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DUKE POWER COMPANY THERMAL-HYDRAULIC STATISTICAL CORE DESIGN METHODOLOGY

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ABSTRACT

This report presents Duke Power Company's methodology for performing statistical core thermal-hydraulic analyses. This method uses the models and thermal-hydraulic code currently approved for the Oconee and the McGuire/Catawba Nuclear Stations. The analyses method is based on DNBR limits that statistically account for the effects on DNB of key parameters such as reactor power, temperature, flow, and core power distribution. This report details the methodology development, the application to Duke plants, and the process for future technical enhancements and application to non-Duke reactors.

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Definitions

Case - A unique set of conditions analyzed by the thermal-hydraulic computer code. These conditions are based on a statepoint and include individual statistical variations of each key parameter.

Design DNBR Limit (DDL) - A numerical DNBR value that includes margin above the statistical design limit and is used for DNBR analyses. The DDL is calculated by multiplying the SDL by a fixed factor such as 1.10.

Key Parameter - A physical parameter that is important to the calculation of DNBR.

Statepoint - A unique set of fluid and reactor conditions evaluated for DNBR performance. These conditions include reactor power, pressure, temperature, coolant flow rate, and a three dimensional nuclear power distribution.

Statistical Core Design (SCD) - An analysis method that statistically combines the effects of all key parameter uncertainties associated with DNB predictions.

Statistical Design Limit (SDL) - A numerical DNBR value resulting from a SCD analysis that ensures, with a 95% probability at a 95% confidence level, DNB will not occur.

Statistical DNBR - The numerical value calculated by the SDL equation for a specific statepoint.

1.0 INTRODUCTION

The thermal-hydraulic design methodology accounts for the effects on DNB of the uncertainties of key parameters such as power, pressure, temperature and flow. Statistically combining these effects yields a better quantification of the DNB margin which, in turn, enhances core reload design flexibility. This report details the thermal-hydraulic statistical core design methodology developed by Duke Power Company for application to pressurized water reactors.

Several different statistical DNB analysis methods have been approved and are currently in use by various vendors and utilities. All the methods have slight differences but the major similarity is the basic concept that statistical behavior is defined by the sensitivity of DNB to key parameters and their associated uncertainties. When this relationship is well defined, a high degree of confidence in the applicability of the statistical DNB limit is assured.

1.1 CURRENT METHODOLOGY

The Thermal-Hydraulic Statistical Core Design (SCD) analysis method currently licensed for use by Duke Power Company is based on a Response Surface Model (RSM) prediction of DNBR behavior over a range of key parameters (Reference 3). The RSM is used to evaluate the impact of uncertainties on each parameter about a statepoint for a large number of cases. Figure 1 shows an overall process flowchart for the RSM

based SCD analysis. This method has been approved by the NRC for use on the McGuire and Catawba Nuclear Stations.

1.2 REVISED METHODOLOGY

Duke Power Company has developed an alternative method to evaluate the statistical behavior of DNBR that both simplifies and enhances the accuracy of the original process. The simplified method uses the VIPRE-01 thermal-hydraulic computer code (Reference 1) to calculate the DNBR values for each set of reactor conditions. With this method, the intermediate step of developing and analyzing DNB response with the RSM is eliminated. Besides this enhancement, the overall process is identical to the currently approved methodology. Figure 2 shows the flowchart for the revised approach. Note that the major difference is the elimination of the first three steps shown in Figure 1. The revised methodology was used to determine the statistical design limit for three transient statepoints in Reference 3. Limited application of this methodology was reviewed and approved by the NRC for McGuire/Catawba thermal-hydraulic analyses as part of the review of Reference 3.

The revised SCD methodology is identical in most respects to other statistical thermal-hydraulic analysis methodologies. Key DNBR parameters are selected, their associated uncertainties are propagated about a statepoint, and a large number of DNBR's are calculated . The statistical behavior at that statepoint is evaluated by observing the distribution of the DNBR values and the mean and standard deviation of DNB for the given conditions. This same approach is repeated over a

range of statepoints. The Statistical Design Limit (SDL) is based on the largest coefficient of variation and therefore the largest statistical DNBR value for the statepoints considered.

The statistical analysis method described in this report is applied to both the Oconee (Babcock and Wilcox) and McGuire/Catawba (Westinghouse) plant designs. The main body of this report details the specifics of the method and gives typical results. Two Appendices are included that contain plant specific information and results. This is necessary due to the differences in CHF correlations, fuel design, and specific uncertainties for each plant design. Appendix A contains the specific information for Oconee and Appendix B contains the same information for McGuire/Catawba. The plant specific thermal-hydraulic models and computer code configurations described in Reference 2 (DPC-NE-2003P-A) and Reference 3 (DPC-NE-2004P-A) are used in this analysis without modification.

This method of developing an SCD limit provides a more accurate representation of statistical DNB behavior because the thermal-hydraulic code is used directly to perform all DNBR calculations. Rather than relying on an algorithm such as the RSM, this methodology consists of over 151,000 individual VIPRE-01 cases at various statepoints. Because of the mechanistic approach used by this analysis, [two distinct modes of DNB behavior have been identified. To most accurately represent this behavior, two SDL limits are used to cover the analysis space. Using more than one limit does not impact

the overall reload design methodology as described in References 4 and 5.]

1.3 FUTURE USES

One benefit of the revised thermal-hydraulic analysis method is the ability to analyze factors outside of the original scope of analysis for a particular plant. This is due to the fact that the thermal-hydraulic code is used directly to determine statistical behavior. For example, if an assumed uncertainty should become non-bounding, the limiting statepoint can be re-evaluated to determine the impact of the changed parameter on the SDL. This method can also be used to evaluate a statepoint outside the range of the original key parameters assumed. If the statepoint statistical DNBR does not exceed the SDL, the statepoint can apply the licensed limit.

If the statepoint statistical DNBR does exceed the limit, appropriate measures, such as increasing the design DNBR limit (DDL) for that statepoint's analyses, can be used to ensure conservative DNBR limits are used. (The design DNBR limit approach is discussed in Section 2.5 of this report and Section 6.5 of Reference 3). This higher design limit will mean lower allowable radial power distributions for the affected statepoint. The higher limit would apply to all the subsequent analyses performed on that set of conditions. Another alternative to increasing the design DNBR limit is to use the available margin between the existing SDL and design DNBR limits to account for the change.

Secondly, this statistical analysis method shows generic DNB behavior that extends across fuel designs and plant types. The limiting SDL value is primarily affected by the particular Critical Heat Flux (CHF) Correlation used, the fuel assembly design, and the key parameter uncertainties. This allows the methodology to be applied to new or revised CHF correlations, new fuel assembly designs, or non-Duke plants, requiring only the submittal of an additional Appendix that provides the same information as included in the two attached.

2.0 STATISTICAL CORE DESIGN METHODOLOGY

The procedure for determining the statistical DNBR limit (SDL) contains four steps:

1. Selection of key parameters
2. Selection of uncertainties
3. Propagation of uncertainties
4. Calculation of the statistical DNBR limit (SDL).

