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VEPCO
RELAXED POWER DISTRIBUTION CONTROL METHODOLOGY and ASSOCIATED FQ SURVEILLANCE TECHNICAL SPECIFICATIONS

by

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ABSTRACT

The Virginia Electric and Power Company (VEPCO) has developed a methodology, called Relaxed Power Distribution Control (RPDC), for determining the maximum amount of axial power skewing permissible in its nuclear reactors. The RPDC methodology provides a relaxation of the current delta-I operating limits by taking advantage of margin to the design bases criteria. This methodology establishes operating limits by sampling a wide range of potential axial power profiles and determining the conditions where the design bases criteria are exceeded. These conditions define the limits of permissible operating space. Power distributions resulting from both normal (Condition I) and abnormal (Condition II) operation are analyzed.

VEPCO intends to use RPDC as the operational strategy for its nuclear units and to implement FQ Surveillance Technical Specifications that compare the measured total peaking factor (FQ), modified by a non-equilibrium operation multiplier, directly to the LOCA total peaking factor limit.

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1.0 Introduction

In response to Loss-of-Coolant Accident (LOCA) Emergency Core Cooling System (ECCS) criteria that imposed new requirements on local power peaking, Westinghouse developed the Constant Axial Offset Control (CAOC) power distribution control procedure [1]. The CAOC strategy restricts axial power skewing in the reactor core during normal operation to within a band of ±5% delta-I around a target value, determined at all-rods-out equilibrium conditions. Delta-I is defined as

$$\text{delta-I } (\%) = 100 * (Pt - Pb) \tag{1-1}$$

where Pt and Pb are the fractions of rated full-core power in the top and bottom halves of the core, respectively. This ±5% limit on axial power skewing reduces the magnitude of axial xenon oscillations which, in turn, decreases the magnitude of any power peaking during abnormal operation. VEPCO's four nuclear units presently operate under the CAOC control strategy. A typical CAOC delta-I band for North Anna or Surry is shown in Figure 1.0.1. The CAOC target value varies with burnup as the all-rods-out equilibrium delta-I changes.

Much of the low power operational flexibility of CAOC was originally centered around the use of the part length rods as a means for axial power distribution control [1]. Full length rods and boron were to be used mainly for reactivity control associated with changes in power. Since the requirement for removal of part

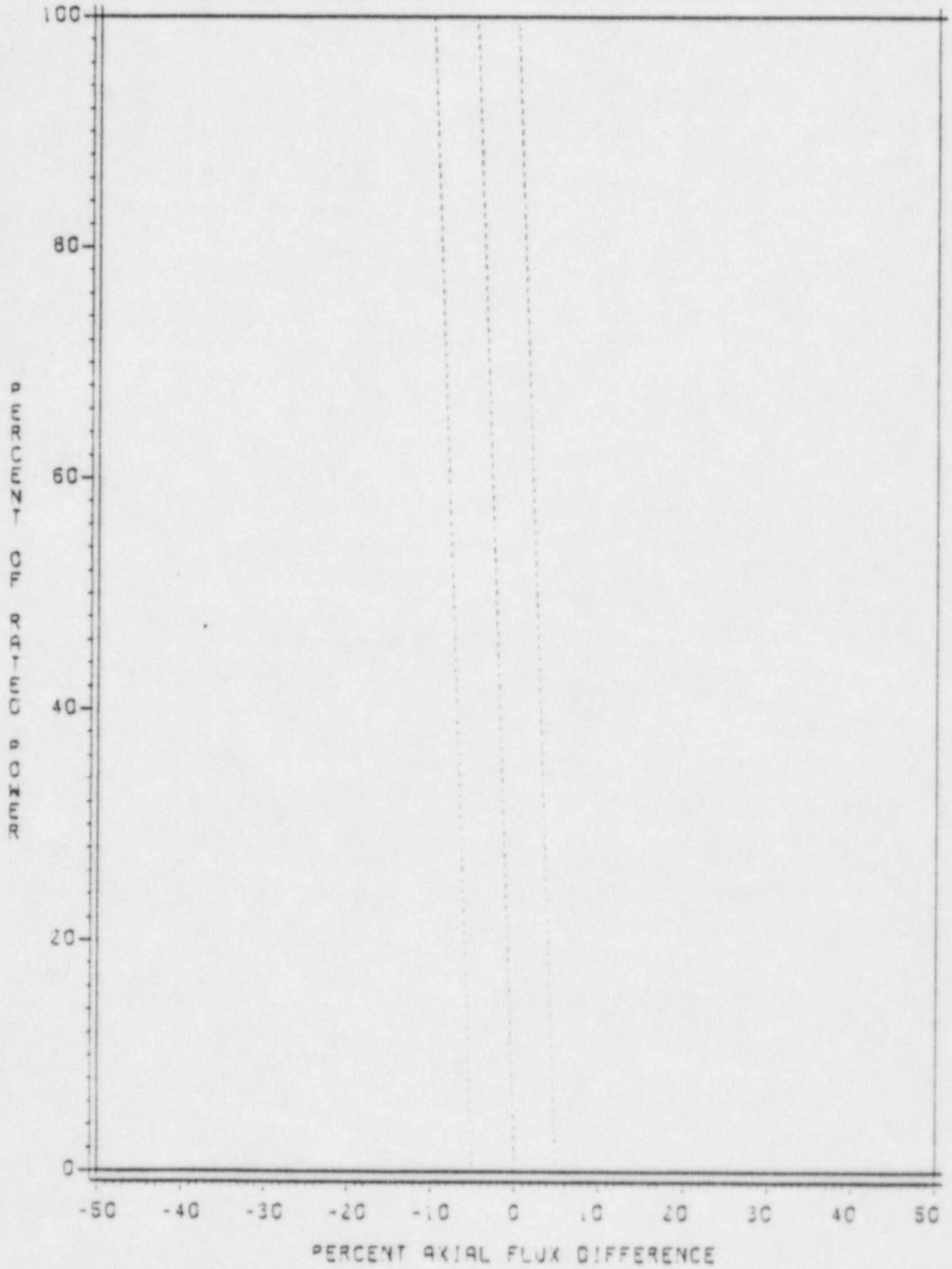

FIGURE 1.0.1 – TYPICAL CAOC LIMITS FOR NORTH ANNA AND SURRY

length rods was imposed, full length rods have had to be used to help control the axial power distributions. As a result, it became more difficult to maintain the axial power distribution within the ±5% delta-I band at low powers. This is especially true near end-of-cycle when the soluble boron concentration has been reduced to a very low level to compensate for the effects of fuel depletion and fission product buildup. Should a trip occur during this portion of the cycle, a plant may not be able to return to full power easily because of difficulty in meeting the delta-I limits. There is insufficient reactivity available from boron dilution to allow the full length rod movement required to offset the buildup of xenon and, at the same time, maintain delta-I within its band. As a result, delta-I limits could be exceeded at low power levels, requiring the plant to remain below 50% power in order to meet the "one hour in twenty-four"* requirement in the plant Technical Specifications.

Some Westinghouse CAOC plants with available full power margin to their LOCA Overall Peaking Factor (FQ) license limits have transformed this margin into operating flexibility through delta-I "band widening." In the past [2], Surry had a delta-I band width of +6, -9% about the target value. This method of gaining operational

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*The CAOC Technical Specifications impose no operational limit on delta-I while a plant operates below 50% power. However, in order to ascend above 50% power, the plant must not have exceeded the delta-I bands for more than one penalty hour of the previous twenty-four.

flexibility does provide some additional full power delta-I operating space, but offers only minimal relief for post-trip return to power at end-of-cycle conditions.

This operational restriction on delta-I imposed by CAOC can be eased by the implementation of a variable delta-I band control strategy that takes credit for the full power delta-I margin available from standard band widening while also providing for an increasing delta-I band with decreasing power. The widened delta-I band is formed by maintaining an approximately constant analysis margin to the Design Bases Limits at all power levels. This is in contrast to CAOC operation which has large amounts of margin available at reduced power. For North Anna and Surry, which have LOCA-limited total peaking factors, this variable delta-I band would be selected such that the margin to the LOCA F2*P*K(z) limit would remain approximately constant for all power levels. An example of a variable delta-I band is given in Figure 1.0.2.

The principal benefits of a variable band delta-I control strategy over current CAOC operation are as follows:

1) The ability to return to power after a trip, particularly at end-of-cycle, is enhanced;

2) Control rod motion necessary to compensate for the previous CAOC ±5% delta-I band restrictions is now reduced to only that motion needed to maintain operation within a much wider band;

