ROD MISALIGNMENT ANALYSIS
7/31/81
13:12:44

TABLE OF CONTENTS

LIST OF TABLES

ition I
Control Rod Lo
e 3.6-1
er Dependent Rod Inse
Maximum FQ At HFP Equilibri
Bank D Inserted To PDIL
Maximum FQ During 3-6-3-12
Load Follow

1.0 INTRODUCTION

1.1 PROBLEM DEFINITION

Current Kewaunee Technical Specifications[1] allow an individual control rod cluster to be misaligned from the bank demand position if the misalignment is less than 24 steps, or 15 inches. The Rod Position Indicator (RPI) system is designed to an accuracy of 5% of span or ±12 rod steps. Thus in order to guarantee a rod misalignment of 24 steps the indicated RPI misalignment must be no larger than 12 steps.

1.2 RPI SIGNALS

A review of the RPI surveillance procedure results (obtained once per shift) demonstrates that RPI misalignments are often (daily) greater than 12 steps. The indications however do not show misalignments greater than 24 steps. Figure 1.2 displays the RPI readings for Control bank D during Cycle 6 operation. It should be noted that there is no evidence that the rods are actually misaligned. When evidence of actual control rod misalignment exists, corrective action is promptly taken.

The burden imposed by requiring actions at a 12 step deviation as indicated by the RPI signals would be unworkable. It is therefore necessary to seek relief from this requirement through analysis of those reactor configurations most likely to occur in the presence of a 36 step rod misalignment, i.e. 24 steps indicated plus 12 steps uncertainty.

2.0 ROD MISALIGNMENT CONCERNS

2.1 REACTIVITY CONTROL

Control rod clusters which are misaligned inward from their bank demand position will insert part of their reactivity during operation. This reactivity is therefore not available for shutdown or trip reactivity insertion (SCRAM). Since scram reactivity is applied to all accident analyses which take credit for a reactor trip, this partial reactivity insertion caused by a misaligned control rod cluster should be accounted for in the computation of the scram reactivity used for reload safety evaluations. The reactivity of a misaligned control cluster was evaluated for allowable rod insertions from HZP to HFP, and the maximum effect on reactivity was less than 50 PCM. This is less than the excess reactivity available at minimum shutdown margin conditions for cycle 7. Thus the reactivity attributed to the rod misalignment is easily accounted for in the cycle specific reload safety analyses.

2.2 ROD MISALIGNMENT ACCIDENT

The worst case rod misalignment accident has been previously analyzed[2] and found to pose no hazard to the safe operation of the plant. The limiting case in the analysis includes a rod misaligned 228 steps from its bank position at hot full power conditions with the resulting MDNBR found to be greater than 1.30. The WPS Reload Safety analyses consider this limiting case for each cycle to verify the conservatism of the results. Rod misalignments at reduced power levels present no DNB concerns due to the larger thermal margins at reduced power.

2.3 ROD EJECTION

The effect of a misaligned rod on the rod ejection accident was evaluated for cycle 7. A control rod cluster is assumed to be misaligned 36 steps from its bank at the power dependent insertion limit (PDIL) thus increasing the available ejected rod worth.

Calculations were performed at zero and full power core conditions. At zero power conditions misalignment of available control rod clusters from the PDIL did not result in a larger ejected rod worth than that of a Bank D rod cluster which is already fully inserted. Thus there was no change in maximum ejected rod worth at zero power core conditions. At full power conditions an increase in worth of less than 50 PCM in the maximum ejected rod was calculated. Adequate margin to the rod ejection accident limits was preserved under the ejected rod assumption. Since margin to the bounding ejected rod limits was preserved, the misaligned rod presents no concern regarding the rod ejection accident.

2.4 OPERATION WITH A MISALIGNED ROD

Previous analyses[2,3] have demonstrated that operation with a control rod misalignment of less than 15 inches from its bank demand position will not cause power distributions worse than design limits. Actual operation with a control rod cluster which is signficantly misaligned from its bank demand position would normally be detected, its position verified, and promptly realigned.

In the unlikely event that operation with a control rod misalignment of greater than 15 inches would occur, the impact on power distribution would be of concern. Power distributions with control rod misalignments of 22 inches were therefore evaluated in detail and the results are presented in Section 3.0 of this report.

