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PALISADES CYCLE 5 RELOAD FUEL SAFETY ANALYSIS REPORT

MAY 1981

RICHLAND, WA 99352

EXXON NUCLEAR COMPANY, Inc.

XN-NF-81-34

Issue Date: 06/10/31

PALISADES CYCLE 5 RELOAD FUEL

SAFETY ANALYSIS REPORT

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1.0 INTRODUCTION

Exxon Nuclear Company (ENC) has performed a Safety Analysis of the Palisades Nuclear plant for the operation of Cycle 5. This consists of evaluating the proposed fuel loading configurations with regard to the power peaking, shutdown margin and transient and accident response. A preliminary analysis was reported in XN-NF-80-58 "Palisades Cycle 5 Fuel Cycle Design Analysis" December, 1980. The Startup and Operations Report to be issued later will confirm in more detail the safety related core parameters discussed in this report. The core in Cycle 5 will consist of sixty-eight (68) twice burned G assemblies, sixty-eight (68) once-burned H assemblies, and sixty-eight (68) fresh I assemblies. All assemblies in the core will have been manufactured by ENC.

The gadolinia program initiated in Cycle 3 will continue in Cycle 5. The use of gadolinia will be extended from an irradiation of thirty-two (32) fuel rods containing 1.0 w/o Gd_2O_3 in Cycle 3 and thirty-two (32) fuel rods containing 4.0 w/o Gd_2O_3 in Cycle 4 to an irradiation of ninety-six (96) fuel rods containing 4.0 w/o Gd_2O_3.

Operating history of Cycle 4 is given in Section 3. The Cycle 5 core is discussed in Section 4. Reload I fuel design is given in Section 5. Section 6 covers the nuclear design of reload I. Safety analysis is discussed in Section 7.

2.0 SUMMARY

The characteristics of the fresh Batch I fuel and of the Cycle 5 reloaded core result in conformance with existing Technical Specification Limits regarding shutdown margin, and moderator temperature coefficients. This document provides the neutronic, thermal hydraulic, and control rod ejection analysis for the operation of Cycle 5. The ENC fuel assembly design for Batch I is similar to the Batch H extended burnup design[1,5]. Batch I contains 8 fuel assemblies made up of Batch I fuel rods and fuel rods left over from Batchs E and G. In addition Batch I fuel assemblies contain a lower enriched fuel pin in each corner than did the Batch H fuel assembly design. The ENC Plant Transient[3], and ECCS[4,5], analyses for Palisades operations at 2,530 MWt are applicable to Cycle 5. A summary of the Cycle 5 plant parameters are compared to the core license limits in Table 2.1.

Since the extended burnup fuel, Batch H, will have pin exposures in excess of 30,000 MWD/MT by the end of Cycle 5 it will be necessary to implement the burnup dependent F_Q limit reported in Appendix A[2] into the Technical Specifications. Due to the replacement of D fuel assemblies, which contain 216 active fuel rods per assembly, with I fuel, which mostly contain 208 active fuel rods per assembly, the total number of rods in the core will be reduced by 1%. This corresponds to a 1% increase in the average linear heat generation rate (LHGR) for Cycle 5. While

the safety limits for allowable LHGR's in ENC assemblies with 208 active rods are unchanged, the reduction in the number of fuel rods in the Cycle 5 core necessitates a corresponding reduction in the allowable relative power peaking factors.

Table 2.1 Palisades Cycle 5 Summary of Core Characteristics

Parameters		Calculated BOC	Calculated EOC	Core License Limits
Moderator Temperature Coefficient ($\Delta\rho/^{o}F \times 10^{-4}$)	HFP (no xenon)	+0.20	-2.56	+0.5 to -3.5
Critical Boron Concentration				
	HZP	1310	-	-
	HFP	950	0	-
Shutdown Margin (%$\Delta\rho$)		2.40	2.33	>2.0
Power Peaking Factors				
	F_Q	2.35	1.84	<2.76*
	F_R^A	1.34	1.30	<1.43
	$F_r^{\Delta H}$	1.62	1.53	<1.64
	F_r^T	1.75	1.59	<1.77

* Based on 208 active fuel rods per assembly and corresponds to the 15.28 kw/ft Technical Specification Limit on LHGR.

3.0 OPERATING HISTORY OF THE REFERENCE CYCLE

The fourth power cycle has been chosen as the reference cycle with respect to Cycle 5 due to the similarity of the neutronic characteristics between the two cycles. Cycle 4 operation began on May 24, 1980 and as of April 19, 1981, the core had accrued a cycle exposure of 7,548 MWD/MT. The plant availability and capacity factor is shown in Figure 3.1.

Appreciable quantities of gadolinia are currently being irradiated in the Cycle 4 core. Each of four (4) assemblies contain eight (8) Gd_2O_3-UO_2 rods with initial concentration of 4.0 w/o Gd_2O_3. The assemblies containing the gadolinia are located near the periphery of the core on the diagonal. The gadolinium bearing assemblies have performed as expected in the Cycle 4 core.

3.1 CYCLE 4 STARTUP TESTS

The startup and low power physics tests performed at the beginning of life for Cycle 4 included boron end point measurements, isothermal temperature coefficient measurements, and rod bank worth measurements. The Palisades Cycle 4 Startup Report details the startup measurements and the comparisons to predictions.

3.2 OPERATING STATUS OF CYCLE 4 (APRIL, 1981)

The Palisades core achieved a cycle burnup of 7,548 MWD/MTM on April 19, 1981, and has operated at or near full power for most of the cycle. Except for the six week outage in November and December the

plant has had a good operating record. For operation through April, 1980, the cycle average capacity factor has been about 72%.

Comparisons of predicted and measured boron concentrations and power distributions for Cycle 4 have been continously maintained. Figure 3.2 displays the calculated and measured boron run down data for Cycle 4.

The calculated and measured power distribution at 6,950 MWD/MTM is shown in Figure 3.3, the standard deviation between predicted and measured values is less than 3%. On an assembly basis, comparisons of measured and predicted powers show deviations within 4.4%. Comparisons of calculated and measured assembly power during Cycle 4 for the assemblies containing 4 w/o Gd_2O_3 are shown in more detail in Appendix B.