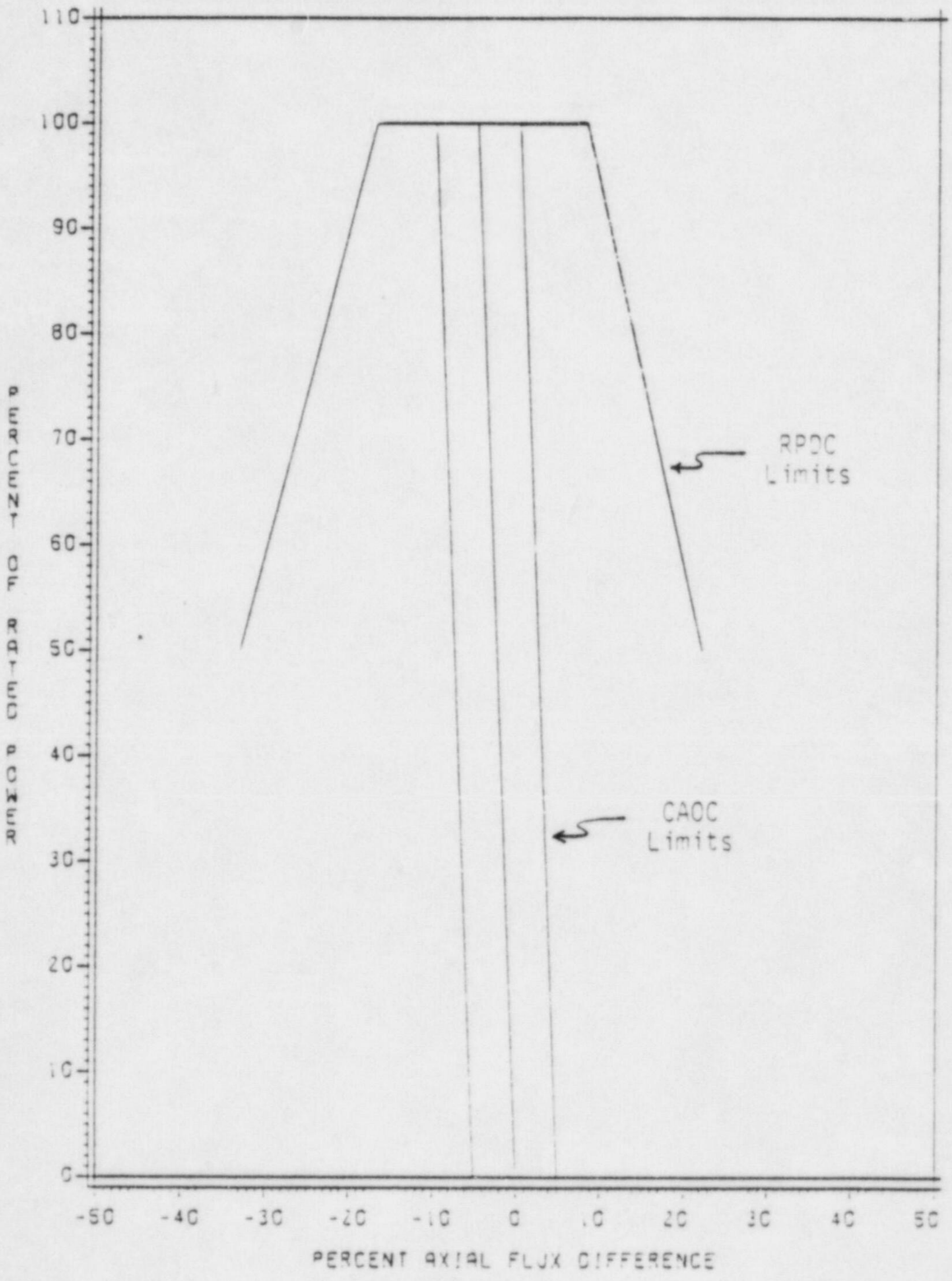

FIGURE 1.0.2 – TYPICAL VARIABLE AXIAL FLUX DIFFERENCE LIMITS

3) The reactor coolant system boration/dilution requirements are decreased, due, in part, to the reduced control rod motion;

4) The plant has enhanced operational flexibility.

The concept of widened delta-I limits at reduced power levels is not a new one. Combustion Engineering [3] and Babcock and Wilcox [4] have supported increased axial skewing at reduced power levels for their reload cores for several years. Westinghouse [5] has also recently developed and licensed a variable delta-I control statagy called RAOC (Relaxed Axial Offset Control) for application to reload cores.

VEPCO has combined some of the concepts from the Combustion Engineering methodology [3] with the current VEPCO analysis techniques [1,6] to form an alternate methodology for variable band delta-I control. This methodology is called Relaxed Power Distribution Control (RPDC). The chapters that follow will discuss the VEPCO procedure for generating the variable width delta-I band. They will also discuss the methods used to ensure that the margin to the design bases criteria, such as Departure from Nucleate Boiling (DNB), fuel centerline melt and Loss of Coolant Accident (LOCA) peak clad temperature is maintained.

This report also discusses the formulation of FQ Surveillance Technical Specifications. The current CAOC radial peaking factor Fxy(z) surveillance is replaced by FQ(z) monitoring, using the measured value of FQ(z) augmented by a non-equilibrium operation multiplier, in order to verify compliance with the LOCA peaking factors. As will be seen in Chapter 5, FQ surveillance complements RPDC to form a consistent but more flexible plant monitoring scheme than that provided by the current CAOC methods.

2.0 Analysis of Axial Shapes Which Result from Normal Operation

The objective of a RPDC analysis is to determine acceptable delta-I band limits that will guarantee that margin to all the applicable design bases criteria has been maintained and, at the same time, will provide enhanced delta-I operating margin over CAOC. Because the RPDC delta-I band is an analysis output quantity rather than a fixed input limit, as in CAOC, axial shapes which adequately bound the potential delta-I range must be generated. These axial shapes must include the effect of all potential combinations of the key parameters such as burnup, control rod position, xenon distribution, and power level. VEPCO has developed the methodology of Section 2.1 to analyze the large number of axial shapes included in RPDC.

After the axial power shapes have been created, two separate allowable delta-I limits for normal operation are established: one based on LOCA FQ considerations and the other one based on a Loss of Flow (the limiting DNB transient) thermal/hydraulic evaluation. The methods used are described in Sections 2.2 and 2.3, respectively. These two separate delta-I bands are combined to form a composite delta-I limit as discussed in Section 2.4.

2.1 Axial Shape Generation

The axial power distributions encountered during normal operation (including load-follow) are primarily a function of four parameters: the xenon distribution, power level, control rod bank position and burnup distribution. For RPDC, reasonable incremental variations that span the entire expected range of values must be considered for each of these parameters. The following method is used to create the axial power distributions needed for the development of the RPDC normal operation delta-I limits.

2.1.1 Axial Xenon Distributions During Normal Operation

The axial xenon distribution is a function of the core's operating history and, as a result, is constantly changing. In order to analyze a sufficient number of xenon distributions to ensure that all possible cases have been accounted for, a xenon "free oscillation" method similar to the one described in Reference 3 is used to form these distributions. By creating a divergent xenon-power oscillation, axial xenon distributions can be obtained that will be more severe than any experienced during normal operation, including load follow maneuvers.

To initiate a xenon-power oscillation, an equilibrium 1-D model [7] of the reload cycle is perturbed. This perturbation will generally be in the form of a change in power, rod position, or both. However, since the core model may be inherently stable due to the presence of feedback mechanisms, these mechanisms must either be modified or bypassed to obtain a divergent oscillation. One way to accomplish this is to reduce the stability of the model by reducing the amount of Doppler (i.e., fuel temperature) feedback in the system. The divergent oscillation provides a spectrum of xenon distributions that will produce power distributions with delta-I values covering the expected delta-I range. The magnitude of the "free oscillations" should be such that the xenon distributions (when combined with normal operating conditions) produce axial power shapes with delta-I values that bound the expected operating limits.

The stability of the calculational model may vary with burnup or core loading. Therefore, the amount of perturbation and feedback modification necessary to achieve a divergent xenon oscillation may vary with cycle burnup or core loading. Typical examples are given in Figures 2.1.1 and 2.1.2 for beginning- and end-of-cycle, respectively. The VEPCO NOMAD [7] 1D diffusion code was used to perform these calculations. These particular oscillations were initiated by reducing power, depleting for several hours and then returning to full power for an additional 100 hours of depletion.