The key parameters associated with DNBR are generic to pressurized water reactors and are independent of reactor design. The important plant specific information is the uncertainties associated with each parameter.

2.1 SELECTION OF KEY PARAMETERS

The key parameters used in this analysis are the same as those used in Reference 3 for SCD calculations. These are the parameters which significantly impact the calculation of DNBR and include:

Reactor Power

Core Flow Rate (including effects of core bypass flow)

Core Exit Pressure

Core Inlet Temperature

Radial Power Distribution (including Hot Channel Factors)

Axial Peak Magnitude

Axial Peak Location

These seven parameters are used to set limits when performing reload thermal-hydraulic analyses. A statepoint in this analysis is a defined by a combination of all seven of these parameters.

The range of individual key parameter values in this analysis are based on statepoints that are using or will use the SCD DNB methodology. A majority of the statepoints analyzed have mean Minimum DNBR (MDNBR) values close to the statistical design limit itself. Table 1 shows typical statepoints that form the basis for the statistical design limit (Table 1 in the Appendices shows the statepoints analyzed for each plant). Table 4 in the Appendices contains the range of values for each key parameter represented by the analyzed statepoints.

Since this method mechanistically evaluates each statepoint, new or revised statepoints can be easily evaluated in the same manner. If, for example, the plant is uprated to a higher licensed power level or the pressure/temperature points change or a new transient statepoint is calculated, a propagation of the revised conditions about the limiting point would be performed. If the licensed SDL is conservative, no further action would be required. If the statistical DNBR value is higher, appropriate compensatory measures will be applied to ensure the allowable DNB behavior for the statepoint is conservatively bounded.

Duke Power's reload methodology, described in References 4 and 5, gives special attention to the axial power distribution (axial peak location and magnitude) in determining acceptable DNB performance. The axial peak location and magnitudes evaluated in this analysis are concentrated about a selected region. The axial power distribution area of interest is based on the peak magnitudes and locations that are typically predicted during the standard cycle design process. Figures 3A and 3B show a graphic representation of typical axial peak values (Fz) and locations (Z) calculated by the physics codes. Figure 3A is for Oconee and Figure 3B shows the same data for McGuire and Catawba.

2.2 SELECTION OF UNCERTAINTIES

A statistical core design analysis combines the effects of individual key parameter uncertainties that significantly affect DNB. Typical uncertainties for a reactor design are shown in Table 2 {Table 2 in each of the Appendices shows the plant specific values}.

Distributions for the uncertainties are assumed to be either normal or uniform. The basis for the type of distribution assumed for each key parameter is included in the Appendices. Two additional uncertainties are included, one for the CHF correlation and one for code/model conservatism. The CHF correlation uncertainty is based on the standard deviation of the correlation data base and accounts for the correlation's uncertainty in DNB predictions. The code/model uncertainty allows for thermal-hydraulic code uncertainties and simplified versus detailed core model differences.

2.3 PROPAGATION OF UNCERTAINTIES

Multiple random cases are generated for each statepoint by independently varying all key parameters according to their associated uncertainty value and distribution. The SAS (Reference 6) statistical computer package random number function generators are used to create the necessary distributions. The key parameter distributions are calculated individually based on the type of uncertainty distribution and uncertainty magnitude.

There are two different types of uncertainties analyzed. The first type, denoted additive, is an uncertainty that has a fixed value. An example of this is the RCS temperature uncertainty of +/- 4 degrees F (see Table 2). The value is the same number of degrees F everywhere it is applied. The second type of uncertainty is called multiplicative and is based on a percentage of the parameter. An example of this is the radial power distribution uncertainty (3.25% in Table 2). Here,

the radial peak used in each statepoint has an impact on the magnitude of the uncertainty. This statistical method of application accounts for both the uncertainty magnitude and distribution type (normal or uniform).

A total of either 500 or 3000 propagated cases (one case being a set of the seven key parameters) are generated for each statepoint. The different propagation sizes are compared to verify that the statistical behavior is consistent between the two levels of analysis and to be confident that the most limiting SDL is determined. Table 3 contains an example of key parameter propagations that together make up ten DNB cases for a given statepoint. The values were extracted from a typical 500 case propagation.

As stated previously, this analysis method allows for direct evaluation of the impact of increased uncertainties. If an uncertainty value assumed in the original analysis is exceeded in the future, the limiting statepoint can be re-analyzed with the changed value. If the statepoint statistical DNBR does not increase above the licensed limit, no further action is required. If it does, proper compensatory measures can be applied.

2.4 CALCULATION OF THE STATISTICAL DNBR LIMIT

After the VIPRE-01 code is used to calculate the MDNBR's for each case in a statepoint, the code/model and CHF correlation uncertainties are applied and the coefficient of variation (CV) is calculated as

described in Reference 3. Cases that yield either a MDNBR value of less than 1.0 or that exceed the quality limit of the CHF correlation used are excluded from the data base prior to calculating the coefficient of variation. The distribution of MDNBR's is checked for normality by performing the D'Agostino (or D Prime) test on the final set of MDNBR values for each statepoint.

The appropriate Chi Square (Chi^2) and K factor (K) multipliers are determined based on the final number of MDNBR's for each statepoint. The statistical DNBR value for each statepoint is then calculated by the same equation as used in Reference 3,

$$SDL = 1.0 / \{1.0 - (K * Chi^2 * CV)\} \quad .$$

Table 4 contains example results of the mean, standard deviation, coefficient of variation, and the statistical DNBR values calculated for the Table 1 statepoints. {Table 3 in the Appendices contains the plant specific data.}

Table 4 contains two groups of statepoints in separate sections. This is because the statistical DNB evaluations in this analysis were completed at two levels. The first level of evaluation (500 propagated cases/statepoint) is used to determine the DNB behavior over the entire analysis space. The intent of the 500 case runs is to determine DNB behavior with respect to axial and radial peaking conditions, core power level, and changes in fluid conditions.

The second group of statepoints have 3000 cases each and are a selected subset of the first group (denoted by -T after the statepoint number). This group is used to determine the SDL of DNB analyses for each reactor type. Figures 4A (500 cases) and 5A (3000 cases) graphically show the results for Oconee at a selected set of fluid conditions. Figure 6A shows the comparisons of the same axial peak locations and magnitudes for different fluid conditions. Figures 4B, 5B, and 6B show the corresponding graphs for the McGuire/Catawba statepoints.

2.4.1 VARIANCE OF STATISTICAL DNB BEHAVIOR

Comparing all these Figures showing the statistical DNBR for [different axial peak magnitudes (Fz) and locations (Z),] across a range of fluid conditions and for different fuel/reactor types, a significant dependency [on Fz and Z] is observed. [The flat axial peaks (Fz of 1.1 through 1.4)] show a more limiting statistical DNBR behavior than the remaining points. To evaluate this, the sensitivity of DNBR [to axial peak location and magnitude] was evaluated in two manners.

