	N	M	L	K	J	H	G	F	E	D	C	B	A	
1							39.13	41.84	39.30							1
							39.01	41.80	39.01							
2					41.25	35.65	19.16	35.61	19.25	35.99	41.39					2
					41.33	35.67	19.14	35.62	19.14	35.67	41.33					
3				44.98	19.74	22.22	39.39	23.87	39.69	22.99	20.20	45.90				3
				44.60	19.69	22.61	39.68	23.96	39.68	22.61	19.69	44.60				
4			45.26	34.37	23.73	44.55	24.62	44.10	24.61	44.62	23.95	35.06	44.40			4
			44.61	34.61	23.74	44.93	24.71	44.44	24.[illegible]1	44.93	23.74	34.61	44.61			
5		40.89	19.32	23.18	44.07	24.38	43.26	43.19	43.61	24.85	44.50	23.44	19.72	41.44		5
		41.34	19.70	23.75	44.56	24.65	43.18	43.15	43.18	24.65	44.56	23.75	[illegible]9.70	41.34		
6		35.20	22.36	44.57	24.39	43.95	25.24	42.01	25.12	44.52	24.30	44.1[illegible]	[illegible].29	35.62		6
		35.67	22.61	44.92	24.65	44.62	24.83	41.87	24.83	44.62	24.65	4[illegible]2	22.61	35.67		
7	39.10	19.13	39.27	24.13	42.61	24.17	44.47	25.28	44.66	25.10	42.84	23.59	38.86	18.8[illegible]	38.67	7
	39.04	19.15	39.69	24.68	43.10	24.70	44.66	24.71	44.66	24.70	43.10	24.68	39.69	19.15	39.04	
8	42.13	36.6[illegible]	23.59	43.85	42.63	42.57	24.28	53.03	24.64	42.78	42.76	43.38	23.40	35.79	41.98	8
	41.80	35.63	23.97	44.42	42.97	42.88	24.65	53.20	24.65	42.88	42.97	44.42	23.97	35.63	41.80	
9	39.09	18.90	38.50	24.23	42.21	24.45	44.43	24.13	45.11	24.64	43.42	24.36	39.69	19.20	38.75	9
	39.04	19.15	39.69	24.68	43.10	24.70	44.66	24.71	44.66	24.70	43.10	24.68	39.69	19.15	39.04	
10		35.24	21.92	44.60	24.75	44.33	24.54	42.20	24.42	44.17	24.53	44.69	22.98	35.75		10
		35.67	22.61	44.92	24.65	44.62	24.83	41.87	24.83	44.62	24.65	44.92	22.61	35.67		
11		41.28	19.76	23.90	44.66	24.28	43.04	42.50	42.32	24.62	44.38	24.19	20.14	41.57		11
		41.34	1[illegible].70	23.75	44.56	24.65	43.18	43.15	43.18	24.65	44.56	23.75	19.70	41.34		
12			45.10	35.10	23.93	44.18	23.91	43.48	24.06	44.38	23.71	35.53	45.76			12
			44.59	34.61	23.74	44.93	24.71	44.44	24.71	44.93	23.74	34.61	44.61			
13				45.95	19.86	21.63	38.75	23.15	38.58	22.18	19.58	44.57				13
				44.60	19.69	22.61	39.68	23.96	39.68	22.61	19.69	44.68				
14					42.34	35.93	19.16	35.38	18.58	35.17	41.09					14
					41.33	35.67	19.14	35.62	19.14	35.67	41.33					
15							38.77	41.82	38.52							15
							39.01	41.80	39.01							
	R	P	N	M	L	K	J	H	G	F	E	D	C	B	A	

MEASURED
PREDICTED

Figure 2.4

NORTH ANNA UNIT 2 - CYCLE 8

ASSEMBLYWISE ACCUMULATED BURNUP

COMPARISON OF MEASURED AND PREDICTED

(GWD/MTU)

		R	P	N	M	L	K	J	H	G	F	E	D	C	B	A	
1	MEASURED							39.13	41.84	39.30							1
	M/P % DIFF							0.31	0.09	0.75							
2	MEASURED					41.25	35.65	19.16	35.61	19.25	35.99	41.39					2
	M/P % DIFF					-0.26	-0.05	0.07	-0.02	0.55	0.89	0.13					
3	MEASURED				44.98	19.74	22.22	39.39	23.87	39.69	22.99	20.20	45.90				3
	M/P % DIFF				0.84	0.24	-1.74	-0.73	-4.37	0.02	1.67	2.59	2.92				
4	MEASURED			45.26	34.37	23.73	44.55	24.62	44.10	24.61	44.62	23.95	35.06	44.40			4
	M/P % DIFF			1.45	-0.69	-0.02	-0.04	-0.36	-0.77	-0.40	-0.67	0.88	1.32	-0.47			
5	MEASURED		40.89	19.32	23.18	44.07	24.38	43.26	43.19	43.61	24.85	44.50	23.46	19.72	41.44		5
	M/P % DIFF		-1.07	-1.93	-2.39	-1.10	-1.12	0.18	0.07	0.99	0.79	[illegible]	-1.24	-0.10	0.24		
6	MEASURED		35.20	22.56	44.57	24.39	43.95	25.24	42.01	[illegible]	[illegible]	[illegible]	44.14	22.29	35.62		6
	M/P % DIFF		-1.33	-1.11	-0.80	-1.04	-1.50	1.64	0.34	1.19	-0.21	-1.43	-1.74	-1.42	-0.14		
7	MEASURED	39.10	19.13	39.27	24.13	42.61	24.17	44.47	25.28	44.66	25.10	42.84	23.59	38.86	18.86	38.67	7
	M/P % DIFF	0.17	-0.09	-1.04	-2.21	-1.12	-2.17	-0.43	2.31	0.01	1.61	-0.58	-4.43	-2.08	-1.52	-0.95	
8	MEASURED	42.13	36.62	23.59	43.85	42.63	42.57	24.28	53.03	24.64	42.78	42.76	[illegible]	23.40	35.79	41.98	8
	M/P % DIFF	0.78	2.79	-1.58	-1.28	-0.60	-0.71	-1.47	-0.32	-0.04	-0.22	-0.48	-2.34	-2.38	0.45	0.47	
9	MEASURED	39.09	18.90	38.50	24.23	42.21	24.45	44.43	24.13	45.11	24.64	43.42	24.36	39.69	19.20	38.75	9
	M/P % DIFF	0.14	-1.31	-2.98	-1.83	-2.06	-1.01	-6.50	-2.35	1.01	-0.25	0.75	-1.30	0.01	0.26	-0.74	
10	MEASURED		35.24	21.92	44.60	24.75	44.33	24.54	42.20	24.42	44.17	24.53	44.69	22.98	35.75		10
	M/P % DIFF		-1.21	-3.05	-0.72	0.42	-0.65	-1.17	0.80	-1.65	-0.99	-0.46	-0.52	1.62	0.24		
11	MEASURED		41.28	19.76	23.90	44.66	24.28	43.04	42.50	42.32	24.62	44.38	24.19	[illegible]	[illegible]		11
	M/P % DIFF		-0.13	0.30	0.41	0.23	-1.51	-0.34	-1.51	-2.00	-0.12	-0.39	1.84	2.24	0.57		
12	MEASURED			45.10	35.10	23.93	44.18	23.91	43.48	24.06	44.38	23.71	35.53	45.76			12
	M/P % DIFF			1.15	1.41	0.80	-1.66	-3.22	-2.17	-2.64	-1.22	-0.11	2.67	2.57			
13	MEASURED				45.95	19.80	21.63	38.75	23.15	38.58	22.18	19.58	44.57				13
	M/P % DIFF				3.01	0.59	-4.35	-2.35	-3.36	-2.27	-1.92	-0.55	-0.07				
14	MEASURED					42.34	35.93	19.16	35.36	18.58	35.17	41.09					14
	M/P % DIFF					2.45	0.73	0.08	-0.67	-2.93	-1.40	-0.59					
15	MEASURED							38.77	41.82	38.52							15
	M/P % DIFF							-0.61	0.04	1.25							

MEASURED
M/P % DIFF

ARITHMETIC AVG PCT DIFF = -0.41

STANDARD DEV = 0.93

AVG ABS PCT DIFF = 1.12

BATCH SHARING

(MWD/MTU)

BATCH	NO. OF ASSEMBLIES	BOC BATCH BURNUP	EOC BATCH BURNUP	CYCLE BURNUP
N1/5	2	22,603	42,104	19,501
N1/6	1	37,921	45,097	7,176
N1/7	1	34,556	53,027	18,471
N1/10A	12	23,945	38,513	14,568
N1/10B	1	23,443	45,108	21,665
4	2	23,869	42,678	18,809
5A	8	33,607	38,916	5,309
7A	7	38,225	45,258	7,033
8A	8	34,997	41,407	6,410
8B	4	35,465	41,945	6,480
9A	16	23,632	44,219	20,587
9B	31	20,543	40,134	19,591
10A	28	0	23,953	23,953
10B	36	0	21,890	21,890
CYCLE AVERAGE ACCUMULATED BURNUP = 18,239				

