North Anna Unit 1 Cycle 11 Core Performance Report

Nuclear Analysis and Fuel
Nuclear Engineering & Services

April, 1996

VIRGINIA POWER

9606050193 960603
PDR ADOCK 05000338
P PDR

North Anna Unit 1 Cycle 11 Core Performance Report

Nuclear Analysis and Fuel
Nuclear Engineering & Services

April, 1996

VIRGINIA POWER

9606050193 960503
PDR ADOCK 05000338
P PDR

TECHNICAL REPORT NE-1068 - REV. 0

NORTH ANNA UNIT 1, CYCLE 11

CORE PERFORMANCE REPORT

NUCLEAR ANALYSIS AND FUEL
NUCLEAR ENGINEERING & SERVICES
VIRGINIA POWER
APRIL, 1996

PREPARED BY: J. M. Mirilovich — 4-19-96 Date

REVIEWED BY: T. S. Psuik — 4/19/96 Date

REVIEWED BY: T. A. Brookmire — 4-19-96 Date

REVIEWED BY: A. P. Main — 4-29-96 Date

APPROVED BY: D. Dziadosz — 4/30/96 Date

QA Category: Nuclear Safety Related

Keywords: N1C11, N1CB, Core Performance Report

CLASSIFICATION/DISCLAIMER

The data, techniques, information, and conclusions in this report have been prepared solely for use by Virginia Electric and Power Company (the Company), and they may not be appropriate for use in situations other than those for which they have been specifically prepared. The Company therefore makes no claim or warranty whatsoever, express or implied, as to their accuracy, usefulness, or applicability. In particular, THE COMPANY MAKES NO WARRANTY OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE, NOR SHALL ANY WARRANTY BE DEEMED TO ARISE FROM COURSE OF DEALING OR USAGE OF TRADE, with respect to this report or any of the data, techniques, information, or conclusions in it. By making this report available, the Company does not authorize its use by others, and any such use is expressly forbidden except with the prior written approval of the Company. Any such written approval shall itself be deemed to incorporate the disclaimers of liability and disclaimers of warranties provided herein. In no event shall the Company be liable, under any legal theory whatsoever (whether contract, tort, warranty, or strict or absolute liability), for any property damage, mental or physical injury or death, loss of use of property, or other damage resulting from or arising out of the use, authorized or unauthorized, of this report or the data, techniques, information, or conclusions in it.

TABLE OF CONTENTS

		PAGE
Table of Contents		2
List of Tables		3
List of Figures		4
Section 1	Introduction and Summary	6
Section 2	Burnup	13
Section 3	Reactivity Depletion	23
Section 4	Power Distribution	25
Section 5	Primary Coolant Activity	45
Section 6	Conclusions	50
Section 7	References	51

LIST OF TABLES

TABLE	TITLE	PAGE
4.1	Summary of Flux Maps for Routine Operation	29

LIST OF FIGURES

FIGURE	TITLE	PAGE
1.1	Core Loading Map	9
1.2	Burnable Poison and Source Assembly Locations	10
1.3	Available Movable Detector Locations	11
1.4	Control Rod Locations	12
2.1	Cycle Burnup History	15
2.2	Monthly Average Load Factors	16
2.3	Assemblywise Accumulated Burnup: Measured and Predicted	17
2.4	Assemblywise Accumulated Burnup: Comparison of Measured and Predicted	18
2.5A	Sub-Batch Burnup Sharing	19
2.5B	Sub-Batch Burnup Sharing	20
2.5C	Sub-Batch Burnup Sharing	21
2.5D	Sub-Batch Burnup Sharing	22
3.1	Critical Boron Concentration versus Burnup - HFP-ARO	24
4.1	Assemblywise Power Distribution - N1-11-04	30
4.2	Assemblywise Power Distribution - N1-11-11	31
4.3	Assemblywise Power Distribution - N1-11-17	32
4.4	Hot Channel Factor Normalized Operating Envelope	33
4.5	Heat Flux Hot Channel Factor, $F_Q(Z)$ - N1-11-04	34
4.6	Heat Flux Hot Channel Factor, $F_Q(Z)$ - N1-11-11	35
4.7	Heat Flux Hot Channel Factor, $F_Q(Z)$ - N1-11-17	36
4.8	Maximum Heat Flux Hot Channel Factor, $F_Q(Z)*P$, vs. Axial Position	37

LIST OF FIGURES

FIGURE	TITLE	PAGE
1.1	Core Loading Map	9
1.2	Burnable Poison and Source Assembly Locations	10
1.3	Available Movable Detector Locations	11
1.4	Control Rod Locations	12
2.1	Cycle Burnup History	15
2.2	Monthly Average Load Factors	16
2.3	Assemblywise Accumulated Burnup: Measured and Predicted	17
2.4	Assemblywise Accumulated Burnup: Comparison of Measured and Predicted	18
2.5A	Sub-Batch Burnup Sharing	19
2.5B	Sub-Batch Burnup Sharing	20
2.5C	Sub-Batch Burnup Sharing	21
2.5D	Sub-Batch Burnup Sharing	22
3.1	Critical Boron Concentration versus Burnup - HFP-ARO	24
4.1	Assemblywise Power Distribution - N1-11-04	30
4.2	Assemblywise Power Distribution - N1-11-11	31
4.3	Assemblywise Power Distribution - N1-11-17	32
4.4	Hot Channel Factor Normalized Operating Envelope	33
4.5	Heat Flux Hot Channel Factor, $F_Q(Z)$ - N1-11-04	34
4.6	Heat Flux Hot Channel Factor, $F_Q(Z)$ - N1-11-11	35
4.7	Heat Flux Hot Channel Factor, $F_Q(Z)$ - N1-11-17	36
4.8	Maximum Heat Flux Hot Channel Factor, $F_Q(Z)*P$, vs. Axial Position	37

LIST OF FIGURES (continued)

FIGURE	TITLE	PAGE
4.9	Maximum Heat Flux Hot Channel Factor, $F_Q(Z)$, vs. Burnup	38
4.10	Maximum Enthalpy Rise Hot Channel Factor, F-delta-H, vs. Burnup	39
4.11	Target Delta Flux vs. Burnup	40
4.12	Core Average Axial Power Distribution - N1-11-04	41
4.13	Core Average Axial Power Distribution - N1-11-11	42
4.14	Core Average Axial Power Distribution - N1-11-17	43
4.15	Core Average Axial Peaking Factor vs. Burnup	44
5.1	Dose Equivalent I-131 vs. Time	47
5.2	I-131/I-133 Activity Ratio vs. Time	48
5.3	Measured RCS Xenon-133 vs. Time	49

Section 1

INTRODUCTION AND SUMMARY

On February 11, 1996, North Anna Unit 1 completed Cycle 11. Since the initial criticality of Cycle 11 on October 08, 1994, the reactor core produced approximately 1.1238 x 10^8 MBTU (18,848 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 11. The physics tests that were performed during the startup of this cycle were covered in the North Anna Unit 1, Cycle 11 Startup Physics Tests Report[1] and, therefore, will not be included here.

North Anna Unit 1 was in coastdown from December 15, 1995, at which time the burnup was approximately 16,950 MWD/MTU. The coastdown accounted for an additional core burnup of roughly 1,898 MWD/MTU from the end of reactivity.

The Cycle 11 core consisted of 10 sub-batches of fuel: four once-burned batches, three from Cycle 10 (batches N2/11A, 12A and 12B) and one from North Anna Unit 2, Cycle 8 (batch N2/10B); four twice-burned batches, two from Cycles 8 and 9 (batches N2/9B and 10B), one from Cycles 7 and 8 (batch 9A), and one from Cycles 9 and 10 (batch 11A); and two fresh batches (batches 13A and 13B). The North Anna Unit 1, Cycle 11 core loading map specifying the fuel batch identifications and fuel assembly locations is

shown in Figure 1.1. The burnable poison locations and source assembly locations are 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 11 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 ±0.20% with the burnup accumulation in each batch deviating from design prediction by no more than 3.33%.

2. Reactivity Depletion - The critical boron concentration, used to monitor reactivity depletion, was consistently within ±0.32% 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 1.4%. 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 11 was approximately 0.00125 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 that there were no defective fuel rods.

Figure 1.1
NORTH ANNA UNIT 1 - CYCLE 11
CORE LOADING MAP

R	P	N	M	L	K	J	H	G	F	E	D	C	B	A	
						11A 1A6	12A 0B9	11A 2A7							1
				N2/11A 0L6	9A J22	13B 5C1	12B 4B3	13B 6C2	9A J34	N2/11A 0L4					2
			10B K60	13B 4C4	13B 5C8	12B 3B1	13B 4C1	12B 2B7	13B 3C4	13B 4C7	10B K58				3
		10B K47	12A 2B3	13B 3C5	12B 3B9	13A 1C0	12A 1B9	13A 0C2	12B 5B3	13B 5C6	12A 1B5	10B K56			4
	N2/11A 0L3	13B 6C3	13B 5C3	12B 5B8	13A 1C9	12A 1B1	13A 2C7	12A 1B2	13A 2C5	12B 5B0	13B 4C0	13B 2C9	N2/11A 0L2		5
	9A J27	13B 3C9	12B 3B6	13A 2C3	12A 2B0	13A 0C6	12B 5B6	13A 1C7	12A 0B3	13A 1C3	12B 3B3	13B 5C9	9A J32		6
11A 1A1	13B 4C6	12B 3B4	13A 0C5	12A 0B6	13A 1C5	12B 4B5	12B 5B2	12B 6B0	13A 0C1	12A 0B2	13A 2C2	12B 3B2	13B 5C0	11A 1A8	7
12A 1B7	12B 3B5	13B 3C1	12A 2B1	13A 0C3	12B 5B1	12B 4B1	N2/10B Y32	12B 2B6	12B 2B5	13A 0C8	12A 0B5	13B 6C4	12B 4B0	12A 0B1	8
11A 1A3	13B 5C7	12B 4B4	13A 1C2	12A 1B6	13A 2C1	12B 3B8	12B 4B7	12B 3B0	13A 1C1	12A 2B4	13A 1C6	12B 5B4	13B 3C3	11A 0A6	9
	9A J18	13B 4C9	12B 4B2	13A 1C8	12A 2B2	13A 2C8	12B 4B6	13A 1C4	12A 0B7	13A 0C4	12B 5B7	13B 4C5	9A J28		10
	N2/11A 0L8	13B 4C2	13B 6C1	12B 5B5	13A 0C9	12A 1B4	13A 2C0	12A 1B8	13A 2C6	12B 4B8	13B 5C5	13B 3C8	N2/11A 0L5		11
		10B K59	12A 0B8	13B 3C7	12B 2B9	13A 2C4	12A 1B3	13A 0C7	12B 4B9	13B 3C2	12A 1B0	10B K52			12
			10B K64	13B 5C4	13B 3C0	12B 5B9	13B 5C2	12B 3B7	13B 6C0	13B 4C8	N2/9B X44				13
				N2/11A 0L1	9A J06	13B 4C3	12B 2B8	13B 3C6	9A J15	N2/11A 0L7					14
						11A 1A2	12A 0B4	11A 0A3							15

|--> BATCH
|--> ASSEMBLY ID

FUEL ASSEMBLY DESIGN PARAMETERS

	SUB-BATCH									
	N2/9B	N2/10B	N2/11A	9A	10B	11A	12A	12B	13A	13B
INITIAL ENRICHMENT (W/O U-235)	4.0057	4.2051	4.0155	3.7944	4.0007	4.0065	4.0036	4.2052	4.0082	4.2097
BURNUP AT BOC 11 (MWD/MTU)	36335	23397	26053	39222	36795	38783	26092	22805	0	0
ASSEMBLY TYPE	17x17	17x17	17x17	17x17	17x17	17x17	17x17	17x17	17x17	17x17
NUMBER OF ASSEMBLIES	1	1	8	8	7	8	24	36	28	36
FUEL RODS PER ASSEMBLY	264	264	264	264	264	264	264	264	264	264

Figure 1.2
NORTH ANNA UNIT 1 - CYCLE 11
BURNABLE POISON AND SOURCE
ASSEMBLY LOCATIONS

R	P	N	M	L	K	J	H	G	F	E	D	C	B	A	
						VSDA	VSDA	VSDA							1
				VSDA		2P BP333		2P BP334		VSDA					2
				6P BP365	18P BP349		20P BP321		18P BP350	6P BP367					3
				20P BP357		24P BP309	SS19	24P BP310		20P BP360					4
	VSDA	6P BP366	20P BP358		24P BP341		24P BP311		24P BP342		20P BP359	6P BP368	VSDA		5
		18P BP356		24P BP343		24P BP325		24P BP326		24P BP344		18P BP351			6
VSDA	2P BP339		24P BP512		24P BP331		4P BP305		24P BP327		24P BP313		2P BP335	VSDA	7
VSDA		20P BP322		24P BP314		4P BP306		4P BP307		24P BP315		20P BP324		VSDA	8
VSDA	2P BP340		24P BP316		24P BP332		4P BP308		24P BP328		24P BP317		2P BP336	VSDA	9
		18P BP355		24P BP345		24P BP329		24P BP330		24P BP346		18P BP352			10
	VSDA	6P BP371	20P BP363		24P BP347		24P BP318		24P BP348		20P BP362	6P BP369	VSDA		11
				20P BP364		24P BP319	SS20	24P BP320		20P BP361					12
				6P BP372	18P BP354		20P BP323		18P BP353	6P BP370					13
				VSDA		2P BP337		2P BP338		VSDA					14
						VSDA	VSDA	VSDA							15

2P - 2 BURNABLE POISON ROD CLUSTER
4P - 4 BURNABLE POISON ROD CLUSTER
6P - 6 BURNABLE POISON ROD CLUSTER
18P - 18 BURNABLE POISON ROD CLUSTER
20P - 20 BURNABLE POISON ROD CLUSTER
24P - 24 BURNABLE POISON ROD CLUSTER
SSxx - SECONDARY SOURCE
VSDA - VIBRATION SUPPRESION DAMPING ASSEMBLY

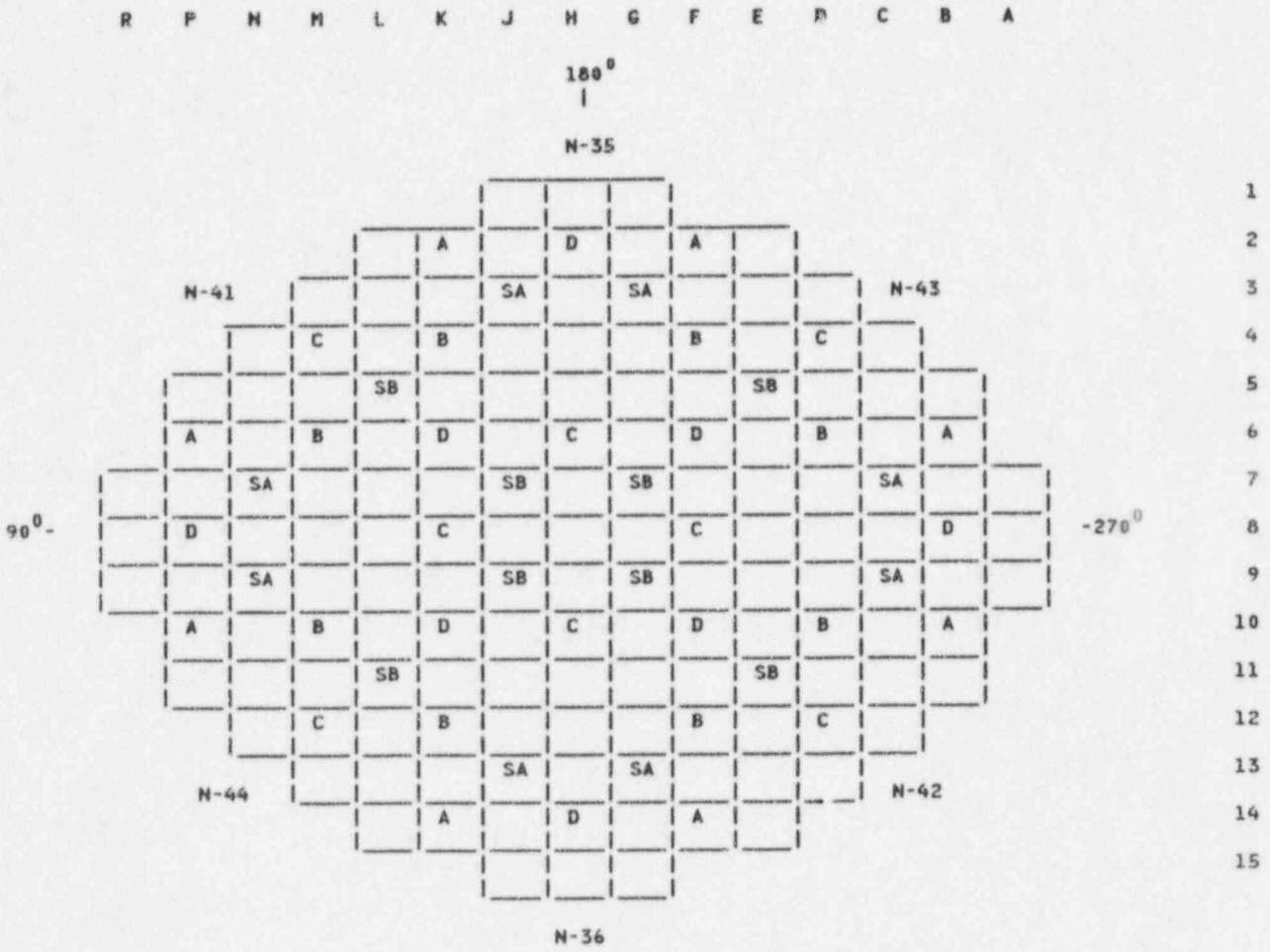
xxP or SSxx	- NO. OF BP RODS or SECONDARY SOURCE ID
BPxxx or VSDA	- BP ASSEMBLY ID or VSDA

