NSP

Prairie Island Units 1 and 2 Transient Power Distribution Methodology NSPNAD-93003-A

April 1993

Northern States Power Company
Nuclear Analysis & Design

NSPNAD 93003

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

July 16, 1993

Docket Nos. 50-282
and 50-306

Mr. Roger O. Anderson, Director
Licensing and Management Issues
Northern States Power Company
414 Nicollet Mall
Minneapolis, Minnesota 55401

Dear Mr. Anderson:

SUBJECT: PRAIRIE ISLAND NUCLEAR GENERATING PLANT, UNIT NOS. 1 AND 2 - DISTRIBUTION METHODOLOGY (TAC NOS. M86201 AND M86202)

In a letter dated April 12, 1993, Northern States Power Company (NSP) requested U.S. Nuclear Regulatory Commission (NRC) review of the topical report NSPNAD-93003, "Prairie Island Units 1 and 2 Transient Power Distribution Methodology." This topical report relates to the NSP method for core power distribution control and presents the methodology used by NSP for determination of V(z) factors. V(z) is the ratio of the transient to equilibrium predicted nuclear hot channel factor (F_Q^N), where F_Q^N is the maximum local heat flux on the surface of a fuel rod divided by the average heat flux in the core. We have completed our review and our safety evaluation (SE) is enclosed. Based on our evaluation, we have concluded that the NSP method used to generate a cycle-specific or generic V(z) factor for application to equilibrium F_Q^N values to bound F_Q^N values that could be measured at non-equilibrium conditions is acceptable; however, a number of requirements for cycle-specific and generic V(z) curves are provided in the enclosed SE.

This completes our review. If you have any questions, you may contact me at (301) 504-3024.

Sincerely,

Marsha Gamberoni

Marsha Gamberoni, Project Manager
Project Directorate III-1
Division of Reactor Projects - III/IV/V
Office of Nuclear Reactor Regulation

Enclosure:
Safety Evaluation

cc: See next page

Mr. Roger O. Anderson, Director
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UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

RELATED TO TRANSIENT POWER DISTRIBUTION METHODOLOGY

NORTHERN STATES POWER COMPANY

PRAIRIE ISLAND NUCLEAR GENERATING PLANT, UNIT NOS. 1 AND 2

DOCKET NOS. 50-282 AND 50-306

1.0 INTRODUCTION

In a letter dated April 12, 1993 (Ref. 1), Northern States Power Company (NSP) requested U.S. Nuclear Regulatory Commission (NRC) review of the topical report NSPNAD-93003, "Prairie Island Units 1 and 2 Transient Power Distribution Methodology" (Ref. 2). This topical report relates to the NSP method for core power distribution control and presents the methodology used by NSP for determination of V(z) factors. V(z) is the ratio of the transient to equilibrium predicted nuclear hot channel factor (F_Q^N), where F_Q^N is the maximum local heat flux on the surface of a fuel rod divided by the average heat flux in the core. This V(z) factor is applied to equilibrium F_Q^N values to bound F_Q^N values that could be measured at non-equilibrium conditions. The V(z) cycle-dependent values for the Prairie Island Units are incorporated into the plant Core Operating Limits Report (COLR).

A meeting was held on February 9, 1993, between the NRC staff and NSP staff to discuss a change in Prairie Island's V(z) analysis. Currently, NSP receives this analysis through Westinghouse in accordance with WCAP-8385 (Ref. 3). It is the intention of NSP to perform its own V(z) analysis based on the information provided in NSPNAD-93003. The main difference between the NSP and Westinghouse analysis is that NSP will be using a three-dimensional calculation versus a one-dimensional/two-dimensional synthesis method performed by Westinghouse. Therefore, the current operational procedures are not affected, only axial offset (AO) limits related to allowed operations outside of the normal offset control band. Axial offset is the ratio of the difference in power between the top and bottom halves of the core to the total power in the core. The target axial offset (TAO) is a 100% power, unrodded, equilibrium AO which is used as a target or reference value for load follow transients.

2.0 EVALUATION

The computer methodology used by NSP to analyze the core power distribution is a three-dimensional nodal code called N3P and is based on the EPRI-NODE-P code (Ref. 4). The NRC has approved this methodology for both core design and transient xenon power analysis (Ref. 5). To further demonstrate that N3P modeling is adequate for both core-wide and localized transient xenon behavior, N3P predictions were compared to four flux maps taken during a load-

follow sequence. The comparisons show excellent agreement and confirm the ability of the N3P code to model transient xenon behavior.

In generating a V(z) curve, NSP first established the initial conditions necessary for a transient power distribution analysis. These initial conditions consisted of a set of TAOs, one being a +TAO which represents an equilibrium core condition in which the power shape is skewed toward the top of the core. The other starting condition is a -TAO which is an equilibrium core condition where the power shape is skewed toward the bottom of the core. Although a specified TAO may be represented by an unlimited number of power distributions, each generated in a variety of ways, NSP has found that for a given TAO, the resulting V(z) is independent of the method used to generate the reference power distribution. Hence, the V(z) curve is dependent on the TAO, not on the power shape used to generate the TAO.

After establishing the initial conditions, NSP defines the various core operating strategies utilized during load follow maneuvers. From these initial conditions, a 72-hour "3-6-3-12" load follow scenario (used by both Westinghouse and Siemens) using two power ramps, 100-30 and 100-50%, are utilized in four operational modes (Rebound, Float, Plus AO, Minus AO). In the Rebound mode, the flux difference (ΔI) is maintained as positive as possible (within the target bandwidth) above 90% power, and as negative as possible (within the target bandwidth) at or below 90% power. The Float operating strategy minimizes operator intervention and only requires ΔI to be maintained within the allowable bandwidth. The Plus AO strategy maintains ΔI as positive as possible (near top of the target bandwidth) and minimizes control rod insertions at all times but maximizes boration/dilution system duty. The Minus AO strategy maintains ΔI as negative as possible (near bottom of target bandwidth) and maximizes control rod insertions at all times during core operations. NSP has shown that these operating strategies observe the allowable plant technical specification operating regime and induce the most severe xenon oscillations possible through various mechanisms (control rods, boration/dilution control, or minimal operational intervention). The NRC, therefore, considers these to be the most operationally feasible and bounding conditions under which the most limiting V(z) curve can be constructed.

NSP has analyzed three cycles of data from Prairie Island core designs, P214, P115, and P215. The analysis was performed at middle-of-cycle (MOC) and end-of-cycle (EOC). The resulting V(z) curves display very similar behavior and magnitudes which lead to the generation of bounding (generic) V(z) curves at MOC and EOC. The qualification for use of generic curves requires that the generic case list shown in Table X.A of NSPNAD-93003 be run and confirm that the resultant V(z) curves do not exceed the generic curve. Otherwise, a cycle-specific analysis will be required.

3.0 CONCLUSION

Based on the above evaluation, the NRC concludes that the NSP method used to generate a cycle-specific or generic V(z) factor for application to equilibrium F_Q^M values to bound F_Q^M values that could be measured at non-equilibrium conditions is acceptable with the following requirements.

For cycle-specific V(z) curves:

(1) The cycle specific case list presented in Table IX.A and Figure IX.A must be used.

(2) The cases run must represent allowable Prairie Island Technical Specification operating conditions.

(3) The analyzed TAO values must bound the measured equilibrium axial offsets over the exposure range of interest.

For generic V(z) curves:

(1) The generic curve must be generated from at least 3 cycles of data with no technical specification changes to power distribution control strategies having occurred since the generation of the generic curve.

(2) The generic case list presented in Table X.A and Figure X.G represents the limiting cases necessary for qualification of the generic curve.

(3) The analyzed TAO values must bound the measured equilibrium axial offsets over the exposure range of interest.

This Safety Evaluation (SE), or an approved version of Topical Report NSPNAD-93003 which incorporates this SE, may be referenced in Section 6.7.A.6, "Core Operating Limits Report," of the Prairie Island Technical Specifications as an approved reference for the V(z) curves in the plant COLR.

4.0 REFERENCES

(1) Letter from R. O. Anderson (NSP) to Document Control Desk (NRC), "Submittal of NSPNAD-93003," April 12, 1993.

(2) NSPNAD-93003, "Prairie Island Units 1 and 2 Transient Power Distribution Methodology," Northern States Power Company, April 1993.

(3) WCAP-8385, "Power Distribution Control and Load Following Procedures - Topical Report," Westinghouse Electric Corporation, September 1974.

(4) Advanced Recycle Methodology Program (ARMP) System Documentation, EPRI CCM-3 Research Project 118-1, September 1977.

(5) NSPNAD-8101-A, Rev. 1, "Qualification of Reactor Physics Methods for Application to PI Units," Northern States Power Company, December 1982.

Principal Contributor: L. Kopp

Date: July 16, 1993

Prairie Island Units 1 and 2
Transient Power Distribution Methodology

NSPNAD-93003
Rev. 0

April 1993

Prepared By Jim Zyduck Date 3/31/93

Reviewed By [signature] Date 3-31-93

Approved By Louis Martin Date 3/31/93

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ABSTRACT

This document is a Topical Report describing the Northern States Power Company (NSP) methodology for determination of V(z) factors.

The methodology employed is explained and data obtained from Prairie Island Unit 1 Cycle 15 and Unit 2 Cycle 14 and Cycle 15 are presented to validate the methodology. This methodology is applicable for both Prairie Island Units 1 and 2.

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I. INTRODUCTION

This report describes NSP's Transient Power Distribution Methodology (TPD) used to generated V(z) curves applied on a cycle specific or generic basis.

Transient Power Distribution control strategies are based primarily on limiting the axial flux difference to a specified bandwidth about a Target Axial Offset (TAO). The target or reference condition is considered to be an ARO, Equilibrium Xenon condition, or Steady State condition, that determines the TAO. Throughout a transient, initiated from Steady State, the ΔI is maintained within a target flux band via control rod motion that results in an axial variation of the heat flux hot channel factor, F_Q^N. This axial variation in F_Q^N with respect to the equilibrium axial F_Q^N defines an axial V(z) factor which is applied to equilibrium F_Q^N values to bound F_Q^N values that could be measured at non-equilibrium conditions.

II. BACKGROUND

The NSP Prairie Island plant is a two loop 1650 MW_{th} Westinghouse PWR. The reactor power distribution monitoring system is a moveable incore fission chamber system combined with four dual section excore ion chambers. The incore system is used to periodically perform a detailed three dimensional power distribution analysis. The excore response is periodically calibrated to match the axial power distribution determined by the incore system. The excore system is continuously on-line and capable of indicating a core average axial power shape. The purpose of the TPD analysis is to assure the reactor operates within acceptable power distribution limits between periodic incore maps by utilizing the on-line excore system.

III. COMPUTER MODEL, N3P

The computer methodology used to analyze the core power distribution uses an NSP code called N3P. NRC approval of this methodology for use on the Prairie Island Units is addressed in NSP topical NSPNAD-8101-A. The methodology has been approved for both core design and transient xenon power analysis. The model is a three dimensional nodal code based on FLARE. It uses 24 axial nodes and 26 radial nodes. The radial component of the code is normalized to the diffusion theory code PDQ. The isotopic number densities and resultant reaction rates are determined from the transport theory code CASMO. The result is a very accurate and efficient three dimensional core analysis model. The speed and efficiency of this model makes a detailed three dimensional transient xenon distribution analysis possible.

A typical computer simulation starts with a specified reference condition and transient modeling strategy. At the reference condition an axially dependent Equilibrium F_Q^N value is obtained. At each time step during a load follow an axial dependent transient F_Q^N value is obtained. The ratio of these axially dependent F_Q^N values, (Trans F_Q^N)÷(Equil F_Q^N), at each time step define a particular axial dependent V(z) curve. The conglomeration of all V(z) curves at each time step in a load follow result in a peak axial V(z) curve for a given reference condition and transient modeling strategy. See figure III.A for a flow chart of this process.

Analysis of transients such as load follow operations are slow enough that N3P modeling is adequate for both gross (core wide) and localized transient xenon behavior. To demonstrate this, N3P predictions were compared to four flux maps taken during a load follow sequence. The first flux map was taken at equilibrium conditions prior to a load follow maneuver. The second flux map was taken after power reduction to 40% power, the third was taken just prior to a ramp up to 100% power, and the fourth was taken shortly after reaching full power. The results of these four flux maps can be found in figures III.B through III.D. The first figure shows the integrated detector response, the second displays measured and predicted detector responses for a typical unrodded location, and the third figure shows the measured and predicted response of a typical rodded location. The excellent comparisons of predicted to measured data display N3P's ability to model transient xenon behavior.

Figure III.A

Computer Model Simulation

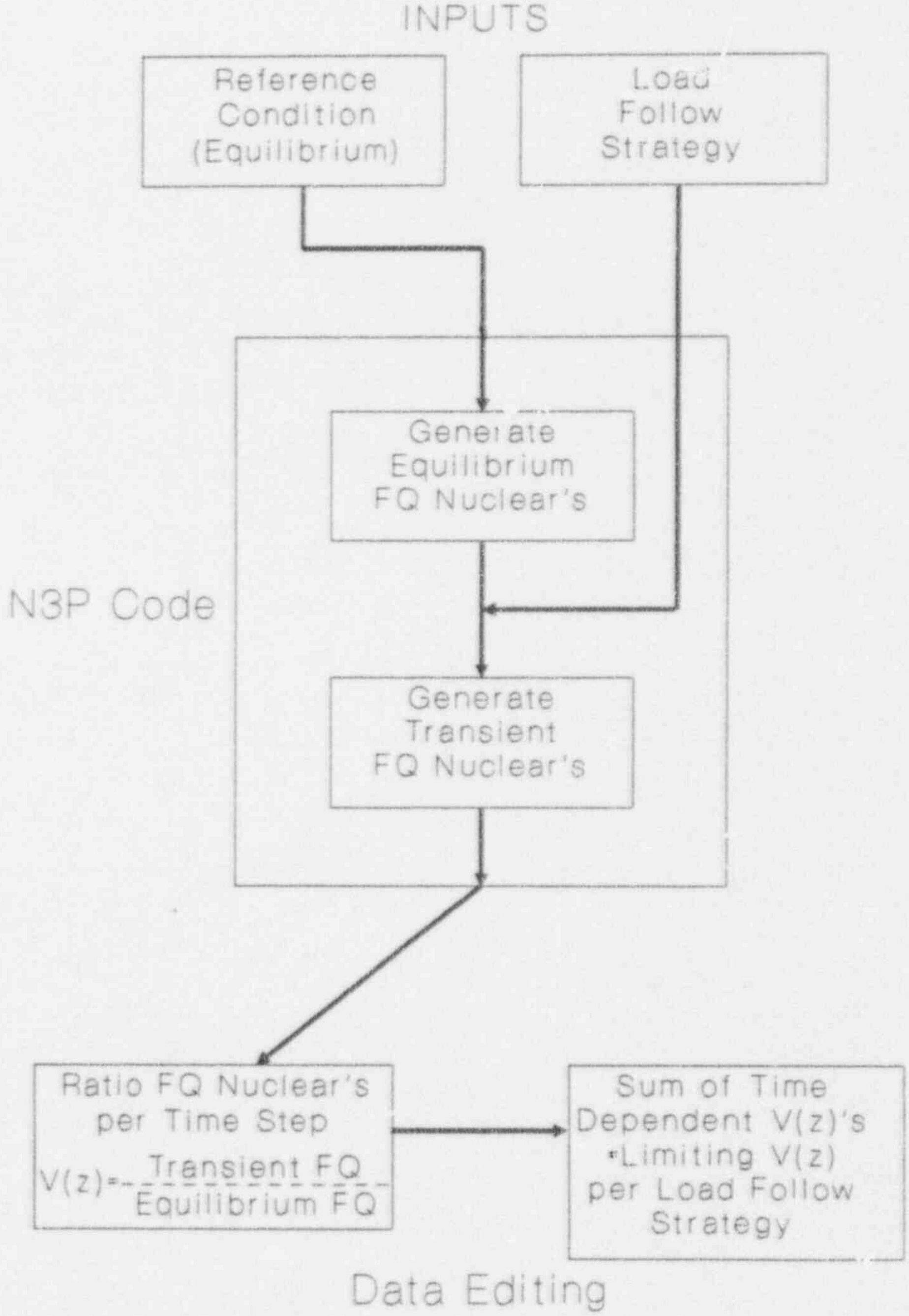


Figure III.B

INTEGRATED DETECTOR RESPONSE

Xenon Modelling
Flux Map Comparisons

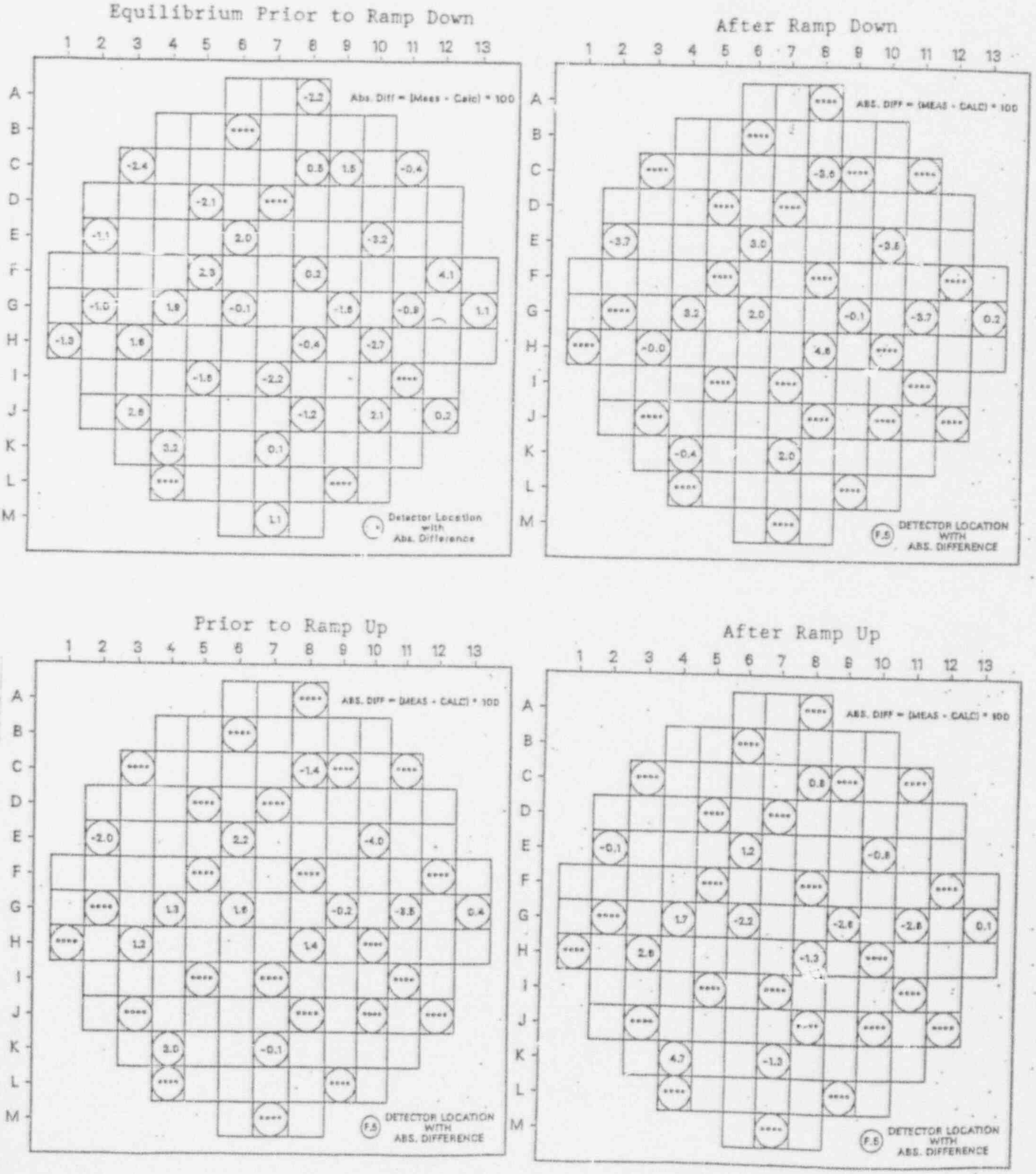
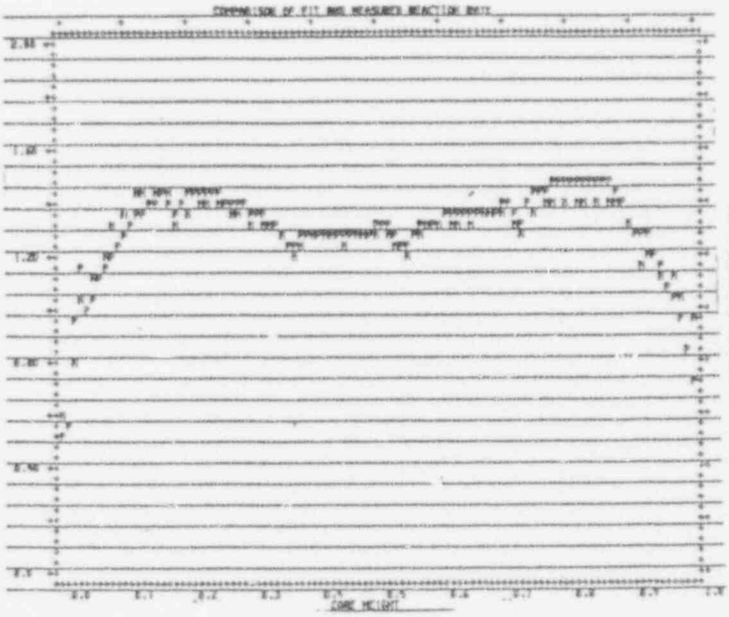