BURNUP TILT

NW = -0.10	NE = 0.30
SW = -0.15	SE = -0.04

Figure 2.5A
NORTH ANNA UNIT 2 - CYCLE 8
SUB-BATCH BURNUP SHARING

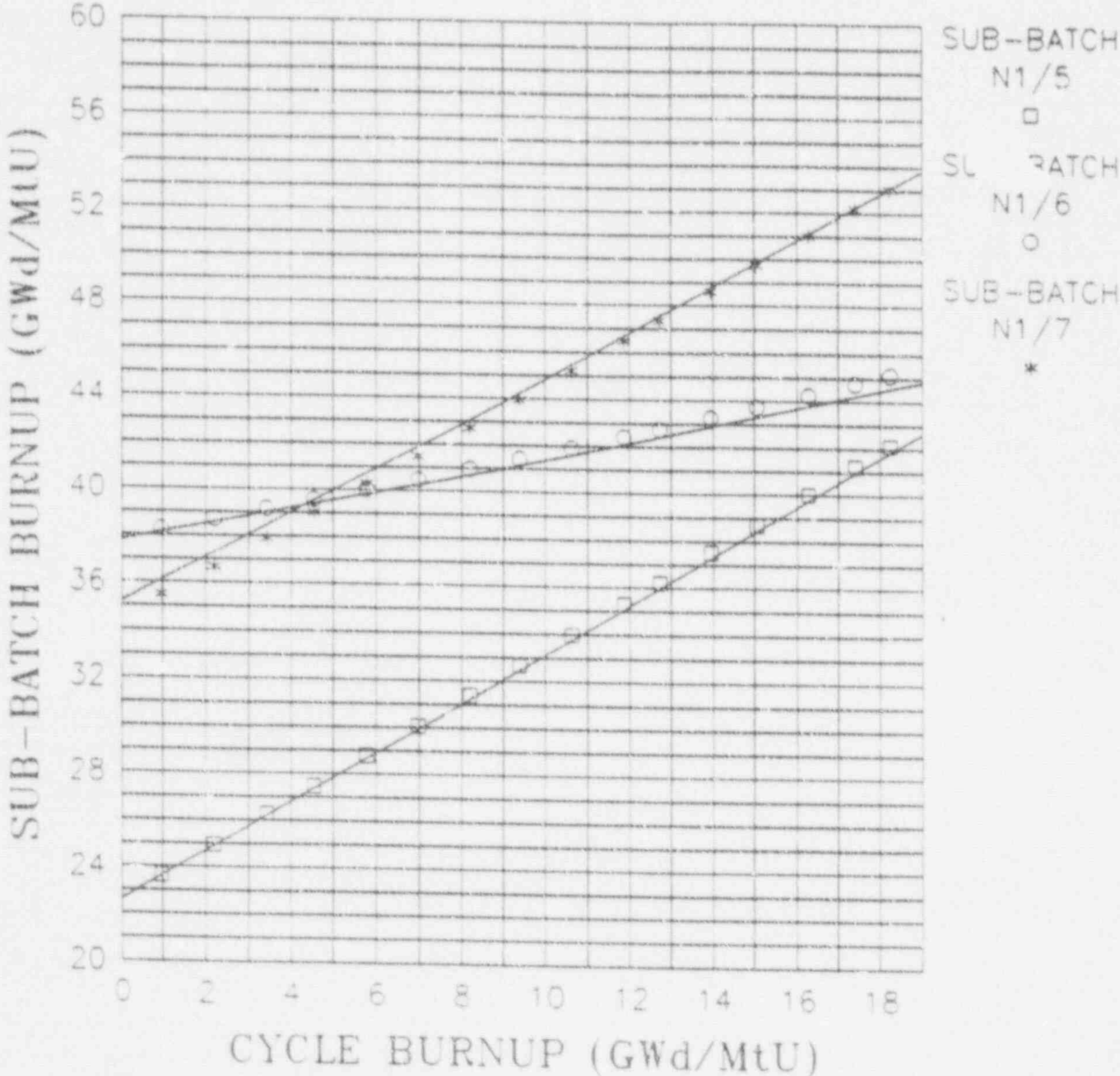


Figure 2.5B
NORTH ANNA UNIT 2 - CYCLE 8
SUB-BATCH BURNUP SHARING

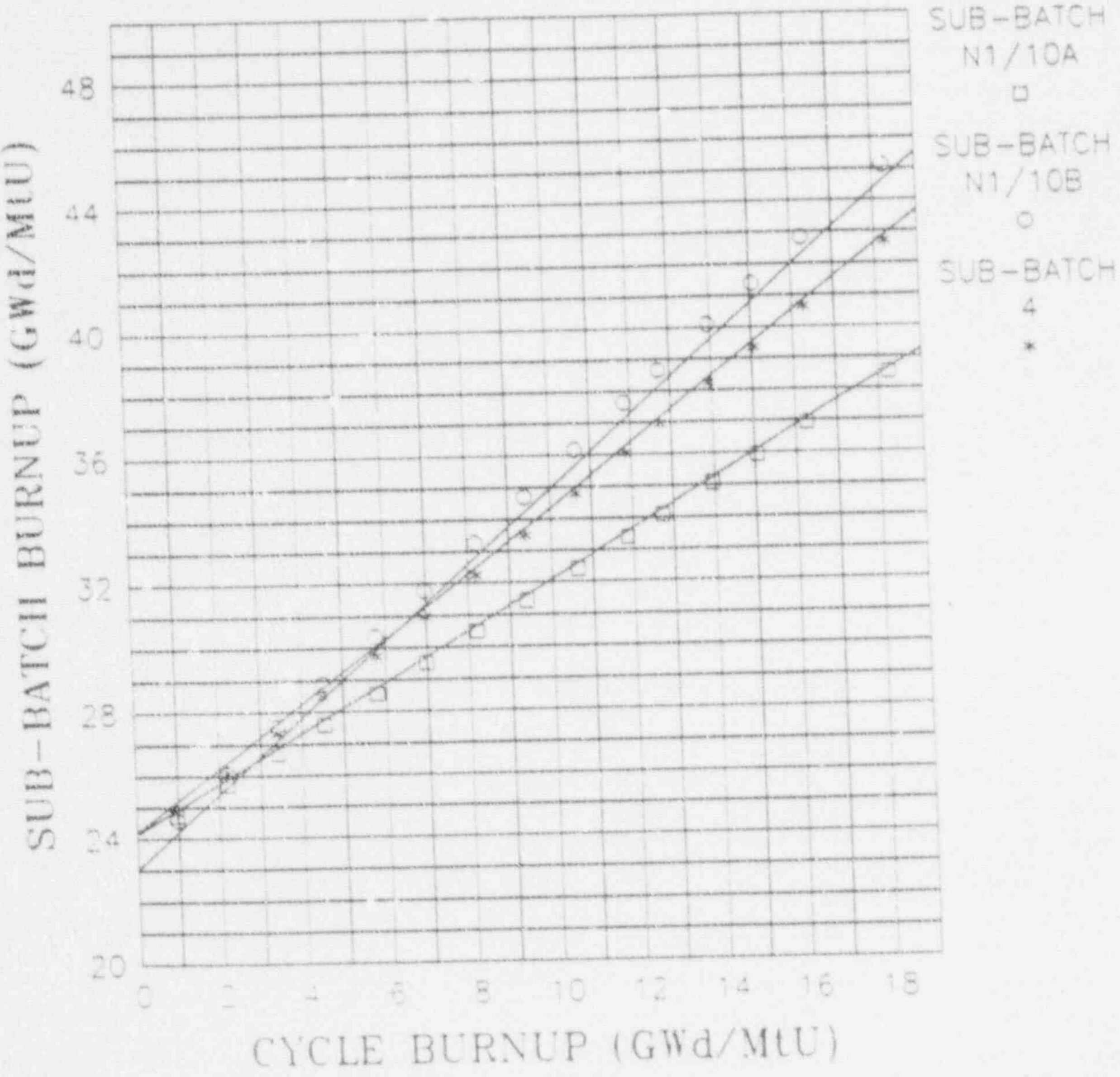


Figure 2.5C
NORTH ANNA UNIT 2 - CYCLE 8
SUB-BATCH BURNUP SHARING

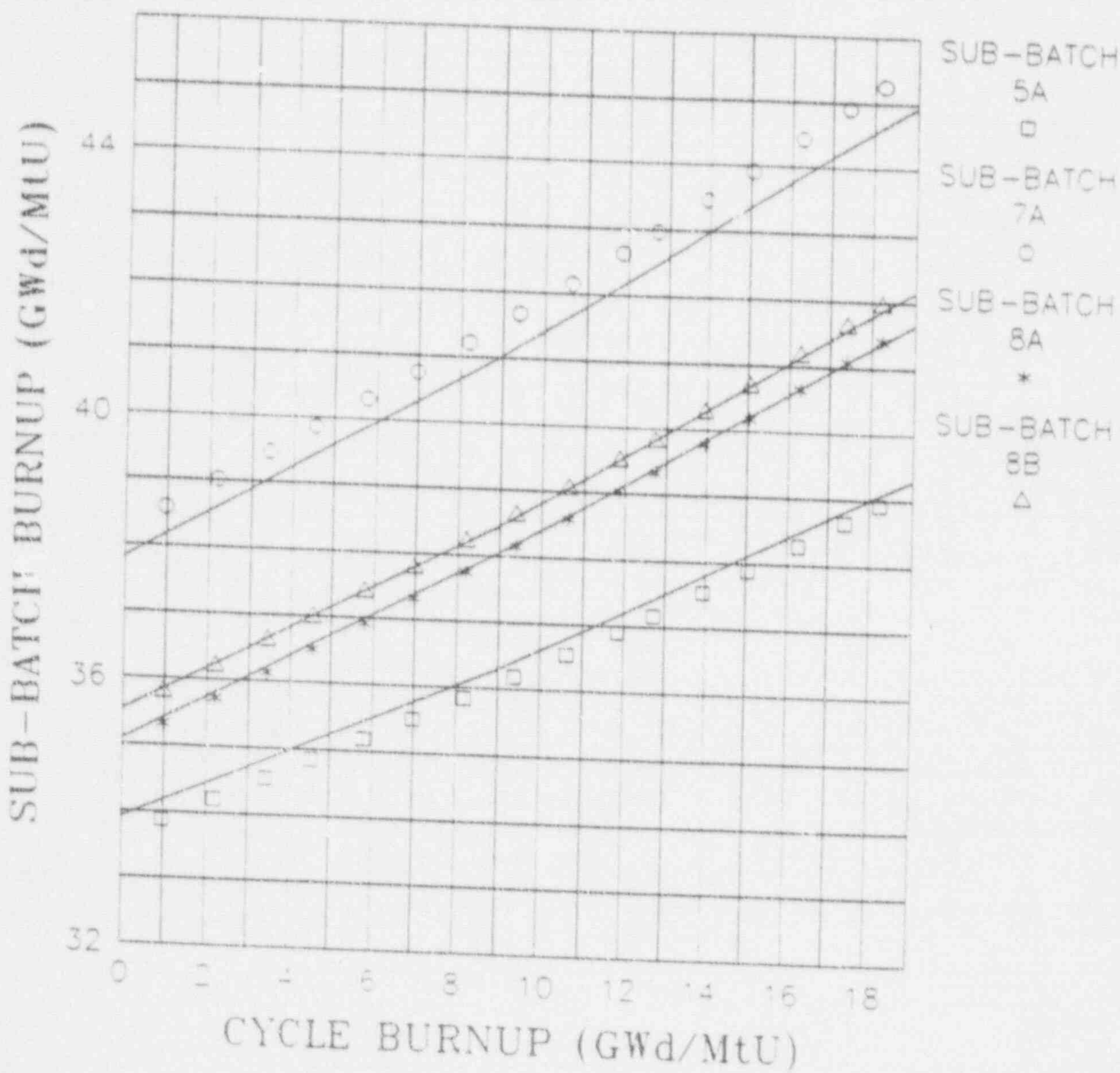


Figure 2.5D
NORTH ANNA UNIT 2 - CYCLE 8
SUB-BATCH BURNUP SHARING

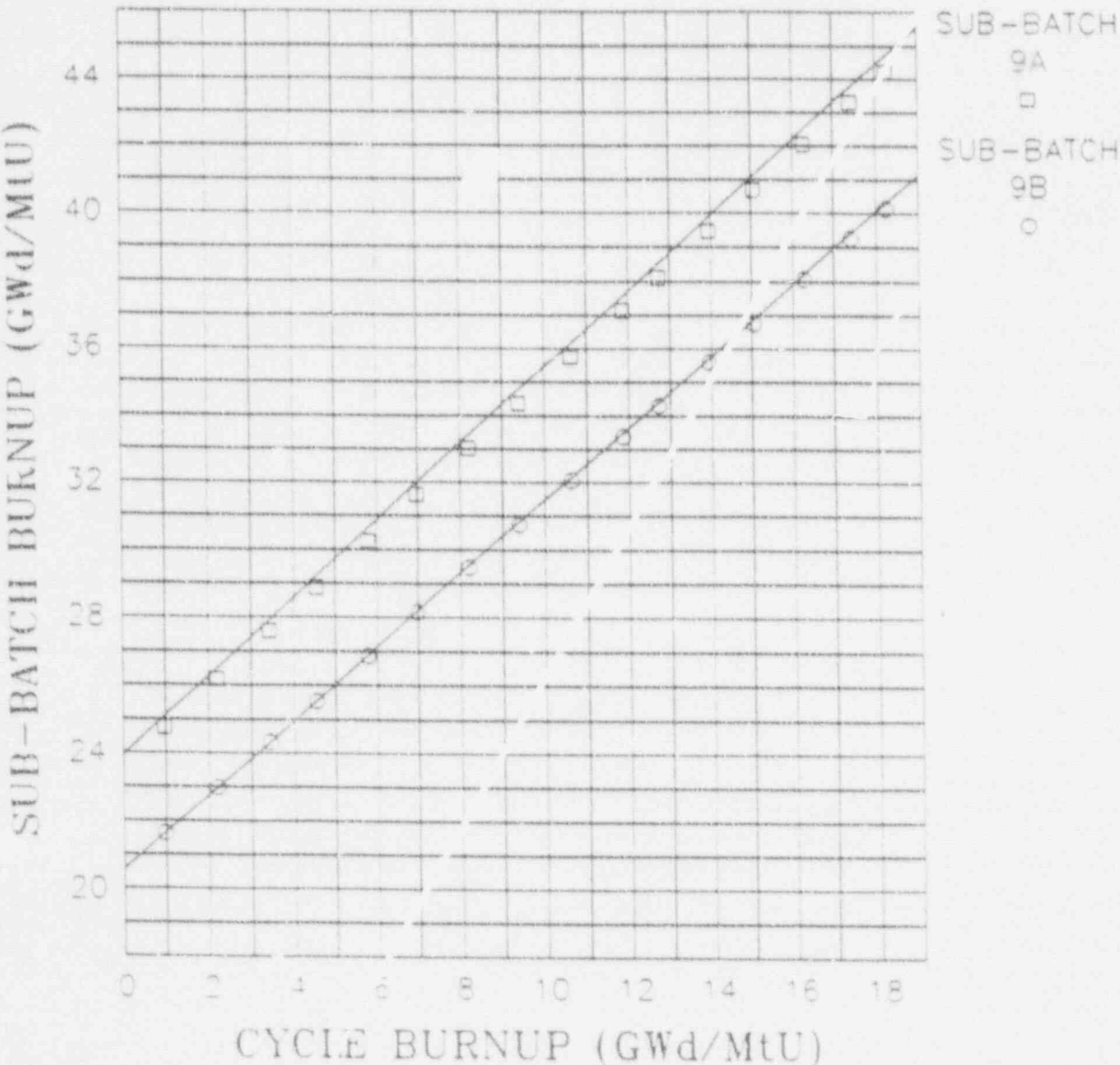
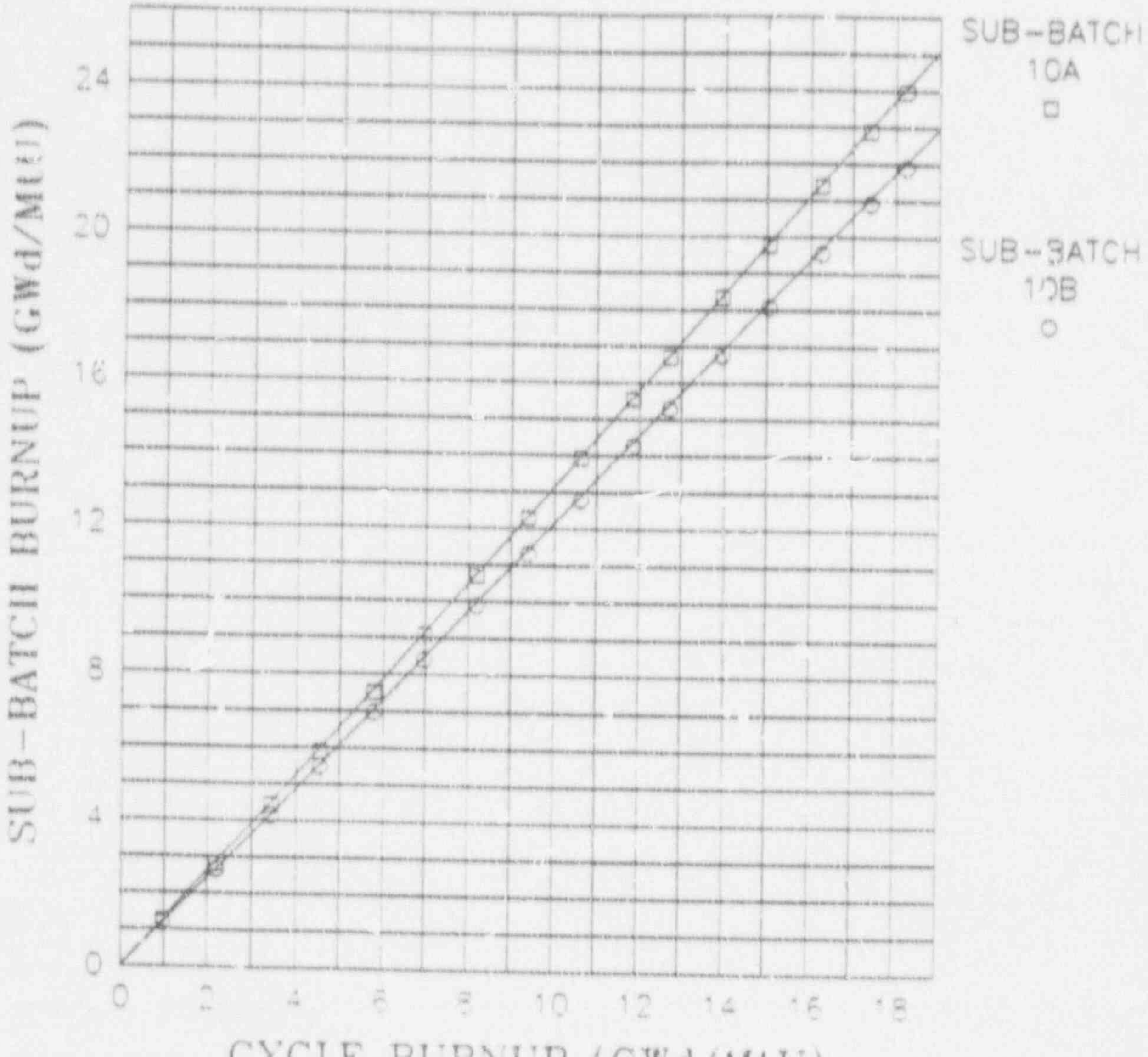