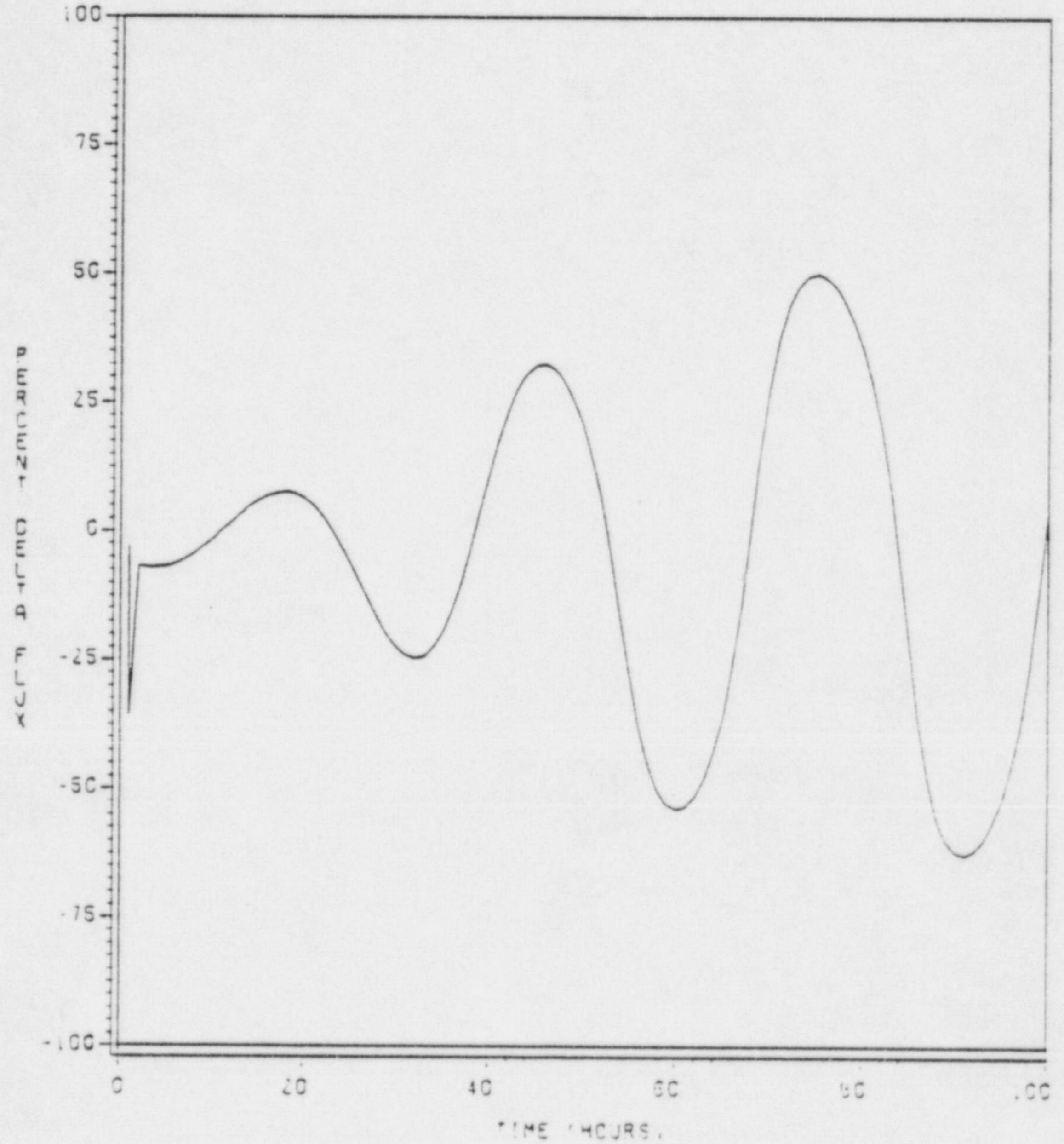

FIGURE 2.1.1 - TYPICAL RPDC BOC XENON OSCILLATION

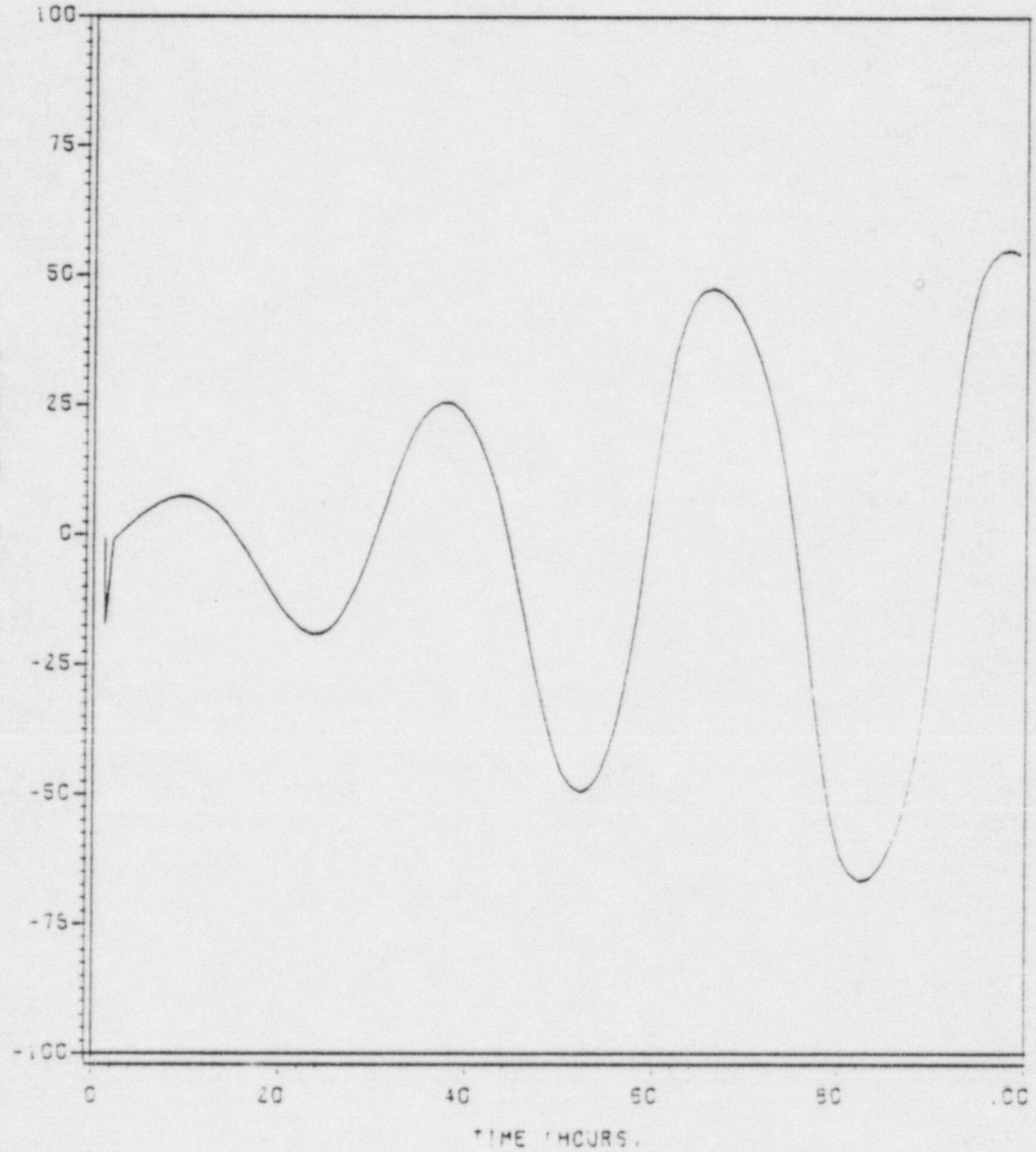

FIGURE 2.1.2 – TYPICAL RPDC EOC XENON OSCILLATION

2.1.2 Power Level During Normal Operation

For the normal operation analysis, power levels spanning the 50% to 100% range are investigated to establish the RPDC delta-I limits. This range is consistent with the current CAOC Technical Specifications which do not impose axial flux difference limits or require CAOC operation below 50% of full power.* The power levels used for RPDC analysis are selected at increments within the 50% to 100% range which are small enough to ensure an adequate number of power distributions are being analyzed; i.e. that all safety-related effects due to the power level are accounted for.

2.1.3 Control Bank Position During Normal Operation

During normal operation, the control rod bank insertion is limited by the Technical Specification rod insertion limits. Figure 2.1.3 gives a set of typical rod insertion limits. The insertion limits are a function of reactor power, and the rods may be anywhere between the fully withdrawn position and the variable insertion limit. In order to adequately analyze the various rod positions allowed, control rod insertions versus power level are selected which cover the range of rod insertions allowed for each particular power.

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* See the footnote on page 9.

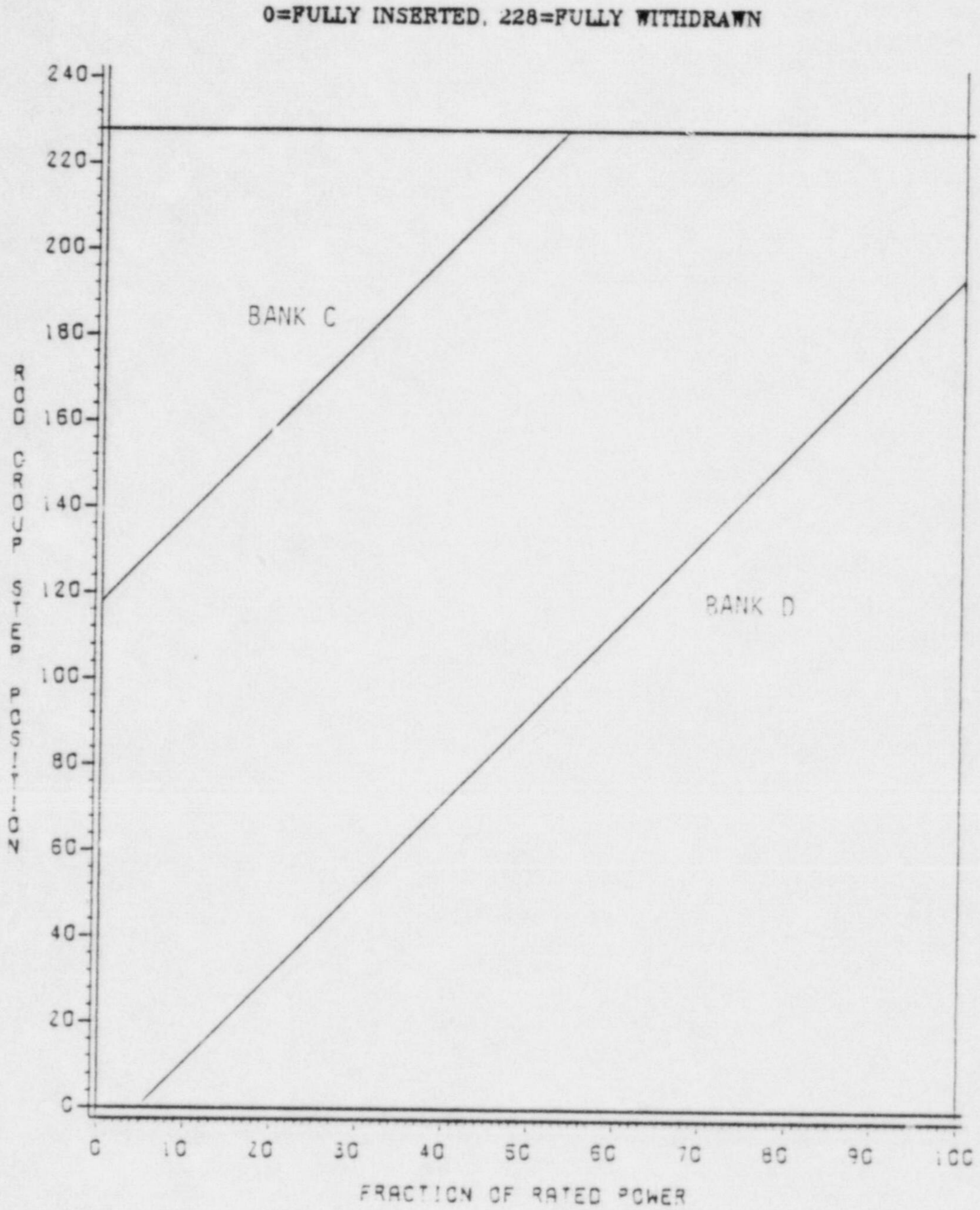

FIGURE 2.1.3 – NORTH ANNA ROD INSERTION LIMITS

2.1.4 Cycle Burnup

The RPDC analysis is performed at several times in cycle life in order to provide limiting delta-I bands for the entire cycle. Typically, three cycle burnups, near beginning-of-cycle (BOC), middle-of-cycle (MOC) and end-of-cycle (EOC), are chosen for the RPDC analysis. The MOC case is chosen to reflect the maximum middle-of-cycle radial peaking factors.

2.1.5 Combining Xenon Shapes, Rod Position, Power Level and Burnup

The final power distributions used in the RPDC normal operation analysis result from combining axial xenon shapes, power levels, rod insertions and cycle burnups. At each selected time in cycle life, the xenon shapes are combined with each power level and rod configuration. A criticality search is then performed for each case using the NOMAD code with normal feedback. Each calculated axial power distribution is stored for use in the LOCA FQ and thermal/hydraulic evaluations discussed in Sections 2.2 and 2.3. The combinations of burnups, power levels, rod configurations and xenon distributions typically evaluated on a reload basis are summarized in Table 2.1.1. The conditions result in a delta-I range of approximately -60% to +50%, bounding the expected final delta-I envelope at all power levels. The combinations of rod insertions and power levels necessary for Surry and North Anna would be slightly different due to the difference in rod insertion limits between the two plants.