First, the sensitivity of DNB [solely to axial peak] was determined. This was done by [keeping the fluid conditions and radial peak] constant and analyzing [an extended range of axial peaks.] Figure 7A shows the sensitivity of DNB [to axial peak] for the BWC correlation (Oconee). Figure 7B shows the sensitivity for the BWCMV correlation (McGuire/ Catawba).

Two items of interest are displayed in this representation. The first fact is that the slope [reverses for the flat axial peaks low in the core (upper left portion of the figures). This reversal is dependent on both peak magnitude and location.] Secondly, the slope in this area [appears slightly steeper than that] on the remainder of the graph. The absolute value of the slope is the important factor in determining the statistical response of a key parameter (slope is the sensitivity of DNBR [to axial peaking).] This indicates that [the flat axial power distribution area] will have a different statistical behavior than the area where the slope is less steep. Note the agreement between Figures 7A and 7B (different fuel assembly designs and CHF correlations). This consistency continues to affirm that this observation is a mechanistic DNB behavior.

The second sensitivity evaluation varied all key DNB parameters of a statepoint by their uncertainty magnitude and calculated the slope for each (Δ DNBR / Δ parameter). These results are shown in Table 5. This type of analysis shows [an increase in the sensitivity (slope) of every key parameter for the axial peaking area with the higher statistical DNBR behavior (flat axial peaks of Statepoints 6 and 25). This increased sensitivity results in a larger standard deviation (σ) and CV, and therefore higher SDL.]

Additionally, there is another phenomenon that is also present with [the same group of flat axial peaks. Figures 8A and 8B show the MDNBR axial location with respect to Z for various Fz's using the BWC and BWCMV CHF correlations. The flat, bottom peaked axial power

distribution shapes (reversed slope) are also end of channel (EOC) limited, meaning the MDNBR always occurs at the last heated node. These two facts, which are probably inter-related, cause higher statistical DNBR behavior. This higher sensitivity (greater slope) of DNBR to most key parameters demonstrated in Table 5 results in a higher SDL for the flat axial peak, EOC limited statepoints.]

This more limiting statistical behavior has been evaluated for generic applicability and was found to occur for each reactor type and CHF correlation as shown by Figures 4A, 4B, and 4C. Figure 4C is the same core geometry and statepoints as 4B but with the DCHF-1 CHF correlation (Reference 7). The statistical behavior [is independent of fluid conditions as shown by Figures 6A and 6B. Specifically, Figure 6B shows this dependence on axial power distribution even when the fluid conditions are different.] All these factors point to the conclusion that this more limiting statistical variance [associated with axial power distribution] is a generic, mechanistic DNB behavior and as such is applicable to any CHF correlation and core model (Oconee, McGuire, Catawba, etc).

2.4.2 FLEXIBILITY OF THE ANALYSIS METHOD FOR MODIFIED PARAMETER EVALUATIONS

Several different comparisons are included to demonstrate the ability of this method to address changes in core models or uncertainty distributions. Table 6 shows the results of three different

evaluations. The first section includes two points that show the results of changing a single key parameter's uncertainty distribution from normal to uniform. Statepoints 33 and 34 from the McGuire/Catawba evaluation were identical in all respects except for the RCS flow distribution. In Statepoint 33, the distribution was normal (same for all other statepoints) and in Statepoint 34 the distribution was changed to uniform. The affects of this single parameter distribution change is readily calculated and shown to be negliable.

The section has two points that show the impact of a VIPRE-01 model change. Statepoints 37 and 38 both have identical conditions and uncertainties. Statepoint 37 used the eight channel McGuire/Catawba model from Reference 3 while Statepoint 38 used the fourteen channel model from Reference 8. Again, the comparison is easily accomplished and Table 6 shows the difference in the statistical DNBR values.

The third section contains a group of points that shows the comparison between Westinghouse OFA and Babcock Wilcox Mark-BW 17x17 mixing vane fuel. Four statepoints were run with both fuel types at the same fluid and power distribution conditions. The difference between the models is the changed subchannel flow areas, wetted and heated perimeters, gap connections, and grid form loss coefficients to correctly reflect each fuel type. The comparison shows that the OFA fuel model's behavior is the same as the Mark-BW model and the Mark-BW SDL conservatively bounds OFA fuel for McGuire and Catawba analyses.

2.4.3 FUTURE APPLICATIONS OF SCD METHODOLOGY

The fact that this analysis method is direct allows this statistical approach to be applied to any fuel type or reactor using an NRC approved thermal-hydraulic model and CHF correlation. Even if DNB behavior showed a stronger or weaker functionality for a different core design or CHF correlation, this method would correctly reflect this behavior in the statistical design limit or limits determined. If a new CHF correlation is used by Duke or if a different plant is analyzed, an additional Appendix will be submitted to the NRC detailing the model, CHF correlation, uncertainties, and statepoints used to determine the SDL for the plant specified.

2.5 APPLICATION OF THE SCD LIMIT

Since the statistical DNBR behavior demonstrated in this analysis shows [two consistent, distinct behavior modes, two statistical design limits can be derived that will conservatively cover the entire range of DNB analysis space without penalizing all points for the more limiting statistical behavior of a specified area. This is done by explicitly defining the area in terms of axial power distribution where the more limiting statistical behavior occurs and applying two separate and conservative statistical design limits.]

The method for applying [two separate Statistical Design Limits is depicted in Figure 9. This graph shows how the two areas would look for a typical application. {The specific SDL limits and applicable areas for each plant/fuel type/CHF correlation are shown in Figure 1 of the Appendices.} The two separate limits are greater than the largest statepoint statistical DNBR in each area.] Additionally, DNB analyses may be performed using a design DNBR limit (DDL) which includes margin above the statistical design limit [for each area.]

Should an analysis be performed that uses a new CHF correlation, for a non-Duke reactor, or for a new fuel design, statepoints [in each axial power distribution region] will be analyzed to confirm the generic DNB behavior assumption and to determine the SDL [for each area.] This information will be reported to the NRC by submitting a new Appendix similar to Appendix A and B.

3.0 CONCLUSIONS

The methodology described in this report shows the major factors affecting statistical DNB behavior are [the axial power distribution, the individual key parameter uncertainties, and the CHF correlation.] Since the statistical DNB behavior is controlled by these global parameters, [two different statistical limits can be derived to provide DNBR protection for all areas of application. Separate limits

will provide more flexibility in cycle core design than a single limit.]

This analysis method can be used to evaluate new fluid statepoints or revised uncertainties directly to determine the statistical limit. As long as the SDL is not exceeded, the established limits can be applied unmodified. If the statistical DNBR value for the new conditions is higher than the current limit, appropriate compensation measures such as increasing the design DNBR limit for the statepoint or using available margin between the design and statistical limits can be used. These actions penalize the statepoint by reducing the allowable radial peaking to ensure acceptable DNB behavior.