Figure 1.3
NORTH ANNA UNIT 1 - CYCLE 11
AVAILABLE 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
** - Locations not available for flux mapping system for Cycle 11

Figure 1.4
NORTH ANNA UNIT 1 - CYCLE 11
CONTROL ROD LOCATIONS



Absober
Material
Ag-In-Cd

Function	Number of Clusters
Control Bank D	8
Control Bank C	8
Control Bank B	8
Control Bank A	8
Shutdown Bank SB	8
Shutdown Bank SA	8

Section 2

BURNUP

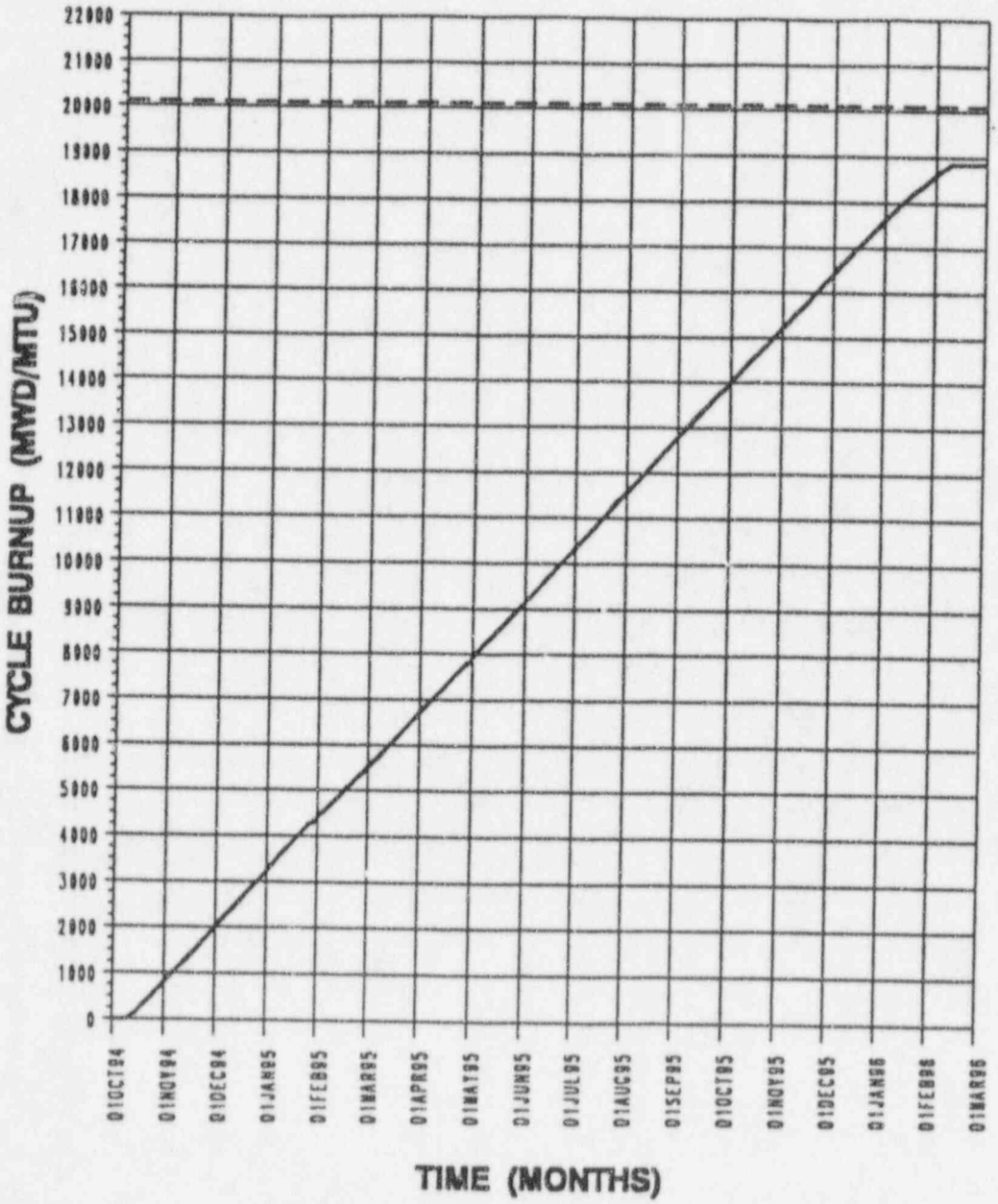
The burnup history for the North Anna Unit 1, Cycle 11 core is graphically depicted in Figure 2.1. The North Anna Unit 1, Cycle 11 core achieved a burnup of 18,848 MWD/MTU. As shown in Figure 2.2, the average load factor for Cycle 11 was 96.8% when referenced to rated thermal power (2893 MW(t)). Unit 1 performed a power coastdown starting on December 15, 1995 until shutdown for refueling on February 11, 1996.

Radial (X-Y) burnup distribution maps show how the core burnup is shared among the various fuel assemblies, and thereby allow a detailed burnup distribution analysis. The TOTE[3] computer code is used to calculate these assemblywise burnups. Figure 2.3 is a radial burnup distribution map in which the core assemblywise burnup accumulation at the end of Cycle 11 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 11 operation is also given. As can be seen from this figure, the accumulated assembly burnups were generally within ±3.33% of the predicted values. In addition, deviation from quadrant symmetry in the core throughout the cycle was no greater than ±0.20%.

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 Unit 1, Cycle 11 followed design predictions closely. The burnups for all batches, except Batch 13A, were within 2% of the predicted values throughout the duration of Cycle 11. The batch 13A burnup difference peaked at 3.36% near BOC and gradually decreased over the remander of the cycle to below 2% at EOC. This difference can be explained by noting that the batch 13A measured powers were generally higher than the predicted powers during the cycle and because this is a fresh batch, the burnup deltas (especially near BOC) result in larger percent differences. Symmetric burnup in conjunction with agreement between actual and predicted assemblywise burnups and batch burnup sharing indicate that the Cycle 11 core did deplete as designed.

Figure 2.1
NORTH ANNA UNIT 1 - Cycle 11
CYCLE BURNUP HISTORY



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

Figure 2.2
NORTH ANNA UNIT 1 - Cycle 11
MONTHLY AVERAGE LOAD FACTORS

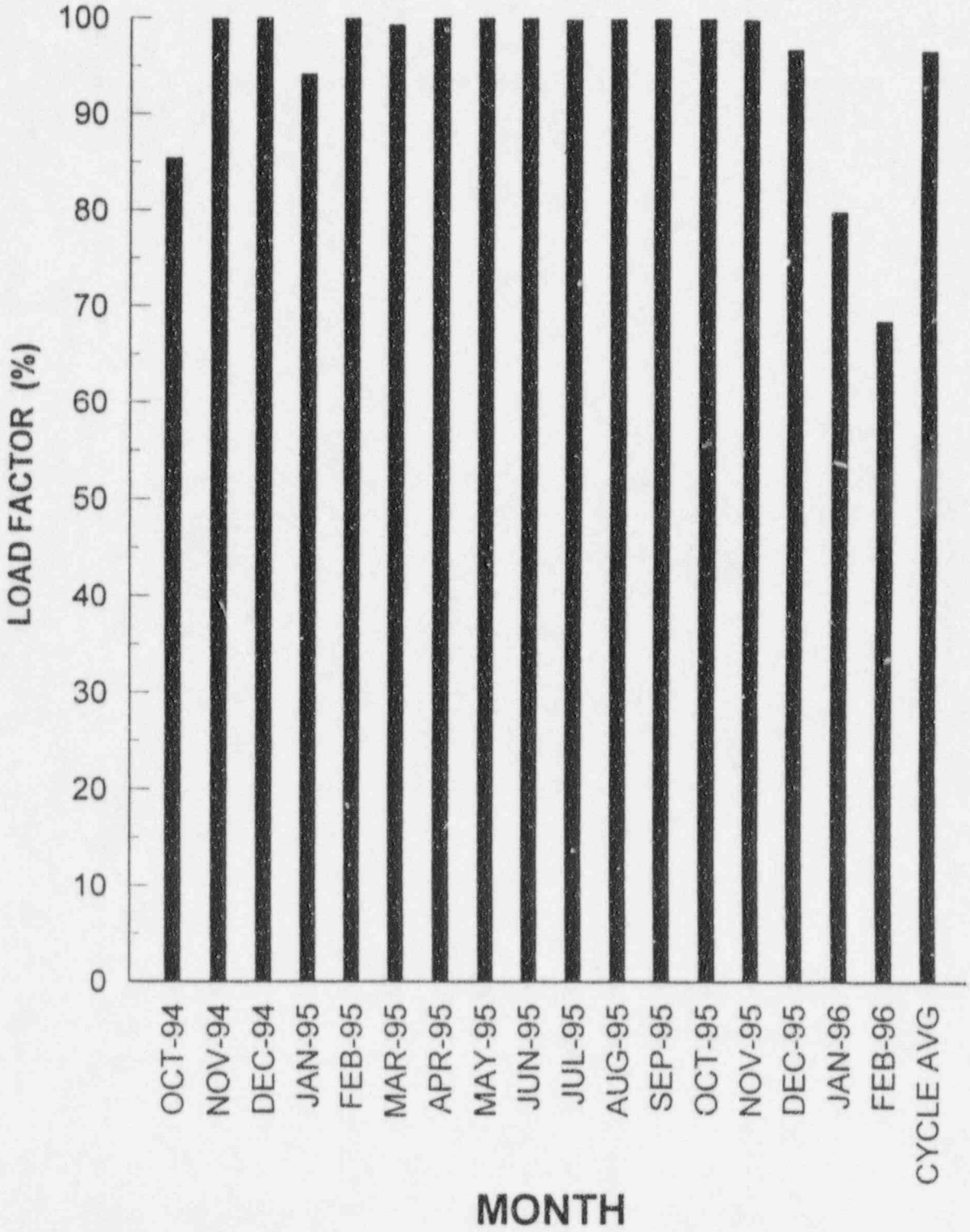


Figure 2.3
NORTH ANNA UNIT 1 - CYCLE 11
ASSEMBLYWISE ACCUMULATED BURNUP
MEASURED AND PREDICTED
(GWD/MTU)

	R	P	N	M	L	K	J	H	G	F	E	D	C	B	A	
1							43.62 / 44.30	34.08 / 33.27	44.51 / 44.30					MEASURED / PREDICTED		1
2					33.81 / 33.50	48.19 / 48.94	18.84 / 19.33	37.84 / 38.28	19.08 / 19.33	48.90 / 48.94	33.96 / 33.50					2
3				44.00 / 43.90	20.06 / 20.50	22.93 / 23.29	44.10 / 44.91	23.63 / 24.17	45.34 / 44.91	23.30 / 23.29	20.49 / 20.50	44.56 / 45.25				3
4			45.54 / 45.25	41.41 / 41.57	23.64 / 24.15	47.77 / 47.29	24.17 / 23.89	47.34 / 47.48	24.33 / 23.89	47.90 / 47.29	24.36 / 24.15	41.56 / 41.57	43.75 / 43.90			4
5		33.40 / 33.49	20.34 / 20.42	24.07 / 24.10	44.06 / 43.96	25.20 / 24.79	48.18 / 47.40	24.54 / 24.00	47.95 / 47.40	25.31 / 24.79	44.52 / 43.96	23.55 / 24.10	20.01 / 20.42	32.92 / 33.49		5
6		49.39 / 48.95	23.19 / 23.26	47.70 / 47.22	24.77 / 24.79	48.08 / 47.95	24.98 / 24.21	47.52 / 47.04	24.97 / 24.21	48.43 / 47.95	25.12 / 24.79	47.64 / 47.22	22.87 / 23.26	48.41 / 48.95		6
7	44.45 / 44.32	19.16 / 19.32	45.10 / 44.91	24.09 / 23.87	48.35 / 47.38	24.66 / 24.09	42.83 / 42.42	41.87 / 41.69	43.05 / 42.42	24.75 / 24.09	48.40 / 47.38	23.67 / 23.87	44.47 / 44.91	19.00 / 19.32	43.72 / 44.32	7
8	34.11 / 33.26	38.58 / 38.26	23.79 / 24.15	47.44 / 47.43	24.38 / 23.94	47.28 / 46.99	41.82 / 41.54	44.74 / 44.85	42.04 / 41.54	47.32 / 46.99	24.44 / 23.94	47.30 / 47.43	23.66 / 24.15	39.22 / 38.26	33.89 / 33.26	8
9	44.22 / 44.32	18.78 / 19.32	43.95 / 44.91	24.07 / 23.87	47.79 / 47.38	24.63 / 24.09	42.85 / 42.42	41.73 / 41.69	42.03 / 42.42	24.21 / 24.09	47.33 / 47.38	24.14 / 23.87	45.64 / 44.91	19.31 / 19.32	44.60 / 44.32	9
10		48.79 / 48.95	22.49 / 23.26	47.02 / 47.22	25.34 / 24.79	49.14 / 47.95	24.59 / 24.21	46.94 / 47.04	24.48 / 24.21	48.12 / 47.95	25.32 / 24.79	47.65 / 47.22	23.39 / 23.26	48.79 / 48.95		10
11		33.27 / 33.49	20.19 / 20.42	24.27 / 24.10	44.7[illegible] / 43.96	25.20 / 24.79	47.80 / 47.40	24.12 / 24.00	48.24 / 47.40	24.74 / 24.79	45.23 / 43.96	24.60 / 24.10	20.63 / 20.42	33.75 / 33.49		11
12			44.49 / 43.90	42.48 / 41.57	24.26 / 24.15	47.55 / 47.29	23.93 / 23.89	48.19 / 47.48	23.89 / 23.89	47.97 / 47.29	24.38 / 24.15	42.17 / 41.57	45.01 / 45.25			12
13				44.87 / 45.25	20.32 / 20.50	23.05 / 23.29	44.89 / 44.91	23.49 / 24.17	43.97 / 44.91	22.72 / 23.29	20.31 / 20.50	44.33 / 43.90				13
14					32.94 / 33.50	49.41 / 48.94	18.99 / 19.33	38.13 / 38.28	19.10 / 19.33	48.83 / 48.94	32.90 / 33.50					14
15							44.50 / 44.30	33.12 / 33.27	44.55 / 44.30							15
	R	P	N	M	L	K	J	H	G	F	E	D	C	B	A	

Figure 2.4
NORTH ANNA UNIT 1 - CYCLE 11
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							43.62	34.08	44.51					MEASURED		1
							-1.54	2.45	0.48					M/P % DIFF		
2					33.81	48.19	18.84	37.84	19.08	48.90	33.96					2
					0.92	-1.53	-2.51	-1.17	-1.28	-0.07	1.38					
3				44.00	20.06	22.93	44.10	23.63	45.34	23.30	20.49	44.56				3
				0.24	-2.17	-1.51	-1.80	-2.22	0.96	0.08	-0.04	-1.51				
4			45.54	41.41	23.64	47.77	24.17	47.34	24.33	47.90	24.36	41.56	43.75			4
			0.66	-0.39	-2.09	1.00	1.17	-0.28	1.84	1.29	0.91	-0.02	-0.34			
5		33.40	20.34	24.07	44.06	25.20	48.18	24.54	47.95	25.31	44.52	23.55	20.01	32.92		5
		-0.26	-0.40	-0.16	0.23	1.65	1.63	2.27	1.16	2.11	1.25	-2.30	-2.00	-1.71		
6		49.39	23.19	47.70	24.77	48.08	24.98	47.52	24.97	48.43	25.12	47.64	22.87	48.41		6
		0.90	-0.31	1.02	-0.05	0.27	3.20	1.00	3.16	1.01	1.34	0.89	-1.71	-1.10		
7	44.45	19.16	45.10	24.09	48.35	24.66	42.83	41.87	43.05	24.75	48.40	23.67	44.47	19.00	43.72	7
	0.28	-0.82	0.43	0.94	2.05	2.36	0.97	0.45	1.48	2.72	2.14	-0.84	-0.96	-1.61	-1.36	
8	34.11	38.58	23.79	47.44	24.38	47.28	41.82	44.74	42.04	47.32	24.44	47.30	23.66	39.22	33.89	8
	2.56	0.82	-1.47	0.01	1.84	0.62	0.68	-0.24	1.22	0.70	2.09	-0.27	-1.99	2.49	1.89	
9	44.22	18.78	43.95	24.07	47.79	24.63	42.85	41.73	42.03	24.21	47.33	24.14	45.64	19.31	44.60	9
	-0.24	-2.77	-2.12	0.83	0.87	2.26	1.03	0.10	-0.90	0.52	-0.10	1.12	1.63	-0.03	0.62	
10		48.79	22.49	47.02	25.34	49.14	24.59	46.94	24.48	48.12	25.32	47.65	23.39	48.79		10
		-0.33	-3.33	-0.43	2.24	2.48	1.56	-0.22	1.14	0.36	2.17	0.92	0.55	-0.33		
11		33.27	20.19	24.27	44.73	25.20	47.80	24.12	48.24	24.74	45.23	24.60	20.63	33.75		11
		-0.64	-1.12	0.69	1.75	1.65	0.84	0.51	1.77	-0.20	2.87	2.05	1.04	0.77		
12			44.49	42.48	24.26	47.55	23.93	48.19	23.89	47.97	24.38	42.17	45.01			12
			1.34	2.17	0.47	0.54	0.19	1.50	0.02	1.43	0.97	1.44	-0.53			
13				44.87	20.32	23.05	44.89	23.49	43.97	22.72	20.31	44.33				13
				-0.83	-0.86	-1.02	-0.04	-2.83	-2.11	-2.42	-0.91	0.98		ARITHMETIC AVG		
														PCT DIFF = 0.26		
14					32.94	49.41	18.99	38.13	9.10	48.83	32.90					14
					-1.66	0.96	-1.75	-0.41	-1.17	-0.22	-1.79					
15	STANDARD DEV						4.50	33.12	44.55					AVG ABS PCT		15
	= 0.80						0.46	-0.44	0.57					DIFF = 1.17		
	R	P	N	M	L	K	J	H	G	F	E	D	C	B	A	