Figure III.C

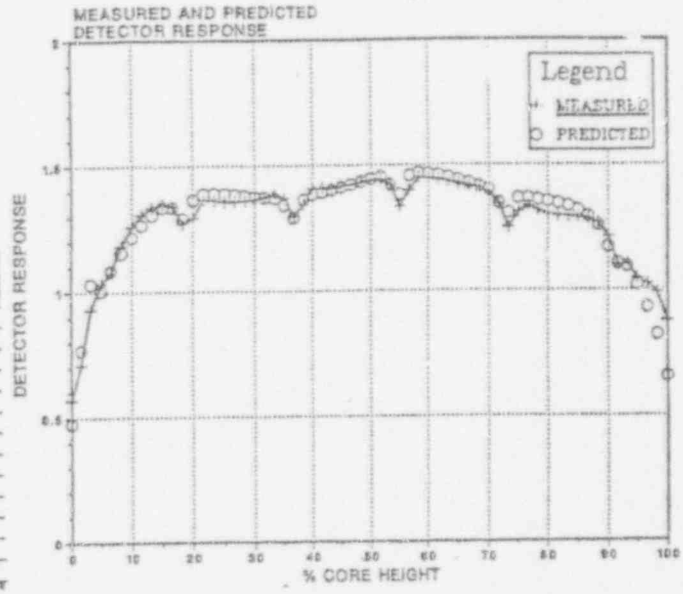
MEASURED & PREDICTED DETECTOR RESPONSE

Xenon Modelling
Flux Map Comparisons

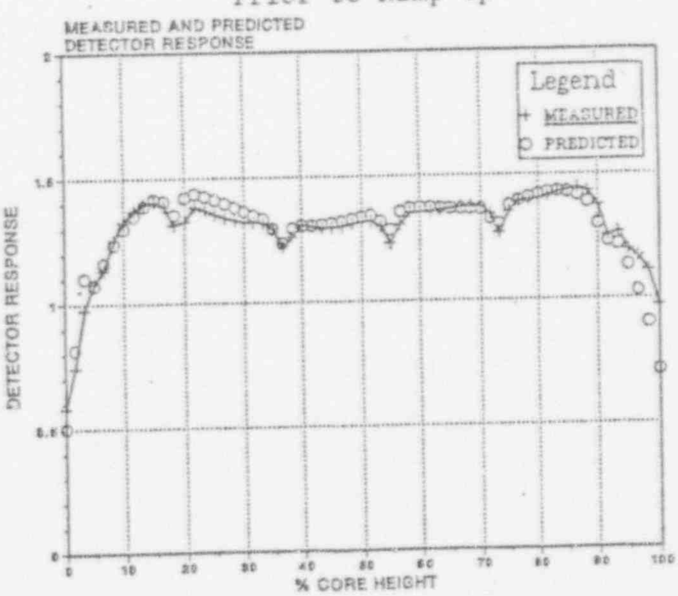
Equilibrium Prior to Ramp Down



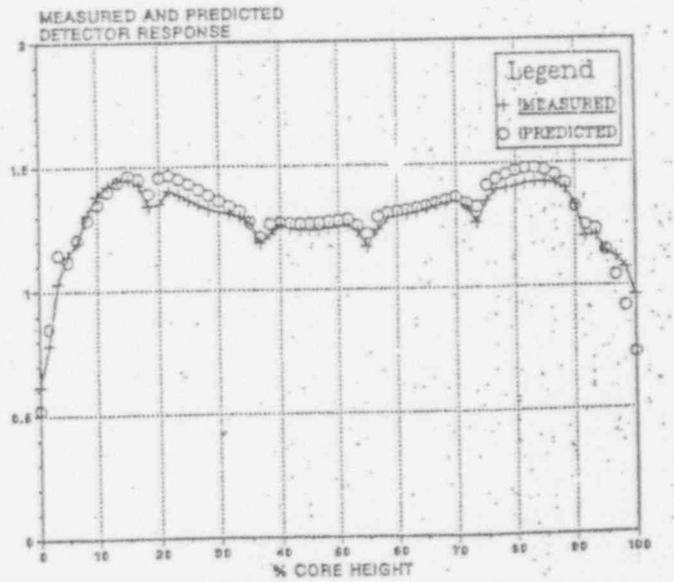
After Ramp Down



Prior to Ramp Up



After Ramp Up

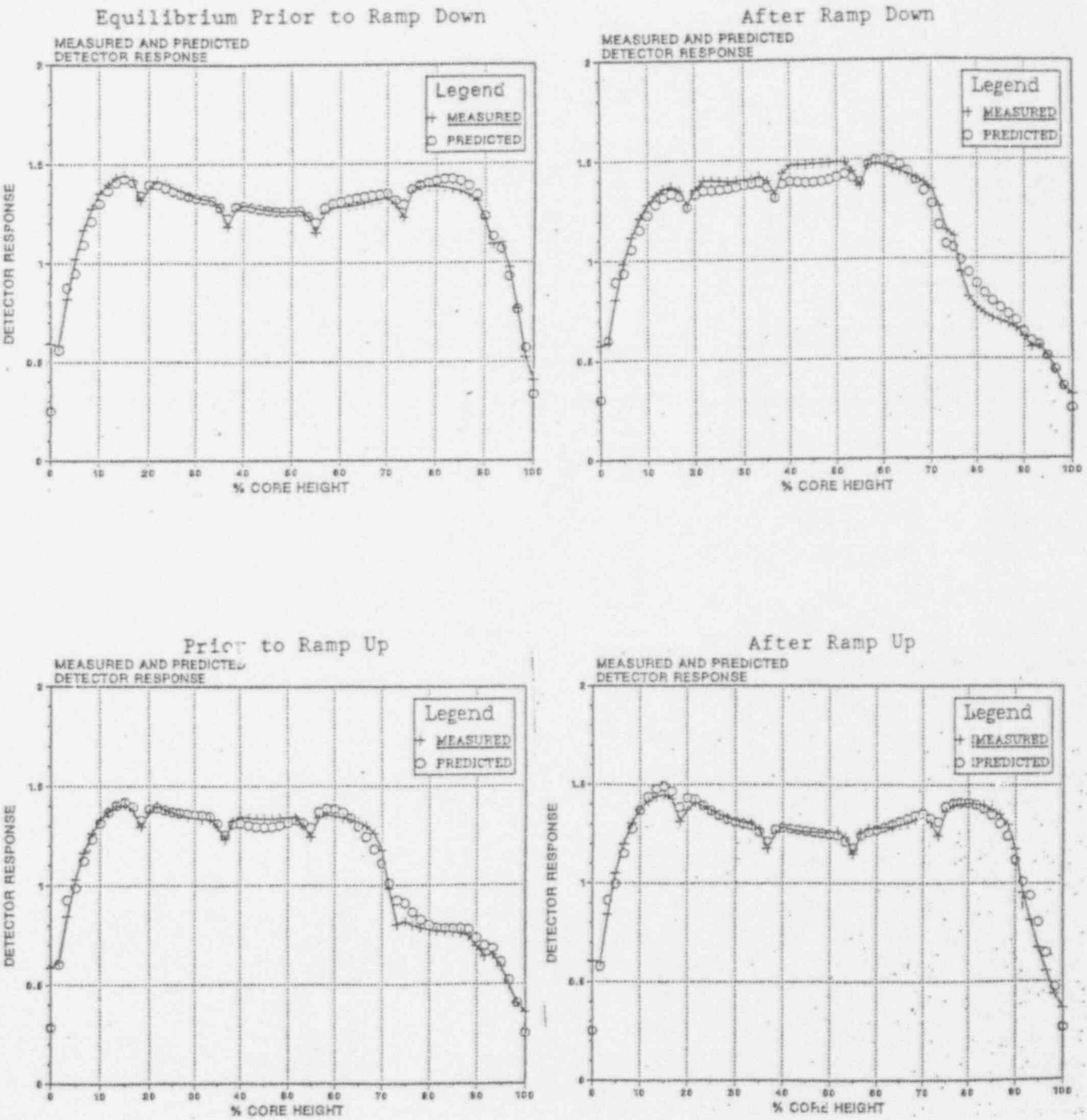


DETECTOR LOCATION G-9 - UNRODDED

Figure III.D

MEASURED & PREDICTED DETECTOR RESPONSE

Xenon Modelling
Flux Map Comparisons



DETECTOR LOCATION K-7 - RODDED

IV. DEFINITIONS/PARAMETERS

A list of various acronyms and/or definitions used in the Transient Power Distribution Methodology are given below. More in depth definitions shall be presented throughout this topical as needed.

TPD Transient Power Distribution Methodology represents the process utilized in the generation of a V(z) curve.

AO Axial Offset represents the ratio of the difference in reactor power, top to bottom, to the total reactor power.

ΔI Flux Difference, product of Axial Offset and fraction of operating power.

TAO Target Axial Offset is an equilibrium (steady state core condition) all rods out Axial Offset used as a reference (target) value for flux difference monitoring.

Bandwidth A window (range) of operationally allowed ΔI values about a TAO.

Load Follow Plant operating maneuver consisting in a decrease and increase in reactor power over a period of time.

Power Ramp Magnitude of power change during load follow operations.

Mode Core operating strategy utilized during load follow operations to control ΔI.

F_Q^N Nuclear Hot Channel Factor, maximum local heat flux on surface of a fuel rod divided by the average heat flux in the core.

V(z) Ratio of transient to equilibrium predicted F_Q^N values applied to equilibrium measured F_Q^N values (for middle 80% of core) to bound F_Q^N values that could be measured at non-equilibrium conditions.

$$V(z) = \frac{Transient\ F_Q^N}{Equilibrium\ F_Q^N}$$

V. Elements Effecting Power Distribution

Axial power distributions are mainly effected by exposure, control rod position, power level swing, and xenon distributions (Figure V.A). Typical axial power distributions at BOC are generally a symmetric dome shape and with exposure tend to flatten out and even become more of a wash tub shape.

Axial Offset (AO) and ΔI values provide a good measure of the power distribution. The AO is a ratio of the difference in power between the top and bottom halves of the reactor core to the total power in the core,

$$A.O. = \frac{P_T - P_B}{P_T + P_B}$$

where P_T=Power in Top Half of Core
P_B=Power in Bottom half of Core

ΔI represents the flux difference which is the product of Axial Offset and the ratio of operating power to rated full power operation,

$$\Delta I = \left(\frac{P_T - P_B}{P_T + P_B}\right)\left(\frac{P}{P_O}\right)$$

where P=Operating Power Level
P_O= Rated Full Power

By maintaining the flux difference within set limits (bandwidth) about an Axial Offset, a controllable power distribution is maintained. Operation outside the ΔI bandwidth is restricted in accordance with NSP's Technical Specifications, section 3.10

The ΔI bandwidth about an axial offset has a pronounced effect upon reactor control and power peaking. The wider bandwidth allows ΔI to drift farther which lends itself to more severe core oscillatory conditions which in turn drives power peaking resulting in a larger V(z). Figure V.B displays the effect of widening the ΔI bandwidth from a straight 5% band to a two tier bandwidth, 5% above 90% power and 10% at or below 90% power. The figure shows that V(z) is dependent upon the ΔI bandwidth.

Below is a discussion of power distribution maintenance throughout a load follow maneuver. The modeling of the load follow scenario is such that boron is used to maintain criticality while control rods are used to maintain ΔI

within a specified bandwidth about an Axial Offset. The driving force behind the load follow scenario is a time dependent power level swing. Utilizing this fact, a typical load follow scenario of a 3 hour power reduction, 6 hours at reduced power, a 3 hour ramp up, and 12 hours at full power has been chosen, referred to as a "3-6-3-12" load follow scenario (figure V.C).

1. <u>3 Hour Ramp Down</u> - Due to power redistribution, Axial Offset shifts in the positive direction, xenon concentration builds in and the iodine concentration depletes. The boron concentration is increased over this time period (less with increasing xenon buildup) to drive the power level down while maintaining criticality. During this power reduction control rods may enter the core to maintain the ΔI within specified bandwidth, thus, lowering the necessary critical boron concentration and driving the Axial Offset toward the bottom of the core.

2. <u>6 Hours at Reduced Power</u> - Here the power level remains constant, control rods are moved to control ΔI, and boron is removed to compensate for xenon buildup.

3. <u>3 Hour Ramp Up</u> - The power level is ramped back up to full power while adjusting boron to maintain criticality. The power distribution shifts toward the bottom of the core and control rods are moved to control ΔI. This also depletes the xenon concentration increasing the need for additional boron and increases iodine production.

4. <u>12 Hours at Full Power</u> - At full power the control rods are basically stationary at some position (generally ARO) as dictated by control of ΔI within the specified bandwidth. The boron concentration initially increases to compensate for the depleted xenon concentration mentioned in the prior step and then decreases with xenon buildup. Over this period of full power operation the oscillation of the xenon distribution will be dampened which will aid in maintaining a stable core.

Figure V.A

Reactor Core Relative Power Distributions
Due to Rods, Exposure, Power Reduction, and Xenon

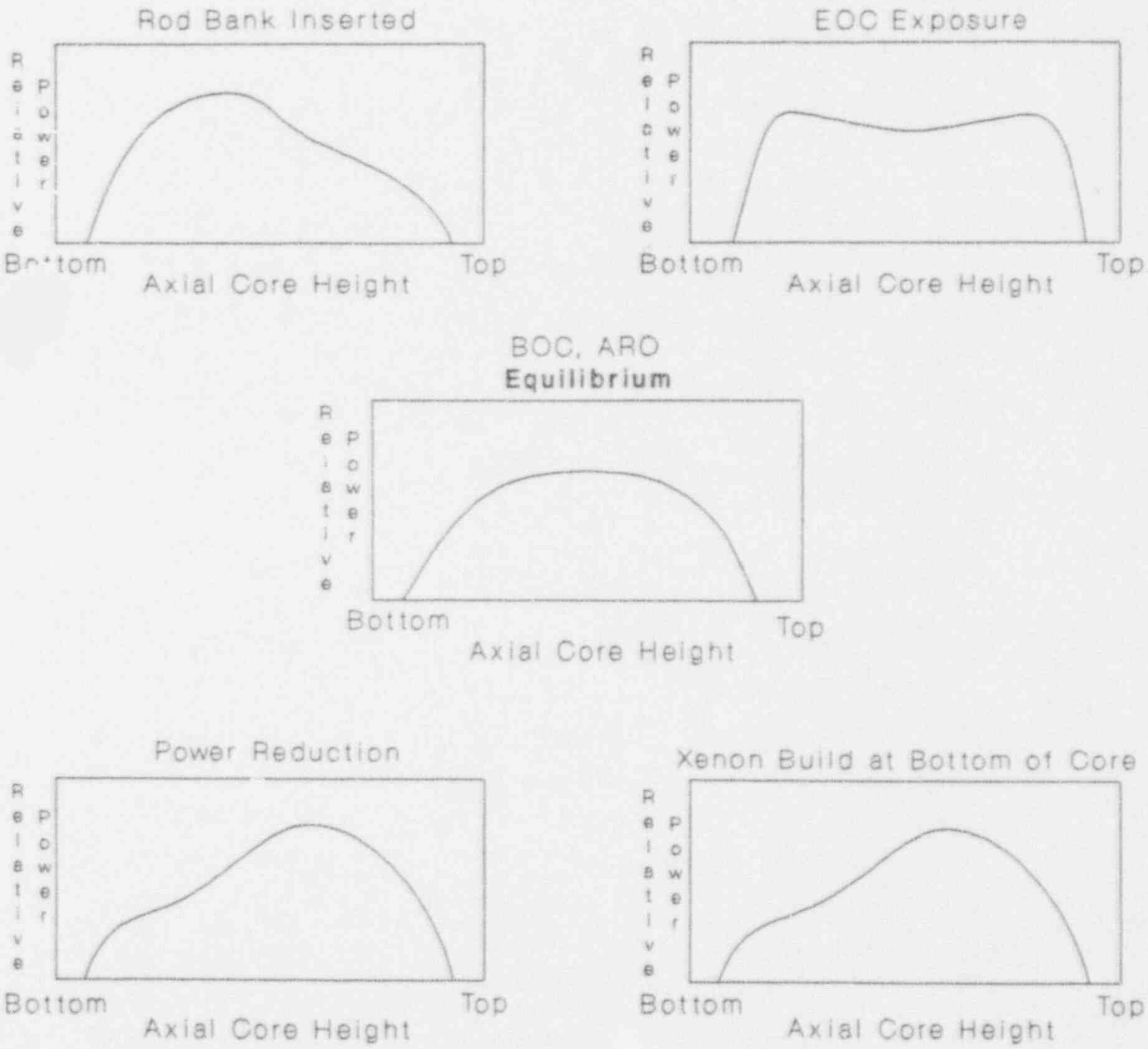
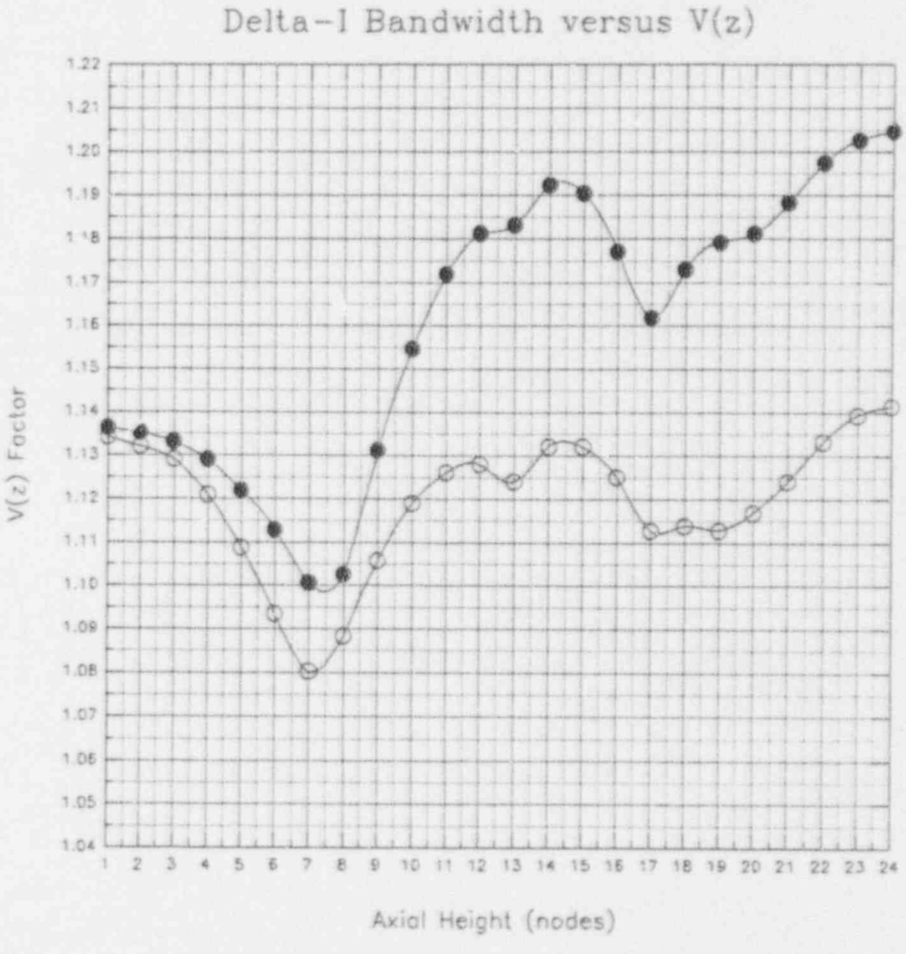


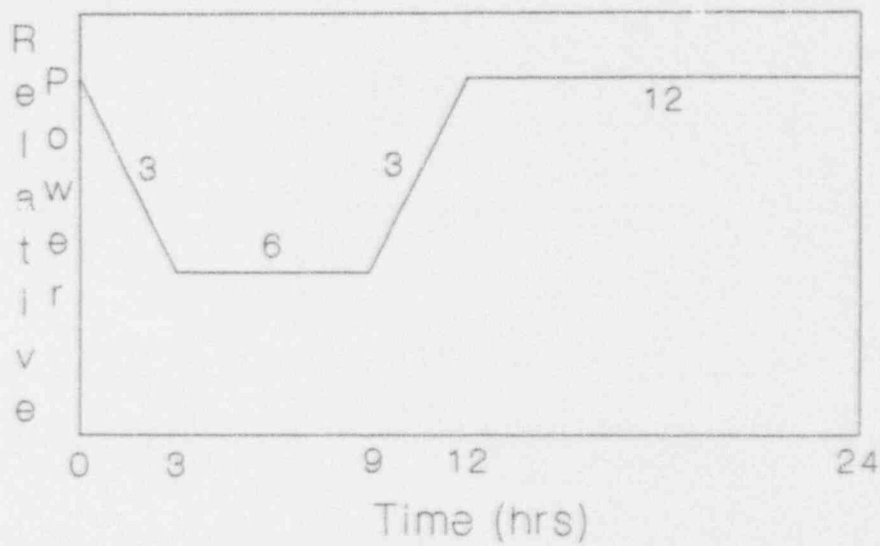
Figure V.B



○ Straight 5% Delta I Bandwidth
● Two-Tier Bandwidth of 5% above 90% PWR and 10% at or below 90% PWR

Figure V.C

"3-6-3-12" Load Follow Scenario



VI. Reference Conditions, TAO's

At a particular exposure, reference conditions are set up to define starting points for initiation of various load follow maneuvers. The reference conditions chosen for this type of analysis are Target Axial Offset values (TAO's). A specified TAO may be represented by an unlimited number of power distributions each of which can be generated in a variety of ways. Through analysis NSP has found that for a given TAO the resulting V(z) is independent of the method of generating the reference power distribution.