TABLE 2.1.1

TYPICAL CONDITIONS ANALYZED FOR

NORMAL OPERATION UNDER RPDC

Cycle Burnups	BOC, MOC, EOC
Xenon Shapes	100 for each time in life
Power Level Range (%)	50-100
Rod Insertions Range Versus Power:	See Figure 2.1.3

(3 burnups) * (100 xenon shapes) * (30 power level/rod position combinations) = 9000 shapes

2.2 LOCA Delta-I Limit Formation

The axial shapes created in Section 2.1 are combined with Fxy(z) data using a standard 1D/2D/3D FQ synthesis [1,7]:

$$FQ(z) = Fxy(z) * P(z) * Xe(z) * FNU * FQE * FGR \quad (2-2)$$

where the following are non-dimensional parameters:

- Fxy(z) = Fxy distribution calculated by FLAME [8] and PDQ07 [9]; dependent upon burnup, core height, rod position and power level
- P(z) = Axial power shape function generated by NOMAD [7]
- Xe(z) = The radial xenon redistribution factor
- FNU = Nuclear uncertainty factor [11]
- FQE = Engineering heat-flux hot-channel factor [11]
- FGR = Grid correction factor [7]

The axially varying radial xenon factor, Xe(z), compensates for increases to FQ(z) resulting from redistribution of the xenon in the radial plane due to rod movement. The radial xenon redistribution effect cannot be explicitly represented in a 1D code and is therefore applied in the synthesis as an uncertainty factor. Xe(z) is calculated as follows:

$$Xe(z) = \frac{\max Fxy(z)T}{Fxy(z)E} \quad (2-3)$$

where Fxy(z)T is the Fxy(z) calculated from a transient resulting in xenon radial redistribution and Fxy(z)E is the Fxy(z) based upon an equilibrium xenon distribution. Fxy(z)T is calculated with the

3D FLAME code by first pre-conditioning the radial xenon distribution for several hours with the core at reduced power and the control rods inserted sufficiently to drive delta-I to the negative edge of the expected band. By withdrawing the rods and increasing power a xenon transient is created. This transient will cause the xenon to redistribute radially as well as axially in the 3D model. Fxy(z)T is calculated for each time step as this transient is followed in small time intervals. The maximum values of Fxy(z)T for the entire transient are used in equation (2-3) to determine Xe(z).

The synthesized FQ*Power for each shape is compared to the LOCA FQ*Power*K(z) limit at each power level to determine which axial shapes approach the LOCA limit, thereby establishing a preliminary allowable delta-I versus power band. This comparison replaces the traditional CAOC FAC analysis [1] and ensures that the margin to the LOCA FQ*Power*K(z) envelope is maintained during the cycle as long as reactor operation remains within the delta-I limits. A typical LOCA delta-I limit is shown in Figure 2.2.1.

A sensitivity study to examine the impact of a change in FQ on the width of the LOCA delta-I limits determined that a change of 1% increase in FQ results in less than a 1% decrease in delta-I at constant power. This conclusion is based on the analyses of a range of FQ values for VEPCO plants using the methods just described.

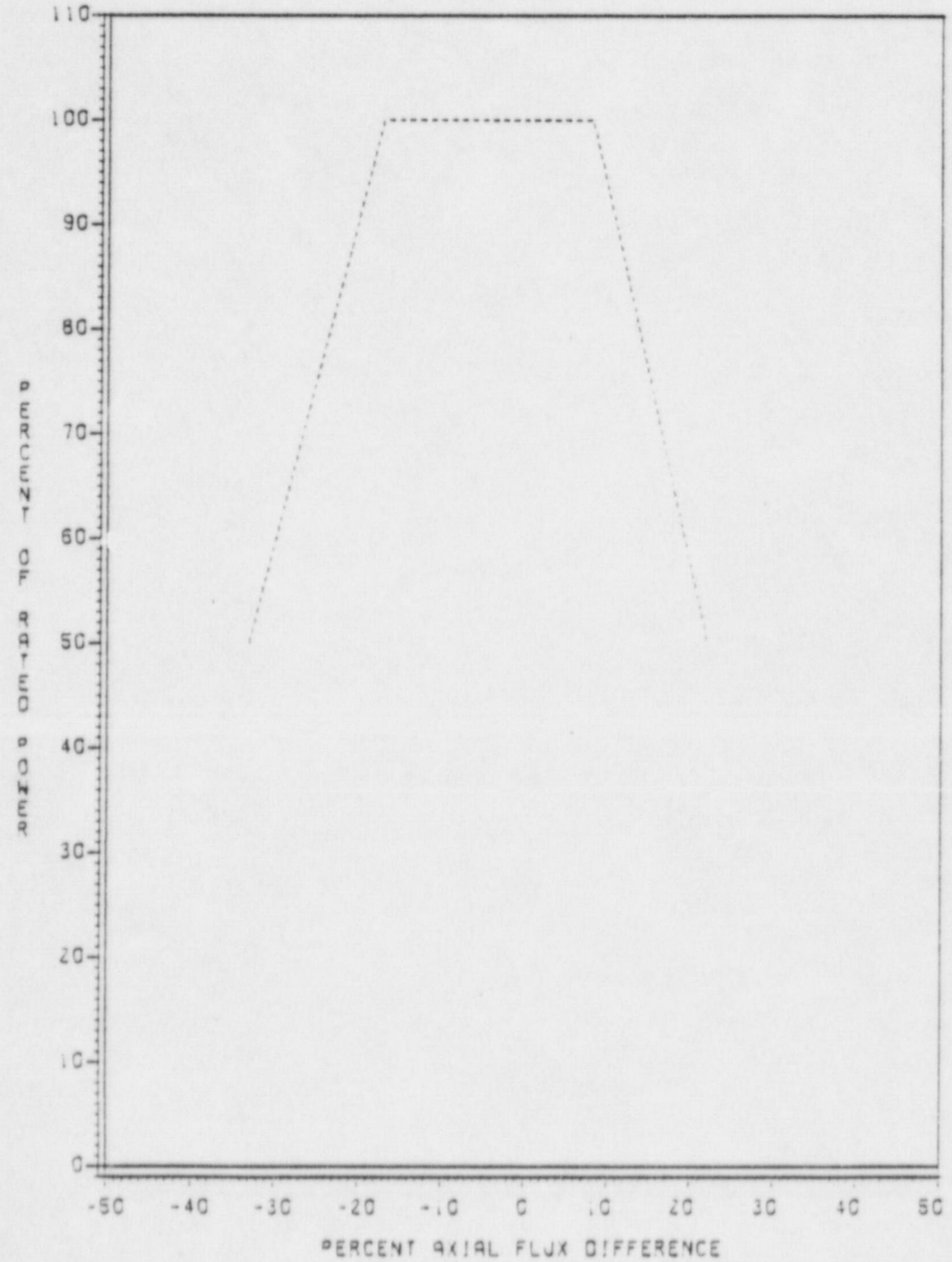

FIGURE 2.2.1 – TYPICAL LOCA DELTA-I LIMITS

2.3 Loss of Flow Thermal/Hydraulic Evaluation

The Loss of Flow Accident (LOFA) represents the most limiting DNB transient not terminated by the Overtemperature Delta-T trip. In order to ensure the applicability of the current LOFA analysis, the entire set of axial power distributions formed by the RPDC normal operation analysis are evaluated against the 1.55 cosine design axial power distribution for the Loss of Flow Accident analysis with the COBRA [10] code. The thermal/hydraulic evaluation methods used in this LOFA evaluation are similar to those of the present CAOC techniques. As a result of this LOFA comparison, a second set of delta-I versus power limits is formed. These delta-I limits delineate the allowable operating band which will ensure that the margin to the DNB design base for LOFA is maintained. The impact of RPDC on other DNB transient events is discussed in Chapter 3.

2.4 Final Normal Operation Delta-I Limit

The results of the LOFA delta-I limit generation are combined with the LOCA delta-I limits (Figure 2.2.1) to produce a set of limits which will ensure that the preconditions for both accidents are met. This set of composite cycle-specific delta-I limits will be made more restrictive than necessary for the first-time analyses in order to bound upcoming reload cycles and minimize future Technical Specification changes. These generic limits will be verified on a cycle-by-cycle basis using the RPDC methods described in this report.

The LOCA FQ based delta-I limits are generally more restrictive than LOFA-based delta-I limits for VEPCO's plants. This will allow the plant Technical Specifications to take advantage of the FQ versus delta-I sensitivity identified in Section 2.2 (see Appendix A.2).

3.0 Analysis of Axial Shapes Which Result from Condition II Events

One of the important features of any axial power distribution control strategy (RPDC, CAOC or any other) is the clear distinction between normal and accident conditions. The delta-I limits established in Chapter 2 and the Technical Specification control rod insertion limits (see Figure 2.1.3) define conditions of normal operation. If the axial power distribution (as measured by delta-I) remains inside the pre-established band during all normal operation, and the control rods remain within the Technical Specification limits, then the margin to the design criteria of fuel centerline melt, DNB and LOCA peak clad temperature, will be maintained.

This chapter examines Condition II or Abnormal Operation events, which may be the result of system malfunctions or operator errors and create reactor conditions that fall outside the bounds analyzed in Section 2. The RPDC analysis examines the more limiting of these Condition II events and confirms that the Overpower Delta-T (OPDT) and the Overtemperature Delta-T (OTDT) setpoints* have been conservatively calculated and ensures that margin to the fuel design limits is maintained. These setpoints are verified on a cycle-by-cycle basis.

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* The OPDT and OTDT setpoints were designed primarily to provide transient and steady state protection against fuel centerline melt and DNB, respectively.

3.1 Determination of Accident Pre-Conditions

Initial condition parameters for Condition II analysis are determined from the core conditions allowed by the normal operation delta-I versus power envelope. These conditions are a function of rod control cluster (RCC) position, boron concentration, xenon distribution, burnup and core power level. Any set of these conditions which produce an axial power distribution within the normal operation delta-I envelope established in Chapter 2 (Figure 2.2.1) can be a potential starting point for a Condition II accident. Each set of valid normal operation conditions is considered in the RPDC Condition II analyses.