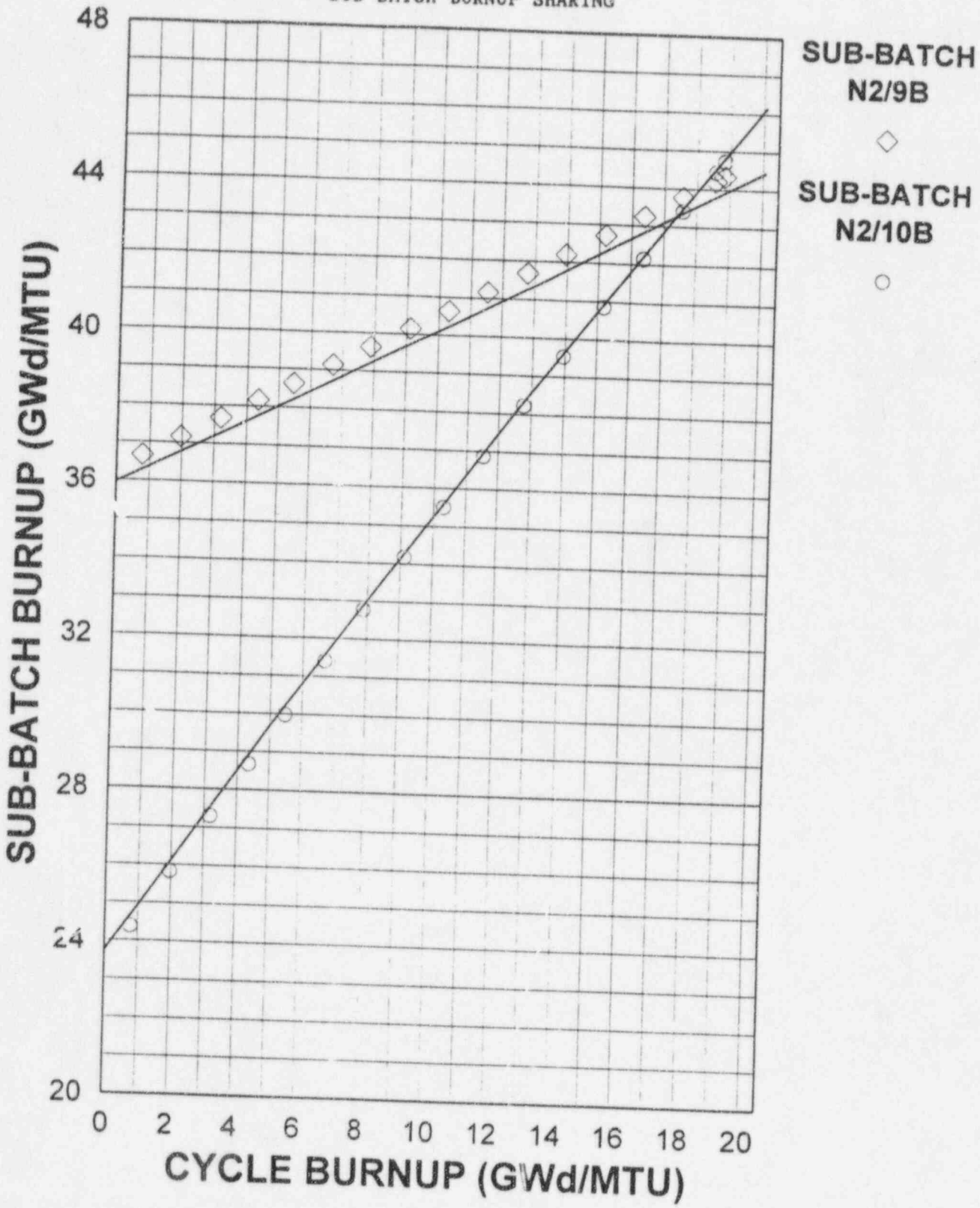
BATCH SHARING
(MWD/MTU)

BATCH	NO. OF ASSEMBLIES	BOC BATCH BURNUP	EOC BATCH BURNUP	CYCLE BURNUP
N2/9B	1	36,335	44,332	7,997
N2/10B	1	23,397	44,739	21,342
N2/11A	8	26,053	33,369	7,316
9A	8	39,222	48,840	9,618
10B	7	36,795	44,605	7,810
11A	8	38,783	44,271	5,488
12A	24	26,092	44,619	18,527
12B	36	22,805	44,394	21,589
13A	28	0	24,573	24,573
13B	36	0	21,842	21,842
CYCLE AVERAGE ACCUMULATED BURNUP = 18,848				

BURNUP TILT

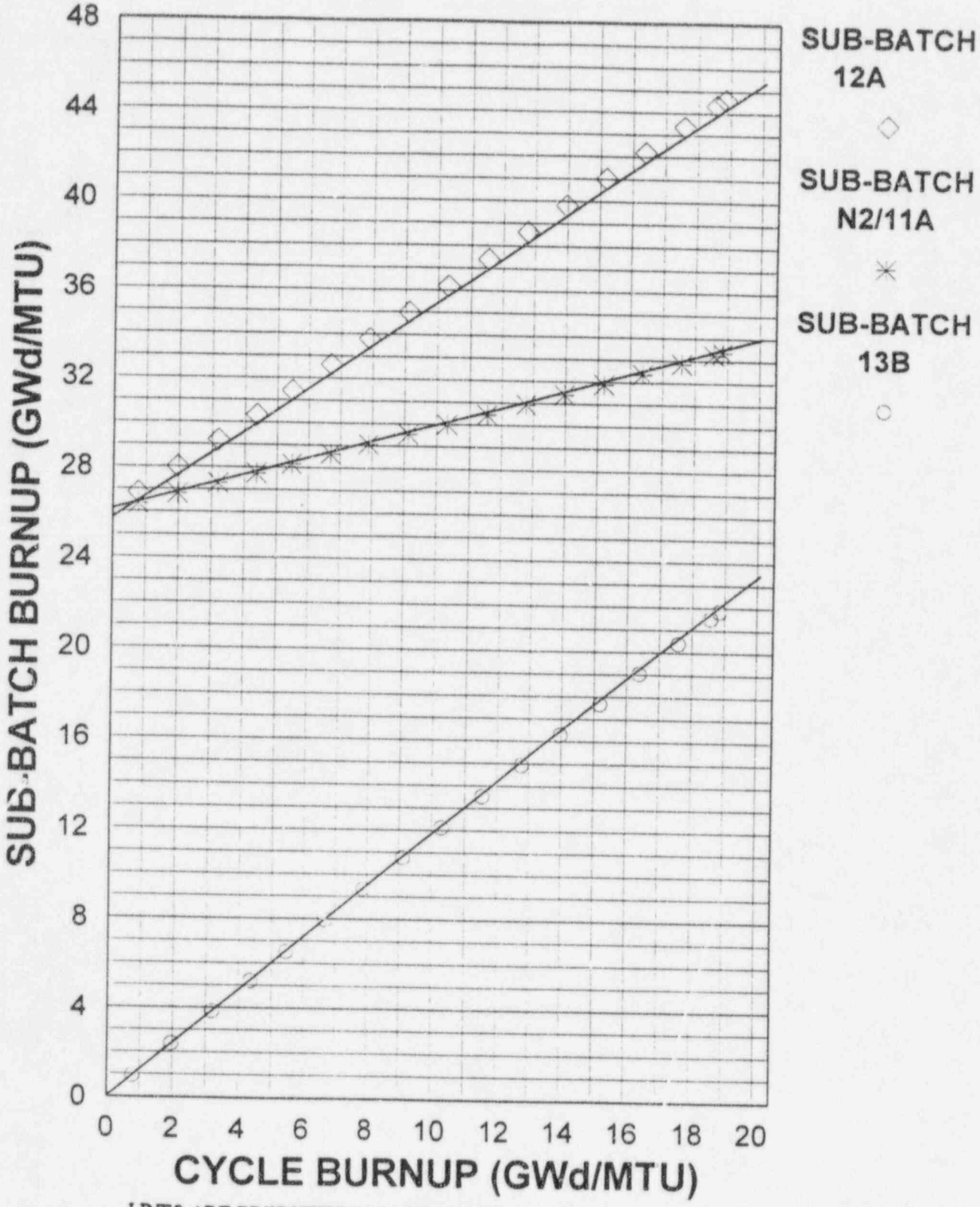
NW = -0.06	NE = 0.01
SW = -0.04	SE = 0.08

Figure 2.5A
NORTH ANNA UNIT 1 - Cycle 11
SUB-BATCH BURNUP SHARING



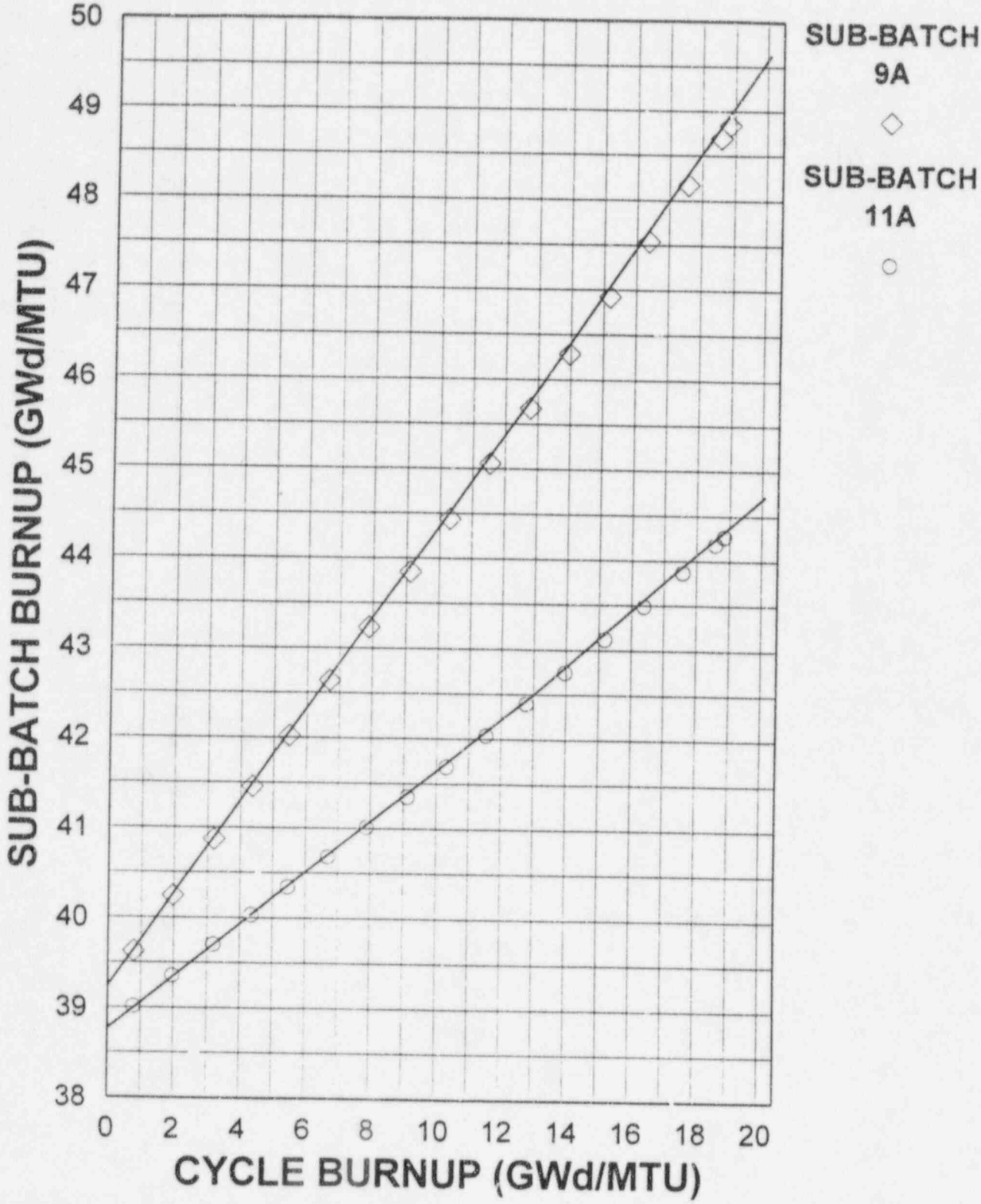
LINES ARE PREDICTED VALUES, SYMBOLS ARE MEASURED VALUES.

Figure 2.5B
NORTH ANNA UNIT 1 - Cycle 11
SUB-BATCH BURNUP SHARING



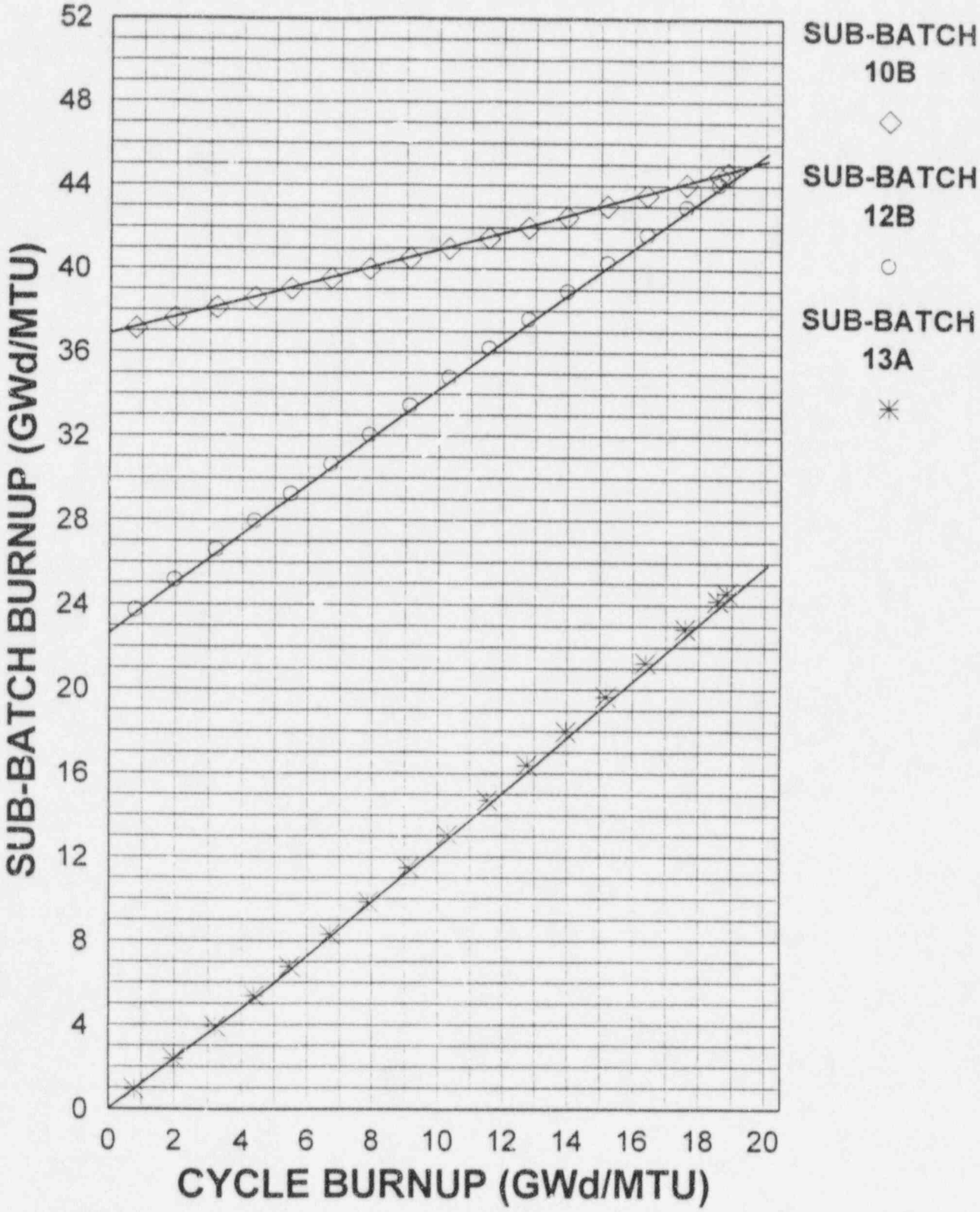
LINES ARE PREDICTED VALUES, SYMBOLS ARE MEASURED VALUES.

Figure 2.5C
NORTH ANNA UNIT 1 - Cycle 11
SUB-BATCH BURNUP SHARING



LINES ARE PREDICTED VALUES, SYMBOLS ARE MEASURED VALUES.

Figure 2.5D
NORTH ANNA UNIT 1 - Cycle 11
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[4] computer code was used to normalize "actual" critical boron concentration measurements to design conditions taking into consideration control rod position, xenon concentration, moderator temperature, and power level. The normalized critical boron concentration versus burnup curve for the North Anna Unit 1, Cycle 11 core is shown in Figure 3.1. It can be seen that the measured data typically compared to within 47 ppm of the design prediction. This corresponds to ±0.32% 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 11 core depleted as expected without any reactivity anomalies.

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)[11]. Figure 4.4 is a plot of the K(Z) curve associated with the 2.19 $F_Q(Z)$ limit.

