North Anna Unit 1 Cycle 9 Core Performance Report

Nuclear Analysis and Fuel
Nuclear Engineering Services

March 1993

VIRGINIA POWER

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NORTH ANNA UNIT 1, CYCLE 9

CORE PERFORMANCE REPORT

NUCLEAR ANALYSIS AND FUEL
NUCLEAR ENGINEERING SERVICES
VIRGINIA POWER
March, 1993

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Section 1

INTRODUCTION AND SUMMARY

On January 04, 1993, North Anna Unit 1 completed Cycle 9. Since the initial criticality of Cycle 9 on March 07, 1991, the reactor core produced approximately 1.1927 x 10^8 MBTU (20,009 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 9. The physics tests that were performed during the startup of this cycle were covered in the North Anna Unit 1, Cycle 9 Startup Physics Test Report[1] and, therefore, will not be included here.

During Cycle 9, a mid-cycle steam generator inspection outage occurred. The additional steam generator tube plugging which occurred as a result of the outage impacted the LOCA analysis for N1C9. Following the outage, the N1C9 LOCA analysis limited the core to 95% of rated power, and the K(Z) curve for Fq surveillence was modified. North Anna Unit 1 was in coastdown from September 07, 1992, at which time the burnup was approximately 16,965 MWD/MTU. The coastdown accounted for an additional core burnup of roughly 3,044 MWD/MTU from the end of 95% power reactivity.

The Cycle 9 core consisted of 11 sub-batches of fuel: five once-burned batches, four from Cycle 8 (batches 10A, 10B, 10C, and N2/9B) and one from Cycle 7 (batch 9B); four twice-burned batches, one from North Anna 1

Cycles 5 and 6 (batch 7A), two from North Anna 1 Cycles 6 and 7 (batches 8A and 8B), and one from North Anna 2 Cycles 4 and 5 (batch N2/6); and two fresh batches (batches 11A and 11B). The North Anna 1 Cycle 9 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 1 Technical Specifications[2].

Each of these four performance indicators for the North Anna Unit 1, Cycle 9 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 ±0.44% with the burnup accumulation in each batch deviating from design prediction by no more than 2.70%.

2. Reactivity Depletion - The critical boron concentration, used to monitor reactivity depletion, was consistently within ±0.54 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 2.1%. 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 9 was approximately 0.00551 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. Ultrasonic testing (UT) performed during the Cycle 9 to Cycle 10 refueling outage confirmed that two fuel rods in two fuel assemblies were defective.

Figure 1.1
NORTH ANNA UNIT 1 - CYCLE 9
CORE LOADING MAP

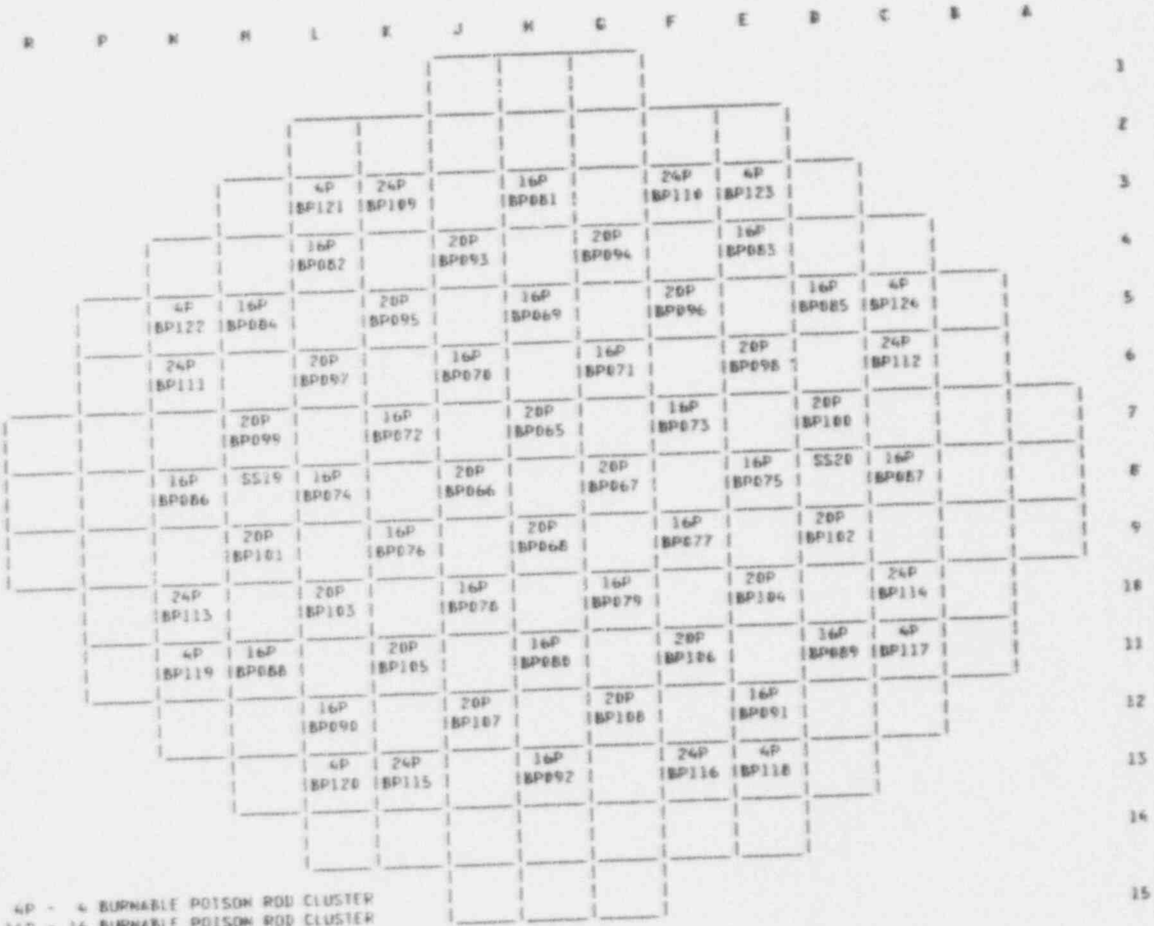
R	P	N	M	L	K	J	H	G	F	E	D	C	B	A
						8A H18	10C K70	8A H26						
				M2/6 T20	10A K35	11B 6A7	10B K52	11B 5A3	10A K33	7A G13				
			8B H68	11B 4A7	11B 6A2	10C K69	11B 3A4	10C K73	11B 4A1	11B 6A1	8A H30			
		8B H29	M2/9B X44	11B 6A8	10B K63	11A 0A8	10B K57	11A 2A5	10B K40	11B 5A0	10B K59	8A H55		
	7A G06	11B 6A0	11B 4A0	10B K49	11A 1A3	10A K15	11A 1A9	10A K27	11A 0A6	10B K54	11B 3A3	11B 4A4	7A G14	
	10A K22	11B 5A1	10B K38	11A 2A7	10B K44	11A 0A1	10A K32	11A 2A8	10B K39	11A 1A6	10B K55	11B 6A6	10B K13	
8A H19	11B 3A6	10C K65	11A 0A5	10A K20	11A 2A2	10A K28	11A 1A0	10A K17	11A 3A1	10A K21	11A 0A9	10C K67	11B 5A2	8A H16
10C K71	10B K58	11B 6A5	10B K46	11A 3A0	10A K34	11A 1A5	9B AM2	11A 0A4	10A K23	11A 2A0	10B K45	11B 3A7	10B K64	10C K76
8A H22	11B 4A5	10C K74	11A 1A7	10A K30	11A 2A4	10A K14	11A 2A1	10A K29	11A 2A6	10A K26	11A 2A9	10C K75	11B 5A9	8A H15
	10A K16	11B 5A7	10B K62	11A 0A3	10B K48	11A 3A2	10A K18	11A 0A7	10B K61	11A 1A2	10B K43	11B 4A3	10A K31	
	7A G54	11B 3A5	11B 4A8	10B K42	11A 1A1	10A K24	11A 1A4	10B K36	11A 1A8	10B K37	11B 5A5	11B 6A3	7A G10	
		8B H47	10B K56	11B 3A9	10B K51	11A 2A3	10B K53	11A 0A2	10B K50	11B 4A6	10B K60	8B H51		
			8B H32	11B 5A4	11B 6A4	10C K72	11B 5A8	10C K68	11B 5A6	11B 3A8	8B H46			
				7A G50	10A K25	11B 4A2	10B K47	11B 4A9	10A K19	7A G03				
						8A H12	10C K66	8A H01						

|--> BATCH
|--> ASSEMBLY ID

FUEL ASSEMBLY DESIGN PARAMETERS

	SUB-BATCH										
	7A	8A	8B	9B	10A	10B	10C	11A	11B	M2/6	M2/9B
INITIAL ENRICHMENT (W/O U-235)	3.60	3.60	3.80	3.99	3.80	4.00	3.82	4.01	4.19	3.60	4.01
ASSEMBLY TYPE	17x17	17x17	17x17	17x17	17x17	17x17	17x17	17x17	17x17	17x17	17x17
NUMBER OF ASSEMBLIES	7	8	8	1	24	27	12	52	36	1	1
FUEL RODS PER ASSEMBLY	264	264	264	264	264	264	264	264	264	264	264

Figure 1.2
NORTH ANNA UNIT 1 - CYCLE 9
BURNABLE POISON AND SOURCE
ASSEMBLY LOCATIONS



4P - 4 BURNABLE POISON ROD CLUSTER
16P - 16 BURNABLE POISON ROD CLUSTER
20P - 20 BURNABLE POISON ROD CLUSTER
24P - 24 BURNABLE POISON ROD CLUSTER
SSxx - SECONDARY SOURCE

Figure 1.3
NORTH ANNA UNIT 1 - CYCLE 9
AVAILABLE MOVABLE DETECTOR LOCAT.O

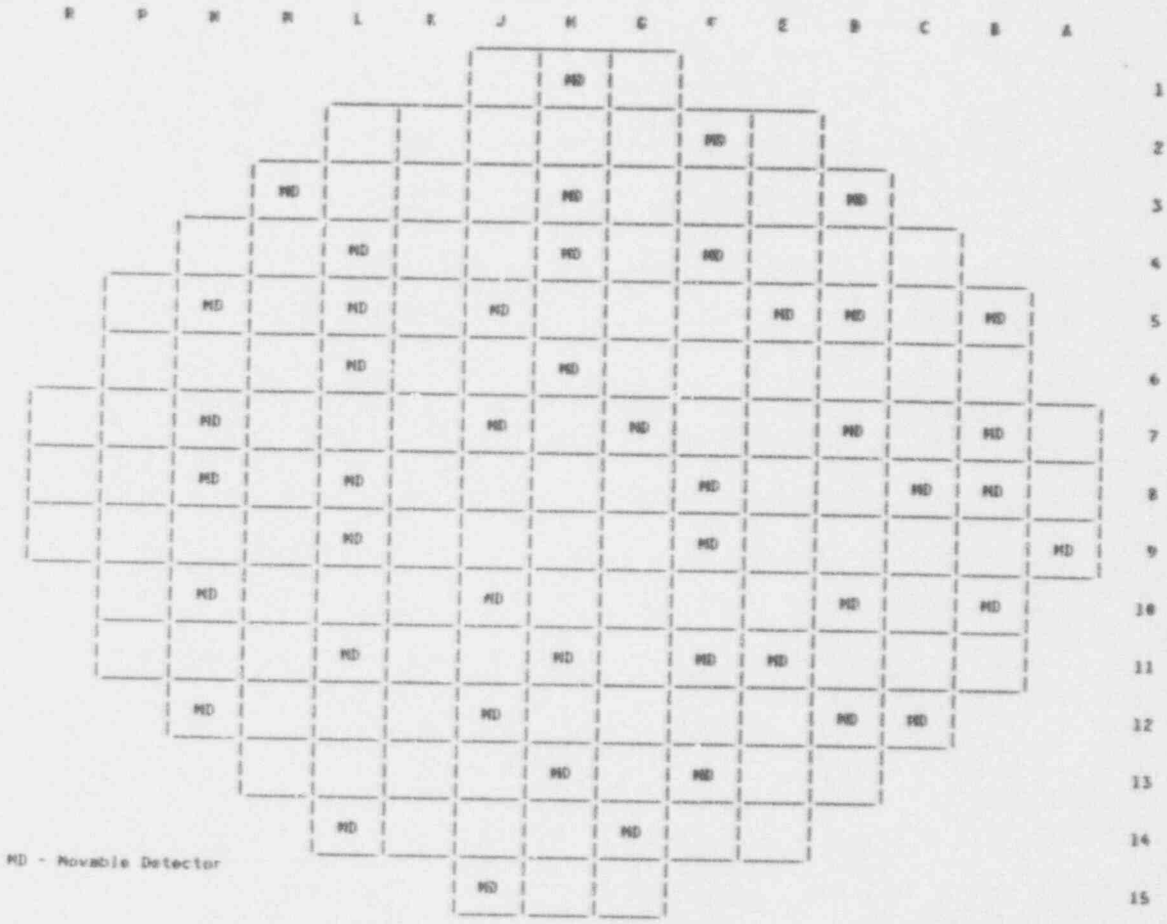
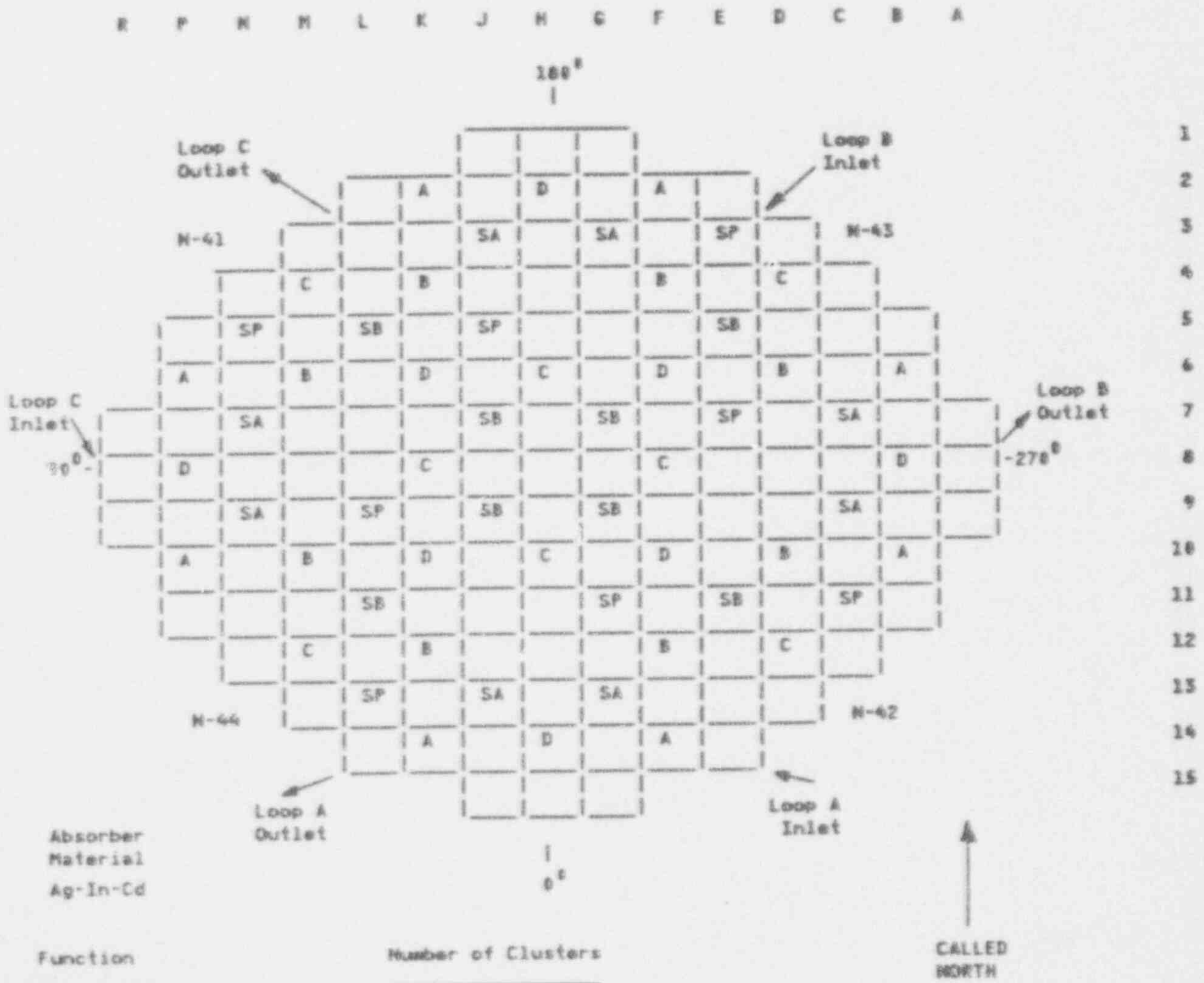