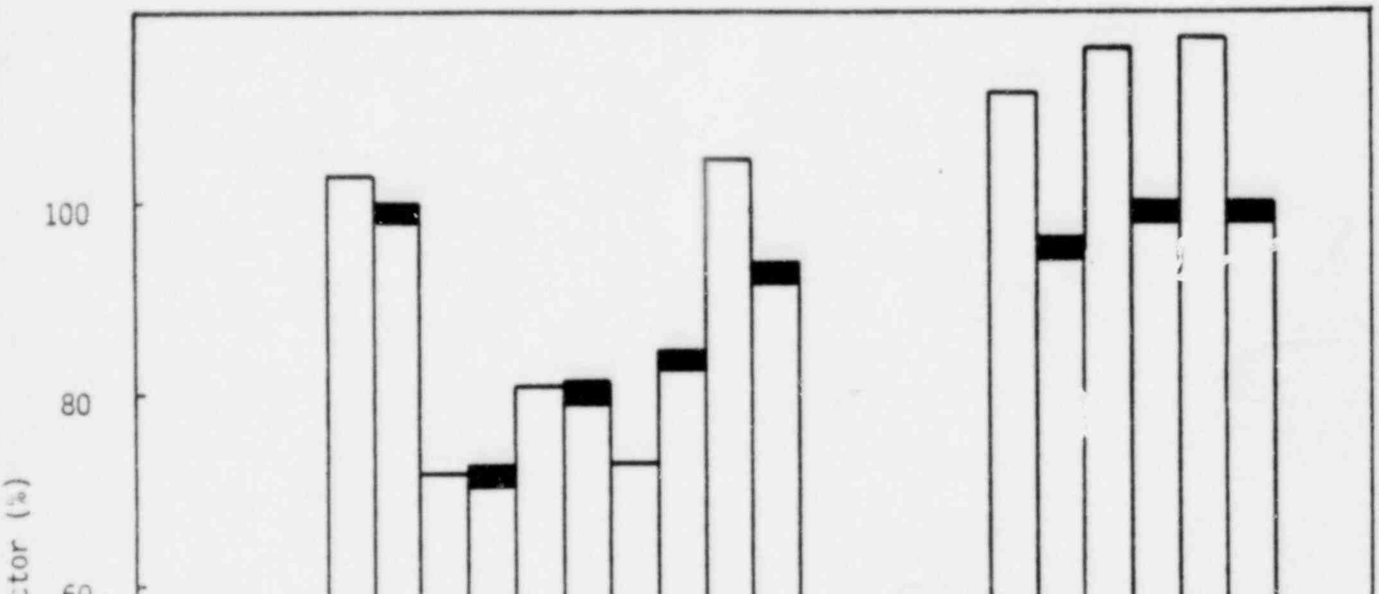


Figure 3.1 Palisades Cycle 4 Operating History

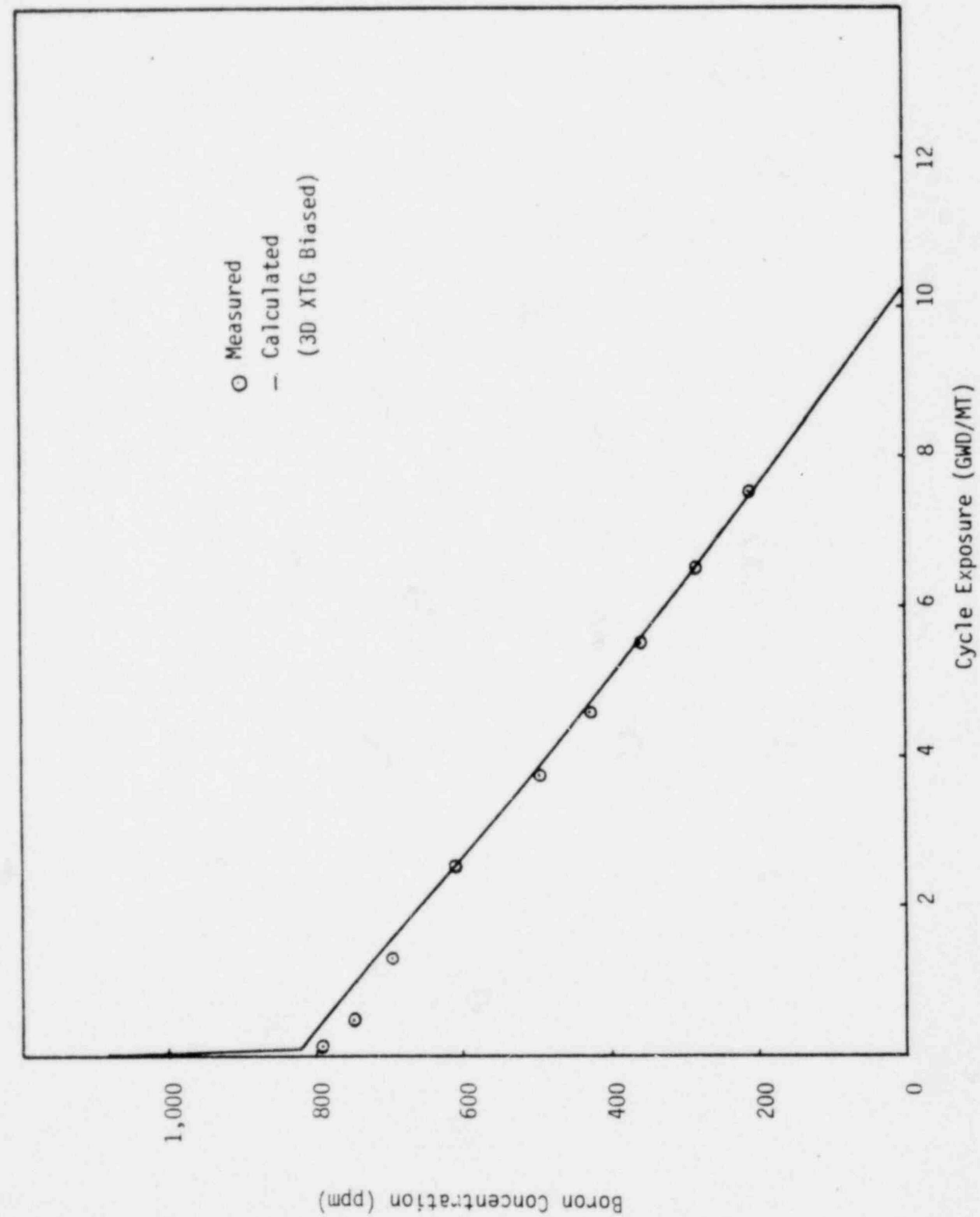
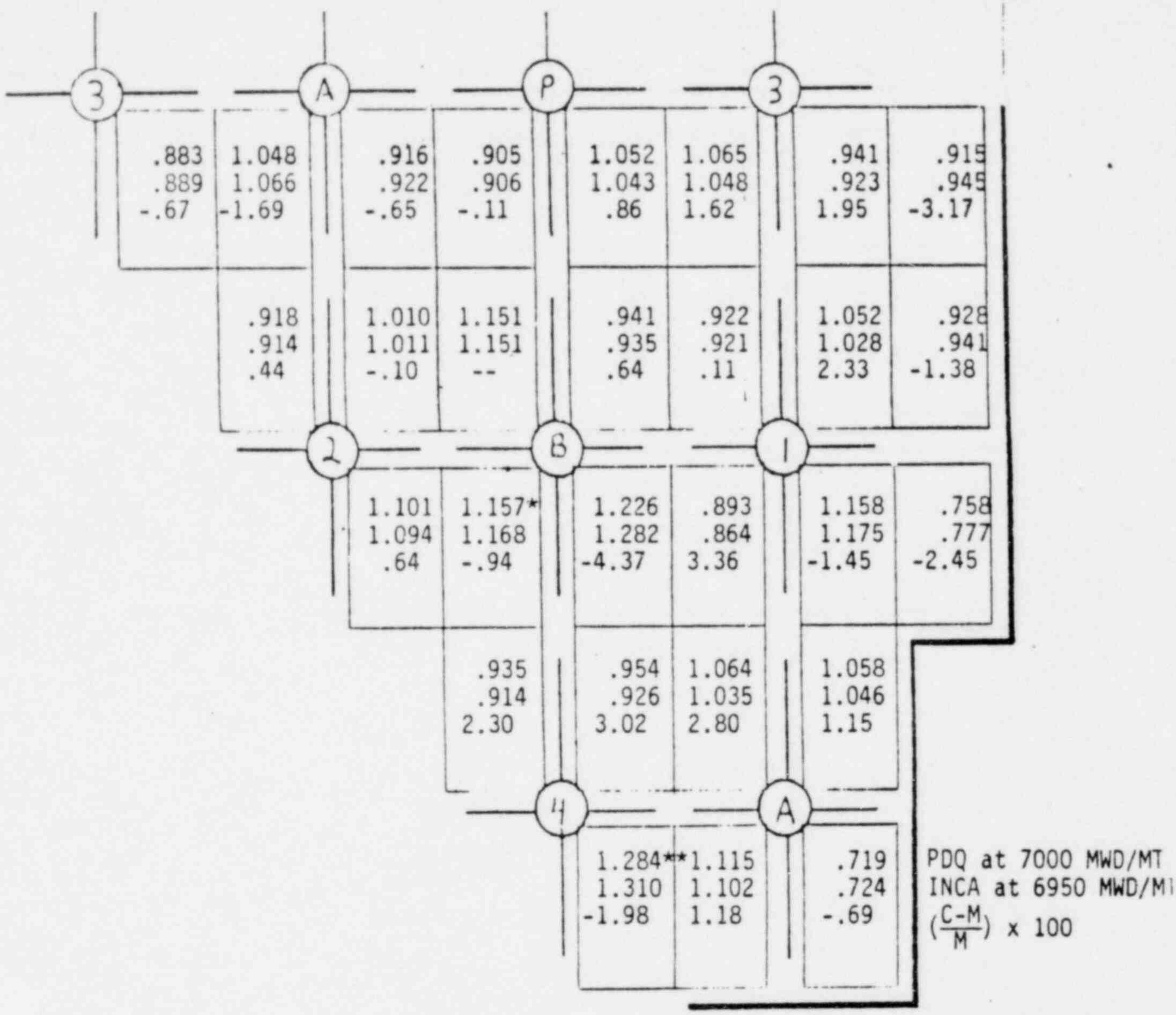


Figure 3.2 Palisades Cycle 4 Critical Boron Concentration vs. Exposure, HFP, ARO



* Cycle 3 Gd_2O_3

** Cycle 4 Gd_2O_3

Figure 3.3 Palisades Cycle 4, INCA Power Distribution (Measured) versus PDQ Calculated Relative Assembly Power, 100% Power

4.0 CYCLE 5 CORE DESCRIPTION

The Palisades Cycle 5 core consists of 204 fuel assemblies, each having a 15 x 15 fuel rod array. The fuel rods consist of slightly enriched (in U-235) UO_2 pellets inserted in zircaloy tubes. The ENC assemblies have provisions for removable burnable absorber shims. Each ENC assembly contains ten zircaloy spacers with Inconel springs, nine of the spacers are located within the active fuel region.

The planned Cycle 5 core loading arrangement is shown in Figure 4.1. The initial enrichments and burnup distributions are displayed in Figure 4.2. The Cycle 5 core consists of twice burned Batch G and once burned Batch H assemblies scatter-loaded throughout the interior of the core. The fresh Batch I fuel are located adjacent to and on the periphery of the core except for the eight assemblies containing boron carbide burnable absorber rods which are loaded in the interior. Batches G, H, and most of I (supplied by ENC) contain 208 fuel rods. The twelve (12) Batch I assemblies containing gadolinia have 216 fuel rods.

Eight (8) Batch I assemblies contain removable boron carbide absorber shims. All eight of these assemblies are loaded in the interior. The twelve (12) gadolinia bearing assemblies are located adjacent to the peripheral assemblies. The remaining 48 Batch I assemblies are located on the periphery and do not contain burnable absorber rods. Pertinent fuel assembly parameters are given in Table 4.1. In this table, the

Batch I fuel is considered in four regions depending upon the assembly makeup.

A comparison of core parameters between Cycles 4 and 5 indicate a close resemblance between the two. As a consequence Cycle 4 is considered the reference cycle. Some of the main core parameters are summarized in Table 4.2.

Table 4.1 Fuel Assembly Design Parameters

Fuel Batch Identification	G_1 (Unshimmed)	G_2 (B_4C)	G_3 (Gd_2O_3)	H_1 (Unshimmed)	H_2 (B_4C)	H_3 (Gd_2O_3)	I_1 (Unshimmed)	I_2 (Spare Rods)	I_3 (B_4C)	I_4 (Gd_2O_3)
Cycle Loaded	3	3	3	4	4	4	5	5	5	5
Initial Region Average Enrichment w/o U-235	3.00	3.00	3.00	3.27	3.27	3.24	3.26	3.23	3.26	3.24
No. of Assemblies	40	20	8	48	16	4	40	8	8	12
Pellet Density, %	94	94	94	94	94	94.0/94.75***	94	94	94	94
Pellet to Clad Gap, (mil)	7.5	7.5	7.5	8.0	8.0	8.0	8.0	7.5/8.0	8.0	8.0
Fuel Stack Height	131.8	131.8	131.8	131.8	131.8	131.8	131.8	131.8	131.8	131.8
Region Average Burnup at BOC 5, MWD/MT	20,420	23,870	22,190	9,273	12,019	12,240	0	0	0	0
No. of Fuel Enrichments Per Assembly	3	3	3	2	2	3	3	7	3	3
No. of Fuel Rod and Enrichment (w/o)	60/2.52 4/3.01 144/3.20	60/2.52 4/3.01 144/3.20	60/2.52 4/3.01 144/3.20	64/2.90 144/3.43	64/2.90 144/3.43	8/2.69 64/2.90 136/3.43	4/2.52 60/2.90 144/3.43	2/1.87 8/2.40 9/2.81 40/2.90 5/3.01 5/3.28 139/3.43	4/2.52 60/2.90 144/3.43	4/2.52 8/2.52 56/2.90++ 148/3.43
No. of Poison Rods Per Assembly	0	8	4*	0	8	8**	0	0	8	8***
No. of Fuel Rods Per Assembly	208	208	208	208	208	208	208	208	208	216

* Fixed 1 w/o Gd_2O_3 in 3.20 w/o Fuel Rods

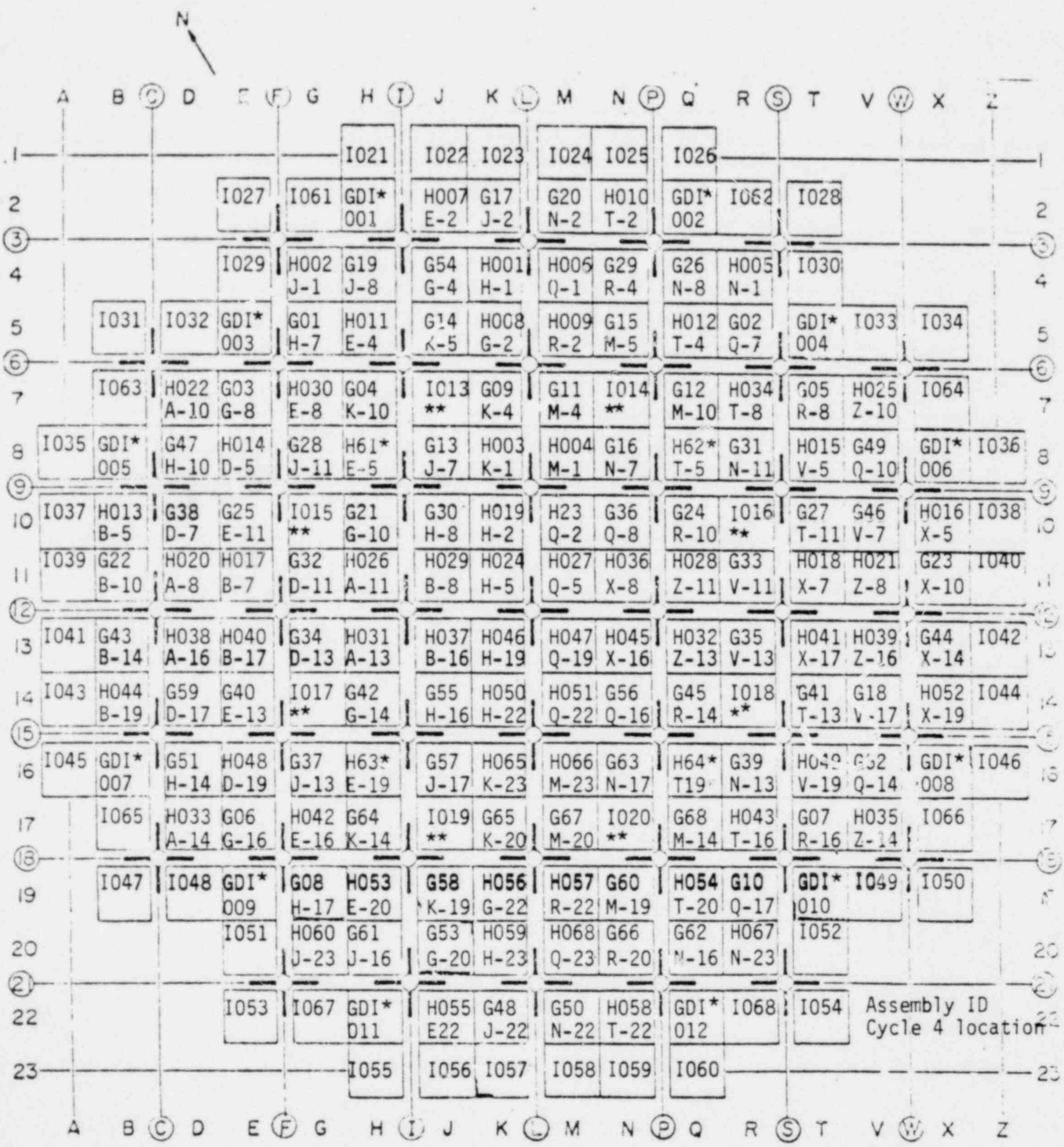
** Fixed 4 w/o Gd_2O_3 in 2.69 w/o Fuel Rods