3.0 POWER DISTRIBUTION ANALYSES

3.1 BOUNDING MISALIGNMENT DETERMINATION

The analysis to be performed would necessarily consider normal operational transients as well as steady state power distributions.

Any control rod cluster may be assumed misaligned inward 36 steps from its bank demand postion. However, only rod banks which are inserted to at least 192 steps can be assumed to have a control rod cluster misaligned outward by 36 steps. Figure 3.1.1 displays the control rod locations in the Kewaunee Reactor. Control rod insertion limits[1] will allow only bank D rods into the core at power levels above 80 percent of full power. Figure 3.1.2 displays the Kewaunee control rod power dependent insertion limits (PDIL). Current technical specifications require target axial offset to be determined with bank D position above 190 steps, thus further limiting practical control bank D positions allowed at full power.

It should be noted that the plant typically operates with control rods essentially withdrawn from the core even at low power and consequently full power misalignment evaluations with bank D inserted to 192 steps would be adequate to bound normal operation.

However, for conservatism, rod misalignment at various power levels with control rod bank positions at the power dependent rod insertion limits were also evaluated.

The actual power distributions would be confined to those allowed by normal operational constraints such as tilt, axial offset, and control rod bank insertion limits.

3.2 ANALYSIS METHODS

The core model used in this analysis is the 3D nodal code (EPRI-NODE), coupled with a 2D PDQ-7 model. Three dimensional, full core calculations performed using the nodal code are used to determine gross (nodal) power distributions. These are then modified by the appropriate peak pin (PDQ) factors and statistical reliability factors in accordance with previously described methods.* The results reported here are thus upper bound values and not best estimate calculations. The maximum FQ's presented in this report were corrected for the axial K(z) penalty as a function of burnup where appropriate.

3.3 INWARD MISALIGNMENT FROM ARO

The mispositioning of a control rod cluster by insertion 36 steps further into the reactor core than its ARO bank position was evaluated for BCC full power equilibrium conditions. The BOC condition was chosen because of the larger assembly burnup gradients providing larger peak rod to assembly average power distributions. Table 3.3.1 displays the list of cases considered, along with the resulting $F\Delta H$ and FQ.

The small reactivity worth of a cluster inserted into the top 22 inches of the core causes little perturbation of the core power distribution.

In view of the insensitivity to this core configuration, no transients were evaluated under these core conditions. Transient effects were addressed and are presented in Section 3.6. It can be concluded that a single cluster misalignment from an ARO core condition produces no power distribution concern.

3.4 ROD MISALIGNMENT WITH TYPICAL D BANK INSERTION

The misalignment of a single cluster of control bank D from its bank demand position of 192 steps was evaluated under hot full power, steady state conditions. The resulting FQ and $F\Delta H$ are displayed in Table 3.4.1. The misalignment of a control rod cluster from the Bank D demand position poses no power distribution limit problem in spite of the radial tilt induced by the inward misalignment. These slight increases in FQ and FΔH are easily accommodated within the existing margins.

3.5 THE ROD MISALIGNMENT AT PDIL

The control bank D was inserted to the FPIL at HFP equilibrium conditions and the rod cluster K-7 was misaligned inward 36 steps and outward 36 steps. Figure 3.5.1 displays the resulting maximum FQ as a function of core height. In spite of this core condition manifesting an axial offset which is out of target band, and a significant radial tilt, sufficient margin exists to accomodate the increased peaking factors caused by the misalignment of 36 steps.

Table 3.5.1 presents the associated FΔH along with the tilt and axial offsets for the above cases.

Similarly, calculations were performed at 50% power and 0% power core conditions. Control rods were inserted to the power dependent insertion limits and various control rod clusters were misaligned 36 steps from the corresponding bank position. Resulting peaking factors, tilts, and axial offsets are presented in Tables 3.5.2 and 3.5.3.

In spite of the increased insertion of control rod banks to the PDIL at lower power levels, sufficient margin to power distribution limits is maintained assuming a misaligned rod of 36 steps.