Figure VI.A displays the effects of generating a particular TAO value in two distinctly different methods. The figure contains two power distributions, one for each method of TAO generation, and the resultant V(z) curves. The first method of obtaining the TAO value was through the use of a continuous load follow depletion to the desired exposure, MOC. The second method of obtaining the same TAO condition was through a base load depletion to MOC adjusting the axial leakage. The plot demonstrates that two feasible yet distinctly different methods of generating a TAO result in virtually the same power shape and V(z) factor. Hence, V(z) is independent of the method of generating the reference condition. For simplicity, method two is the preferable choice of TAO generation since it allows a feasible means of generating the extreme negative TAO values and method one does not.

Furthermore, as will be discussed later, this analysis will use a bounding TAO approach. The bounding TAO approach dictates that the measured equilibrium axial offsets must be within the analyzed TAO values or additional analysis to bound the measured values will be necessary. Hence, the method of TAO generation is relatively insignificant.

Figure VI.B displays three MOC V(z) curves as a result of generating the reference conditions using Method 2 (leakage depletion). This figure displays three V(z) curves generated from three TAO's and shows that as the absolute magnitude of the TAO value increases so does V(z). The figure displays a behavior that suggests the +TAO case is most limiting at the bottom and middle of the core and the -TAO case is most limiting at the top of the core. Additional analysis has shown this behavior to be consistent.

The dependence of V(z) on a target axial offset may also be deduced from the definition of axial offset, where $A.O.=(P_T-P_B)\div(P_T+P_B)$. If the TAO is nearly equal to zero than $P_T \simeq P_B$ and we have fairly uniform axially xenon and power distributions, thus, local power peaking and V(z), by definition, are well behaved. If the TAO is much greater or less than zero (+5% or -10%), large xenon and power gradients exist axially across the core. This results in higher local power peaking which has a large effect on the V(z) factor. The

gradients will tend to induce oscillatory core conditions when load following, further aggravating local power peaking and increasing the V(z) factor.

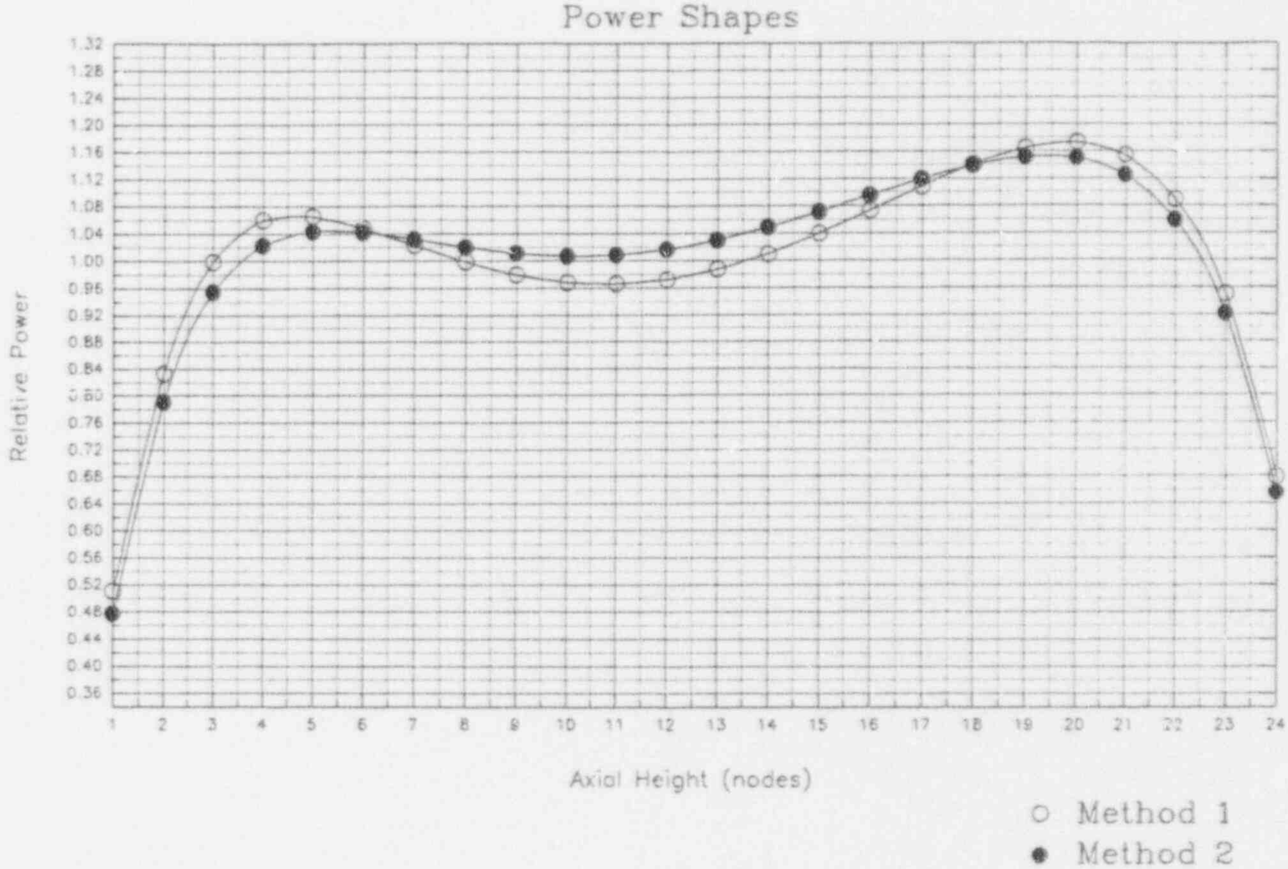
Utilizing the above information a bounding set of TAO values can be generated based upon past core operations. Figure VI.C contains measured Axial Offset data from cycle 10 through 15 for Prairie Island units 1 and 2. This data suggests that the TAO is exposure dependent and trends from about +3% to -5%, BOC to EOC, respectively. The V(z) factors dependence on exposure has also been shown through analysis, figure VI.D. This exposure dependence is due in part to the ability of maintaining the balance of core reactivity. As exposure is accumulated the reactor core boron concentration decreases. This decrease in boron concentration makes reactivity maintenance more difficult due to slower dilution capabilities. Hence, control rods are utilized significantly more for reactivity management which induce larger ΔI changes, thus, increasing power peaking and V(z). Furthermore, near EOC the xenon distribution has a greater tendency to oscillate, aggravating ΔI and V(z) even more.

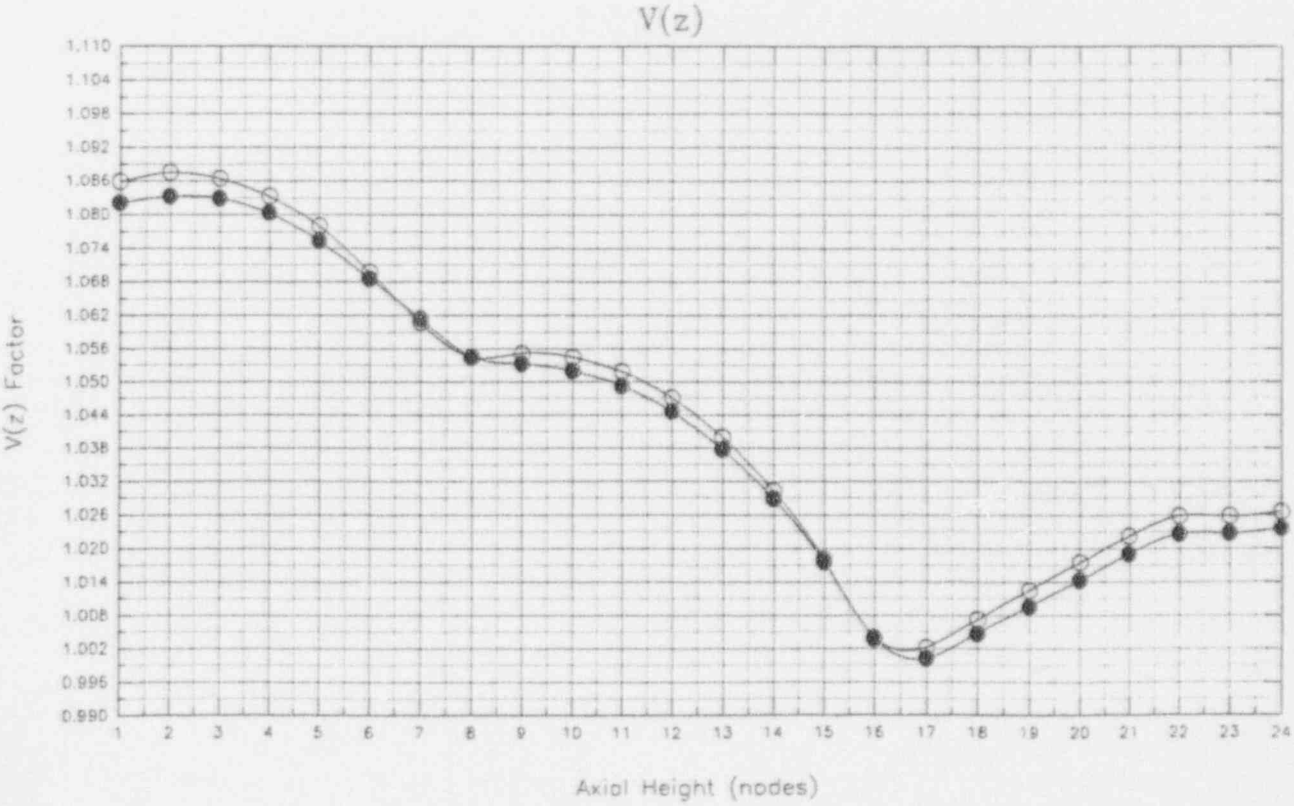
To avoid unrealistic V(z) factors due to uncontrollable oscillations near EOC a definition of what EOC represents is needed. EOC, for purposes of a V(z) analysis, is defined as the point in core life when approximately 150ppm boron remains in the core. This value was chosen as a reasonable value beyond which the plant will not "typically" load follow for two reasons. The first is that load follow maneuvers beyond this boron concentration are avoided if possible due to the reduced dilution rate available and the second being the cost of processing the large amount of waste water generated.

The end result of all the above information is that exposure dependent V(z) curves or an EOC V(z) curve could be generated that would bound possible core operations from EOC to BOC through the use of extreme TAO reference conditions. These curves would apply for exposures at or below which they were analyzed provided the measured equilibrium axial offset values are within the TAO values used in the TPD analysis.