3.2 Condition II Accident Simulation

Three categories of credible accidents bound the range of abnormal operation events which must be considered in terms of their effect upon the axial power distribution or local power peaking. These three accidents are rod withdrawal, excessive heat removal and erroneous boration/dilution. The rod withdrawal and boration/dilution events [1] are the most limiting Condition II events with respect to the impact of control rod position on the axial power distribution or local power peaking. In the excessive heat removal event the impact of temperature is investigated.

3.2.1 Uncontrolled Rod Withdrawal Event

The rod withdrawal event [6] is an erroneous control rod withdrawal starting from a normal operation condition with the control banks operating in their normal overlap sequence. To perform the analysis of this accident, the xenon distribution and boron concentration are fixed at values allowed by the normal operation analysis. The lead control bank is then withdrawn in increments from the fully inserted to the fully withdrawn position. After each incremental movement a criticality search is performed with the NOMAD code [7] and the axial power distribution is saved for use in the Condition II evaluation of Sections 3.3 and 3.4. The analysis is limited to those cases producing power levels between 50% of rated power and the high flux trip limit.

3.2.2 Excessive Heat Removal Event

The Excessive Heat Removal (or cooldown) event, like the rod withdrawal event, is an overpower accident. The accident assumes a decrease in the reactor core inlet temperature as a result of a sudden load increase, steam-dump valve opening, excessive feedwater flow or a turbine valve opening [6]. Since the control rods are assumed to be in manual control for this event, they will remain at their original position, which allows the reactor power to increase.

To simulate this accident, allowable normal operation xenon distributions, control rod positions and boron concentrations are provided as input to the NOMAD code [7]. The inlet temperature is reduced and a criticality search is performed. The axial power distribution from each case is saved for use in the Condition II evaluation of Sections 3.3 and 3.4. Reduction of the inlet temperature is limited to 30°F, which has been shown to bound the results of the above accidents in the Surry and North Anna FSAR's [12-13]. Cases producing a power level greater than the high flux trip limit are excluded from consideration.

3.2.3 Boration/Dilution

The Boration/Dilution event causes a movement in the control rods to compensate for the reactivity changes due to a change in soluble boron concentration as a result of inadvertent boration or dilution. In this analysis the control banks are assumed to be in automatic mode and to operate in a normal overlap sequence. The manual mode of operation could result in an overpower transient during a dilution incident. However, the consequances of this event are bounded by those of the rod withdrawal accident [6].

To perform the boration/dilution analysis, NOMAD reads each allowable xenon distribution from the Condition I analysis and runs a series of cases inserting the rods from fully withdrawn to the insertion limits in fixed increments. At each step a criticality search is performed. Once the rods reach the insertion limits, a rod position search is performed to determine the amount of control rod insertion necessary to compensate for the reactivity associated with a dilution of fifteen minutes. The rods are then stepped in from the insertion limits to the determined rod position, again performing criticality searches. All axial power distributions from the boration/dilution event are saved for the Condition II evaluation of Sections 3.3 and 3.4.

3.3 Overpower Limit Evaluation

The axial power distributions and power levels produced by the Condition II accident simulations are combined with calculated Fxy(z) data using the FQ synthesis techniques as described in Section 2.2 (with the addition of the densification spike factor S(z)) to determine the maximum linear power density for each distribution. The results are generally plotted in the "flyspeck" format shown in Figure 3.3.1, which shows typical results for the three limiting Condition II accidents described in Section 3.2.

The peak power density "flyspeck" is compared to the design basis limit for fuel centerline melt. If necessary, the OPDT f(delta-I) function (which provides protection against this design limit) is modified to ensure that margin to the fuel centerline melt limit is maintained. If needed at all, this modification would be required only for very large values of delta-I. An alternative approach would be to maintain the margin to fuel centerline melt by restricting the OTDT f(delta-I) function beyond the DNBR requirement, effectively eliminating the need for the OPDT f(delta-I) function.

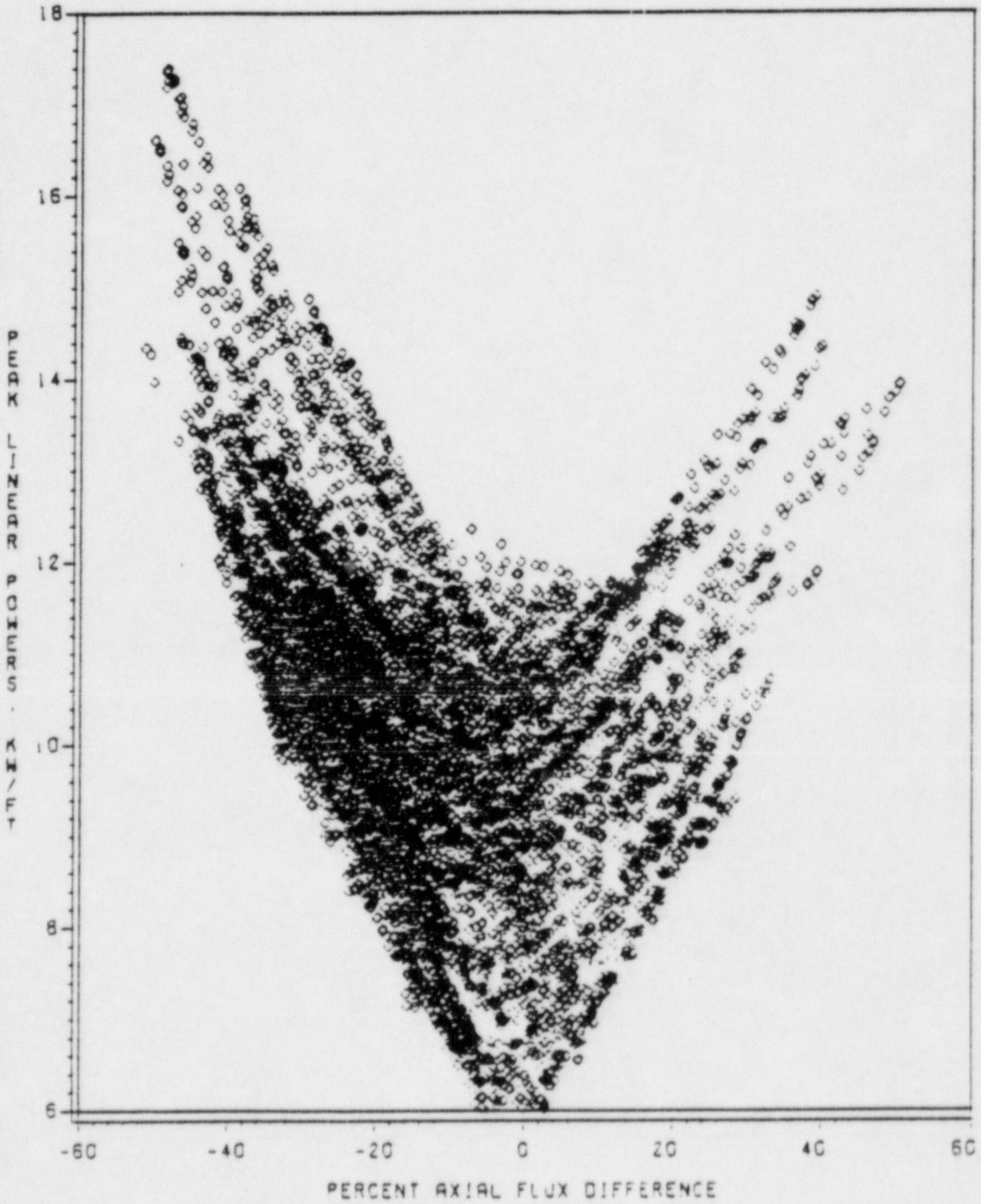

FIGURE 3.3.1 – MAXIMUM POWER DENSITY FLYSPECK

3.4 DNB Evaluation

The OTDT trip function and setpoints [14] provide DNB protection for Condition II accidents. Part of this function, the f(delta-I) term, responds to changes in the indicated delta-I created by skewed axial power distributions. The axial power distributions formed by the RPDC Condition II accident simulations are evaluated to confirm that the assumptions [14] used to form the f(delta-I) term and the rest of the OTDT trip function remain valid. If the RPDC power distributions for any subsequent reload should be more limiting than those previously used to establish the OTDT trip setpoints, the OTDT setpoints will be reformulated using standard techniques [14] and the appropriate RPDC power distribution parameters.

4.0 Other Safety Analyses

No changes will be required to the other safety analysis methods described in Reference 6 to incorporate the effect of the widened delta-I band resulting from the RPDC methodology. The current CAOC methods used by VEPCO already employ a conservative method for incorporating the effect of skewed axial power distributions. However, as is currently the practice with CAOC, the accident analyses will be evaluated on a reload basis for RPDC to ensure that the key input parameters remain bounding. Should an accident analysis be determined to be impacted by a reload design, that accident will be re-evaluated or reanalyzed, as appropriate.

5.0 FQ Surveillance

VEPCO proposes to institute FQ Surveillance Technical Specifications as part of the RPDC procedures. Sample generic Technical Specifications (not specific to any VEPCO unit), incorporating both FQ Surveillance and RPDC, are enclosed in Appendix A. FQ Surveillance Technical Specifications [15,16] are a convenient method for overall power distribution monitoring during plant operation to ensure compliance with the specified LOCA FQ*K(z) limit. In FQ Surveillance, the current radial peaking factor Fxy(z) surveillance is replaced by FQ(z) monitoring which uses the measured equilibrium Fq(z) augmented by a non-equilibrium operation multiplier and compares this value to the LOCA limit. Fxy is implicitly included in the FQ values. The FQ relationship becomes:

$$FQM(z)*N(z) < \frac{FQL * K(z)}{P} \quad \text{for } P > 0.5 \qquad (5\text{-}1)$$

$$FQM(z)*N(z) < \frac{FQL * K(z)}{0.5} \quad \text{for } P \leq 0.5 \qquad (5\text{-}2)$$

where the nondimensional parameters are defined as

FQM(z) = the measured plant FQ(z) at equilibrium conditions

FQL = the plant LOCA FQ limit

K(z) = the normalized LOCA FQ(z) limit

P = the fraction of rated thermal power

N(z) = the maximum potential increase in FQM(z) resulting from non-equilibrium normal operation.