Figure 1.4
NORTH ANNA UNIT 1 - CYCLE 9
CONTROL ROD LOCATIONS



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

Section 2

BURNUP

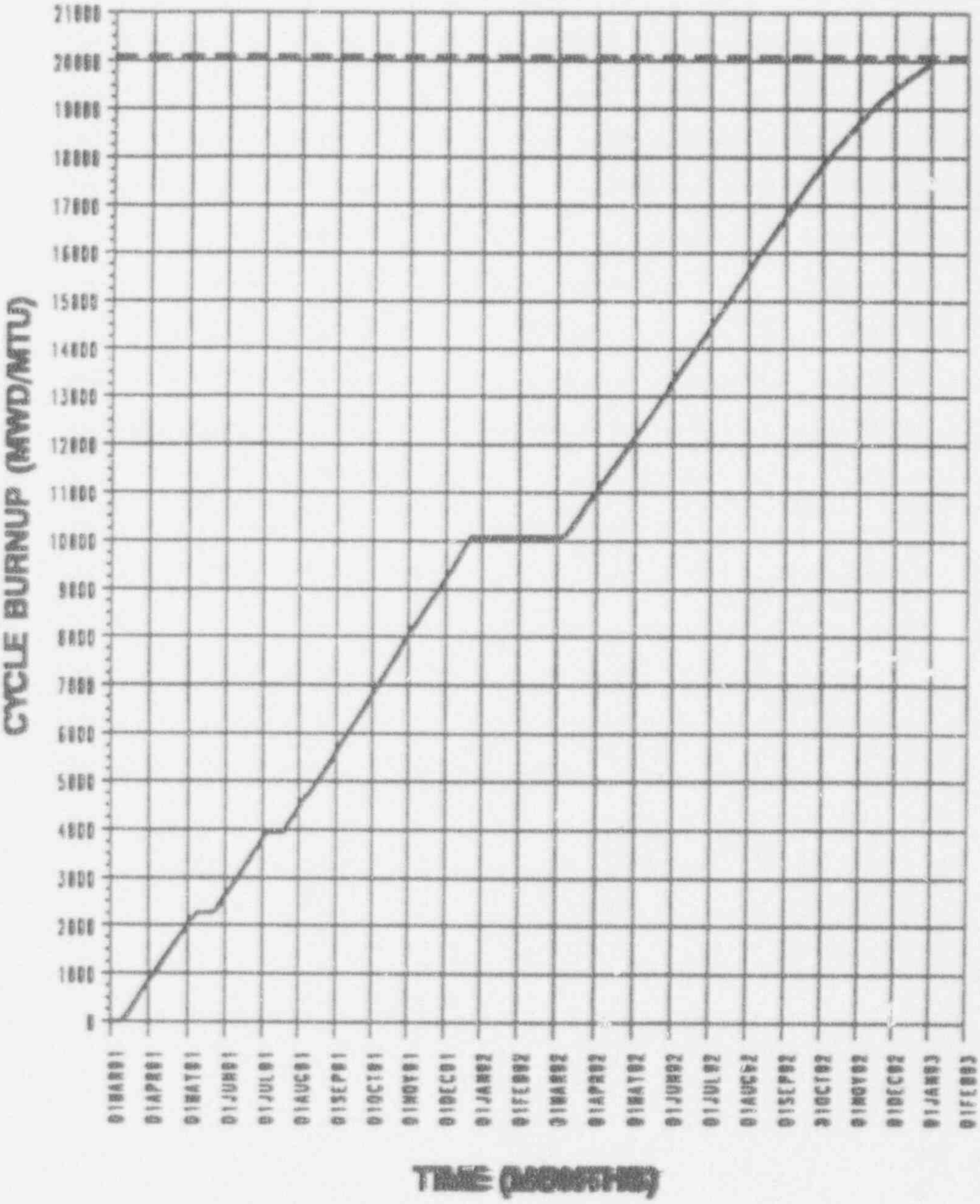
The burnup history for the North Anna Unit 1, Cycle 9 core is graphically depicted in Figure 2.1. The North Anna 1, Cycle 9 core achieved a burnup of 20,009 MWD/MTU. As shown in Figure 2.2, the average load factor for Cycle 9 was 75.3% when referenced to rated thermal power (2893 MW(t)). Unit 1 experienced a mid-cycle steam generator inspection outage of over two months in duration. Following the inspection outage, the Unit 1 core was limited to 95% power due to the results of the LOCA analysis in conjunction with the additional steam generator tube plugging. Unit 1 performed a power coastdown starting on September 07, 1992 until shutdown for refueling on January 04, 1993.

Radial (X-Y) burnup distribution maps show how the core burnup is shared among the various fuel assemblies, and thereby allow a detailed burnup distr_‵ution 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 9 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 9 operation is also given. As can be seen from this figure, the accumulated assembly burnups were generally within ±3.82% 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 1, Cycle 9 followed design predictions closely. Batches N1/9B and N1/7 had batch burnups that deviated from predicted by 2.70% and 2.26% respectively. Each of these batches were comprised of single assemblies, and the burnup differences decreased as the cycle progressed. The burnups for all other batches did not deviate from predictions by more than 2%. Symmetric burnup in conjunction with agreement between actual and predicted assemblywise burnups and batch burnup sharing indicate that the Cycle 9 core did deplete as designed.

Figure 2.1
NORTH ANNA UNIT 1 - CYCLE 9
CORE BURNUP HISTORY



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

Figure 2.2
NORTH ANNA UNIT 1 - CYCLE 9
MONTHLY AVERAGE LOAD FACTORS

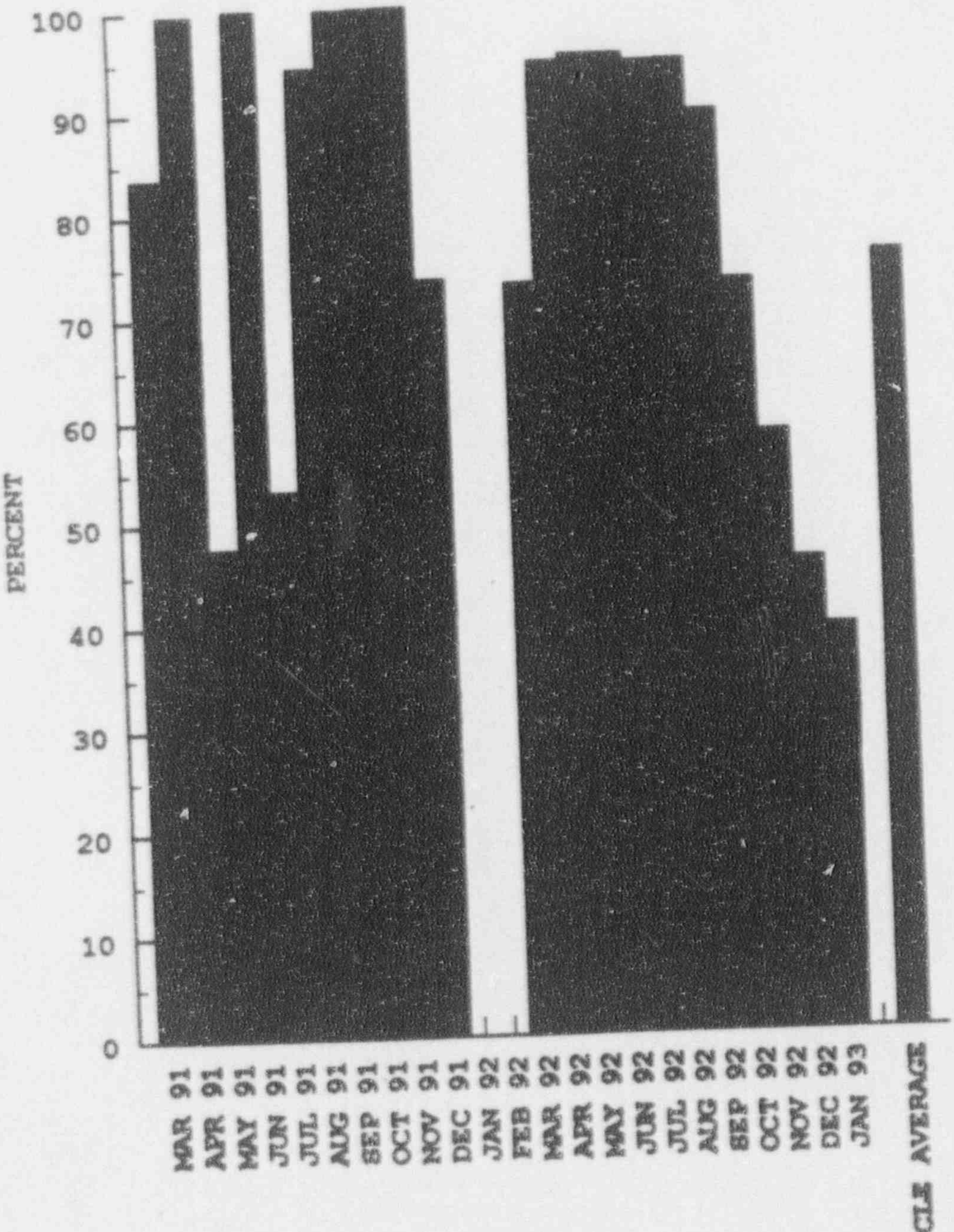


Figure 2.3
NORTH ANNA UNIT 1 - CYCLE 9
ASSEMBLYWISE ACCUMULATED BURNUP
MEASURED AND PREDICTED
(GWD/MTU)

Row		R	P	N	M	L	K	J	H	G	F	E	D	C	B	A
1	MEASURED							38.34	34.05	38.05						
	PREDICTED							38.10	33.44	38.18						
2	MEASURED					40.90	37.08	20.99	37.25	21.09	37.30	39.90				
	PREDICTED					40.42	37.80	20.96	37.53	20.96	37.80	40.41				
3	MEASURED				46.70	21.61	23.91	41.80	25.78	42.38	24.66	21.95	47.28			
	PREDICTED				46.51	21.44	24.36	42.00	26.16	42.00	24.36	21.44	46.51			
4	MEASURED			46.21	36.33	25.64	46.84	26.72	46.87	26.57	47.57	25.65	36.56	46.67		
	PREDICTED			46.47	36.14	25.47	47.38	26.62	47.82	26.62	47.38	25.47	36.14	47.10		
5	MEASURED		39.92	21.06	25.15	46.49	26.79	48.56	27.58	48.76	27.16	46.93	24.89	21.23	39.61	
	PREDICTED		40.60	21.37	25.39	47.39	26.99	48.47	27.15	48.47	26.99	47.39	25.39	21.37	40.60	
6	MEASURED		37.49	24.25	47.06	26.67	47.34	27.73	48.95	27.64	47.49	26.44	46.63	23.97	37.52	
	PREDICTED		37.71	24.33	47.29	26.99	47.47	27.38	48.37	27.38	47.47	26.99	47.29	24.33	37.71	
7	MEASURED	38.39	20.69	41.50	26.21	47.58	26.94	48.04	27.57	48.98	27.70	47.97	25.68	41.79	20.53	37.70
	PREDICTED	38.11	20.94	41.96	26.61	48.52	27.32	48.53	27.19	48.53	27.32	48.52	26.61	41.96	20.94	38.11
8	MEASURED	33.94	36.60	25.76	46.83	26.98	47.83	27.52	45.75	27.24	48.70	26.80	46.46	25.58	37.15	33.53
	PREDICTED	33.46	37.47	26.05	47.01	27.17	48.38	27.19	46.20	27.19	48.38	27.17	47.01	26.05	37.47	33.46
9	MEASURED	38.12	20.14	41.39	26.14	48.37	26.96	47.55	26.39	48.05	27.10	48.26	26.31	42.59	21.18	38.35
	PREDICTED	38.11	20.94	41.96	26.61	48.52	27.32	48.53	27.19	48.53	27.32	48.52	26.61	41.96	20.94	38.11
10	MEASURED		36.60	23.40	47.18	27.32	46.40	26.46	47.26	26.53	47.00	26.77	46.96	25.24	37.79	
	PREDICTED		37.71	24.33	47.29	26.99	47.47	27.38	48.37	27.38	47.67	26.99	47.29	24.33	37.71	
11	MEASURED		39.67	21.21	25.46	47.36	26.68	47.32	26.29	47.47	26.62	46.42	25.78	22.02	40.59	
	PREDICTED		40.60	21.37	25.39	47.39	26.99	48.47	27.15	48.47	26.99	47.39	25.39	21.37	40.60	
12	MEASURED			46.54	35.95	25.74	46.95	25.78	45.72	25.82	47.07	25.15	36.16	45.52		
	PREDICTED			46.47	36.14	25.47	47.38	26.62	47.82	26.62	47.38	25.47	36.14	46.47		
13	MEASURED				46.26	21.88	24.10	42.28	25.46	41.17	23.72	21.04	46.81			
	PREDICTED				46.51	21.44	24.36	42.00	26.16	42.00	24.36	21.44	46.51			
14	MEASURED					39.59	37.96	21.22	37.90	20.34	37.11	39.29				
	PREDICTED					40.41	37.80	20.96	37.53	20.96	37.80	40.41				
15	MEASURED							38.03	32.97	39.05						
	PREDICTED							38.10	33.44	39.04						

Figure 2.4
NORTH ANNA UNIT 1 - CYCLE 9
ASSEMBLYWISE ACCUMULATED BURNUP
COMPARISON OF MEASURED AND PREDICTED
(GWD/MTU)

Row	R	P	N	M	L	K	J	H	G	F	E	D	C	B	A
1							38.34	34.05	38.05						
							0.63	1.04	-0.13						
2					40.90	37.00	20.99	37.25	21.09	37.30	39.90				
					1.19	-1.91	0.16	-0.75	0.62	-1.32	-1.27				
3				46.70	21.61	23.91	41.00	25.70	42.30	24.66	21.95	47.20			
				0.40	0.79	-1.83	-0.48	-1.43	0.91	1.25	2.42	1.66			
4			46.21	36.33	25.64	46.04	26.72	46.07	26.57	47.37	25.65	36.56	46.67		
			-0.55	0.53	0.65	-1.15	0.35	-2.02	-0.20	0.00	0.71	1.15	-0.90		
5		39.92	21.06	25.15	46.49	26.79	40.56	27.50	40.76	27.16	46.93	24.09	21.23	39.61	
		-1.20	-1.46	-0.93	-1.08	-0.76	0.19	1.57	0.59	0.63	-0.96	-1.96	-0.66	-1.96	
6		37.49	24.25	47.06	26.67	47.34	27.73	40.95	27.64	47.49	26.46	46.63	23.97	37.52	
		-0.59	-0.33	-0.49	-1.18	-0.29	1.57	1.20	1.24	0.04	-2.05	-1.41	-1.46	-0.51	
7	38.39	20.69	41.50	26.21	47.58	26.94	40.04	27.57	40.90	27.70	47.97	25.60	41.79	20.53	37.70
	0.73	-1.17	-1.08	-1.51	-1.93	-1.40	0.64	1.39	0.92	1.30	-1.14	-3.48	-0.39	-1.94	-1.07
8	33.94	36.60	25.76	46.83	26.98	47.83	27.52	45.75	27.24	40.70	26.00	46.46	25.50	37.15	33.53
	1.61	-2.30	-1.12	-0.37	-0.70	-1.13	1.23	-1.15	0.21	0.67	-1.36	-1.15	-2.14	-0.04	0.20
9	38.12	20.14	41.39	26.14	40.57	26.96	47.55	26.39	40.05	27.10	40.26	26.31	42.59	21.10	38.35
	0.02	-3.82	-1.36	-1.75	-0.31	-1.33	-2.02	-2.97	-0.90	-0.83	-0.53	-1.13	1.50	1.16	0.62
10		36.60	23.40	47.10	27.32	46.40	26.66	47.26	26.53	47.00	26.77	46.96	25.24	37.79	
		-2.94	-3.81	-0.24	1.23	-2.26	-3.00	-2.30	-2.81	-1.00	-0.81	-0.70	3.74	0.22	
11		39.67	21.21	25.46	47.36	26.40	47.32	26.29	47.47	26.62	46.42	25.70	22.02	40.59	
		-1.79	-0.73	0.26	-0.06	-1.09	-2.37	-3.18	-2.07	-1.37	-2.04	1.54	3.03	0.47	
12			46.56	35.95	25.74	46.95	25.70	45.72	25.02	47.07	25.15	36.14	46.52		
			0.16	-0.55	1.05	-0.09	-3.18	-2.77	-3.03	-0.64	-1.27	-0.01	0.10		
13				46.26	21.00	24.10	42.20	25.46	41.17	23.72	21.04	46.01			
				-0.53	2.07	-0.73	0.67	-2.60	-1.90	-2.61	-1.85	0.65			
14					39.59	37.96	21.22	37.90	20.34	37.11	39.29				
					-2.03	0.42	1.26	0.99	-2.93	-1.04	-2.78				
15							38.03	32.97	39.05						
							-0.10	-1.40	0.04						