*** Gadolinia bearing rods only

++ Fixed 4 w/O Gd_2O_3 in 2.52 w/o Fuel Rods

Table 4.2 Summary of Core Parameters

	Cycle 4	Cycle 5
Power Rating, MW Thermal	2,530	2,530
Expected Cycle Burnup (MWD/MT)	10,000	11,500
Beginning of Cycle Expected Core Average Burnup (MWD/MT)	11,000	10,500
End of Cycle Expected Core Average Burnup (MWD/MT)	21,000	22,000
Cycle Time (EFPH)	7,663	8,641
Moderator Temperature Coefficient ($\Delta\rho/^{o}F$) x 10^{-4} (HFP, eq. xenon)	+0.2	+0.3
Doppler Coefficient $\Delta\rho{}^{o}F$ x 10^{-5} (HFP, BOC)	-1.25	-1.29
Delayed Neutron Fraction	.0061	.0061
Boron Concentration (ppm) HFP equilibrium xenon 100 hr. sm. (at 100 MWD/MT)	743	945



* 4.0 w/o gd_2O_3

** B_4C shimmed assemblies

Figure 4.1 Planned Cycle 5 Loading Pattern

	M	N	Q	R	T	V	X	Z
13	H2 Q-19 12,320	H2 X-16* 11,710	H1 Z-13 9,650	G1 V-13* 21,490	H1 X-17*** 10,620	H1 Z-16*** 7,710	G1 X-14 21,640	I1 0
14	H2 Q-22*** 11,710	G2 Q-16 24,020	G1 R-14* 18,570	I3 0	G1 T-13 21,580	G2 V-17 23,340	H1 X-19 7,020	I1 0
16	H1 M-23 9,650	G1 N-17*** 18,550	H3 T-19 12,240	G1 N-13* 18,880	H1 V-19 10,930	G2 Q-14 24,310	I4 0	I1 0
17	G1 M-20*** 21,490	I3 0	G1 M-14*** 18,800	H2 T-16** 12,330	G3 R-16*** 22,190	H1 Z-14* 9,700	I2	
19	H1 R-22* 10,620	G1 M-19 21,560	H1 T-20 10,930	G3 Q-17* 22,180	I4 0	I1 0	I1 0	
20	H1 Q-23* 7,410	G2 R-20 23,340	G2 N-16 24,270	H1 N-23*** 9,700	I1			
22	G1 N-22 21,640	H1 T-22 7,020	I4 0	I2 0	I1 0			
23	I1 0	I1 0	I1 0					

Fuel Type
Cycle 4 Location
BOC5 Exposure (MWD/MT)

Region	Initial Average Enrichment
G	3.00
H	3.27
I	3.25

Rotations Counter-clock wise

* 90^{0}
** 180^{0}
*** 270^{0}

Figure 4.2 Cycle 5 Loading Pattern and Anticipated BOC Assembly Average Exposure Distribution

5.0 RELOAD I FUEL ASSEMBLY DESIGN

A description of the Exxon Nuclear supplied fuel design for the previous reload batches is contained in References 1, 7, 8 and 9. From a mechanical standpoint the reload batch I design is essentially identical to the reload batch H except for the eight (8) "spare rods" assemblies and the low enriched fuel pins in the corners of all the assemblies (2.52 w/o U-235). The "spare rods" assemblies contain fuel rods of the reload E/G design as well as that of the reload I design. These assemblies will, therefore, be required to operate within the design burnup envelope of the reload E/G design. The exposure limitation being applied to the "spare rod" assemblies will not restrict the operation of reload Batch I since the anticipated assembly exposure for the spare rod assemblies is below the batch I average which is less than the maximum assembly exposure permitted for batch E. A comparison of the design parameters is presented in Table 5.1.

The gadolinia demonstration program will continue in Cycle 5. The demonstration program began with the irradiation of thirty-two fuel rods containing 1 w/o Gd_2O_3 in Cycle 3 and was followed by the irradiation of thirty two fuel rods containing 4 w/o Gd_2O_3 in Cycle 4. In the latter assemblies, 2.69 w/o UO_2 fuel rods containing 4 w/o gadolinia replaced eight standard 3.43 w/o UO_2 fuel rods.

In Cycle 5 ninety-six (96) fuel rods will contain eight (8) 4 w/o Gd_2O_3 fuel rods evenly distributed in twelve (12) assemblies. These gadolinia bearing fuel rods will be mixed with uranium enriched to 2.52 w/o. For these assemblies the guide tubes have been replaced with the high enrichment (3.43 w/o) fuel rods and the eight gadolinia rods replace four (4) 2.90 w/o and four (4) 3.43 w/o fuel rods.

Thermal margins have been calculated for the Cycle 5 core including the gadolinia demonstration program and it is concluded that the program will have no impact on the safety and performance of the Cycle 5 core and Reload I.

Table 5.1 Fuel Design Summary

Reload Design	E/G	H	I
Number of Assemblies	68	68	68
Initial Average Enrichment (%)	3.00	3.27	3.25
Pellet Density (% TD)	94.0	94.0/94.75*	94.0
Pellet Clad Gap (in)	0.0075	0.0080	0.0080
Fill Gas Pressure (psia He)	300	321	321
Wall Thickness (in)	.0285	.0295	.0295
Number of Assemblies with $B_4C-Al_2O_3$ Burnable Poison	20	16	8
$B_4C-Al_2O_3$ Rods/Assembly	8	8	8
Poison Loading, gm B10/in	0.0204	0.0204	0.0204
Number of Assemblies with Gd_2O_3 Burnable Poison	8	4	12
Urania-Gadolinia Rods/Assembly	4	8	8
Wt. % Gd_2O_3	1.00	4.0	4.0
BOC 5 Batch Average Exposure (MWD/MT)	21,640	10,090	0

* Gadolinia bearing rods only

6.0 NUCLEAR DESIGN

The neutronic characteristics of the projected Cycle 5 core consisting of three regions of ENC fuel (Batches G, H, and I) are quite similar to those of the Cycle 4 core (see Section 4.0). The nuclear design bases for the Cycle 5 core are as follows:

1. The design shall permit operation of the Cycle 5 core at full power within the constraints established for the Palisades reactor.
2. The length of Cycle 5 shall be determined on the basis of a 2,530 MWt power rating and on an assumed Cycle 4 energy production equivalent to 10,000 MWD/MT.
3. The Region I assembly average enrichment shall be 3.25 w/o which is slightly less than the Batch H assembly average enrichment of 3.27 w/o. The Batch I Reload shall consist of 68 assemblies (one-third core reload).
4. The Cycle 5 loading pattern shall be optimized to achieve non-limiting power distributions and control rod reactivity worths according to the following constraints:
   a. The peak LHGR shall not exceed 15.28 kw/ft including uncertainties in any single fuel rod throughout the cycle under nominal steady state full power operating conditions;
   b. The peak assembly power shall not exceed 17.78 MW in assemblies containing 208 fuel rods which corresponds to a peaking factor of 1.43 and 18.08 MW in assemblies

containing 216 fuel rods which corresponds to a peaking factor (F_r^A) of 1.46 in the corresponding assembly throughout the cycle.

c. The peak rod power for an internal rod shall not exceed 97.90 KW which corresponds to a peaking factor ($F_r^{\Delta H}$) of 1.64 for assemblies with 208 fuel rods. The peak rod power for an internal rod shall not exceed 95.86 KW which corresponds to a peaking factor ($F_R^{\Delta H}$) of 1.67 for assemblies with 216 fuel rods throughout the cycle.

d. The peak rod power for all rods in batch G shall not exceed 104.3 KW which corresponds to a peaking factor (F_r^T) of 1.75. The peak rod power for all rods in batches H and I shall not exceed 105.5 KW, which corresponds to a peaking factor (F_R^T) of 1.77 and 1.84 for assemblies with 208 and 216 fuel rods, respectively. These peaking factor limits apply throughout the cycle under nominal full power steady state conditions.

e. The N-1 scram worth shall not violate the HZP and HFP, BOC and EOC shutdown requirements;

5. The Cycle 5 core shall have a negative power coefficient.

The neutronic design methods are described in References 11, 12, and 13.

In order to simplify the Technical Specificatio..., it is recommended that the peaking factor limits be established at 1.43, 1.64 and 1.77 for F_R^A, $F_r^{\Delta H}$, and F_r^T, respectively. These values represent the lower peaking factor of the different assembly types. Calculations show that by monitoring the core to the minimum allowable peaking factors, Cycle 5 will be able to operate at full power for the duration of the cycle.

6.1 PHYSICS CHARACTERISTICS

6.1.1 Power Distribution Considerations

Representative radial and axial power maps for the planned core loading are shown in Figure 6.1 through 6.5. Figures 6.1, 6.2 and 6.3 show the radial power maps at 100 MWD/MT, 4000 MWD/MT, and 8,500 MWD/MT, respectively. The highest assembly power factor calculated for Cycle 5 is 1.30 and occurs at 100 MWD/MT. The corresponding core average axial profiles are shown in Figures 6.4 and 6.5. These power distributions were obtained from a three-dimensional analysis accounting for feedbacks including moderator density and Doppler.

The radial maps are representative of a hot full power, equilibrium xenon core configuration. The Cycle 5 loading pattern was designed to minimize $F^{\Delta H}$ and F_Q^N. The largest calculated F_Q^N was 2.03 diminishing to 1.59 at EOC conditions. The calculated xenon free, full power value of F_Q^N is 2.06.

The axial power profiles are core average distributions. For Cycle 5 the peak axial is predicted to remain at or below

1.26. This value is typical for a reload core like the Cycle 5 design and is nearly identical to the Cycle 4 core axial of 1.24.

Figure 6.6 and 6.7 show the radial power maps with the Group 4 regulating rods inserted to the power dependent insertion limit at HFP (25% insertion) for BOL and EOL, respectively. Assembly powers and F_Q^N are similar to the all rods out values shown in Figures 6.1 and 6.3.

Additional neutronic characteristics of the Cycle 5 core are compared with the Cycle 4 core in Table 6.1 for both BOC and EOC conditions. The Cycle 5 projected critical boron concentration as a function of cycle burnup is shown in Figure 6.8.