Figure 2.5E
NORTH ANNA UNIT 2 - CYCLE 8
SUB-BATCH BURNUP SHARING

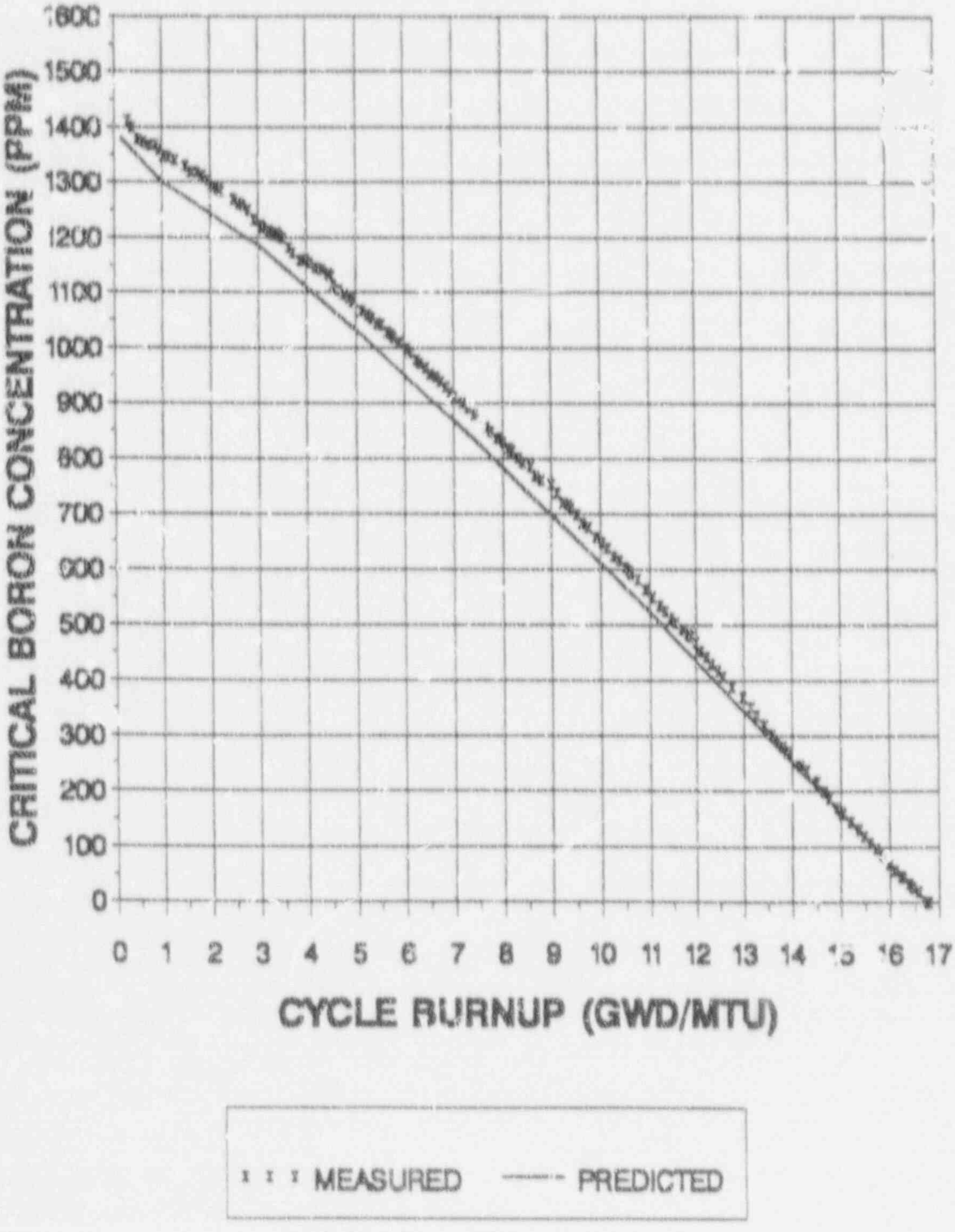


Section 3

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 FOLLOW* 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 8 core is shown in Figure 3.1. It can be seen that the measured data typically compared to within 58 ppm of the design prediction. This corresponds to ±0.39% 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 8 core depleted as expected without any reactivity anomalies.

Figure 3.1
NORTH ANNA UNIT 2 - CYCLE 8
CRITICAL BORON CONCENTRATION vs. BURNUP
(HFP,ARO)



Section 4

POWER DISTRIBUTION

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 2, Cycle 8 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 distribution for a representative series of incore flux maps are given in Figures 4.1, 4.2, and 4.3. Figure 4.1 show 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 8. The measured relative assembly powers were generally within 7.0% and the maximum average percent difference was equal to 2.5%. In addition, as indicated by the INCORE 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)[8] Figure 4.4 is a plot of the K(Z) curve 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 8, 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 8 is given in Figure 4.8. This figure indicates that the minimum margin to the F_Q limit in the axial region covered by the Technical Specification 4.2.2.2 is 11.4%. (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.)

Figure 4.9 shows the maximum values for the heat flux hot channel factor measured during Cycle 8. As can be seen from the figure, there was an approximate 16.00% margin from the maximum $F_Q(Z)$ to the 2.19 limit at the beginning of the cycle, which was the minimum margin seen for the cycle.

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 8, 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 8 is given in Figure 4.10. As can be seen from this figure, the minimum margin to the limit was approximately 2.2%.

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 -1.4% 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 8. Delta flux values decreased steadily to -5.3% near a cycle burnup of 14,300 MWD/MTU, where it then gradually increased to -3.6% before the coastdown. At the end of Cycle 8, the target delta flux increased to +4.2% 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 N2-8-07 (Figure 4.12), taken at 1505 MWD/MTU, the axial power distribution had a shape peaked toward the middle of the core with a peaking factor of 1.208. In Map N2-8-14 (Figure 4.13), taken at approximately 9129 MWD/MTU, the axial power distribution peaked slightly toward the bottom of the core with an axial peaking factor of 1.157. Finally, in Map N2-8-25 (Figure 4.14), taken at 16,640 MWD/MTU, the axial peaking factor was 1.157, with the axial power distribution shifted slightly back toward the top. 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 8 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 8
SUMMARY OF FLUX MAPS FOR ROUTINE OPERATION

MAP NO. (3)	DATE	BURN UP MWD/MTU	PWR (%)	BANK D STEPS	F-Q(T) HOT CHANNEL FACTOR ASSY	PIN	AXIAL POINT	F-Q(T)	F-DH(N) HOT CHNL. FACTOR ASSY	PIN	F-DH(N)	CORE F(Z) MAX AXIAL POINT	F(Z)	F(XY) MAX	CORE TILT (2) MAX	LOC	AXIAL OFF SET (%)	NO. OF THIMBLES
7	12-14-90	1505	100	228	D11	IP	57	1.874	D11	IP	1.419	56	1.208	1.428	1.004	NE	-2.088	46
8	01-09-91	2534	100	228	D11	IP	37	1.861	H07	IJ	1.433	56	1.191	1.441	1.006	NE	-2.316	46
9	02-12-91	3894	100	228	D11	IP	37	1.839	H07	IJ	1.445	57	1.171	1.448	1.008	NE	-2.449	46
10	03-02-91	4592	100	228	D11	IP	58	1.877	H07	IJ	1.447	58	1.166	1.447	1.007	NE	-3.047	46
11	04-03-91	5680	100	228	D11	FM	39	1.806	H07	IJ	1.456	45	1.156	1.451	1.008	NE	-3.438	46
12	04-25-91	6673	100	228	F05	IH	47	1.820	H07	IJ	1.459	46	1.157	1.454	1.007	NE	-4.087	46
13	05-23-91	7854	100	228	F05	IH	47	1.833	H07	IJ	1.457	47	1.160	1.455	1.007	NE	-4.671	46
14	06-26-91	9129	100	228	F05	IH	48	1.831	H07	IJ	1.458	48	1.157	1.459	1.007	NE	-4.532	46
15	07-17-91	10046	100	228	F05	IH	48	1.834	H07	IJ	1.453	48	1.156	1.456	1.007	NE	-4.536	46
16	08-13-91	11118	100	228	H07	IJ	53	1.833	H07	IJ	1.451	48	1.155	1.458	1.007	NE	-4.747	46
17	09-13-91	12350	100	228	H07	IJ	54	1.835	H07	IJ	1.437	53	1.158	1.451	1.006	NE	-4.542	46
18	09-28-91	12640	47	151	L06	JI	29	1.870	J04	HI	1.463	30	1.177	1.467	1.015	NW	-5.770	40
19	10-01-91	12733	100	228	H07	IJ	53	1.855	F07	FM	1.439	52	1.171	1.448	1.006	NE	-5.209	45
20	10-15-91	13286	100	228	H07	IJ	54	1.855	H07	IJ	1.433	53	1.172	1.445	1.006	NE	-5.086	45
23	11-12-91	14307	100	228	H07	IJ	53	1.865	H07	IJ	1.428	53	1.179	1.436	1.006	NE	-5.282	45
24	12-12-91	15492	100	228	H07	IJ	54	1.848	F07	FM	1.422	53	1.171	1.431	1.006	NE	-4.619	45
25	01-10-92	16640	100	228	H07	IJ	54	1.837	F07	FM	1.426	53	1.157	1.439	[illegible]	SE	-3.573	45
26	02-10-92	17739	84	228	H07	IJ	12	1.805	J06	EF	1.403	17	1.164	1.413	1.002	NW	-4.223	45

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.

3. MAPS 21 and 22 WERE QUARTER-CORE FLUX MAPS TAKEN FOR INCORE/EXCORE CALIBRATION.(I/E CALIBRATION)

Figure 4.1
NORTH ANNA UNIT 2 - CYCLE 8
ASSEMBLYWISE POWER DISTRIBUTION N2-8-07

		R	P	N	M	L	K	J	H	G	F	E	D	C	B	A
1	Predicted							0.26	0.32	0.26						
	Measured							0.28	0.34	0.28						
	Pct difference							5.3	5.3	4.2						
2	Predicted					0.33	0.62	1.09	0.95	1.09	0.62	0.33				
	Measured					0.34	0.64	1.11	0.96	1.11	0.64	0.34				
	Pct difference					4.5	2.6	1.8	1.8	2.1	3.2	3.3				
3	Predicted				0.35	1.10	1.25	1.20	1.30	1.20	1.25	1.10	0.35			
	Measured				0.35	1.10	1.25	1.21	1.31	1.21	1.28	1.12	0.36			
	Pct difference				1.0	0.5	-0.4	1.1	0.9	1.2	2.2	2.6	3.4			
4	Predicted			0.35	0.84	1.29	1.16	1.32	1.14	1.32	1.16	1.29	0.84	0.35		
	Measured			0.36	0.84	1.30	1.16	1.34	1.15	1.33	1.17	1.30	0.84	0.35		
	Pct difference			1.0	0.0	0.5	0.6	1.4	1.4	0.7	1.1	0.4	0.1	0.8		
5	Predicted		0.33	1.10	1.29	1.15	1.29	1.19	1.12	1.19	1.29	1.15	1.29	1.10	0.33	
	Measured		0.32	1.07	1.27	1.14	1.29	1.23	1.15	1.22	1.31	1.15	1.27	1.09	0.34	
	Pct difference		-2.3	-2.3	-1.5	-1.2	-0.3	2.8	2.9	2.2	1.1	-0.1	-1.7	-0.6	2.8	
6	Predicted		0.62	1.25	1.16	1.29	1.18	1.32	1.04	1.32	1.18	1.29	1.16	1.25	0.62	
	Measured		0.62	1.24	1.15	1.29	1.18	1.36	1.07	1.35	1.19	1.28	1.13	1.23	0.63	
	Pct difference		-0.9	-0.9	-0.6	-0.4	0.5	2.9	2.9	2.3	1.1	-1.3	-2.2	-1.5	0.7	
7	Predicted	0.26	1.09	1.20	1.32	1.19	1.31	1.19	1.30	1.19	1.31	1.19	1.32	1.20	1.09	0.26
	Measured	0.27	1.09	1.18	1.30	1.17	1.29	1.23	1.35	1.21	1.33	1.18	1.27	1.17	1.07	0.26
	Pct difference	3.1	0.0	-1.3	-1.3	-1.1	-1.1	3.4	3.4	2.2	1.6	-0.2	-3.5	-2.1	-1.6	-0.7
8	Predicted	0.32	0.93	1.30	1.13	1.10	1.00	1.30	0.95	1.30	1.00	1.10	1.13	1.30	0.93	0.32
	Measured	0.33	0.93	1.28	1.13	1.10	1.00	1.29	0.97	1.30	1.01	1.09	1.09	1.27	0.92	0.33
	Pct difference	3.1	0.0	-1.6	-0.8	0.0	0.0	-0.5	2.0	0.1	0.2	-1.1	-3.5	-2.1	-0.5	0.6
9	Predicted	0.26	1.09	1.20	1.32	1.19	1.31	1.19	1.30	1.19	1.31	1.19	1.32	1.20	1.09	0.26
	Measured	0.27	1.07	1.16	1.29	1.19	1.30	1.17	1.29	1.19	1.31	1.19	1.30	1.19	1.09	0.27
	Pct difference	3.1	-1.3	-3.4	-1.7	0.1	-0.3	-1.1	-1.1	0.0	-0.1	0.2	-1.4	-0.5	0.4	1.8
10	Predicted		0.62	1.25	1.16	1.29	1.18	1.3[illegible]	1.04	1.32	1.18	1.29	1.16	1.25	0.62	
	Measured		0.60	1.21	1.15	1.30	1.18	1.32	1.04	1.31	1.17	1.29	1.17	1.27	0.64	
	Pct difference		-3.3	-3.3	-0.7	0.7	0.1	-0.3	-0.2	-1.0	-0.8	-0.4	1.0	1.1	2.4	
11	Predicted		0.33	1.10	1.29	1.15	1.29	1.19	1.12	1.19	1.29	1.15	1.29	1.10	0.33	
	Measured		0.32	1.09	1.29	1.16	1.28	1.18	1.11	1.19	1.29	1.15	1.31	1.12	0.34	
	Pct difference		-0.5	-0.5	0.0	1.0	-0.8	-0.8	-0.7	-0.5	-0.3	0.2	1.5	1.7	2.8	
12	Predicted			[illegible]	0.84	1.29	1.16	1.32	1.14	1.32	1.16	1.29	0.84	[illegible]		
	Measured			[illegible]	0.85	1.30	1.15	1.30	1.12	1.30	1.15	1.29	0.86	0.36		
	Pct difference			[illegible]	1.7	1.0	-0.7	-1.4	-1.6	-1.6	-0.7	-0.4	1.8	2.3		
13	Predicted				0.35	1.10	1.25	1.20	1.30	1.20	1.25	1.10	0.35			
	Measured				0.36	1.11	1.23	1.17	1.28	1.18	1.24	1.09	0.36			
	Pct difference				2.4	1.0	-2.2	-2.4	-1.8	-1.6	-1.2	-0.7	2.1			
14	Predicted					0.33	0.62	1.09	0.93	1.09	0.62	0.33				
	Measured					0.34	0.65	1.10	0.93	1.07	0.62	0.32				
	Pct difference					4.5	4.5	1.0	0.4	-1.5	-1.1	-1.8				
15	Predicted							0.26	0.32	0.26						
	Measured							0.28	0.33	0.26						
	Pct difference							6.5	2.1	-0.4						