Figure VI.A

Power Shapes for a +5% TAO vs Relationship to V(z) MOC





V(z) Dependence on TAO Magnitude

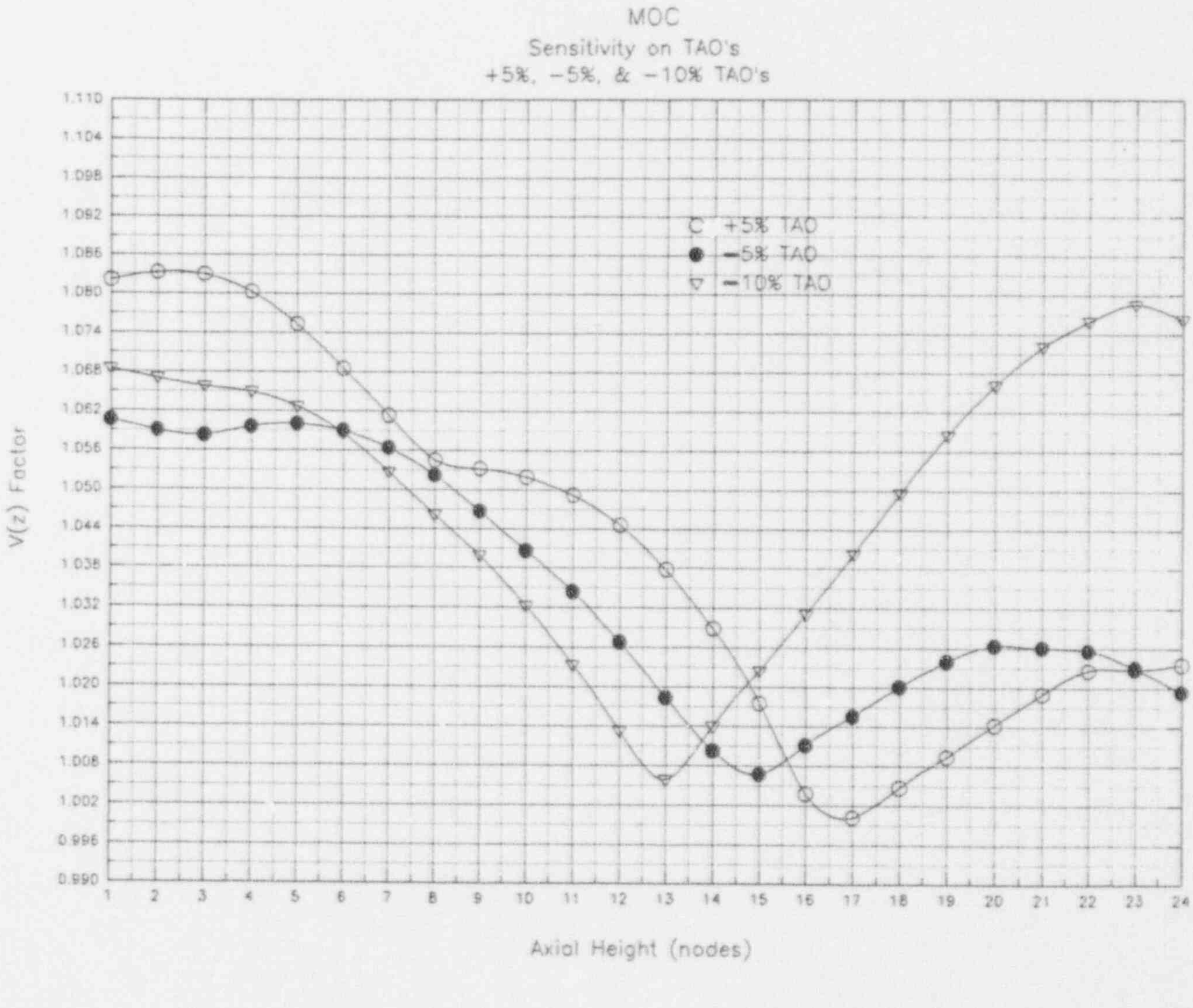


Figure VI.C

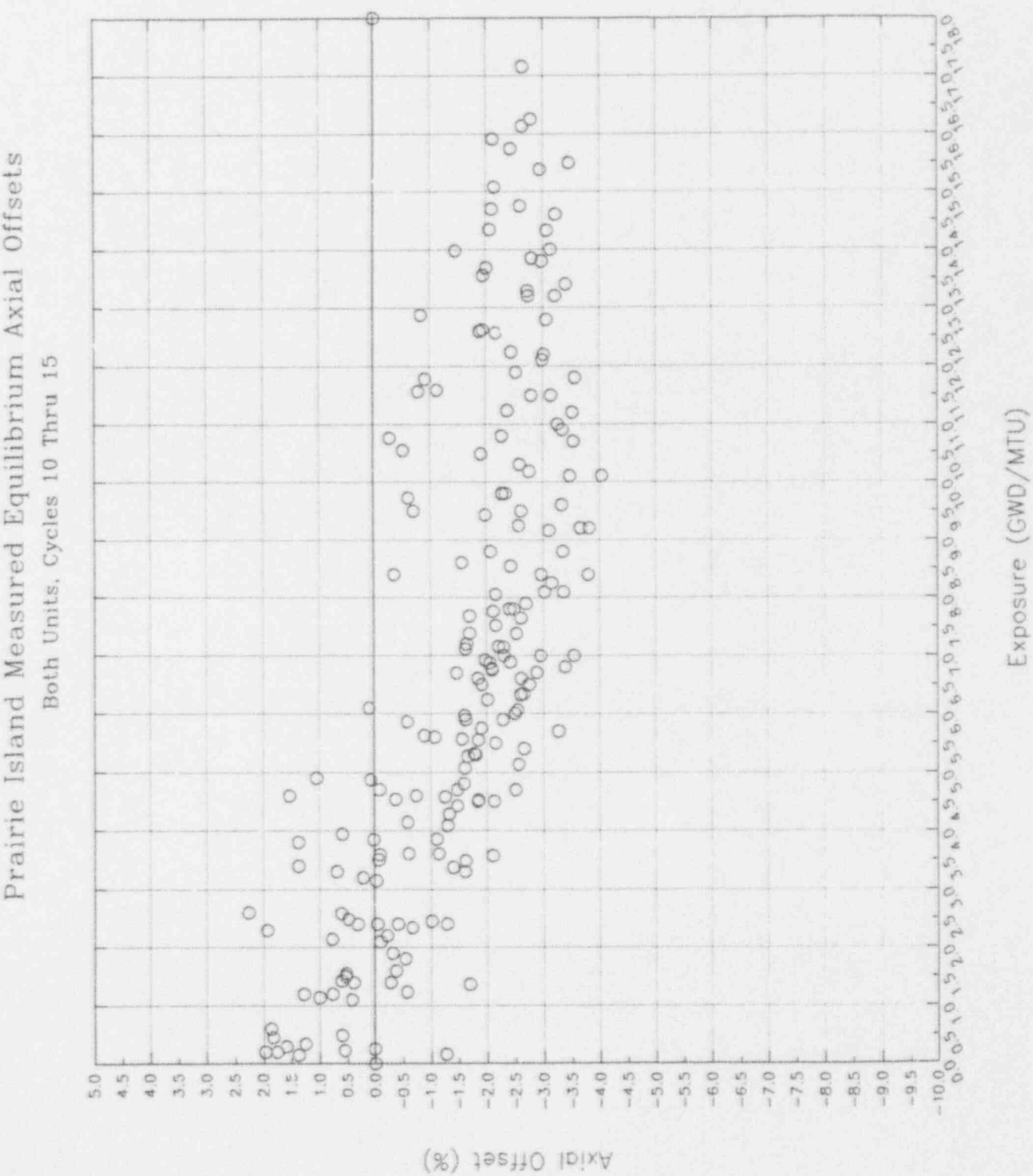
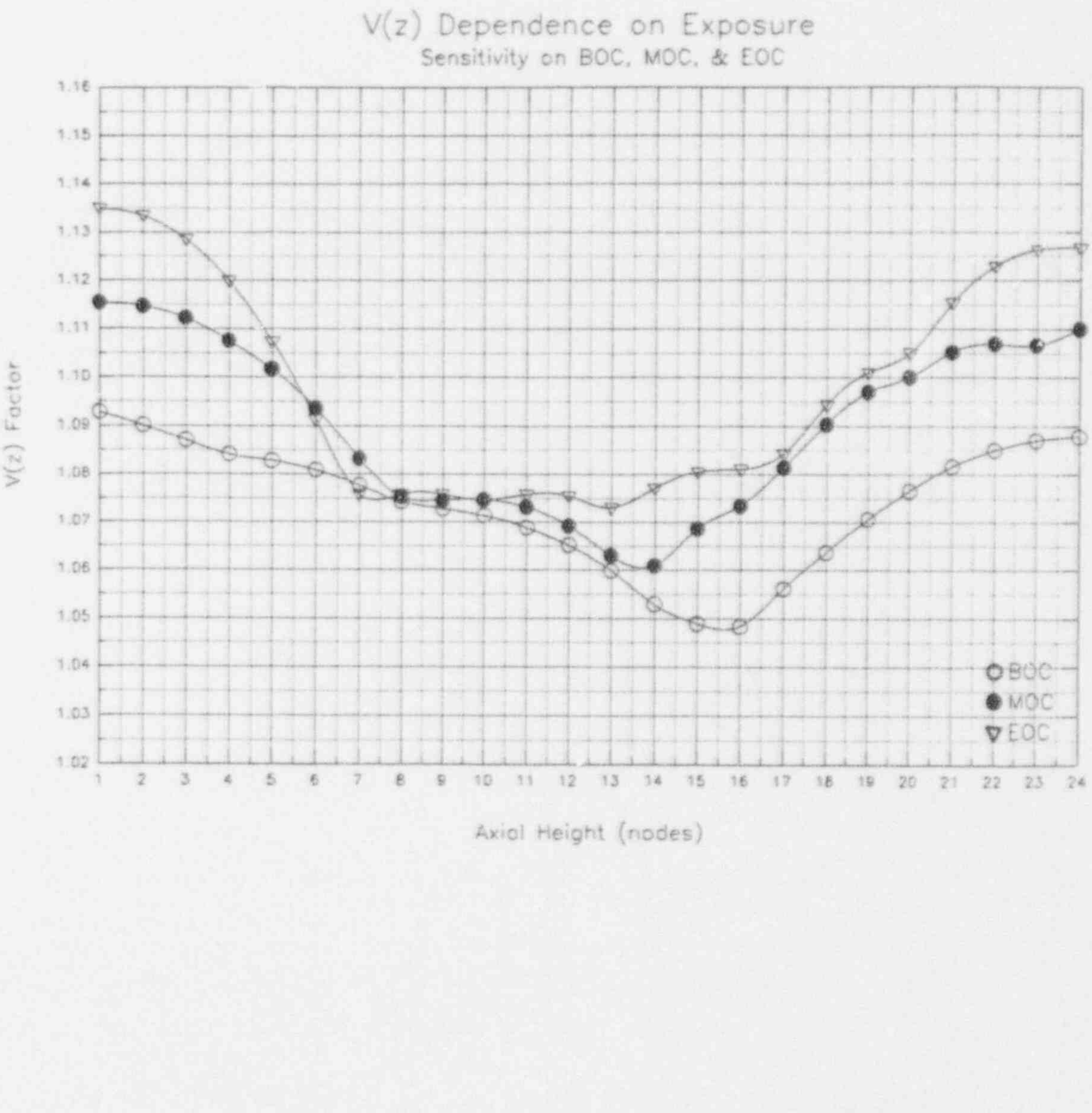

Prairie Island Measured Equilibrium Axial Offsets
Both Units, Cycles 10 Thru 15
Exposure (GWD/MTU)
Axial Offset (%)

Figure VI.D



V(z) Dependence on Exposure
Sensitivity on BOC, MOC, & EOC
1.16
1.15
1.14
1.13
1.12
1.11
1.10
1.09
1.08
1.07
1.06
1.05
1.04
1.03
1.02
V(z) Factor
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Axial Height (nodes)
BOC
MOC
EOC

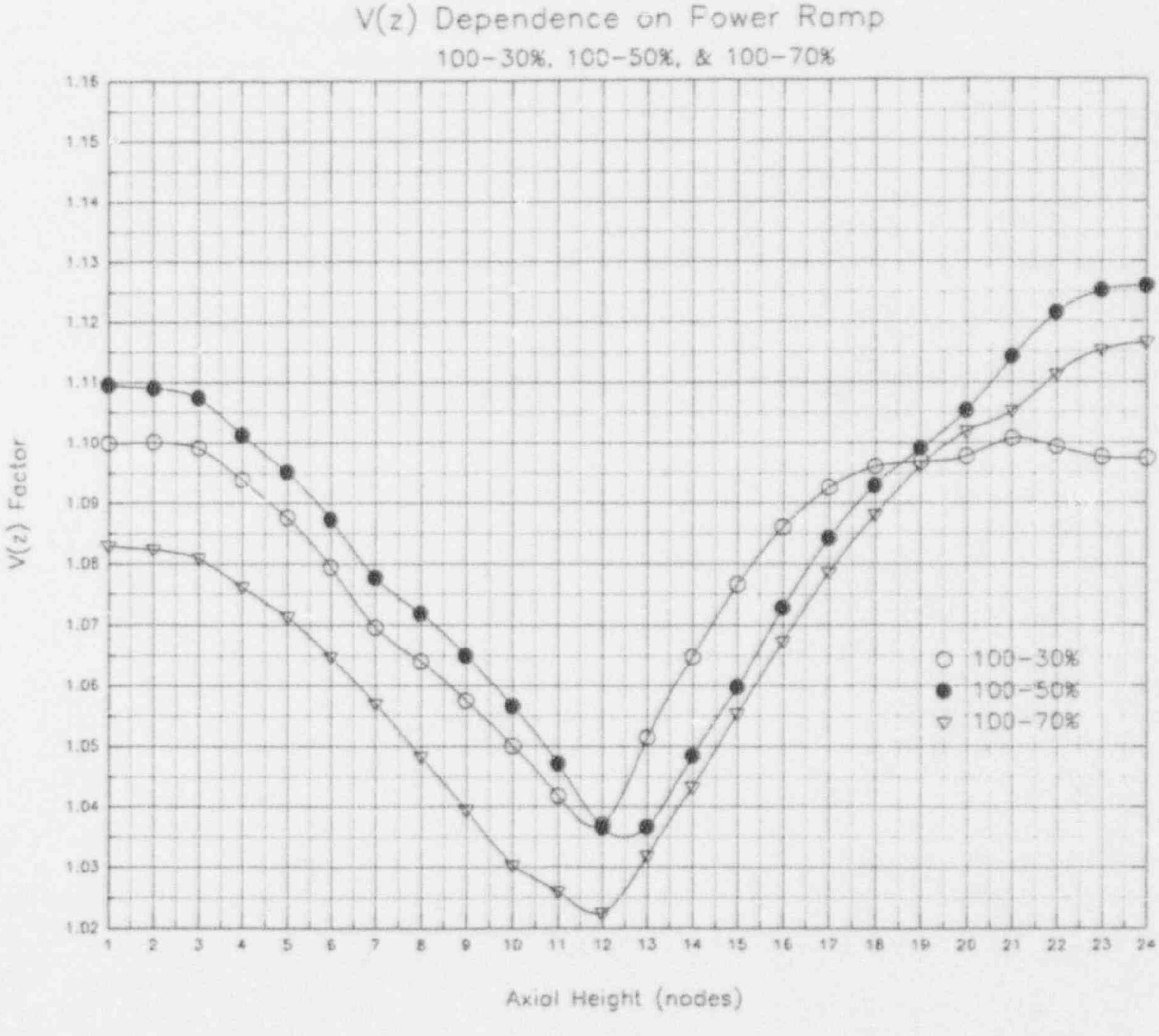
VII. **Load Follow Power Ramps**

Given a reference condition (TAO), a transient is induced by performing a load follow maneuver. The industry standard "3-6-3-12" load follow scenario is used with two power ramps,

1. 100% Power to 30% Power, 100-30%
2. 100% Power to 50% Power, 100-50%

A third power ramp, 100-70%, was found (through a sensitivity study and reasoning) to be bounded by the 100-50% ramp. An explanation for this is that while the control rod insertion is similar in both ramps it is slightly deeper in the 100-50% ramp. The deeper rod insertion leads to larger ΔI swings and larger $V(z)$ values. The sensitivity study went on to show that the 100-30% ramp did not always bound the 100-50% ramp due to rod insertion beyond core mid-plane. Rod insertion beyond core mid-plane allows the power distribution to shift in the positive direction (opposite of the control rod insertion), thus, depending on the reference condition being used, may increases or decrease the subsequent ΔI swing and $V(z)$ values upon return to full power. Hence, the 100-30% ramp will not always bound the 100-50% ramp and both power ramps are utilized in the TPD analysis.

Figure VII.A


V(z) Dependence on Power Ramp
100-30%, 100-50%, & 100-70%
V(z) Factor
Axial Height (nodes)
100-30%
100-50%
100-70%
1.16
1.15
1.14
1.13
1.12
1.11
1.10
1.09
1.08
1.07
1.06
1.05
1.04
1.03
1.02
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24

VIII. Load Follow Operating Modes

After establishing the reference conditions and the load follow structure the various core operating strategies utilized during load follow maneuvers must be defined. The intent of the operating strategies/modes is to provide a set of conditions that bound the allowable operating regime. Since there are an unlimited number of operationally allowed strategies/modes, a list of bounding modes has been developed. The list consists of four modes, Rebound, Float, Plus AO, and Minus AO, described below (graphically in figure VIII.A).

Rebound - RBD - This operating strategy dictates that during a load follow ΔI will be maintained as positive as possible (within target bandwidth) above 90% power. At or below 90% power the ΔI shall be maintained as negative as possible (within target bandwidth). The purpose of this mode is to maximize control rod duty and impose control rod forced xenon oscillations. This mode effects the V(z) significantly near the top and bottom of the core which would be expected due to the control rod motion dictated.

Float - FLT - This operating strategy dictates that during a load follow ΔI will be maintained within the target bandwidth. The purpose of this mode is to minimize operator intervention by allowing ΔI to float within the target bandwidth. This mode of operation effects the V(z) significantly just below the middle of the core since this mode of operation allows ΔI to drift preferentially in the negative direction.

Plus AO - PAO - This operating strategy dictates that during a load follow ΔI will be maintained as positive as possible (within target bandwidth) and minimize control rod insertions at all times. The purpose of this mode is to maximize the boration/dilution system duty. This mode of operation effects V(z) significantly just above the middle of the core since this mode of operation pulls ΔI in the positive direction.

Minus AO- MAO - This operating strategy dictates that during a load follow ΔI will be maintained as negative as possible (within target bandwidth) at all times. The purpose of this mode is to maximize control rod insertions at all times during core operations. This mode of operation effects V(z) near the bottom of the core due to deep insertion of control rods.

Of these four modes, the MAO mode has the least effect on V(z) due to constant control rod insertions which dampen ΔI swings, therefore, minimizing xenon and power oscillations. Figure VIII.C displays the MAO mode V(z) factors which show very little difference between the ramps and TAO's. This data suggests that only the -TAO cases be run using the MAO mode. This can be explained since the MAO mode will maintain ΔI as negative as possible at all times using control rod insertions. These rod insertions will have a dampening effect upon a +TAO but not on a -TAO condition. The other three modes are fairly unique and provide various areas of limiting V(z) factors so no elimination of cases can be performed.

Figure VIII.B displays the general shape of the four modes.

Figure VIII.A

Operating Modes/Delta I Control

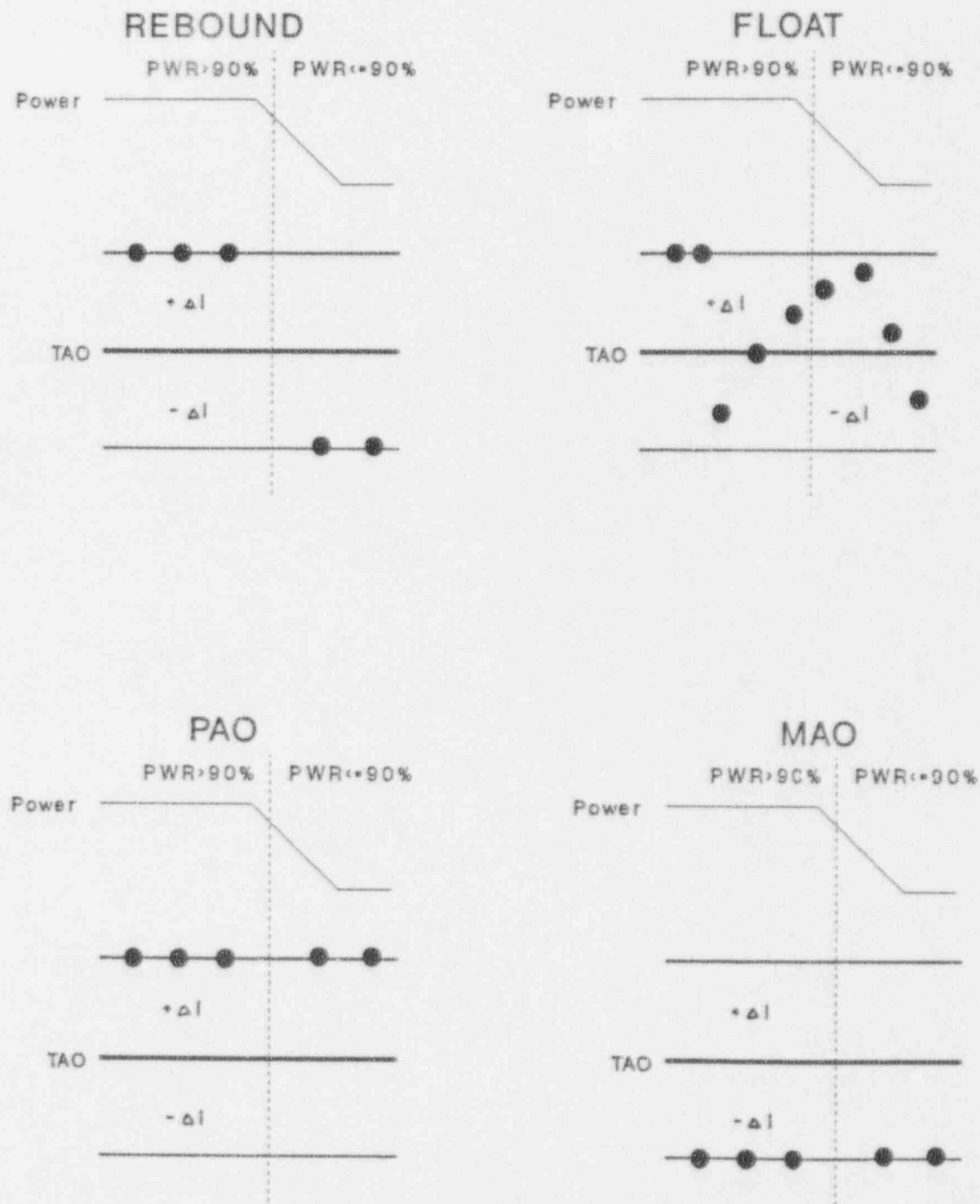
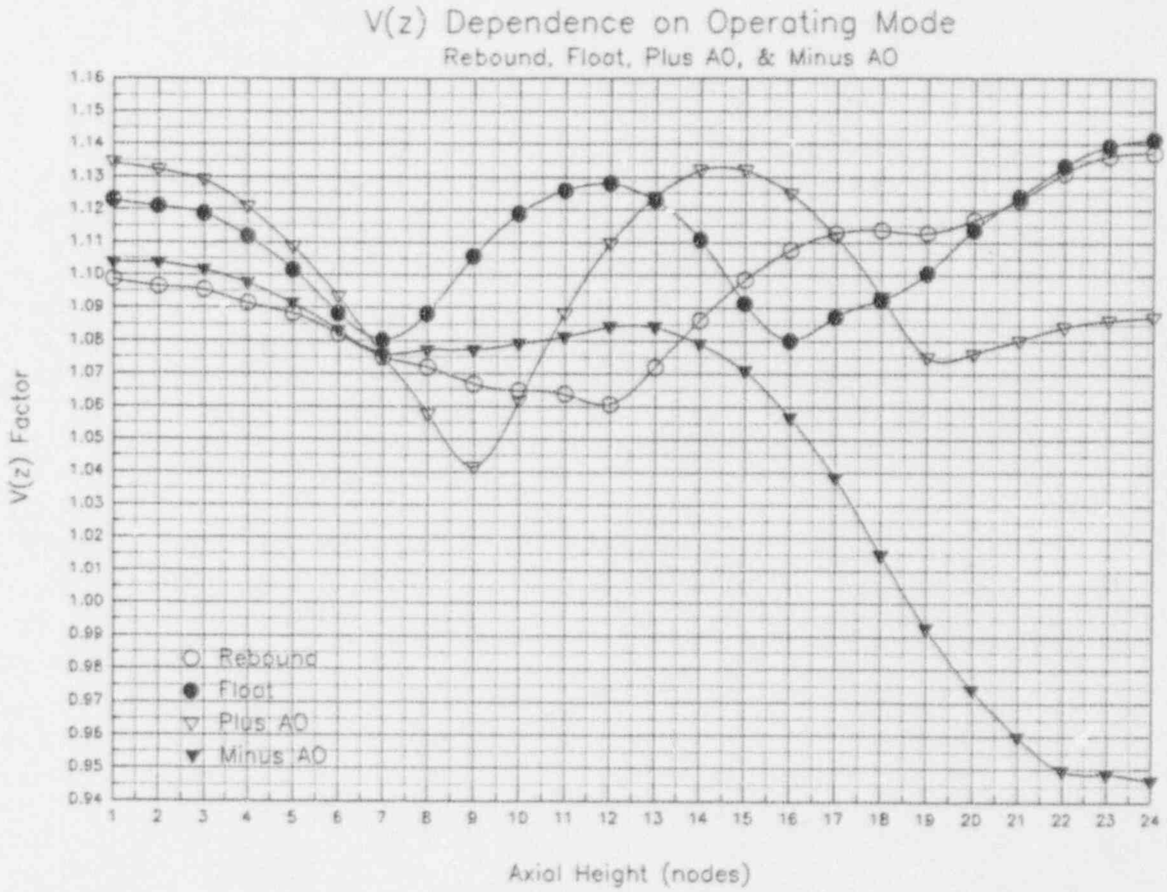
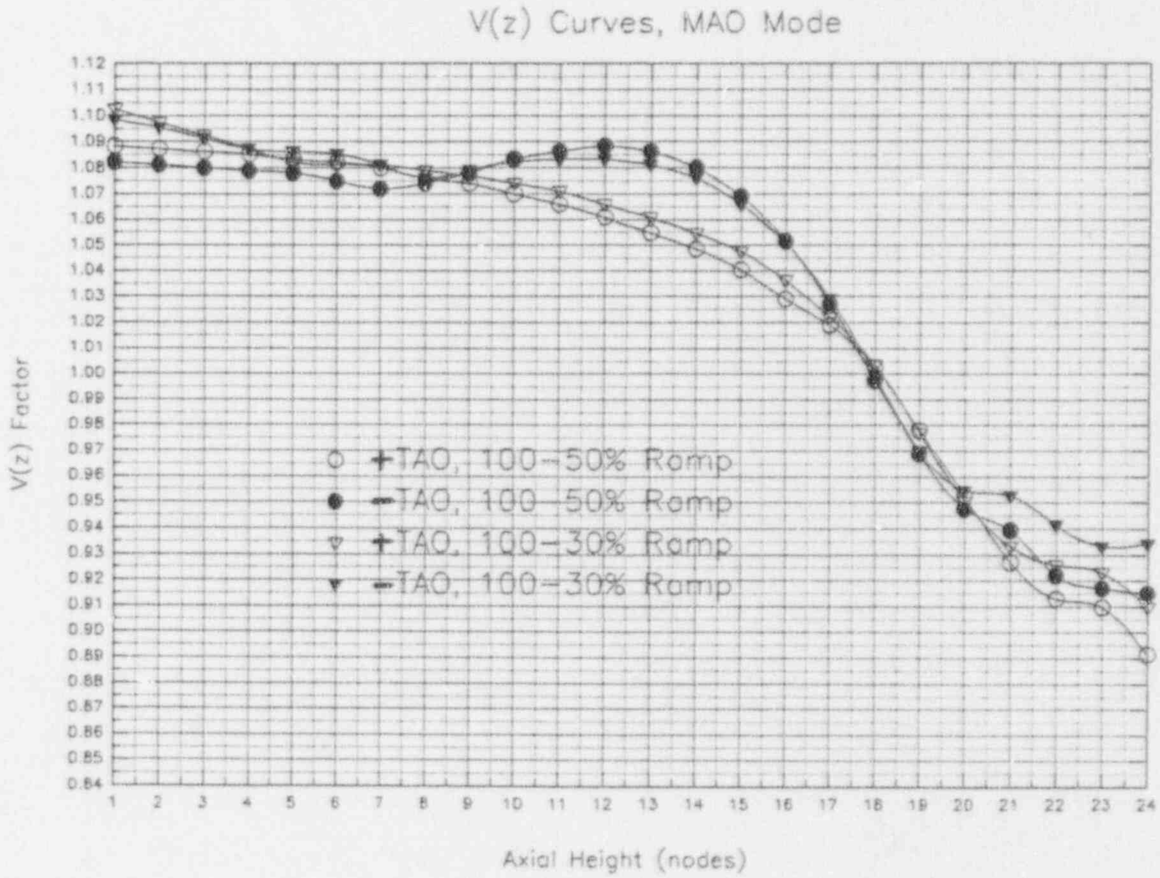