6.1.2 Control Rod Reactivity Requirements

Detailed calculations of shtudown margins for Cycle 5 are compared with the data for Cycle 4 in Table 6.2. For Palisades the minimum shutdown requirement at HFP and HZP is 2% $\Delta\rho$ assuming the most reactive control rod stuck out. A minimum excess shutdown margin of .33% $\Delta\rho$ is indicated for Cycle 5 at HFP.

6.1.3 Moderator Temperature Coefficient Considerations

The reference Cycle 5 design calculations indicate a HZP critical boron concentration at BOC5 of 1,310 ppm. This value is 150 ppm higher than the measured HZP BOC 4 critical boron concentration where the moderator temperature coefficient was determined to be +0.09 x 10^{-4} $\Delta\rho/^{o}F$. The moderator temperature coefficients at HZP and HFP for

BOC5 and HFP for EOC5 are shown in Table 6.1. The BOC values fall well within the safety analysis limits of $+0.5 \times 10^{-4}\ \Delta\rho/^{o}F \geq MTC \geq -3.5 \times 10^{-4}\ \Delta\rho/^{o}F$.

6.2 NUCLEAR DESIGN METHODOLOGY

The methods used in the Cycle 5 core analyses are described in References 10, 11, and 12. In summary, the reference neutronic design analysis of the reload core was performed using a combination of the PDQ7[13]/HARMONY[14] depletion system and the XTG[15] reactor simulator system along with the XPOSE[16] and XPIN[17] pin cell codes. For each model, the input isotopics data were based on quarter core calculations performed through Cycle 4 using the respective models. The fuel shuffling between cycles was accounted for in the calculations.

With the XTG reactor model, including 3-D effects such as moderator density and doppler feedbacks, values of F_q, F_{xy}, and F_z were studies. The calculated thermal-hydraulic feedback and axial exposure distribution effects on power shapes, rod worths, and cycle lifetime are explicitly included in the analysis.

In the PDQ model detailed pin-by-pin depletion analyses are performed. Local variations in power and isotopic distributions are explicitly calculated.

The in-core-measurement/calculation constants are obtained from the quarter core pin-by-pin calculational results.

Table 6.1 Calculated Neutronics Characteristics of Cycle 5 Compared with Cycle 4

Parameters	Cycle 4 BOC (2,530 MWt)	Cycle 4 EOC (2,530 MWt)	Cycle 5 BOC (2,530 MWt)	Cycle 5 EOC (2,530 MWt)
Moderator Temp. Coefficient at HFP (x 10^{-4} $\Delta\rho/^{0}F$) (ppm)	-.63 (820)	-2.56 (0)	-.45 (950)	-2.56 (0)
Moderator Temp. Coefficient at HZP (x 10^{-4} $\Delta\rho/^{0}F$) (ppm)	+.04 (1,200)	-- --	+.30 (1,310)	-- --
Doppler Defect (% $\Delta\rho$)	-0.76	-.62	-0.76	-0.62
Power Defect (Doppler + Moderator)	-1.01	-1.49	-1.00	-1.60
Delayed Neutron Fraction	0.0061	0.0051	0.0061	0.0052
Prompt Neutron Lifetime (μ sec)	23.0	27.4	22.3	24.7
Inverse Boron Worth (ppm/% $\Delta\rho$)	102	92	95	82
Ejected Rod Worths				
100% Power	<0.20	<0.20	0.15	0.20
0% Power	<0.90	<0.90	1.02	0.94
Peaking Factors				
Radial	1.26	1.27	1.30	1.25
Axial	1.23	1.09	1.26	1.09
Excess Shutdown Margin (% $\Delta\rho$)	0.48	0.46	0.40	0.33

Table 6.2 Control Rod Shutdown Margins and Requirements for Cycle 5

	Cycle 4				Cycle 5			
	BOC		EOC		BOC		EOC	
	HZP	HFP	HZP	HFP	HZP	HFP	HZP	HFP
Control Rod Worth (% Δρ)								
Total Minus Stuck Rod	4.69	4.69	5.22	5.22	4.59	4.59	5.28	5.28
Uncertainty (10%)	0.47	0.47	0.52	0.52	0.46	0.46	0.53	0.53
Net Shutdown Rod Worth (1)	4.22	4.22	4.70	4.70	4.13	4.13	4.75	4.75
Reactivity Insertion (% Δρ)								
Doppler Defect	0	0.76	0	0.62	0	0.76	0	0.62
Moderator Temperature Defect	0	0.25	0	0.87	0	0.24	0	0.98
Moderator Void Defect	0	0.10	0	0.10	0	0.10	0	0.10
Axial Flux Redistribution	0	0.50	0	0.50	0	0.50	0	0.50
Required Shutdown Margin	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Total Reactivity Allowances (2)	2.00	3.61	2.00	4.09	2.00	3.60	2.00	4.20
Available for Maneuvering (1-2)	2.24	.061	2.70	0.61	2.13	.053	2.75	0.55
PDIL Rod Insertion	1.47	0.13	1.69	0.15	1.84	0.13	2.14	0.22
Excess Margin % Δρ	0.77	0.48	1.01	0.46	0.60	0.40	0.56	0.33

	M	N	Q	R	T	V	X	Z
13	H* 1.18	H* 1.18	H 1.28	G 1.03	H 1.27	H 1.30	G .93	I .88
14	H* 1.18	G* .91	G 1.01	I* 1.24	G .94	G* .88	H 1.17	I .90
16	H 1.28	G 1.01	HG 1.11	G .95	H 1.04	G* .83	IG 1.07	I .67
17	G 1.03	I* 1.24	G .95	H* .98	GG .86	H 1.06	IS .92	
19	H 1.27	G .94	H 1.04	GG .86	IG 1.04	I .93	I .56	
20	H 1.30	G* .88	G* .83	H 1.06	I .93			
[illegible]	G .93	H 1.17	IG 1.07	IS .92	I .57			
[illegible]	I .89	I .90	I .67					

Assembly Type
Relative Assembly Power (PDQ)

F_Q = 2.03 (M-14)

F_R^A = 1.30 (M-20)

$F_R^{\Delta H}$ = 1.54 (M-20)

F_R^T = 1.67 (M-14)

* B_4C Shimmed

G Gadolinia Shimmed

S Spare Rod

Figure 6.1 Palisades Cycle 5 Power Distribution
100 MWD/MT ARO, HFP

	M	N	O	R	T	V	X	Z
13	H* 1.14	H* 1.12	H 1.18	G .96	H 1.16	H 1.19	G .90	I .88
14	H* 1.12	G* .88	G .97	I* 1.20	G .91	G* .88	H 1.16	I .91
16	H 1.18	G .97	HG 1.08	G .96	H 1.05	G* .87	IG 1.14	I .72
17	G .96	I* 1.20	G .96	H* 1.02	GG .92	H 1.12	IS .99	
19	H 1.16	G .91	H 1.05	GG .92	IG 1.17	I 1.02	I .63	
20	H 1.19	G* .88	G* .87	H 1.12	I 1.02			
22	G .90	H 1.16	IG 1.10	IS .99	I .63			
23	I .88	I .91	I .72					

Assembly Type
Relative Assembly Power (PDQ)

F_Q = 1.67 (M-14)
F_R^A = 1.20 (R-14)
$F_R^{\Delta H}$ = 1.41 (V-19)
F_R^T = 1.49 (M-14)

* - B_4C Shimmed
G - Gadolinia Shimmed
S - Spare Rods

Figure 6.2 Palisades Cycle 5 Power Distribution
4,000 MWD/MT, ARO, HFP

	M	N	O	R	T	V	X	Z
13	H* 1.12	H* 1.10	H 1.12	G .93	H 1.10	H 1.13	G .88	I .87
14	H* 1.10	G* .87	G .95	I* 1.18	G .90	G* .88	H 1.14	I .91
16	H 1.12	G .95	HG 1.06	G .96	H 1.06	G* .90	IG 1.22	I .76
17	G .93	I* 1.18	G .96	H* 1.05	GG .96	H 1.14	IS 1.02	
19	H 1.10	G .90	H 1.06	GG .96	IG 1.26	I 1.06	I .67	
20	H 1.13	G* .88	G* .90	H 1.14	I 1.06			
22	G .88	H 1.14	IG 1.22	IS 1.02	I .67			
23	I .87	I .91	I .76					

Assembly Type
Relative Assembly Power (PDQ)

F_Q = 1.59 (T-19)

F_R^A = 1.26 (T-19)

$F_R^{\Delta H}$ = 1.42 (V-19)

F_R^T = 1.51 (T-19)