PREDICTED
MEASURED
PCT DIFFERENCE

PREDICTED
MEASURED
PCT DIFFERENCE

STANDARD DEVIATION =1.178

AVERAGE PCT DIFFERENCE = 1.5

SUMMARY

MAP NO: N2-8-07 DATE: 12/14/90 POWER: 100%

CONTROL ROD POSITION: F-Q(T) = 1.874 QPTR:

D BANK AT 228 STEPS F-DH(N) = 1.419

NW 1.0035	NE 1.0043
SW 0.9952	SE 0.9970

F(Z) = 1.208

F(XY) = 1.428

BURNUP = 1505 MWD/MTU A.O. = -2.008%

Figure 4.2
NORTH ANNA UNIT 2 - CYCLE 8
ASSEMBLYWISE POWER DISTRIBUTION N2-8-14

PREDICTED / MEASURED / PCT DIFFERENCE

	R	P	N	M	L	K	J	H	G	F	E	D	C	B	A	
							0.28	0.34	0.28							
							0.29	0.35	0.28							1
							3.5	3.5	3.5							
					0.34	0.61	1.02	0.89	1.02	0.61	0.34					
					0.36	0.62	1.05	0.89	1.03	0.63	0.35					2
					4.5	0.9	0.3	0.2	1.0	3.1	3.7					
				0.37	1.07	1.23	1.13	1.31	1.13	1.23	1.07	0.37				
				0.37	1.07	1.21	1.13	1.30	1.14	1.26	1.10	0.39				3
				0.8	0.4	-1.5	-0.5	-0.7	0.4	2.2	3.0	4.4				
			0.37	0.85	1.30	1.13	1.36	1.11	1.36	1.13	1.30	0.85	0.37			
			0.38	0.85	1.31	1.12	1.36	1.11	1.36	1.14	1.32	0.86	0.38			4
			1.2	0.0	0.3	-0.7	-0.1	-0.1	-0.3	1.3	1.2	1.2	1.9			
		0.34	1.07	1.30	1.13	1.37	1.17	1.10	1.17	1.37	1.13	1.30	1.07	0.34		
		0.33	1.05	1.28	1.12	1.36	1.19	1.11	1.19	1.39	1.14	1.29	1.07	0.35		5
		-1.9	-1.9	-1.6	-1.5	-0.9	1.6	1.6	1.6	1.4	0.5	-0.6	0.6	3.5		
		0.61	1.23	1.13	1.37	1.17	1.37	1.06	1.37	1.17	1.37	1.13	1.23	0.61		
		0.61	1.22	1.12	1.36	1.17	1.40	1.08	1.40	1.19	1.36	1.11	1.22	0.63		6
		-0.6	-0.6	-0.6	-0.7	-0.0	1.8	1.9	2.0	1.5	-0.7	-1.6	-0.5	2.1		
	0.28	1.02	1.13	1.36	1.17	1.37	1.19	1.37	1.19	1.37	1.17	1.36	1.13	1.02	0.28	
	0.28	1.03	1.12	1.34	1.15	1.34	1.22	1.41	1.21	1.40	1.17	1.31	1.11	1.02	0.28	7
	3.5	0.2	-1.3	-1.5	-1.6	-1.6	2.5	2.5	2.7	2.0	0.1	-3.6	-1.6	-0.8	0.4	
	0.34	0.89	1.31	1.11	1.09	1.03	1.37	1.00	1.37	1.03	1.09	1.11	1.31	0.89	0.34	
	0.35	0.89	1.29	1.10	1.08	1.03	1.36	1.02	1.38	1.04	1.08	1.07	1.29	0.89	0.34	8
	3.5	0.2	-1.6	-1.0	-0.5	-0.4	-1.0	2.6	0.8	0.6	-0.7	-3.6	-1.7	0.4	1.8	
	0.28	1.02	1.13	1.36	1.17	1.37	1.19	1.37	1.19	1.37	1.17	1.36	1.13	1.02	0.28	
	0.28	1.01	1.10	1.34	1.16	1.36	1.17	1.35	1.20	1.37	1.18	1.35	1.13	1.03	0.28	9
	3.5	-0.9	-3.1	-1.7	-0.4	-0.8	-1.7	-1.7	0.6	0.6	1.0	-0.9	0.1	1.0	2.5	
		0.61	1.23	1.13	1.37	1.17	1.37	1.06	1.37	1.17	1.37	1.13	1.23	0.61		
		0.60	1.20	1.12	1.38	1.17	1.36	1.05	1.36	1.17	1.38	1.15	1.26	0.63		10
		-2.5	-2.5	-0.3	0.9	0.0	-1.0	-1.0	-1.2	-0.2	0.4	2.2	2.1	3.4		
		0.34	1.07	1.30	1.13	1.37	1.17	1.10	1.17	1.37	1.13	1.30	1.07	0.34		
		0.34	1.08	1.32	1.15	1.35	1.15	1.08	1.16	1.37	1.15	1.34	1.10	0.35		11
		0.[illegible]	0.8	1.0	1.6	-1.4	-2.0	-1.9	-1.1	0.2	1.1	2.7	2.7	3.5		
			0.37	0.85	1.30	1.13	1.36	1.11	1.36	1.13	1.30	0.85	0.37			
			0.39	0.87	1.32	1.11	1.32	1.08	1.33	1.12	1.30	0.87	0.38			12
			4.1	2.8	1.6	-1.6	-3.0	-2.9	-2.1	-0.5	0.2	3.0	3.3			
				0.37	1.07	1.23	1.13	1.31	1.13	1.23	1.07	0.37				
				0.39	1.08	1.18	1.08	1.27	1.10	1.20	1.07	0.38				13
				4.1	1.6	-4.2	-4.2	-3.5	-2.7	-2.0	-0.1	3.2				
					0.34	0.61	1.02	0.89	1.02	0.61	0.34					
					0.35	0.64	1.02	0.88	1.00	0.60	0.33					14
					3.7	3.7	-0.1	-0.9	-2.6	-2.0	-2.1					
							0.28	0.34	0.28							
							0.29	0.34	0.27							15
							3.7	1.0	-1.8							

STANDARD DEVIATION =1.172

AVERAGE PCT DIFFERENCE = 1.6

SUMMARY

MAP NO: N2-8-14 DATE: 06/24/91 POWER: 100%

CONTROL ROD POSITION: F-Q(T) = 1.831 QPTR:

D BANK AT 228 STEPS F-DH(N) = 1.458

NW 0.9990	NE 1.0068
SW 0.9939	SE 1.0002

F(Z) = 1.157

F(XY) = 1.459

BURNUP = 9129 MWD/MTU A.O. = -4.532%

Figure 4.3
NORTH ANNA UNIT 2 - CYCLE 8
ASSEMBLYWISE POWER DISTRIBUTION N2-8-25

		R	P	N	M	L	K	J	H	G	F	E	D	C	B	A
1	PREDICTED							0.31	0.38	0.31						
	MEASURED							0.33	0.41	0.33						
	PCT DIFFERENCE							7.2	7.2	6.4						
2	PREDICTED					0.37	0.64	1.03	0.91	1.03	0.64	0.37				
	MEASURED					0.40	0.65	1.05	0.92	1.06	0.67	0.39				
	PCT DIFFERENCE					8.0	1.4	1.5	1.5	2.9	5.6	6.9				
3	PREDICTED				0.40	1.06	1.21	1.12	1.31	1.12	1.21	1.06	0.40			
	MEASURED				0.41	1.08	1.20	1.11	1.30	1.12	1.25	1.11	0.43			
	PCT DIFFERENCE				2.6	2.0	-1.2	-0.6	-0.8	0.7	3.2	4.9	8.2			
4	PREDICTED			0.40	0.86	1.28	1.11	1.36	1.10	1.36	1.11	1.28	0.86	0.40		
	MEASURED			0.41	0.87	1.30	1.10	1.35	1.09	1.35	1.12	1.31	0.88	0.41		
	PCT DIFFERENCE			3.7	1.1	1.1	-0.5	-0.4	-0.4	-0.8	1.0	1.8	2.2	4.2		
5	PREDICTED		0.37	1.06	1.28	1.11	1.36	1.15	1.09	1.15	1.36	1.11	1.28	1.06	0.37	
	MEASURED		0.36	1.06	1.26	1.09	1.34	1.16	1.10	1.16	1.37	1.11	1.27	1.08	0.39	
	PCT DIFFERENCE		-0.5	-0.5	-1.9	-2.3	-1.8	0.8	0.8	0.9	0.8	-0.1	-1.1	2.2	7.5	
6	PREDICTED		0.64	1.22	1.11	1.37	1.16	1.37	1.06	1.37	1.16	1.37	1.11	1.22	0.64	
	MEASURED		0.64	1.22	1.10	1.34	1.14	1.38	1.07	1.38	1.16	1.34	1.08	1.21	0.66	
	PCT DIFFERENCE		0.2	0.2	-0.8	-1.9	-1.2	0.8	0.9	0.9	0.7	-1.6	-2.4	-0.3	3.6	
7	PREDICTED	0.31	1.03	1.12	1.36	1.15	1.36	1.17	1.36	1.17	1.36	1.15	1.36	1.12	1.03	0.31
	MEASURED	0.33	1.05	1.10	1.33	1.12	1.32	1.19	1.38	1.19	1.38	1.14	1.29	1.09	1.02	0.31
	PCT DIFFERENCE	7.4	1.5	-1.5	-2.3	[illegible]	-3.0	1.6	1.6	1.5	1.5	-0.8	-4.9	-2.3	-1.1	0.4
8	PREDICTED	0.38	0.91	1.31	1.10	1.08	1.04	1.36	1.00	1.36	1.04	1.08	1.10	1.31	0.91	0.38
	MEASURED	0.41	0.92	1.28	1.08	1.07	1.03	1.34	1.03	1.36	1.04	1.07	1.06	1.28	0.90	0.38
	PCT DIFFERENCE	7.4	1.4	-1.9	-1.3	-1.0	-1.0	-1.8	2.8	0.0	0.1	-1.7	-4.9	-2.3	-1.1	0.4
9	PREDICTED	0.31	1.03	1.12	1.36	1.15	1.36	1.17	1.36	1.17	1.36	1.15	1.36	1.12	1.03	0.31
	MEASURED	0.33	1.04	1.08	1.33	1.14	1.34	1.13	1.32	1.17	1.36	1.16	1.34	1.12	1.04	0.32
	PCT DIFFERENCE	7.4	0.3	-3.2	-2.1	-0.9	-1.6	-3.0	-3.0	-0.2	-0.3	0.4	-1.6	0.7	0.6	3.0
10	PREDICTED		0.64	1.22	1.11	1.37	1.16	1.37	1.06	1.37	1.16	1.37	1.11	1.22	0.64	
	MEASURED		0.62	1.19	1.10	1.38	1.15	1.34	1.04	1.33	1.14	1.36	1.13	1.25	0.67	
	PCT DIFFERENCE		-2.3	-2.3	-0.3	0.8	-0.5	-1.9	-1.8	-2.5	-1.5	-0.5	2.0	3.2	4.9	
11	PREDICTED		0.37	1.06	1.28	1.11	1.36	1.15	1.09	1.15	1.36	1.11	1.28	1.06	0.37	
	MEASURED		0.38	1.09	1.32	1.13	1.34	1.12	1.06	1.13	1.36	1.13	1.34	1.11	0.39	
	PCT DIFFERENCE		3.1	3.1	2.6	1.8	-2.0	-2.9	-2.8	-2.1	-0.6	1.2	[illegible]	4.9	6.2	
12	PREDICTED			0.40	0.86	1.28	1.11	1.36	1.10	1.36	1.11	1.28	0.86	0.40		
	MEASURED			0.43	0.90	1.31	1.09	1.31	1.06	1.32	1.09	1.29	0.90	0.42		
	PCT DIFFERENCE			8.4	5.2	1.8	-1.8	-3.6	-3.5	-2.7	-1.0	0.5	5.1	[illegible]		
13	PREDICTED				0.40	1.06	1.21	1.12	1.31	1.12	1.21	1.06	0.40			
	MEASURED				0.43	1.08	1.15	1.06	1.26	1.09	1.20	1.07	0.42			
	PCT DIFFERENCE				8.4	1.8	-5.1	-4.9	-3.6	-2.6	-1.2	1.1	6.3			
14	PREDICTED					0.37	0.64	1.03	0.91	1.03	0.64	0.37				
	MEASURED					0.40	0.69	1.05	0.91	1.01	0.63	0.36				
	PCT DIFFERENCE					8.4	8.4	2.0	0.9	-2.3	-1.2	-1.9				
15	PREDICTED							0.31	0.38	0.31						
	MEASURED							0.33	0.39	0.31						
	PCT DIFFERENCE							8.4	4.1	-0.5						

STANDARD DEVIATION = 2.208

AVERAGE PCT DIFFERENCE = 2.5

SUMMARY

MAP NO: N2-8-25 DATE: 01/10/92 POWER: 100%

CONTROL ROD POSITION: F-Q(T) = 1.837 QPTR:

D BANK AT 228 STEPS F-DH(N) = 1.424

F(Z) = 1.157

F(XY) = 1.439

BURNUP = 16640 MWD/MTU A.O.= -3.573%

QPTR	
NW 0.9983	NE 1.0060
SW 0.9961	SE 0.9996

Figure 4.4
NORTH ANNA Unit 2 - CYCLE 8
HOT CHANNEL FACTOR NORMALIZED
OPERATING ENVELOPE

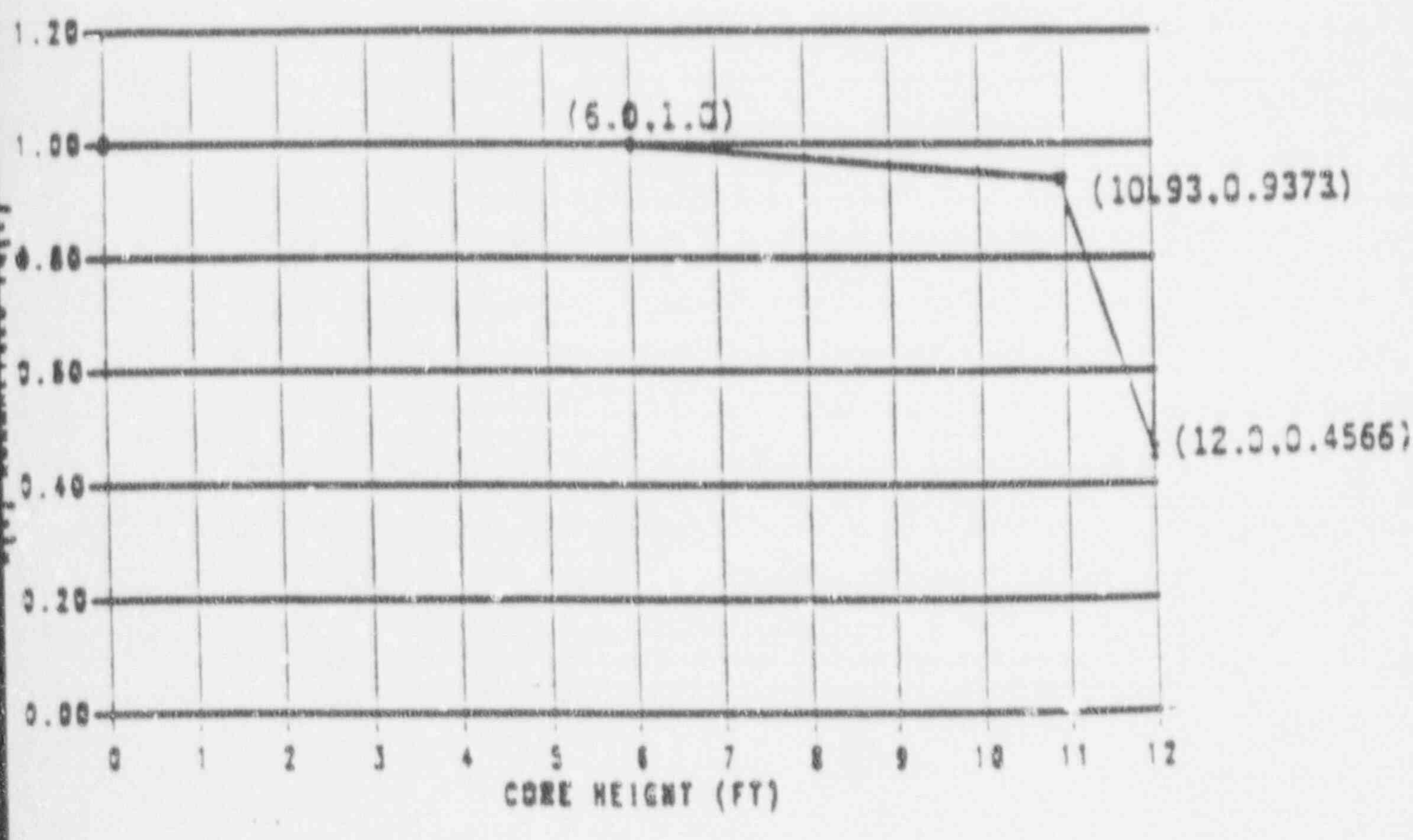


Figure 4.5
NORTH ANNA Unit 2 - CYCLE 8
HEAT FLUX HOT CHANNEL FACTOR, $F_Q(Z)$
N2-8-07

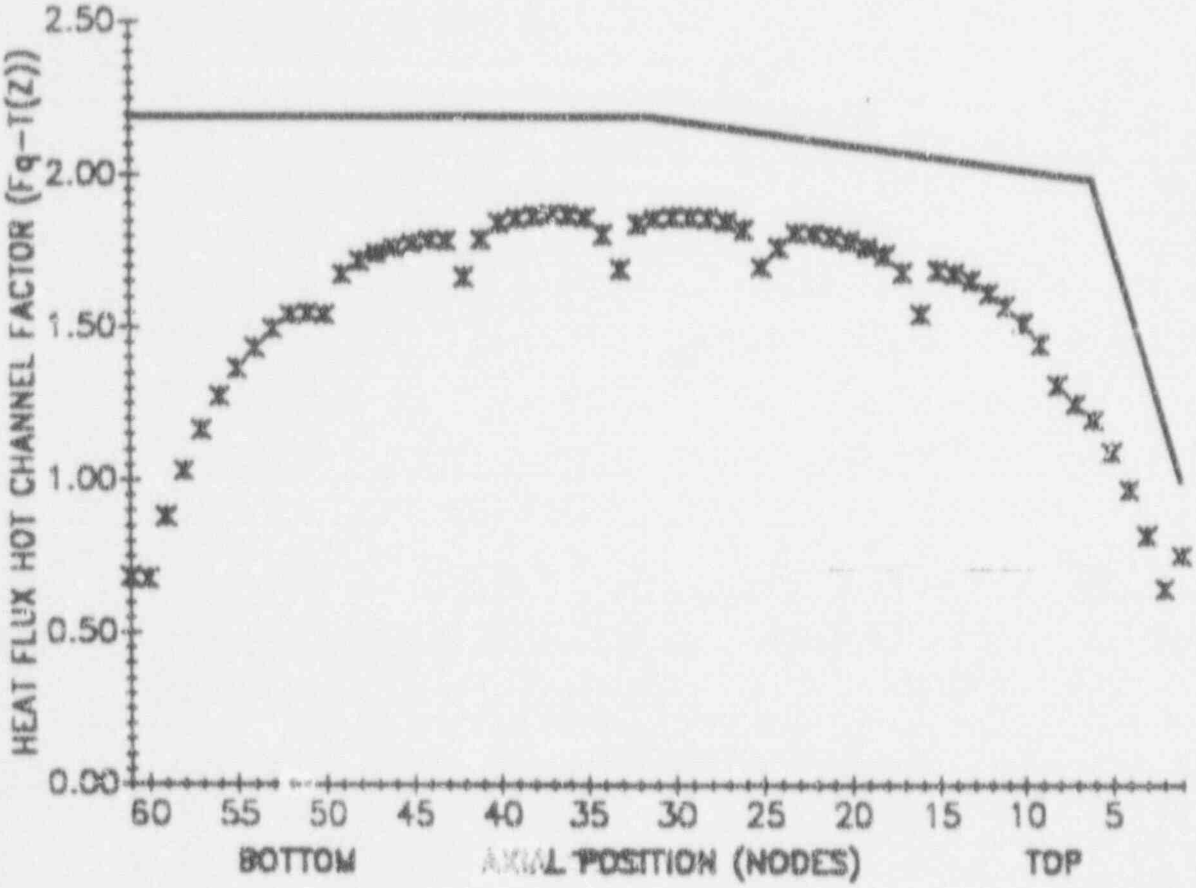


Figure 4.6
NORTH ANNA Unit 2 - CYCLE 8
HEAT FLUX HOT CHANNEL FACTOR, $F_Q(Z)$
N2-8-14

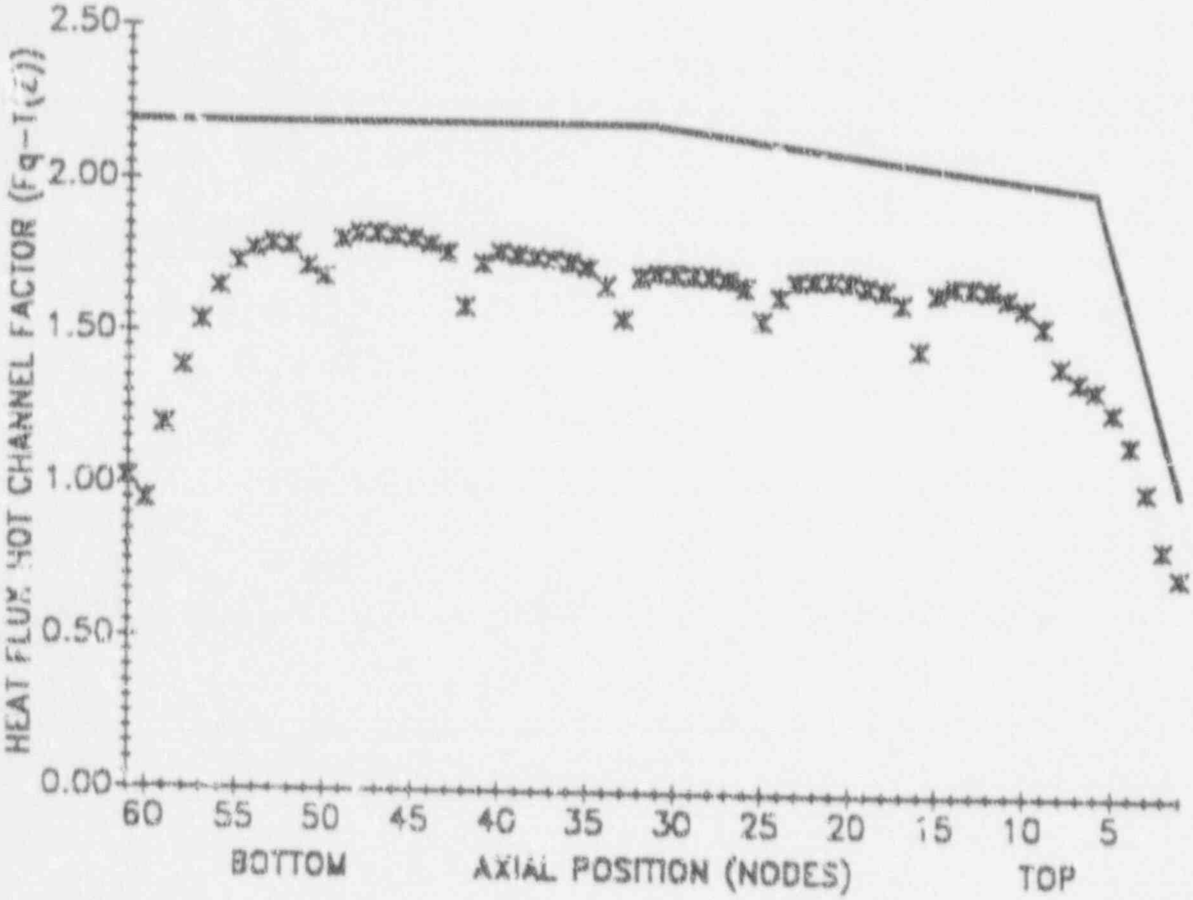


Figure 4.7