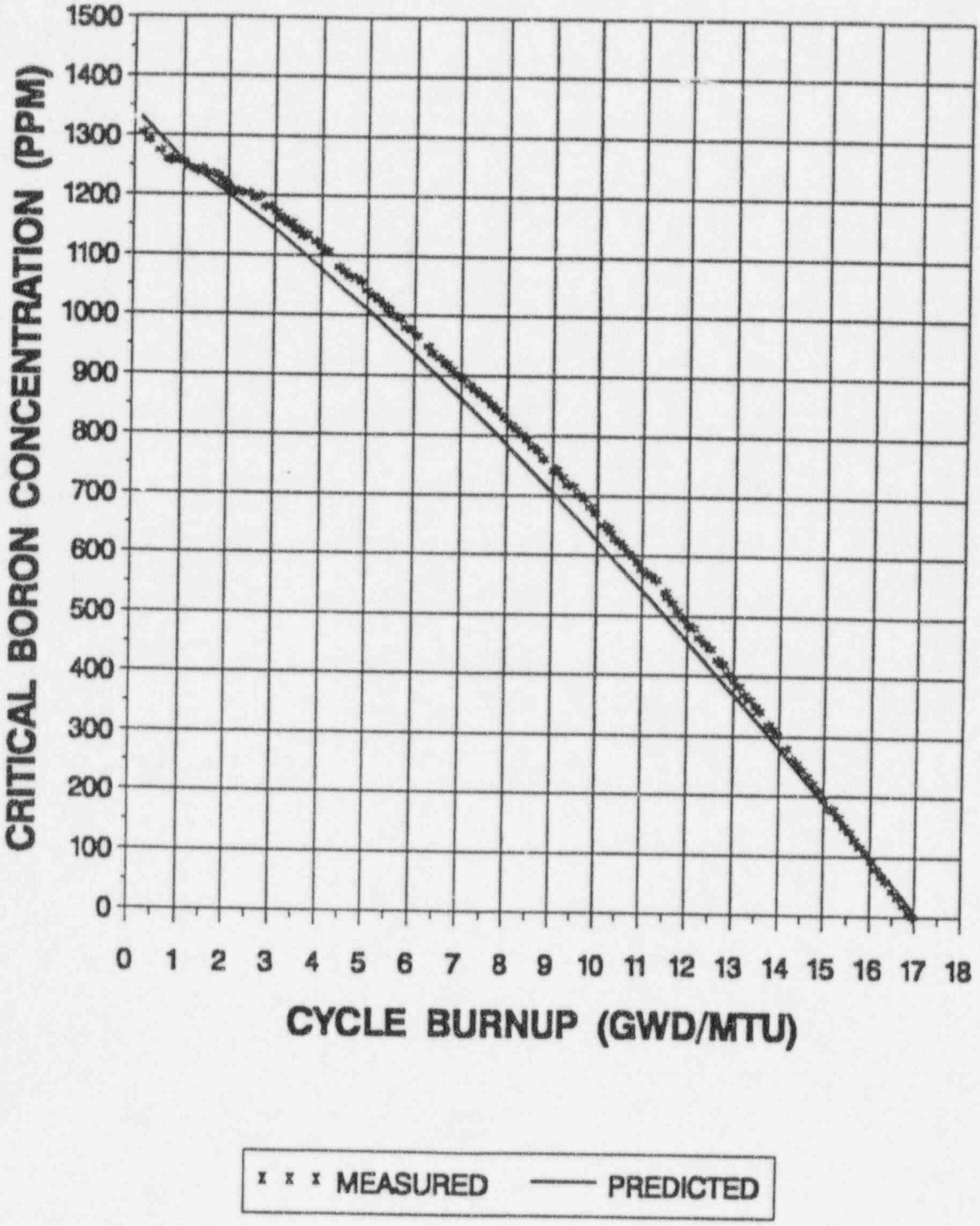
The axially dependent heat flux hot channel factors, $F_Q(Z)$, for a representative set of flux maps are given in Figures 4.5, 4.6, and 4.7. Throughout Cycle 11, the measured values of $F_Q(Z)$ were within the Technical Specifications limit. A summary of the maximum values of axially-dependent heat flux hot channel factors measured during Cycle 11 is given in Figure 4.8. Figure 4.9 shows the maximum values for the heat flux measured during Cycle 11. The rise in the EOC maximum FQ(Z) data is due to being at reduced power (during the 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 16.3% 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.)

Section 3

REACTIVITY DEPLETION

The primary coolant critical boron concentration is monitored for the purposes of following core reactivity and to identify any anomalous reactivity behavior. The FOLOW[4] computer code was used to normalize "actual" critical boron concentration measurements to design conditions taking into consideration control rod position, xenon concentration, moderator temperature, and power level. The normalized critical boron concentration versus burnup curve for the North Anna Unit 1, Cycle 11 core is shown in Figure 3.1. It can be seen that the measured data typically compared to within 47 ppm of the design prediction. This corresponds to ±0.32% 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 11 core depleted as expected without any reactivity anomalies.

Figure 3.1
NORTH ANNA UNIT 1 - Cycle 11
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 were determined from movable detector flux map measurements using the CECOR[5] computer program. A summary of all full core flux maps taken for North Anna Unit 1, Cycle 11 is given in Table 4.1, excluding the initial power ascension flux maps which were included in the N1C11 Startup Physics Tests Report[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 CECOR 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 11. The measured relative assembly powers were generally within 5.2% and the maximum average percent difference was equal to 1.4%. In addition, as indicated by the CECOR tilt factors, the power distributions were essentially symmetric for each case.

An important aspect of core power distribution follow is the monitoring of nuclear hot channel factors. Verification that these factors are within Technical Specifications limits ensures that linear power density and critical heat flux limits will not be violated, thereby providing adequate thermal margin and maintaining fuel cladding integrity. North Anna Unit 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)[11]. 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 11, 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 11 is given in Figure 4.8. Figure 4.9 shows the maximum values for the heat flux measured during Cycle 11. The rise in the EOC maximum FQ(Z) data is due to being at reduced power (during the 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 16.3% 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 11, 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 11 is given in Figure 4.10. As can be seen from this figure, the minimum margin to the limit was approximately 4.4%.

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 monthly with the core at or as near to these conditions as possible and the target delta flux is established at this measured point. To avoid adverse axial power shapes due to xenon redistribution, Cycle 11 was monitored to ensure that it was operated as much as possible at the conditions at which the target delta flux was determined.

The plot of the target delta flux versus burnup, given in Figure 4.11, shows the value of this parameter to have been approximately -3.5% at the

---

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

beginning of Cycle 11, decreasing to approximately -4.7% near MOC, increasing to approximately -3.2% before EOR, and then increasing to approximately 5.2% due to the coastdown. The axial power shift during the cycle can also be observed in the corresponding core average axial power distributions for a representative series of maps given in Figures 4.12 through 4.14. In Map N1-11-04 (Figure 4.12), taken at 1908 MWD/MTU, the axial power distribution had a shape peaked just below the middle of the core with a peaking factor of 1.200. In Map N1-11-11 (Figure 4.13), taken at 9852 MWD/MTU, the axial power distribution peaked more toward the bottom of the core with an axial peaking factor of 1.158. Finally, in Map N1-11-17 (Figure 4.14), taken at 16,963 MWD/MTU, the axial peaking factor was 1.150, with the axial power distribution peaked even further toward the bottom of the core. 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 11 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 11
SUMMARY OF FLUX MAPS FOR ROUTINE OPERATION

MAP NO.	DATE	BURNUP MWD/ MTU	PWR (%)	BANK D STEPS	F-Q(T) HOT CHANNEL FACTOR 1			F-DH(N) HOT CHNL. FACTOR		CORE F(Z) MAX		CORE TILT 2		AXIAL OFF SET (%)	NO. OF THIMBLES
					ASSY	AXIAL POINT	F-Q(T)	ASSY	F-DH(N)	AXIAL POINT	F(Z)	MAX	LOC		
4	11-29-94	1908	100.04	225	D11	38	1.820	D11	1.396	36	1.200	1.002	NW	-3.438	45
5	12-28-94	3061	100.13	225	D11	38	1.810	D11	1.403	36	1.186	1.001	SE	-3.510	45
6	02-01-95	4379	100.05	225	D11	38	1.799	D11	1 412	38	1.173	1.004	SE	-3.665	45
7	02-28-95	5453	99.99	225	D11	40	1.789	D11	1.416	44	1.163	1.004	SE	-4.024	45
8	03-31-95	6675	100.02	225	D11	46	1.777	D11	1.416	45	1.158	1.003	SE	-4.261	45
9	04-26-95	7716	100.03	225	D11	46	1.772	D11	1.413	46	1.157	1.003	SE	-4.429	45
10	05-18-95	8580	99.97	225	K11	46	1.777	D11	1.410	47	1.156	1.003	SE	-4.380	45
11	06-19-95	9852	100.01	225	E10	48	1.789	F05	1.420	48	1.158	1.003	NE	-4.660	45
12	07-21-95	11125	100.02	225	F05	49	1.796	F05	1.427	48	1.155	1.003	NE	-4.634	45
13	08-21-95	12353	99.98	225	F05	49	1.790	F05	1.427	52	1.153	1.005	NE	-4.449	45
14	09-19-95	13505	100.01	225	F05	49	1.774	F05	1.424	52	1.155	1.005	NE	-4.211	45
15	10-19-95	14696	99.93	225	L08	52	1.768	F05	1.415	52	1.155	1.006	NE	-4.027	45
16	11-14-95	15732	100.00	225	L08	52	1.763	F05	1.410	52	1.159	1.005	NE	-3.800	45
17	12-15-95	16963	99.98	225	L08	53	1.745	F05	1.408	52	1.150	1.006	NE	-3.190	45
18	01-15-96	18080	81.48	225	F05	11	1.840	F05	1.415	11	1.186	1.008	NE	5.184	45

NOTES: HOT SPOT LOCATIONS ARE SPECIFIED BY GIVING ASSEMBLY LOCATIONS (E.G. H-8 IS THE CENTER-OF-CORE ASSEMBLY). 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. QUADRANT POWER TILT AS DEFINED BY THE CECOR CODE.

Figure 4.1
NORTH ANNA UNIT 1 - Cycle 11
ASSEMBLYWISE POWER DISTRIBUTION N1-11-04

R	P	N	M	L	K	J	H	G	F	E	D	C	B	A	
	PREDICTED MEASURED PCT DIFFERENCE					0.291 0.286 -1.6	0.391 0.384 -1.8	0.293 0.289 -1.4			PREDICTED MEASURED PCT DIFFERENCE				1
				0.387 0.382 -1.4	0.518 0.511 -1.4	1.087 1.069 -1.6	0.980 0.962 -1.9	1.096 1.082 -1.3	0.520 0.516 -0.6	0.388 0.388 0.0					2
			0.413 0.409 -0.8	1.138 1.122 -1.4	1.285 1.270 -1.2	1.1[illegible] 1.158 -1.5	1.287 1.253 -2.7	1.179 1.166 -1.1	1.287 1.284 -0.2	1.137 1.141 0.3	0.403 0.416 3.3				3
		0.399 0.399 0.1	0.842 0.837 -0.6	1.285 1.261 -1.8	1.225 1.217 -0.7	1.201 1.197 -0.3	1.138 1.134 -0.4	1.202 1.201 0.0	1.225 1.229 0.3	1.285 1.282 0.0	0.843 0.832 -1.3	0.414 0.405 -2.2			4
	0.387 0.389 0.5	1.134 1.142 0.7	1.282 1.286 0.4	1.257 1.269 0.9	1.244 1.252 0.7	1.145 1.158 1.2	1.174 1.188 1.2	1.145 1.156 1.0	1.244 1.251 0.6	1.257 1.259 0.1	1.287 1.239 -3.7	1.1[illegible]1 1.108 -2.9	0.388 0.382 -1.7		5
	0.519 0.519 0.1	1.285 1.289 0.3	1.226 1.228 0.2	1.243 1.240 -0.2	1.156 1.171 1.3	1.203 1.235 2.6	1.167 1.200 2.8	1.202 1.230 2.3	1.154 1.166 1.0	1.243 1.236 -0.5	1.227 1.195 -2.6	1.286 1.251 -2.7	0.518 0.508 -1.9		6
0.293 0.292 -0.6	1.096 1.092 -0.4	1.178 1.181 0.2	1.201 1.202 0.1	1.141 1.147 0.6	1.196 1.223 2.2	1.210 1.272 5.1	1.190 1.234 3.7	1.203 1.255 4.3	1.192 1.213 1.8	1.140 1.133 -0.6	1.200 1.156 -3.6	1.174 1.140 -2.9	1.084 1.072 -1.1	0.291 0.287 -1.2	7
0.391 0.386 -1.2	0.978 0.965 -1.3	1.285 1.260 -1.9	1.136 1.131 -0.5	1.169 1.170 0.1	1.156 1.176 1.8	1.177 1.211 2.9	1.187 1.219 2.7	1.179 1.209 2.6	1.157 1.183 2.2	1.170 1.168 -0.2	1.136 1.112 -2.1	1.285 1.236 -3.8	0.978 0.969 -1.0	0.391 0.386 -1.4	8
0.291 0.286 -1.5	1.084 1.067 -1.6	1.174 1.154 -1.7	1.200 1.198 -0.1	1.140 1.162 1.9	1.191 1.212 1.8	1.202 1.226 1.9	1.190 1.209 1.6	1.211 1.223 1.0	1.196 1.191 -0.4	1.142 1.139 -0.2	1.201 1.191 -0.8	1.178 1.165 -1.1	1.096 1.092 -0.4	0.293 0.284 -3.3	9
	0.518 0.507 -2.2	1.286 1.249 -2.9	1.227 1.223 -0.3	1.243 1.260 1.4	1.154 1.171 1.5	1.201 1.220 1.5	1.167 1.175 0.7	1.203 1.206 0.2	1.156 1.154 -0.2	1.244 1.249 0.5	1.226 1.228 0.2	1.285 1.293 0.6	0.519 0.539 3.9		10
	0.388 0.384 -1.3	1.141 1.131 -0.9	1.287 1.293 0.5	1.257 1.288 2.4	1.244 1.258 1.2	1.144 1.148 0.3	1.174 1.166 -0.7	1.145 1.138 -0.6	1.244 1.231 -1.0	1.257 1.282 2.0	1.282 1.301 1.5	1.134 1.148 1.3	0.387 0.395 2.1		11
		0.414 0.419 1.3	0.843 0.850 0.8	1.283 1.296 1.0	1.225 1.230 0.4	1.202 1.194 -0.7	1.138 1.125 -1.1	1.201 1.190 -0.9	1.225 1.216 -0.8	1.285 1.296 0.9	0.842 0.869 3.2	0.399 0.406 1.9			12
			0.403 0.405 0.6	1.137 1.142 0.4	1.287 1.286 -0.1	1.179 1.169 -0.9	1.287 1.260 -2.1	1.175 1.161 -1.2	1.285 1.259 -2.1	1.138 1.134 -0.4	0.413 0.418 1.2				13
				0.388 0.386 -0.6	0.520 0.518 -0.4	1.096 1.089 -0.6	0.980 0.973 -0.8	1.087 1.093 0.5	0.518 0.514 -0.8	0.387 0.385 -0.5					14
	STANDARD DEVIATION =1.008					0.293 0.294 0.2	0.391 0.390 -0.4	0.291 0.292 0.3			AVERAGE PCT DIFFERENCE = 1.3				15

SUMMARY

MAP NO: N1-11-04 DATE: 11/29/94 POWER: 100.04%

CONTROL ROD POSITION: F-Q(T) = 1.820 CORE TILT:

D BANK AT 225 STEPS F-DH(N) = 1.396 NW 1.0022 | NE 0.9957

F(Z) = 1.200 SW 1.0017 | SE 1.0004

BURNUP = 1908 MWD/MTU A.O. = -3.438%

Figure 4.2
NORTH ANNA UNIT 1 - Cycle 11
ASSEMBLYWISE POWER DISTRIBUTION N1-11-11

R	P	N	M	L	K	J	H	G	F	E	D	C	B	A	
	PREDICTED MEASURED PCT DIFFERENCE					0.285 0.280 -1.6	0.382 0.374 -2.0	0.286 0.283 -1.1			PREDICTED MEASURED PCT DIFFERENCE				1
				0.383 0.376 -1.9	0.502 0.495 -1.5	0.986 0.972 -1.4	0.896 0.883 -1.5	0.991 0.984 -0.8	0.503 0.503 0.1	0.383 0.385 0.6					2
			0.416 0.408 -2.0	1.069 1.046 -2.1	1.221 1.204 -1.4	1.099 1.086 -1.2	1.284 1.257 -2.1	1.101 1.096 -0.4	1.221 1.228 0.5	1.067 1.076 0.9	0.496 0.417 2.6				3
		0.404 0.399 -1.2	0.826 0.812 -1.7	1.294 1.257 -2.9	1.187 1.176 -0.9	1.298 1.298 0.1	1.150 1.157 0.6	1.298 1.307 0.7	1.187 1.201 1.2	1.292 1.302 0.8	0.826 0.821 -0.6	0.417 0.411 -1.4			4
	0.382 0.380 -0.7	1.066 1.057 -0.8	1.292 1.283 -0.7	1.235 1.237 0.1	1.358 1.363 0.3	1.183 1.203 1.7	1.318 1.337 1.4	1.182 1.199 1.4	1.358 1.376 1.3	1.235 1.251 1.3	1.295 1.258 -2.8	1.070 1.049 -2.0	0.38 0.378 -1.5		5
	0.503 0.500 -0.7	1.221 1.214 -0.6	1.188 1.180 -0.7	1.358 1.340 -1.3	1.191 1.197 0.5	1.326 1.350 1.8	1.179 1.204 2.1	1.325 1.352 2.0	1.191 1.208 1.4	1.358 1.364 0.5	1.188 1.173 -1.3	1.222 1.204 -1.5	0.502 0.497 -1.1		6
0.286 0.284 -0.9	0.992 0.985 -0.7	1.101 1.099 -0.2	1.298 1.294 -0.3	1.181 1.182 0.1	1.321 1.337 1.2	1.183 1.218 3.0	1.141 1.171 2.6	1.179 1.218 3.3	1.318 1.344 1.9	1.181 1.186 0.5	1.297 1.279 -1.4	1.099 1.083 -1.4	0.986 0.982 -0.4	0.284 0.284 -0.2	7
0.382 0.377 -1.3	0.896 0.884 -1.4	1.283 1.262 -1.7	1.150 1.146 -0.3	1.315 1.325 0.7	1.173 1.188 1.3	1.154 1.156 2.0	1.098 1.120 2.0	1.135 1.160 2.2	1.173 1.203 2.6	1.315 1.325 0.8	1.150 1.143 -0.6	1.283 1.256 -2.1	0.896 0.906 1.1	0.382 0.383 0.2	8
0.284 0.280 -1.6	0.986 0.968 -1.7	1.099 1.080 -1.7	1.297 1.295 -0.1	1.181 1.203 1.9	1.318 1.337 1.5	1.179 1.196 1.5	1.141 1.156 1.3	1.184 1.196 1.0	1.321 1.324 0.2	1.181 1.188 0.6	1.298 1.301 0.3	1.101 1.100 -0.1	0.992 0.998 0.6	0.286 0.279 -2.4	9
	0.502 0.490 -2.5	1.222 1.181 -3.3	1.188 1.182 -0.5	1.358 1.373 1.1	1.191 1.205 1.2	1.325 1.340 1.2	1.179 1.189 0.8	1.326 1.331 0.4	1.192 1.194 0.2	1.358 1.373 1.1	1.188 1.202 1.1	1.221 1.234 1.1	0.503 0.518 3.0		10
	0.384 0.376 -1.9	1.070 1.053 -1.6	1.295 1.295 0.0	1.235 1.259 1.9	1.358 1.370 0.9	1.182 1.188 0.5	1.318 1.320 0.2	1.183 1.180 -0.3	1.358 1.347 -0.8	1.235 1.264 2.4	1.292 1.312 1.6	1.066 1.079 1.3	0.382 0.389 1.8		11
		0.417 0.412 -1.1	0.826 0.826 0.0	1.292 1.298 0.5	1.187 1.188 0.1	1.298 1.292 -0.4	1.150 1.139 -1.0	1.298 1.285 -1.0	1.187 1.176 -0.9	1.294 1.300 0.5	0.826 0.838 1.4	0.404 0.405 0.3			12
			0.406 0.406 -0.2	1.067 1.063 -0.3	1.221 1.213 -0.6	1.101 1.085 -1.4	1.284 1.247 -2.9	1.099 1.080 -1.8	1.221 1.191 -2.5	1.069 1.060 -0.8	0.416 0.417 0.2				13
				0.383 0.374 -2.3	0.503 0.496 -1.4	0.991 0.973 -1.9	0.896 0.880 -1.9	0.986 0.981 -0.5	0.502 0.495 -1.5	0.383 0.379 -1.0					14
	STANDARD DEVIATION =0.807					0.286 0.274 -4.4	0.382 0.374 -2.2	0.285 0.282 -0.9			AVERAGE PCT DIFFERENCE = 1.2				15

SUMMARY

MAP NO: N1-11-11 DATE: 6/19/95 POWER: 100.01%

CONTROL ROD POSITION: F-Q(T) = 1.789 CORE TILT:

D BANK AT 225 STEPS F-DH(N) = 1.420 NW 0.9975 | NE 1.0027

F(Z) = 1.158 SW 0.9981 | SE 1.0017

BURNUP = 9852 MWD/MTU A.O. = -4.660%

Figure 4.3
NORTH ANNA UNIT 1 - Cycle 11
ASSEMBLYWISE POWER DISTRIBUTION N1-11-17

R	P	N	M	L	K	J	H	G	F	E	D	C	B	A	
	PREDICTED					0.317	0.425	0.318			PREDICTED				
	MEASURED					0.315	0.423	0.317			MEASURED				1
	PCT DIFFERENCE					-0.8	-0.5	-0.3			PCT DIFFERENCE				
				0.407	0.528	0.994	0.911	0.997	0.529	0.407					
				0.403	0.524	0.985	0.902	0.995	0.533	0.414					2
				-1.0	-0.9	-0.9	-1.0	-0.2	0.6	1.6					
			0.440	1.043	1.185	1.084	1.287	1.086	1.185	1.042	0.430				
			0.440	1.032	1.176	1.075	1.261	1.087	1.201	1.063	0.451				3
			0.0	-1.0	-0.8	-0.9	-2.0	0.1	1.4	2.0	4.8				
		0.428	0.829	1.261	1.152	1.330	1.152	1.330	1.152	1.260	0.828	0.440			
		0.430	0.825	1.239	1.147	1.333	1.160	1.345	1.178	1.282	0.833	0.439			4
		0.4	-0.4	-1.7	-0.4	0.2	0.7	1.1	2.2	1.8	0.6	-0.2			
	0.407	1.041	1.260	1.189	1.355	1.176	1.361	1.176	1.355	1.189	1.261	1.044	0.408		
	0.410	1.052	1.264	1.203	1.361	1.191	1.376	1.192	1.377	1.211	1.239	1.035	0.409		5
	0.8	1.1	0.4	1.2	0.5	1.2	1.1	1.3	1.7	1.9	-1.7	-0.9	0.3		
	0.529	1.186	1.153	1.355	1.173	1.345	1.166	1.345	1.173	1.355	1.154	1.186	0.528		
	0.531	1.192	1.147	1.323	1.171	1.359	1.180	1.364	1.187	1.364	1.146	1.179	0.529		6
	0.4	0.5	-0.5	-2.4	-0.2	1.0	1.2	1.4	1.3	0.7	-0.6	-0.6	0.1		
0.319	0.998	1.086	1.331	1.176	1.343	1.157	1.111	1.155	1.341	1.175	1.330	1.085	0.994	0.317	
0.319	1.000	1.096	1.328	1.167	1.347	1.177	1.126	1.176	1.358	1.179	1.317	1.078	1.002	0.321	7
0.0	0.2	0.9	-0.2	-0.7	0.2	1.8	1.4	1.8	1.2	0.3	-1.0	-0.6	0.9	1.1	
0.425	0.911	1.287	1.153	1.361	1.163	1.107	1.062	1.108	1.163	1.361	1.153	1.287	0.911	0.425	
0.423	0.905	1.272	1.147	1.353	1.164	1.113	1.067	1.116	1.180	1.365	1.148	1.268	0.934	0.432	8
-0.6	-0.7	-1.2	-0.5	0.6	0.1	0.5	0.5	0.7	1.5	0.3	-0.5	-1.5	2.5	1.6	
0.317	0.994	1.085	1.330	1.175	1.341	1.154	1.111	1.158	1.343	1.176	1.331	1.086	0.998	0.319	
0.314	0.984	1.073	1.328	1.190	1.344	1.151	1.105	1.147	1.313	1.172	1.334	1.092	1.017	0.317	9
-0.9	-1.0	-1.1	-0.2	1.2	0.2	-0.3	-0.5	-0.9	-2.2	-0.3	0.3	0.5	1.9	-0.6	
	0.528	1.186	1.154	1.355	1.173	1.345	1.166	1.345	1.173	1.355	1.153	1.186	0.529		
	0.520	1.162	1.150	1.362	1.171	1.329	1.150	1.329	1.159	1.363	1.168	1.208	0.556		10
	-1.5	-2.0	-0.3	0.5	-0.2	-1.2	-1.3	-1.3	-1.2	0.6	1.3	1.8	5.2		
	0.408	1.044	1.262	1.189	1.355	1.176	1.361	1.176	1.355	1.189	1.260	1.041	0.407		
	0.404	1.036	1.263	1.206	1.351	1.160	1.332	1.157	1.331	1.219	1.286	1.063	0.420		11
	-1.0	-0.8	0.1	1.4	-0.3	-1.4	-2.1	-1.7	-1.8	2.5	2.1	2.1	3.1		
		0.440	0.828	1.260	1.152	1.330	1.152	1.330	1.152	1.261	0.829	0.428			
		0.441	0.829	1.260	1.141	1.300	1.128	1.309	1.140	1.272	0.848	0.436			12
		0.3	0.1	0.0	-0.9	-2.2	-2.1	-1.5	-1.0	0.9	2.4	1.8			
			0.430	1.042	1.185	1.086	1.287	1.084	1.185	1.043	0.440				
			0.429	1.036	1.172	1.066	1.253	1.069	1.167	1.042	0.444				13
			-0.3	-0.6	-1.1	-1.8	-2.7	-1.4	-1.6	-0.1	1.0				
				0.407	0.529	0.997	0.911	0.994	0.528	0.407					
				0.402	0.523	0.986	0.902	1.001	0.526	0.406					14
				-1.4	-1.1	-1.1	-1.1	0.7	-0.5	-0.2					
	STANDARD					0.318	0.425	0.317			AVERAGE				
	DEVIATION					0.322	0.424	0.318			PCT DIFFERENCE				15
	=0.800					1.2	-0.3	0.4			= 1.0				

SUMMARY

MAP NO: N1-11-17 DATE: 12/15/95 POWER: 99.98%

CONTROL ROD POSITION: F-Q(T) = 1.745 CORE TILT:

D BANK AT 225 STEPS F-DH(N) = 1.408 NW 0.9995 | NE 1.006

F(Z) = 1.150 SW 0.9938 | SE 1.000

BURNUP = 16963 MWD/MTU A.O.= -3.190%

Figure 4.4
NORTH ANNA UNIT 1 - Cycle 11
HOT CHANNEL FACTOR NORMALIZED
OPERATING ENVELOPE

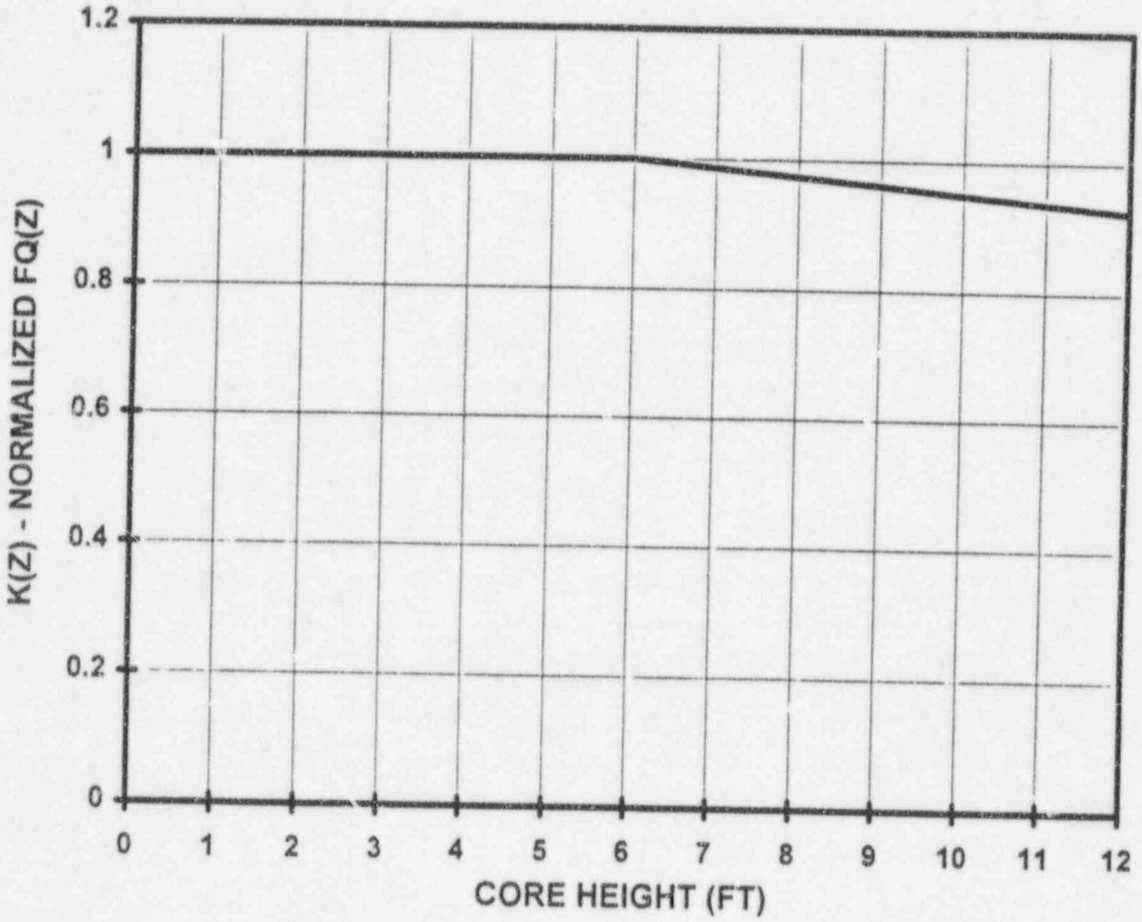
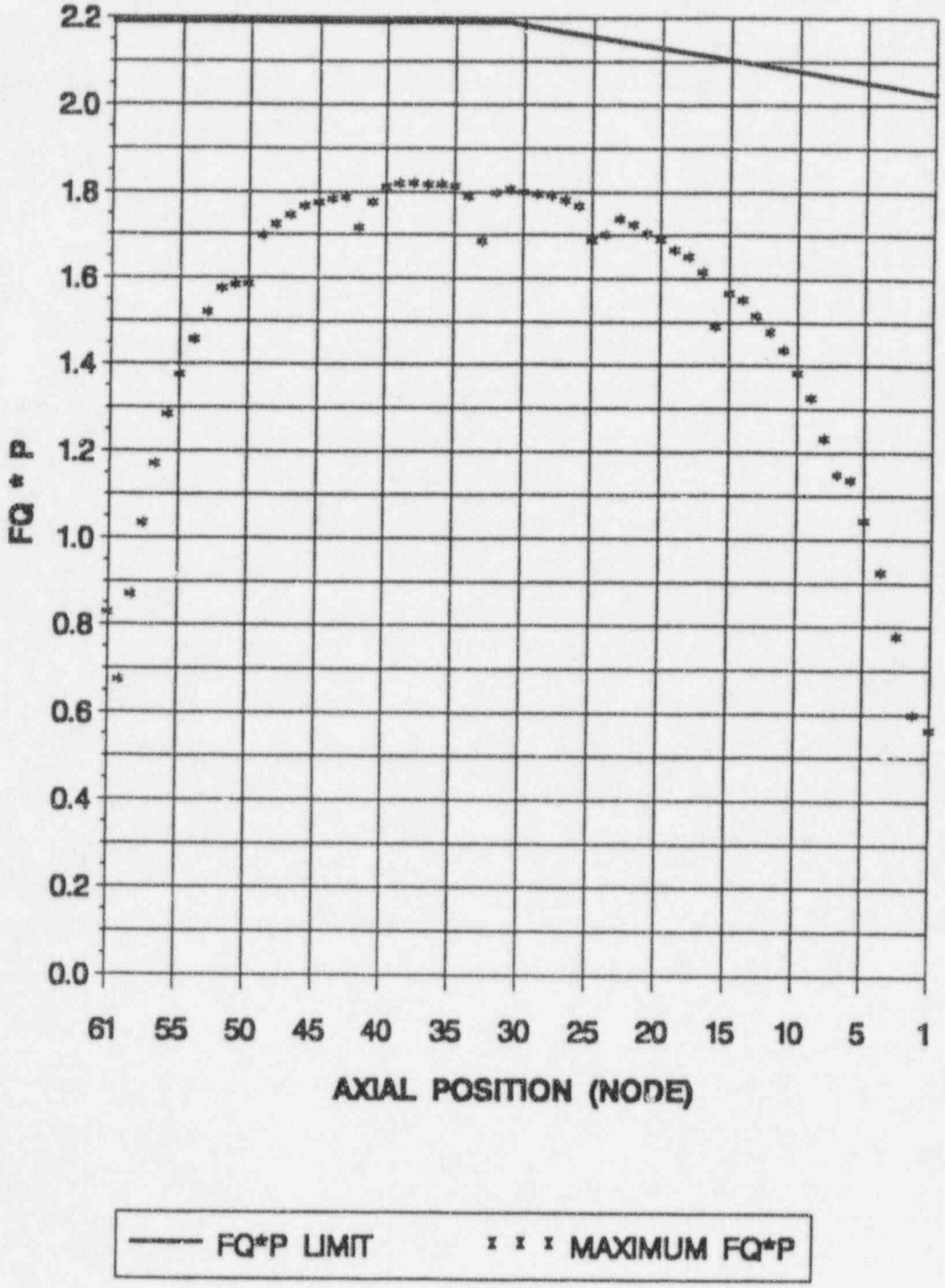


