RELAXED POWER DISTRIBUTION CONTROL METHODOLOGY AND ASSOCIATED FQ SURVEILLANCE TECHNICAL SPECIFICATIONS

By

K. F. Flaig
A. H. Nicholson
N. A. Smith
R. W. Twitchell

NUCLEAR ANALYSIS & FUEL STAFF

DOMINION RESOURCES SERVICES

RICHMOND, VIRGINIA

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Recommended for Approval:

C. B. LaRoe, Supervisor
Nuclear Core Design

J. R. Harrell, Supervisor
Nuclear Safety Analysis

Approved:

K. L. Basehore, Director
Nuclear Analysis & Fuel

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Nuclear Operations
Licensing Supervisor

Mr. W. L. Stewart, Vice President
Nuclear Operations
Virginia Electric and Power Company
Richmond, Virginia 23261

Dear Mr. Stewart:

SUBJECT: ACCEPTANCE FOR REFERENCING OF LICENSING TOPICAL REPORT VEP-NE-1, "VEPCO RELAXED POWER DISTRIBUTION CONTROL METHODOLOGY AND ASSOCIATED FQ SURVEILLANCE TECHNICAL SPECIFICATIONS"

We have completed our review of the subject topical report submitted by the Virginia Electric and Power Company (VEPCO) by letter dated December 10, 1984. We find the report to be acceptable for referencing in license applications to the extent specified and under the limitations delineated in the report and the associated NRC evaluation, which is enclosed. The evaluation defines the basis for acceptance of the report.

We do not intend to repeat our review of the matters described in the report and found acceptable when the report appears as a reference in license applications, except to assure that the material presented is applicable to the specific plant involved. Our acceptance applies only to the matters described in the report.

In accordance with procedures established in NUREG-0390, it is requested that VEPCO publish accepted versions of this report, proprietary and non-proprietary, within three months of receipt of this letter. The accepted versions shall incorporate this letter and the enclosed evaluation between the title page and the abstract. The accepted versions shall include an -A (designating accepted) following the report identification symbol.

Should our criteria or regulations change such that our conclusions as to the acceptability of the report are invalidated, VEPCO and/or the applicants referencing the topical report will be expected to revise and resubmit their respective documentation, or submit justification for the continued effective applicability of the topical report without revision of their respective documentation.

Sincerely,

Herbert N. Berkow

Herbert N. Berkow, Director
Standardization and Special
Projects Directorate
Division of PWR Licensing-B

Enclosure:
As stated

[illegible]

SAFETY EVALUATION REPORT

Report Title: Vepco Relaxed Power Distribution Control Methodology and Associated F Q Surveillance Technical Specifications

Report Number: VEP-NE-1

Report Date: October, 1984

INTRODUCTION

The Virginia Electric and Power Company (Vepco) has developed the relaxed power distribution control (RPDC) methodology to replace the constant axial offset control (CAOC) strategy currently employed at its Surry and North Anna reactors. Associated with the RPDC methodology is direct monitoring of the maximum peaking factor (F_Q) relative to plant limits; this replaces the present Fxy Technical Specifications. The analyses performed in support of relaxed power distribution control, and sample generic F_Q surveillance Technical Specifications are described in the subject report. Additional information considered in this review is given in Ref. 1.

SUMMARY OF TOPICAL REPORT

The constant axial offset control (CAOC) strategy currently employed by Vepco was developed by Westinghouse (W) in order to meet power peaking limits imposed by loss of coolant accident (LOCA) analyses. The CAOC procedure requires the maintenance of the axial flux difference (ΔI) within a specified, constant band about a target axial offset defined at equilibrium conditions. While maintenance of ΔI within these limits insures that the F_Q is bounded by a specified limit, CACO is unnecessarily restrictive, particularly below full power where significant margin to peaking limits exits. These restrictive ΔI limits have a negative impact on operational flexibility, especially in the ability to return to full power quickly following a reactor trip near end-of-cycle (EOC). The development of the relaxed power distribution control approach by Vepco was motivated primarily by this limitation.

ENCLOSURE

Under RPDC the ΔI vs. power operating domain is typically broader than that permitted under CAOC (even with band widening), with the width of the band increasing with decreasing power levels. (Similar variable width operating bands are employed by all three PWR vendors in their axial power distribution control procedures). The variable ΔI vs. power operating band takes advantage of the increased F_Q limits permitted at reduced power by maintaining a roughly constant margin to design limits at all power levels (vs. an increasing margin with decreasing power in CAOC)

The major elements of the RPDC methodology are:

1. Axial power distributions are generated with the Vepco one-dimensional NOMAD (Ref. 2) code which bound the potential ΔI operating band. The NOMAD analysis produces a spectrum of xenon distributions at selected burnups via a free-oscillation technique similar to that developed by Combustion Engineering (CE) (Ref. 3). The resulting xenon distributions are combined with rod insertions and power levels permitted by the power dependent rod insertion limit curve at the selected burnups to produce a range of power distributions (and associated ΔI's) at power levels between 50% and full power.

2. The axial power distributions from (1) are used in a 1D/2D/3D synthesis of F_Q (z) based on values of Fxy(z) generated by the Vepco FLAME (Ref. 4) and PDQ07 (Ref. 5) models. The synthesis includes an axial height dependent radial xenon redistribution factor calculated by FLAME, and uncertainty factors which account for the calculational uncertainty, and manufacturing variabilities.

3. Comparison of the resultant F_Q's to limits prescribed by LOCA analyses defines a preliminary ΔI vs. power operating domain.

4. The entire set of axial power distributions is also analyzed with the COBRA (Ref. 6) code relative to the 1.55 design axial power distribution for the loss of flow accident (LOFA). This analysis defines a second ΔI-power operating space that insures that the margin to the DNB design basis for LOFA is maintained.

5. The most restrictive ΔI-power domain (based on LOCA and/or LOFA) defines the permissible space for normal operation (Condition I). (For Vepco plants, the LOCA based band is usually more restrictive). Maintenance of ΔI within this operating space, coupled with adherence to control rod insertion limits, ensures that the margin to fuel centerline melt, DNB, and LOCA peak clad temperature design criteria are maintained during normal operation.

6. Three abnormal operation (Condition II) events are also considered in the analyses supporting RPDC: uncontrolled rod withdrawal, excessive heat removal, and erroneous boration/dilution. The purpose of these analyses is to confirm that the over-power delta-T (OPDT) and over-temperature delta-T (OTDT) trip setpoints have been conservatively calculated, and insures that required margins are maintained. The OPDT and OTDT trips provide transient and steady-state protection against fuel center-line melt and DNB, respectively. The initial conditions for the analyses of these events consist of the axial power distributions allowed by the Δ-I power operating domain determined in (5).