* B_4C Shimmed
G Gadolinia Shimmed
S Spare Rods

Figure 6.3 Palisades Cycle 5 Power Distribution
8,500 MWD/MT, ARO, HFP

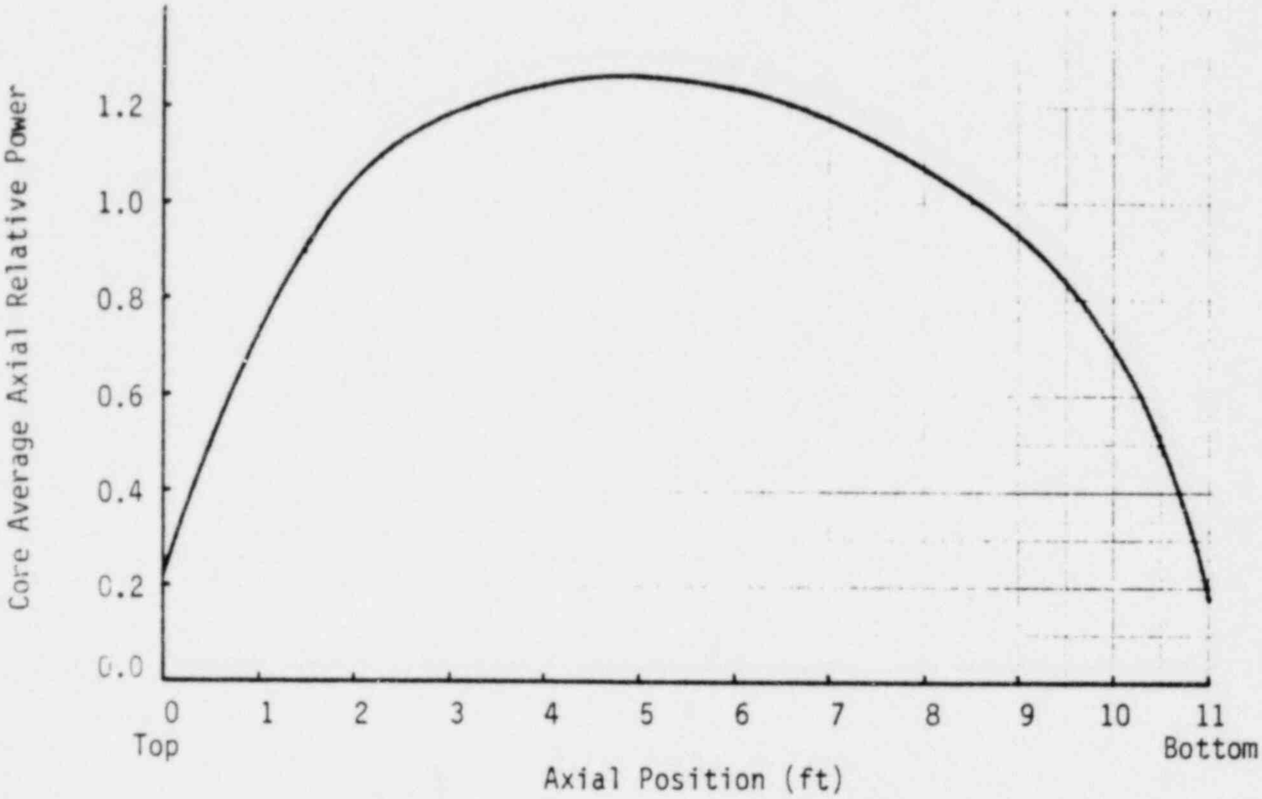


Figure 6.4 Palisades Cycle 5 Core Average Power vs. Axial Position 0 MWD/MT

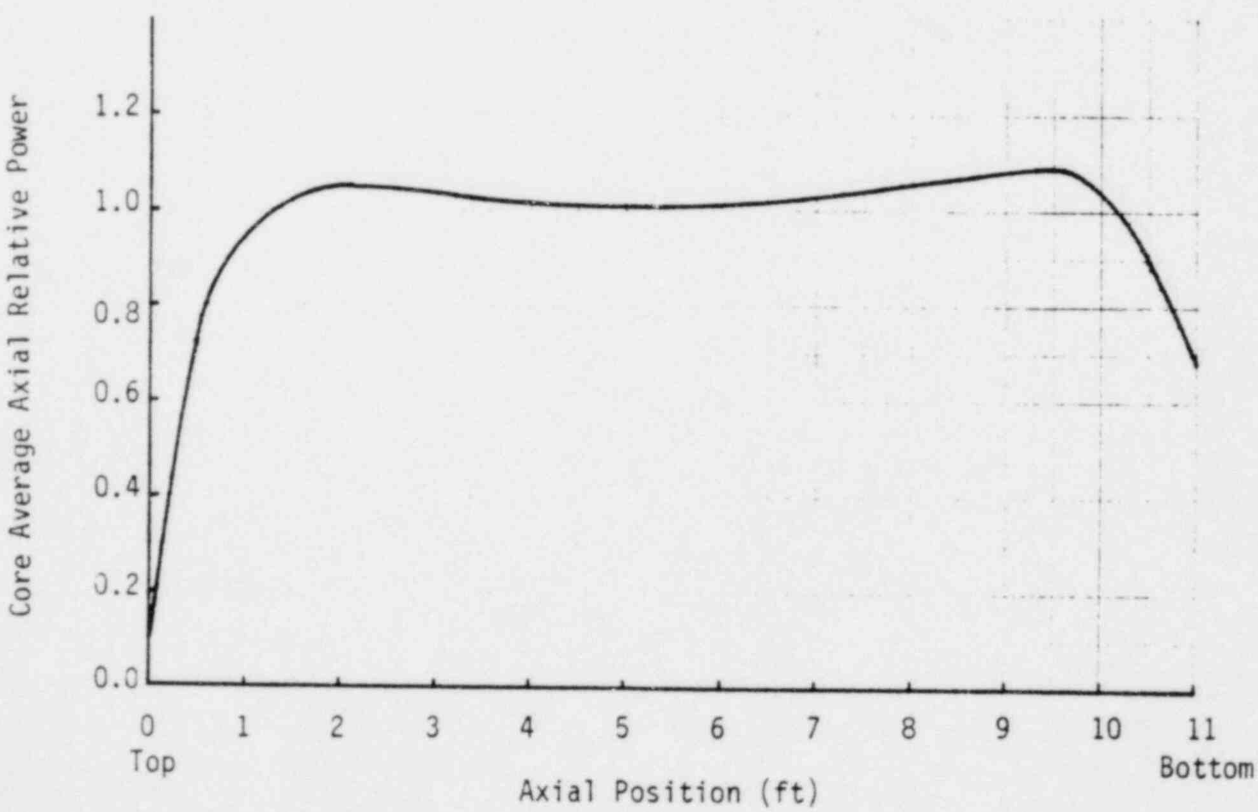


Figure 6.5 Palisades Cycle 5 Core Average Power vs. Axial Position 11,500 MWD/MT

	M	N	O	R	T	V	X	Z
13	H* 1.19	H* 1.16	H 1.23	G .99	H 1.24	H 1.28	G .94	I .99
14	H* 1.16	G* .89	G .97	I* 1.22	G .91	G* .88	H 1.19	I .99
16	H 1.23	G .98	HG 1.04	G .90	H 1.00	G* .81	IG 1.13	I .73
17	G .99	I* 1.22	G .91	H* .90	GG .80	H 1.03	IS 1.00	
19	H 1.24	G .91	H 1.00	GG .80	IG 1.04	I .97	I .61	
20	H 1.28	G* .88	G* .82	H 1.04	I .97			
22	G .94	H 1.19	IG 1.13	IS 1.00	I .61			
23	I .99	I .99	I .73					

Assembly Type
Relative Assembly Power (XTG)

F_Q = 2.08 (M-14)
F_R^A = 1.28 (M-20)
$F_R^{\Delta H}$ = 1.52 (M-20)
F_R^T = 1.64 (M-14)

* B_4C Shimmed
G Gadolinia Shimmed
S Spare Rods

Figure 6.6 Palisades Cycle 5 Power Distribution
75 MWD/MT, HFP, Group 4 Rods in 25%

	M	N	Q	R	T	V	X	Z
13	H* 1.20	H* 1.17	H 1.18	G .98	H 1.14	H 1.16	G .90	I .91
14	H* 1.17	G* .94	G 1.00	I* 1.22	G .93	G* .89	H 1.13	I .92
16	H 1.18	G 1.00	HG 1.07	G .96	H 1.04	G* .87	IG 1.21	I .74
[illegible]	G .98	I* 1.22	G .96	H* .98	GG .87	H 1.04	IS .99	
19	H 1.14	G .93	H 1.04	GG .87	IG 1.16	I .96	I .63	
20	H 1.16	G* .89	G* .87	H 1.04	I .96			
22	G .90	H 1.13	IG 1.21	IS .99	I .63			
23	I .91	I .92	I .74					

Assembly Type
Relative Assembly Power (XTG)

$F_Q = 1.91$ (X-16)
$F_R^A = 1.22$ (R-14)
$F_R^{\Delta H} = 1.44$ (X-16)
$F_R^T = 1.48$ (X-16)

* B_4C Shimmed
G Gadolinia Shimmed
S Spare Rods

Figure 6.7 Palisades Cycle 5 Power Distribution
10,000 MWD/MT, HFP, Group 4 Rods in 25%

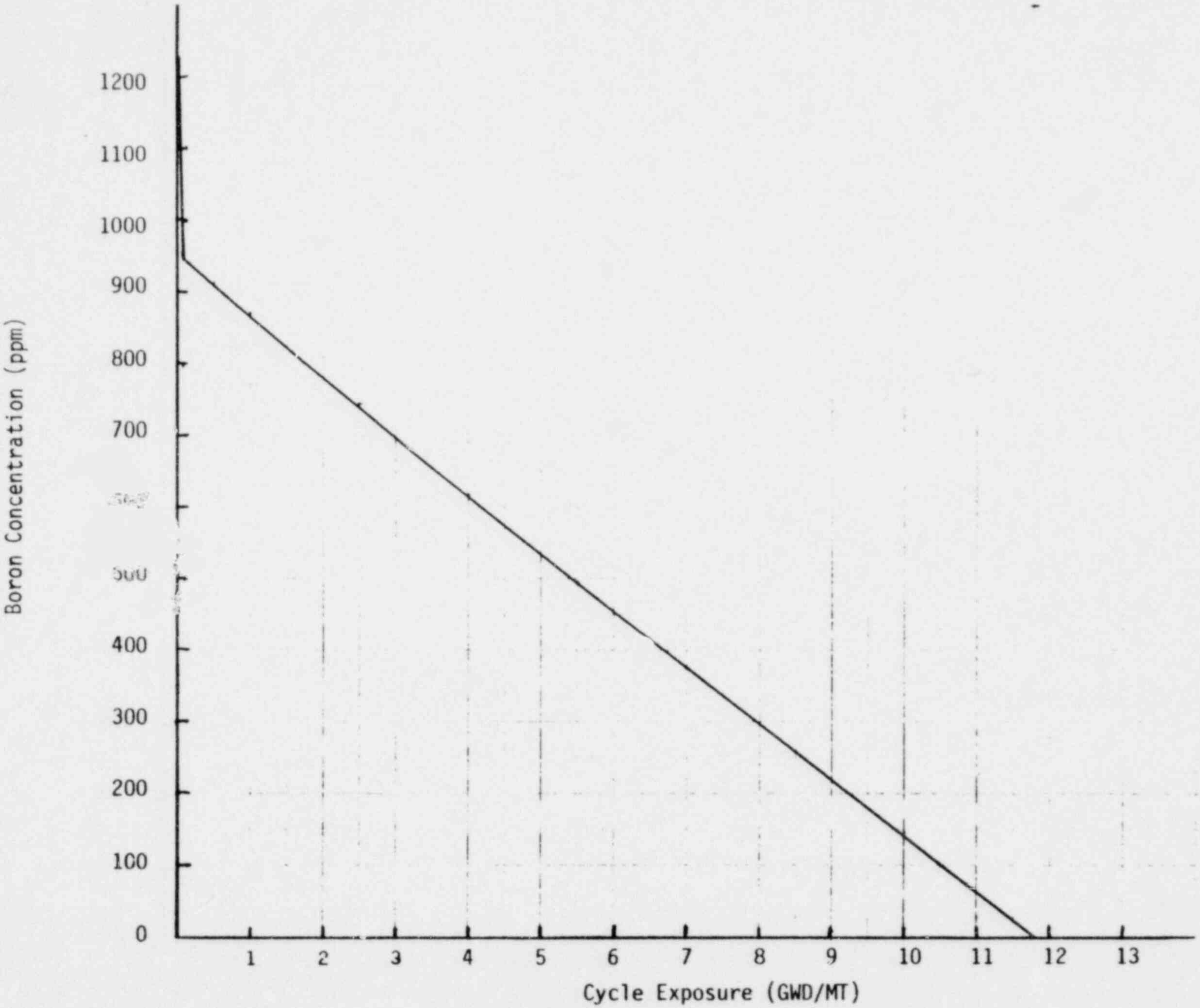


Figure 6.8 Palisades Cycle 5 Critical Boron Concentration vs. Exposure

7.0 SAFETY ANALYSIS

Safety analysis considerations for Cycle 5 is the normal cycle specific analysis. This analysis is described in each of the following subsections.

7.1 THERMAL HYDRAULIC ANALYSIS

The ENC Reload I fuel is designed to be compatible with the Palisades Reactor core and with the existing fuel. The thermal hydraulic design criteria for ENC reload fuel at Palisades are:

- The maximum fuel temperature at 115% overpower shall not exceed the fuel melting temperature.
- The minimum DNBR shall be greater than or equal to 1.30 at 115% of rated power based on the W-3 correlation (or an accepted equivalent) plus correction factors which have been accepted by the NRC for the purpose of licensing the fuel design described herein.
- The cladding temperature at nominal operating conditions (based on crud-free surface) shall be less than:

  $850^{o}F$ internal surface

  $675^{o}F$ external surface

  $750^{o}F$ volume average (local)
- The fuel assemblies must be thermally and hydraulically compatible with the existing fuel and the reactor core during the design life of the fuel.

ENC reload fuel in the Palisades Cycle 5 core is calculated to satisfy the thermal hydraulic design criteria for the following limits on assembly and interior rod power levels:

- o the maximum assembly average linear heat generation rate is equal to or less than 7.78 kw/ft. for assemblies with 208 fuel rods, and is equal to or less than 7.62 kw/ft. for assemblies with 216 fuel rods.
- o The maximum interior rod linear heat generation rate does not exceed 8.91 kw/ft. for assemblies with 208 fuel rods, and does not exceed 8.73 kw/ft. for assemblies with 216 fuel rods.