3.6 LOAD FOLLOW TRANSIENT WITH ROD MISALIGNMENT

Thus far all analysis has been under steady state conditions. During load follow, the limiting points (from the FAC analysis without rod misalignment) occur at full power time steps where the control rods are required to be nearly full out. Outward misaligments during load follow are not expected to impact the limiting FQ analysis. Downward misalignments have been shown to be of minimal impact (in steady state) and are not expected to cause a large impact on the load follow analysis.

A typical load follow maneuver, designated as a 3-6-3-12, was evaluated. Control rod bank D was inserted approximately 25% to control a 3 hour ramp from 100% power to 50% power. After a 6 hour hold at 50% power with control rods inserted, a 3 hour ramp and control rod withdrawal return the reactor to 100% power. Xenon redistribution was then tracked for 12 hours at 100% power.

The load follow transient cases were executed at

EOL due to the greater propensity for axial xenon oscillations at end of life. The load follow cases were executed with a) K-7 misaligned outward from the D bank demand position, with b) K-7 misaligned inward, and with c) no misalignment. The maximum FQ at each elevation from the above calculations are displayed in Figure 3.6.1. As expected the impact on maximum FQ during a load follow transient was small (on the order of (1-2%) and can be easily accomodated within existing margins.

4.0 CONCLUSIONS AND SUMMARY

Various single control rod cluster misalignments of 36 steps (22 inches) were evaluated for impact on peaking factors, reactivity worths, and thermal margins. A review of the results with regard to plant transient analyses revealed that adequate conservatism exists in the bounding transient analyses to absorb the penalties associated with the rod misalignment in cycle 7. These penalties can be quantified and easily included in future reload safety analyses for each fuel cycle.

Power distributions were evaluated under steady state and load follow conditions with rod misalignment. The peaking factor penalties were shown to be accomodated within the inherent conservatisms associated with control rod insertion limits and constant axial offset control. Typical plant operation is with control rods essentially withdrawn from the core. This coupled with the fact that actual control rod misalignments are rare corroborate the conservatism of this analysis. An actual control rod misalignment would be promptly realigned upon verification of its position.

Based on the considerations addressed in this report it can be concluded that a 36 step control rod misalignment does not increase the probability of an accident or decrease safety margins previously established.

Table 3.3.1

Control Rod Cluster Inward Misalignment

Cluster Position	FQ	FΔH
ARO	1.815	1.490
G-7 =192	1.832	1.489
K-7 =192	1.834	1.500
J-10=192	1.831	1.502
H-8 =192	1.836	1.500
L-8 =192	1.828	1.497
K-9 =192	1.829	1.499

FQ Limit = 2.16

FΔH Limit = 1.55

Table 3-4-1

Control Rod Cluster Misalignment With Bank D Inserted

Bank D Position	Cluster K-7 Position	FQ	FΔH	Tilt	AO
192	228	1.893	1.511	1.014	+0.3
192	219	1.878	1.507	1.012	+0.2
192	210	1.860	1.496	1.009	0.0
192	201	1.865	1.493	1.005	-0.3
192	192	1.871	1.480	.998	-0.8
192	183	1.878	1.485	.993	-1.5
192	174	1.887	1.491	.987	-1.6
192	165	1.895	1.496	.980	-2.0
192	156	1.902	1.501	.974	-2.4

FQ Limit = 2.16

FΔH Limit = 1.55

Table 3.5.1

100% Power

Rod Misalignment of 36 Steps at PDIL

Bank D Position	Cluster K-7 Position	FΔH	TILT	AO
153	153	1.496	1.001	-8.0 *
153	189	1.535	1.025≠	-6.3 *
153	117	1.515	1.012	-9.0 *

≠ exceeds tilt specification

* exceeds full power target band limit

FQ Limit = 2.16

FΔH Limit = 1.55

Table 3.5.2

50% Power
Rod Misalignment of 36 Steps at PDIL

Control Bank Position	Cluster Position	FQ	FΔH	Tilt	AO
D=32,C=162		2.032	1.567	1.003	-8.7
D=32,C=162	K7=68	3.108	1.596	1.047	-10.9
D=32,C-162	K7=0	2.022	1.583	.979	-7.5
D=32,C=162	J-10=198	2.032	1.645	1.033	-6.8
D=32,C=162	J-10=126	2.066	1.591	.968	-10.2
D=32,C=162	G-7=198	1.986	1.589	1.003	-6.4
D=32,C=162	G-7=126	2.068	1.551	1.003	-10.4