7. The maximum linear power density for each resulting Condition II distribution is determined by using the F_Q (z) synthesis techniques (with an allowance for densification) and compared to the design basis for fuel centerline melt. The OPDT f(ΔI) function is modified, if necessary, to insure that margin to the fuel center-line melt limit is maintained. The axial power distributions from the Condition II analyses are also evaluated to confirm that the OTDT trip function and its associated f(ΔI) term remain valid.

In conjunction with the implementation of the RPDC methodology, Vepco proposed to replace the current Fxy surveillance with direct monitoring of F_Q (z). In F_Q surveillance the measured F_Q at equilibrium conditions is augmented by a factor, N(z), which accounts for the maximum potential increase in F_Q (z) during normal opertion. The resultant augmented F_Q (z) is compared to the plant LOCA F_Q (z) limits to determine acceptability, or to initiate remedial actions. Sample Technical Specifications to be used with F_Q surveillance are given.

While the greatest benefit of relaxed power distribution control to Vepco is the ability to return to power quickly following a trip near EOC, institution of this methodology with its wider operating band is expected to yield additional operational benefits including reduced control rod motion and coolant system boration/dilution requirements.

SUMMARY OF TECHNICAL EVALUATION

All the analyses performed in support of RPDC employed codes which have been previously reviewed and approved by the staff (FLAME, PDQ07, NOMAD, COBRA). The approach used for generating bounding axial power distributions is based on the free xenon oscillation technique employed for a number of years by Combustion Engineering in their axial power distribution control methodology. (CE served as a consultant to Vepco in the implementation and application of this technique). Vepco has determined that this approach results in axial power distributions that sufficiently span the ΔI-power domain to ensure there is confidence that the most adverse conditions are available for subsequent analyses. In addition, relevant analyses performed by CE show that the sensitivity of the results obtained employing the free xenon oscillation methodology to variations in the impacting parameters are small, and are more than compensated for by the "bounding" nature of the approach, and the extreme distributions considered. This approach has been found acceptable for CE reactors for many years, and is acceptable for RPDC.

The calculation of F_Q via a 1D/2D/3D synthesis is similar to accepted approaches. Uncertainties associated with the calculation of F_Q are based on comparisons to measurements. The measurements included situations where azimuthal tilts spanning the range permitted by the technical specification limits were present. The combination of the FNU and FGR components of the uncertainty given in the report is greater than the 95/95 upper tolerance limit determined on the basis of comparisons to measurements. The magnitude of the uncertainty assigned to the calculated value of F_Q in the RPDC analyses is therefore acceptable.

Calculations of the radial xenon redistribution factor, Xe(z), component of the F_Q synthesis employed the FLAME code and considered a number of cycles, times in life and initiating conditions. The final Xe(z) was chosen such that it bounded all observed increases in Fxy(z). Even though this factor is now less than the previously used axially uniform value of 1.03, the analyses performed to justify the lower values are adequate.

The LOFA analyses performed with COBRA, and the Condition II events considered are similar to those included in the Westinghouse relaxed axial offset control (RAOC) methodology.

The over-power and over-temperature ΔT trip functions will be evaluated on a reload basis to assure protection against fuel center-line melt and DNB design basis limits. Other accident analyses will be reevaluated on a reload basis to insure that the assumption used in the RPDC analyses remain bounding.

Monitoring of adherence to operation within the permissible ΔI-power domain is accomplished by reliance on the ex-core detectors. The calculated ΔI domain will be reduced by 3% to accommodate the maximum excore detector calibration uncertainty permitted by the Technical Specifications. In addition, Vepco plans to further reduce the ΔI limits for the first-time analysis. The bounding nature of the RPDC approach provides further conservatism.

The Vepco RPDC methodology contains elements similar to those included in the W (Ref. 7) and CE variable-width ΔI band axial power distribution control strategies. Approved methods have been used in the analyses supporting RPDC and justification has been provided for the uncertainties assigned. These analyses and uncertainties are consistent with currently approved methods and practices. In addition, the impact of cycle specific variations on the ΔI - power domain, the over-power and over-temperature ΔT trip setpoints, and other safety analyses will be evaluated on a reload basis. Based on these considerations the RPDC approach represents an acceptable methodology for use with reload cores similar to those of the Surry and North Anna reactors.

The proposed F_Q surveillance is similar to the approach approved for W in conjunction with RAOC. The N(z) factor by which the measured F_Q (z) distribution is augmented to account for non-equilibrium normal operation is similar to the W(z) and V(z) functions used by W and Exxon, respectively, and approved for use with RAOC and PD II power distribution control strategies. The sample Technical Specifications given in the subject report replace Fxy surveillance with F_Q surveillance. This is acceptable because the F_Q surveillance is more appropriate for RPDC.

The sample Technical Specifications in the report acceptably implement RPDC with the following modifications:

- Specification 3/4.2, page 3/4 2-1

  The asterisk at the end of the APPLICABILITY line and the footnote should be deleted.

- Figure 3.2-1, 3/4 2-4

  This figure should be blank and contain the legend: "This curve is given in the Core Surveillance Report as per Specification 6.9.1.10."

- Specification 3.2.2, page 3/4 2-5

  Parenthetical comments should be added to the final three lines of action a as follows: "subsequent POWER OPERATION may preceed provided the Overpower ΔT Trip Setpoints (value of K_4) have been reduced at least 1% (in ΔT span) for each 1% $F_Q(z)$ exceeds the limit.

- Specification 6.9.1.10 (page unnumbered)

  After "initial criticality", add "unless otherwise approved by the Commission by letter", and change the end of the first paragraph to "approved by the Commission by letter".

A complete set of these revisions will be approved for North Anna Unit 2, Cycle 4 and could be used as a model.

CONCLUSION

We find the subject report suitable for reference as support for use of RPDC in licensing applications.

REFERENCES

1. Letter from W.L. Stewart (Vepco) to H.R. Denton (USNRC), "Virginia Electric and Power Company Relaxed Power Distribution Control (RPDC) Supplemental Information," (Oct. 21, 1985).

2. S.M. Bowman, "The Vepco NOMAD Code and Model," VEP-NFE-1A, Virginia Electric and Power Company (May 1985).

3. "C-E Setpoint Methodology," CENDP-199-NP Rev. 1-NP, Combustion Engineering Inc. (March 1985).