The linear heat generation rate limits above for Batch H and I assemblies with 208 active fuel rods and the associated rod surface heat fluxes are unchanged from the previous analysis[5]. The results above for assemblies with 216 active fuel rods are new limits from thermal hydraulic analyses for Batch I assemblies with 216 active fuel rods.

Cycle 5 peaking factors which correspond to the above limits for assemblies with 208 active rods and 216 active rods are given in Table 7.1. The relative peaking limits are slightly reduced from those in Cycle 4 reflecting the reduction in the total number of active fuel rods in the Cycle 5 core versus the Cycle 4 core.

The thermal hydraulic analysis for the Palisades Cycle 5 was performed in a manner consistent with applicable thermal margin analyses for the Palisades plant at 2530 MWt[5,6,19]. The thermal hydraulic

design conditions for this analysis are shown in Table 7.1. It is concluded that the performance of Palisades Cycle 5 falls within the thermal hydraulic design criteria. The thermal hydraulic acceptability of E reload fuel for Palisades Cycle 5 operation is thus confirmed.

7.2 PLANT TRANSIENT ANALYSIS

The transient events listed in Table 7.2 were analyzed for Cycle 5 operation. Predicted Cycle 5 core kinetics parameters considered in the analysis appear in Table 7.3, and are identical to those used in the reference stretch power analysis[3]. The conclusion of this analysis is that MDNBR values for Class II and III events initiated during Cycle 5 operation will remain greater than the accepted minimum value of 1.3. This analysis also concludes that the Class IV locked rotor and main steam line break accidents will result in MDNBR values equal to or greater than those reported in the reference analysis. Predicted operating thermal margin for Cycle 5 is therefore judged adequate to maintain the integrity of the fuel cladding within acceptable limits.

7.3 ECCS ANALYSIS

Previous LOCA/ECCS analyses[2,19] for Palisades E/G and H fuel were made with a maximum linear heat generation rate of 15.28 kw/ft at 102% of full core power (1.02 x 2530 MWt). This corresponds to an allowable assembly radial peaking limit of 1.45 and an F_Q limit of 2.76. These limits remain applicable to the Palisades reload fuel design I and

to the eight (8) fuel assemblies built from spare rods left from fabricating reloads G and H. These assemblies will be loaded into the reactor in Cycle 5.

7.3.1 Reload I ECCS Limits

Palisades reload designs H and I have the same mechanical design but have slightly different neutronic designs. The neutronic bundle fuel design for reload I incorporated four (4) low enrichment rods in corner locations to reduce the local assembly peaking observed in the reload H design. Since the mechanical designs are identical, the hydraulic flow behavior for the I assemblies will be the same as that calculated in the LOCA analysis for the H assemblies. The ECCS limits established for previous reloads are therefore conservatively applicable to reload I. The reduction in local peaking for reload I will result in greater margin to ECCS limits.

7.3.2 Spare Rods Assembly ECCS Limits

The fuel rods for reload I have a 2 mil larger clad outer diameter than fuel rods for reload G. In the ECCS analysis, the larger clad outer diameter results in improved reflood rates and in a larger surface heat transfer with reduced PCT's. The ECCS limits established for previous reloads are therefore conservatively applicable to the reload fuel assemblies fabricated from G and I fuel rods. For the bundles fabricated from G and I rods, the maximum calculated bundle local peaking (1.205) is lower than that used in the G/H (1.22) analyses.

Therefore the combined effect of lower bundle peaking, higher reflood rates and larger surface heat transfer areas will result in improved margin to ECCS limits for the spare rod bundles relative to that for the G bundle.

7.4 ROD EJECTION ANALYSIS

A Control Rod Ejection Accident is defined as the mechanical failure of a control rod mechanism pressure housing, resulting in the ejection of a Rod Cluster Control Assembly (RCCA) and drive shaft. The consequence of this mechanical failure is a rapid reactivity insertion together with an adverse core power distribution, possibly leading to localized fuel rod damage.

The rod ejection accident has been evaluated with the procedures developed in the ENC Generic Rod Ejection Analysis[20]. The ejected rod worths and hot pellet peaking factors were calculated using the XTG code. No credit was taken for the power flattening effects of Doppler or moderator feedback in the calculation of ejected rod worths or peaking factors. The calculations made for Cycle 5 using XTG were two-dimensional. The pellet energy deposition resulting from an ejected rod was evaluated explicitly for BOC and found to be 164 cal/gm at HFP and 143 cal/gm at HZP. The results for EOC conditions were found to be 173 cal/gm at HFP and 126 cal/gm at HZP. The rod ejection accident was found to result in energy deposition of less than 280 cal/gm as required by Regulatory Guide 1.77. The significant parameters for the analysis, along with the results are summarized in Table 7.4.

Table 7.1 Thermal Hydraulic Design Conditions

Reactor Conditions	Design	Nominal
Core Power (MWt)	2910	2530
Total reactor flow rate (Mlb/hr)	121.7	121.7
Active core flow rate (Mlb/hr)	114.4	114.4
Coolant inlet temperature (^{o}F)	542.5	537.5
Core pressure (psia)	2010	2060

Thermal Hydraulic Limits on Relative Power Factors	208 Rod Assemblies	216 Rod Assemblies
Assembly Radial Factor, F_R	1.43	1.46
Pin Peaking Factor (interior rod), $F_R x F_\ell$	1.64	1.67
Pin Peaking Factor (narrow gap edge rod), $F_R x F_\ell$	1.75+	1.74+
Pin Peaking Factor (wide gap edge rod), $F_R x R_\ell$	1.88+*	1.84+
Engineering Factor	1.03	1.03

LOCA/ECCS Limits on Relative Power Factors	All Assemblies
Assembly radial factor, F_R	1.45
Pin Peaking Factor (all rods), $F_R x R_\ell$	1.77
Total Peaking	2.76

* The corresponding peaking factor for G fuel is 1.75.
\+ At these peaking factors the interior rod remains limiting.

Table 7.2 Transient Events Considered in the Palisades Cycle 5 Plant Transient Analysis

1. Uncontrolled Rod Withdrawals
   - At 102% power ($1.0 \times 10^{-5} \leq \Delta\rho/s \leq 1.4 \times 10^{-4}$)
   - At 52% power ($6.0 \times 10^{-5} \leq \Delta\rho/s \leq 6.0 \times 10^{-4}$)
2. Control Rod Drop
3. Four Pump Coastdown
4. Locked Rotor
5. Reduction in Feedwater Enthalpy
6. Increased Feedwater Flow (@ 52% power)
7. Excessive Load (from 102% power and 52% power)
8. Loss of Load
9. Loss of Feedwater
10. Steam Line Break (from 102% power and hot standby)
11. Single Rod Withdrawal

Table 7.3 Important Core Kinetics Parameters Used in the Palisades Cycle 5 Plant Transient Analysis

	EOC	BOC
Moderator Coefficient ($\Delta\rho/^{o}F \times 10^{4}$)	+0.5	-3.50
Doppler Coefficient ($\Delta\rho/^{o}F \times 10^{5}$)	-1.09	-1.38
Delayed Neutron Fraction, %	0.75	0.45
Net* Rod Worth (% $\Delta\rho$)**	-2.90	-2.90

* Total rod worth minus stuck rod worth.

** 2.0% at hot standby.

Table 7.4 Palisades Rod Ejection Accident

	BOC		EOC	
	HFP	HZP	HFP	HZP
F_Q^N After Ejection	2.76	13.4	3.02	12.1
Ejected Rod Worth (%$\Delta\rho$)	.15	1.02	.20	.94
Doppler Coefficient (%$\Delta\rho$ x $10^{-3}/^{o}F$)	-1.29	-1.55	-1.49	-1.73
Delayed Neutron Fraction	.0061	.0061	.0052	.0052
Energy Deposition (cal/gm)	164	143	173	126

REFERENCES

1. XN-75-29, "Generic Fuel Design for 15 x 15 Reload Assemblies for Palisades", C. A. Brown, November 25, 1975.

2. XN-NF-81-34, Appendix A "ECCS Exposure Sensitivity Study for the Palisades Reload H Design", May 1981.

3. XN-NF-77-18, "Plant Transient Analysis of the Palisades Reactor for Operation at 2,530 MWt", July, 1977.

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18. Technical Specifications contained in Provisional Operating License DPR-20, Docket 50-255 issued to Consumers Power Company for the Palisades Nuclear Plant, October, 1972.

19. XN-NF-78-16, "Analysis of Axial Power Distribution Limits for the Palisades Nuclear Reactor at 2530 MWt", June, 1978.

20. XN-NF-78-44, "A Generic Analysis of the Control Rod Ejection Transient for Pressurized Water Reactors", R. J. Burnside, et al., February, 1978.

APPENDIX A

ECCS EXPOSURE SENSITIVITY STUDY FOR THE PALISADES H FUEL DESIGN

In 1978, Exxon Nuclear Company (ENC) evaluated the performance of the Palisades H fuel design during a postulated loss-of-coolant accident (LOCA). The analysis used conditions reported in XN-NF-77-24(A1) for the limiting DEG/PD break as boundary conditions for multiple fuel heatup calculations to establish a burnup dependent F_Q^T limit for reload H fuel. The calculations included the effects of the NRC model for enhanced fission gas release and fuel rod internal pressure uncertainties.

The results of the calculations are shown in Figure A-1 which provides the maximum LOCA ECCS allowed peaking with exposure, normalized to BOC, for the Palisades H fuel design. Corresponding linear heat generation rates and ECCS results are given in Table A-1. The ECCS limiting F_Q^T versus exposure curve for the Palisades H fuel design is a constant F_Q^T value of 2.76 (14.98 kw/ft total; 14.61 kw/ft heat release in the fuel) out to a peak rod burnup of 27,250 MWD/MTM. At higher exposures, up to a maximum exposure of 43,600 MWD/MTM, the F_Q^T limit decreases as shown in Figure A-1 by about 20%. The reduction in F_Q^T is necessary to offset the adverse effects of fission gas release at high burnup on predicted clad rupture and flow blockage in the postulated

LOCA. The analysis shows that the Palisades reactor can operate with the H fuel design and satisfy licensing criteria specified by NRC 10 CFR 50.46 and Appendix K provided the F_Q^T limits given in Figure A-1 are not violated.

A-1 Exxon Nuclear Company, "LOCA Analysis for Palisades at 2530 MWt Using the ENC WREM-II PWR ECCS Evaluation Model", XN-NF-77-24, July 1977, and XN-NF-77-24, Supplement 1, August 1977.