NORTH ANNA Unit 2 - CYCLE 8
HEAT FLUX HOT CHANNEL FACTOR, $F_Q(Z)$
N2-8-25

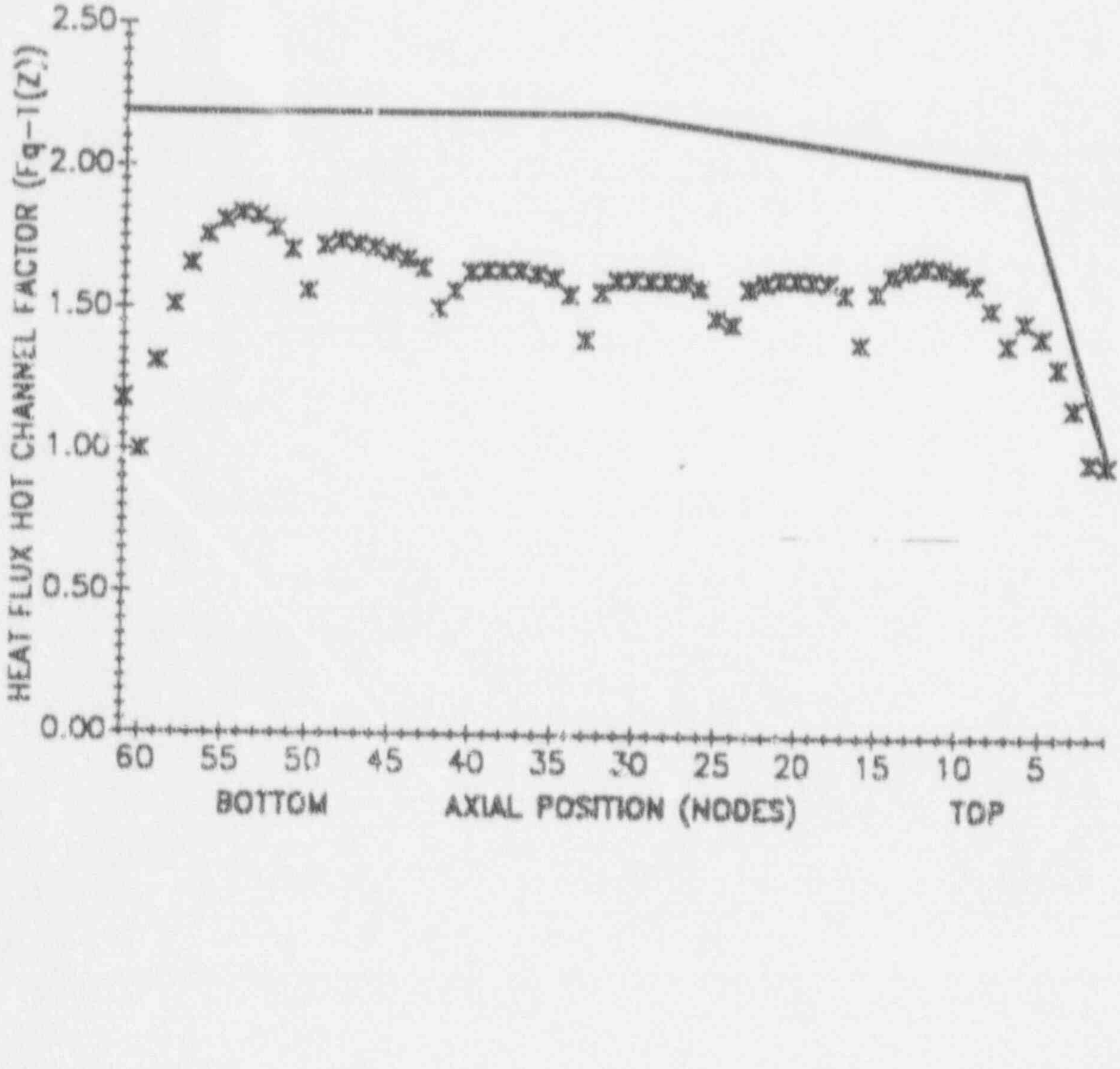
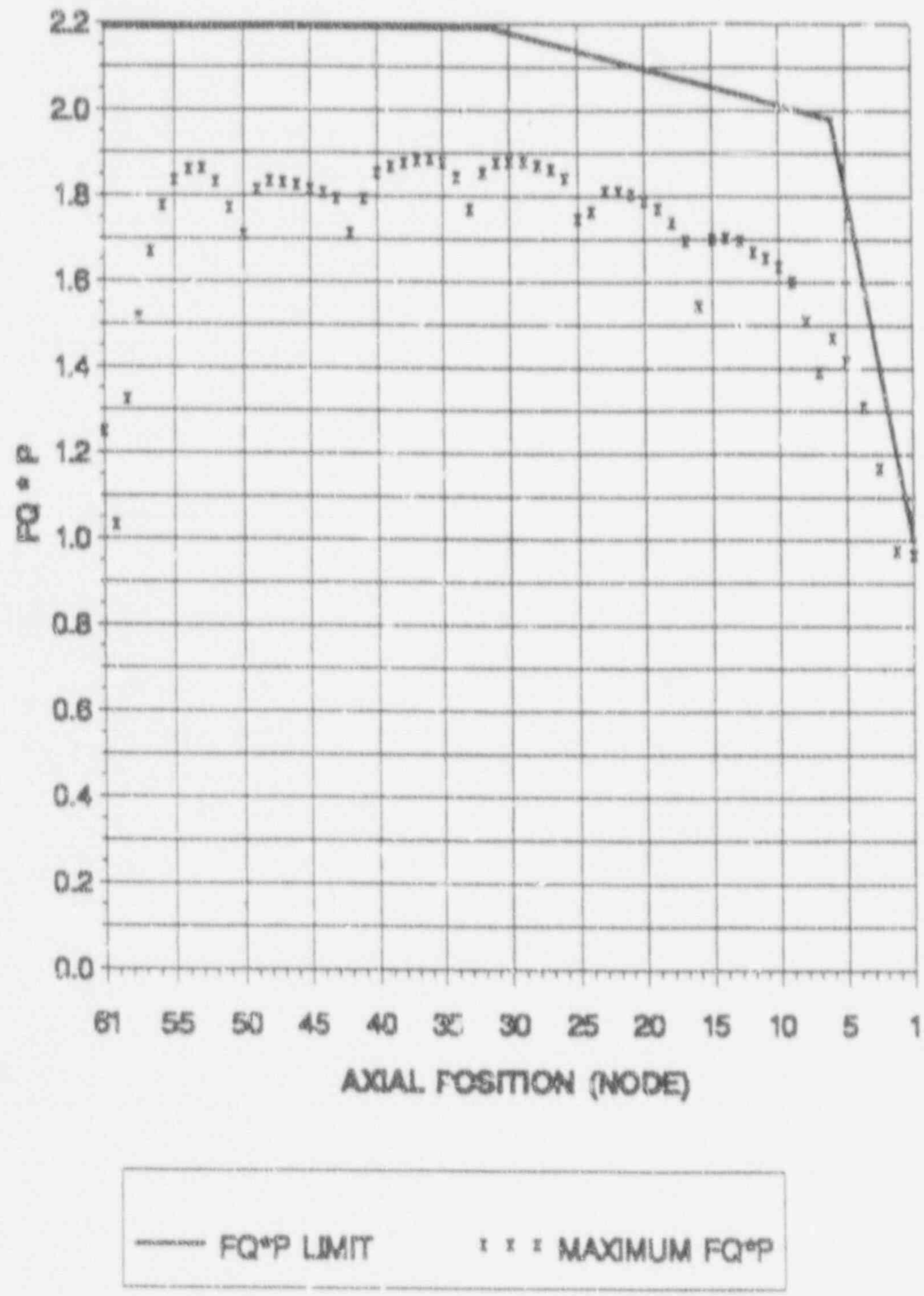


Figure 4.8
NORTH ANNA Unit 2 - CYCLE 8
MAXIMUM HEAT FLUX HOT CHANNEL FACTOR, $F_Q(Z)*P$, vs. AXIAL POSITION



BOTTOM OF CORE

TOP OF CORE

Figure 4.9
NORTH ANNA Unit 2 - CYCLE 8
MAXIMUM HEAT FLUX HOT CHANNEL FACTOR, $F_Q(Z)$, vs. BURNUP

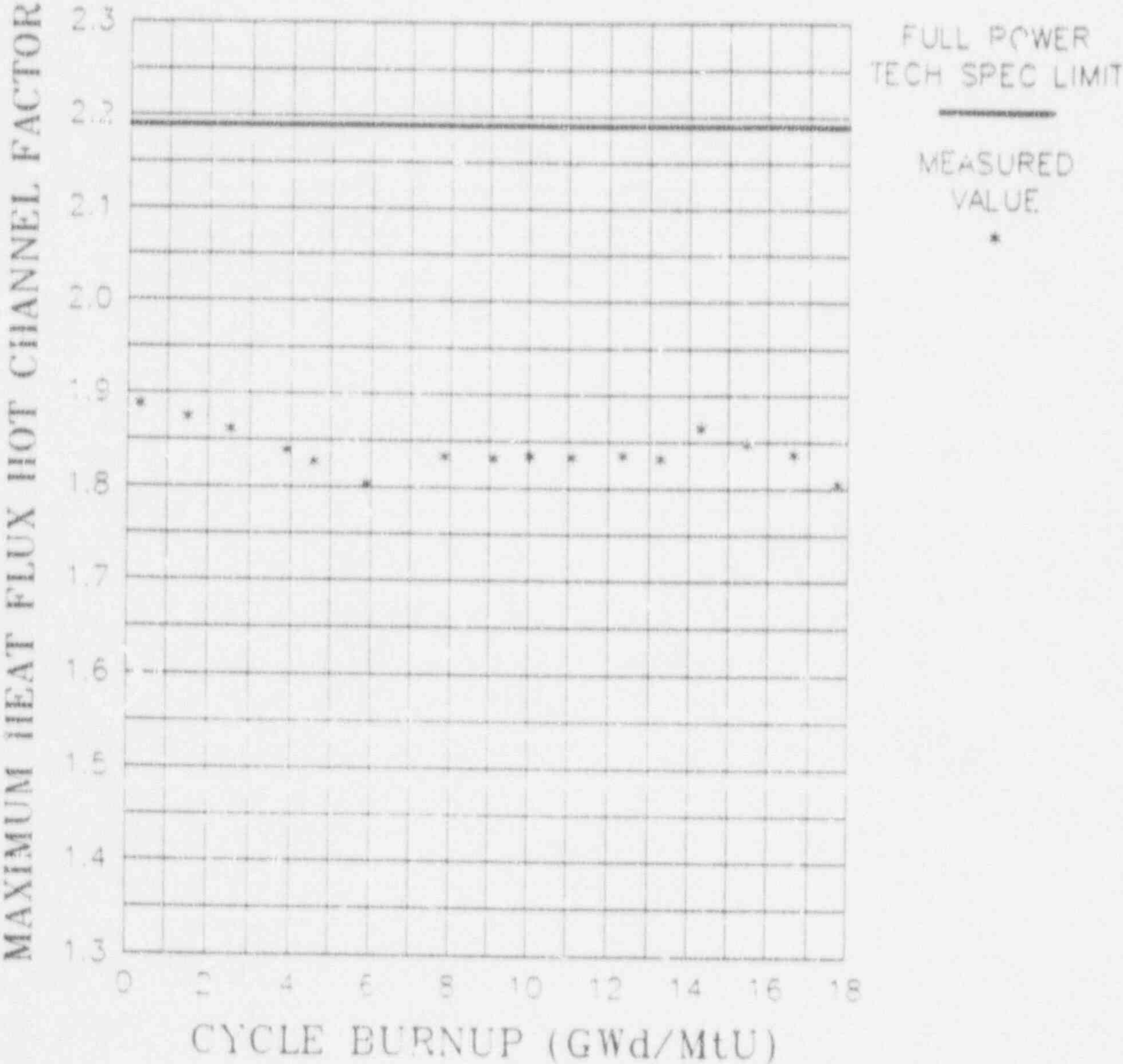


Figure 4.10
NORTH ANNA Unit 2 - CYCLE 8
MAXIMUM ENTHALPY RISE HOT CHANNEL FACTOR, F-delta-H, vs. BURNUP