| MEASURED |
| M/P % DIFF |

| ARITHMETIC AVG |
| PCT DIFF = -0.61 |

| AVG ABS PCT |
| DIFF = 1.27 |

| STANDARD DEV |
| = 0.80 |

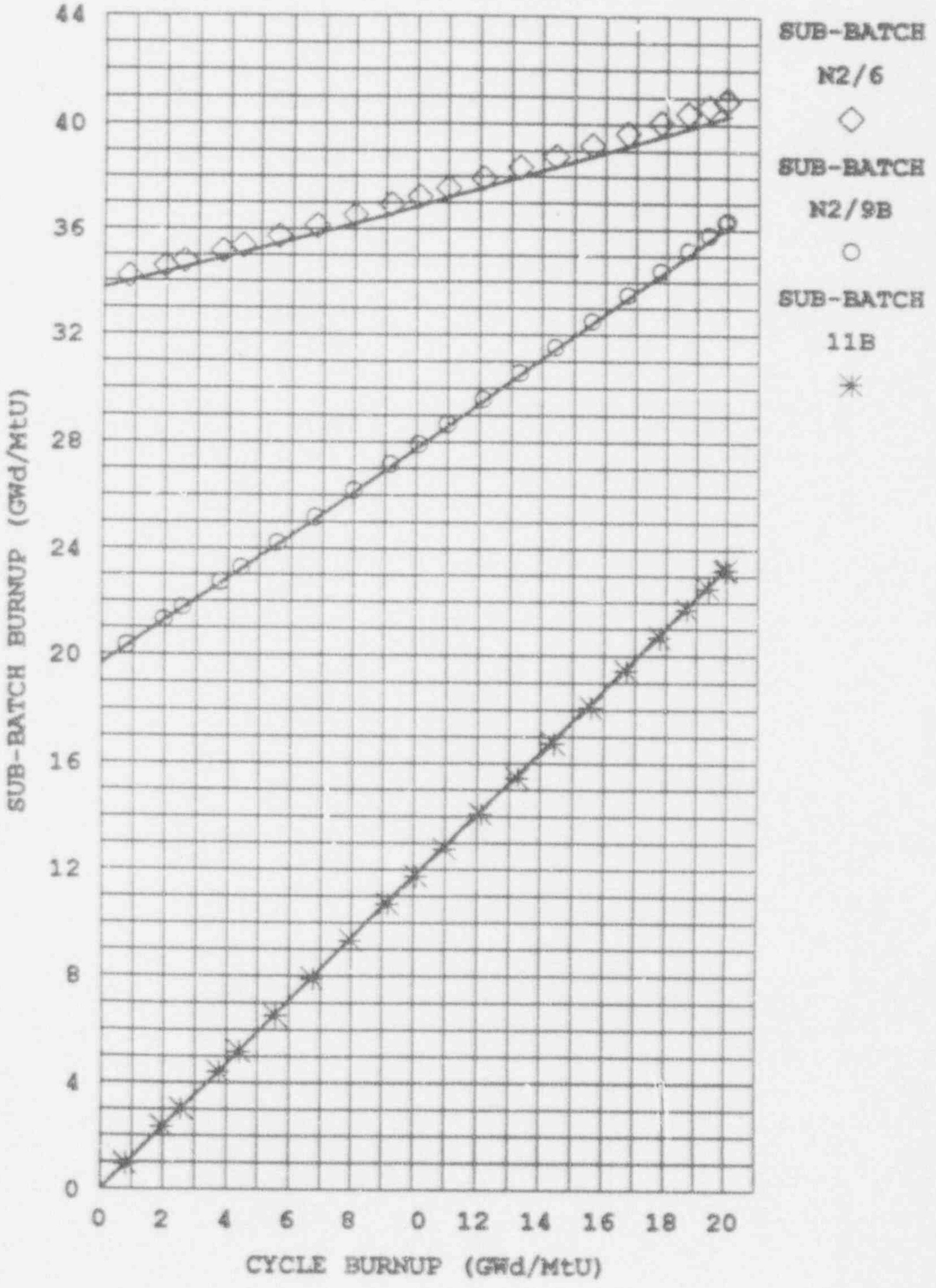
BATCH SHARING
(MWD/MTU)

BATCH	NO. OF ASSEMBLIES	BOC BATCH BURNUP	EOC BATCH BURNUP	CYCLE BURNUP
N2/9B	1	19,664	36,335	16,671
N2/6	1	33,942	40,899	6,957
7	7	32,943	39,795	6,852
8A	8	31,980	38,253	6,273
8B	8	38,876	46,623	7,747
9B	1	21,136	45,754	24,618
10A	24	25,491	44,556	19,065
10B	27	22,850	44,227	21,377
10C	12	22,246	39,113	16,867
11A	32	0	26,779	26,779
11B	36	0	23,263	23,263
CYCLE AVERAGE ACCUMULATED BURNUP = 20,009				

BURNUP TILT

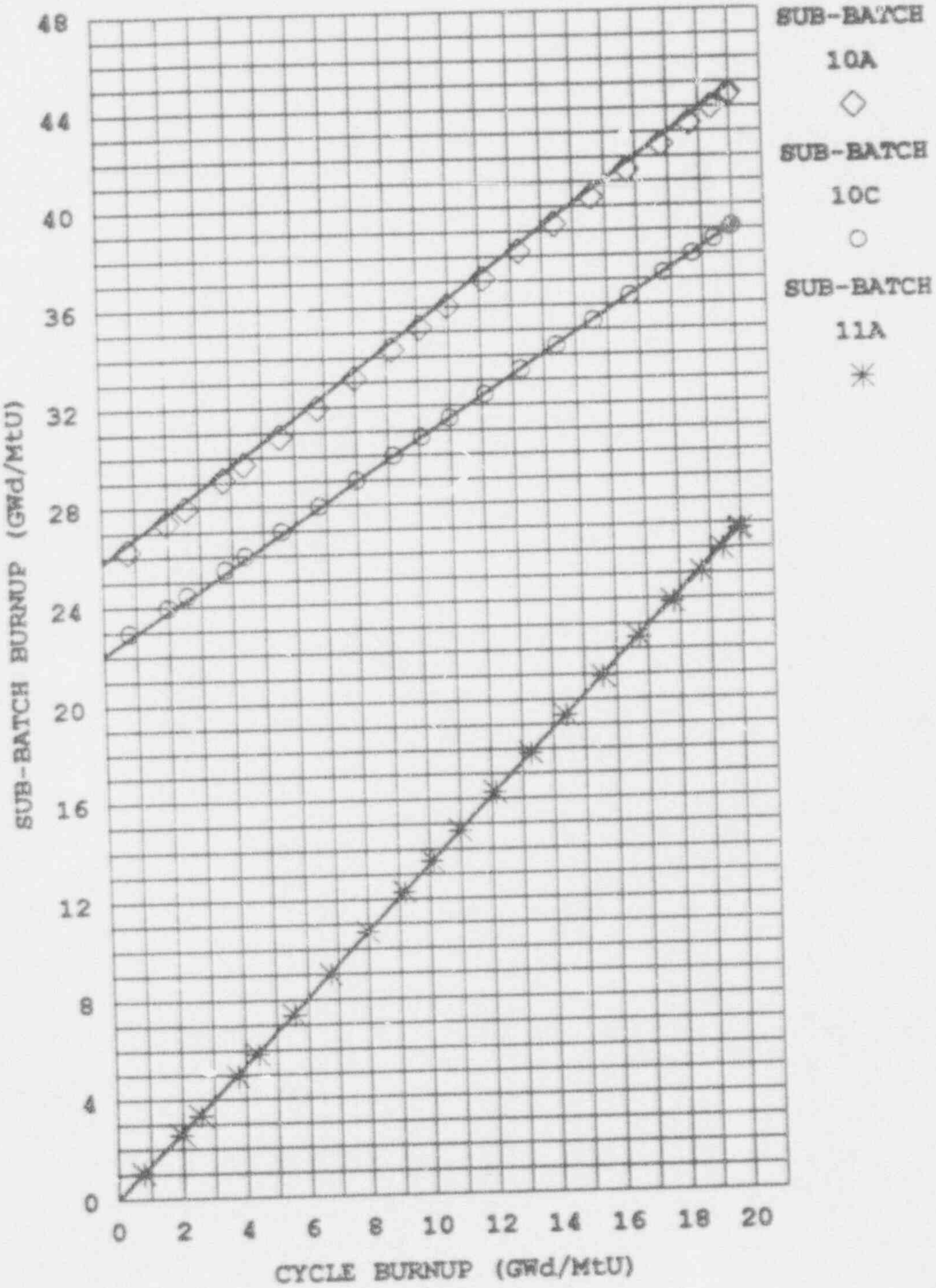
NW = 0.19	NE = 0.55
SW = -0.63	SE = -0.11

Figure 2.5A
NORTH ANNA UNIT 1 - CYCLE 9
SUB-BATCH BURNUP SHARING



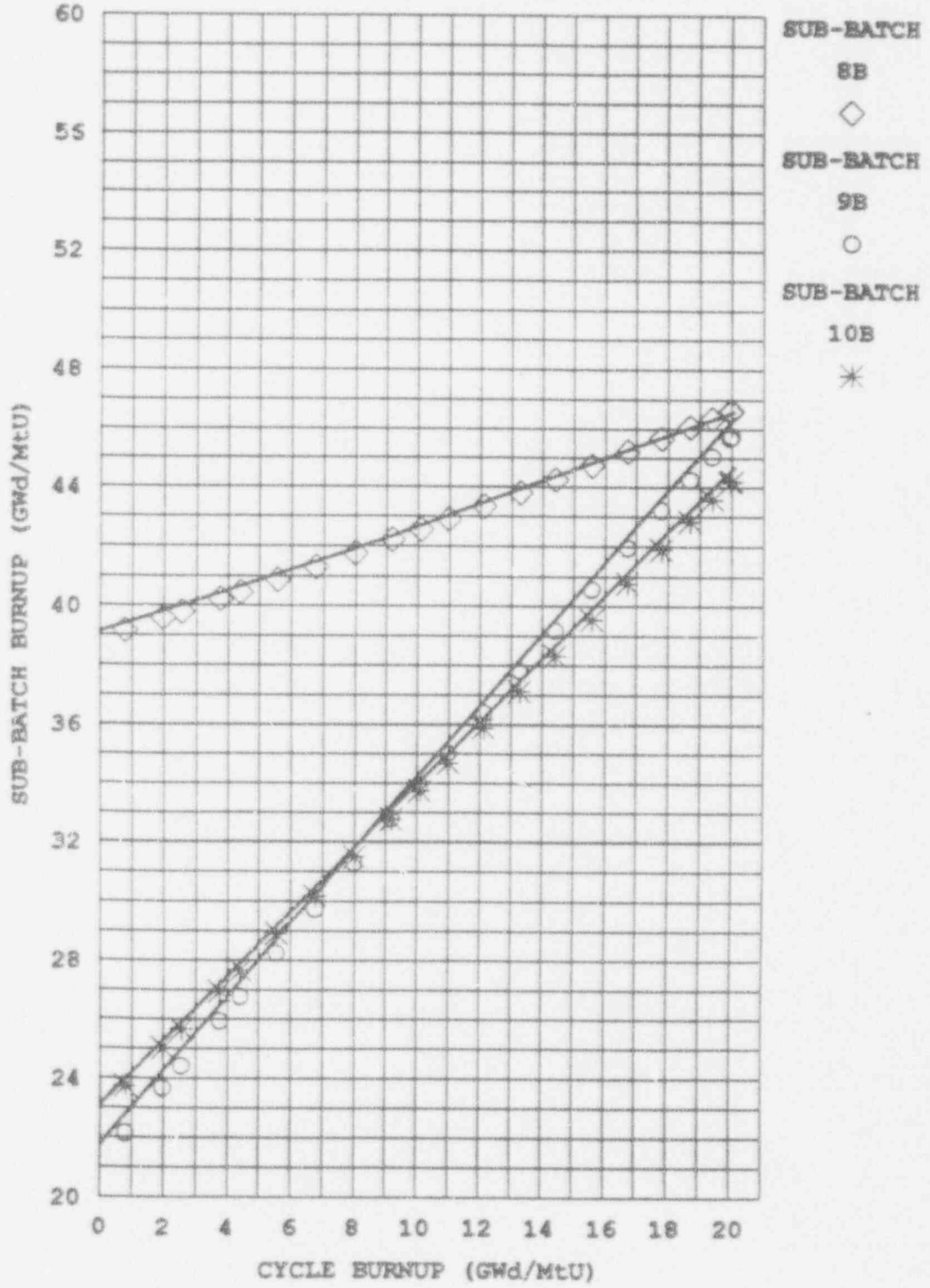
LINES ARE PREDICTED VALUES, SYMBOLS ARE MEASURED VALUES.

Figure 2.5B
NORTH ANNA UNIT 1 - CYCLE 9
SUB-BATCH BURNUP SHARING



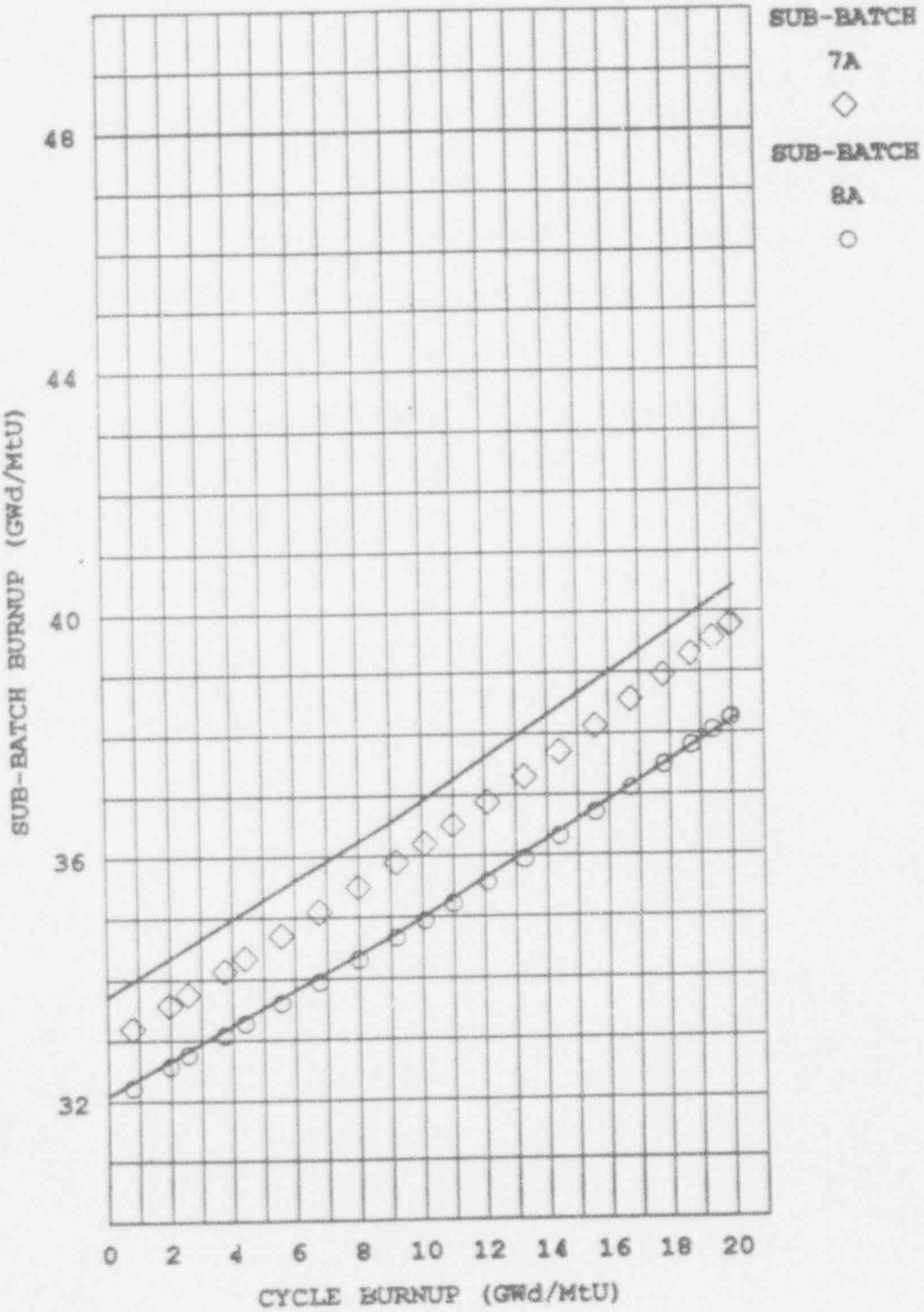
LINES ARE PREDICTED VALUES, SYMBOLS ARE MEASURED VALUES.

Figure 2.5C
NORTH ANNA UNIT 1 - CYCLE 9
SUB-BATCH BURNUP SHARING



LINES ARE PREDICTED VALUES, SYMBOLS ARE MEASURED VALUES.