Table A-1: Palisades Exposure Sensitivity Results for
H-Fuel at 2530 MWT

Rod Burnup (GWD/MTM)	BOL	2.5	17.4	22.5	27.2	33.6	38.6	43.6
Total Peaking, F_Q^T	2.76	2.76	2.76	2.76	2.76	2.263	2.208	2.153
Peak Clad Temperature (PCT), ^oF	2057	2176	1928	1936	2015	1635	1598	1560
Max. Local Zr/H_2O - Reaction, percent	5.0	7.0	4.0	4.0	5.0	1.0	1.0	1.0
Hot Rod Burst Time, sec.	42.1	123.1	80.1	81.1	82.1	--	No Rupture	--
Hot Rod Burst Node (TOODEE2 SLAB NO.)	8	11	8	8	[illegible]	--	--	--
Rupture Pressure, psid	668	411	691	714	757	--	--	--
Subchannel Flow Blockage, %	22.0	34.5	25.0	29.8	39.0	0.0	0.0	0.0
Time of PC, Sec	189	255	217	226	244	214	213	212
PCT Node	12	12	13	13	9	13	13	13
Max. Local Zr/H_2O - Reaction Node	13	12	14	14	15	14	14	17

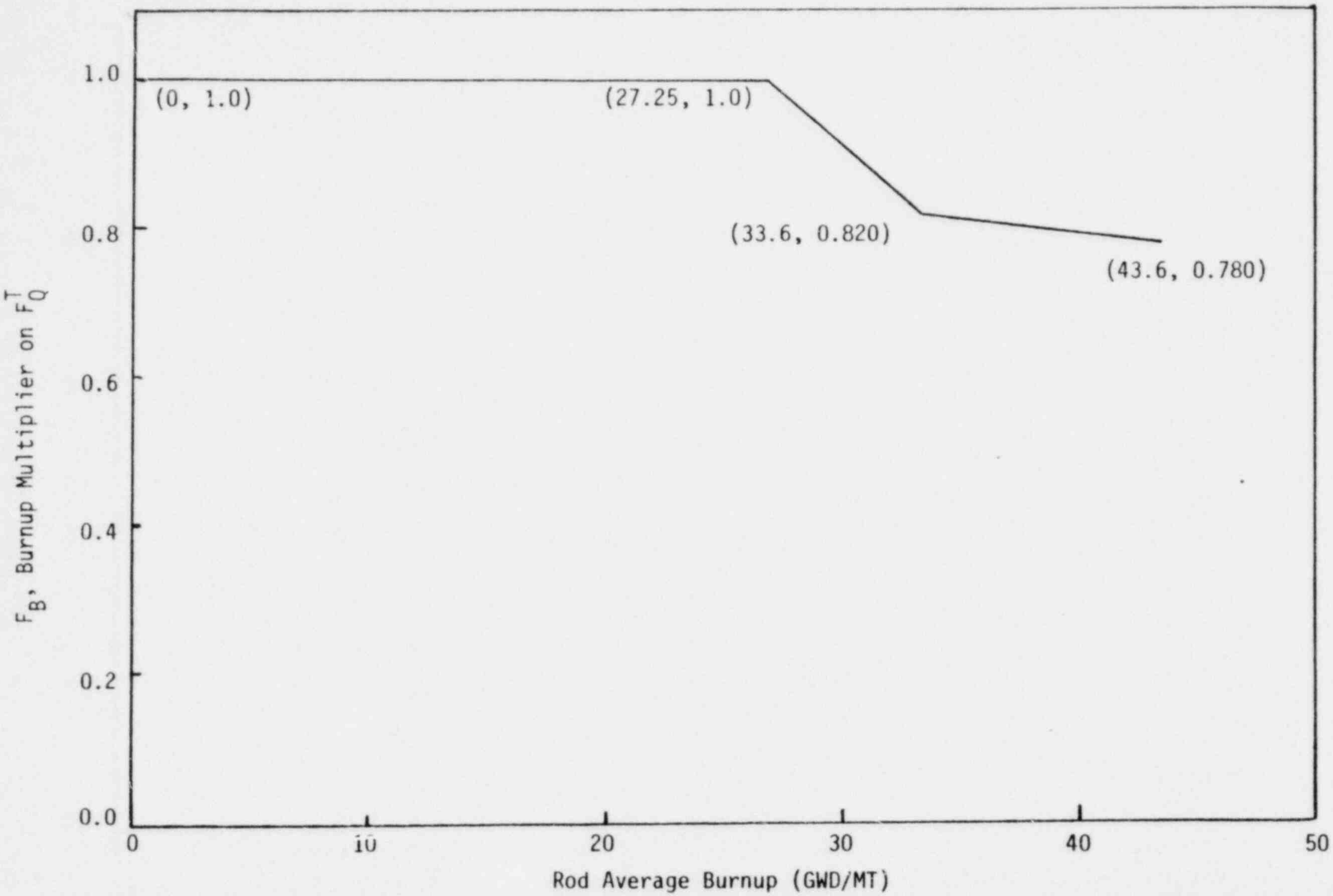


Figure A-1 Palisades H-Fuel, F_Q^T versus Peak Rod Burnup

APPENDIX B

COMPARISONS OF CALCULATED AND MEASURED ASSEMBLY POWERS FOR THE PALISADES 4.0 w/o Gd_2O_3 DEMONSTRATION

Currently there are a total of 64 gadolinia bearing fuel rods being irradiated at Palisades. The initial loading of gadolinia occurred at the start of Cycle 3 (Spring 1978). A total of 32 gadolinia bearing fuel rods containing 1.0 w/o Gd_2O_3 were distributed among eight (8) assemblies. Additional gadolinia bearing fuel rods were loaded at the start of Cycle 4 (May 1980). In this reload 32 gadolinia bearing fuel rods containing 4.0 w/o Gd_2O_3 were distributed among four (4) assemblies.

Comparisons of measured and calculated assembly powers indicated a variance of less than 3% during Cycle 3. This is typical for all assemblies and since no particular trends were observed it was felt that the calculational models adequately accounted for the effects of gadolinia.

A more severe test of the ENC calculational methodology was initiated at the start of Cycle 4 with the irradiation of 4.0 w/o Gd_2O_3. Cycle 4 comparisons indicate a systematic bias between the measured and calculated assembly powers in the core locations where the gadolinia bearing assemblies are located. A relative constant difference of less than 3.0 percent has been observed between calculated and measured data through a Cycle 4 exposure of about 7,500 MWD/MT. Figure B-1 shows the Cycle 4 fuel

assembly loading configuration. Figures B-2 through B-4 display quarter core power map comparisons at 500 MWD/MT, 2,200 MWD/MT, and 7,000 MWD/MT. The Cycle 3 gadolinia bearing assemblies continue to show good agreement between the measured and calculated assembly powers. Figure B-5 shows a more detailed comparison of the power history for the gadolinia assembly.

Due to the close comparisons of measured and calculated assembly powers the ENC calculational methodology is adequately accounting for the presence of gadolinia in the core.

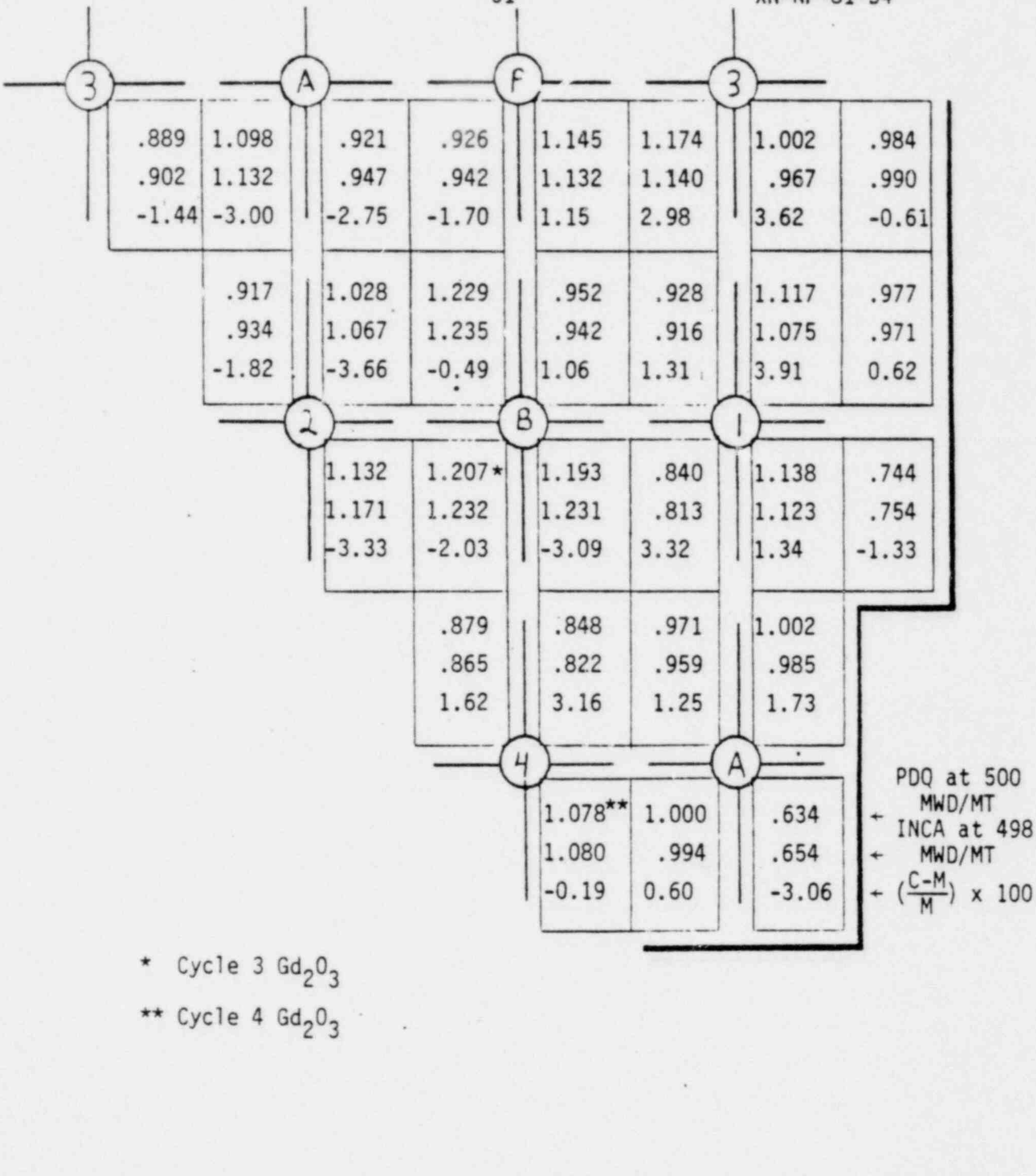
	M	N	Q	R	T	V	X	Z
13	2	1	2	2	1	1	2	Fresh
14	1	2	1	1	2	2	1	Fresh
16	2	1	1	1*	Fresh	2	Fresh	Fresh
17	2	1	1*	2	2	1	Fresh	
19	1	2	Fresh	2	Fresh**	Fresh	Fresh	
20	1	2	2	1	Fresh			
22	2	1	Fresh	Fresh	Fresh			
23	Fresh	Fresh	Fresh					

Fresh - No Burnup
1 - Once Burned
2 - Twice Burned

* Contains 4 Gadolinia (1 w/o Gd_2O_3) Rods Per Assembly (Loaded Fresh in Cycle 3)