Since Duke's statistical thermal-hydraulic design methodology relies solely on DNB behavior, any PWR facility can be analyzed using this approach with an appropriate core model and bounding uncertainties. Also, new fuel designs or critical heat flux correlations can be evaluated to determine the appropriate SDL. The results of such an analysis would be submitted to the NRC for approval in the form of an additional Appendix that would contain the following:

1) Identification of the plant, fuel type, and CHF correlation with appropriate references to the approved fuel design and CHF correlation topicals.

2) Statement of the thermal-hydraulic code and model used with appropriate references to the approved code topical report.

3) A list of the key parameters, their uncertainty values, and distributions.

4) A list of the statepoints analyzed.

5) The Statistical Design Limits and how they are applied.

Table 7 contains a listing of some anticipated conditions and the corresponding actions.

4.0 SUMMARY

This report describes the analysis method used to determine the statistical core design DNB limit for reactor core thermal-hydraulic analyses. This methodology is used to account for the impact on DNB of the uncertainties of key parameters such as power, pressure, temperature, and core peaking. The methodology determines the statistical behavior of DNBR with respect to all these key parameters for many different statepoints and provides a method of applying the SCD DNB limits derived.

Duke has observed a significant statistical DNB behavior dependency [on the axial power distribution for all statepoints analyzed. Two distinct areas with different DNB behavior can be defined that are independent of fuel type and CHF correlation. To take advantage of this generic DNB performance, two separate statistical design limits are used to conservatively envelope the analysis space.] The

specific SCD DNB limits for the Oconee and McGuire/Catawba units are stated in the Conclusions section of the attached Appendices.

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TABLE 1. Typical Reactor SCD Statepoints

Stpt #	Power	Pressure	Temperature	Flow	Axial Peak	FΔh
DNB Limit Line Statepoints						
1	118%	2455 psia	589.8 deg F	385 Kgpm	1.20 @ 0.2	1.610
3	118%	2455 psia	589.8 deg F	385 Kgpm	1.20 @ 0.5	1.582
4	118%	2455 psia	589.8 deg F	385 Kgpm	1.20 @ 0.7	1.554
12	118%	2455 psia	589.8 deg F	385 Kgpm	1.55 @ 0.7	1.500
14	118%	2455 psia	589.8 deg F	385 Kgpm	1.80 @ 0.8	1.265
17	120%	1945 psia	561.4 deg F	385 Kgpm	1.55 @ 0.5	1.500
26	75%	2455 psia	629.4 deg F	385 Kgpm	1.55 @ 0.5	1.500
Loss Of RCS Flow Transient Statepoints						
21	96.1%	2286 psia	575.3 deg F	309.5 Kgpm	1.80 @ 0.2	1.606
24	96.1%	2286 psia	575.3 deg F	309.5 Kgpm	1.20 @ 0.3	1.641
29	49.1%	2283 psia	558.5 deg F	261 Kgpm	1.55 @ 0.7	2.798
Uncontrolled Bank Withdrawal Transient Statepoint						
33	80.8%	2444 psia	558.4 deg F	250.6 Kgpm	1.55 @ 0.7	1.725
Nominal Operating Statepoints						
16	100%	2250 psia	561.6 deg F	385 Kgpm	1.30 @ 0.2	2.103
27	100%	2250 psia	561.6 deg F	385 Kgpm	1.55 @ 0.7	1.500

TABLE 2. Typical Statistically Treated Uncertainties

Parameter	Uncertainty / Standard Deviation	Type of Distribution
Reactor Power	+/- 2% / +/- 1.22%	Normal
Core Flow		
Measurement	+/- 2.2% / +/- 1.34%	Normal
Bypass Flow	+/- 1.5%	Uniform
Pressure	+/- 30 psi	Uniform
Temperature	+/- 4 deg F	Uniform
$F^N_{\Delta H}$		
Measurement	+/- 3.25% / 1.98%	Normal
$F^E_{\Delta H}$	+/- 3.0% / 1.82%	Normal
Spacing	+/- 2.0% / 1.22%	Normal
F_Z	+/- 4.41% / 2.68%	Normal
Z	+/- 6 inches	Uniform
DNBR		
Correlation	+/- 16.78% / 10.2%	Normal
Code/Model	[+/- 5.0% / 3.04%]	Normal

TABLE 3. Typical Monte Carlo Propagation Statepoint Values

(Values After Uncertainty Propagation of Stpt. # 1 from TABLE 1)

Base Statepoint

Case#	Power	Press	Temp	Flow	Fz	Z	FΔh
0	118.0%	2455	589.8	100.0%	1.200	0.200	1.610

Propagation

Case#	Power	Press	Temp	Flow	Fz	Z	FΔh
1	118.2%	2439	586.6	97.8%	1.179	0.187	1.576
50	117.1%	2474	592.2	100.9%	1.188	0.181	1.631
100	117.9%	2465	591.9	99.5%	1.208	0.165	1.568
150	117.4%	2437	588.0	98.2%	1.191	0.225	1.620
200	120.2%	2482	592.3	100.5%	1.190	0.222	1.604
250	116.5%	2455	590.9	103.9%	1.219	0.215	1.652
300	118.6%	2444	586.5	94.2%	1.214	0.170	1.598
350	118.6%	2443	589.5	98.0%	1.147	0.163	1.633
400	119.4%	2435	590.3	103.1%	1.186	0.169	1.586
450	114.7%	2466	586.9	100.0%	1.107	0.218	1.604
500	117.4%	2437	591.8	99.8%	1.234	0.186	1.570

TABLE 4. Example of Typical Statepoint Statistical Results

Section 1 - 500 Case Runs

Statepoint #	Mean	σ	Coefficient of Variation	Statistical DNBR
DNB Limit Line Statepoints				
1	1.537	0.229	0.1492	1.397
3	1.572	0.231	0.1469	1.376
4	1.517	0.210	0.1387	1.348
12	1.517	0.194	0.1279	1.312
14	1.508	0.184	0.1222	1.294
17	1.520	0.196	0.1292	1.317
26	1.595	0.209	0.1313	1.323
Loss Of RCS Flow Transient Statepoints				
21	1.642	0.215	0.1311	1.323
24	1.797	0.270	0.1501	1.389
29	1.702	0.222	0.1305	1.321
Uncontrolled Bank Withdrawal Transient Statepoint				
33	1.914	0.238	0.1244	1.301
Nominal Operating Statepoints				
16	1.660	0.257	0.1546	1.404
27	2.245	0.260	0.1160	1.275

TABLE 4 - continued Example of Typical Statepoint Statistical Results

Section 2 - 3000 Case Runs

Statepoint #	Mean	σ	Coefficient of Variation	Statistical DNBR
DNB Limit Line Statepoints				
3-T	1.524	0.235	0.1540	1.363
4-T	1.485	0.220	0.1484	1.345
12-T	1.508	0.201	0.1335	1.300
14-T	1.503	0.191	0.1269	1.281
Nominal Operating Statepoint				
16-T	1.659	0.268	0.1613	1.387