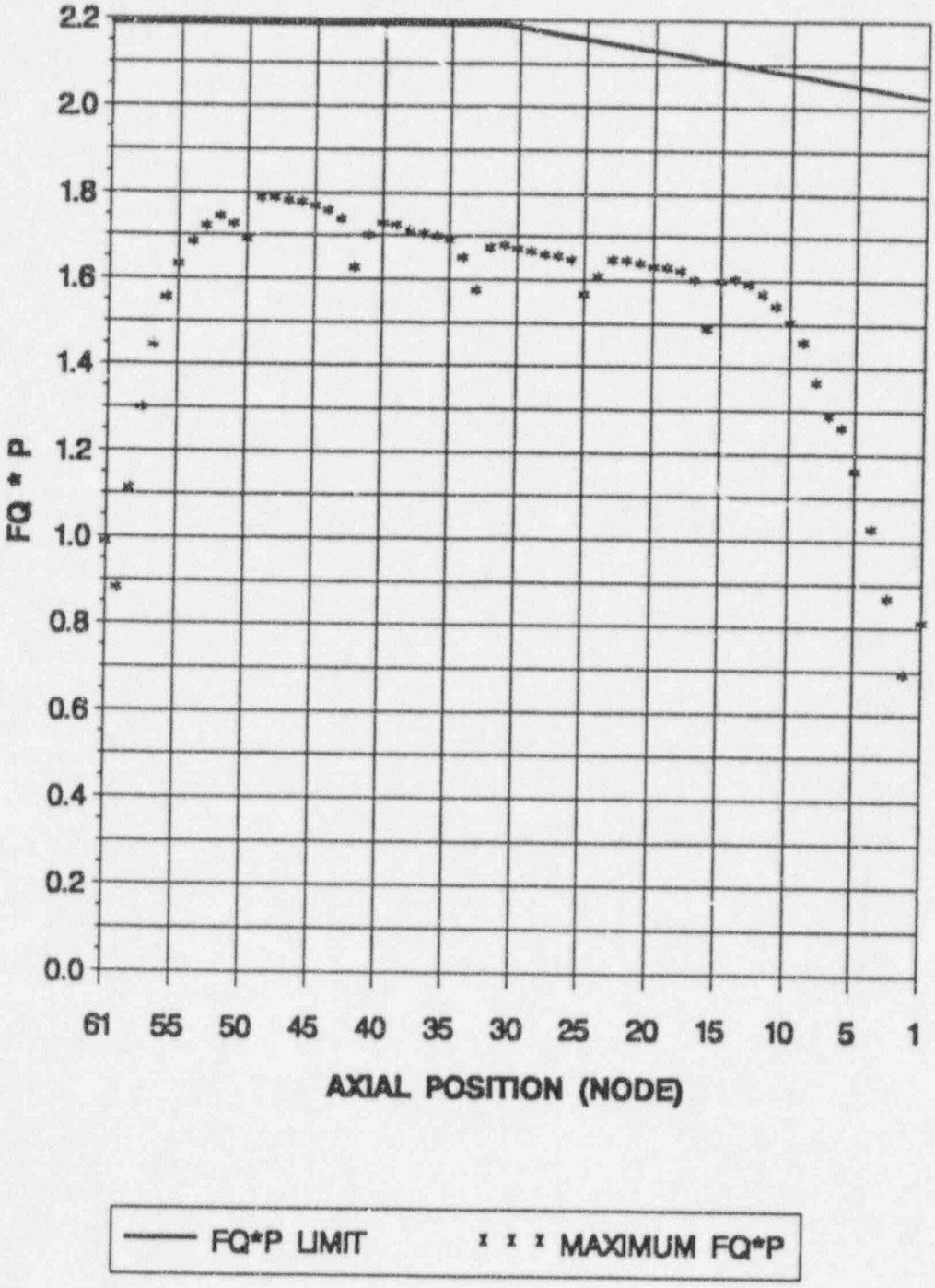
Figure 4.5
NORTH ANNA UNIT 1 - Cycle 11
HEAT FLUX HOT CHANNEL FACTOR, $F_Q(Z)$
N1-11-04



BOTTOM OF CORE

TOP OF CORE

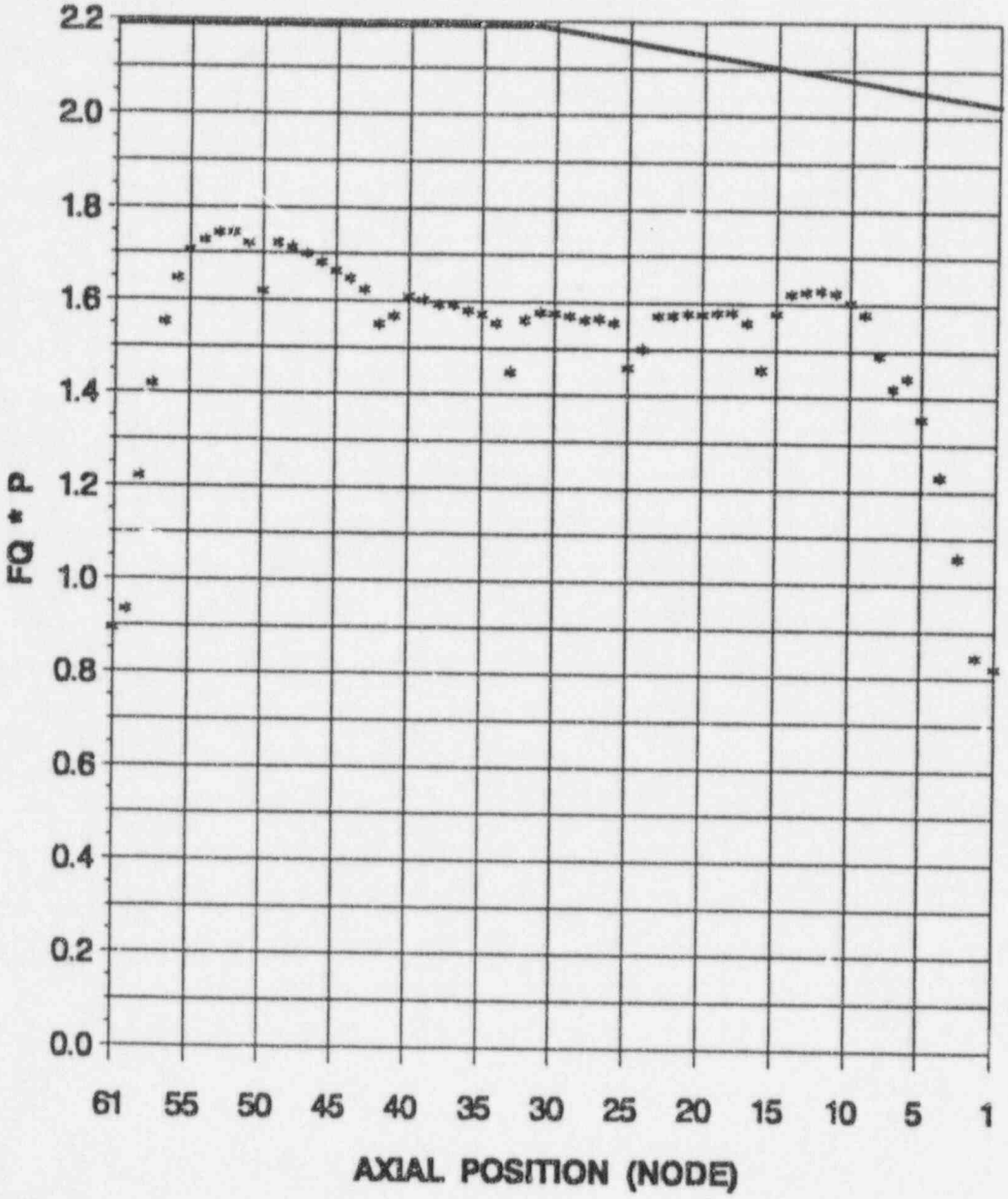
Figure 4.6
NORTH ANNA UNIT 1 - Cycle 11
HEAT FLUX HOT CHANNEL FACTOR, $F_Q(Z)$
N1-11-11



BOTTOM OF CORE

TOP OF CORE

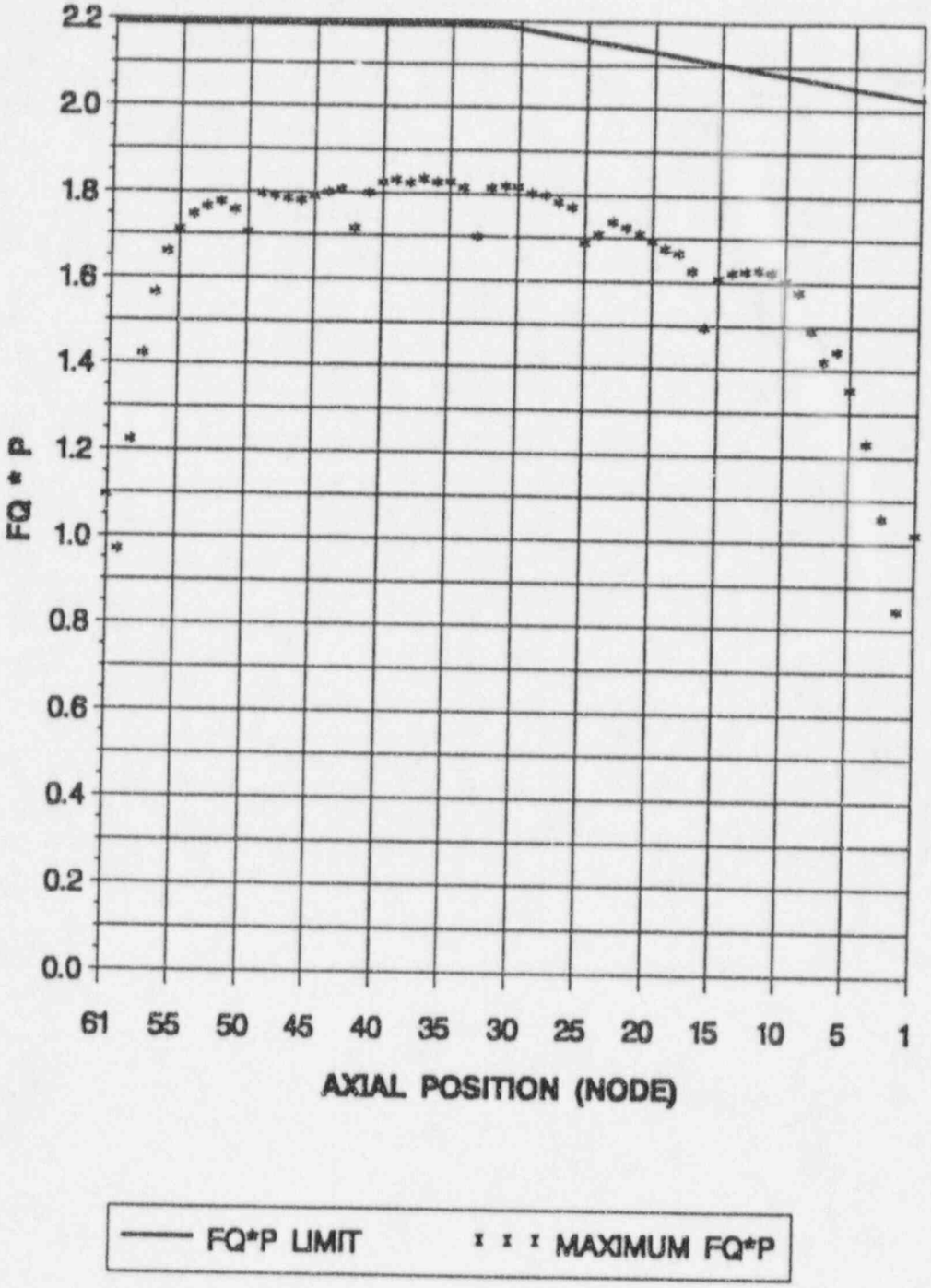
Figure 4.7
NORTH ANNA UNIT 1 - Cycle 11
HEAT FLUX HOT CHANNEL FACTOR, $F_Q(Z)$
N1-11-17



FQ*P LIMIT x x x MAXIMUM FQ*P

BOTTOM OF CORE TOP OF CORE

Figure 4.8
NORTH ANNA UNIT 1 - Cycle 11
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 11
MAXIMUM HEAT FLUX HOT CHANNEL FACTOR, $F_Q(Z)$, vs. BURNUP

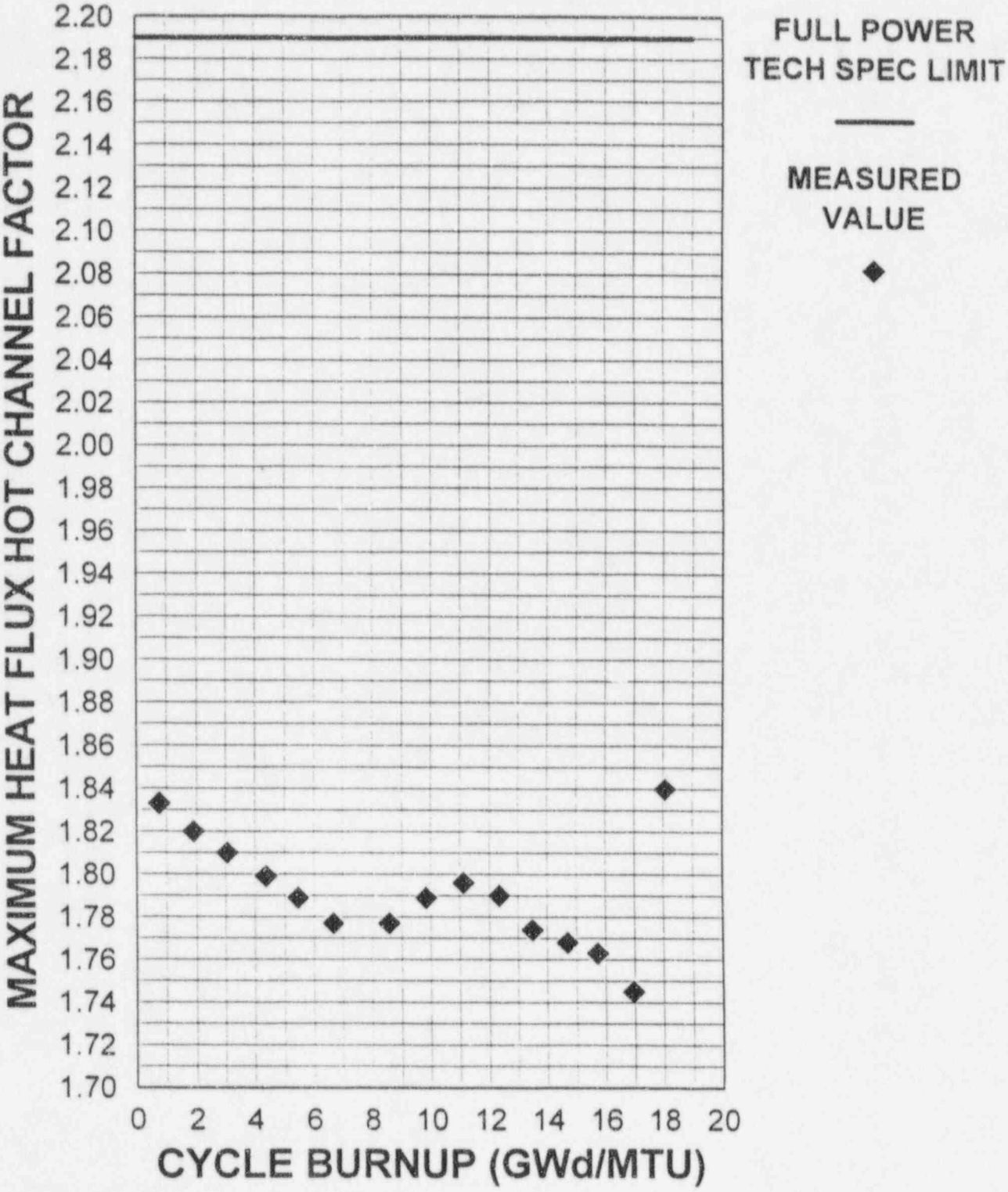


Figure 4.10
NORTH ANNA UNIT 1 - Cycle 11
MAXIMUM ENTHALPY RISE HOT CHANNEL FACTOR, F-delta-H, vs. BURNUP