N(z) is a factor that represents the largest possible increase in FQ(z) that could result from changes in the power level and delta-I allowed during normal plant operation:

$$N(z) = \frac{FQ(z), \text{ max Condition I}}{FQ(z), \text{ equilibrium depletion}}. \qquad (5\text{-}3)$$

The impact of control rod insertion and xenon transients, both axial and radial, are all included in N(z). The FQ(z)'s in equation (5-3) are formed by the standard FQ synthesis methods discussed previously in this report. N(z) is similar to V(z) given in Reference 16 and W(z) given in Reference 15. A typical N(z) function is given in Figure 5.0.1.

When FQM(z)*N(z) exceeds the LOCA FQ*K(z) limit, the delta-I versus FQ sensitivity discussed in Section 2.2 permits compensation by means of a reduction in the normal operation delta-I band. This provision and the other changes to the plant Technical Specifications resulting from FQ surveillance are shown in the sample Technical Specifications given in Appendix A.

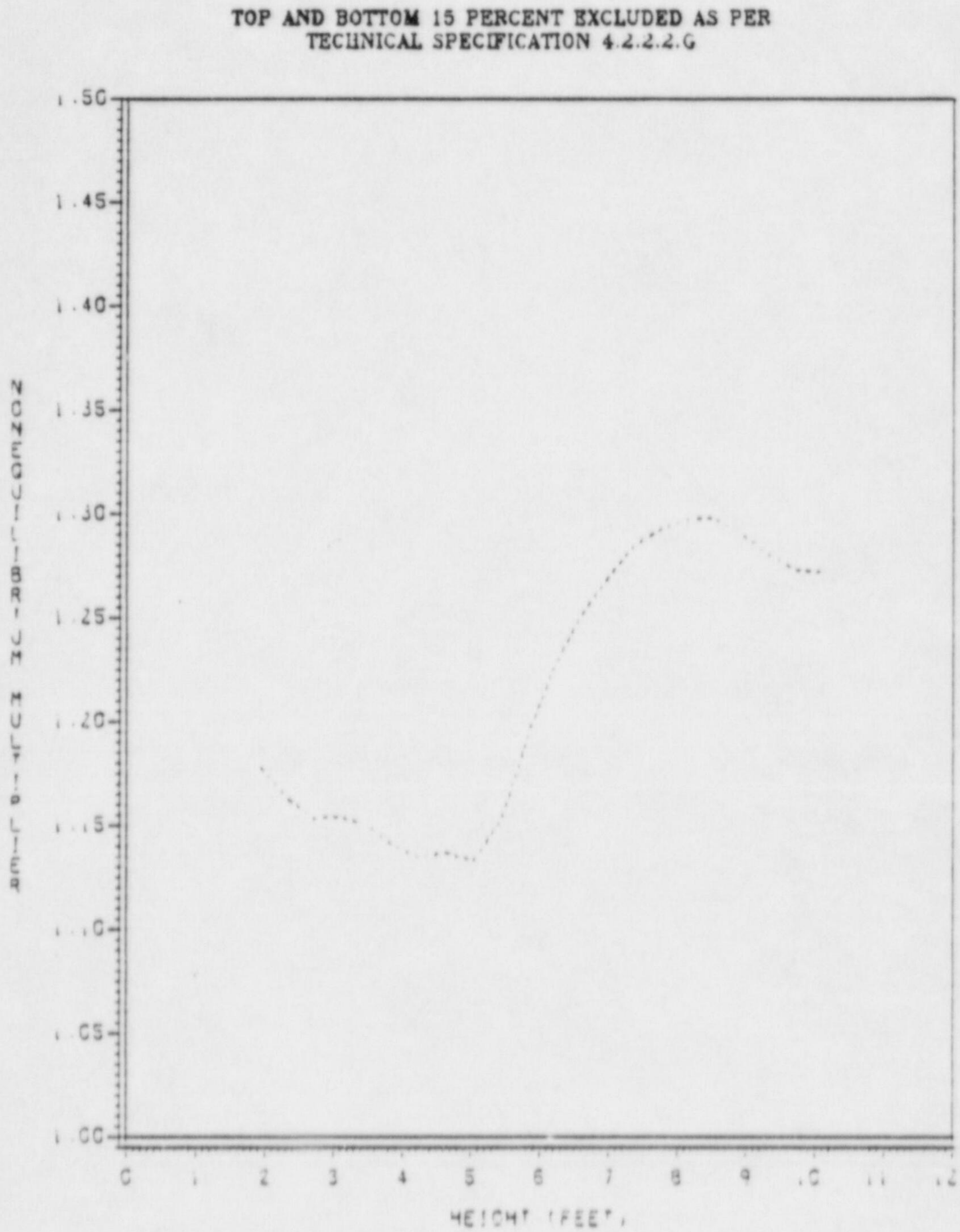

FIGURE 5.0.1 – TYPICAL N(Z) FUNCTION

6.0 Conclusions

The RPDC methodology takes advantage of the large amounts of margin to the design bases limits available at reduced power levels in CAOC and forms wider delta-I limits at all powers. The RPDC methodology may be summarized as follows:

1. A full range of normal-operation axial power shapes is obtained by combining the key parameters upon which each shape is dependent: xenon distribution, boron concentration, core power level and control rod position. A xenon "free oscillation" method is used to create the many and varied axial xenon dist+ ibutions required for this analysis.

2. These axial power profiles are analyzed to determine which shapes result in an approach to the LOCA and LOFA limits.

3. A final normal operation delta-I limit is established by conservatively bounding both the LOCA and the LOFA limits.

4. Conditions which yield shapes within the final delta-I limit are used as initial conditions for the bounding Condition II accident simulations.

5. The resultant transient shapes are analyzed and the overpower and overtemperature trip function/setpoints are specified to ensure that margin to fuel design limits is maintained.

6. A W(z) function is formulated based on calculated Condition I FQ's to support the implementation of FQ Surveillance Technical Specifications.

All neutronics and thermal/hydraulic calculations are performed with NRC-approved codes [7-10].

The RPDC methodology presented in this report will allow the VEPCO nuclear units to operate with additional operational flexibility while at the same time ensuring that the design bases limits are met with an appropriate margin. The Technical Specification changes proposed in Appendix A provide the mechanism by which the RPDC methodology can be properly implemented.

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APPENDIX A

SAMPLE TECHNICAL SPECIFICATIONS

A.1 CHANGES TO TECHNICAL SPECIFICATION 3/4.2.1

The Actions and Surveillance Requirements relating to the Constant Axial Offset Control delta-I band have been removed from Technical Specification (TS) 3/4.2.1 and replaced with the RPDC requirements. The Axial Flux Difference (AFD) limit in Figure 3.2-1 is replaced with the RPDC delta-I limits derived in Section 2.4 of this report. The modified TS 3/4.2.1 requires that delta-I be maintained within the AFD limit or thermal power be reduced. Sample Technical Specifications are attached.

AXIAL FLUX DIFFERENCE (AFD)

LIMITING CONDITION FOR OPERATION

3.2.1 The indicated AXIAL FLUX DIFFERENCE (AFD) shall be maintained within the allowed operational space defined by Figure 3.2-1.

APPLICABILITY: MODE 1 ABOVE 50% RATED THERMAL POWER*

ACTION:

a. With the indicated AXIAL FLUX DIFFERENCE outside of the Figure 3.2-1 limits,

   1.) Either restore the indicated AFD to within the Figure 3.2-1 limits within 15 minutes, or

   2.) Reduce THERMAL POWER to less than 50% of RATED THERMAL POWER within 30 minutes and reduce the Power Range Neutron Flux - High Trip setpoints to less than or equal to 55 percent of RATED THERMAL POWER within the next 4 hours.

b. THERMAL POWER shall not be increased above 50% of RATED THERMAL POWER unless the indicated AFD is within the Figure 3.2-1 limits.

*See Special Test Exception 3.10.2.

SURVEILLANCE REQUIREMENTS

4.2.1.1 The indicated AXIAL FLUX DIFFERENCE shall be determined to be within its limits during POWER OPERATION above 50% of RATED THERMAL POWER by:

a. Monitoring the indicated AFD for each OPERABLE excore channel:

1. At least once per 7 days when the AFD Monitor Alarm is OPERABLE, and

2. At least once per hour for the first 24 hours after restoring the AFD Monitor Alarm to OPERABLE status.

b. Monitoring and logging the indicated AXIAL FLUX DIFFERENCE for each OPERABLE excore channel at least once per hour for the first 24 hours and at least once per 30 minutes thereafter, when the AXIAL FLUX DIFFERENCE Monitor Alarm is inoperable. The logged values of the indicated AXIAL FLUX DIFFERENCE shall be assumed to exist during the interval preceding each logging.

4.2.1.2 The indicated AFD shall be considered outside of its limits when at least 2 OPERABLE excore channels are indicating the AFD to be outside of the limit shown in Figure 3.2-1.