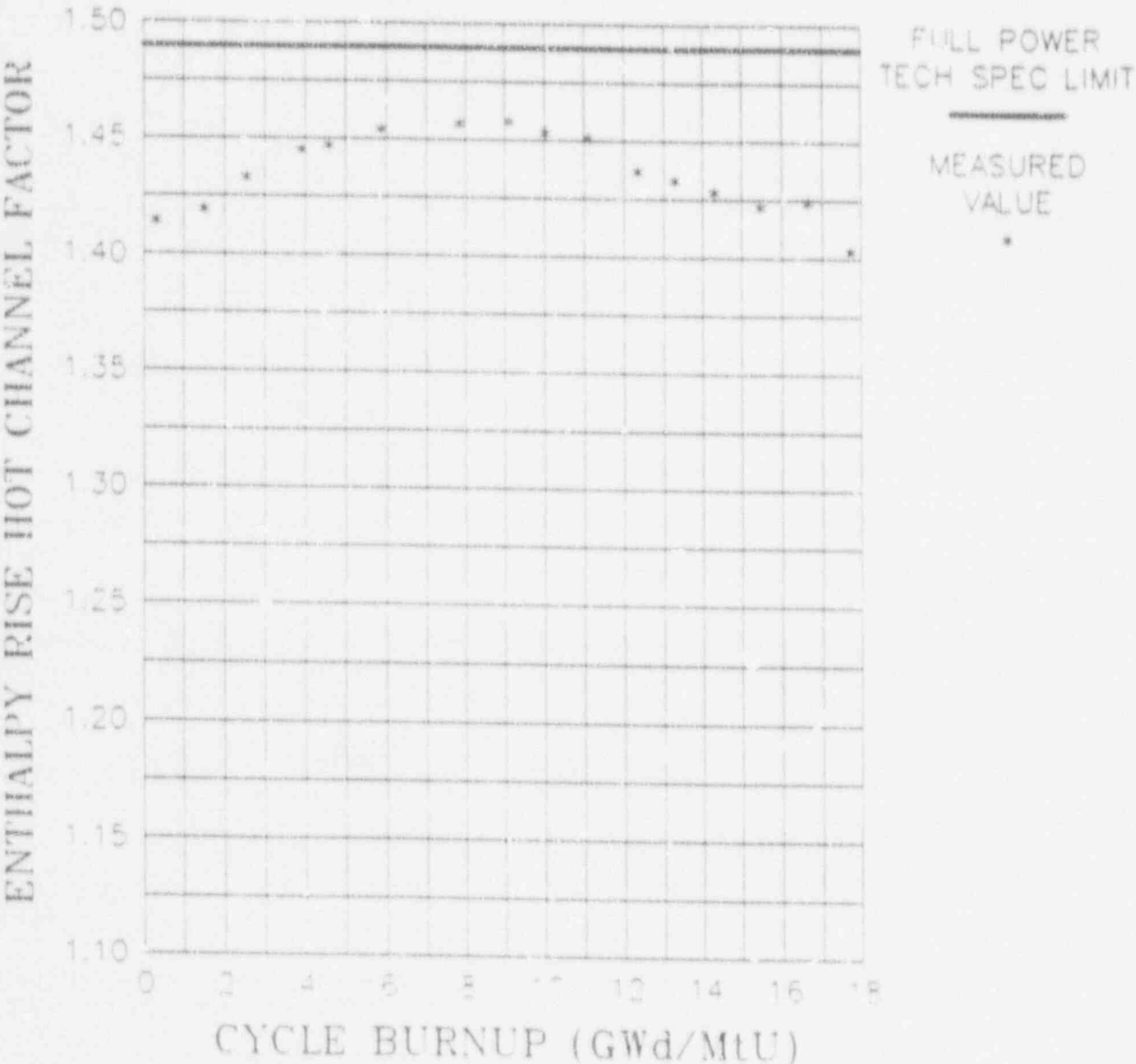


Figure 4.11
NORTH ANNA Unit 2 - CYCLE 8
TARGET DELTA FLUX vs. BURNUP

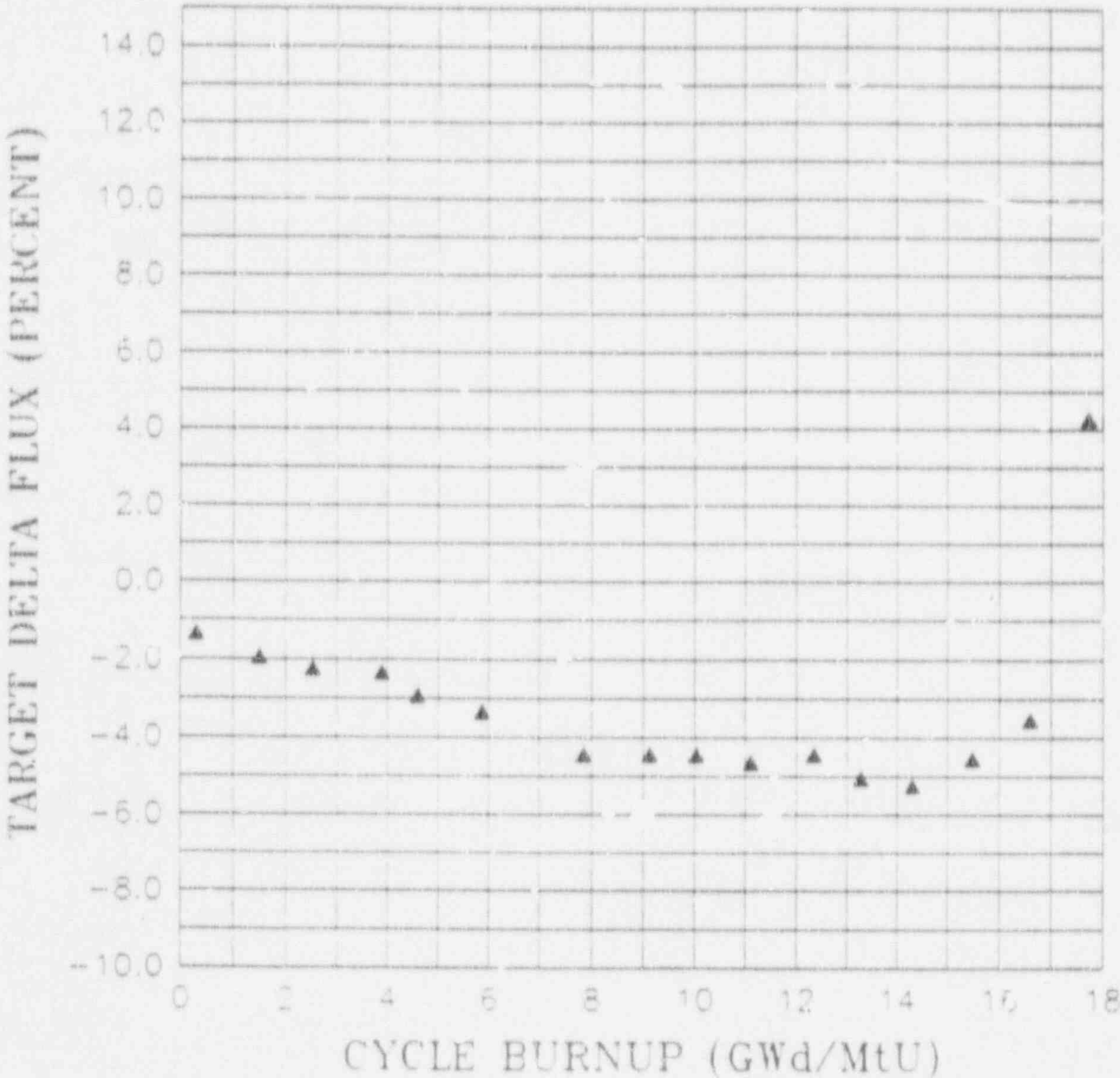


Figure 4.12
NORTH ANNA Unit 2 - CYCLE 8
CORE AVERAGE AXIAL POWER DISTRIBUTION
N2-8-07

Fz = 1.208
AXIAL OFFSET = -2.008

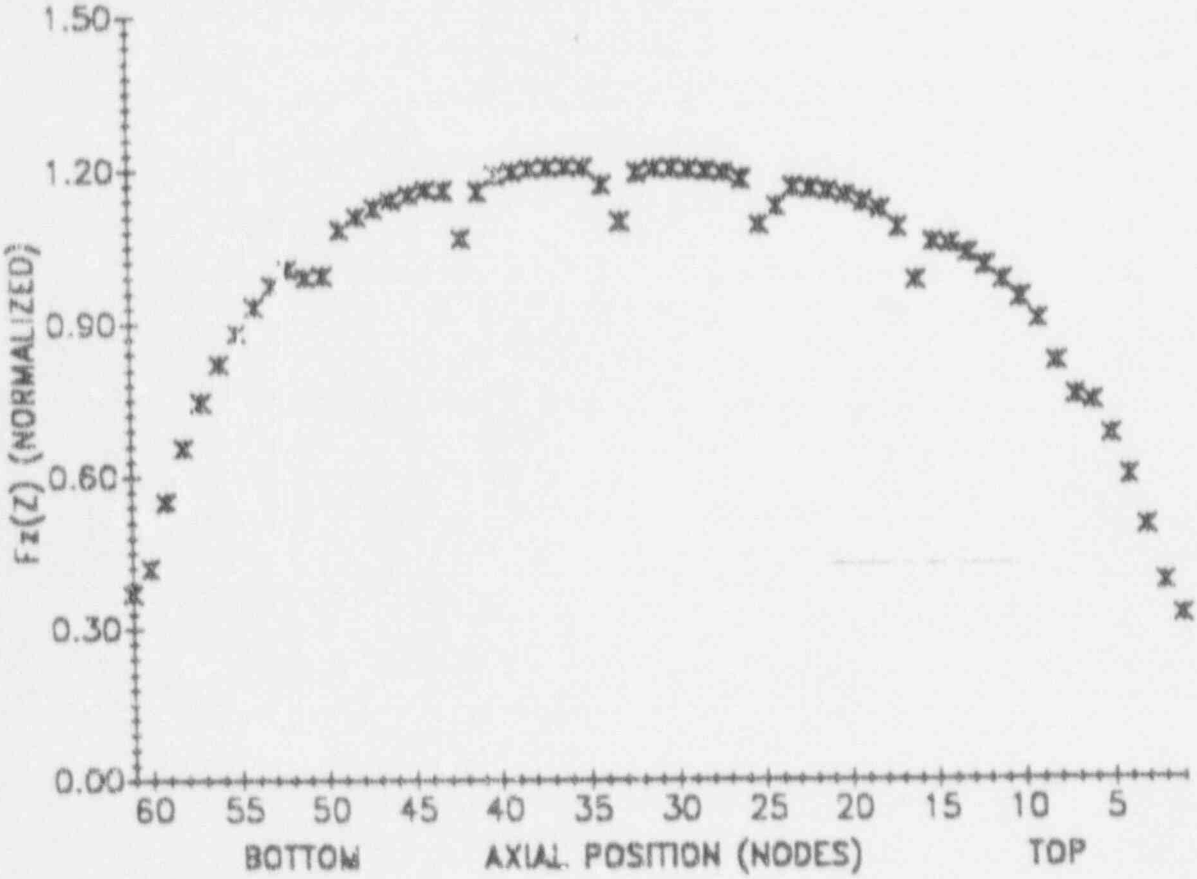


Figure 4.13
NORTH ANNA Unit 2 - CYCLE 8
CORE AVERAGE AXIAL POWER DISTRIBUTION
N2-8-14

Fz = 1.157
AXIAL OFFSET = -4 532

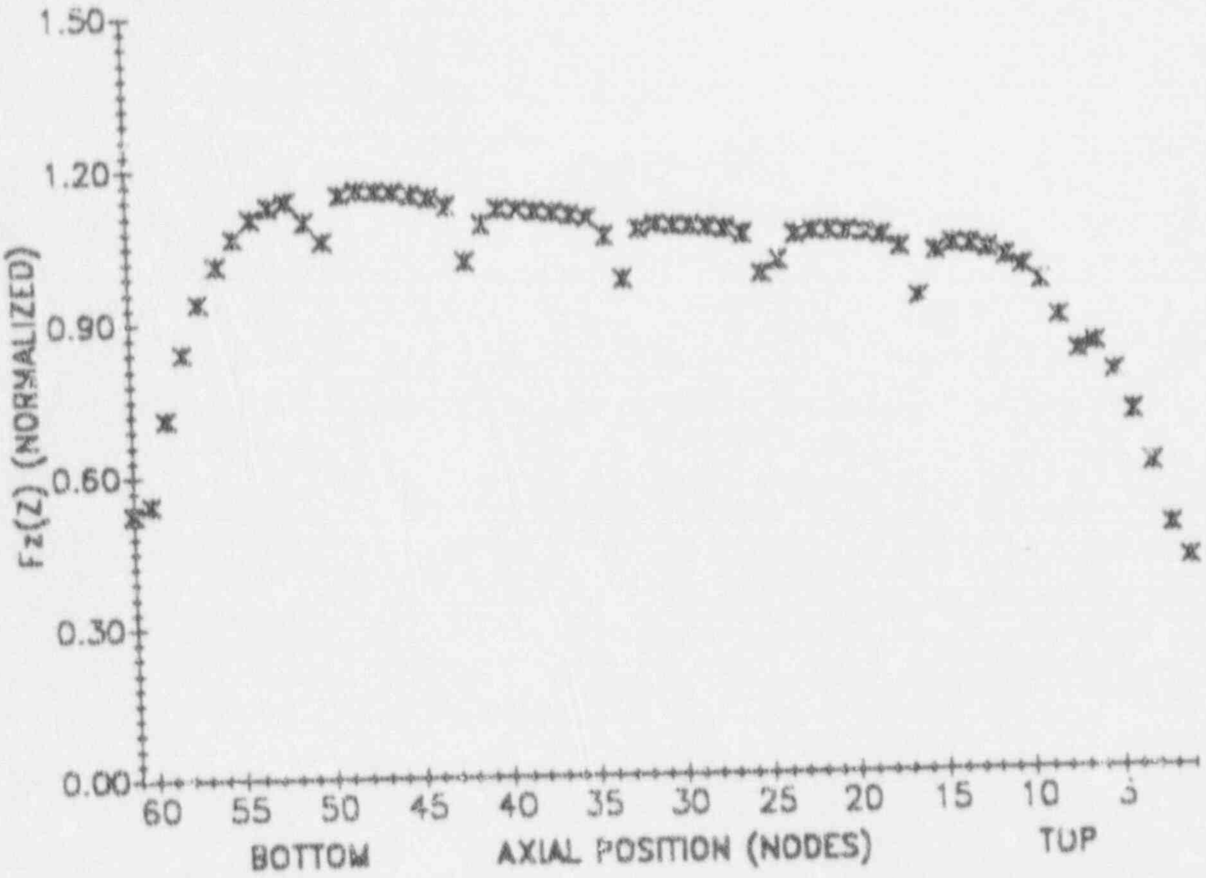


Figure 4.14
NORTH ANNA Unit 2 - CYCLE 8
CORE AVERAGE AXIAL POWER DISTRIBUTION
N2-8-25

Fz = 1.157
AXIAL OFFSET = -3.573

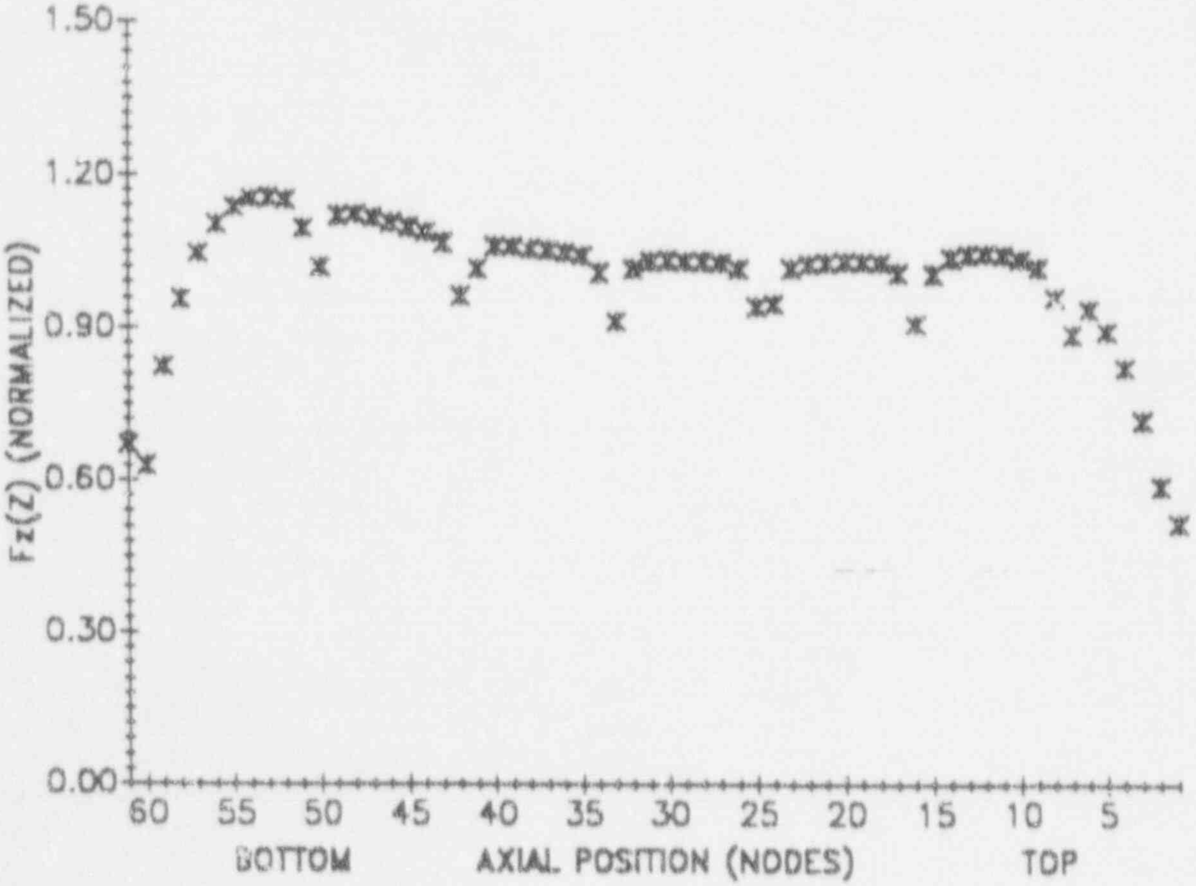
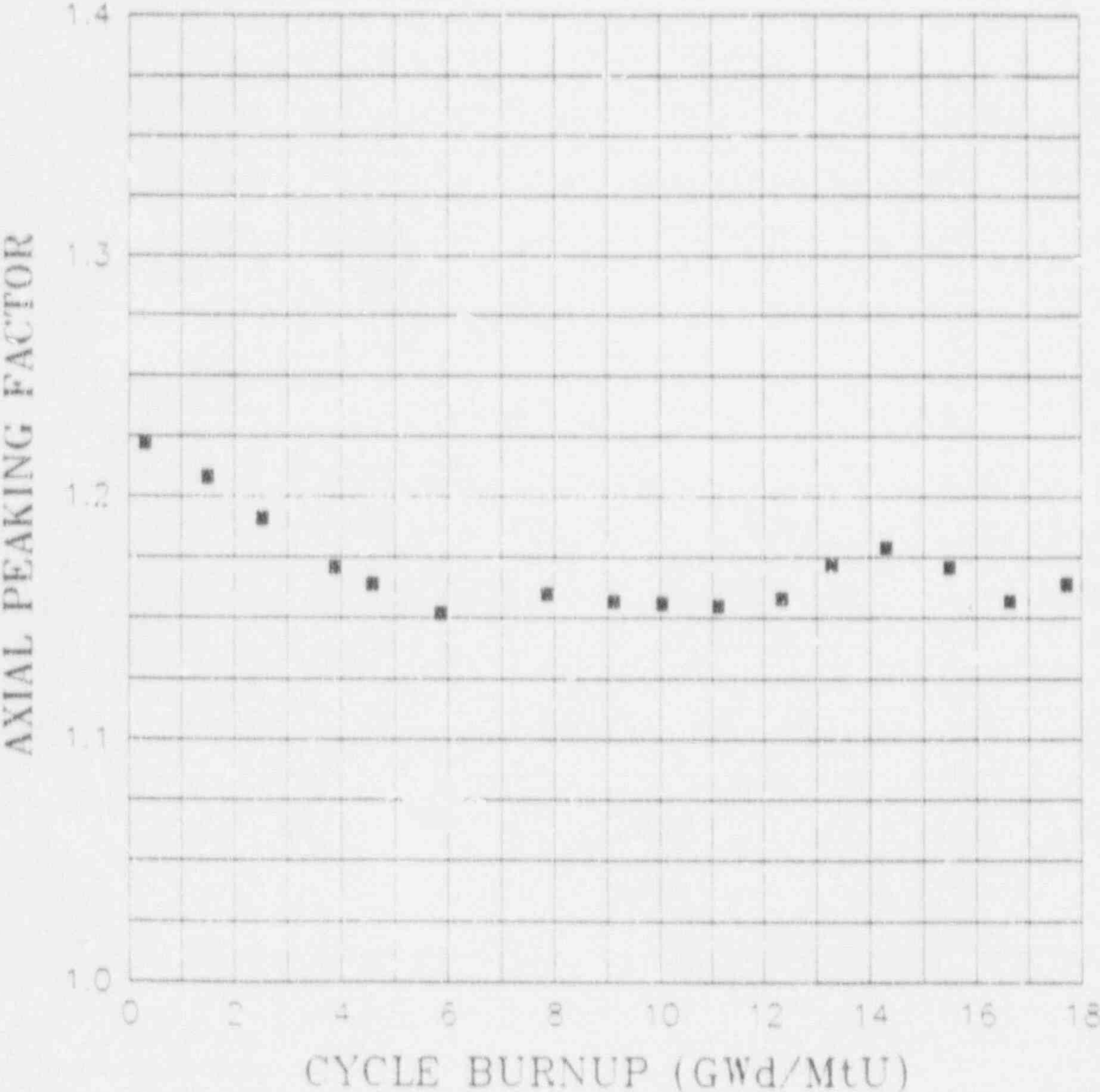