FQ Limit = 4.320

FΔH Limit = 1.705

Table 3.5.3

0% Power
Rod Misalignment of 36 Steps at PDIL

Control Bank Position	Cluster Position	FQ	FΔH	Tilt	AO
D=0,C=41,B=173		2.116	1.633	1.002	-5.9
D=0,C=41,B=173	K7=36	3.676	1.853	1.055	-11.5
D=0,C=41,B=173	J-10=77	3.390	1.824	1.076	-11.8
D=0,C=41,B=173	J-10=5	2.156	1.658	.971	-5.0
D=0,C=41,B=173	G-7=77	2.418	1.680	1.002	-12.6
D=0,C=41,B=173	G-7=5	2.146	1.612	1.002	-3.1
D=0,C=41,B=173	H-8=209	2.076	1.716	1.025	-1.8
D=0,C=41,B=173	H-8=137	2.208	1.666	.968	-10.9

FQ Limit = 4.320

FΔH Limit = 1.860

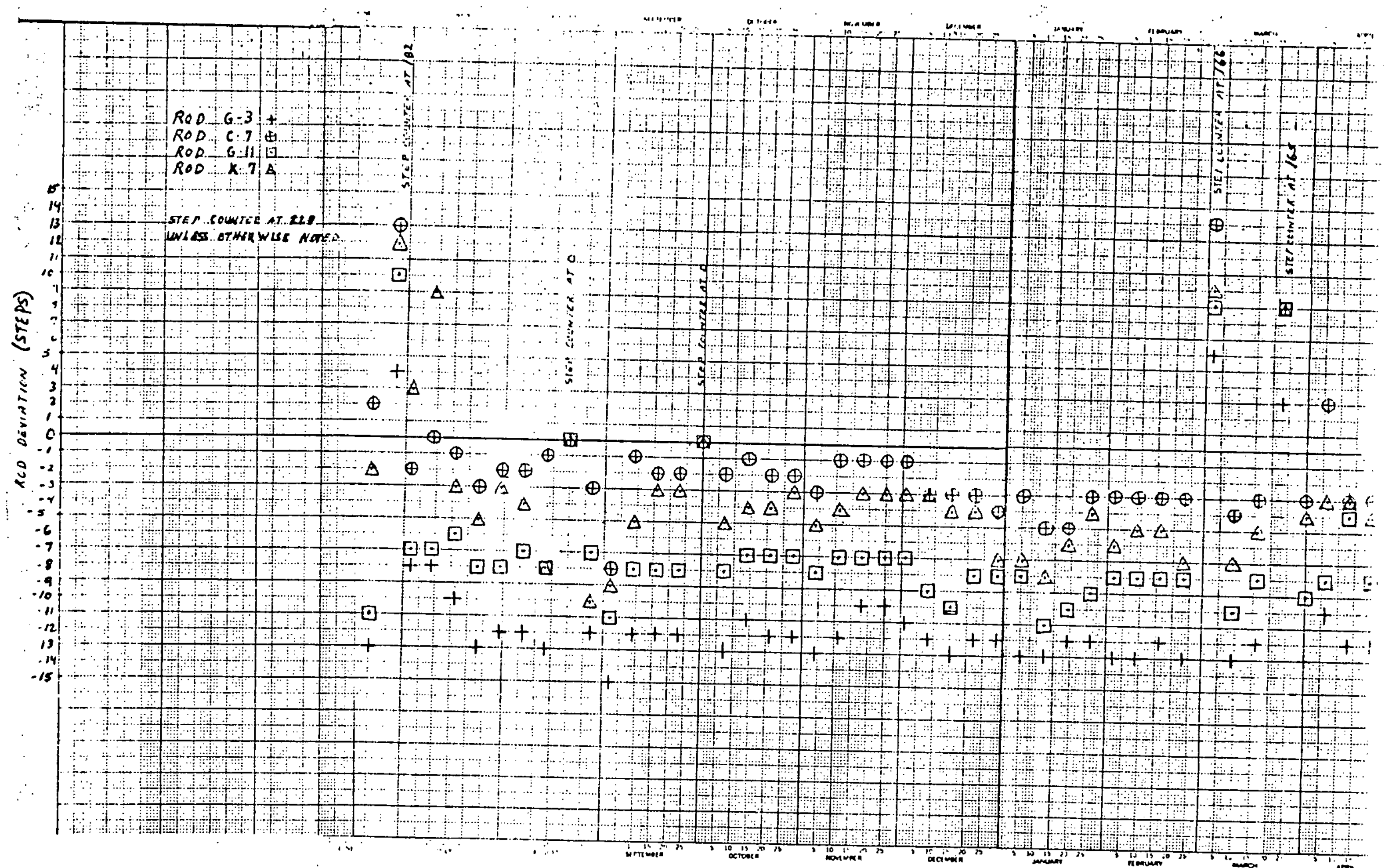


Figure 1.2
BANK D ROD POSITION INDICATIONS

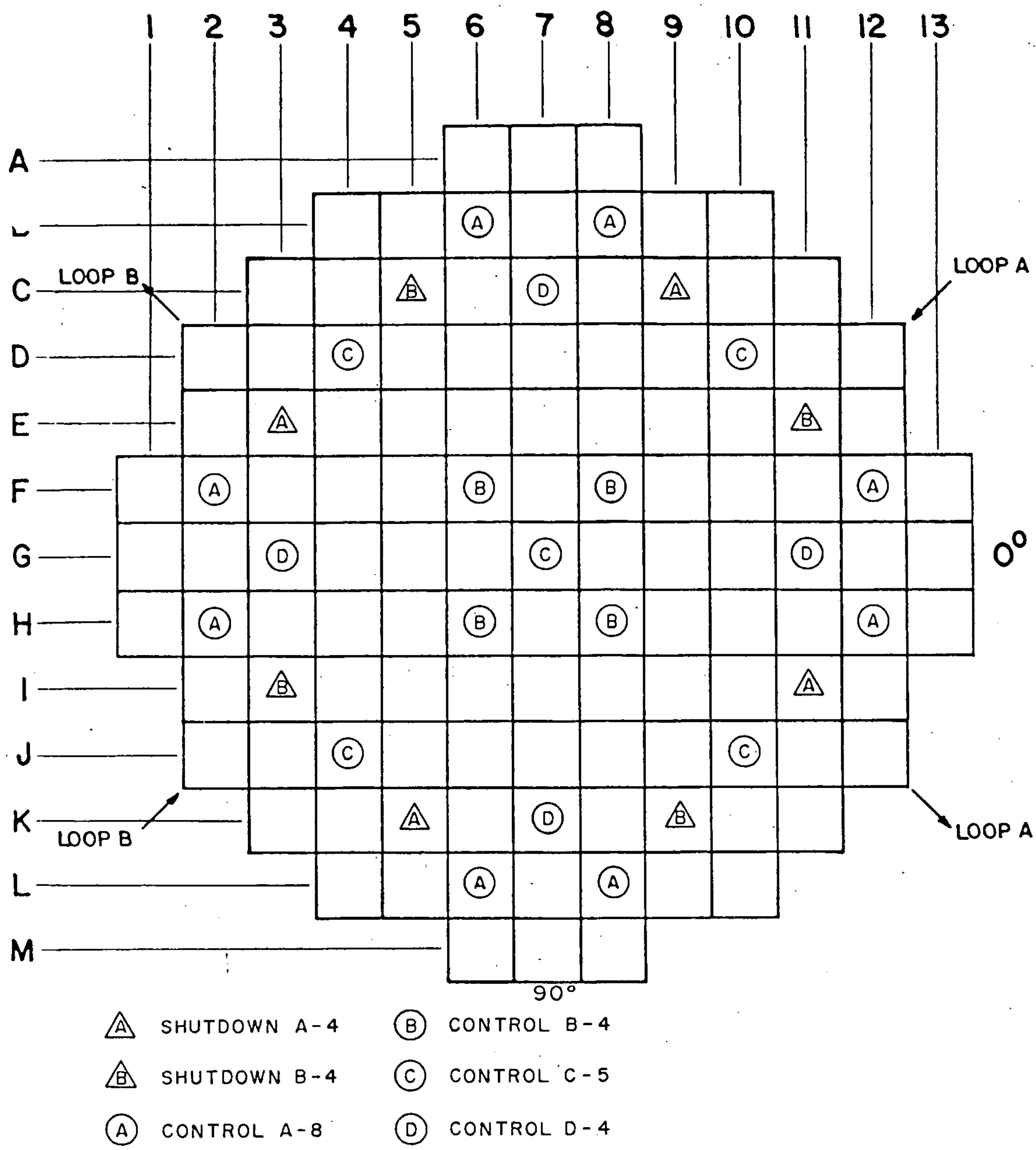