TABLE 5. Individual Key Parameter Slopes At Statepoint Conditions

Key Parameter*	Stpt 6	Stpt 25	Stpt 9	Stpt 21
Power	3.54%	3.51%	2.11%	2.37%
Pressure	0.16%	0.11%	0.08%	0.07%
Temperature	2.83%	2.02%	1.56%	1.42%
Flow	3.41%	2.68%	1.79%	1.46%
FΔH	4.19%	3.37%	2.46%	2.15%
Fz	1.24%	1.00%	0.91%	1.14%
Z	1.04%	0.63%	3.80%	2.39%
Statepoint SDL =	1.385	1.388	1.325	1.323
Axial Power Dist. (Fz @ Z)	1.3@0.2	1.2@0.3	1.3@0.8	1.8@0.2

The statepoints listed above are from the McGuire/Catawba 500 case runs. [All four statepoints are identical except for the axial power distributions and maximum FΔh.] Statepoints 6 and 25 [have the location of MDNBR at the end of the heated length or channel exit.] Statepoints 9 and 21 [have the location of MDNBR at some intermediate point in the upper third of the channel (not at the exit).]

* All values shown are in %DNBR per unit of parameter (Δ DNBR / Δ parameter). For example, the first entry in the table of [3.54%] means a [3.54%] DNBR change for every 1% power change.)

Table 6. Uncertainty and Model Changes - Impact On Statistical DNBR Behavior

Uncertainty Distribution Change

The following two statepoints show the change in the statistical behavior for a fixed set of conditions if the RCS flow uncertainty distribution is changed from normal to uniform.

Statepoint #	RCS Flow Uncertainty Dist.	Coefficient Of Variation	Statistical DNBR
33	Normal	0.1244	1.301
34	Uniform	0.1226	1.295

Thermal-Hydraulic Model Detail Change

The following two statepoints show the change in the statistical behavior for a fixed set of conditions using two different VIPRE-01 models.

Statepoint #	McGuire/Catawba VIPRE-01 Model	Coefficient Of Variation	Statistical DNBR
37	8 Channel	0.1244	1.301
38	14 Channel	0.1256	1.305

Minor Fuel Geometry and Design Changes

The following eight statepoints show the change in the statistical behavior for the geometry and form loss coefficient changes between Mark-BW and OFA fuel assemblies for the same fluid and peaking conditions.

MARK-BW			OFA		
Statepoint #	Coefficient Of Variation	Stat. DNBR	Statepoint #	Coefficient Of Variation	Stat. DNBR
6	0.1489	1.385	40	0.1518	1.397
12	0.1279	1.312	41	0.1258	1.306
14	0.1222	1.294	42	0.1212	1.291
16	0.1546	1.404	43	0.1512	1.391

TABLE 7. SDL Evaluation And Re-Submittal Criteria

The following table lists different events or conditions that would require an evaluation of the applicability of an approved SDL and the subsequent actions based on the results of the analysis.

CONDITION	ACTION
Revised uncertainty larger than the limiting value used in the original analysis.	SDL $\leq$ Limit, No Action. SDL > Limit, Specifically compensate.
Revised uncertainty distribution.	SDL $\leq$ Limit, No Action. SDL > Limit, Specifically compensate.
New statepoint.	SDL $\leq$ Limit, No Action. SDL > Limit, Specifically compensate.
Minor modifications to the current fuel design.	SDL $\leq$ Limit, No Action. SDL > Limit, Specifically compensate.
Change to a new fuel design/fuel type.	Evaluate, re-submit a new Appendix for NRC approval regardless of SDL values.
A new or modified CHF correlation.	Evaluate, re-submit a new Appendix for NRC approval regardless of SDL values.
Duke analysis of a non-Duke reactor.	Evaluate, re-submit a new Appendix for NRC approval regardless of SDL values.
New Thermal-Hydraulic Code.	Evaluate, re-submit a new Appendix for NRC approval regardless of SDL values.