Figure VIII.B




V(z) Curves, MAO Mode
1.12
1.11
1.10
1.09
1.08
1.07
1.06
1.05
1.04
1.03
1.02
1.01
1.00
0.99
0.98
0.97
0.96
0.95
0.94
0.93
0.92
0.91
0.90
0.89
0.88
0.87
0.86
0.85
0.84
V(z) Factor
+TAO, 100→50% Ramp
−TAO, 100→50% Ramp
+TAO, 100→30% Ramp
−TAO, 100→30% Ramp
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
Axial Height (nodes)

IX. TPD Case List Generation

The result of using reference conditions (TAO's), power ramps, and operating modes to bound the allowable operating space is a cycle specific V(z) case list (Table IX.A), or what NSP refers to as the "Cube" of cases (Figure IX.A).

The "Cube" of cases is a finite set of transient modeling strategies which, through analysis and arguments presented earlier, bound the Tech Spec allowable operating regime. A summarization of the results used to generate the "Cube" are provided below as well as a discussion of how to generate a V(z) curve for a given cycle.

Summary of Criteria for Generation of the "Cube" of Cases

1. V(z) increases with an increase in absolute magnitude of TAO's.
2. V(z) increases with Exposure.
3. V(z) increases with an increase in ΔI bandwidth.
4. V(z) increases with larger power reductions (i.e. 100-50% vs 100-70%).
5. V(z) increases at mid-core with power reductions >50% (i.e. 100-30%).
6. V(z) varies with mode of load follow (RBD, FLT, PAO, or MAO).
7. The MAO mode using both ramps off the +TAO may be eliminated.

Utilizing the above criteria a V(z) case li_t, the "Cube" of cases, was generated. Using the case list and a flow chart (figure IX.B) a cycle specific V(z) curve can be produced as discussed in the steps below.

1. At a particular Exposure N=E_1, E_2, E_3, ... E_{EOC} generate reference conditions, +TAO and -TAO, that bound feasible operating TAO's.
2. Using both ±TAO's generate equilibrium axial F_Q^N values.
3. From each TAO a "3-6-3-12" load follow scenario is performed for various power ramps and modes while observing a specified ΔI bandwidth.
4. 100-50% and 100-30% power ramps are used during the load follow from each TAO.
5. For each power ramp at each TAO, four modes of operation are modeled, Rebound, Float, Plus AO, and Minus AO (MAO from -TAO only).
6. Each of 14 load follow scenarios result in a set of time dependent transient axial F_Q^N curves which are reduced to a maximum transient axial F_Q^N curve for a total of 14 unique F_Q^N curves per exposure point.
7. The 14 maximum transient axial F_Q^N values are then divided by the equilibrium axial F_Q^N values to obtain 14 maximum axial V(z) curves for the particular exposure point chosen, figure IX.C. These 14 V(z) curves are then summarized into one bounding exposure dependent V(z) curve, figure IX.D.
8. Repetition steps 1 through 7, for each exposure point chosen constitutes

the generation of an exposure dependent set of V(z) curves.

- There are approximately 170 individual transient F_Q^N curves per unique load follow scenario that make up a maximum transient axial F_Q^N curve. Thus, there are a total of 2380 transient axial F_Q^N curves that make up one maximum curve at a particular exposure point.

Figures IX.E and IX.F contain typical data output during the first 12 hours of a load follow scenario at one particular exposure for one particular case in the "Cube" of V(z) cases. A "3-6-3-12" load follow scenario was used starting from a TAO of +5%. The operating strategy consisted of a 100-50% power ramp in Rebound Mode. Figure IX.E shows power, boron, core average temperature, control rod position, ΔI behavior, and the resultant V(z) curve during the load follow .

A set of exposure dependent V(z) curves can be reduced by the choice of bounding TAO values and exposure points analyzed. This type of reduction is possible since the V(z) factor becomes more conservative with exposure and increasing the magnitude of the TAO values chosen as reference conditions. For example, TAO's of +5 and -10% could be chosen at EOC then the 14 cases would represent a V(z) curve that is bounding from BOC to EOC, though it would be very conservative at BOC. A less conservative yet legitimate analysis may include 3 or 4 exposure points and exposure dependent TAO's. The choice of TAO values would be made to bound possible measured equilibrium axial offsets over a specified exposure range. For example, if an exposure of 2 GWD/MTU was chosen with +4% and -1% TAO values then the resultant V(z) factor from a TPD analysis would be applicable from BOC to 2 GWD/MTU provided the measured equilibrium axial offset values remain within the TAO values analyzed. If the next exposure chosen for analysis was 5 GWD/MTU and TAO values of +2% and -4% were analyzed. The resulting V(z) factor would be applicable from 2 GWD/MTU to 5 GWD/MTU provided the measured equilibrium axial offsets are within the +2% to -4% TAO range analyzed. Furthermore, the TPD analysis at 5 GWD/MTU could be applied from BOC to 5 GWD/MTU provided the measured equilibrium axial offsets remain within +2% to -4%. This process may be continued to EOC at various exposures and TAO values. The underlying principle in the whole process is that the measured equilibrium axial offsets must be within the analyzed TAO values across the applicable exposure range. If the measured equilibrium axial offset were to exceed this window of analysis, additional analysis would be necessary.

Table IX.A

Cycle Specific Case List

Exposures	Targets	Power Ramps	Modes
#E_N	+TAO	100-30%	Rebound Float Plus AO
		100-50%	Rebound Float Plus AO
	-TAO	100-30%	Rebound Float Plus AO Minus AO
		100-50%	Rebound Float Plus AO Minus AO

N represents one particular exposure step.

FIGURE IX.A

TPD CASE LIST CYCLE SPECIFIC ANALYSIS

CONDITIONS

A. Exposures - Various (EOC at a minimum)
B. Target A.O. - Various (Two at a minimum)
C. 3-6-3-12 Load Follow Power Swings - 100-50%, 100-30%
D. Delta-I Bandwidth - Various

MODES

A. Rebound - PWR>90% Maintain delta I at top of band
PWR<=90% Maintain delta I at bottom of band
B. Float - Let system define delta I path, operator intervention only to keep delta I within band
C. +A.O. - Keep delta I at top of band always
D. -A.O. - Keep delta I at bottom of band always

Cycle Specific Case List (per Exposure Point)

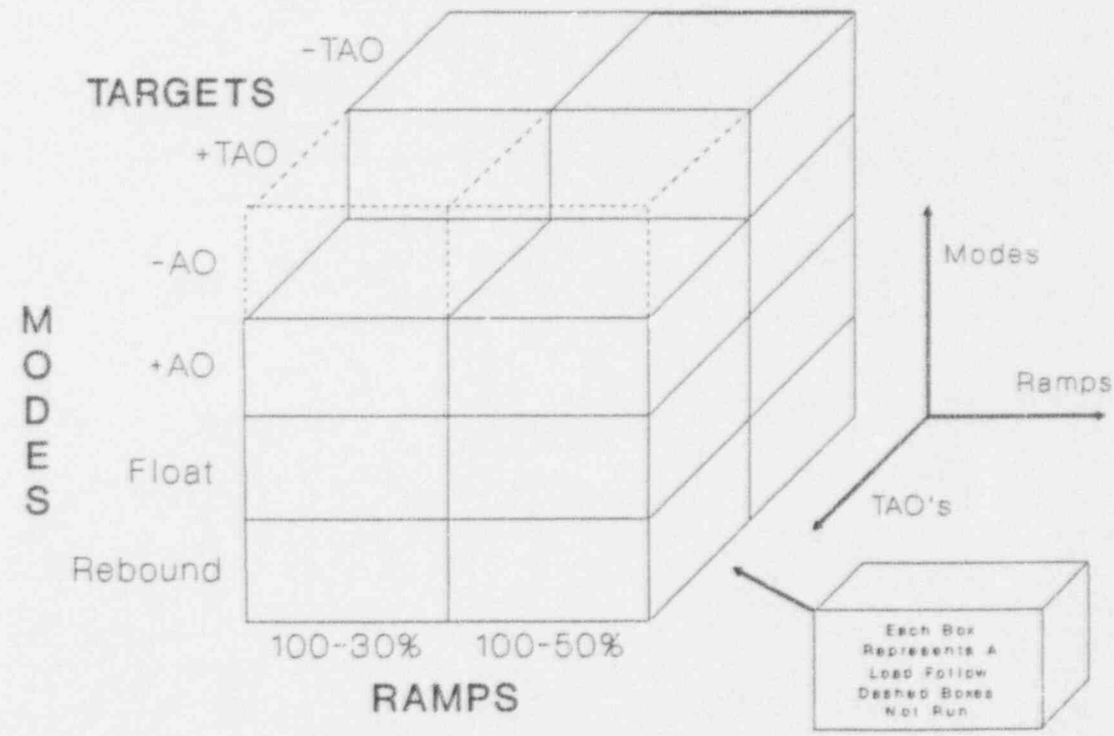


Figure IX.B

V(z) Generation Flow Chart

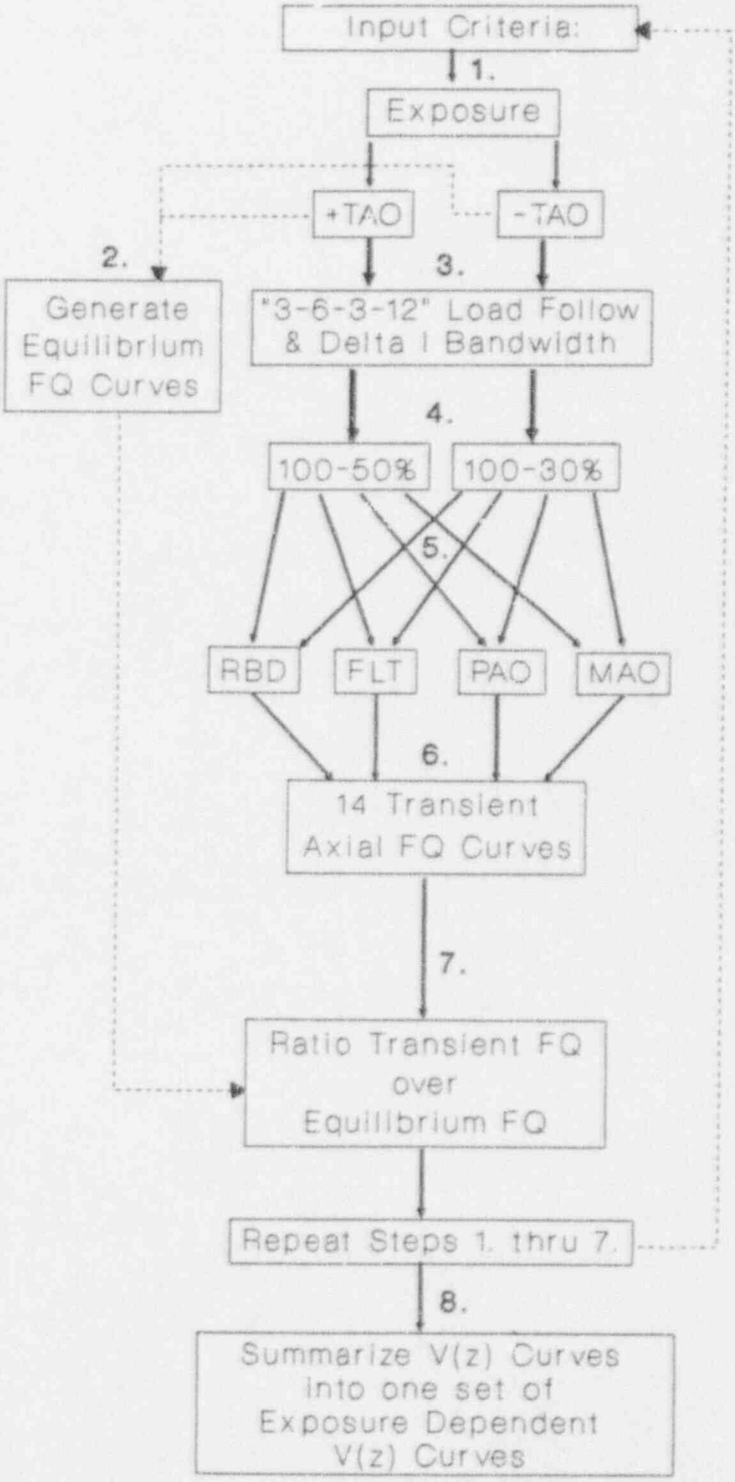


Figure IX.C

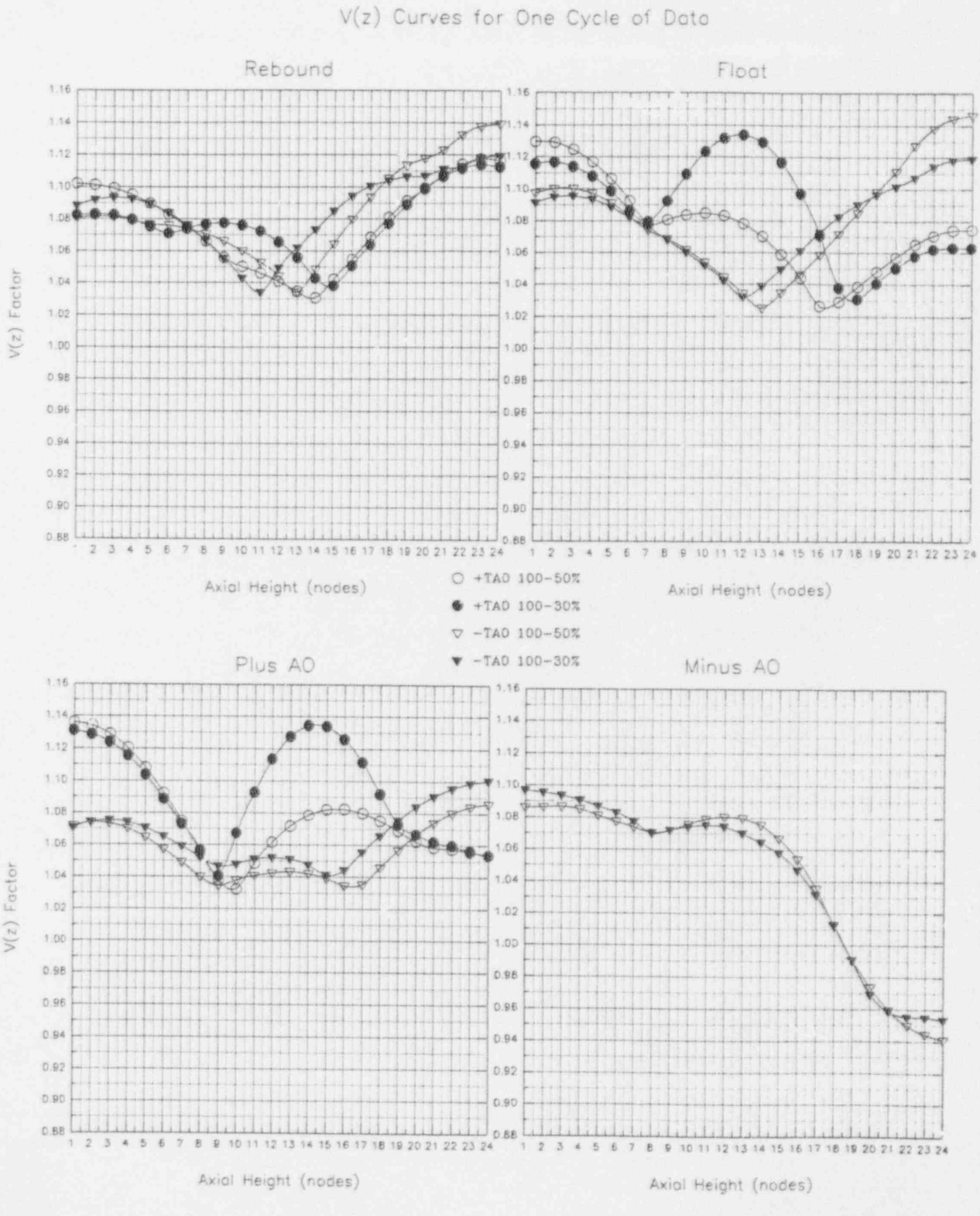

V(z) Curves for One Cycle of Data
Rebound
Float
Plus AO
Minus AO
V(z) Factor
Axial Height (nodes)
+TAO 100-50%
+TAO 100-30%
-TAO 100-50%
-TAO 100-30%