Figure 2.5D
NORTH ANNA UNIT 1 - CYCLE 9
SUB-BATCH BURNUP SHARING



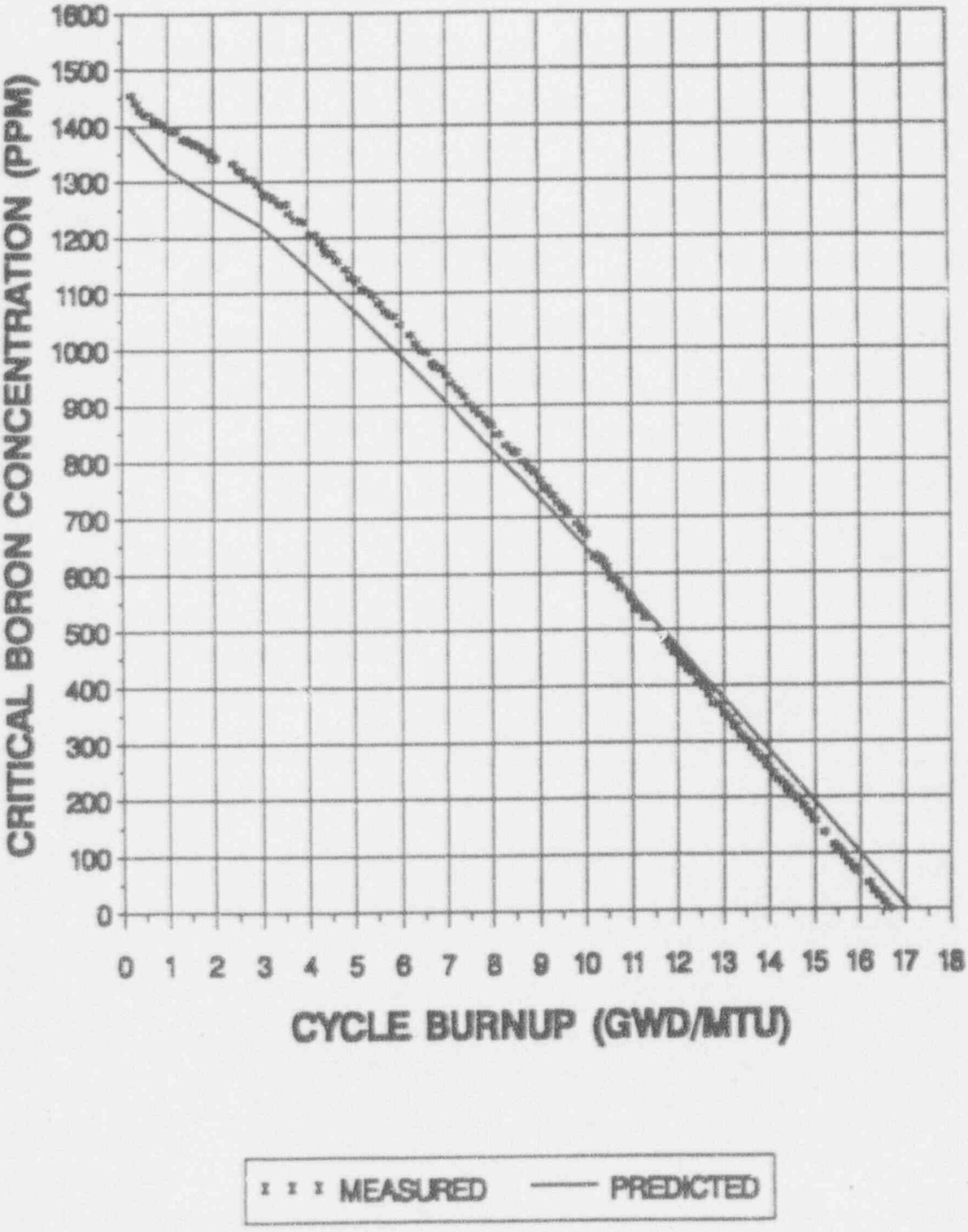
LINES ARE PREDICTED VALUES, SYMBOLS ARE MEASURED VALUES.

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* 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 1, Cycle 9 core is shown in Figure 3.1. It can be seen that the measured data typically compared to within 82 ppm of the design prediction. This corresponds to ±0.54% 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 9 core depleted as expected without any reactivity anomalies.

Figure 3.1
NORTH ANNA UNIT 1 - CYCLE 9
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] computer program. A summary of all full core flux maps taken for North Anna 1, Cycle 9 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 9. The measured relative assembly powers were generally within 8.7% and the maximum average percent difference was equal to 2.1%. 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 1 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 before and after the mid-cycle steam generator inspection outage.

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 9, 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 9 is given in Figure 4.8. The FQ*P Limit included in Figure 4.8 was the more limiting specification, for the majority of core heights, which was the limit following the mid-cycle steam generator tube plugging. Figure 4.9 shows the maximum values for the heat flux measured during Cycle 9. 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 12.4% 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 9, 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 9 is given in Figure 4.10. As can be seen from this figure, the minimum margin to the limit was approximately 1.7%.

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 -4.2% 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 9. Delta flux values oscillated between -4.2% and -5.0% and then, at a burnup of nearly 14000 MWD/MTU, began an increase to -2.4% before the coastdown. At the end of Cycle 9, the target delta flux increased to 14.5% 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 N1-9-06 (Figure 4.12), taken at 305 MWD/MTU, the axial power distribution had a shape peaked toward the middle of the core with a peaking factor of 1.245. In Map N1-9-19 (Figure 4.13), taken at 9842 MWD/MTU, the axial power distribution peaked slightly toward the bottom of the core with an axial peaking factor of 1.162. Finally, in Map N1-9-29 (Figure 4.14), taken at 16,830 MWD/MTU, the axial peaking factcr was 1.138, 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 1, Cycle 9 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 1 - CYCLE 9
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 [1] 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)	CORE TILT [2] MAX	LOC	AXIAL OFF SET (%)	NO. OF THIMBLES
6	03-19-91	305	99.87	228	H03	IB	37	1.922	J08	PI	1.413	37	1.245	1.012	NW	-3.861	46
7	03-25-91	549	99.42	228	H03	IB	36	1.915	J08	PI	1.417	37	1.243	1.010	NW	-6.233	45
8	04-01-91	823	99.21	228	H03	IB	37	1.911	J08	PI	1.421	37	1.242	1.010	NW	-3.886	46
11	04-22-91	1647	100	228	J08	PI	38	1.912	J08	PI	1.436	37	1.235	1.009	NW	-4.172	46
12	05-28-91	2626	98.75	228	J08	PI	37	1.935	J08	PI	1.458	37	1.230	1.008	NW	-4.642	46
13	06-17-91	3228	99.84	228	J06	MI	37	1.896	J08	PI	1.457	38	1.208	1.007	NW	-4.365	46
14	07-22-91	4037	99.50	228	J06	MI	38	1.896	J08	PI	1.466	38	1.199	1.006	NW	-4.262	46
15	08-21-91	5159	99.70	228	J08	PI	45	1.867	J08	PI	1.461	44	1.176	1.005	NW	-4.643	46
16	09-19-91	6306	100	228	J08	PI	46	1.871	J08	PI	1.461	46	[illegible]	1.004	NE	-5.043	46
17	10-18-91	7459	99.80	228	J08	PI	46	1.856	F07	IJ	1.460	47	1.167	1.005	NE	-4.816	46
18	11-19-91	8729	99.90	228	J08	OM	48	1.849	F07	IJ	1.459	47	1.163	1.005	NE	-4.638	46
19	12-17-91	9842	99.98	228	J08	OM	48	1.845	F07	IJ	1.457	48	1.162	1.005	NE	-6.931	46
20	03-16-92	10411	94.92	228	F07	IJ	49	1.827	F07	IJ	1.455	48	1.152	1.005	NE	-4.303	46
21	03-22-92	10642	95.08	228	F07	IJ	49	1.826	F07	IJ	1.454	48	1.154	1.006	NE	-4.496	46
22	03-27-92	10823	94.89	228	F07	IJ	52	1.816	F07	IJ	1.450	48	1.150	1.006	NE	-4.187	46
23	04-09-92	11310	94.89	228	F07	IJ	53	1.818	J06	MI	1.445	52	1.153	1.005	NE	-6.358	46
25	05-11-92	12508	94.95	228	F07	IJ	53	1.836	F07	IJ	1.439	52	1.161	1.006	NE	-4.743	46
26	06-09-92	13608	94.85	228	F07	IJ	53	1.831	F07	IJ	1.430	53	1.165	1.005	NE	-6.621	46
27	07-09-92	14734	94.91	228	F07	IJ	53	1.798	J06	MI	1.419	53	1.152	1.006	NE	-3.786	46
28	08-06-92	15788	94.86	228	F07	IJ	53	1.778	J06	MI	1.410	53	1.151	1.006	NE	-3.386	46
29	09-03-92	16830	94.91	228	F07	IJ	53	1.746	F07	IJ	1.404	53	1.138	1.006	NE	-2.407	46
30	10-02-92	17850	80.71	228	C10	DM	11	1.814	F07	IJ	1.388	11	1.192	1.007	NE	5.463	46
31	10-30-92	18661	66.27	228	F05	IM	11	1.931	F05	IM	1.393	10	1.275	1.006	NE	10.500	46
32	11-30-92	19304	52.09	228	L10	JI	10	2.036	F05	IM	1.390	10	1.345	1.005	NE	16.475	46

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 9 AND 10 WERE QUARTER-CORE FLUX MAPS TAKEN FOR INCORE/EXCORE CALIBRATION (I/E CALIBRATION). MAP 24 WAS A FLUX MAP TAKEN TO CHECK DETECTOR DRIFT.

Figure 4.1
NORTH ANNA UNIT 1 - CYCLE 9
ASSEMBLYWISE POWER DISTRIBUTION N1-9-06

(Each location: PREDICTED / MEASURED / PCT DIFFERENCE)

Row		R	P	N	M	L	K	J	H	G	F	E	D	C	B	A
1	Predicted							0.30	0.38	0.30						
	Measured							0.30	0.39	0.30						
	Pct Difference							1.8	1.0	1.3						
2	Predicted					0.31	0.60	1.13	0.95	1.14	0.61	0.31				
	Measured					0.32	0.59	1.14	0.95	1.14	0.61	0.32				
	Pct Difference					3.0	-1.5	0.2	0.2	0.3	0.7	1.5				
3	Predicted				0.34	1.10	1.21	1.14	1.33	1.14	1.22	1.10	0.35			
	Measured				0.35	1.12	1.22	1.14	1.33	1.15	1.22	1.11	0.35			
	Pct Difference				2.2	2.0	0.2	0.0	-0.0	0.3	0.6	1.2	2.4			
4	Predicted			0.34	0.80	1.25	1.17	1.28	1. 9	1.28	1.17	1.25	0.81	0.34		
	Measured			0.35	0.82	1.28	1.20	1.30	1.21	1.28	1.17	1.25	0.80	0.34		
	Pct Difference			1.9	1.7	2.1	2.3	1.5	1.4	0.2	0.2	-0.1	-0.2	-0.6		
5	Predicted		0.31	1.09	1.24	1.15	1.28	1.14	1.30	1.14	1.28	1.15	1.24	1.10	0.31	
	Measured		0.31	1.09	1.25	1.17	1.31	1.17	1.34	1.16	1.28	1.14	1.22	1.07	0.31	
	Pct Difference		0.0	0.0	0.9	1.2	1.9	3.1	3.1	1.8	0.1	-0.8	-1.6	-2.1	-1.3	
6	Predicted		0.60	1.21	1.17	1.28	1.19	1.30	1.12	1.30	1.19	1.28	1.17	1.21	0.60	
	Measured		0.61	1.22	1.18	1.30	1.22	1.35	1.16	1.34	1.20	1.25	1.14	1.18	0.59	
	Pct Difference		0.7	0.7	1.1	1.5	2.8	3.8	3.4	2.7	1.0	-2.1	-2.1	-2.7	-2.4	
7	Predicted	0.30	1.13	1.14	1.28	1.14	1.30	1.13	1.28	1.13	1.30	1.14	1.28	1.14	1.13	0.30
	Measured	0.30	1.12	1.13	1.28	1.14	1.32	1.17	1.32	1.16	1.33	1.13	1.23	1.10	1.09	0.29
	Pct Difference	1.4	-0.5	-0.4	-0.2	0.1	1.3	3.5	3.1	2.3	1.9	-0.9	-3.8	-3.4	-3.4	-2.9
8	Predicted	0.38	0.94	1.32	1.19	1.30	1.12	1.28	1.23	1.28	1.12	1.30	1.19	1.32	0.94	0.38
	Measured	0.37	0.93	1.31	1.19	1.32	1.15	1.33	1.27	1.29	1.13	1.29	1.14	1.27	0.92	0.38
	Pct Difference	-2.5	-0.6	-0.7	0.3	1.2	2.1	3.8	3.0	0.8	0.8	-1.0	-3.8	-3.4	-2.3	-1.5
9	Predicted	0.30	1.13	1.14	1.28	1.14	1.30	1.13	1.28	1.13	1.30	1.14	1.28	1.14	1.13	0.30
	Measured	0.29	1.10	1.11	1.27	1.15	1.31	1.12	1.27	1.13	1.30	1.14	1.26	1.13	1.12	0.30
	Pct Difference	-2.4	-2.4	-2.4	-0.5	1.5	0.7	-0.8	-0.8	0.0	-0.0	0.2	-1.8	-1.0	-0.7	0.5
10	Predicted		0.60	1.21	1.17	1.28	1.19	1.30	1.12	1.30	1.19	1.28	1.17	1.21	0.60	
	Measured		0.59	1.18	1.18	1.31	1.21	1.29	1.11	1.28	1.18	1.28	1.18	1.23	0.61	
	Pct Difference		-2.4	-2.4	0.9	2.6	1.4	-1.0	-1.0	-1.3	-0.7	-0.4	0.6	1.5	1.0	
11	Predicted		0.31	1.09	1.24	1.15	1.28	1.14	1.30	1.14	1.28	1.15	1.24	1.09	0.31	
	Measured		0.31	1.10	1.25	1.18	1.28	1.12	1.29	1.12	1.28	1.15	1.25	1.10	0.32	
	Pct Difference		0.1	0.1	0.8	2.1	-0.0	-1.2	-1.2	-1.2	-0.4	-0.1	0.2	0.6	1.2	
12	Predicted			0.34	0.81	1.25	1.17	1.28	1.19	1.28	1.17	1.25	0.81	0.34		
	Measured			0.35	0.82	1.28	1.18	1.26	1.17	1.25	1.16	1.24	0.81	0.34		
	Pct Difference			2.5	2.3	2.1	0.3	-1.9	-1.9	-2.2	-1.4	-1.1	-0.0	-0.2		
13	Predicted				0.35	1.10	1.22	1.14	1.33	1.14	1.22	1.10	0.35			
	Measured				0.35	1.11	1.21	1.12	1.30	1.11	1.18	1.08	0.34			
	Pct Difference				1.7	0.9	-0.3	-2.2	-2.4	-3.0	-3.1	-2.0	-0.2			
14	Predicted					0.31	0.61	1.14	0.95	1.13	0.60	0.31				
	Measured					0.32	0.62	1.14	0.94	1.10	0.59	0.30				
	Pct Difference					0.9	2.1	0.3	-0.8	-3.0	-3.0	-3.5				
15	Predicted							0.30	0.38	0.29						
	Measured							0.31	0.39	0.28						
	Pct Difference							3.4	0.5	-2.5						

STANDARD DEVIATION =1.067

AVERAGE PCT DIFFERENCE = 1.5

SUMMARY

MAP NO: N1-9-06 DATE: 03/19/91 POWER: 99.87%

CONTROL ROD POSITION: F-Q(T) = 1.922 QPTR:

D BANK AT 228 STEPS F-DH(N) = 1.413

NW 1.0121	NE 0.9973
SW 1.0003	SE 0.9904

F(Z) = 1.245

F(XY) = 1.422

BURNUP = 305 MWD/MTU A.O. = -3.861%

Figure 4.2
NORTH ANNA UNIT 1 - CYCLE 9
ASSEMBLYWISE POWER DISTRIBUTION N1-9-19

PREDICTED
MEASURED
PCT DIFFERENCE

Row	R	P	N	M	L	K	J	H	G	F	E	D	C	B	A
1							0.30	0.38	0.30						
							0.31	0.40	0.31						
							[illegible]	3.9	3.1						
2					0.33	0.59	1.01	0.87	1.01	0.59	0.33				
					0.34	0.58	1.02	0.88	1.03	0.61	0.34				
					4.7	-1.7	1.1	1.1	1.5	2.4	4.0				
3				0.37	1.05	1.21	1.06	1.29	1.06	1.21	1.05	0.37			
				0.38	1.07	1.19	1.06	1.29	1.07	1.23	1.09	0.39			
				1.8	1.5	-1.7	-0.2	-0.3	0.7	1.8	3.1	5.7			
4			0.37	0.82	1.27	1.13	1.34	1.15	1.34	1.13	1.27	0.82	0.37		
			0.37	0.82	1.28	1.14	1.35	1.16	1.35	1.14	1.29	0.83	0.38		
			1.6	0.7	1.1	0.7	0.9	0.8	0.3	0.9	1.1	1.1	1.8		
5		0.33	1.05	1.27	1.13	1.37	1.13	1.37	1.13	1.37	1.13	1.27	1.05	0.33	
		0.33	1.04	1.25	1.12	1.37	1.16	1.40	1.15	1.38	1.13	1.25	1.05	0.34	
		-1.2	-1.2	-1.1	-1.0	-0.1	2.2	2.1	1.6	0.9	-0.4	-1.3	-0.2	2.5	
6		0.59	1.21	1.13	1.37	1.18	1.38	1.13	1.38	1.18	1.37	1.13	1.21	0.59	
		0.59	1.21	1.13	1.36	1.19	1.41	1.16	1.41	1.20	1.34	1.11	1.20	0.60	
		0.2	0.2	-0.4	-1.0	0.7	2.3	2.3	2.1	1.3	-1.8	-1.9	-1.0	1.0	
7	0.30	1.01	1.06	1.34	1.13	1.38	1.14	1.38	1.14	1.38	1.13	1.34	1.06	1.01	0.30
	0.30	1.01	1.06	1.33	1.11	1.37	1.16	1.41	1.17	1.41	1.13	1.30	1.05	1.01	0.30
	1.6	-0.1	-0.1	-1.2	-2.2	-0.8	2.0	2.0	2.3	2.4	-0.3	-2.9	-1.4	-0.7	0.1
8	0.39	0.86	1.29	1.15	1.37	1.13	1.38	1.22	1.38	1.13	1.37	1.15	1.29	0.86	0.39
	0.38	0.86	1.29	1.15	1.37	1.14	1.41	1.25	1.40	1.14	1.36	1.12	1.27	0.87	0.39
	-2.0	-0.3	-0.3	-0.1	0.1	0.7	1.9	2.0	1.1	1.1	-0.6	-2.9	-1.4	0.8	2.1
9	0.30	1.01	1.06	1.34	1.13	1.38	1.14	1.38	1.14	1.38	1.13	1.34	1.06	1.01	0.30
	0.29	0.98	1.03	1.33	1.14	1.37	1.11	1.35	1.15	1.39	1.14	1.34	1.08	1.04	0.31
	-3.8	-2.9	-2.9	-1.3	0.3	-0.7	-2.6	-2.6	0.5	0.4	1.0	-0.2	1.7	2.7	4.5
10		0.59	1.21	1.13	1.37	1.18	1.38	1.13	1.38	1.18	1.37	1.13	1.21	0.59	
		0.57	1.16	1.13	1.39	1.18	1.35	1.10	1.35	1.17	1.37	1.15	1.26	0.63	
		-3.8	-3.8	-0.2	1.7	0.2	-2.5	-2.5	-2.2	-1.0	-0.2	1.7	4.3	6.2	
11		0.33	1.05	1.27	1.13	1.37	1.13	1.37	1.13	1.37	1.13	1.27	1.05	0.33	
		0.33	1.05	1.27	1.14	1.35	1.10	1.33	1.10	1.36	1.14	1.30	1.09	0.35	
		-0.1	-0.1	0.4	1.3	-1.4	-2.7	-2.7	-2.4	-0.8	0.7	2.3	3.7	5.5	
12			0.37	0.82	1.27	1.13	1.34	1.15	1.34	1.13	1.27	0.82	0.37		
			0.38	0.84	1.29	1.12	1.31	1.12	1.31	1.11	1.26	0.84	0.38		
			3.6	2.5	1.3	-1.0	-2.7	-2.6	-2.7	-1.6	-0.6	2.4	3.2		
13				0.37	1.05	1.21	1.06	1.29	1.06	1.21	1.05	0.37			
				0.38	1.08	1.21	1.03	1.27	1.04	1.19	1.05	0.38			
				3.2	2.8	-0.2	-2.7	-1.9	-2.0	-2.0	-0.8	3.0			
14					0.33	0.59	1.01	0.87	1.01	0.59	0.33				
					0.34	0.62	1.04	0.88	0.99	0.58	0.32				
					2.8	4.9	2.6	1.5	-1.8	-1.8	-3.4				
15							0.30	0.38	0.29						
							0.32	0.40	0.29						
							7.2	3.7	-0.1						

STANDARD DEVIATION =1.339

AVERAGE PCT DIFFERENCE = 1.8

SUMMARY

MAP NO: N1-9-19 DATE: 12/17/91 POWER: 99.98%

CONTROL ROD POSITION: F-Q(T) = 1.845 QPTR:

D BANK AT 228 STEPS F-DH(N) = 1.457

NW 1.0019	NE 1.0049
SW 0.9942	SE 0.9991

F(Z) = 1.162

F(XY) = 1.472

BURNUP = 9842 MWD/MTU A.O. = -4.931%

Figure 4.3
NORTH ANNA UNIT 1 - CYCLE 9
ASSEMBLYWISE POWER DISTRIBUTION N1-9-29

PREDICTED
MEASURED
PCT DIFFERENCE

Row	R	P	N	M	L	K	J	H	G	F	E	D	C	B	A
1							0.34	0.44	0.34						
							0.36	0.46	0.36						
							4.4	4.4	4.8						
2					0.36	0.63	1.04	0.90	1.04	0.63	0.37				
					0.38	0.62	1.05	0.92	1.06	0.65	0.39				
					6.0	-1.9	1.3	1.3	2.0	3.5	5.5				
3				0.41	1.06	1.20	1.06	1.30	1.06	1.20	1.06	0.41			
				0.42	1.08	1.17	1.05	1.29	1.07	1.23	1.10	0.44			
				2.4	2.0	-2.0	-0.6	-0.6	1.0	2.6	4.3	7.5			
4			0.41	0.85	1.27	1.10	1.32	1.13	1.32	1.10	1.27	0.85	0.41		
			0.42	0.86	1.28	1.11	1.32	1.13	1.32	1.12	1.29	0.87	0.42		
			2.0	1.1	1.2	0.1	0.4	0.4	0.3	1.3	1.7	1.8	2.6		
5		0.37	1.06	1.27	1.11	1.33	1.11	1.35	1.11	1.33	1.11	1.27	1.06	0.37	
		0.37	1.05	1.25	1.09	1.33	1.12	1.37	1.12	1.35	1.11	1.25	1.06	0.38	
		-0.2	-0.2	-1.2	-1.5	-0.6	1.5	1.5	1.3	1.3	-0.2	-1.3	0.2	3.5	
6		0.63	1.20	1.11	1.33	1.15	1.35	1.11	1.35	1.15	1.33	1.11	1.20	0.63	
		0.63	1.20	1.10	1.31	1.15	1.37	1.12	1.37	1.16	1.31	1.08	1.19	0.64	
		0.5	0.5	-0.5	-1.6	-0.0	1.5	1.4	1.3	1.0	-2.0	-2.1	-0.7	2.0	
7	0.34	1.04	1.06	1.32	1.11	1.35	1.11	1.35	1.11	1.35	1.11	1.32	1.06	1.04	0.34
	0.35	1.03	1.05	1.30	1.08	1.33	1.12	1.36	1.13	1.38	1.10	1.28	1.05	1.04	0.35
	1.1	-0.4	-0.3	-1.6	-2.8	-1.5	1.1	1.1	1.5	1.6	-1.0	-3.2	-1.2	-0.1	0.9
8	0.45	0.90	1.29	1.13	1.35	1.11	1.35	1.18	1.35	1.11	1.35	1.13	1.29	0.90	0.45
	0.44	0.90	1.29	1.12	1.34	1.11	1.36	1.19	1.35	1.11	1.33	1.09	1.28	0.92	0.46
	-2.1	-0.5	-0.6	-0.5	-0.5	0.0	0.9	1.0	0.2	0.3	-1.4	-3.1	-1.2	1.5	3.0
9	0.34	1.04	1.06	1.32	1.11	1.35	1.11	1.35	1.11	1.35	1.11	1.32	1.06	1.04	0.34
	0.33	1.01	1.03	1.30	1.10	1.34	1.07	1.30	1.11	1.35	1.11	1.32	1.08	1.07	0.36
	-3.2	-2.6	-2.6	-1.4	-0.2	-1.4	-3.7	-3.7	-0.4	-0.5	0.5	-0.1	2.1	3.5	5.5
10		0.63	1.20	1.11	1.33	1.15	1.35	1.11	1.35	1.15	1.33	1.11	1.20	0.63	
		0.61	1.16	1.11	1.36	1.14	1.31	1.07	1.31	1.13	1.33	1.12	1.26	0.68	
		-3.2	-3.2	-0.1	1.6	-0.2	-3.5	-3.4	-3.1	-1.7	-0.6	1.7	5.0	7.4	
11		0.37	1.06	1.27	1.11	1.33	1.11	1.35	1.11	1.33	1.11	1.27	1.06	0.37	
		0.37	1.06	1.28	1.13	1.31	1.07	1.30	1.07	1.32	1.12	1.30	1.10	0.39	
		0.6	0.6	1.0	1.6	-1.9	-3.5	-3.5	-3.3	-1.3	0.6	3.0	4.7	6.9	
12			0.41	0.85	1.27	1.10	1.32	1.13	1.32	1.10	1.27	0.85	0.41		
			0.43	0.88	1.29	1.09	1.28	1.09	1.28	1.08	1.26	0.88	0.43		
			4.4	3.0	1.6	-1.2	-3.2	-3.2	-3.1	-1.8	-0.6	3.3	4.5		
13				0.41	1.06	1.20	1.06	1.29	1.06	1.20	1.06	0.41			
				0.43	1.10	1.20	1.02	1.27	1.04	1.18	1.05	0.43			
				4.6	4.5	0.4	-3.2	-1.9	-1.6	-1.3	-0.2	4.3			
14					0.37	0.63	1.04	0.90	1.04	0.63	0.37				
					0.38	0.67	1.07	0.92	1.02	0.62	0.36				
					4.5	6.5	3.2	2.1	-1.4	-1.1	-2.9				
15							0.34	0.44	0.34						
							0.37	0.47	0.34						
							8.6	4.8	0.0						

STANDARD DEVIATION =1.696

AVERAGE PCT DIFFERENCE = 2.1

SUMMARY

MAP NO: N1-9-29

DATE: 09/03/92

POWER: 94.91%

CONTROL ROD POSITION:

D BANK AT 228 STEPS

F-Q(T) = 1.746

F-DH(N) = 1.484

F(Z) = 1.138

F(XY) = 1.416

BURNUP = 16830 MWD/MTU

QPTR:

NW 0.9997	NE 1.0061
SW 0.9945	SE 0.9997

A.O.=-2.407%

Figure 4.4
NORTH ANNA Unit 1 - CYCLE 9
HOT CHANNEL FACTOR NORMALIZED
OPERATING ENVELOPE

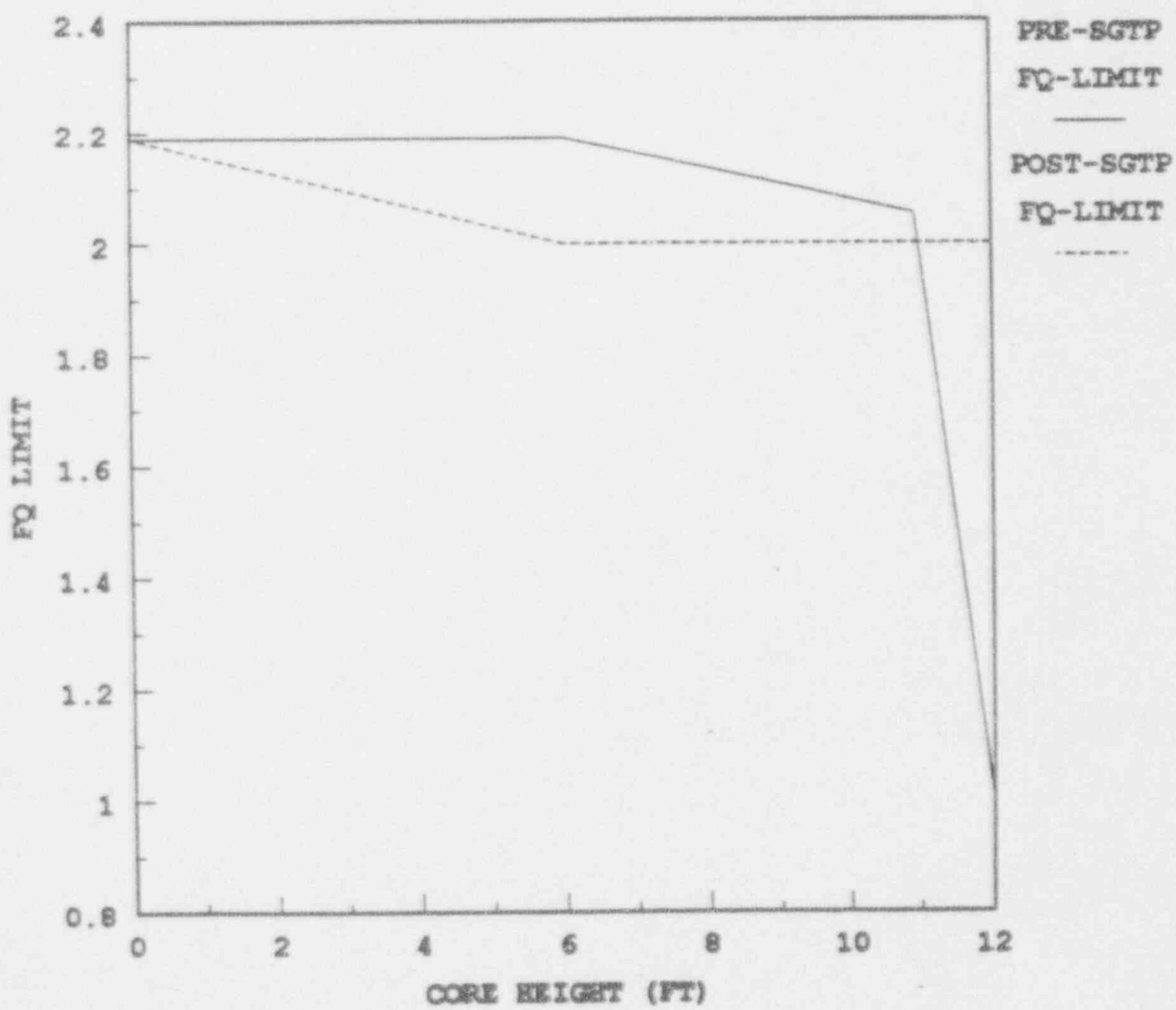


Figure 4.5
NORTH ANNA Unit 1 - CYCLE 9
HEAT FLUX HOT CHANNEL FACTOR, $F_Q(Z)$
N1-9-06

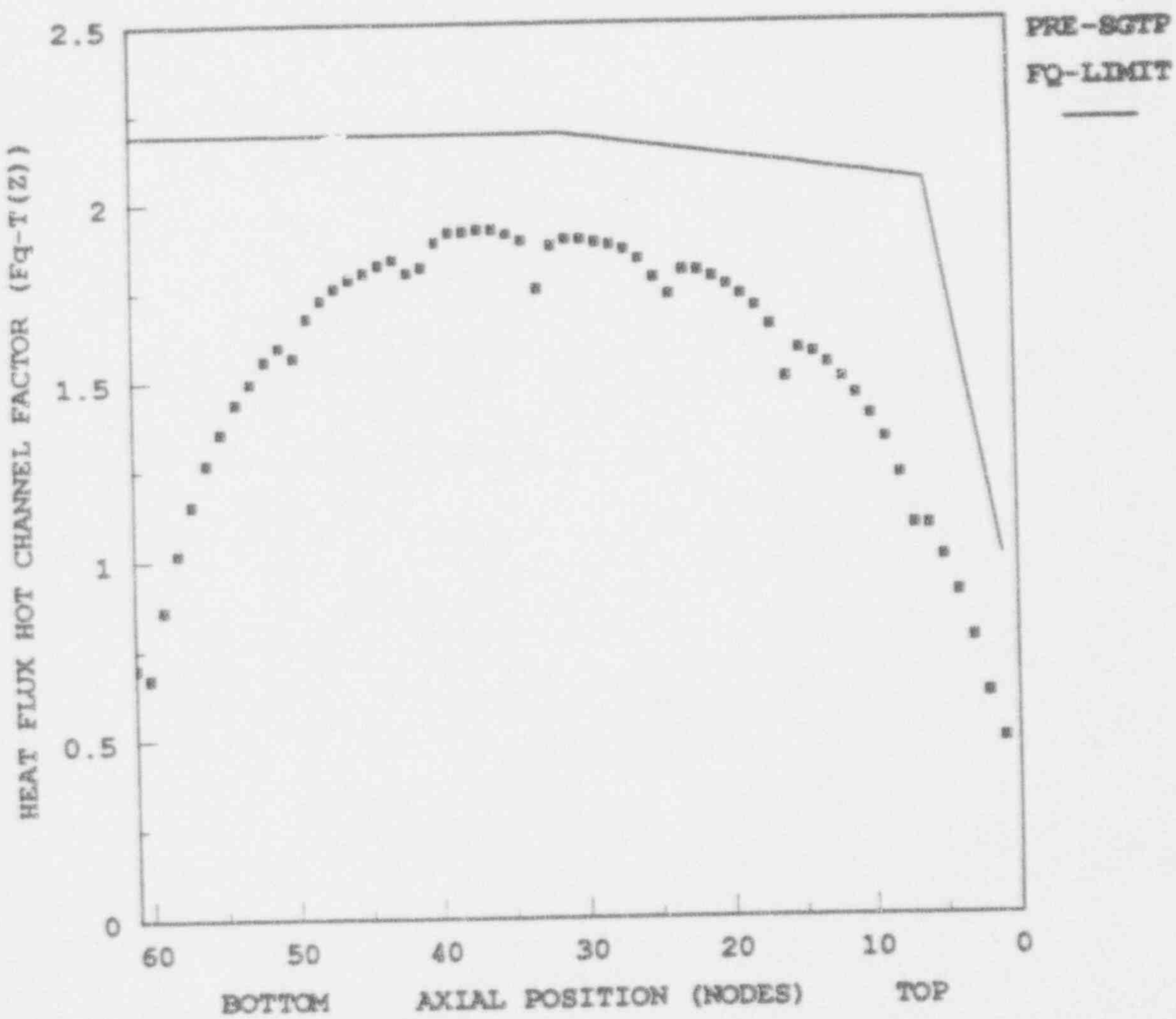


Figure 4.6
NORTH ANNA Unit 1 - CYCLE 9
HEAT FLUX HOT CHANNEL FACTOR, $F_Q(Z)$
N1-9-19

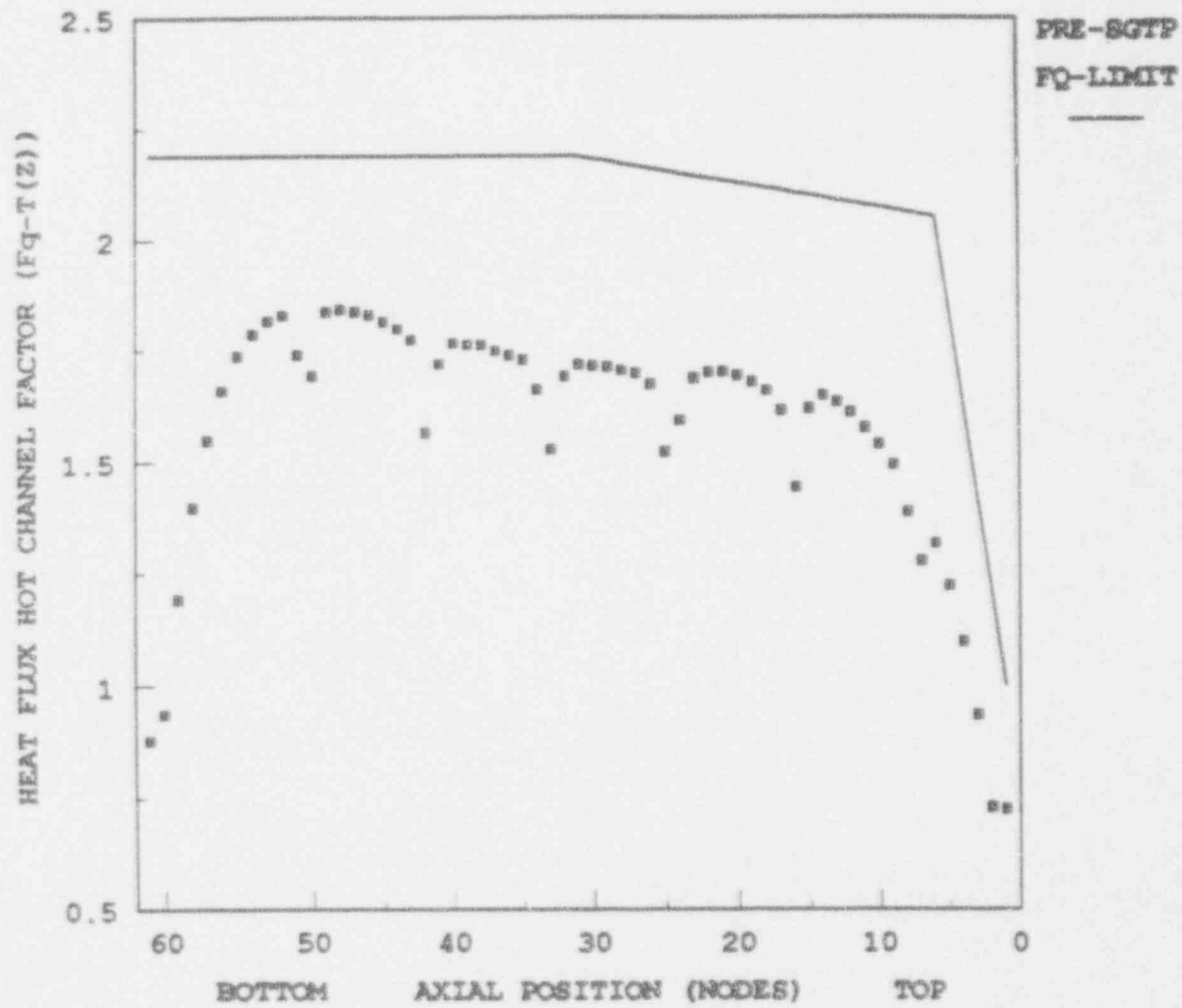


Figure 4.7
NORTH ANNA Unit 1 - CYCLE 9
HEAT FLUX HOT CHANNEL FACTOR, $F_Q(Z)$
N1-9-29

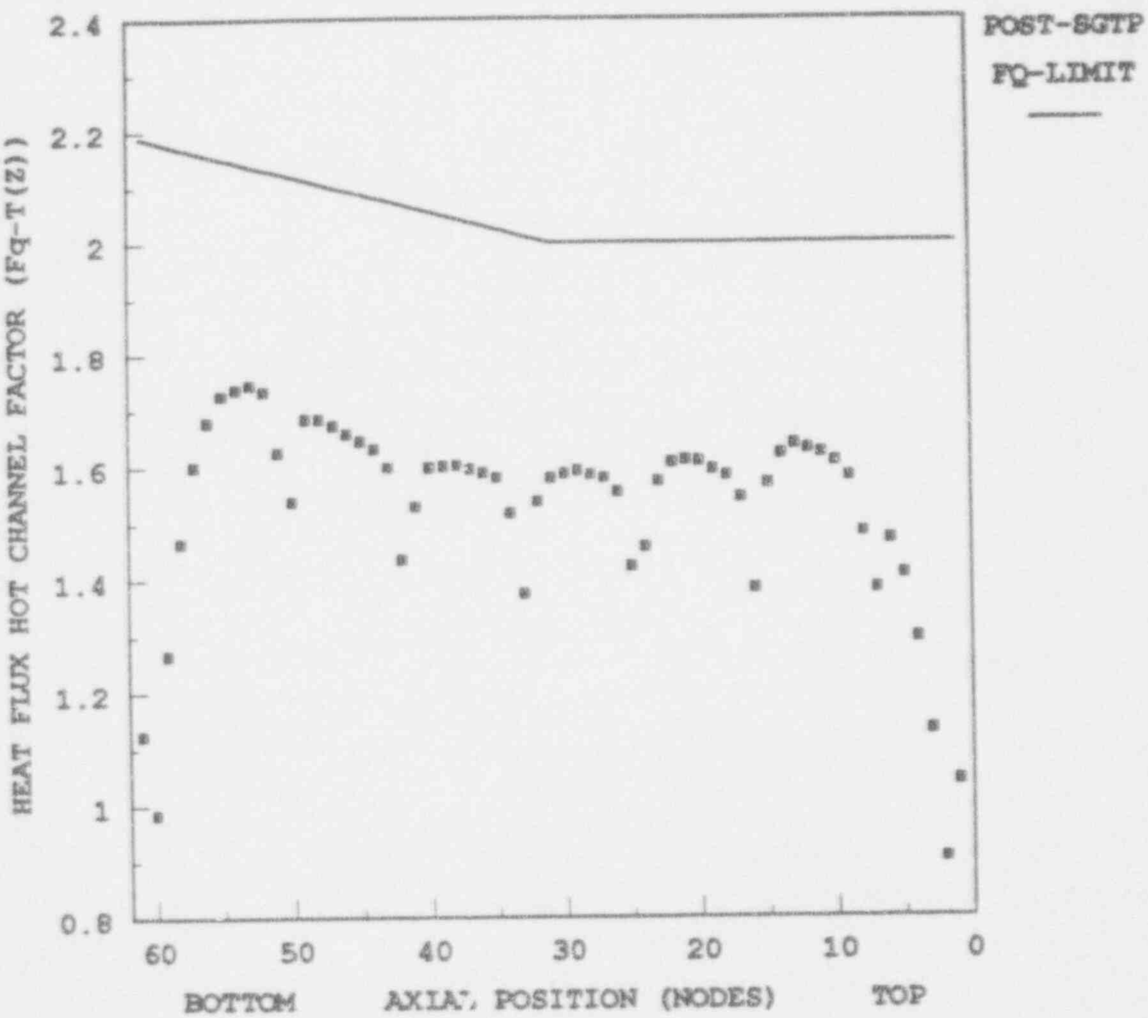
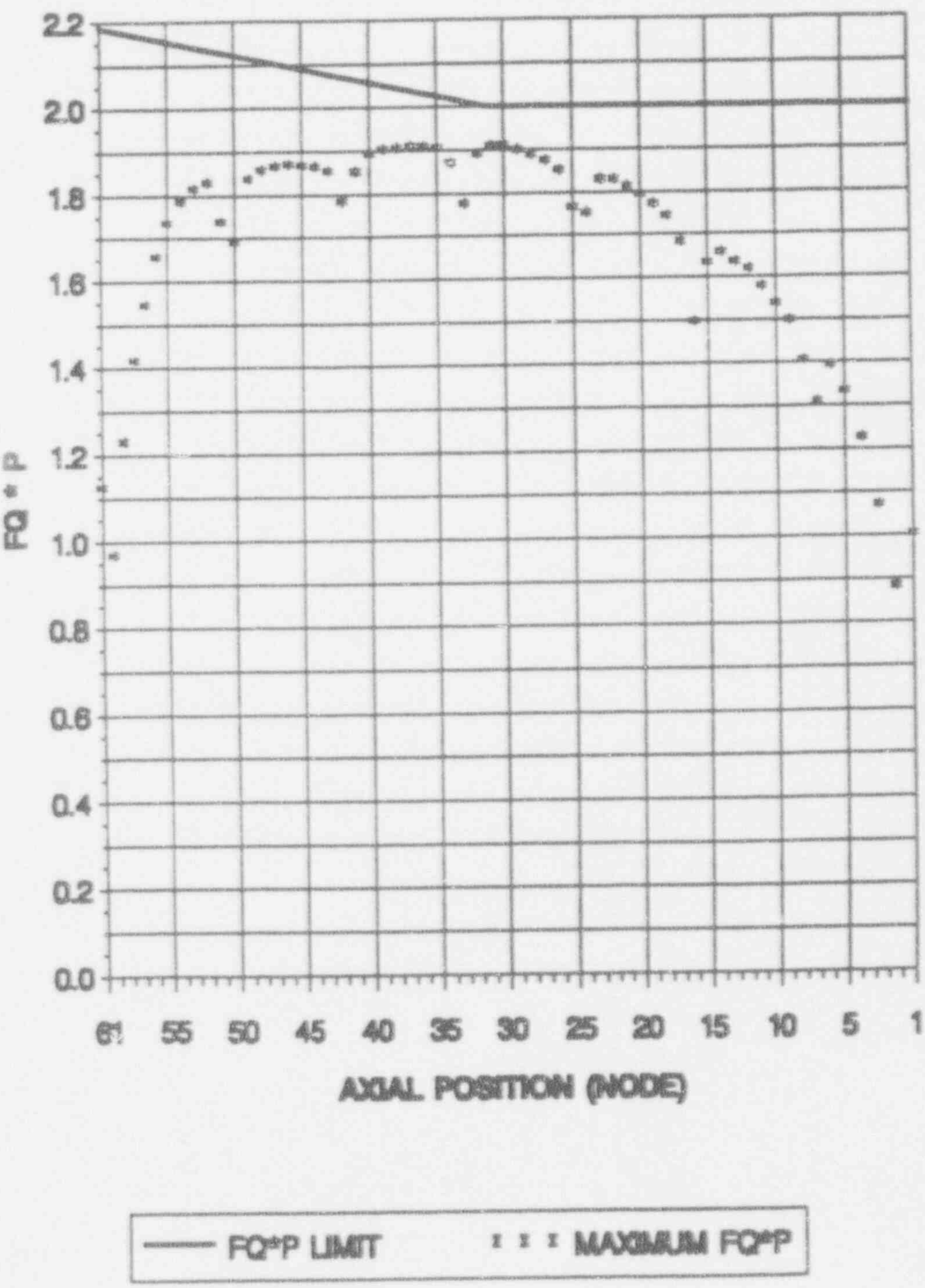


Figure 4.8
NORTH ANNA Unit 1 - CYCLE 9
MAXIMUM HEAT FLUX HOT CHANNEL FACTOR, $F_Q(Z)*P$, vs. AXIAL POSITION



BOTTOM OF CORE

TOP OF CORE

Figure 4.9
NORTH ANNA Unit 1 - CYCLE 9
MAXIMUM HEAT FLUX HOT CHANNEL FACTOR, $F_Q(Z)$, vs. BURNUP

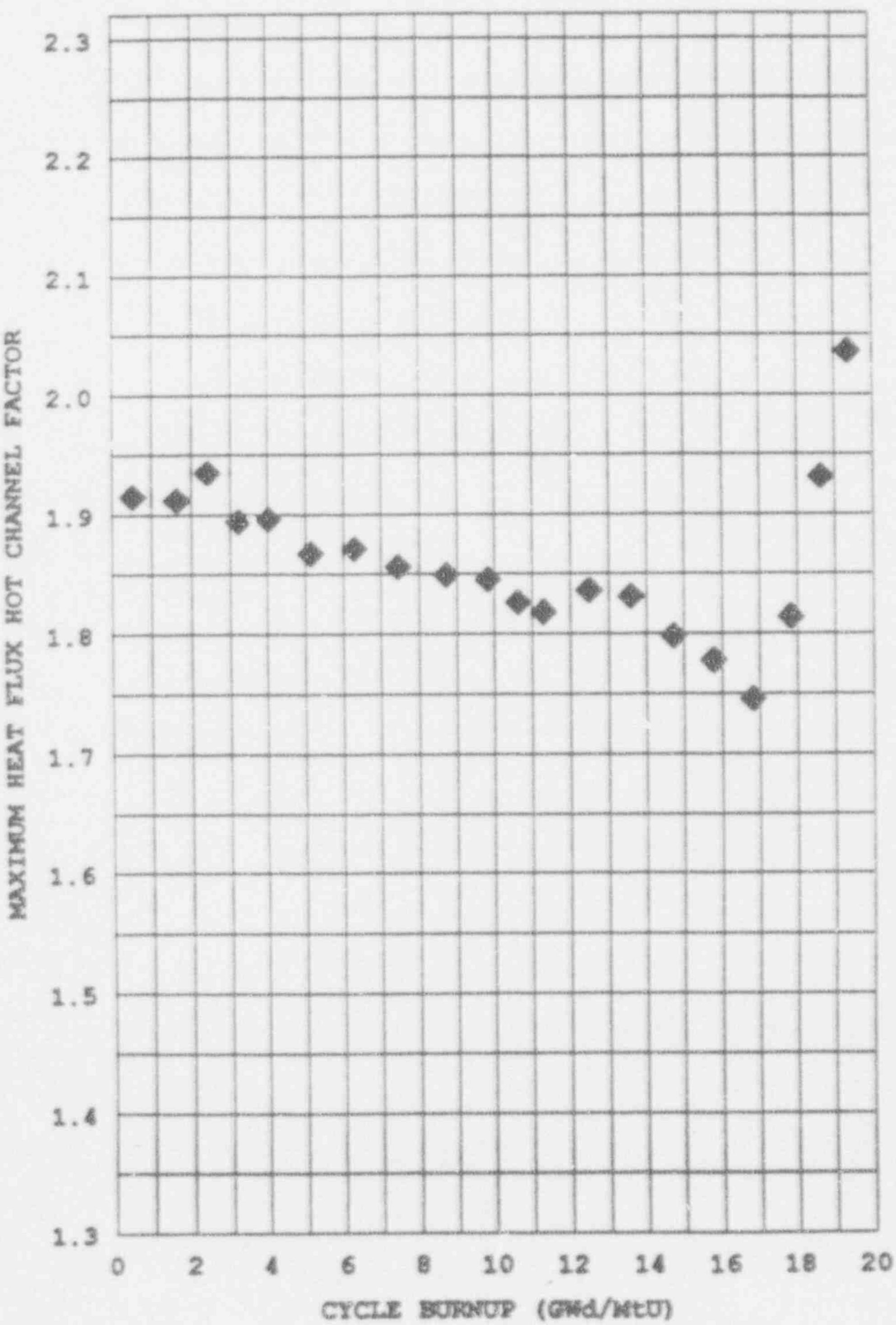


Figure 4.10
NORTH ANNA Unit 1 - CYCLE 9
MAXIMUM ENTHALPY RISE HOT CHANNEL FACTOR, F-delta-H, vs. BURNUP