Figure 4.15
NORTH ANNA Unit 2 - CYCLE 8
CORE AVERAGE AXIAL PEAKING FACTOR vs. BURNUP



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 structured 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 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 8. 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 2.42 X 10^{-2} µCi/gm which corresponds to less than 3% 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 cycle average tramp corrected iodine-131 concentration was 1.57 X 10^{-2} µCi/gm with an average demineralizer flow rate of approximately 77 gpm during power operation. This magnitude of tramp corrected I-131 typically indicates the presence of defective fuel rods. Another positive indication of defective fuel is the presence of spikes in radioiodine during large or rapid power transients. Several iodine spikes can be seen 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 5.2 shows the I-131/I-133 ratio data for North Anna 2 Cycle 8. Aside from the large increases in the ratio during the time when the defects occurred, the I-131/I-133 ratio settled out below a ratio of 0.5 toward the middle and end of cycle. This indicates that the defects in the cladding were likely to be moderately sized.

Fuel ultrasonic testing was performed during the Cycle 8 to Cycle 9 refueling outage. Eight fuel rods in five fuel assemblies were confirmed to be defective. The five fuel assemblies are X49, Y39, Y40, Y42, Y47. Assembly X49 was used for two cycles. Visual confirmation of the defective rod showed a through-wall defect on a corner rod below the bottom grid. This defect appears to be externally generated, but it is not clear whether debris or some other external mechanism induced the primary defect. Extensive hydriding was also observed toward the upper spans of this rod. Assemblies Y39, Y40, Y42, and Y47 are all from the new fuel batch for Cycle 8. No evidence of debris induced failures was found during the visual examination of these assemblies. There was evidence of hydriding of the fuel cladding just above the bottom grid on the failed fuel rods that were visible. Possible failure mechanisms are currently being evaluated with the fuel vendor (Westinghouse). These fuel assemblies will be restricted from further use pending any repair projects to replace the defective fuel rods.

Figure 5.1
NORTH ANNA UNIT 2 - CYCLE 8
DOSE EQUIVALENT I-131 vs. TIME

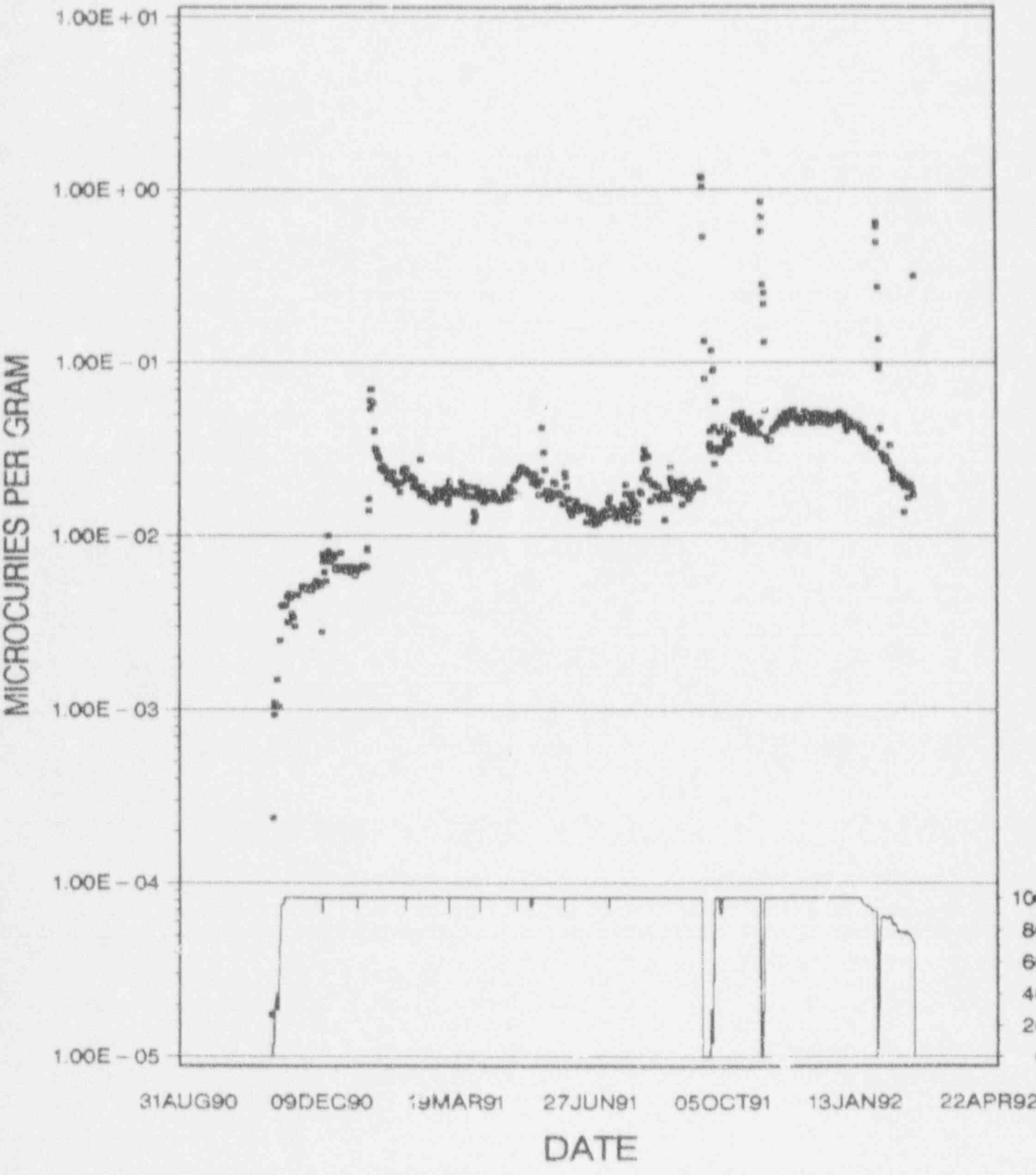
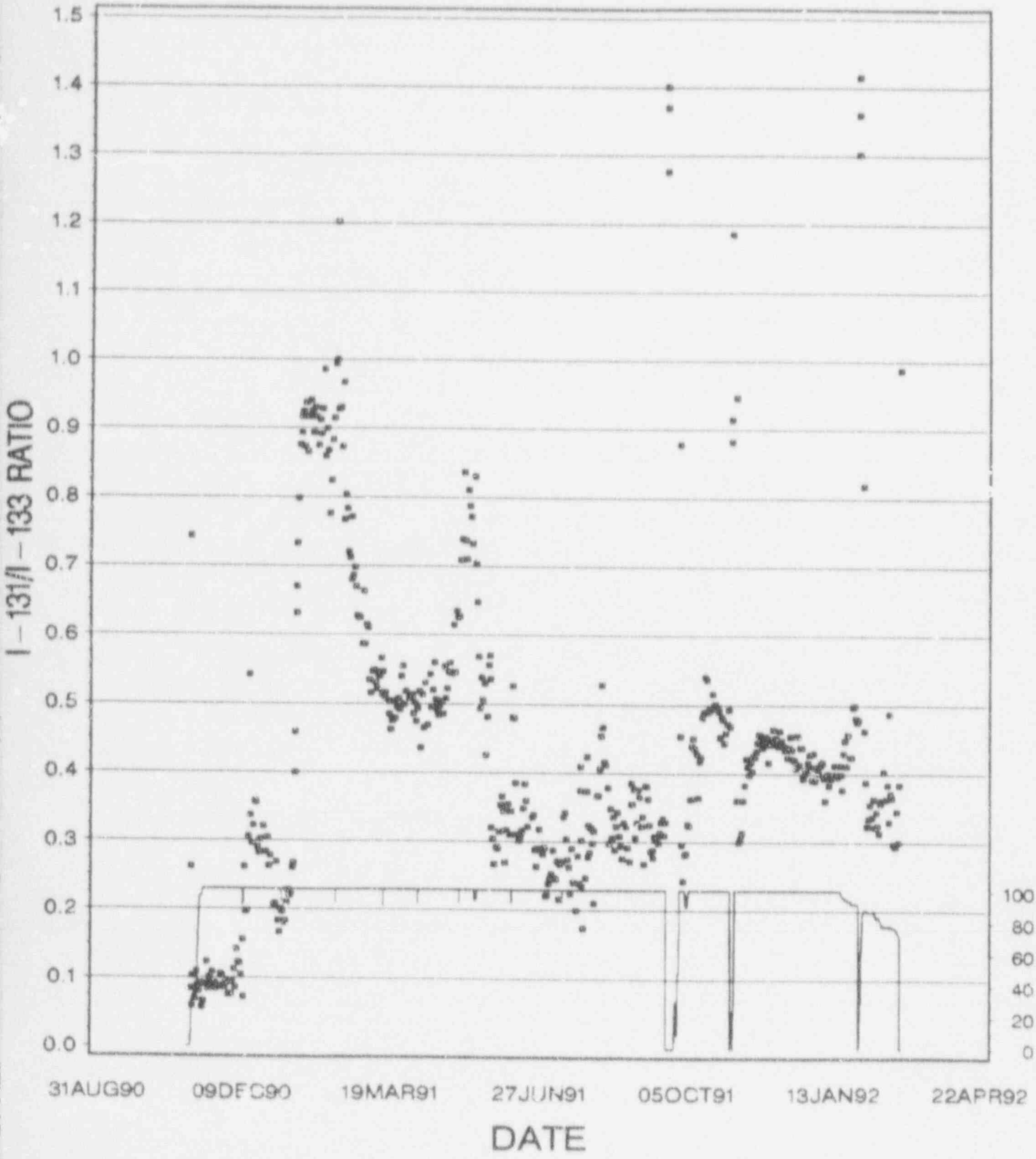


Figure 5.2
NORTH ANNA UNIT 2 - CYCLE 8
I-131 / I-133 ACTIVITY RATIO vs. TIME



Section 6

CONCLUSIONS

The North Anna 2, Cycle 8 core has completed operation. Throughout this cycle, all core performance indicators compared favorably with the design predictions and the core related Technical Specifications limits were met with significant margin. No significant abnormalities in reactivity or burnup accumulation were detected. Radioiodine analysis indicated that there were apparent fuel rod defects during Cycle 8. During ultrasonic testing of the fuel, eight fuel rods in five fuel assemblies were determined to be defective. One of the five fuel assemblies was used for two cycles of operation. The remining four asemblies were used only one cycle. These five assemblies will be restricted from further use pending repair.

Section 7

REFERENCES

1) E. A. Hoffman, "North Anna Unit 2, Cycle 8 Startup Physics Test Report," NE-817 January, 1991.

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

3) T. K. Ross, "NEWTOTE Code", VEPCO NFO-CCR-6 , Rev. 9, 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.

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

7) T. T. Nguyen, "North Anna 2, Cycle 8 FOLLOW Input and Calculations", PM-363, Rev. 0, Addendum B, May 1992.