** Contains 8 Gadolinia (4 w/o Gd_2O_3) Rods Per Assembly

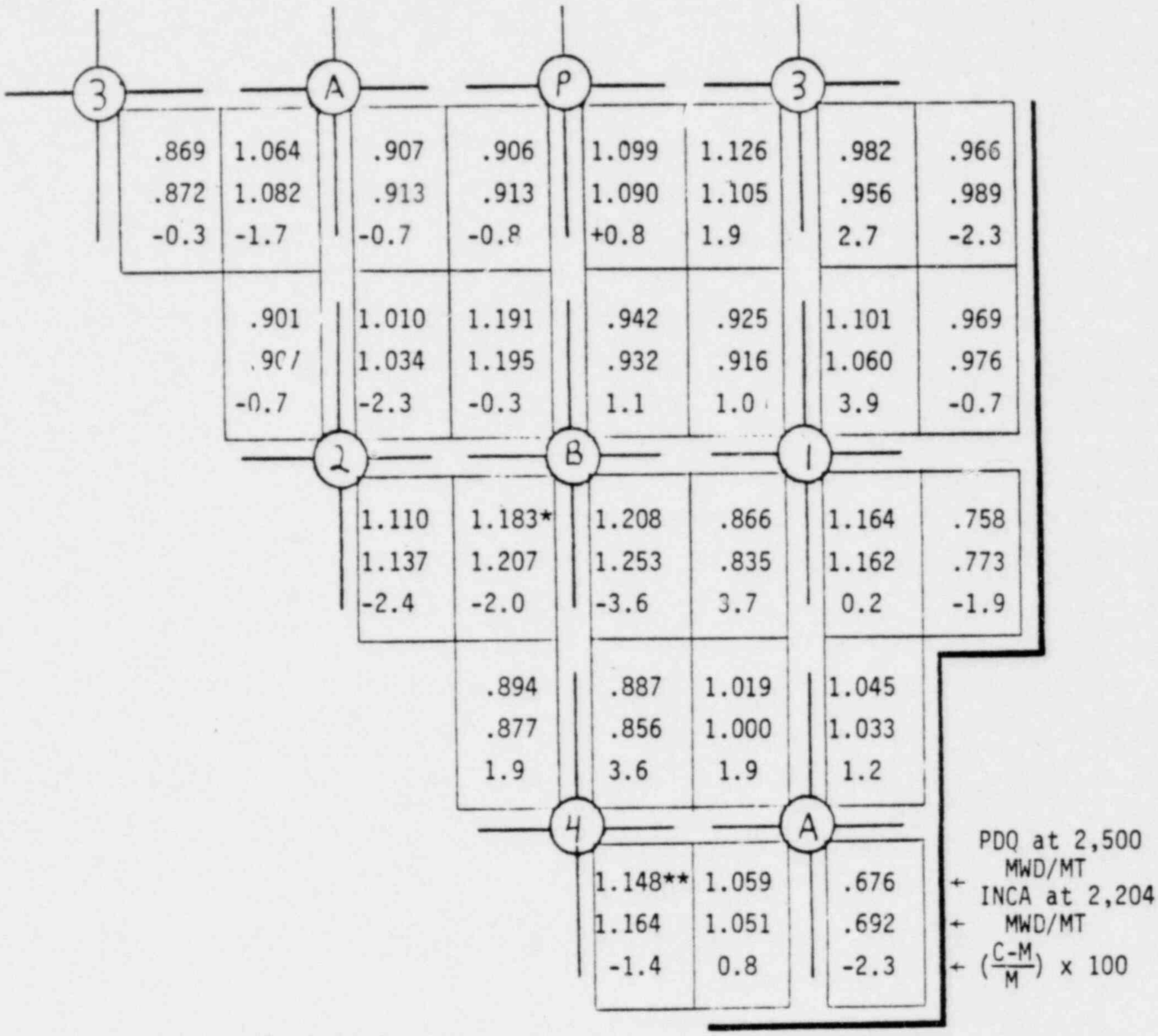
Figure B-1 Palisades Gadolinia (Gd_2O_3) Loading, Cycle 4



* Cycle 3 Gd_2O_3

** Cycle 4 Gd_2O_3

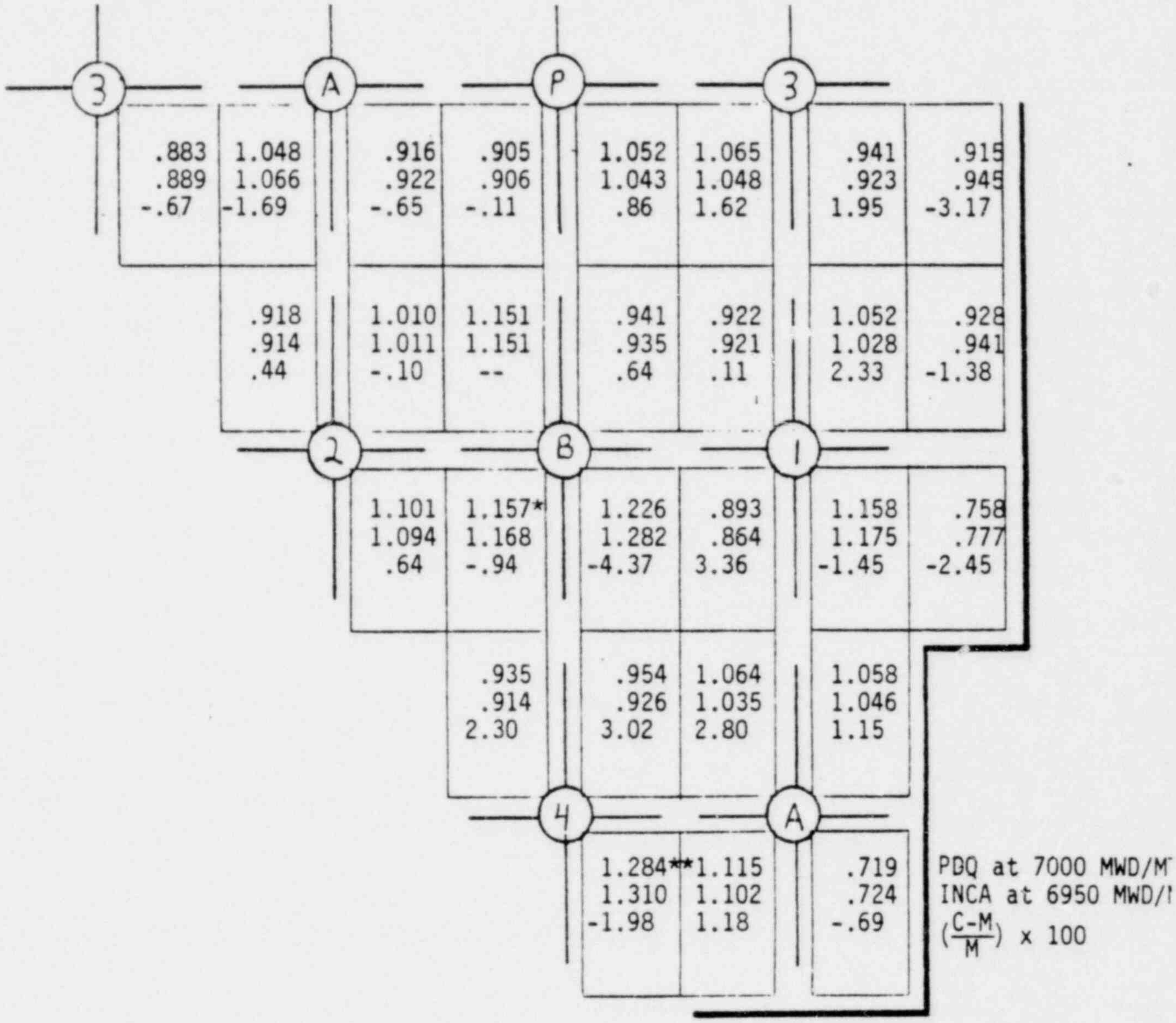
Figure B-2 Palisades Cycle 4, INCA Power Distribution (Measured) versus PDQ Calculated Relative Assembly Power



* Cycle 3 Gd_2O_3

** Cycle 4 Gd_2O_3

Figure B-3 Palisades Cycle 4 Power Distribution Comparison Measured versus Calculated, 100% Power



* Cycle 3 Gd_2O_3
** Cycle 4 Gd_2O_3

Figure B-4 Palisades Cycle 4, INCA Power Distribution (Measured) versus PDQ Calculated Relative Assembly Power, 100% Power

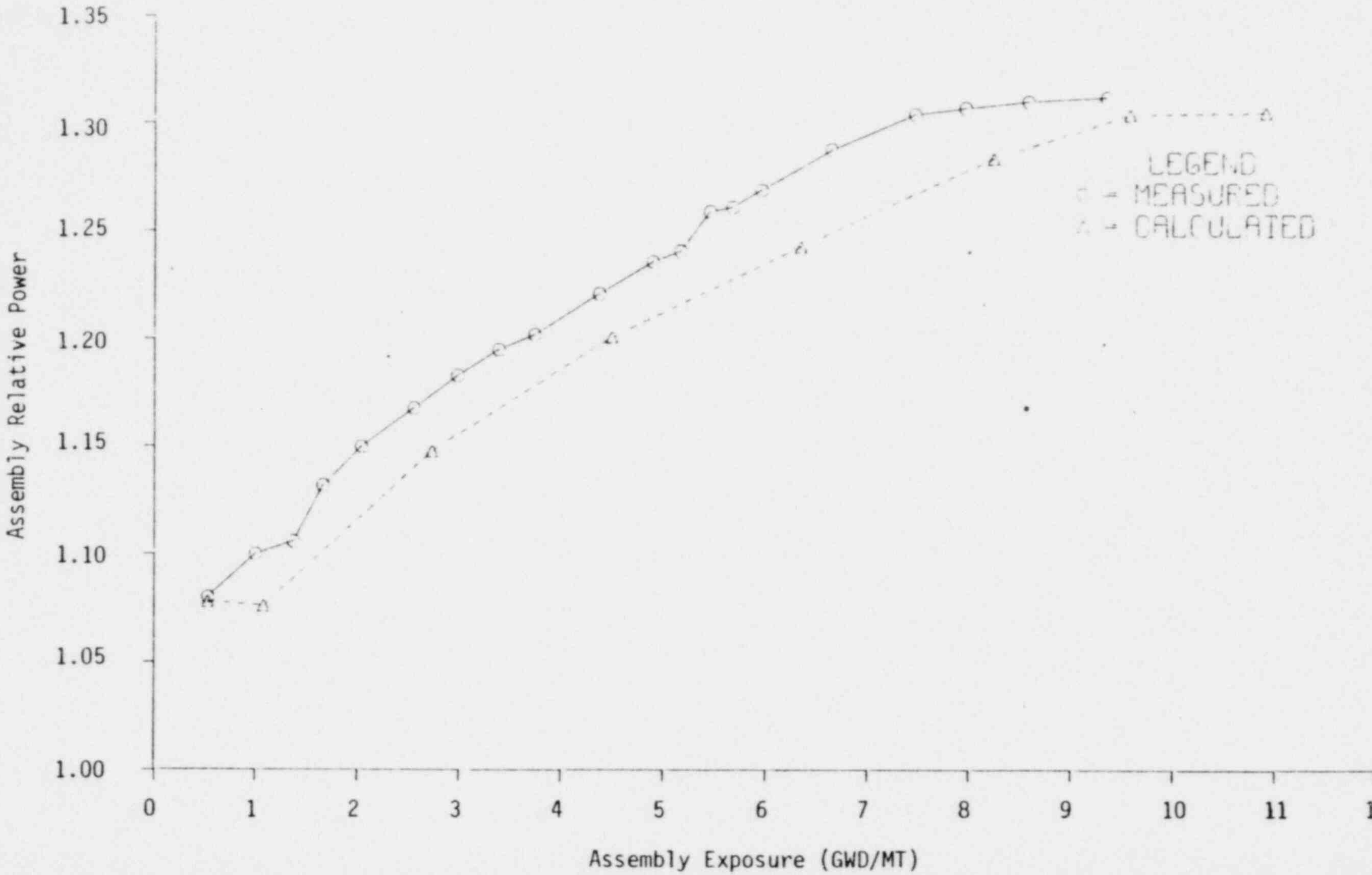


Figure B-5 Palisades Cycle 4 Gadolinia Assembly Power versus Exposure

PALISADES NUCLEAR PLANT CYCLE 5

SAFETY ANALYSIS REPORT

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GF OWSLEY

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ATTACHMENT B

to

Technical Specification

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