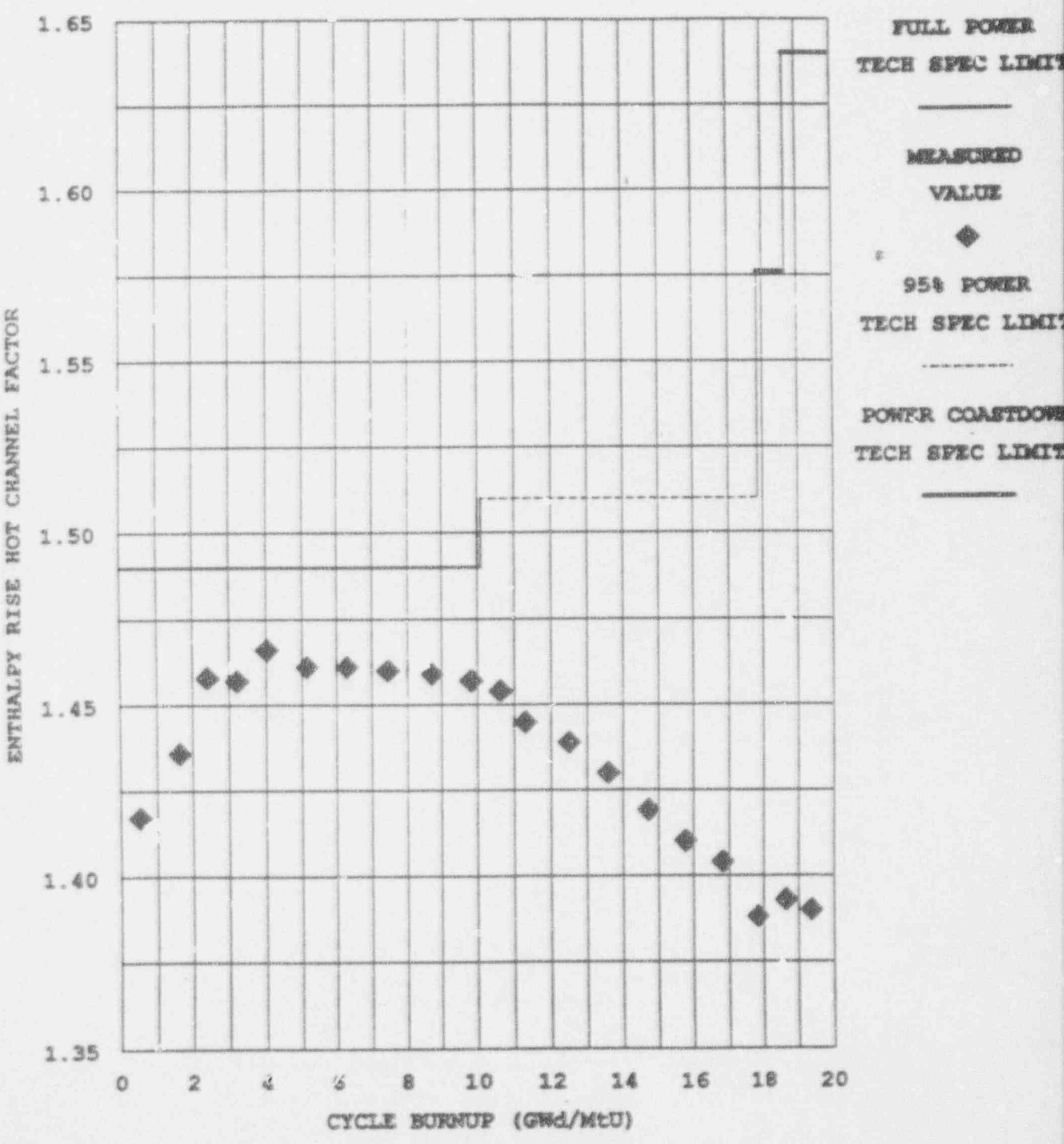


Figure 4.11
NORTH ANNA Unit 1 - CYCLE 9
TARGET DELTA FLUX vs. BURNUP

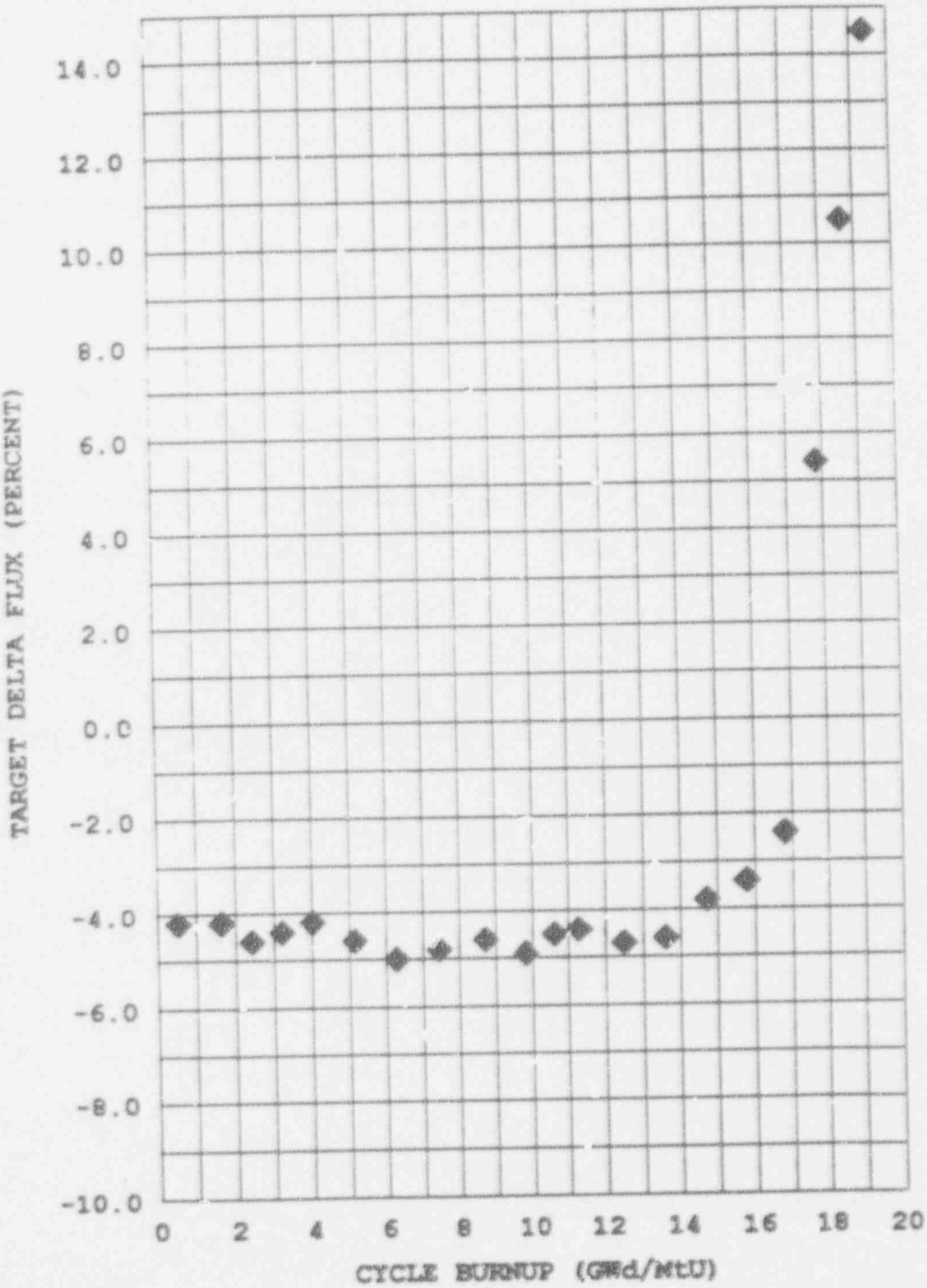


Figure 4.12
NORTH ANNA Unit 1 - CYCLE 9
CORE AVERAGE AXIAL POWER DISTRIBUTION
N1-9-06

Fz = 1.245
AXIAL OFFSET = -3.861%

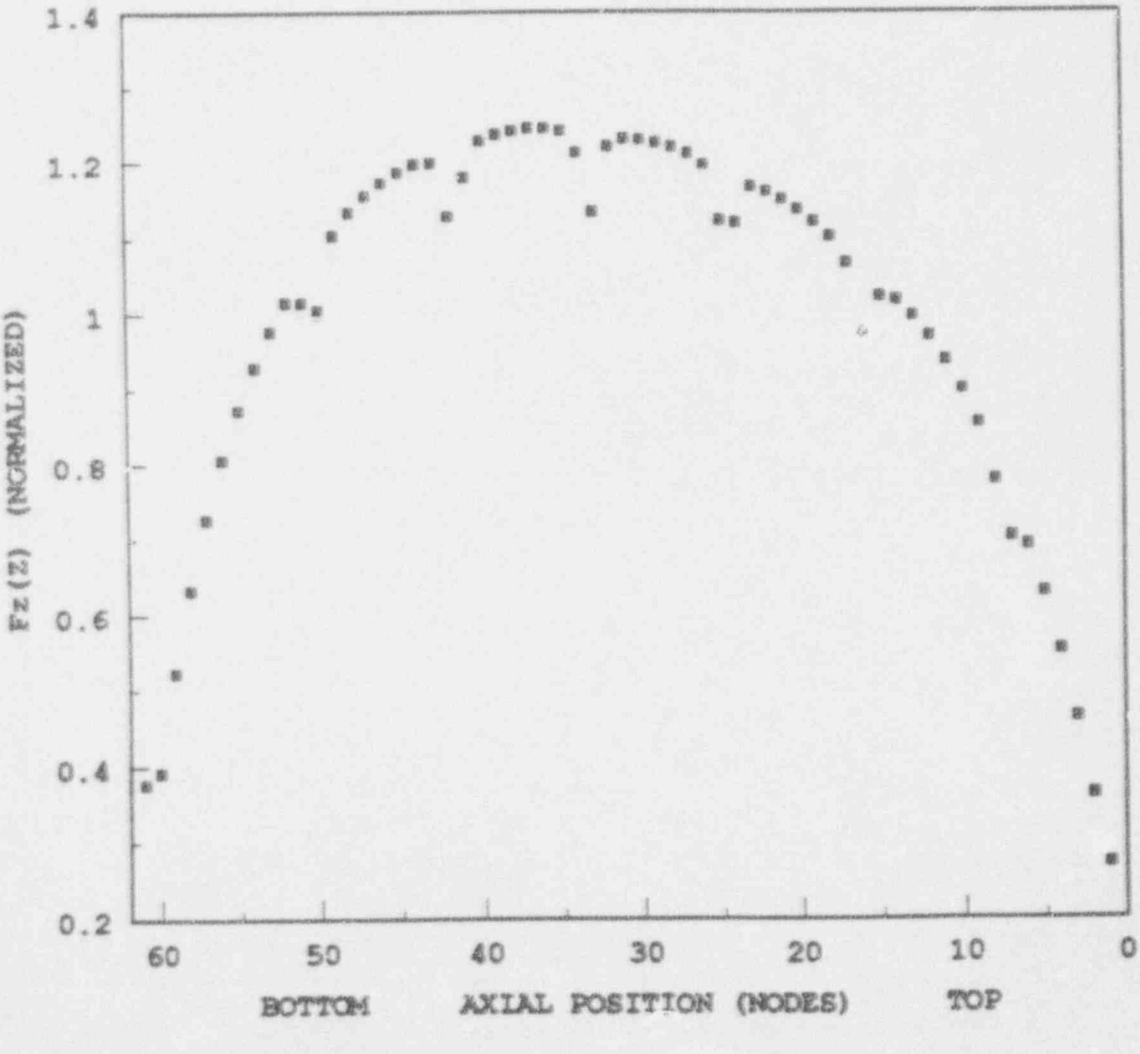


Figure 4.13
NORTH ANNA Unit 1 - CYCLE 9
CORE AVERAGE AXIAL POWER DISTRIBUTION
N1-9-19

Fz = 1.162
AXIAL OFFSET = -4.931%

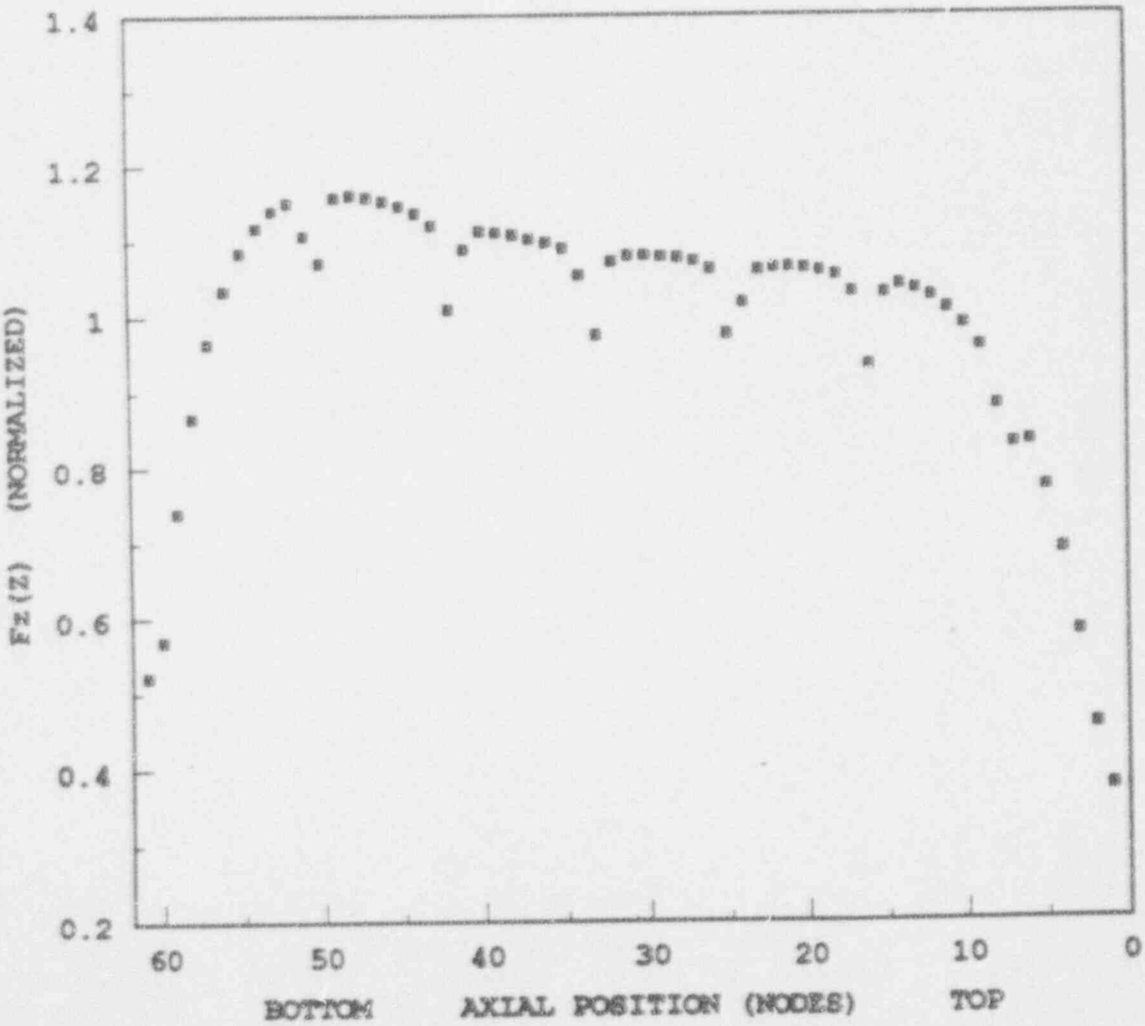


Figure 4.14
NORTH ANNA Unit 1 - CYCLE 9
CORE AVERAGE AXIAL POWER DISTRIBUTION
N1-9-29

Fz = 1.138
AXIAL OFFSET = -2.407

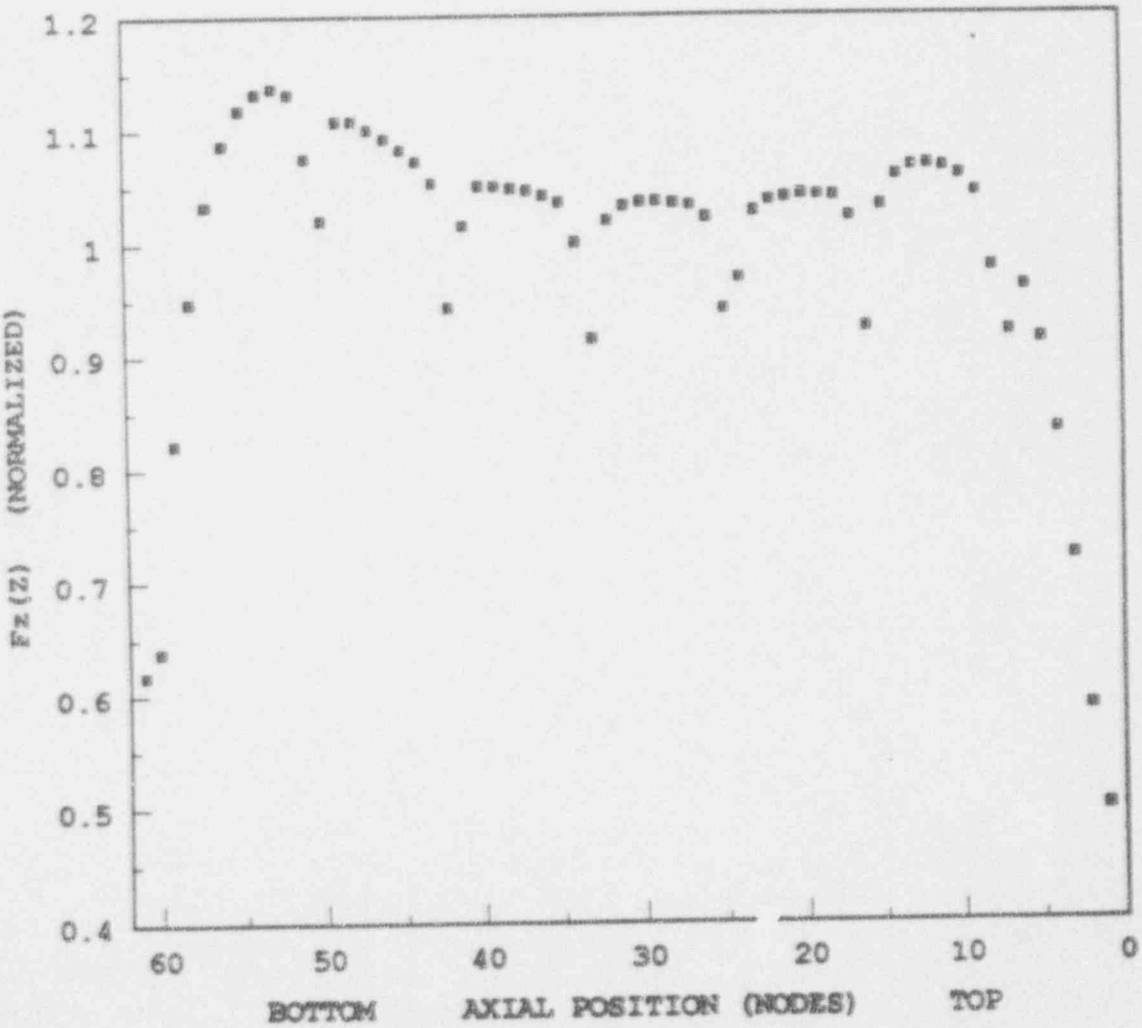
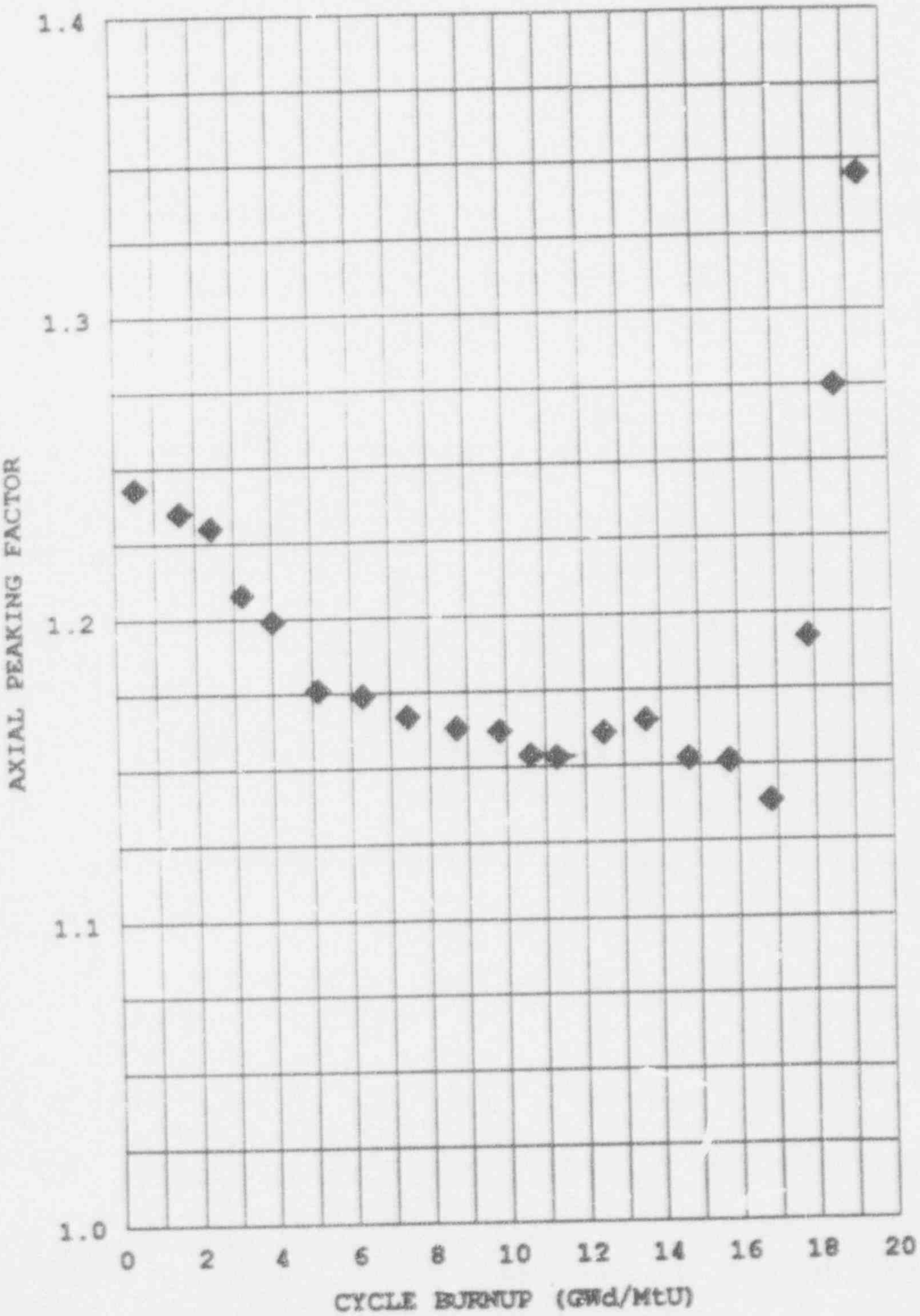


Figure 4.15
NORTH ANNA Unit 1 - CYCLE 9
CORE AVERAGE AXIAL PEAKING FACTOR vs. BURNUP



Section 5

PRIMARY COOLANT ACTIVITY

The specific activity levels of radioiodines in the primary coolant are important to core and fuel performanc 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, when present, are generally the predominant source of radioiodines in the primary coolant.

North Anna 1 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 9. 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 5.51 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 cycle average tramp corrected iodine-131 concentration was 2.58 X 10^{-3} μCi/gm with an average demineralizer flow rate of approximately 99 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 1 Cycle 9. 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 0.4 to 0.3 toward the middle and end of cycle. This indicates that the defects in the cladding were likely to be small to moderately sized.