4. W.C. Beck, "The Vepco FLAME Model," VEP-FRD-24A, Virginia Electric and Power Co. (July 1981).

5. M.L. Smith, "The PDQ07 Discrete Model," VEP-FRD-19A, Virginia Electric and Power Co., (July 1981).

6. F.W. Silz, "Vepco Reactor Core Thermal-Hydraulic Analysis Using the COBRA IIIC/MIT Computer Code," Vepco-FRD-33A, Virginia Electric and Power Co. (Oct. 1983).

7. R.W. Miller et al., "Relaxation of Constant Axial Offset Control," NS-EPR-2649 Part A, Westinghouse Electric Corp. (August 1982).

CLASSIFICATION/DISCLAIMER

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PREFACE

This topical report (Mod 1) presents a modified version of the Relaxed Power Distribution Control Methodology provided in VEP-NE-1-A, Revision 0 published in March 1986. This report updates the references to the current 3-D PDQ Two Zone and enhanced NOMAD models as well as outlines the use of the NRC approved Studsvik Core Management System in the RPDC methodology. This report also refers to the COLR section of the plant Technical Specifications for the applicable thermal-hydraulic codes(s) and correlation(s) for DNB analyses.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

SECTION 1 - 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

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

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. A typical CAOC delta-I band 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 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 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 FQ*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.

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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.

The principal benefits of a variable band delta-I control strategy over 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 CAOC ±5% delta-I band restrictions is reduced to only that motion needed to maintain operation within a much wider band;

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 developed and licensed a variable delta-I control strategy called RAOC (Relaxed Axial Offset Control) for application to reload cores.

Dominion has combined some of the concepts from the Combustion Engineering methodology [3] with the current Dominion 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 Sections that follow will discuss the Dominion 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 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 Section 5, FQ surveillance complements RPDC to form a consistent but more flexible plant monitoring scheme than that provided by the CAOC methods.