FIGURE 1

RSM BASED SCD FLOWCHART

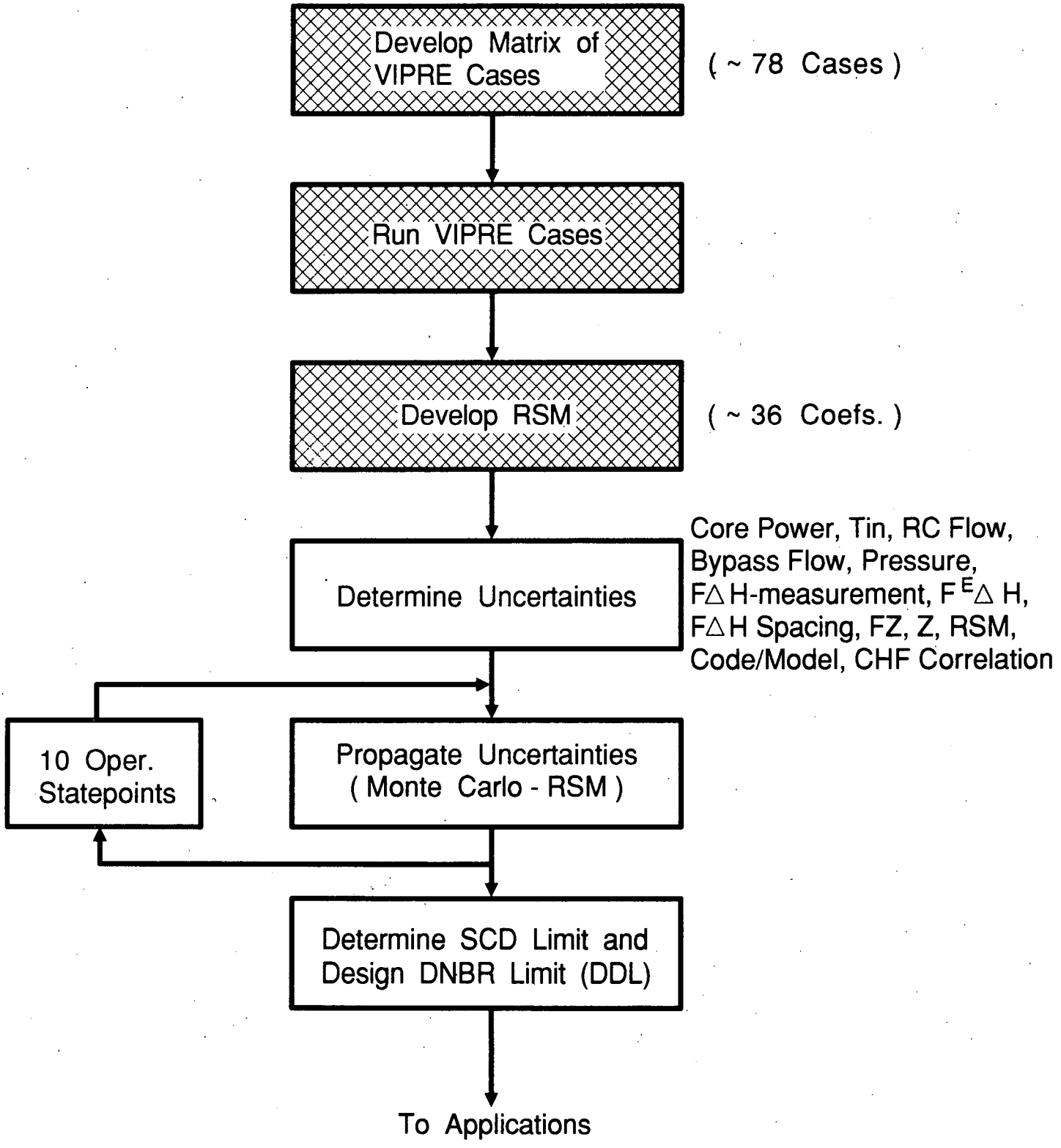

FIGURE 2

REVISED SCD FLOWCHART

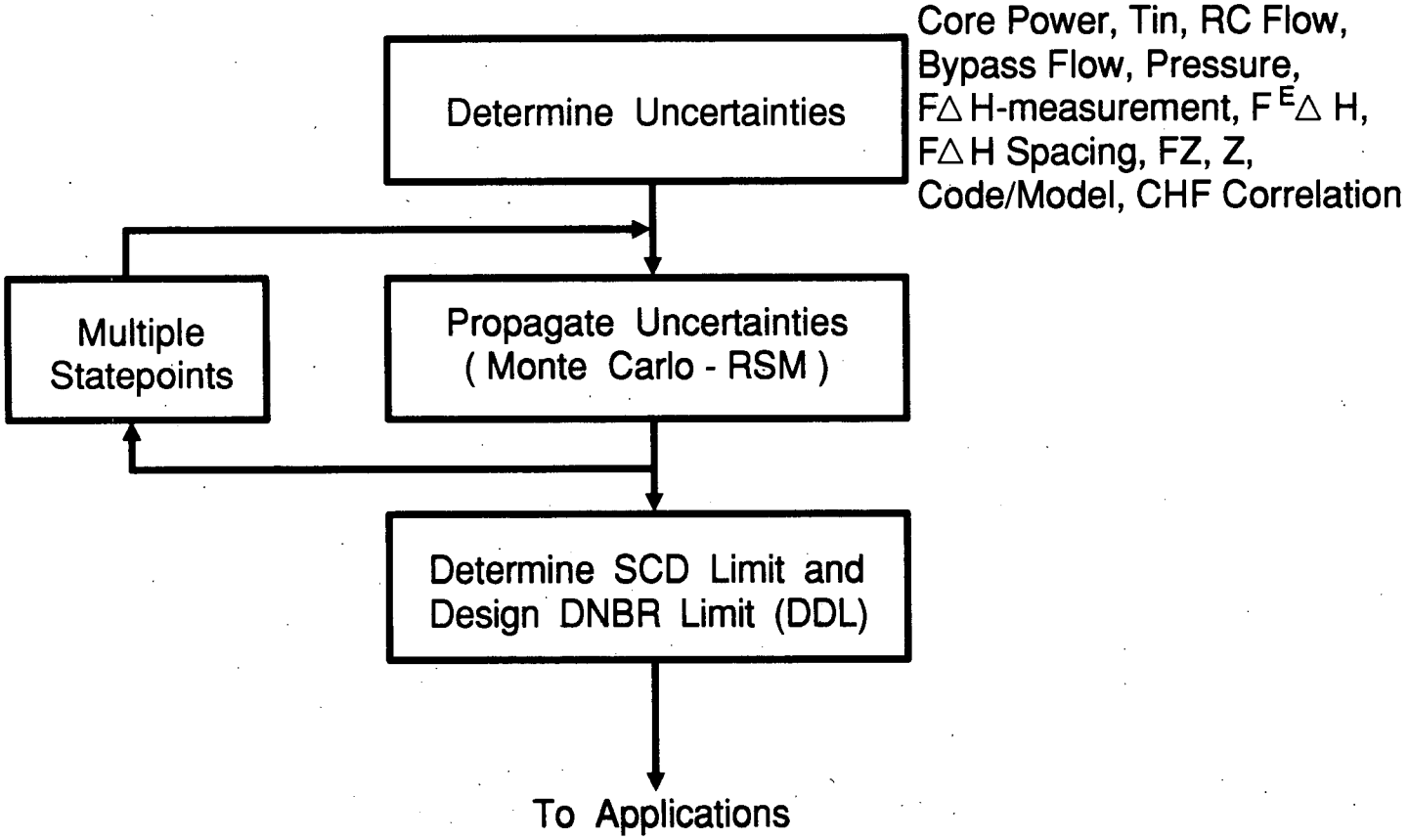

FIGURE 3A Oconee Physics Code Axial Power Distributions (Peak Magnitude and Locations)