Fuel ultrasonic testing was performed during the Cycle 9 to Cycle 10 refueling outage. Two fuel rods in two fuel assemblies were confirmed to be defective. The two fuel assemblies are 1A9 and 3A4. Both assemblies are from the new fuel batch for Cycle 9. Evaluation of possible failure mechanisms is currently in process. These fuel assemblies will be restricted from further use in accordance with the Zero Defect Policy[12] pending any repair projects to replace the defective fuel rods.

Figure 5.1
NORTH ANNA UNIT 1 - CYCLE 9
DOSE EQUIVALENT I-131 vs. TIME

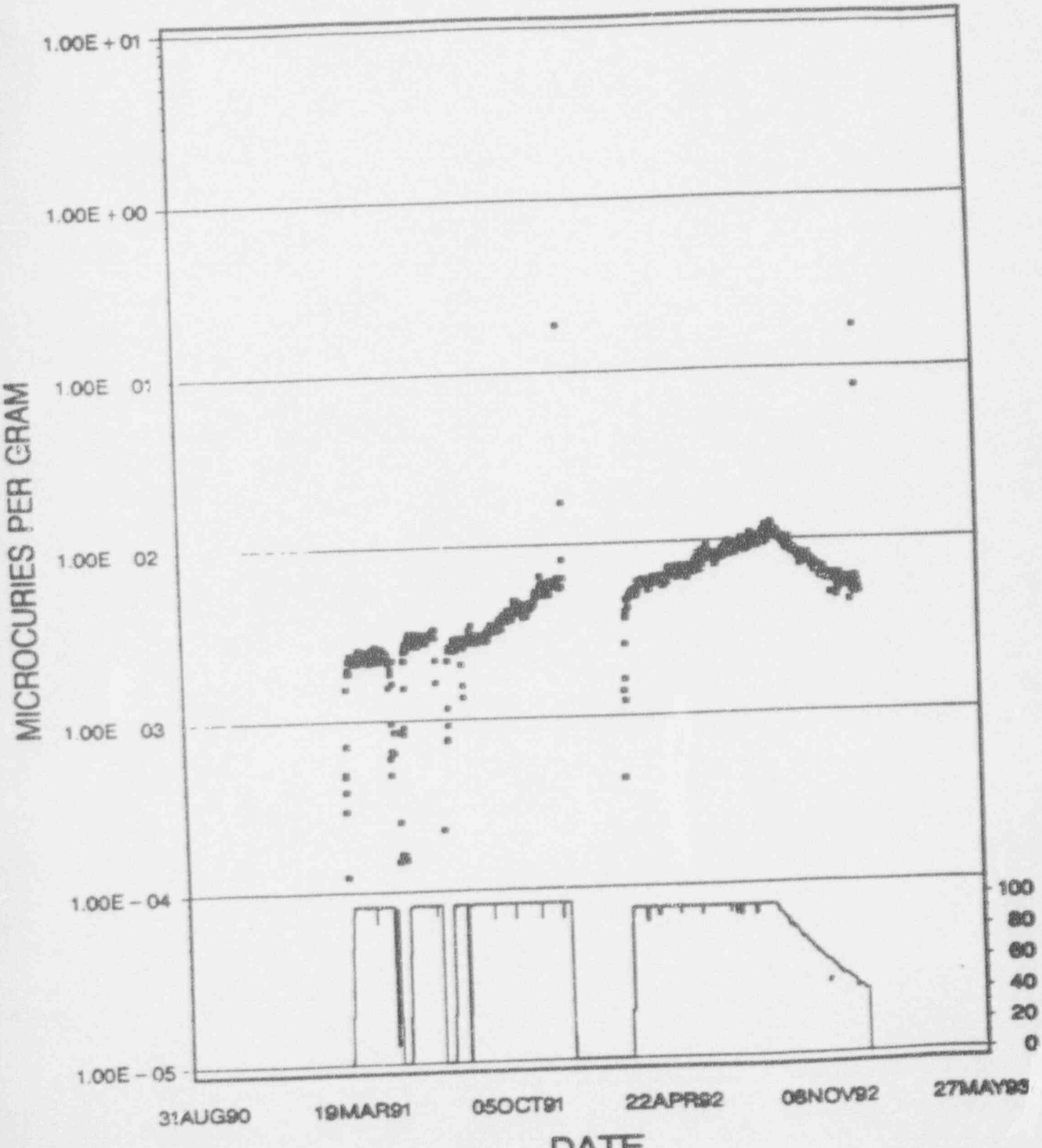
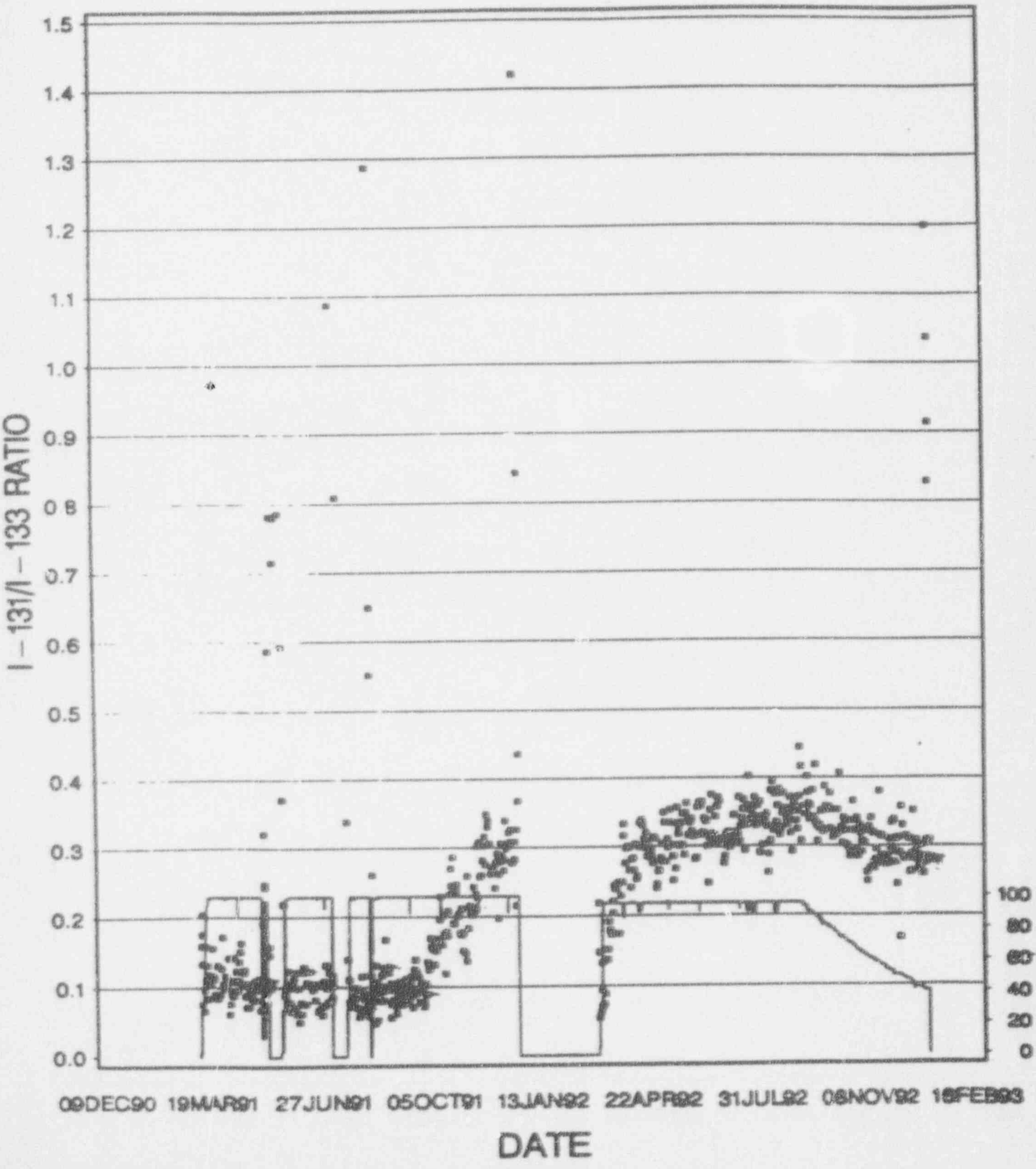


Figure 5.2
NORTH ANNA UNIT 1 - CYCLE 9
I-131 / I-133 ACTIVITY RATIO vs. TIME



Section 6

CONCLUSIONS

The North Anna 1, Cycle 9 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 9. During ultrasonic testing of the fuel, two fuel rods in two fuel assemblies were determined to be defective, where both of the fuel assemblies were fresh. These two assemblies will be restricted from further use in accordance with the Zero Defect Policy[12], pending repair.

Section 7

REFERENCES

1) A. H. Nicholson, "North Anna Unit 1, Cycle 9 Startup Physics Test Report," NE-840, May, 1991.

2) North Anna Power Station Unit 1 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) D. M. Chapman,"North Anna 1, Cycle 9 FOLOW Input and Calculations", PM-371, Rev. 0, Addendum D, January 1993.

8) R. T. Robins, "Reload Safety Evaluation North Anna 1 Cycle 9 Pattern R8 Restart and Continued Operation, Appendix A: North Anna 1 Cycle 9 Core Operating Limits Report Revision 1". NE-879, Virginia Power, February, 1992.

REFERENCES (cont.)

9) T. S. Psuik, "North Anna 1 Cycle 9 Design Report" NE-824, Virginia Power, February, 1991.

10) P. D. Banning, "North Anna 1 Cycle 9 TOTE Calculations", PM-369, March, 1991.

11) D. A. Trace, "Evaluation of North Anna 1 Cycle 9 Movable Detector Flux Maps", PM-370, March, 1991.

12) Nuclear Standard, "Fuel Integrity Monitoring", ENNS-2904 Rev. 0, 5/26/92.