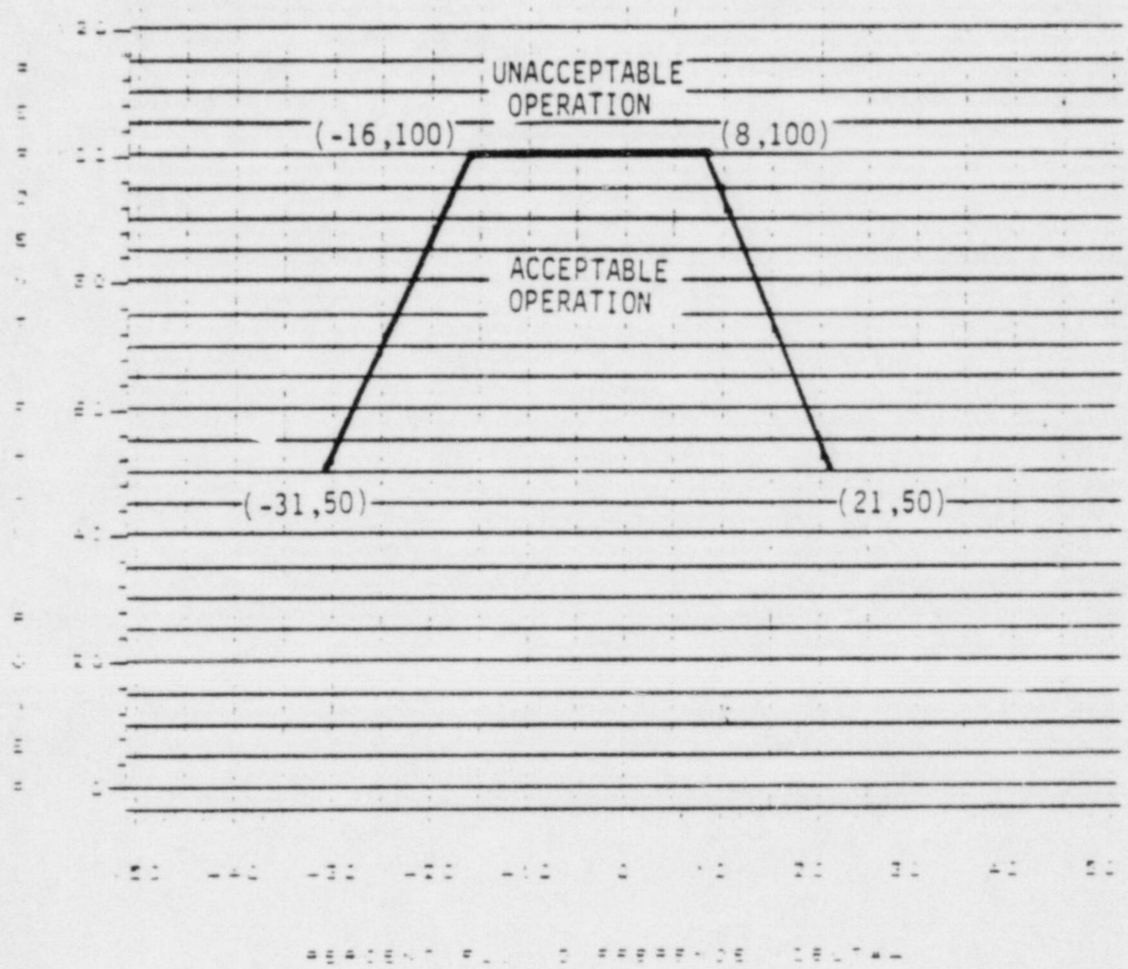

FIGURE 3.2-1

AXIAL FLUX DIFFERENCE LIMITS AS A FUNCTION OF RATED THERMAL POWER
(TYPICAL EXAMPLE)

A.2 CHANGES TO TECHNICAL SPECIFICATION 3/4.2.2

The Surveillance Requirements given in TS 4.2.2.2 have been modified to incorporate FQ Surveillance Technical Specifications as discussed in Chapter 5 of this report. The measured overall peaking factor FQM(z), formed by increasing the full core flux map FQ(z) by 3% for manufacturing tolerances and 5% for measurement uncertainties, is used to confirm that the plant is operating within the LOCA FQ(z) limit. The top and bottom 15% of the core are not considered in the FQ(z) evaluation due to difficulty in obtaining flux measurements and the small likelihood of obtaining a limiting FQ in these core zones. Since FQM(z) is based on equilibrium conditions, the LOCA FQ(z) limit is modified by the N(z) factor defined in Chapter 5 of this report.

FQ Surveillance is required at least once every 31 effective full power days. If any two consecutive FQ measurements show an increase in peak FQM(z), as sometimes occurs near beginning-of-cycle, more frequent mapping (every 7 effective full power days) is necessary to accurately determine FQM(z). As an alternative, TS 4.2.2.2e provides for a 2% penalty to be applied to FQM(z), allowing 31 day mapping to continue. A review of recent VEPCO plant cycles has shown this penalty to conservatively bound any expected increase in FQM(z).

Should the actual plant FQ measurements indicate that there is not adequate FQ margin to the limit to allow utilization of the entire RPDC AFD band, the AFD limits can be reduced 1% for every 1% in FQ violation. This action is based on the FQ versus delta-I sensitivity study described in Section 2.2 of this report.

Sample Technical Specifications are attached.

HEAT FLUX HOT CHANNEL FACTOR-$F_Q(Z)$

LIMITING CONDITION FOR OPERATION

3.2.2 $F_Q(Z)$ shall be limited by the following relationships*:

$$F_Q(Z) \leq \frac{[F_Q^\ell]\,[K(Z)]}{P} \text{ for } P > 0.5$$

$$F_Q(Z) \leq \frac{[F_Q^\ell]\,[K(Z)]}{0.5} \text{ for } P \leq 0.5$$

where $P = \frac{\text{THERMAL POWER}}{\text{RATED THERMAL POWER}}$

and K(Z) is the function obtained from Figure 3.2-2 for a given core height location.

APPLICABILITY: MODE 1.

ACTION:

With $F_Q(Z)$ exceeding its limit:

a. Reduce THERMAL POWER at least 1% for each 1% $F_Q(Z)$ exceeds the limit within 15 minutes and similarly reduce the Power Range Neutron Flux-High Trip Setpoints within the next 4 hours; POWER OPERATION may proceed for up to a total of 72 hours; subsequent POWER OPERATION may proceed provided the Overpower ΔT Trip Setpoints have been reduced at least 1% for each 1% $F_Q(Z)$ exceeds the limit.

b. Identify and correct the cause of the out of limit condition prior to increasing THERMAL POWER above the reduced limit required by a, above; THERMAL POWER may then be increased provided $F_Q(Z)$ is demonstrated through incore mapping to be within its limit.

*For an actual plant submittal, F_Q^ℓ would be replaced with the plant specific value for the F_Q LOCA limit.

SURVEILLANCE REQUIREMENTS

4.2.2.1 The provisions of Specification 4.0.4 are not applicable.

4.2.2.2 $F_Q(Z)$ shall be evaluated to determine if $F_Q(Z)$ is within its limit by:**

a. Using the moveable incore detectors to obtain a power distribution map at any THERMAL POWER greater than 5 percent of RATED THERMAL POWER.

b. Increasing the measured $F_Q(Z)$ component of the power distribution map by 3 percent to account for manufacturing tolerances and further increasing the value by 5 percent to account for measurement uncertainties.

c. Satisfying the following relationship:

$$F_Q^M(Z) \leq \frac{F_Q^\ell \times K(Z)}{P \times N(Z)} \quad \text{for } P > 0.5$$

$$F_Q^M(Z) \leq \frac{F_Q^\ell \times K(Z)}{N(Z) \times 0.5} \quad \text{for } P \leq 0.5$$

where $F_Q^M(Z)$ is the measured $F_Q(Z)$ increased by allowances for manufacturing tolerances and measurement uncertainty, F_Q^ℓ is the F_Q limit, K(Z) is given in Figure 3.2-2, P is the relative THERMAL POWER, and N(Z) is the cycle dependent function that accounts for non-equilibrium power distribution effects encountered during normal operation. This function is given in the Core Surveillance Report as per Specification 6.9.1.10.

d. Measuring $F_Q^M(Z)$ according to the following schedule:

1. Upon achieving equilibrium conditions after exceeding by 10 percent or more of RATED THERMAL POWER, the THERMAL POWER at which $F_Q(Z)$ was last determined,* or

*During power escalation at the beginning of each cycle, power level may be increased until a power level for extended operation has been achieved and a power distribution map obtained.

**F_Q^ℓ will be replaced with the plant specific value for the F_Q LOCA limit in an actual plant submittal.

2. At least once per 31 effective full power days, whichever occurs first.

e. With measurements indicating

$$\underset{\text{over } Z}{\text{maximum}} \left(\frac{F_Q^M(Z)}{K(Z)} \right)$$

has increased since the previous determination of $F_Q(Z)$ either of the following actions shall be taken:

1. $F_Q^M(Z)$ shall be increased by 2 percent over that specified in 4.2.2.2.c, or

2. $F_Q^M(Z)$ shall be measured at least once per 7 effective full power days until 2 successive maps indicate that

$$\underset{\text{over } Z}{\text{maximum}} \left(\frac{F_Q^M(Z)}{K(Z)} \right) \text{ is not increasing.}$$

f. With the relationships specified in 4.2.2.2.c above not being satisfied:

1. Calculate the percent $F_Q(Z)$ exceeds its limit by the following expression:

$$\left\{ \left(\underset{\text{over } Z}{\text{maximum}} \left[\frac{F_Q^M(Z) \times N(Z)}{\frac{F_Q^L}{P} \times K(Z)} \right] \right) -1 \right\} \times 100 \text{ for } P \geq 0.5$$

$$\left\{ \left(\underset{\text{over } Z}{\text{maximum}} \left[\frac{F_Q^M(Z) \times N(Z)}{\frac{F_Q^L}{P} \times K(Z)} \right] \right) -1 \right\} \times 100 \text{ for } P < 0.5$$

2. Either of the following actions shall be taken:

   a. Power operation may continue provided the AFD limits of Figure 3.2-1 are reduced 1% AFD for each percent $F_Q(Z)$ exceeded its limit, or

b. Comply with the requirements of Specification 3.2.2 for $F_Q(Z)$ exceeding its limit by the percent calculated above.

g. The limits specified in 4.2.2.2.c, 4.2.2.2.e, and 4.2.2.2.f above are not applicable in the following core plane regions:

1. Lower core region 0 to 15 percent inclusive.

2. Upper core region 85 to 100 percent inclusive.

4.2.2.3 When $F_Q(Z)$ is measured for reasons other than meeting the requirements of Specification 4.2.2.2 an overall measured $F_Q(Z)$ shall be obtained from a power distribution map and increased by 3 percent to account for manufacturing tolerances and further increased by 5 percent to account for measurement uncertainty.