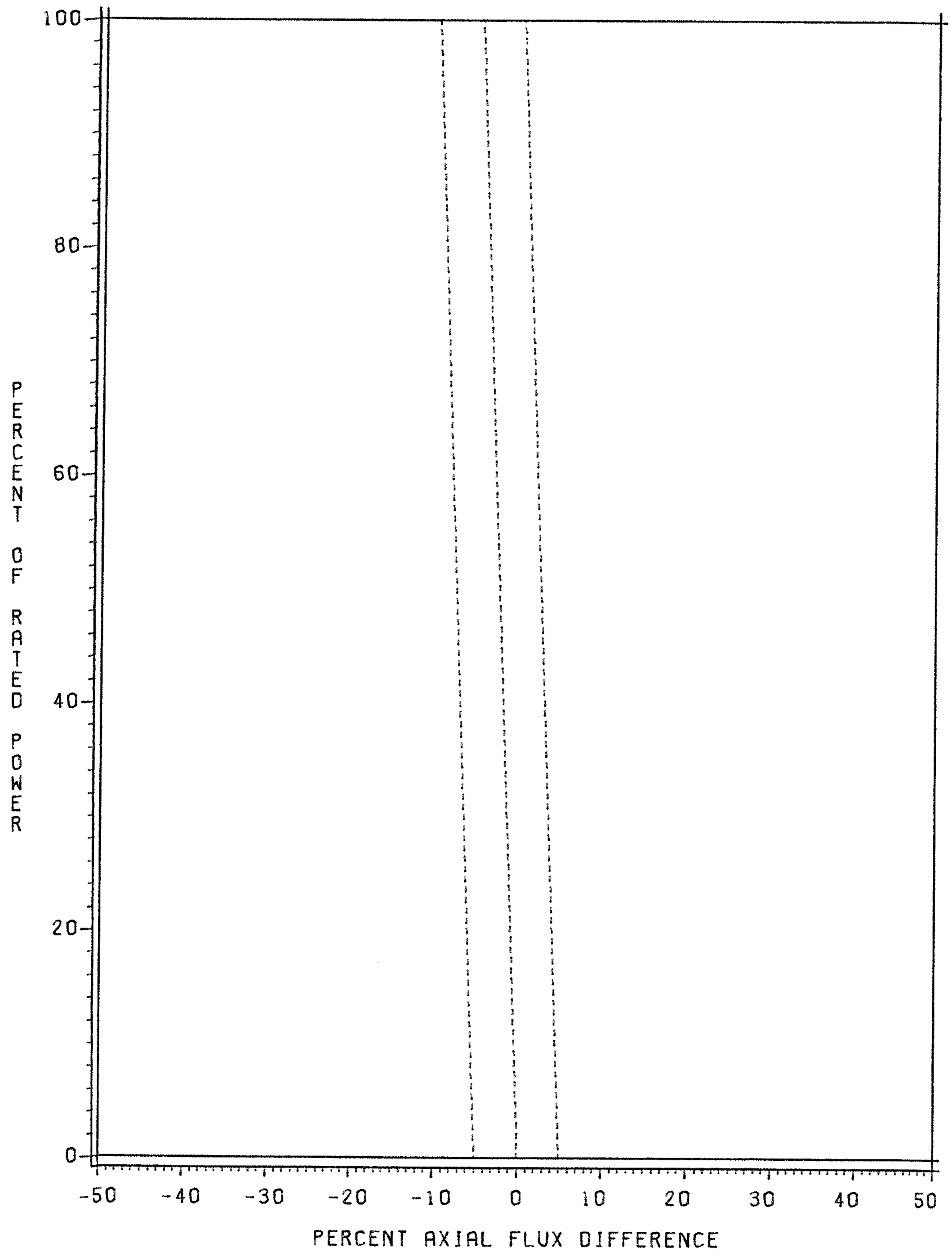

FIGURE 1.0-1 – TYPICAL CAOC LIMITS

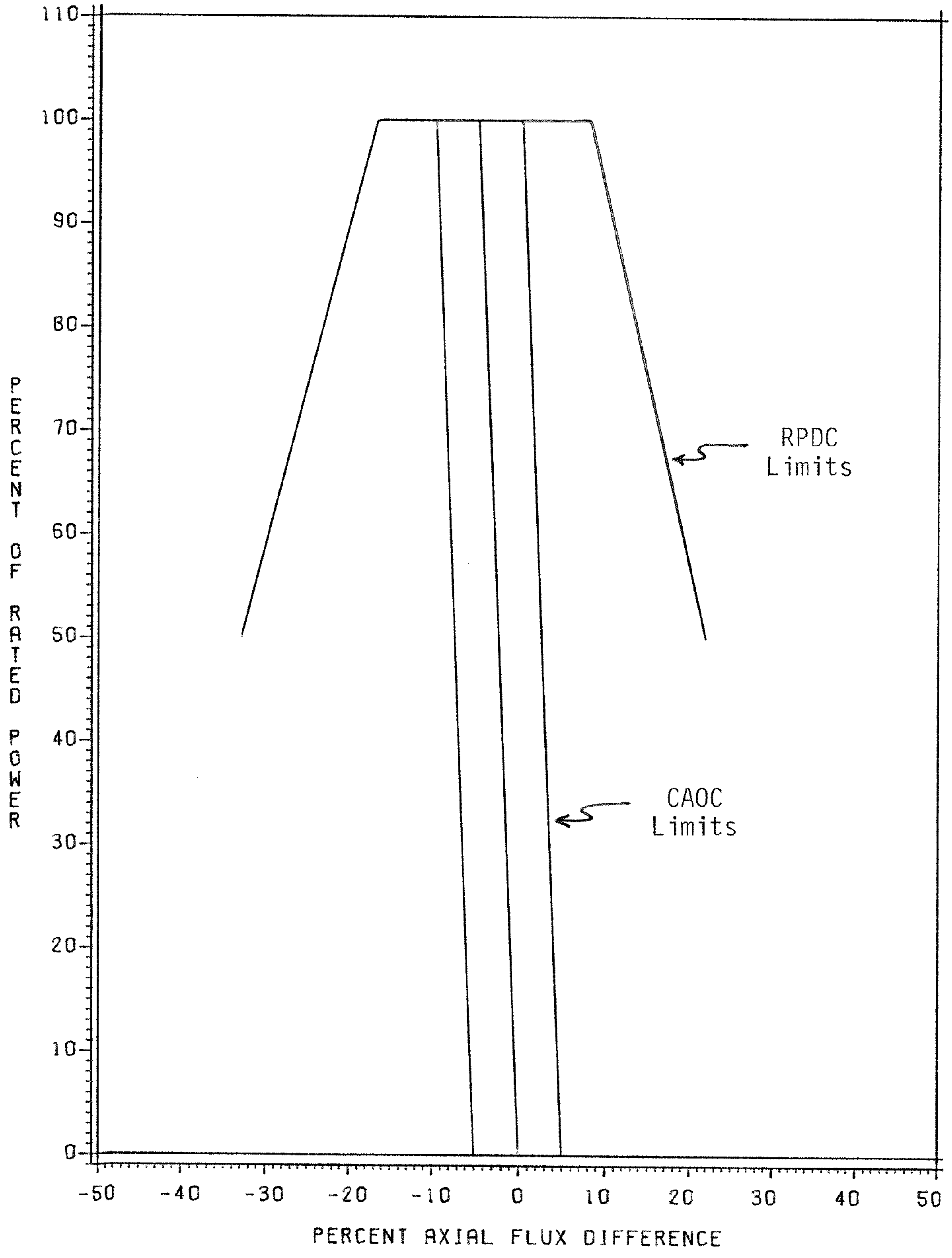

FIGURE 1.0-2 – TYPICAL VARIABLE AXIAL FLUX DIFFERENCE LIMITS

SECTION 2 – CONDITION I ANALYSIS

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. Dominion has developed the methodology of Section 2.1 to generate 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 [7,17] or 3-D model [16] 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 Dominion NOMAD [7,17] 1-D diffusion code was used to perform these examples. 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.