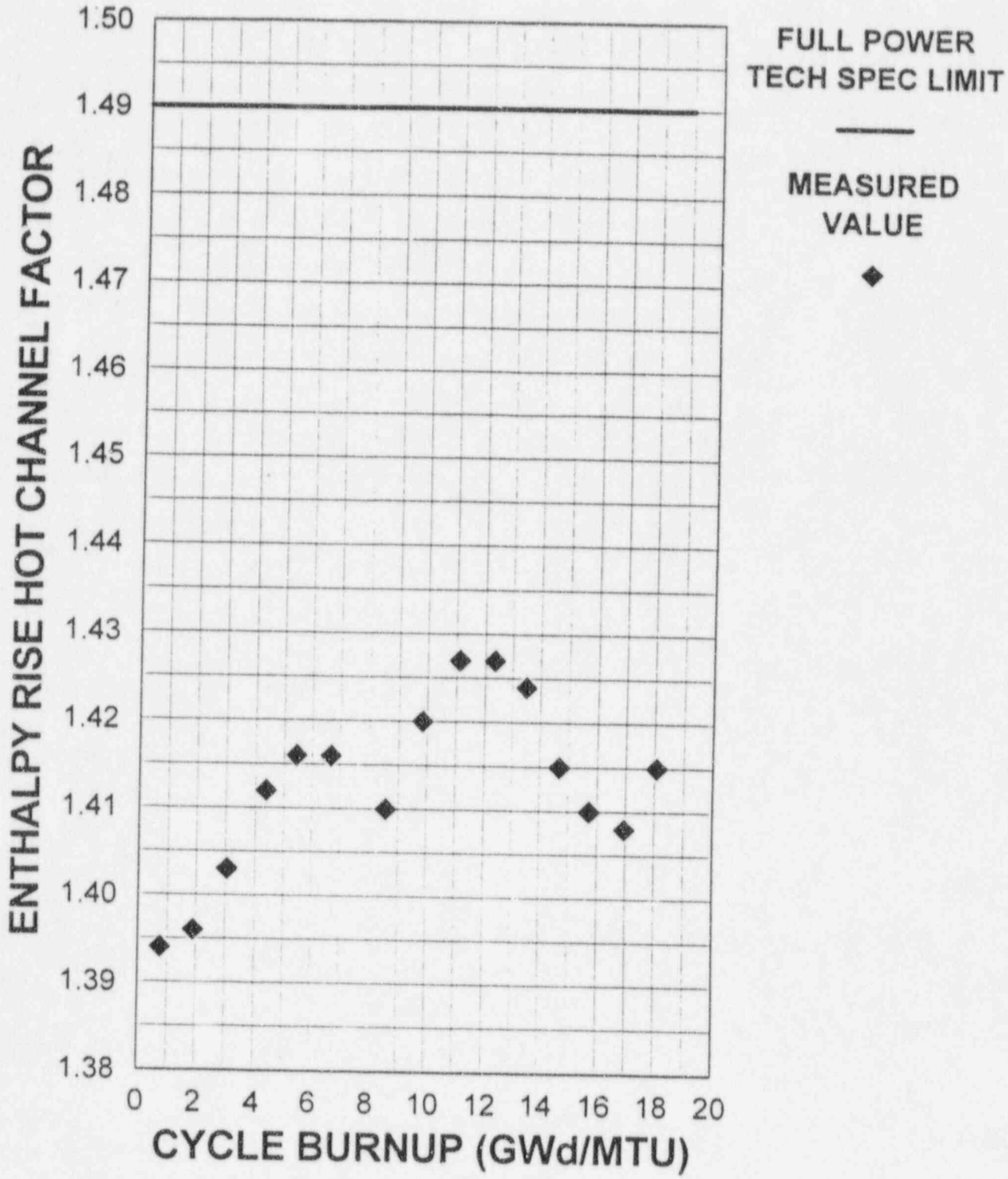


Figure 4.11
NORTH ANNA UNIT 1 - Cycle 11
TARGET DELTA FLUX vs. BURNUP

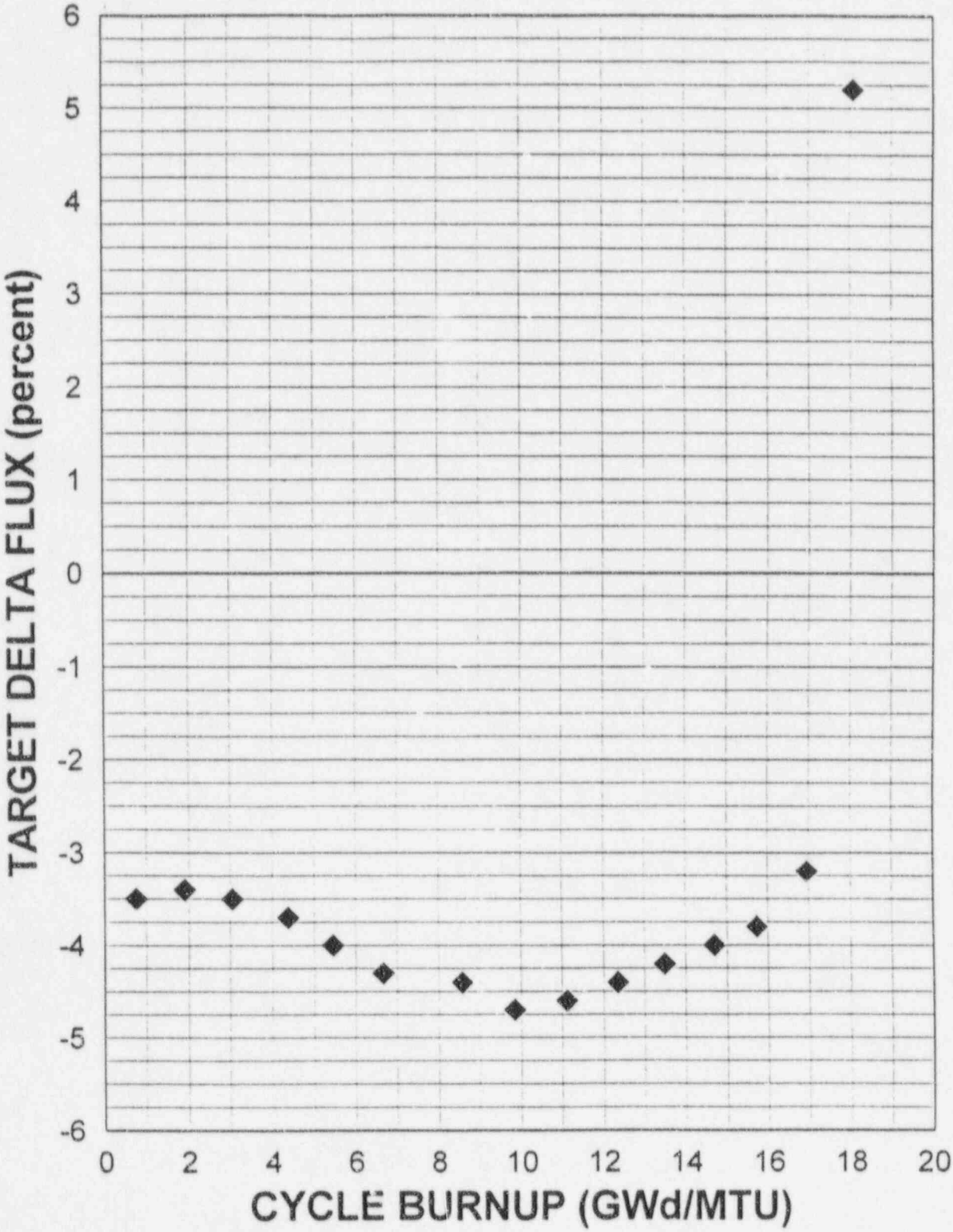


Figure 4.12
NORTH ANNA UNIT 1 - Cycle 11
CORE AVERAGE AXIAL POWER DISTRIBUTION
N1-11-04

Fz = 1.200
AXIAL OFFSET = -3.438%

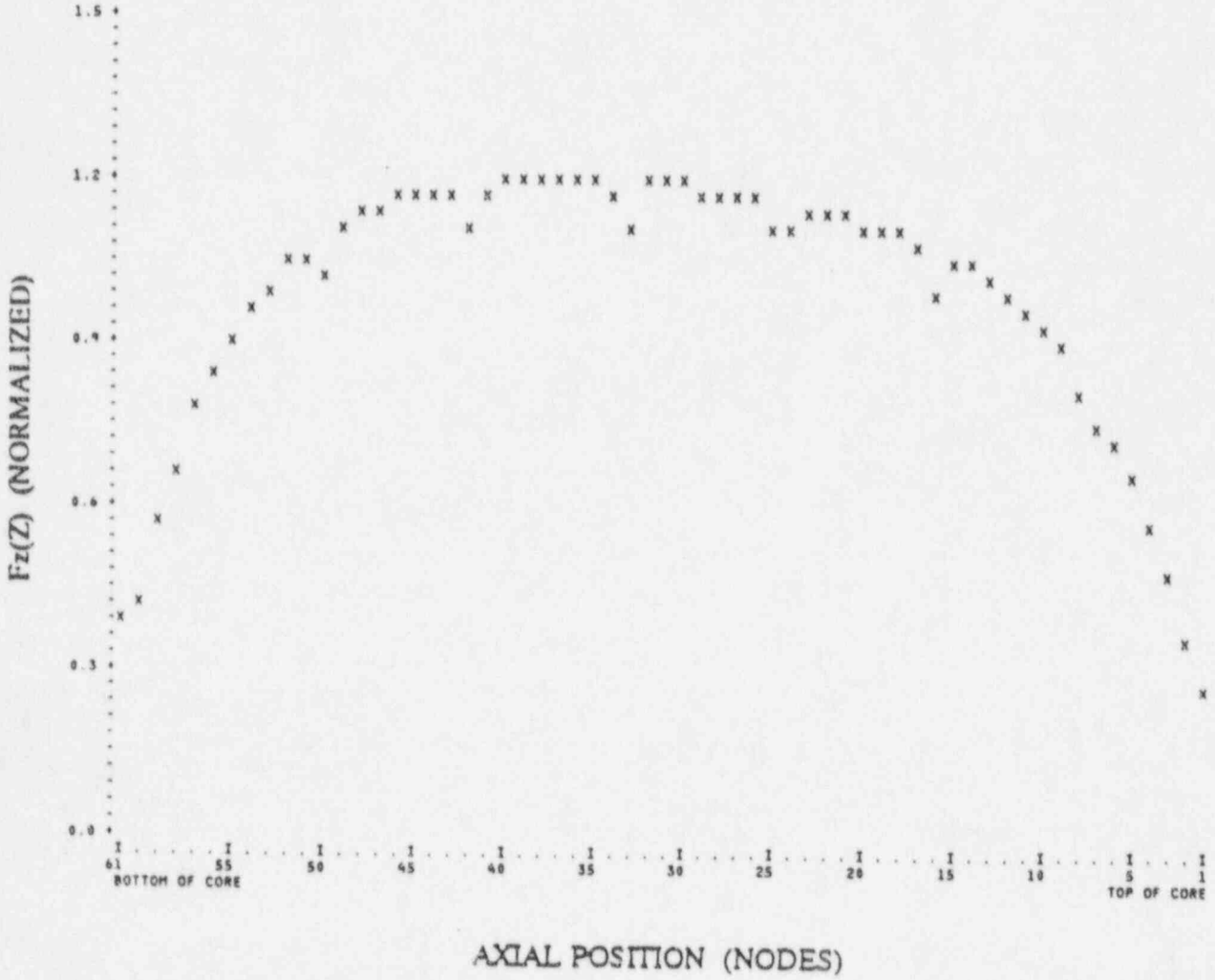


Figure 4.13
NORTH ANNA UNIT 1 - Cycle 11
CORE AVERAGE AXIAL POWER DISTRIBUTION
N1-11-11

Fz = 1.158
AXIAL OFFSET = -4.660%

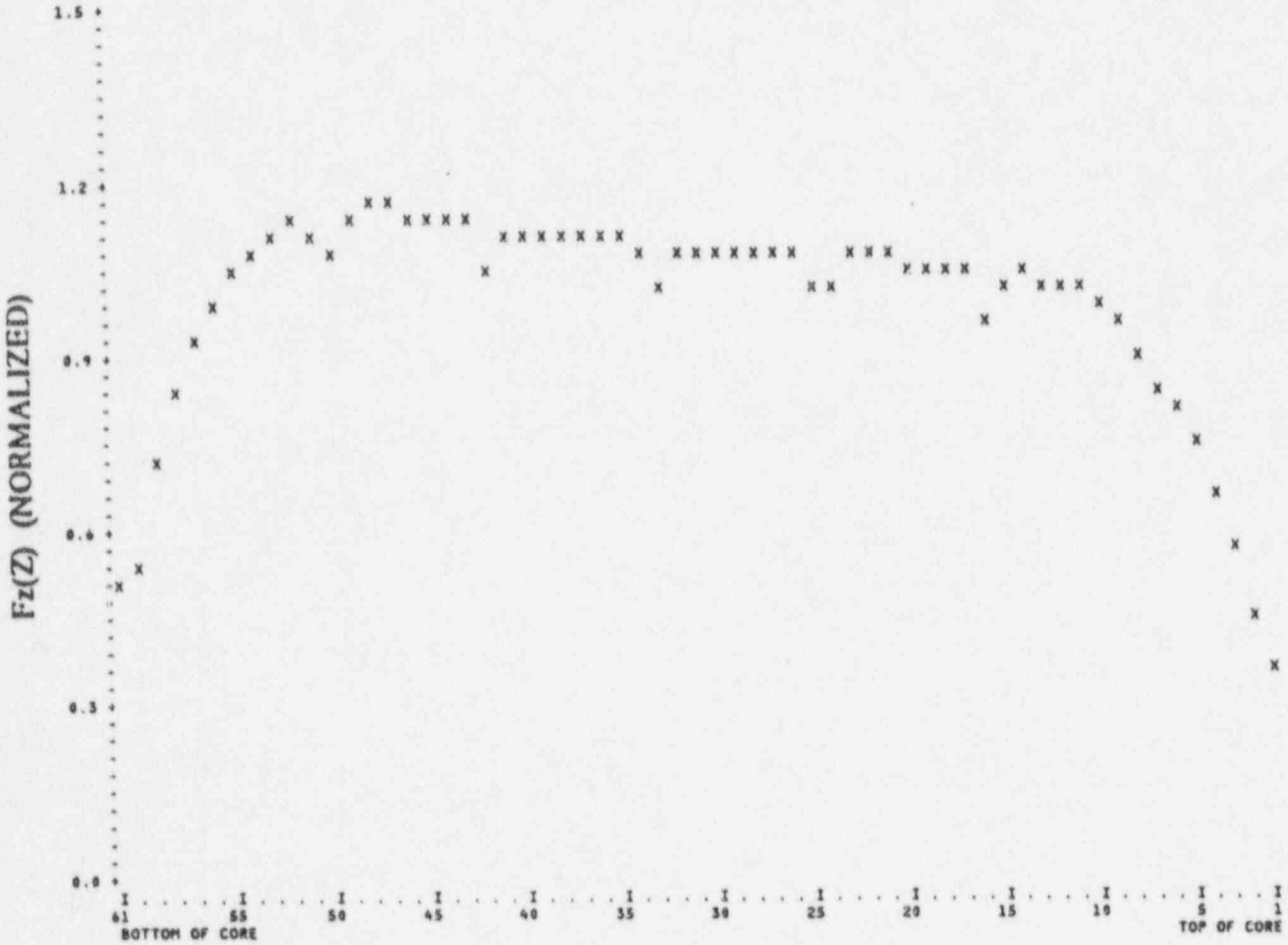


Figure 4.14
NORTH ANNA UNIT 1 - Cycle 11
CORE AVERAGE AXIAL POWER DISTRIBUTION
N1-11-17

Fz = 1.150
AXIAL OFFSET = -3.190%

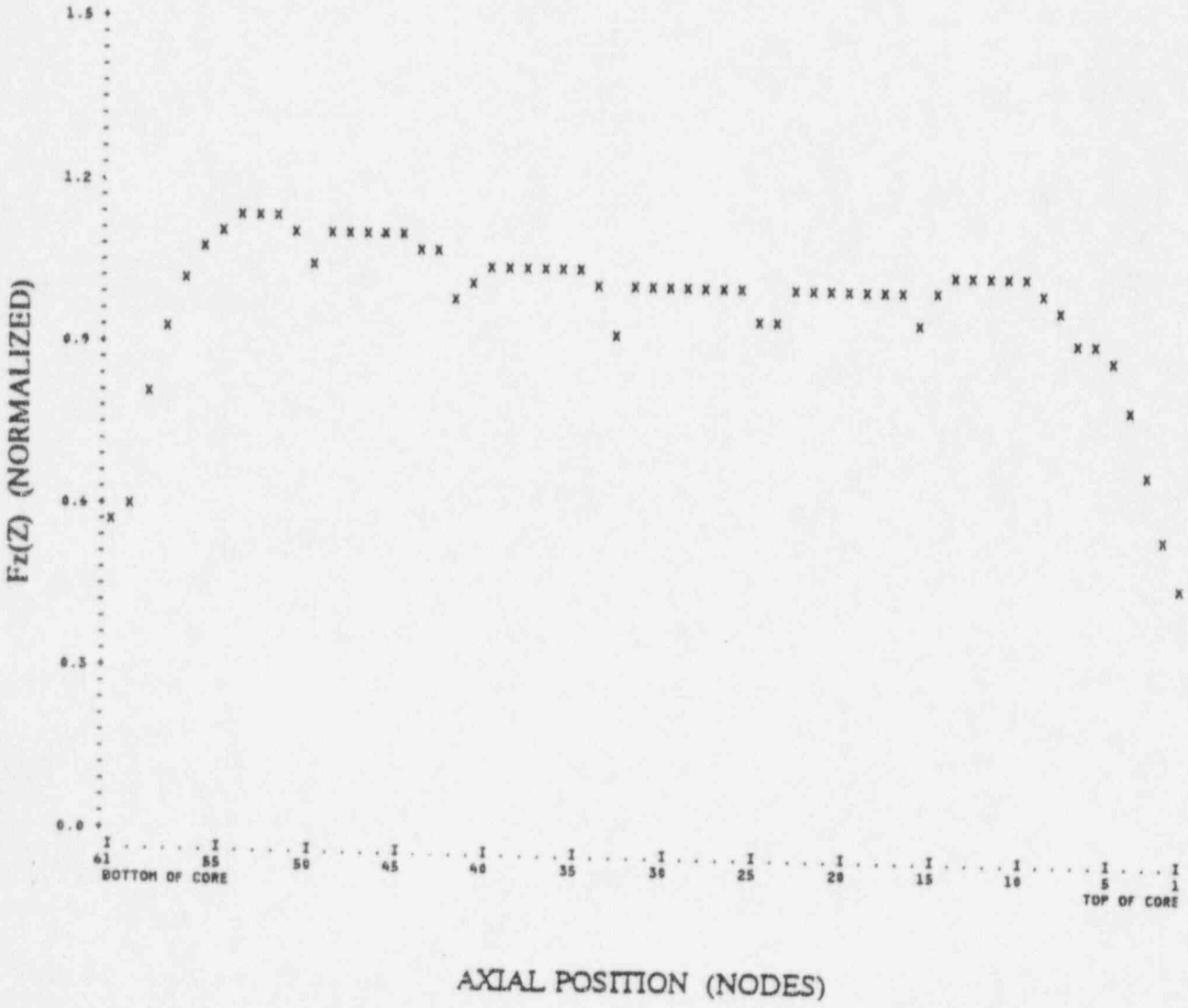
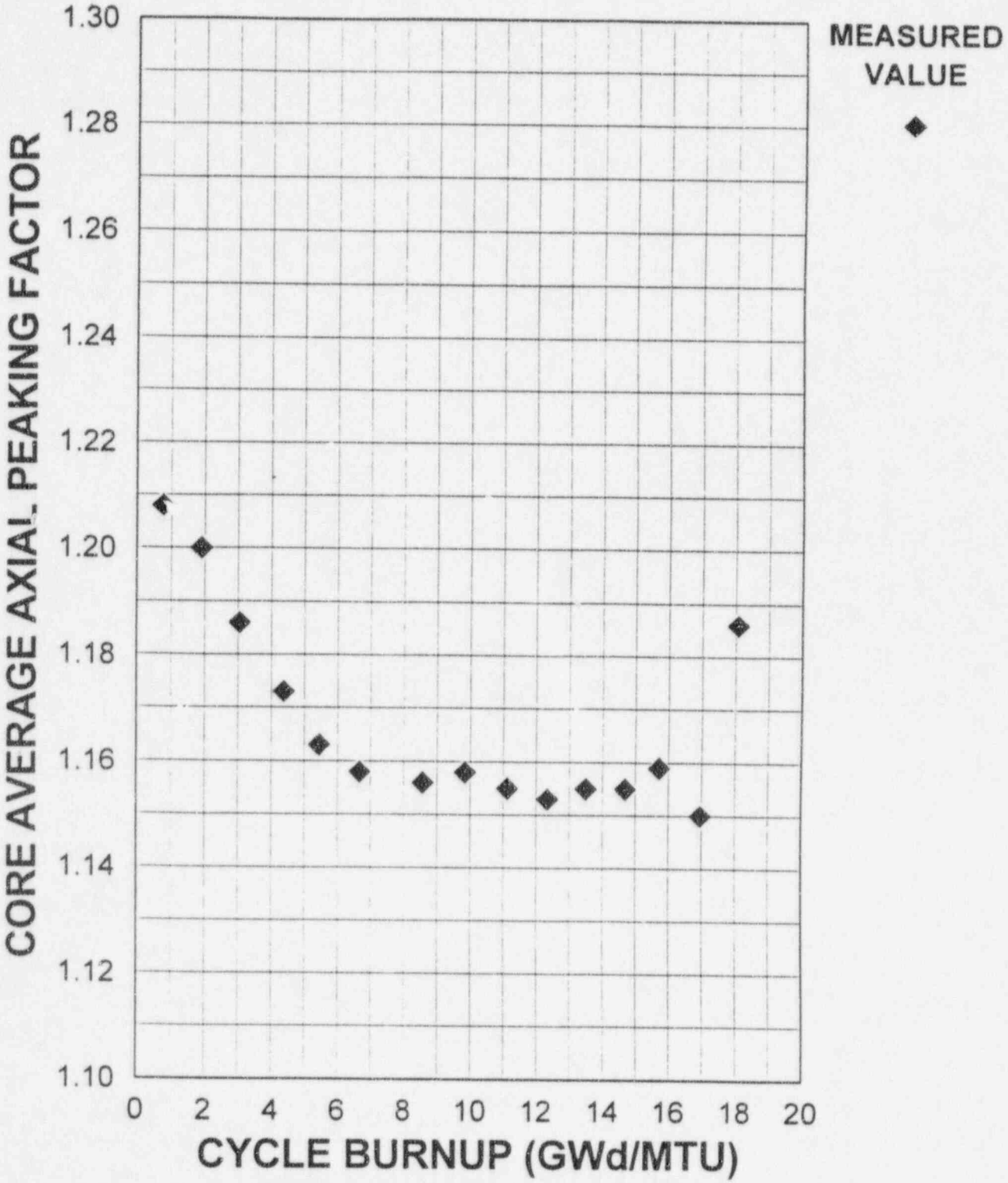