Figure IX.D

Summation of 14 V(z) Curves
on Prior Figure into 1 Curve

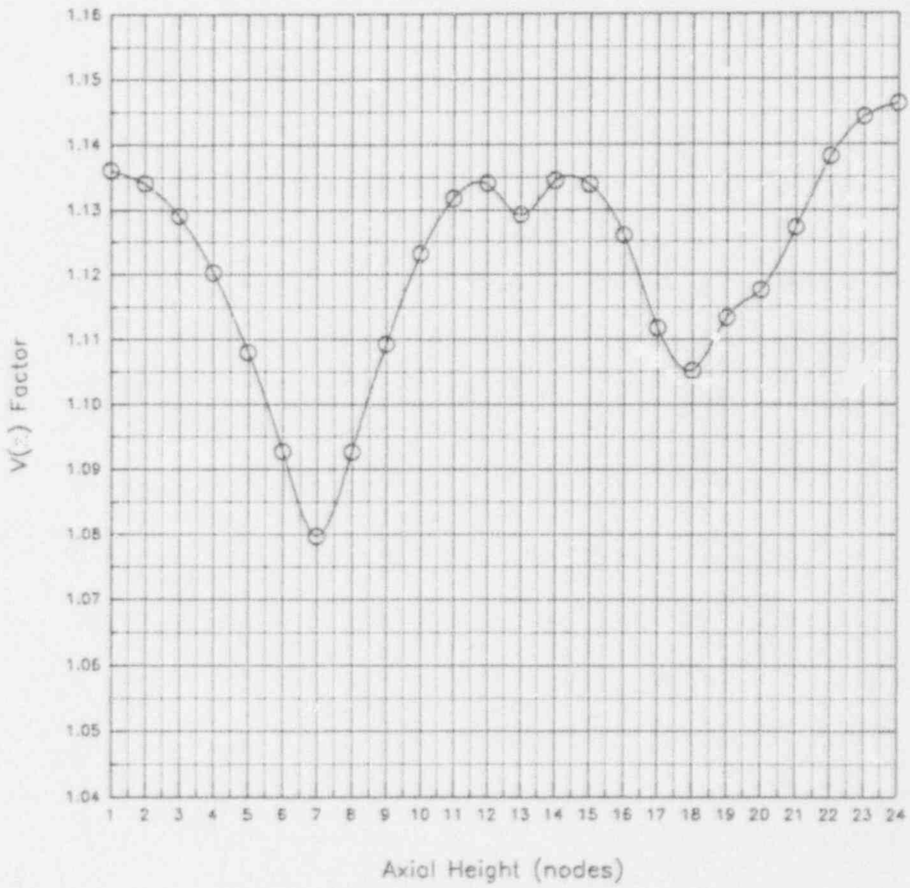
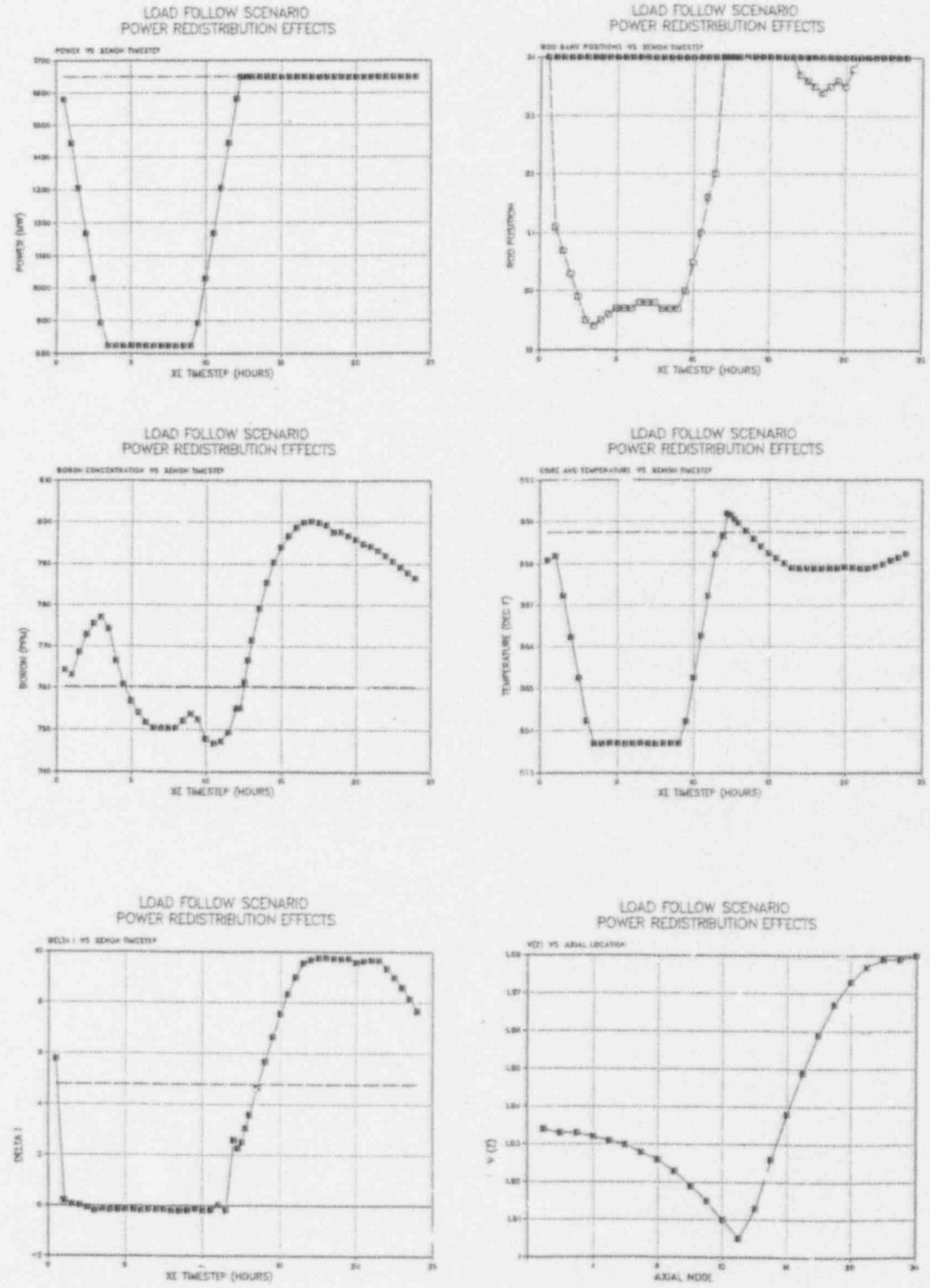


Figure IX.E

Typical Output



X. Generic V(z) Analysis and Case List

NSP has utilized the "Cube" of cases to analyze three cycles of data, P214, P115, and P215. The analysis was performed at MOC and EOC using TAO's of +5% and -10% and the "Cube" of cases. The resulting V(z) curves are displayed in figure X.A and display very similar behavior and magnitudes which lead to the generation of bounding (Generic) V(z) curves at MOC and EOC (figure X.B).

The three cycles chosen represent a varied selection of core design strategies utilized by NSP. These strategies include such design criteria as 48 and 52 bundle reloads, mixed enrichment reloads, Nat-U blanketed and non-blanketed cores, and various amounts and concentrations of Gadolinia loadings. The end result shows very consistent V(z) results from cycle to cycle.

The choice of +5% and -10% TAO values came from the measured Axial Offset data accumulated over 10 cycles provided earlier in figure VI.C. The TAO's were chosen since they bound all plant measured Axial Offsets at any exposure. Only two exposures were chosen, MOC and EOC, to reduce the volume of data output. EOC, for purposes of this analysis, is defined as the point in core life when about 150ppm boron exists at 100% full power steady state operation. One reason for a boron concentration definition of EOC is that the boron concentration will dictate the manner of ΔI control due to boration/dilution system constraints, thus, driving the V(z) factor. Other reasons for a boron concentration definition of EOC were provided earlier. MOC is based on a Core Average Exposure (CAE) of approximately 23 GWD/MTU. The choice to use core average exposure for a generic analysis versus other variables such as boron concentration or cycle exposure was that these variables vary more from cycle to cycle than core average exposure.

The three cycles of data resulted in over 7000 individual V(z) curves, 170 per case in the "Cube", that make up the resultant Generic V(z) curve. The resultant V(z) data from three cycles (14 cases per cycle) are plotted in figure X.C along with the Generic V(z) curve. The generic curve was drawn to bound the maximum axial V(z) values generated during the three cycles of analysis.

Figures X.D, X.E, and X.F display three cycles of maximum MOC and EOC V(z) curves, the Generic Curve, and seven cycle specific curves that represent the bounding V(z) curves from the set of 14 cases. This set of seven curves represent the Generic Case list necessary to run each cycle to qualify the use of the generic V(z) curves. The choice of these cases was made because they provide the limiting V(z) values upon which the Generic curve is based. The Generic case list is provided in Table X.A and Figure X.G.

Qualification for use of generic curves require that the generic case list be run and show that the resultant V(z) curves do not exceed the generic curve. Otherwise, a cycle specific analysis will need to be run.

An expansion of the generic set of curves for more exposure points, different TAO's, other ΔI bandwidths, and the such would be possible provided at least 3 cycles of data were analyzed using the full "Cube" of cases.

Table X.A

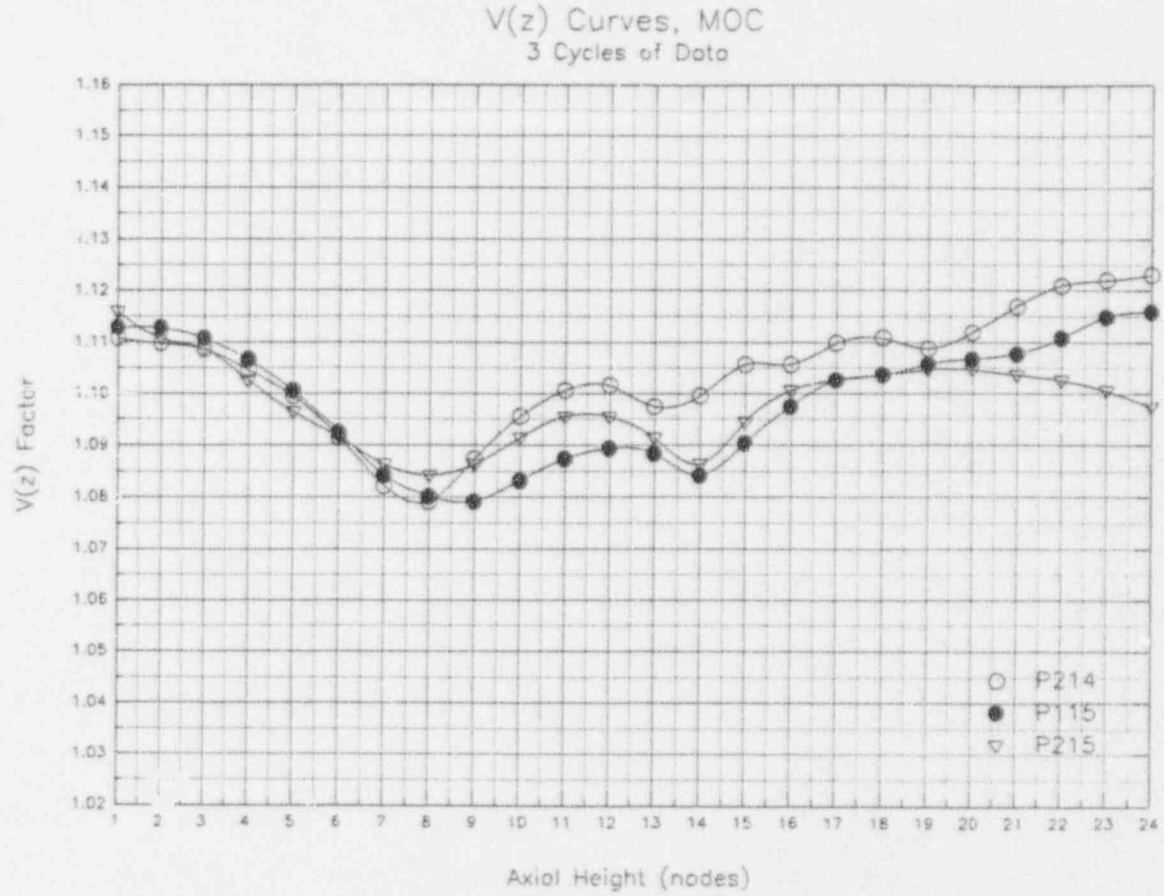
Generic Case List

Exposures	Targets	Power Ramps	Modes
##E_x	+TAO	100-30%	Float Plus AO
		100-50%	Plus AO
	-TAO	100-30%	Rebound Minus AO
		100-50%	Rebound Float

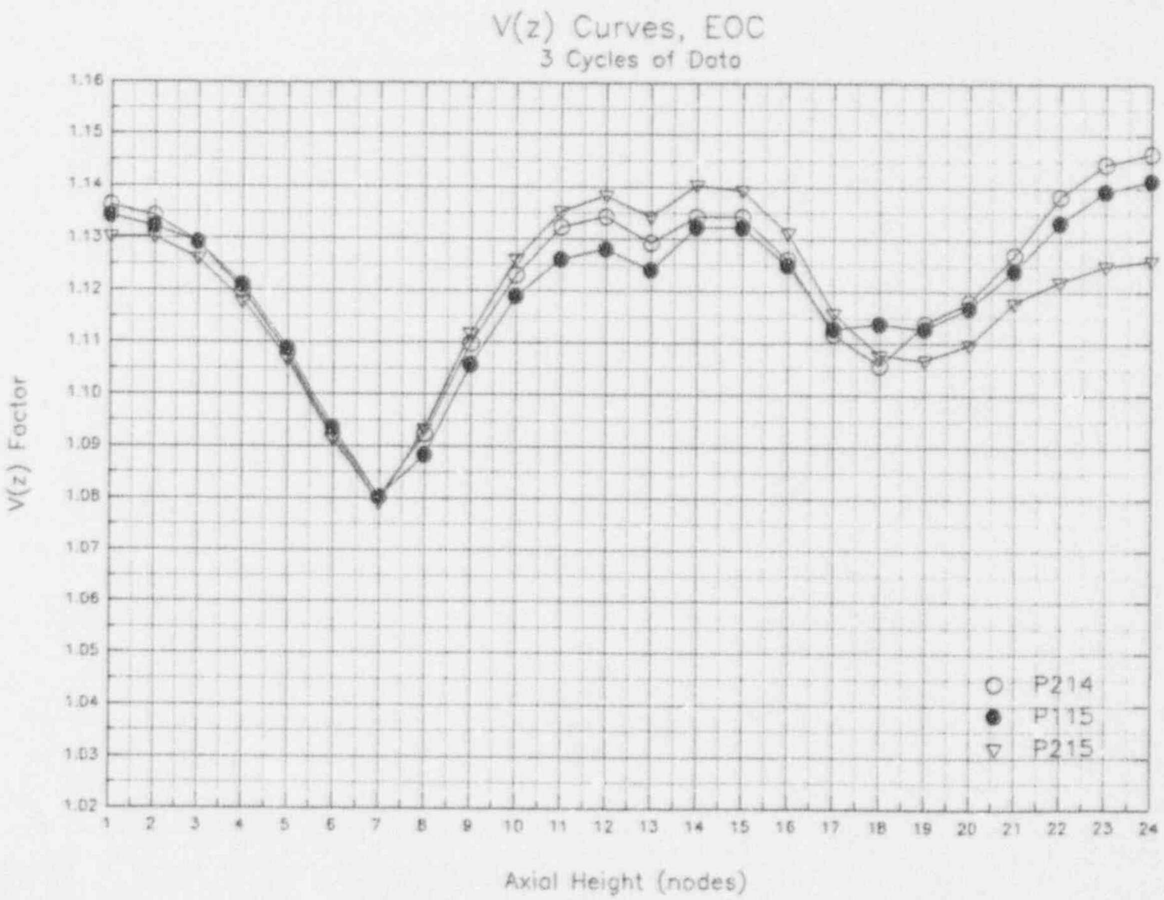
MOC E_x = a CAE of 23 GWD/MTU

EOC E_x = 150ppm boron remains at equilibrium 100% power ARO conditions.

Figure X.A

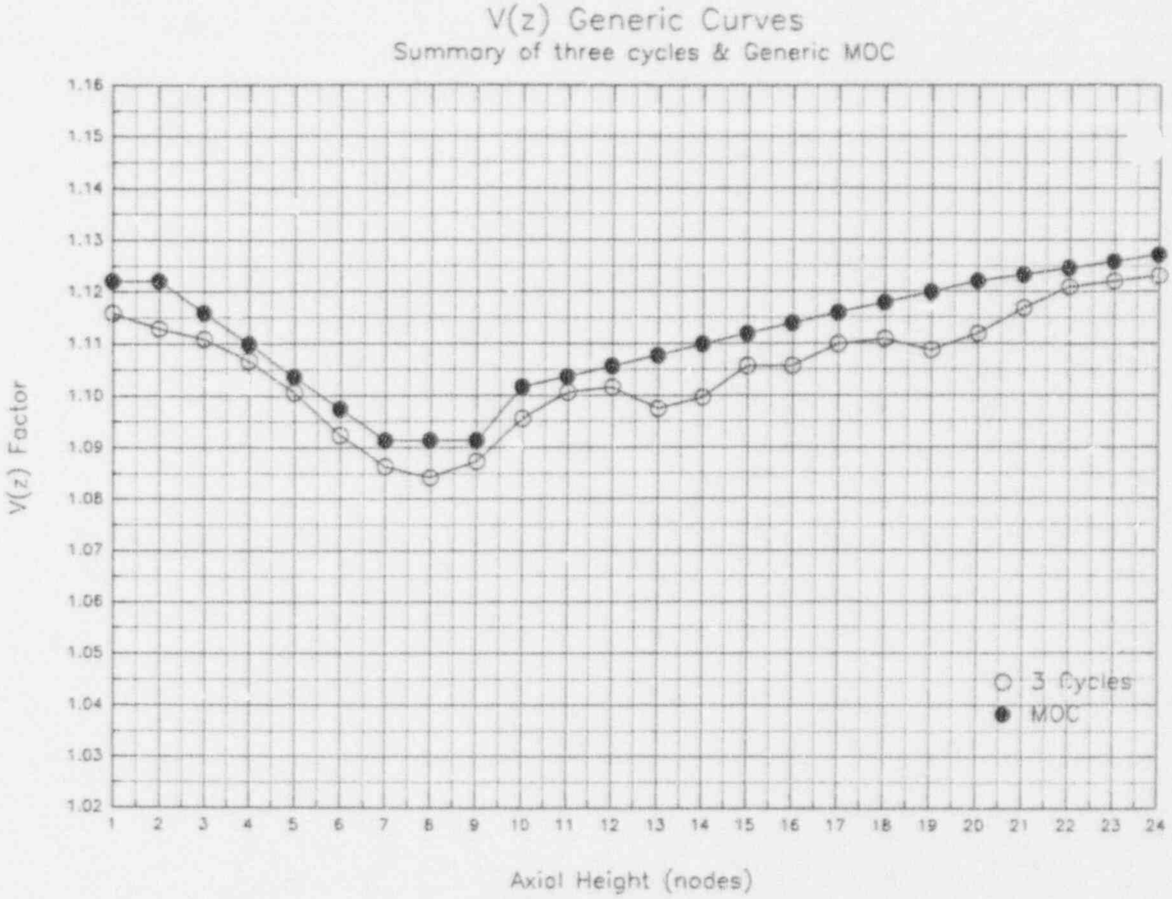


V(z) Curves, MOC
3 Cycles of Data
V(z) Factor
Axial Height (nodes)
P214
P115
P215



V(z) Curves, EOC
3 Cycles of Data
V(z) Factor
Axial Height (nodes)
P214
P115
P215

Figure X.B


V(z) Generic Curves
Summary of three cycles & Generic MOC
V(z) Factor
Axial Height (nodes)
3 Cycles
MOC