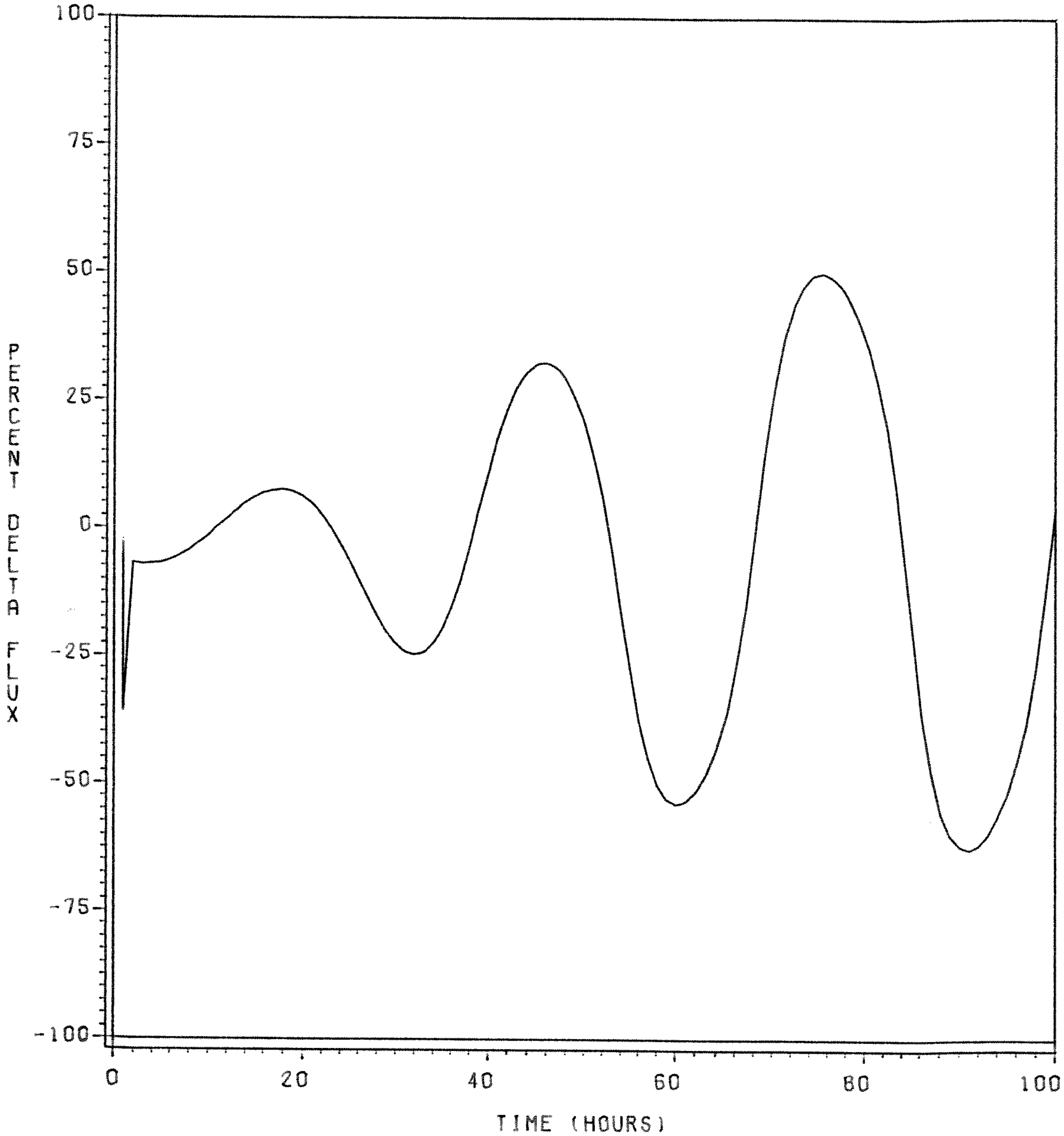

FIGURE 2.1-1 – TYPICAL RPDC BOC XENON OSCILLATION

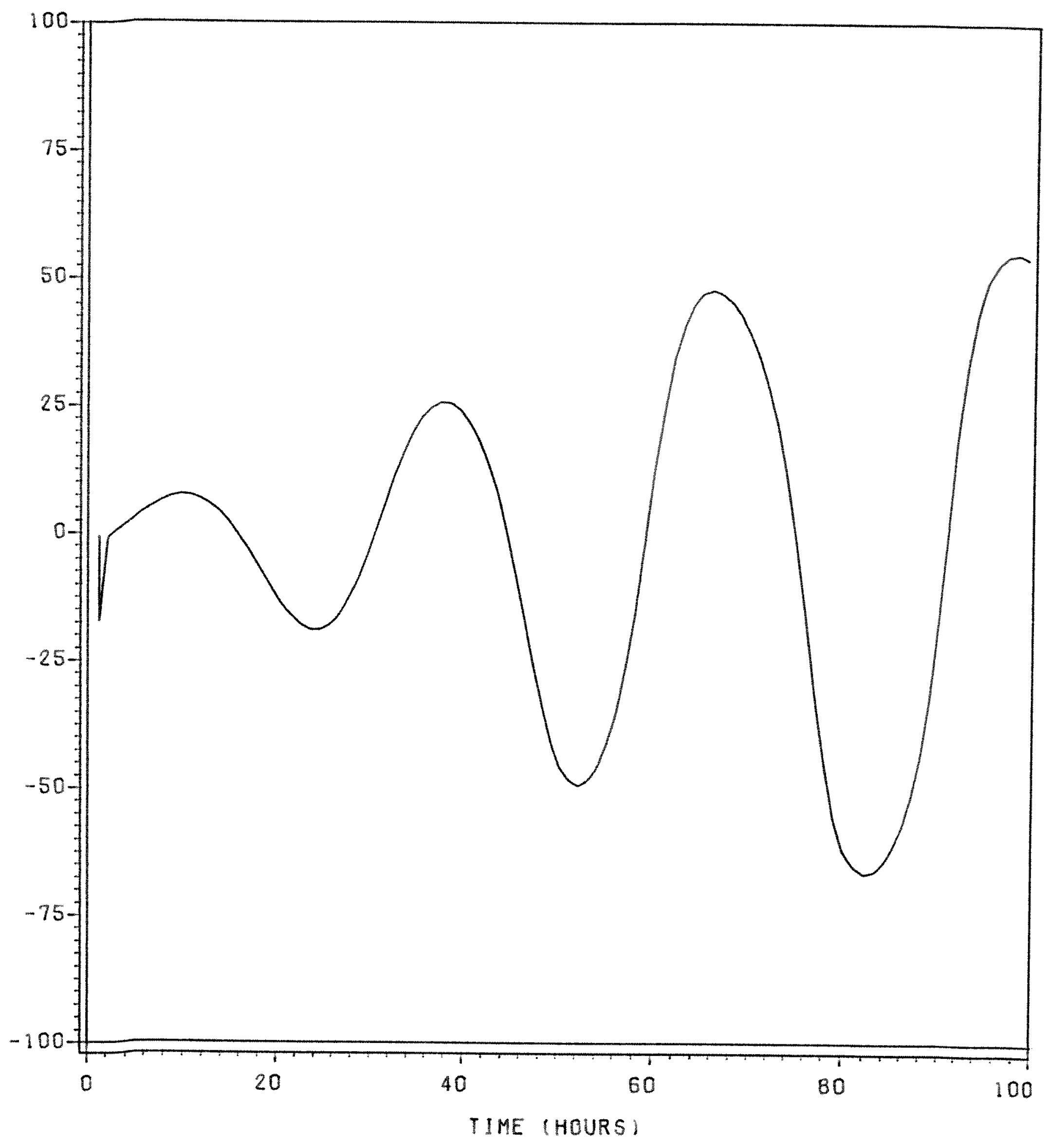

FIGURE 2.1-2 – TYPICAL RPDC EOC XENON OSCILLATION

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 cycle-specific Core Operating Limits Report (COLR) 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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*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.