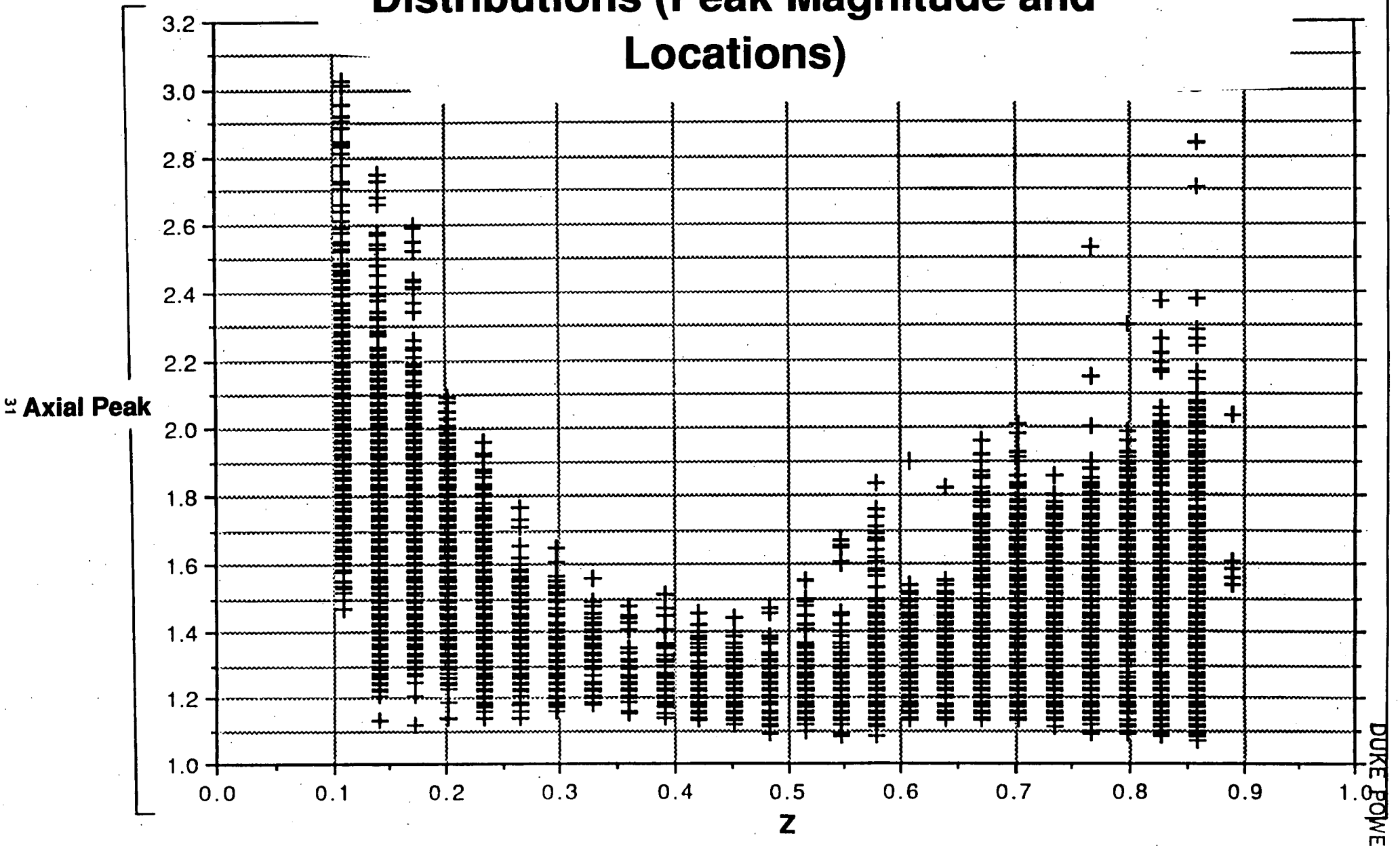

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FIGURE 3B M/C Physics Code Axial Power Distributions (Peak Magnitude and Location)