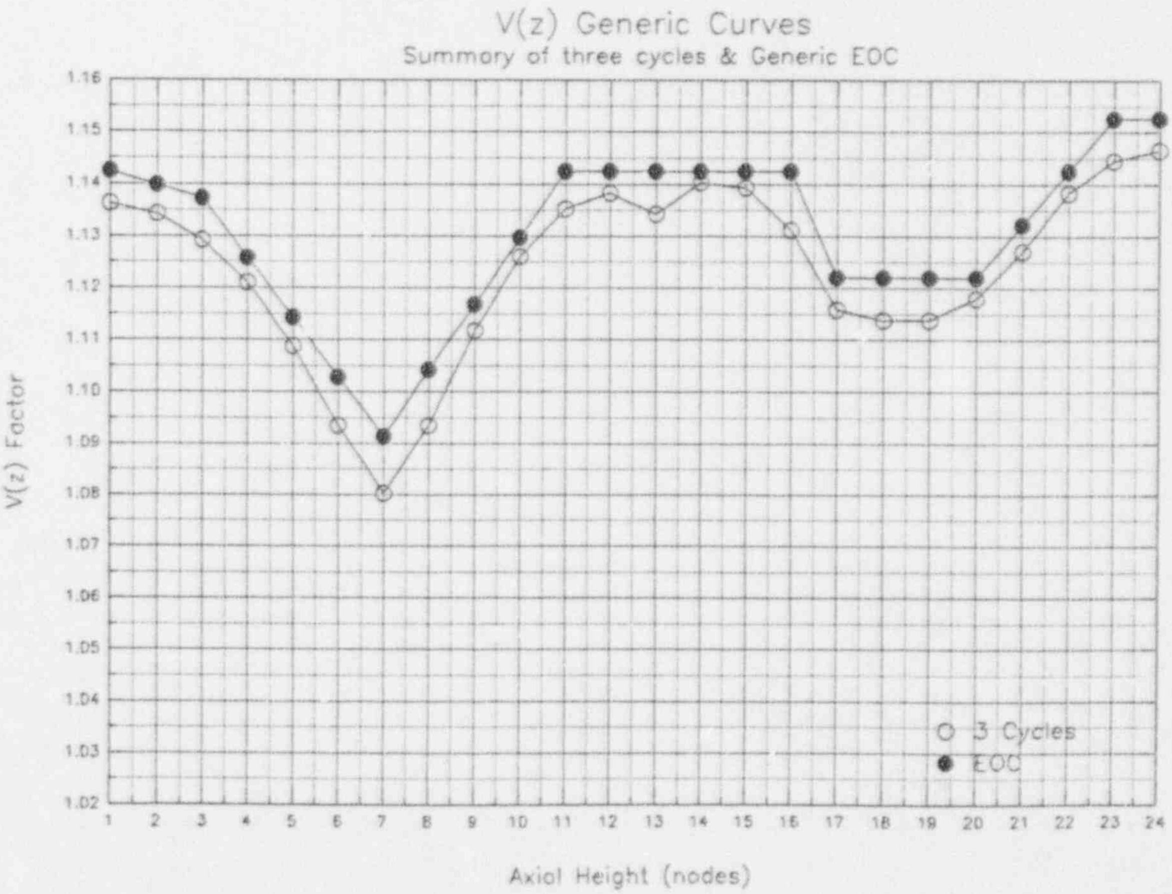
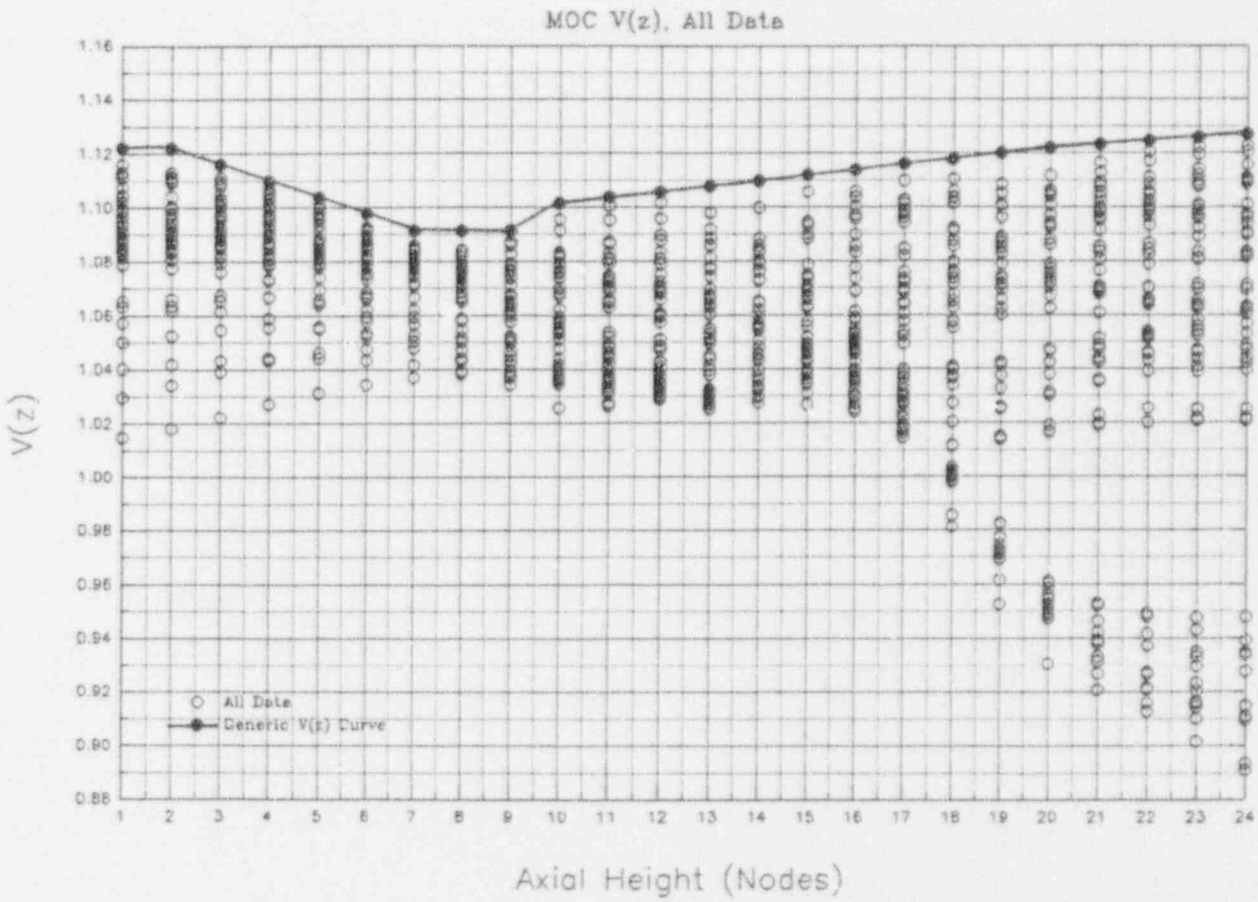
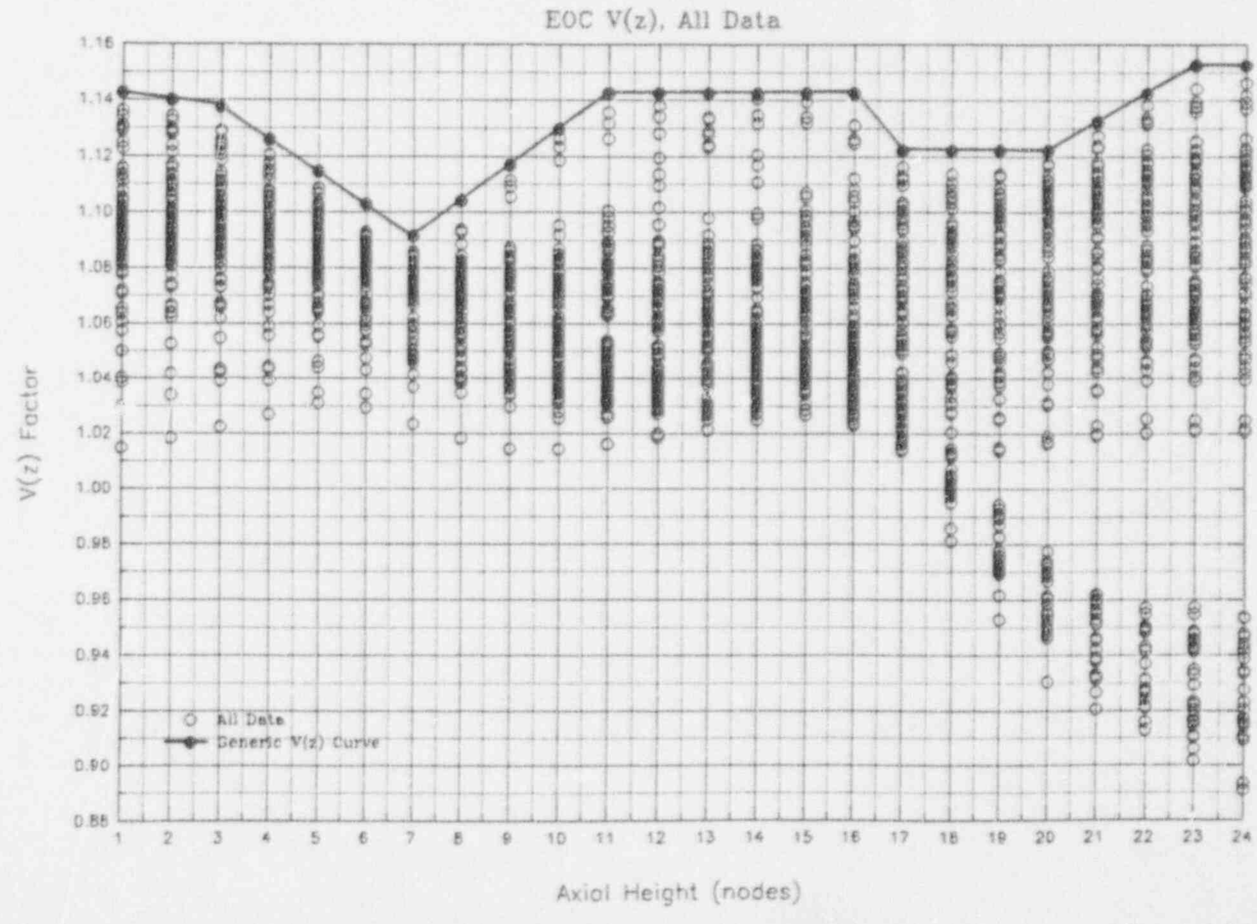
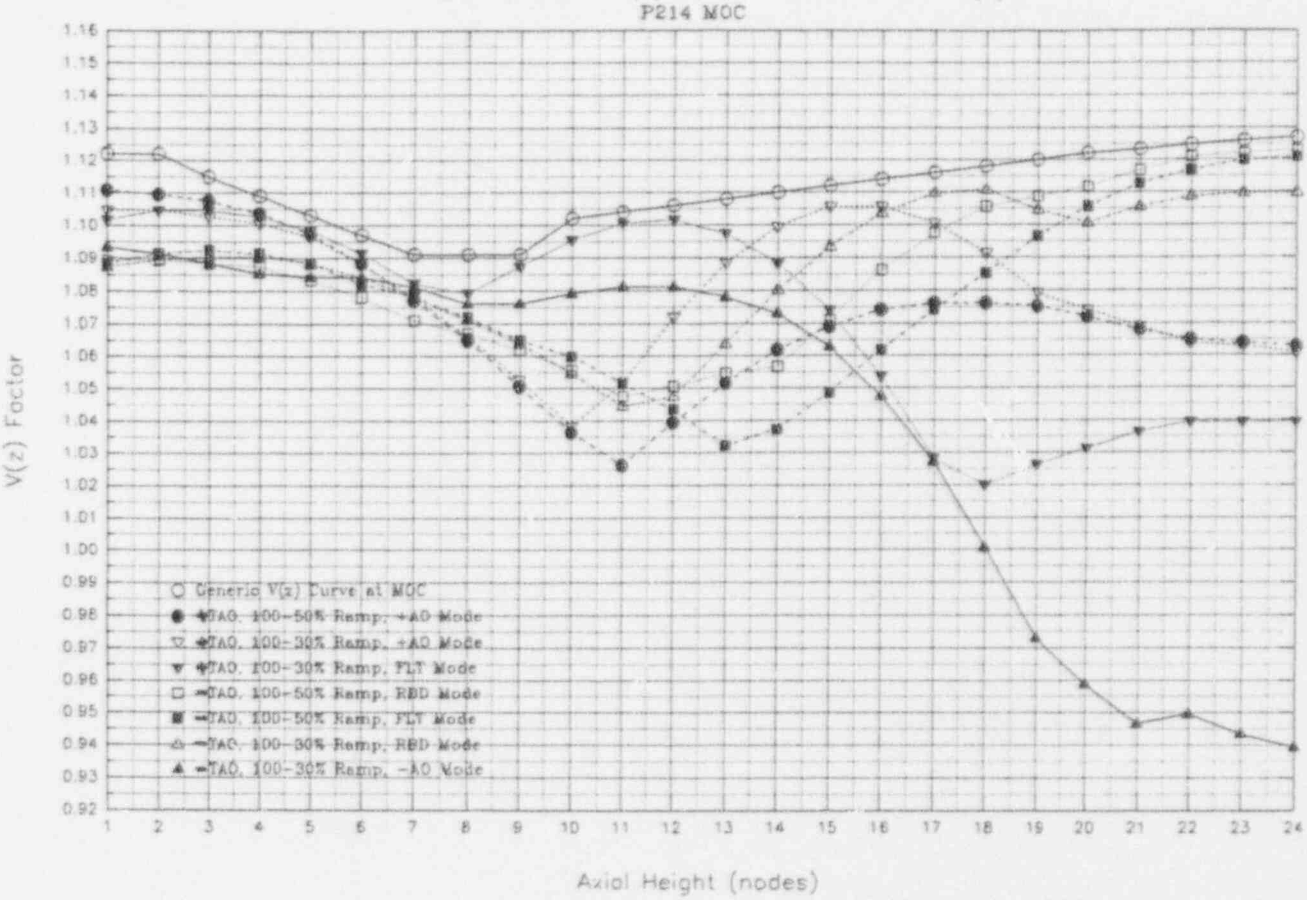

V(z) Generic Curves
Summary of three cycles & Generic EOC
V(z) Factor
Axial Height (nodes)
3 Cycles
EOC

Figure X.C

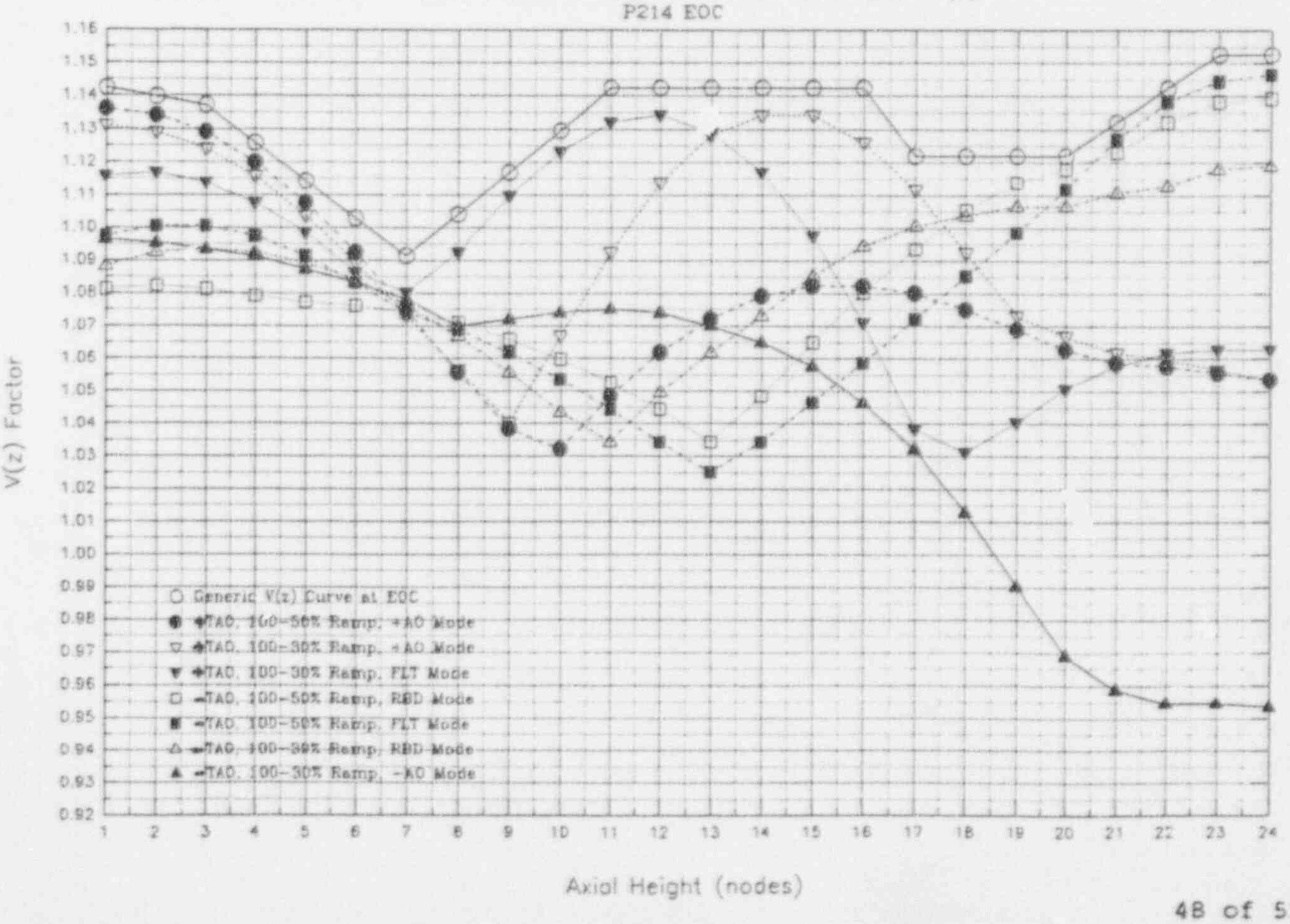

MOC V(z), All Data
V(z)
1.16
1.14
1.12
1.10
1.08
1.06
1.04
1.02
1.00
0.98
0.96
0.94
0.92
0.90
0.88
All Data
Generic V(z) Curve
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Axial Height (Nodes)

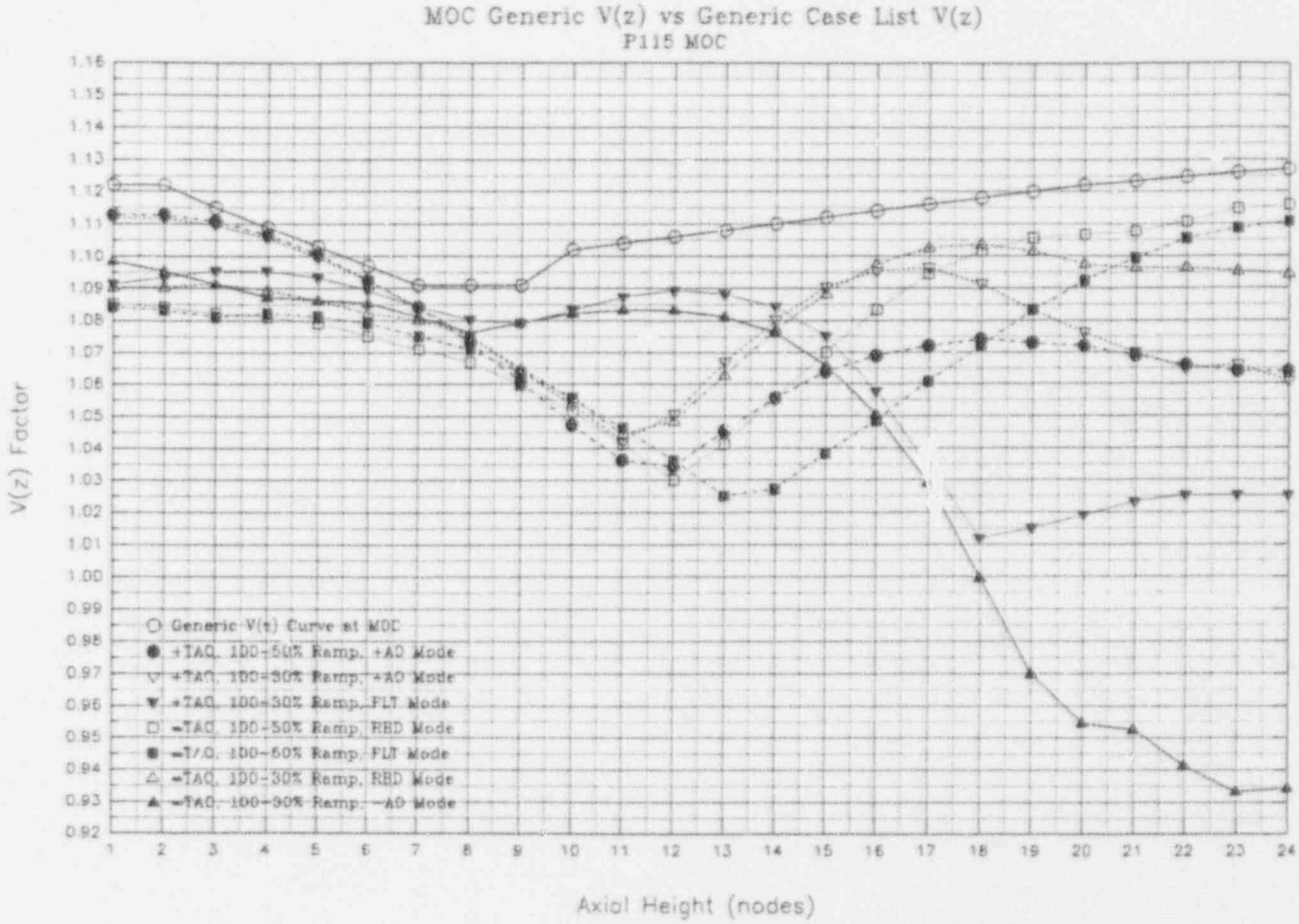

EOC V(z), All Data
V(z) Factor
1.16
1.14
1.12
1.10
1.08
1.06
1.04
1.02
1.00
0.98
0.96
0.94
0.92
0.90
0.88
All Data
Generic V(z) Curve
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Axial Height (nodes)