Figure 4.15
NORTH ANNA UNIT 1 - Cycle 11
CORE AVERAGE AXIAL PEAKING FACTOR vs. BURNUP



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, when present, are generally the predominant source of radioiodines in the primary coolant.

North Anna Unit 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 Operational Modes 1 through 5, inclusive. Figure 5.1 shows the dose-equivalent I-131 activity history for Cycle 1' 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 steady state power equilibrium dose equivalent I-131 concentration for the cycle was

1.25×10^{-3} µCi/gm which corresponds to less than 1% of the Technical Specification limit.

A combination of RCS iodine activity and noble gas activity is used during operation to determine if fuel defects are present. Figure 5.2 is the measured RCS I-131 data versus time for Cycle 11. This trend is consistent with a core operating with no defective fuel rods. There were also no indications of large increases in the RCS I-131 during rapid power transients (iodine spikes). This is futher evidence that Cycle 11 ended with no fuel defects.

The average tramp tramp-corrected I-131 for Cycle 11 was 6.73×10^{-5} µCi/gm. To correct I-131 for tramp sources, the calculated I-131 activity from tramp fissile sources (sources from other than fuel defects) is subtracted from the measured I-131. The difference is the tramp-corrected I-131, and the magnitude calculated for Cycle 11 is consistent with PWR cores with no fuel defects.

Figure 5.3 is the RCS Xenon-133 activity trend for Cycle 11. The magnitude of Xe-133 in the RCS is consistent with PWR cores operating with no fuel defects. There was a small increase in the steady state Xe-133 activity between the end of February 1995 and the middle of April 1995. This increase is not judged to be fuel related. Based on experience, fuel defects generally result in a much greater level of Xe-133 in the RSC (generally greater than 10^{-1} µCi/gm). Also, past data from North Anna Unit 1 and North Anna Unit 2 indicate that a typical level of Xe-133 in the RCS is on the order of 10^{-2} µCi/gm for cores with no fuel defects.

Figure 5.1
NORTH ANNA UNIT 1 - Cycle 11
DOSE EQUIVALENT I-131 vs. TIME

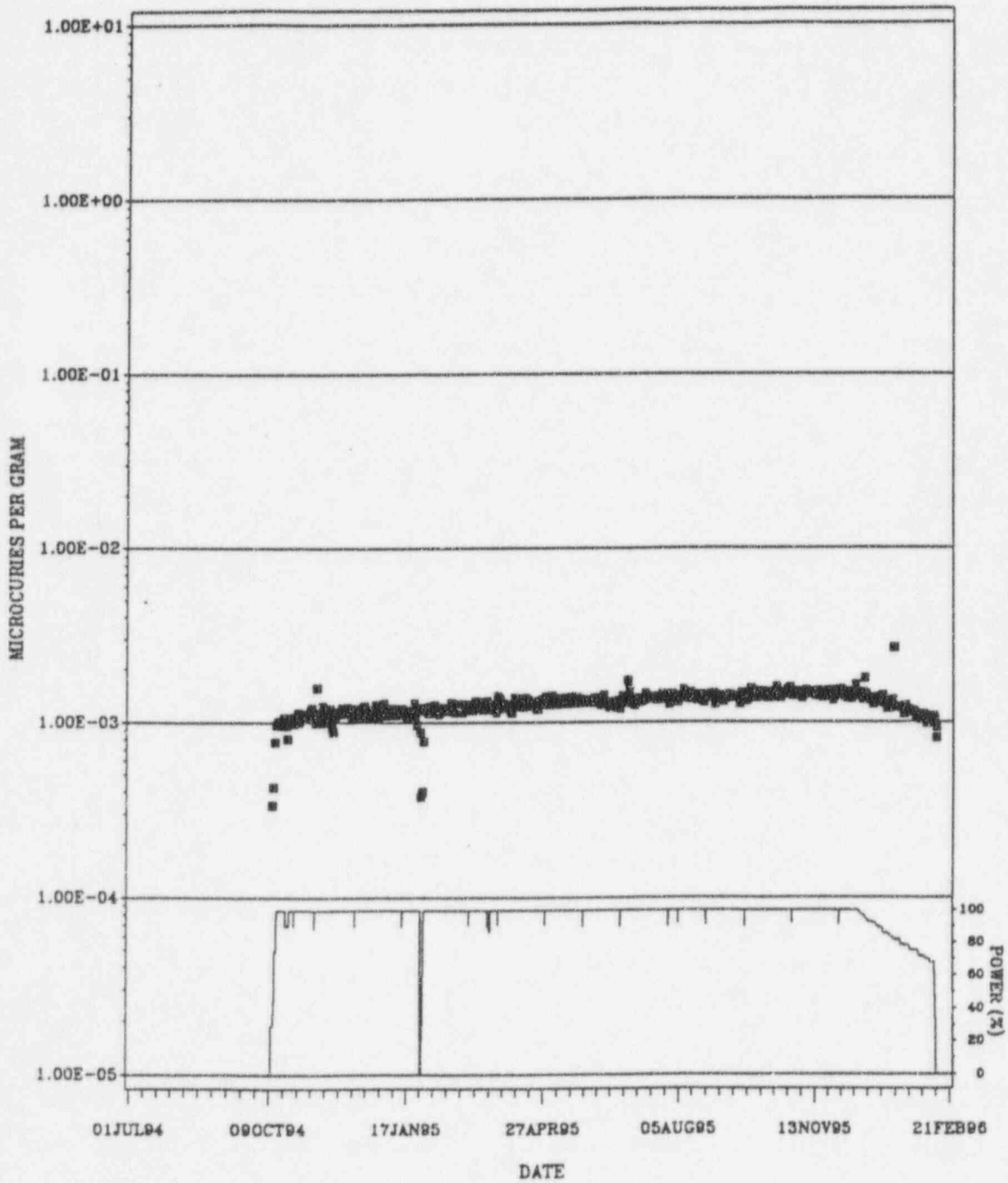


Figure 5.2
NORTH ANNA UNIT 1 - Cycle 11
MEASURED I-131 vs. TIME

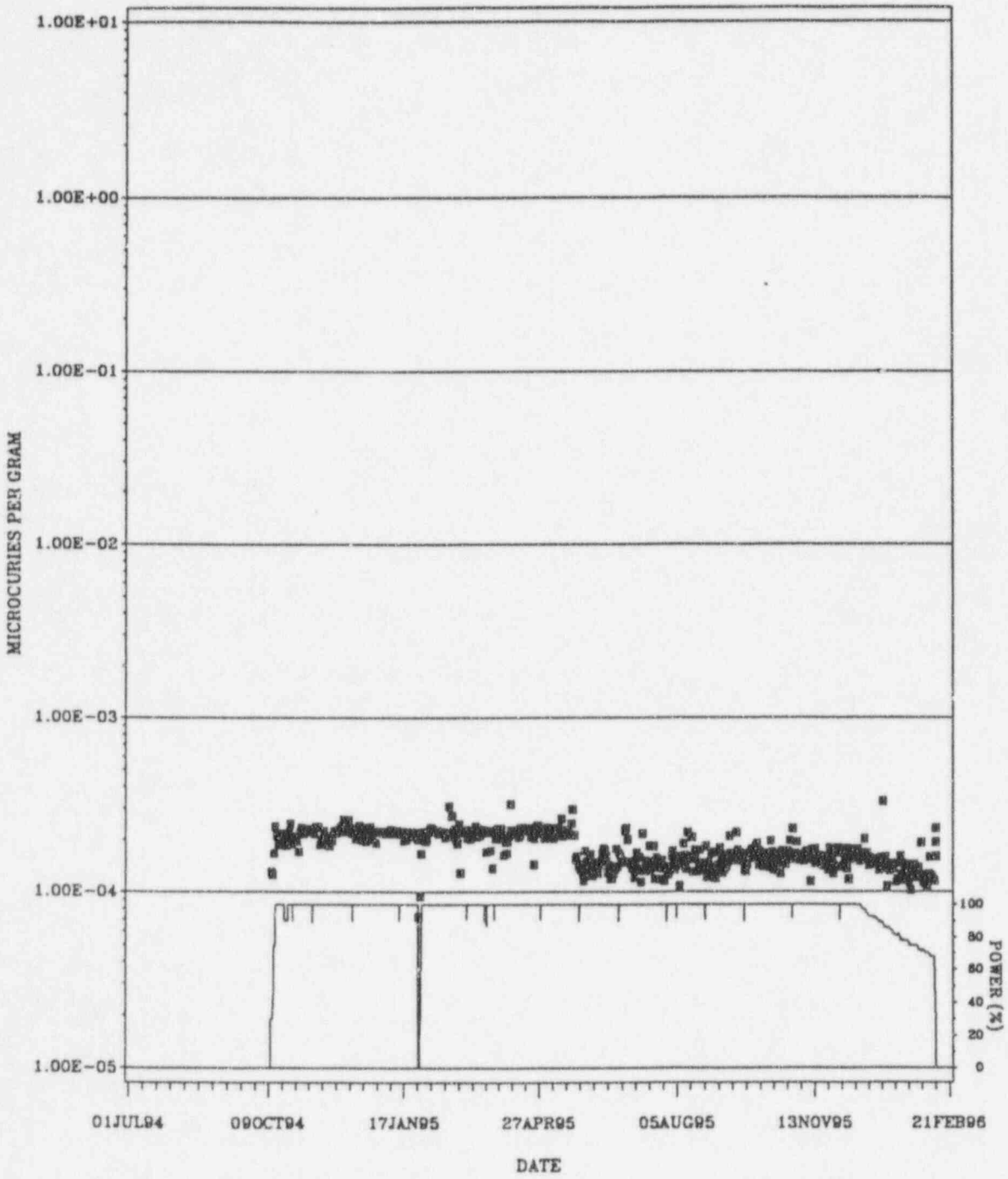
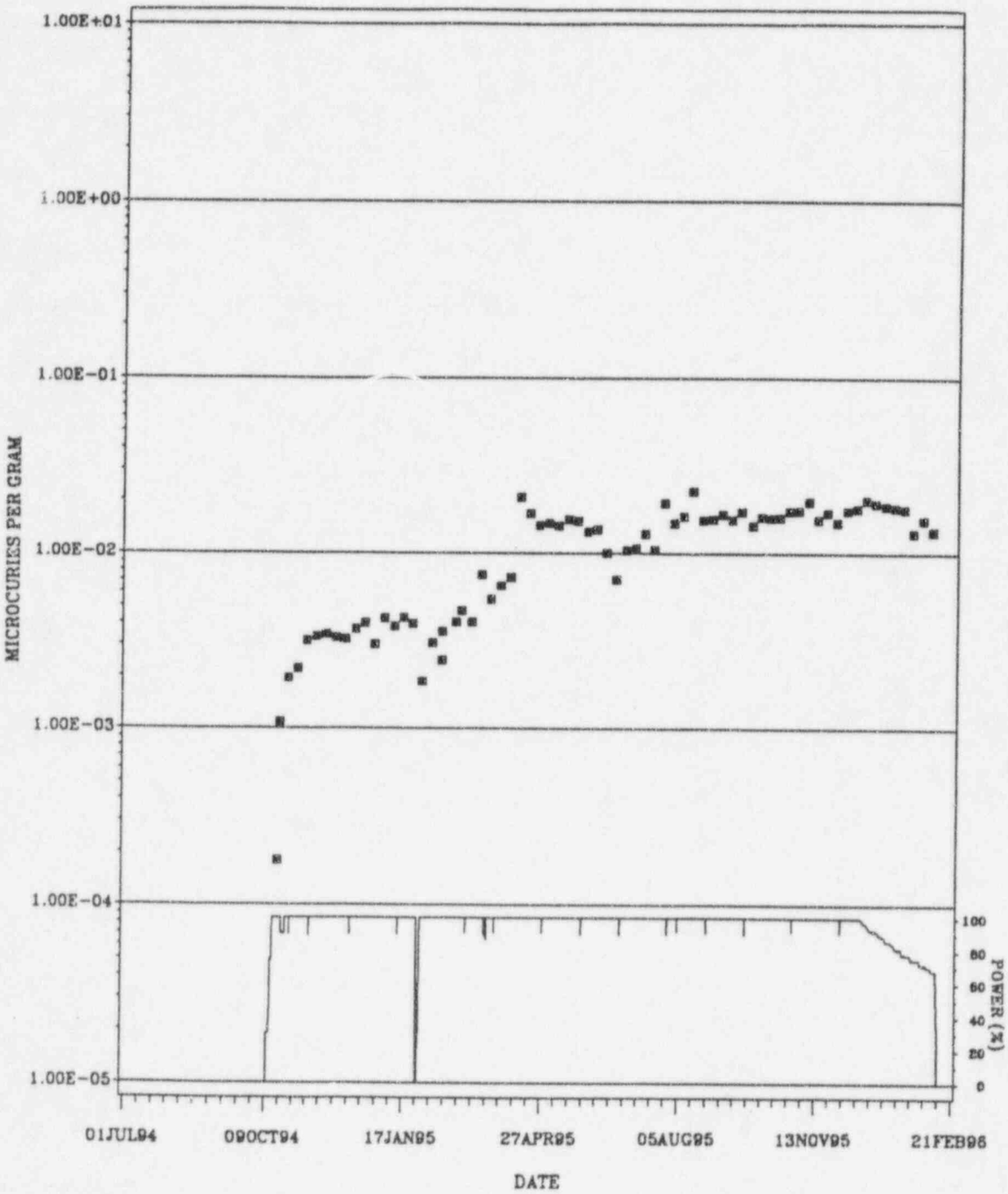


Figure 5.3
NORTH ANNA UNIT 1 - Cycle 11
MEASURED RCS XENON-133 vs. TIME



Section 6

CONCLUSIONS

The North Anna Unit 1, Cycle 11 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. An evaluation of the radioiodine and noble gas concentration in the RCS indicated that there were no apparent fuel rod defects during Cycle 11.

Section 7

REFERENCES

1) W. S. Miller, "North Anna Unit 1, Cycle 11 Startup Physics Tests Report", NE-1000, Rev. 0, December, 1994.

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, "Virginia Power Fuel Assembly Burnup and Isotopics Calculation Code Manual", NE-726, Rev. 1, March, 1995.

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

5) T.W. Schleicher, "The Virginia Power CECOR Code Package", NE-831, Rev. 3, Virginia Power, July, 1995.

6) J. M. Mirilovich, "North Anna 1, Cycle 11 FOLOW Input and Calculations", PM-564, Rev. 0, Addendum A, March, 1996.

7) P. D. Banning, "North Anna Unit 1, Cycle 11 Design Report", NE-997, Rev. 0, October, 1994.

8) J. M. Mirilovich, "North Anna Unit 1, Cycle 11 TOTE Calculations", PM-553, Rev. 0, Add. Q, February, 1996.

REFERENCES (cont.)

9) R. A. Hall, et al, "North Anna Unit 1 Cycle 11 Flux Map Analysis", PM-560, Rev. 0, and Addenda, October 1994 - January 1996.

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

11) "Core Operating Limits Report North Anna 1 Cycle 11 Pattern BW", NE-992, Rev. 0, July, 1994.