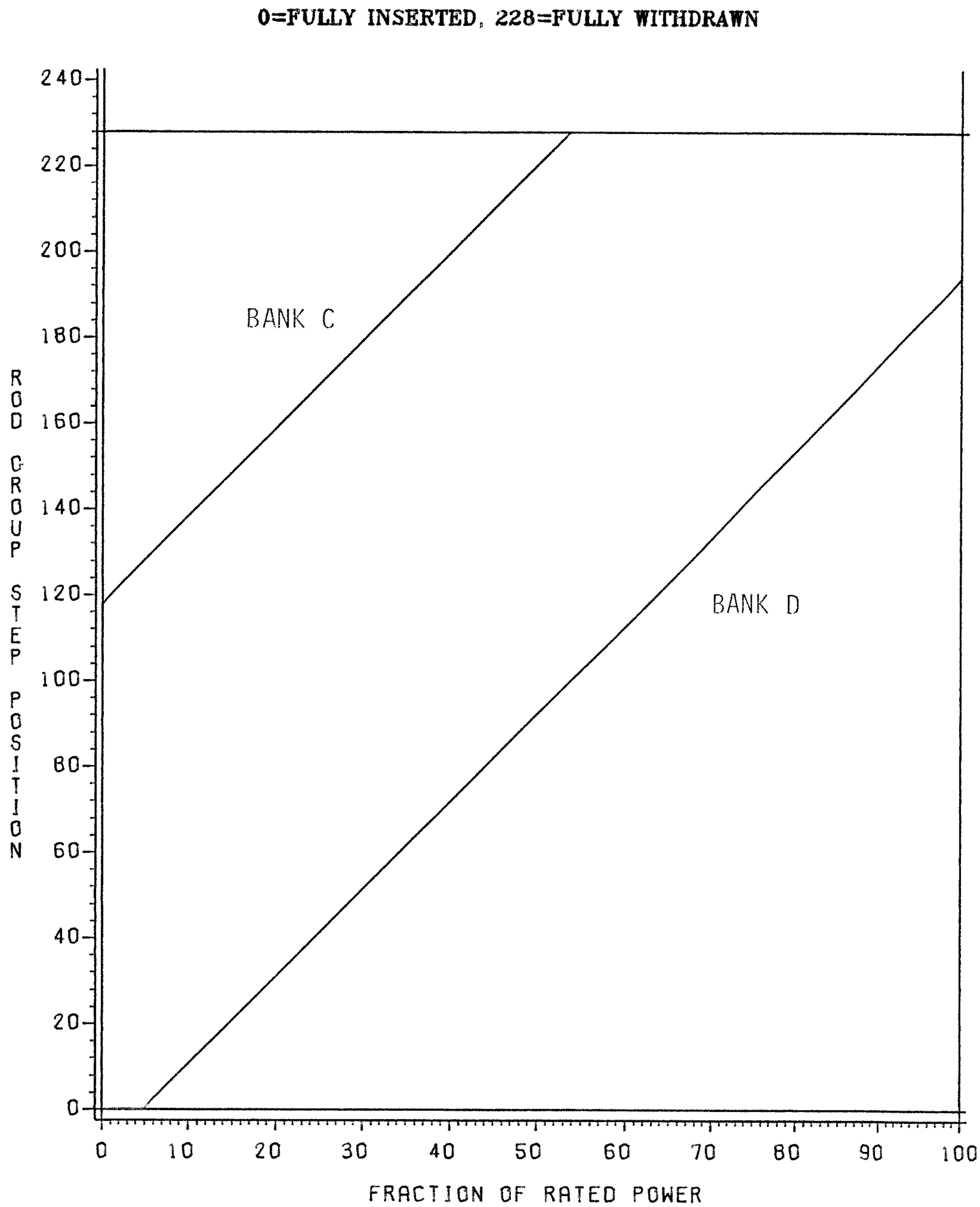

FIGURE 2.1-3 – TYPICAL ROD INSERTION LIMITS

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 [7,17] or the SIMULATE [16] code with normal feedback. Calculated axial power distributions are identified 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 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 Dominion plants using the methods just described.

2.2.1 FQ Using Standard 1-D/3-D Synthesis

The axial shapes created in Section 2.1 using NOMAD are combined with Fxy(z) data using a standard 1-D/3-D FQ synthesis [1,7,8,17]:

$$FQ(z) = Fxy(z) * P(z) * Xe(z) * FNU * FQE * FGR$$

where the following are non-dimensional parameters:

Fxy(z)	=	Fxy distribution calculated by 3-D PDQ Two Zone [8,17], dependent upon burnup, core height and rod position and power level.
P(z)	=	Axial power shape function generated by NOMAD [7,17]
Xe(z)	=	The radial xenon redistribution factor
FNU	=	Nuclear uncertainty factor [7,17]
FQE	=	Engineering heat-flux hot-channel factor [9,10]
FGR	=	Grid correction factor [7,17]

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 1-D code and is therefore applied in the synthesis as an uncertainty factor. Xe(z) is calculated as follows:

$$Xe(z) = \frac{\max Fxy(z)T}{Fxy(z)E}$$

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 a 3-D 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 3-D 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 to determine Xe(z).

2.2.2 FQ Using 3-D Model

The axial shapes created in Section 2.1 using SIMULATE are used directly [16]:

FQ(z) = Fq(z) * FNU * FQE

where the following are non-dimensional parameters:

Fq(z)	=	Fq distribution calculated by 3-D SIMULATE [16], dependent upon burnup, core height and rod position and power level. (Includes xenon redistribution and grid effects).
FNU	=	Nuclear uncertainty factor [16]
FQE	=	Engineering heat-flux hot-channel factor [9,10]