Figure 3.1.1
KEWAUNEE CONTROL ROD LOCATIONS

CONTROL BANK INSERTION LIMITS

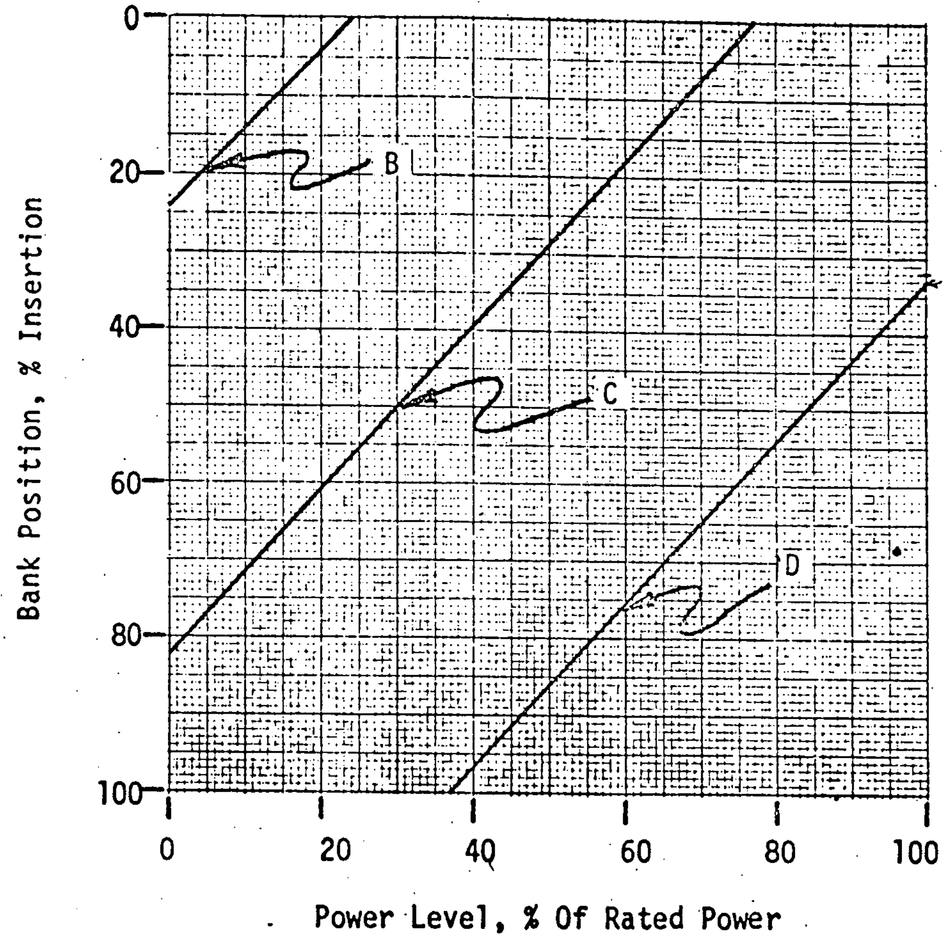
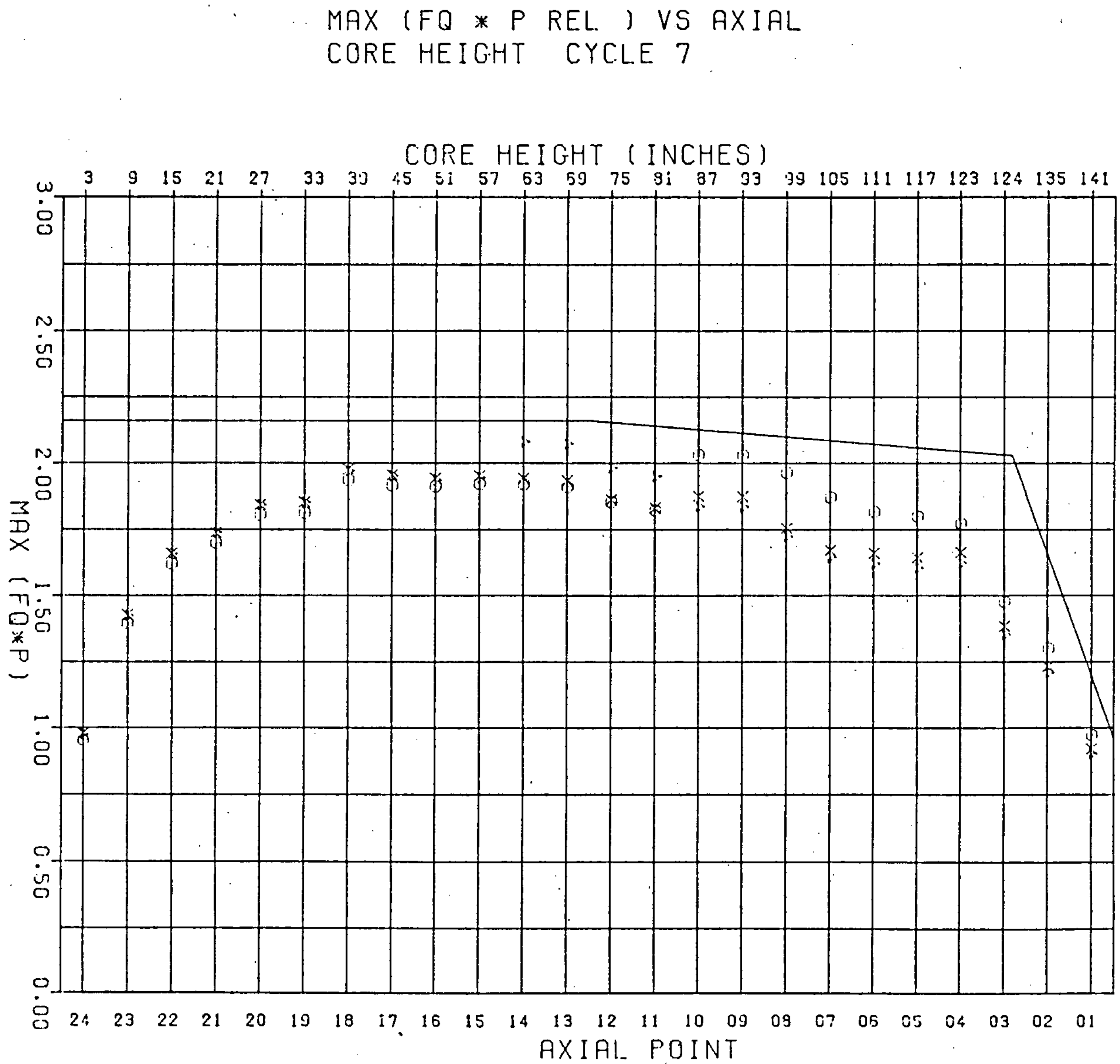
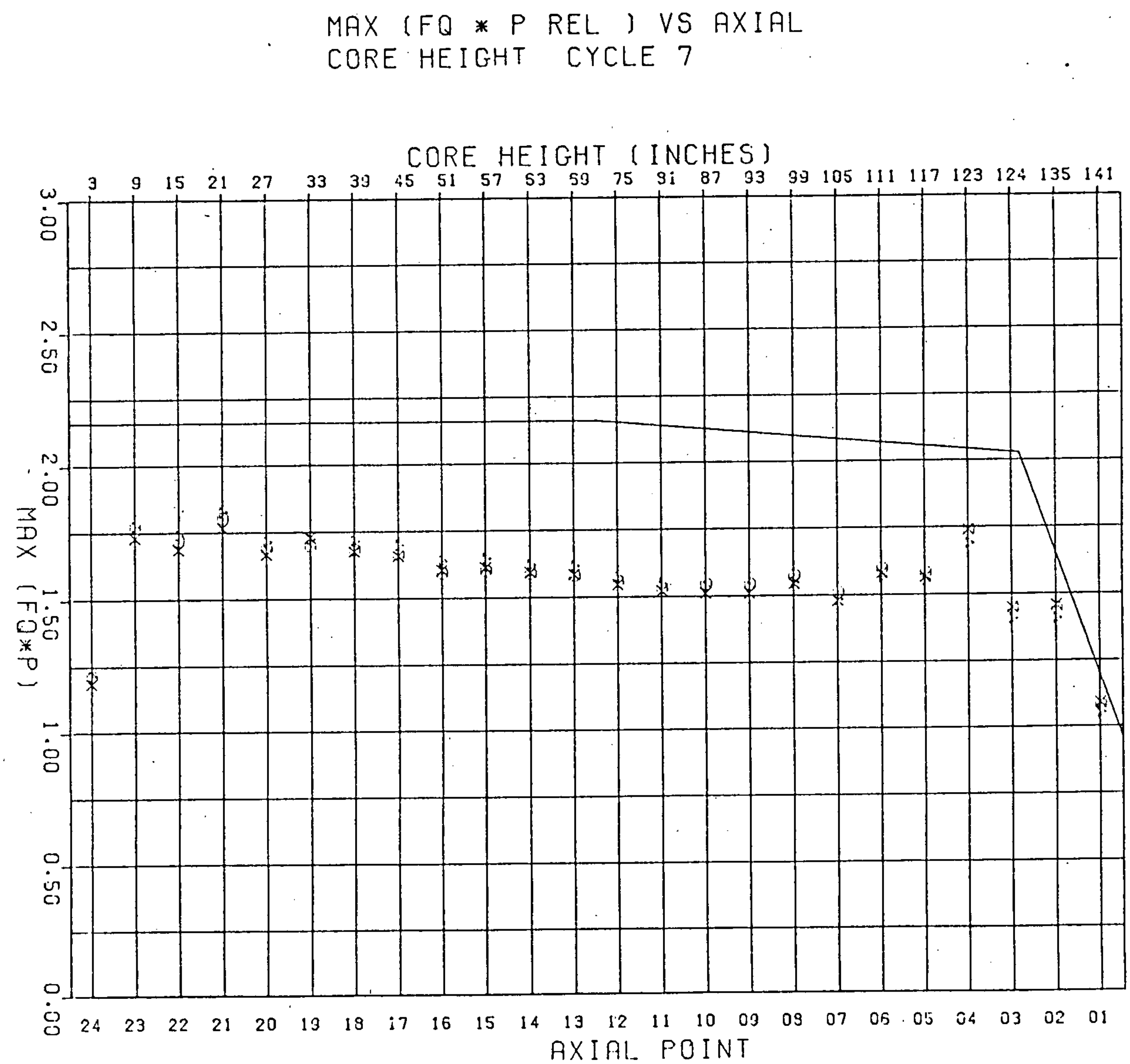


Figure 3.1.2
POWER DEPENDENT ROD INSERTION
LIMIT



X - No Misalignment
0 - Upward Misalignment
Δ - Downward Misalignment

Figure 3.5.1
MAXIMUM FQ AT HFP EQUILIBRIUM
BANK D INSERTED TO PDIL



X - No Misalignment
O - Upward Misalignment
Δ - Downward Misalignment

Figure 3.6.1
MAXIMUM FQ DURING 3-6-3-12
LOAD FOLLOW

5.0 REFERENCES

1. Wisconsin Public Service Corporation, Technical Specifications for Kewaunee Nuclear Power Plant.

2. Wisconsin Public Service Corporation, Kewaunee Nuclear Plant Final Safety Analysis Report, Chapter 14, Pages 14.1-14 thru 14.1-16.

3. "Power Distributions Control and Load Follow Procedures", WCAP 8385, September 1974.

4. Wisconsin Public Service Corporation, "Qualification of Reactor Physics Methods for Application to Kewaunee", September 1978.