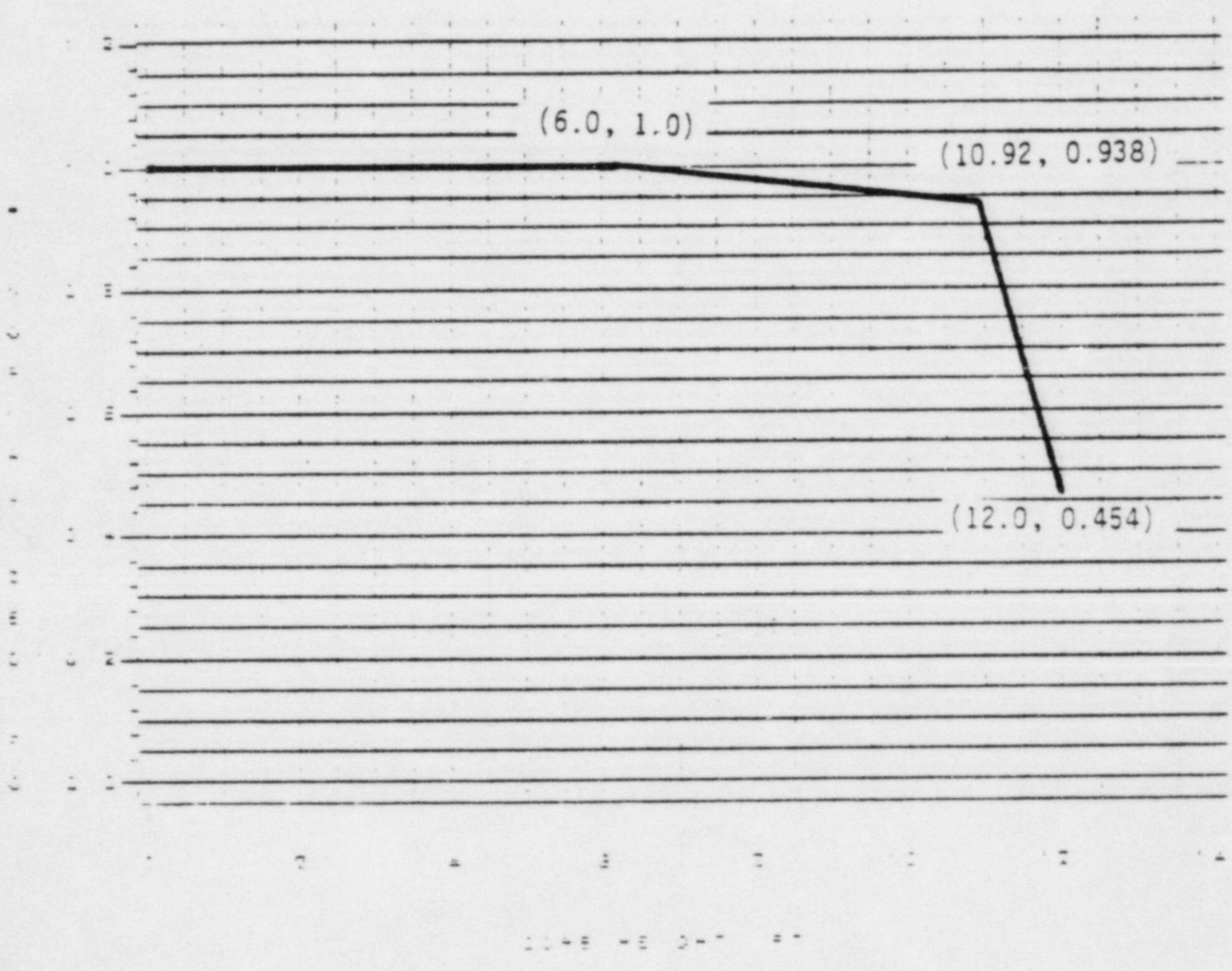

Figure 3.2-2 K(Z) - Normalized $F_Q(Z)$ as a Function of Core Height

A.3 CHANGES TO TECHNICAL SPECIFICATION

B 3/4.2.1

The Bases in TS B 3/4.2.1 have been modified to remove references to the CAOC target flux difference. Sample Technical Specifications are attached.

3/4.2 POWER DISTRIBUTION LIMITS

BASES

The specifications of this section provide assurance of fuel integrity during Condition I (Normal Operation) and II (Incidents of Moderate Frequency) events by: (a) maintaining the minimum DNBR in the core $\geq$ 1.30 during normal operation and in short term transients, and (b) limiting the fission gas release, fuel pellet temperature and cladding mechanical properties to within assumed design criteria. In addition, limiting the peak linear power density during Condition I events provides assurance that the initial conditions assumed for the LOCA analyses are met and the ECCS acceptance criteria limit of 2200°F is not exceeded.

The definitions of certain hot channel and peaking factors as used in these specifications are as follows:

$F_Q(Z)$ Heat Flux Hot Channel Factor, is defined as the maximum local heat flux on the surface of a fuel rod at core elevation Z divided by the average fuel rod heat flux, allowing for manufacturing tolerances on fuel pellets and rods.

$F^N_{\Delta H}$ Nuclear Enthalpy Rise Hot Channel Factor, is defined as the ratio of the integral of linear power along the rod with the highest integrated power to the average rod power.

3/4.2.1 AXIAL FLUX DIFFERENCE (AFD)

The limits on AXIAL FLUX DIFFERENCE assure that the $F_Q(Z)$ upper bound envelope, as given in Specification 3.2.2, is not exceeded during either normal operation or in the event of xenon redistribution following power changes.

Provisions for monitoring the AFD on an automatic basis are derived from the plant process computer through the AFD Monitor Alarm. The computer determines the one minute average of each of the OPERABLE excore detector outputs and provides an alarm message immediately if the AFD for at least 2 of 4 or 2 of 3 OPERABLE excore channels are outside the allowed ΔI-power operating space and the THERMAL POWER is greater than 50% of RATED THERMAL POWER.

A.4 CHANGES TO TECHNICAL SPECIFICATIONS

B 3/4.2.2 and 3/4.2.3

The Bases of TS B 3/4.2.2 and B 3/4.2.3 have been modified to describe the N(z) function and allow for its update through the Core Surveillance Report. Sample Technical Specifications are attached.

3/4.2.2 and 3/4.2.3 HEAT FLUX AND NUCLEAR ENTHALPY HOT CHANNEL FACTORS $F_Q(Z)$ and $F^N_{\Delta H}$

The limits on heat flux and nuclear enthalpy hot channel factors ensure that 1) the design limits on peak local power density and minimum DNBR are not exceeded and 2) in the event of a LOCA the peak fuel clad temperature will not exceed the 2200°F ECCS acceptance criteria limit.

Each of these hot channel factors are measurable but will normally only be determined periodically as specified in Specifications 4.2.2 and 4.2.3. This periodic surveillance is sufficient to ensure that the hot channel factor limits are maintained provided:

a. Control rod in a single group move together with no individual rod insertion differing by more than $\pm$ 12 steps from the group demand position.

b. Control rod groups are sequenced with overlapping groups as described in Specification 3.1.3.6.

c. The control rod insertion limits of Specifications 3.1.3.5 and 3.1.3.6 are maintained.

d. The axial power distribution, expressed in terms of AXIAL FLUX DIFFERENCE, is maintained within the limits.

The relaxation in $F^N_{\Delta H}$ as a function of THERMAL POWER allows changes in the radial power shape for all permissible rod insertion limits. $F^N_{\Delta H}$ will be maintained within its limits provided conditions a thru d above are maintained.

When a F_Q measurement is taken, both experimental error and manufacturing tolerance must be allowed for. 5% is the appropriate allowance for a full core map taken with the incore detector flux mapping system and 3% is the appropriate allowance for manufacturing tolerance.

When $F^N_{\Delta H}$ is measured, experimental error must be allowed for and 4% is the appropriate allowance for a full core map taken with the incore detection system. The specified limit for $F^N_{\Delta H}$ also contains an 8% allowance for uncertainties which mean that normal operation will result in $F^N_{\Delta H} \leq 1.55/1.08$. The 8% allowance is based on the following considerations:

a. abnormal perturbations in the radial power shape, such as from rod misalignment, effect $F^N_{\Delta H}$ more directly than F_Q,

b. although rod movement has a direct influence upon limiting F_Q to within its limit, such control is not readily available to limit $F^N_{\Delta H}$, and

c. errors in prediction for control power shape detected during startup physics tests can be compensated for in F_Q by restricting axial flux distributions. This compensation for $F^N_{\Delta H}$ is less readily available.

The hot channel factor $F^M_{Q(Z)}$ is measured periodically and increased by a cycle and height dependent power factor, N(Z), to provide assurance that the limit on the hot channel factor, $F_Q(Z)$, is met. N(Z) accounts for the non-equilibrium effects of normal operation transients and was determined from expected power control maneuvers over the full range of burnup conditions in the core. The N(Z) function for normal operation is provided in the Core Surveillance Report per Specification 6.9.1.10.

3/4.2.4 QUADRANT POWER TILT RATIO

The quadrant power tilt ratio limit assures that the radial power distribution satisfies the design values used in the power capability analysis. Radial power distribution measurements are made during startup testing and periodically during power operation.

The limit of 1.02 at which corrective action is required provides DNB and linear heat generation rate protection with x-y plane power tilts.

The two hour time allowance for operation with a tilt condition greater than 1.02 but less than 1.09 is provided to allow identification and correction of a dropped or misaligned rod. In the event such action does not correct the tilt, the margin for uncertainty on F_Q is reinstated by reducing the power by 3 percent for each percent of tilt in excess of 1.0.

For purposes of monitoring QUADRANT POWER TILT RATIO when one excore detector is inoperable, the moveable incore detectors are used to confirm that the normalized symmetric power distribution is consistent with the QUADRANT POWER TILT RATIO. The incore detector monitoring is done with a full incore flux map or two sets of 4 symmetric thimbles. The two sets of 4 symmetric thimbles are a unique set of 8 detector locations. These locations are C-8, E-5, E-11, H-3, H-13, L-5, L-11, and N-8.

A.5 TECHNICAL SPECIFICATION

6/9.1.10

Technical Specification 6/9.1.10 gives a description of the Core Surveillance Report which is to be provided to the NRC for every cycle.

CORE SURVEILLANCE REPORT

6.9.1.10

The N(Z) function for normal operation shall be provided to the Regional Administrator, Region II, with a copy to:

> Director, Office of Nuclear Reactor Regulation
> Attention: Chief, Core Performance Branch
> U. S. Nuclear Regulatory Commission
> Washington, D.C. 20555

at least 60 day prior to cycle initial criticality. In the event that the limits would be submitted at some other time during core life, they shall be submitted 60 days prior to the date the limits would become effective unless otherwise exempted by the Commission.

Any information needed to support N(Z) will be by request from the NRC and need not be included in this report.