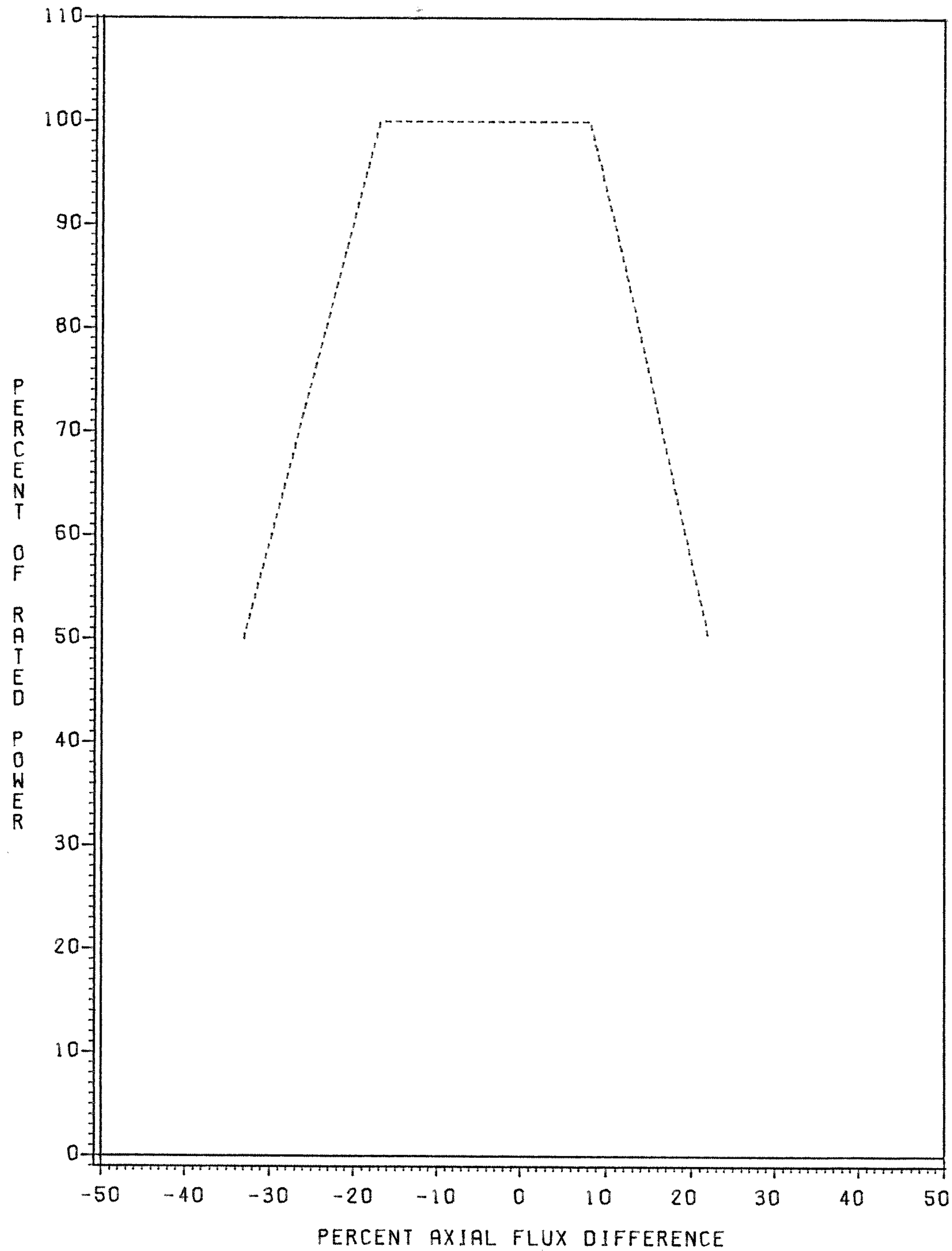

FIGURE 2.2-1 – TYPICAL LOCA DELTA-I LIMITS

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 applicable thermal-hydraulic code(s) and correlation(s) that are listed in the COLR section of the plant Technical Specification. The thermal/hydraulic evaluation methods used in this LOFA evaluation are similar to those of the 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 Section 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. 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 Dominion's plants. This will allow the plant cycle specific COLR to take advantage of the FQ versus delta-I sensitivity identified in Section 2.2.

SECTION 3 – CONDITION II ANALYSIS

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 Section 2 and the cycle specific COLR 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 cycle specific COLR limits, then the margin to the design criteria of fuel centerline melt, DNB and LOCA peak clad temperature, will be maintained.

This Section 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.

* 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 Section 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 either NOMAD [7,17] or SIMULATE [16] and the axial power distribution is identified 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 [7,17] or SIMULATE [16] code. The inlet temperature is reduced and a criticality search is performed. The axial power distribution from each case is identified for use in the Condition II evaluation of Sections 3.3 and 3.4. Reduction of the inlet temperature is limited to 30^{o}F, which has been shown to bound the results of the above accidents in the Surry and North Anna UFSAR's [11,12]. 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 consequences 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. For SIMULATE, a restart case is read for each allowed xenon distribution from the Condition I analysis. For both NOMAD and SIMULATE, 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 identified for the Condition II evaluation of Sections 3.3 and 3.4.

3.3 Overpower Limit Evaluation

The maximum linear power density for each distribution produced by the Condition II accident simulations is determined using the 1-D/3-D FQ synthesis or the 3-D model techniques as described in Section 2.2 (with the addition of the densification spike factor S(z)). The results may be 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.

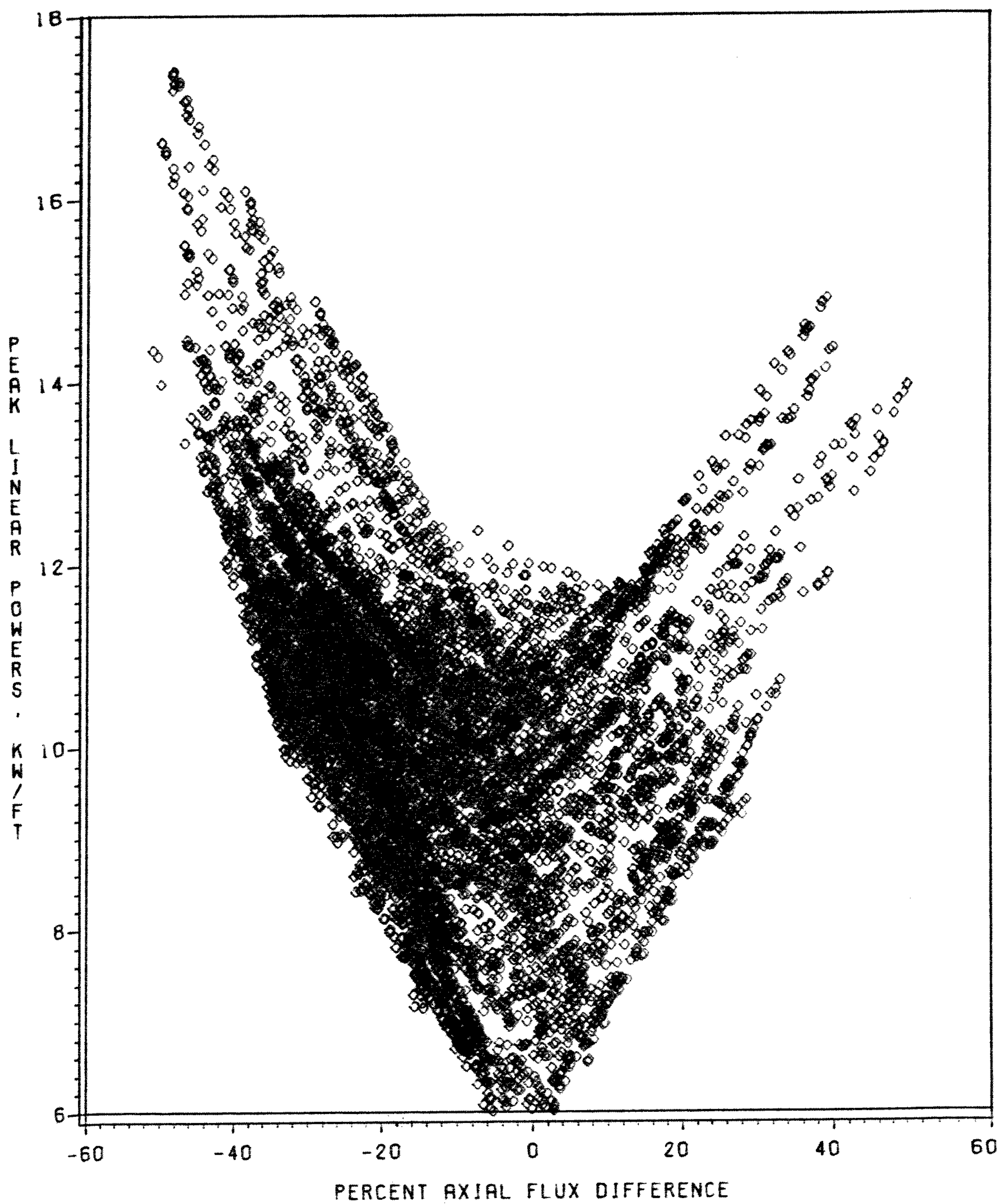

FIGURE 3.3-1 – TYPICAL MAXIMUM POWER DENSITY FLYSPECK

3.4 DNB Evaluation

The OTDT trip function and setpoints [13] 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 [13] 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 [13] and the appropriate RPDC power distribution parameters.