MOC Generic V(z) vs Generic Case List V(z)
P214 MOC



EOC Generic V(z) vs Generic Case List V(z)
P214 EOC




MOC Generic V(z) vs Generic Case List V(z)
P115 MOC
V(z) Factor
Axial Height (nodes)
Generic V(z) Curve at MOC
+TAO, 100-50% Ramp, +AO Mode
+TAO, 100-30% Ramp, +AO Mode
+TAO, 100-30% Ramp, FLT Mode
-TAO, 100-50% Ramp, RBD Mode
-TAO, 100-50% Ramp, FLT Mode
-TAO, 100-30% Ramp, RBD Mode
-TAO, 100-30% Ramp, -AO Mode

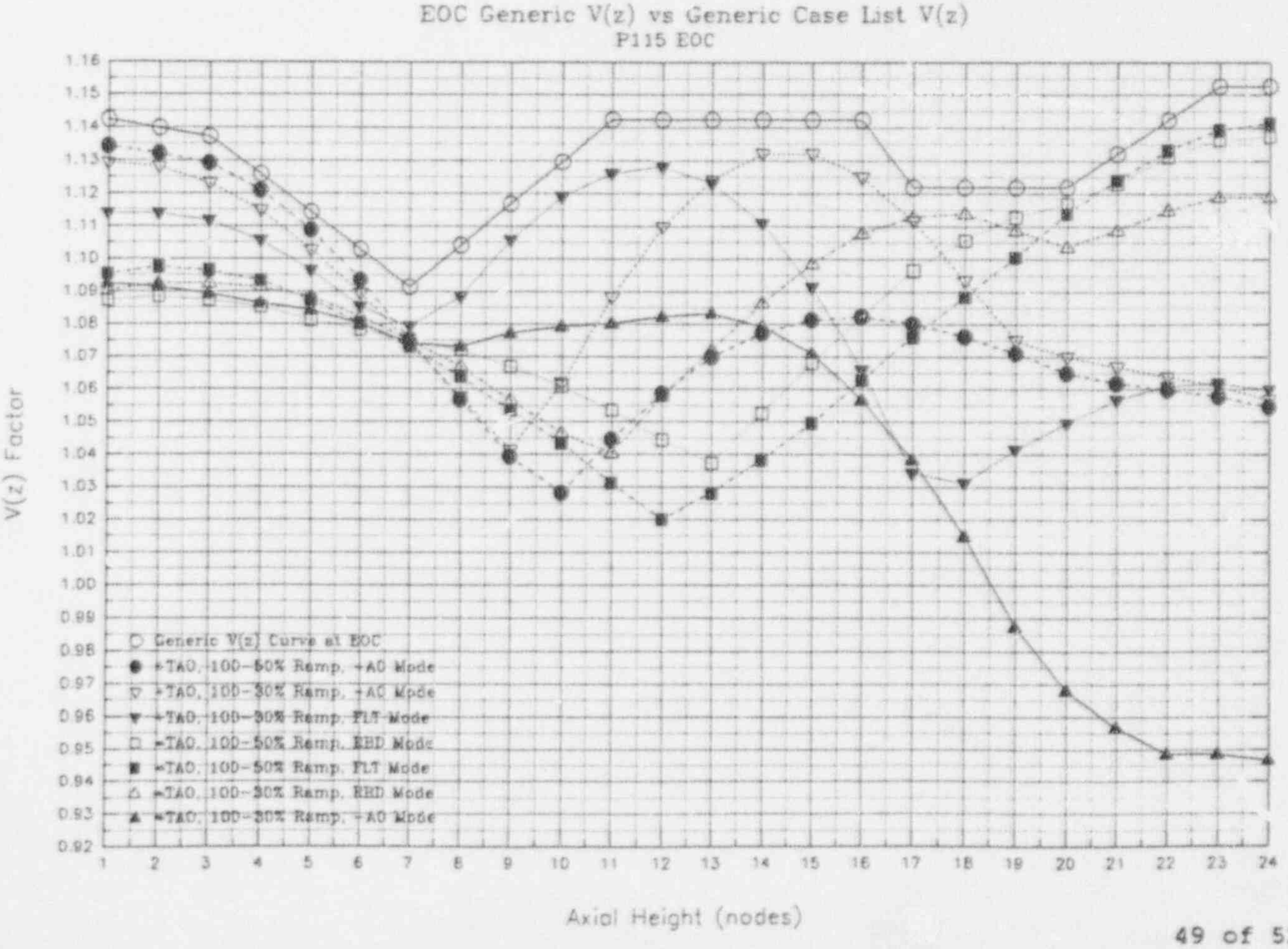
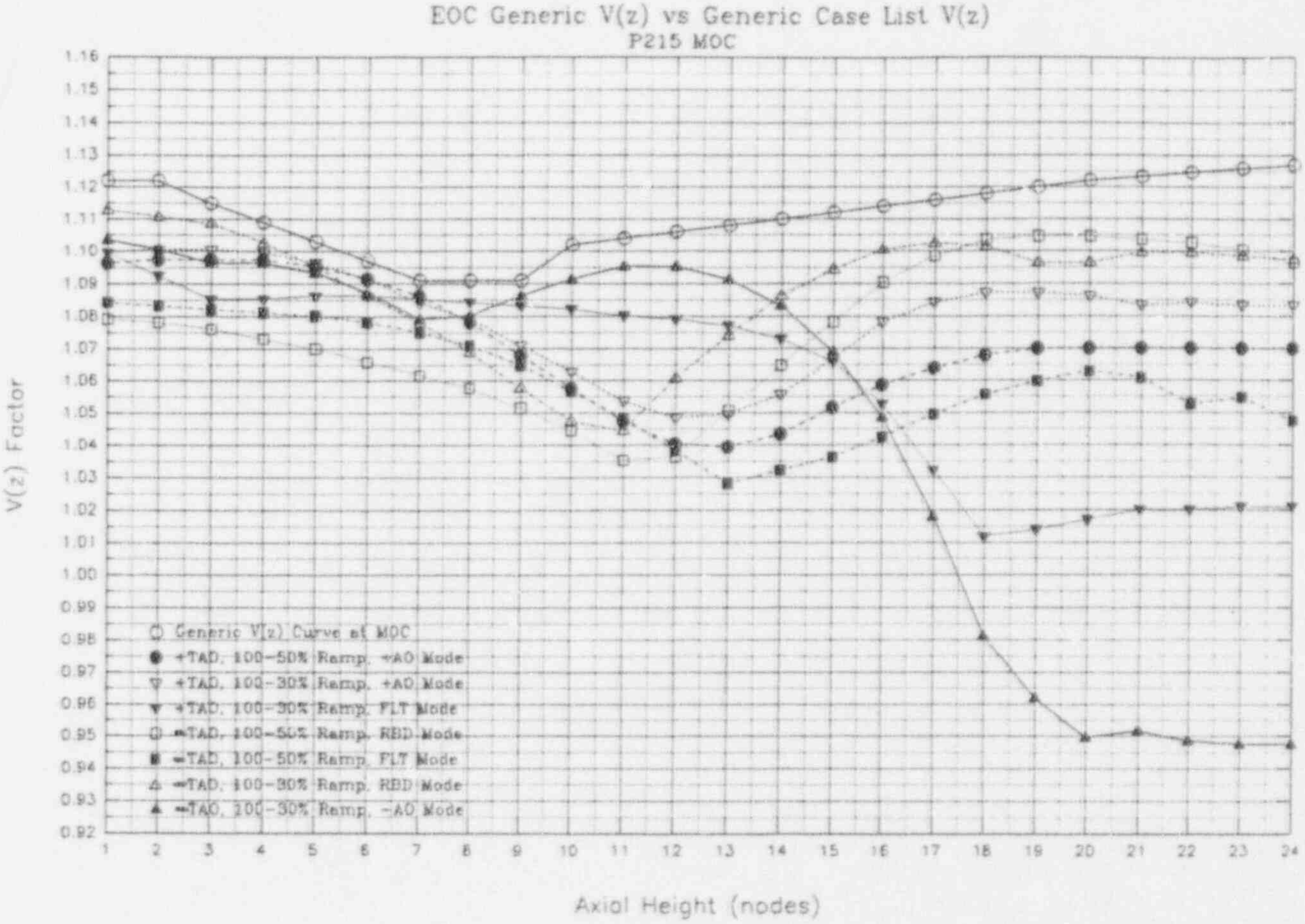

EOC Generic V(z) vs Generic Case List V(z)
P115 EOC
V(z) Factor
Axial Height (nodes)
Generic V(z) Curve at EOC
+TAO, 100-50% Ramp, +AO Mode
+TAO, 100-30% Ramp, +AO Mode
+TAO, 100-30% Ramp, FLT Mode
-TAO, 100-50% Ramp, RBD Mode
-TAO, 100-50% Ramp, FLT Mode
-TAO, 100-30% Ramp, RBD Mode
-TAO, 100-30% Ramp, +AO Mode

Figure X.F


EOC Generic V(z) vs Generic Case List V(z)
P215 MOC
V(z) Factor
Axial Height (nodes)
Generic V(z) Curve at MOC
+TAO, 100-50% Ramp, +AO Mode
+TAO, 100-30% Ramp, +AO Mode
+TAO, 100-30% Ramp, FLT Mode
-TAO, 100-50% Ramp, RBD Mode
-TAO, 100-50% Ramp, FLT Mode
-TAO, 100-30% Ramp, RBD Mode
-TAO, 100-30% Ramp, -AO Mode

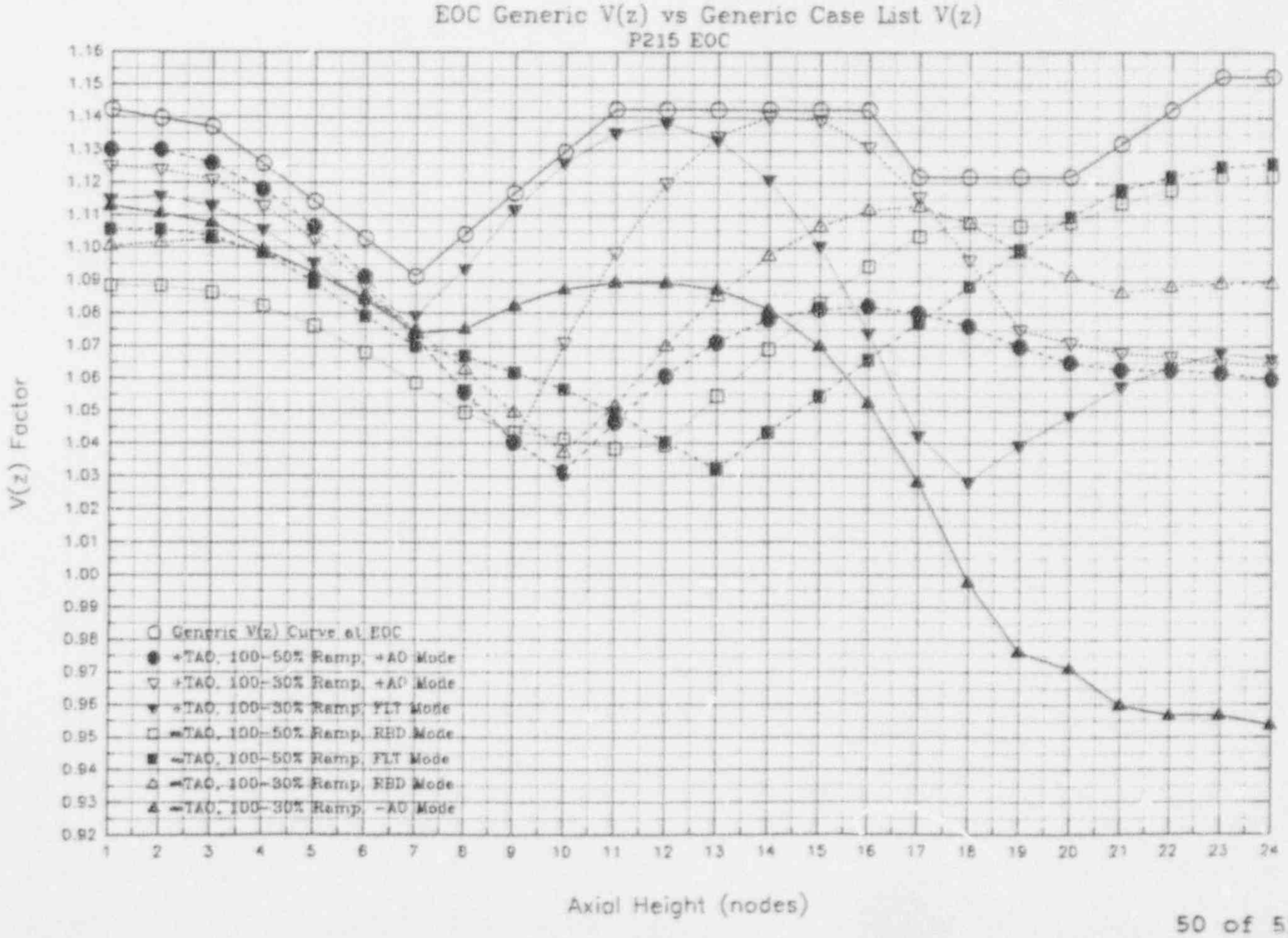
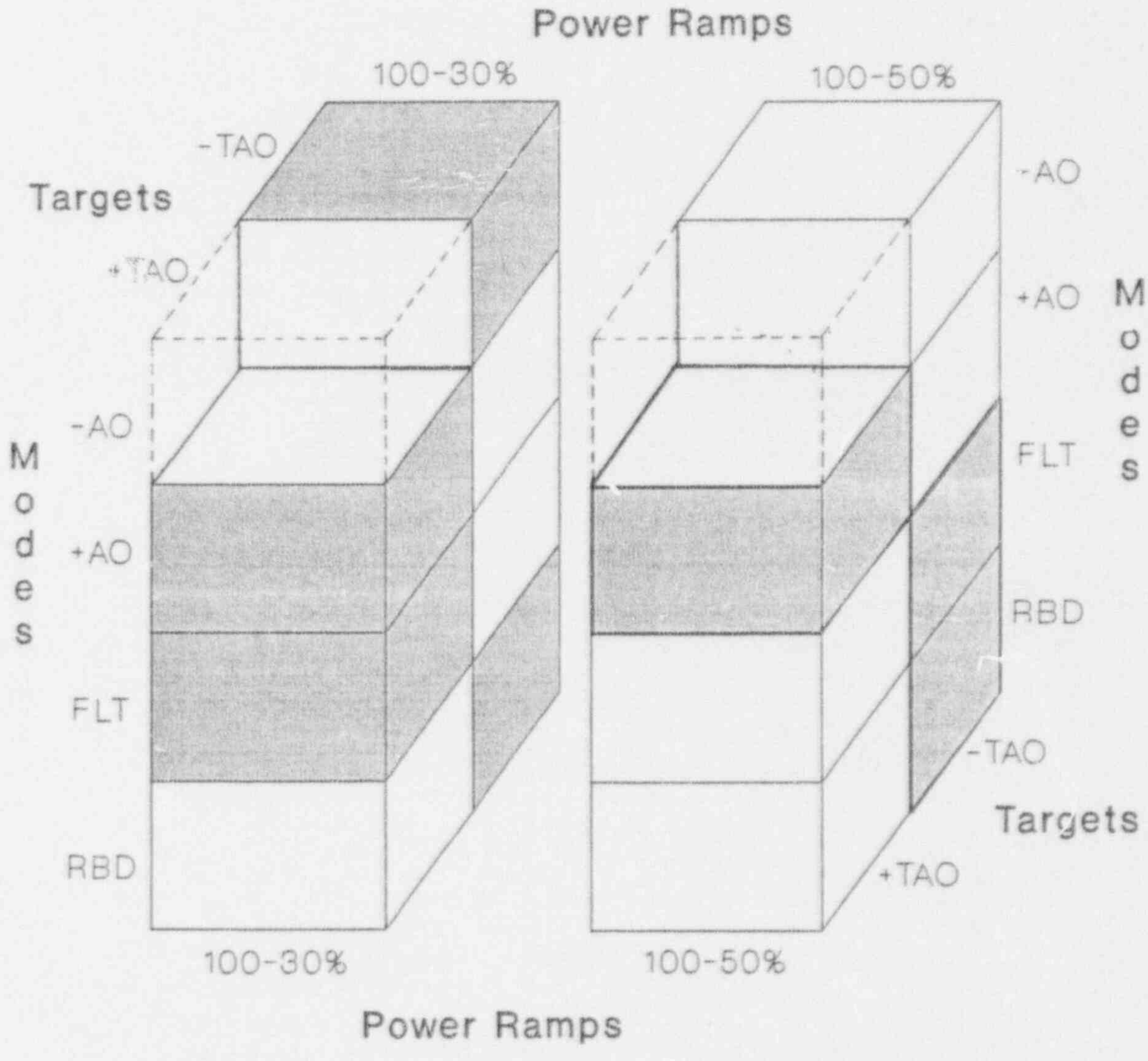

EOC Generic V(z) vs Generic Case List V(z)
P215 EOC
V(z) Factor
Axial Height (nodes)
Generic V(z) Curve at EOC
+TAO, 100-50% Ramp, +AO Mode
+TAO, 100-30% Ramp, +AO Mode
+TAO, 100-30% Ramp, FLT Mode
-TAO, 100-50% Ramp, RBD Mode
-TAO, 100-50% Ramp, FLT Mode
-TAO, 100-30% Ramp, RBD Mode
-TAO, 100-30% Ramp, -AO Mode

Figure X.G

Generic Case List

Shaded boxes represent generic case list.



XI. **TPD Analysis Summary**

The Transient Power Distribution Methodology presented within this report is intended to provide NSP with a method of generating a cycle specific or generic V(z) factor for application to equilibrium F_Q^N values to bound F_Q^N values that could be measured at non-equilibrium conditions. This methodology consists of using an industry standard "3-6-3-12" load follow scenario, two power ramps, 100-30% and 100-50%, and four operating strategies, Rebound, Float, Plus AO, and Minus AO at various TAO conditions and exposures to generate V(z) factors that bound allowable Tech Spec operating regimes.

Utilization of this methodology on a cycle specific basis is quite simple and straight forward with only three requirements;

1. The cycle specific case list be used as presented within this methodology, the "Cube" of cases (see table IX.A and Figure IX.A).
2. The cases run represent allowable Tech Spec operating conditions.
3. The analyzed Target Axial Offset values bound the measured equilibrium axial offsets over the exposure range of interest.

Utilization of this methodology on a generic basis requires the following;

1. The generic curve being used was generated from at least 3 cycles of data and that no Tech Spec changes to power distribution control strategies have occurred since the generation of the generic curve.
2. The generic case list represents the limiting cases necessary to run for qualification of the generic V(z) curve (see table X.A and Figure X.G).
3. The analyzed Target Axial Offset values bound the measured equilibrium axial offsets over the exposure range of interest.

Regardless of the case list utilized the Transient Power Distribution methodology allows the following.

1. Analysis using various reference conditions (TAO's).
2. Analysis using various exposures.
3. Analysis using various ΔI bandwidths.

Items not specifically addressed that may influence power distribution control will need to be evaluated on an item specific basis.