SECTION 4 – OTHER SAFETY ANALYSES

No changes are 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 CAOC methods used by Dominion employ a conservative method for incorporating the effect of skewed axial power distributions. However, as is 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.

SECTION 5 – FQ SURVEILLANCE

Dominion instituted FQ Surveillance Technical Specifications as part of the RPDC implementation process. FQ Surveillance Technical Specifications [14,15] are a convenient method for overall power distribution monitoring during plant operation to ensure compliance with the specified LOCA FQ*K(z) limit. The FQ relationship is:

$$F_Q^M(z) \le \frac{CFQ}{P} * \frac{K(z)}{N(z)} \qquad for\ P > 0.5 \qquad [5-1]$$

$$F_Q^M(z) \le \frac{CFQ}{0.5} * \frac{K(z)}{N(z)} \qquad for\ P \le 0.5 \qquad [5-2]$$

where the nondimensional parameters are defined as

$F_Q^M(z)$ = the measured plant FQ(z) at equilibrium conditions

CFQ = the plant LOCA FQ limit

K(z) = the normalized LOCA FQ(z) limit as a function of core height

P = the fraction of rated thermal power

N(z) = the maximum potential increase in $F_Q^M(z)$ resulting from non-equilibrium normal operation.

N(z) is a cycle dependent 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:

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

The impact of control rod insertion and xenon transients, both axial and radial, are included in N(z). The FQ(z)'s in equation [5-3] are formed by the standard 1-D/3-D FQ synthesis or the 3-D model techniques as described in Section 2.2. N(z) is similar to V(z) given in Reference 15 and W(z) given in Reference 14. A typical N(z) function is given in Figure 5.0-1.

When $F_Q^M(z)$ exceeds the LOCA FQ*K(z)/N(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.

TOP AND BOTTOM 15 PERCENT EXCLUDED
AS PER TECHNICAL SPECIFICATION BASES

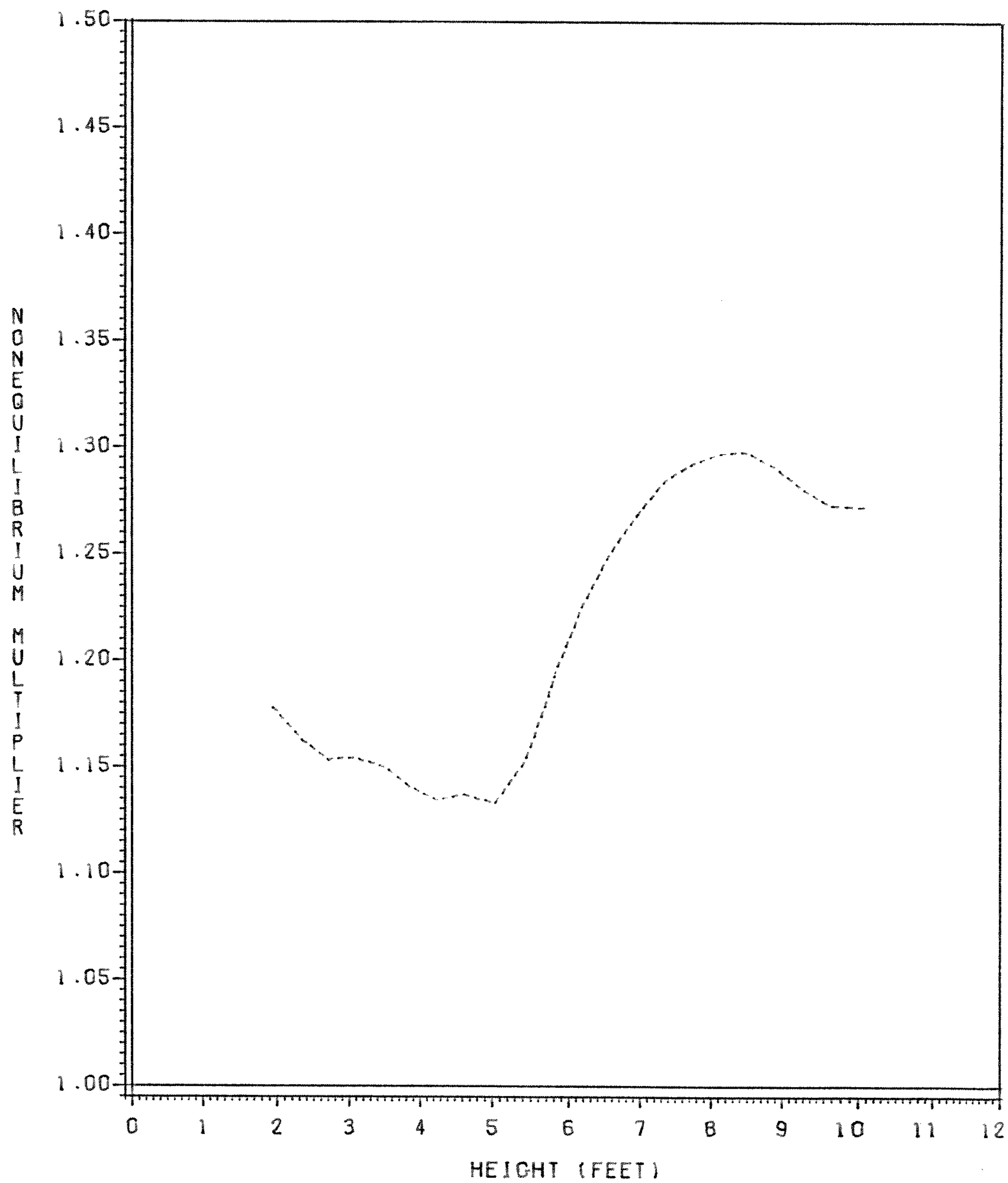

FIGURE 5.0-1 – TYPICAL N(Z) FUNCTION

SECTION 6 – CONCLUSION

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 distributions 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 normal operation 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 N(z) function is formulated based on calculated Condition I Fq's to support the implementation of Fq Surveillance Technical Specifications.

All neutronics calculations are performed with NRC approved codes. All DNBR calculations are performed using the applicable thermal-hydraulic code(s) and correlation(s) that are listed in the COLR section of the plant Technical Specification.

The RPDC methodology presented in this report allows the Dominion 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.

Section 7 – References

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