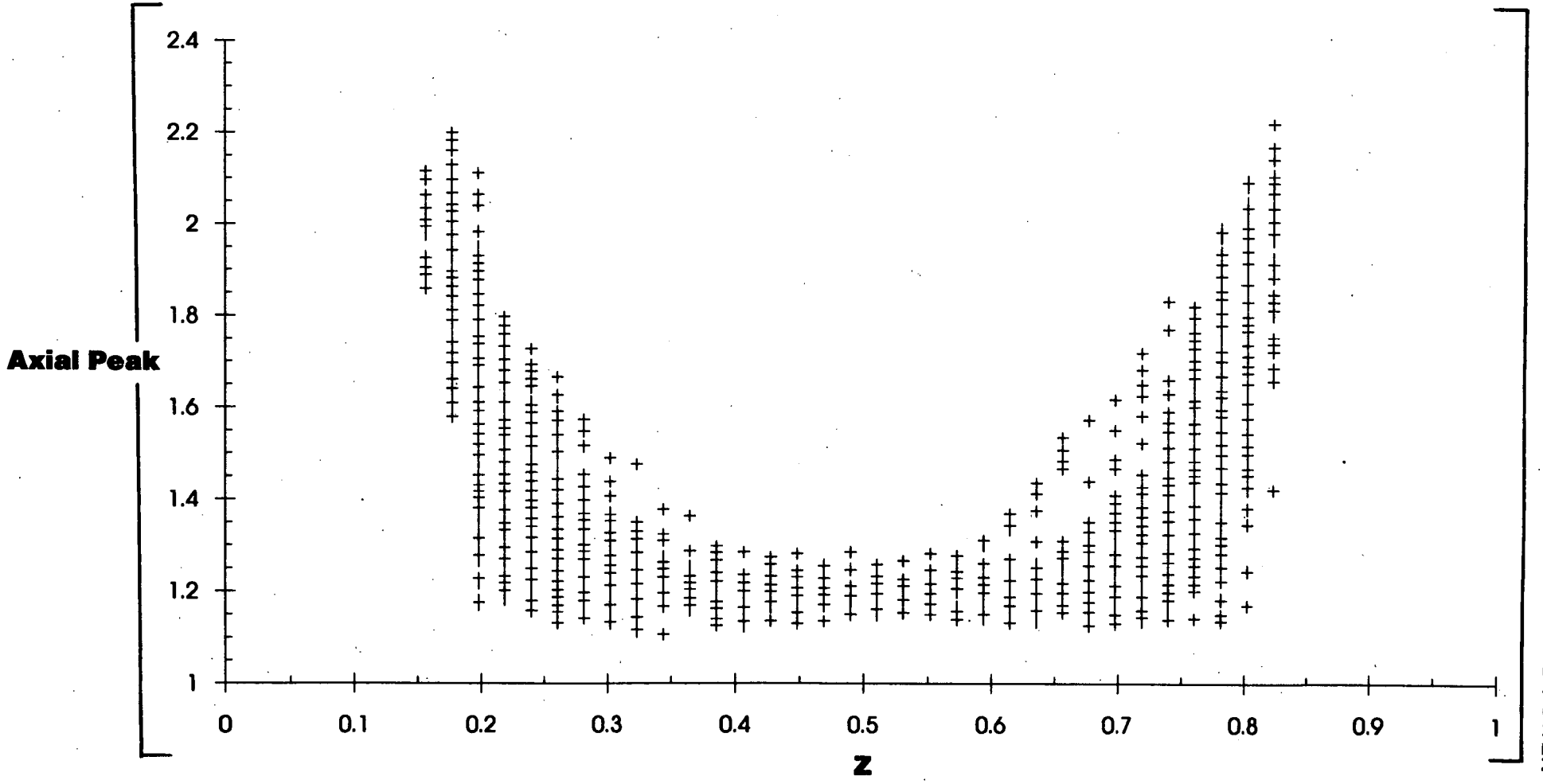

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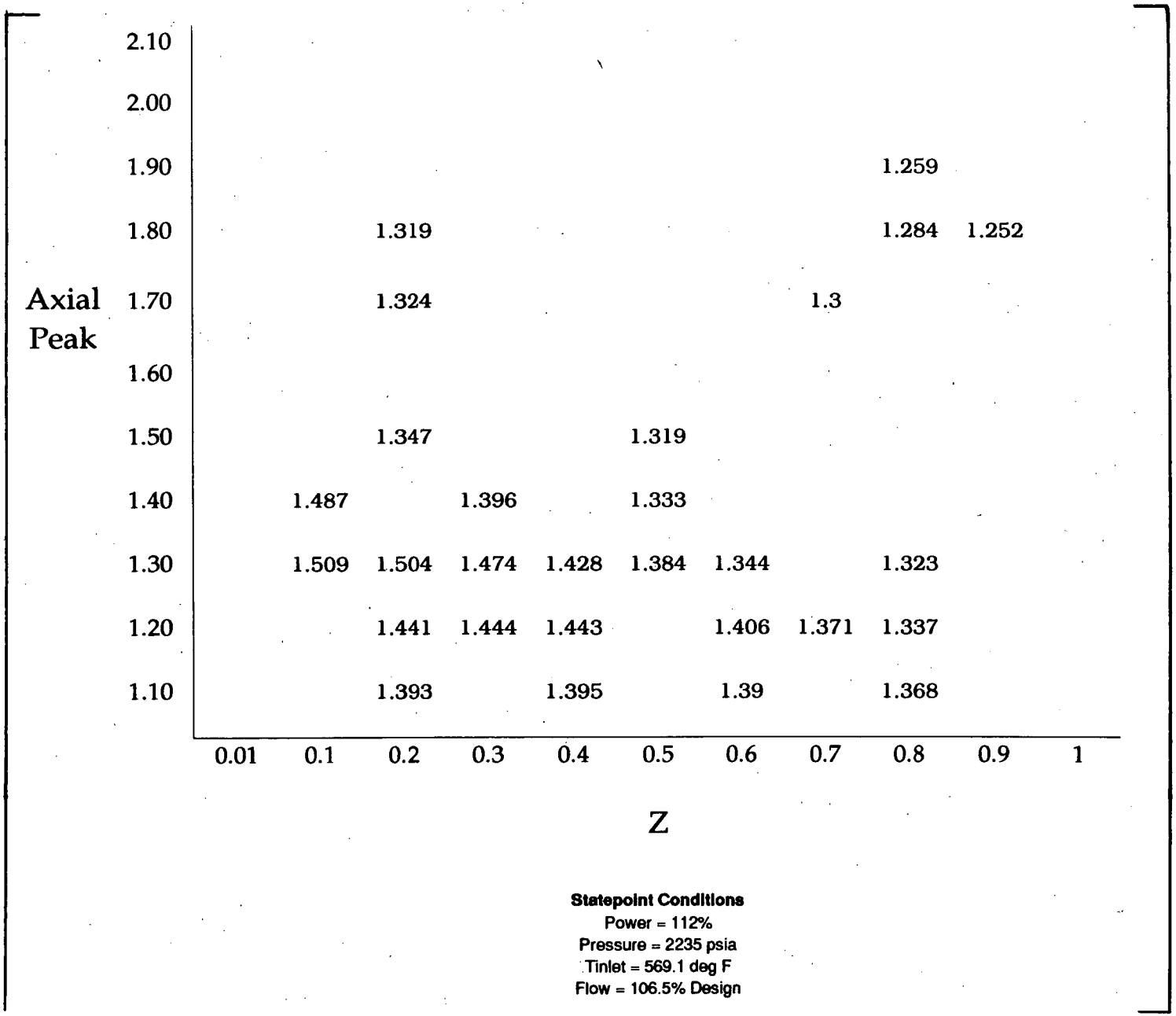
FIGURE 4A
Oconee SDL Distribution At Constant Conditions, BWC

500 Case Propagations



Statepoint Conditions
Power = 112%
Pressure = 2235 psia
Tinlet = 569.1 deg F
Flow = 106.5% Design

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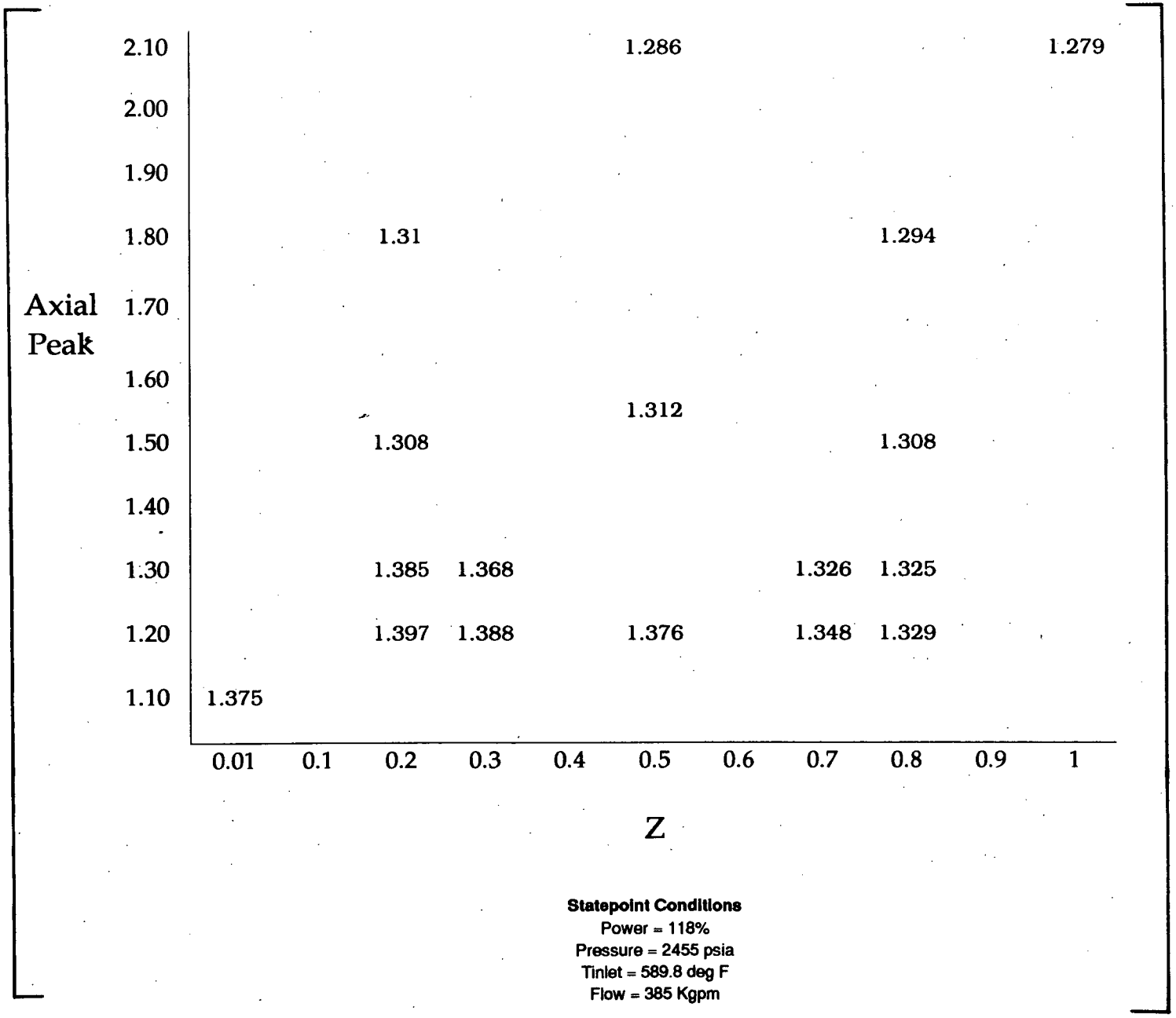
FIGURE 4B
M/C SDL Distribution At Constant Conditions, BWCMV

500 Case Propagations



Statepoint Conditions
Power = 118%
Pressure = 2455 psia
Tinlet = 589.8 deg F
Flow = 385 Kgpm

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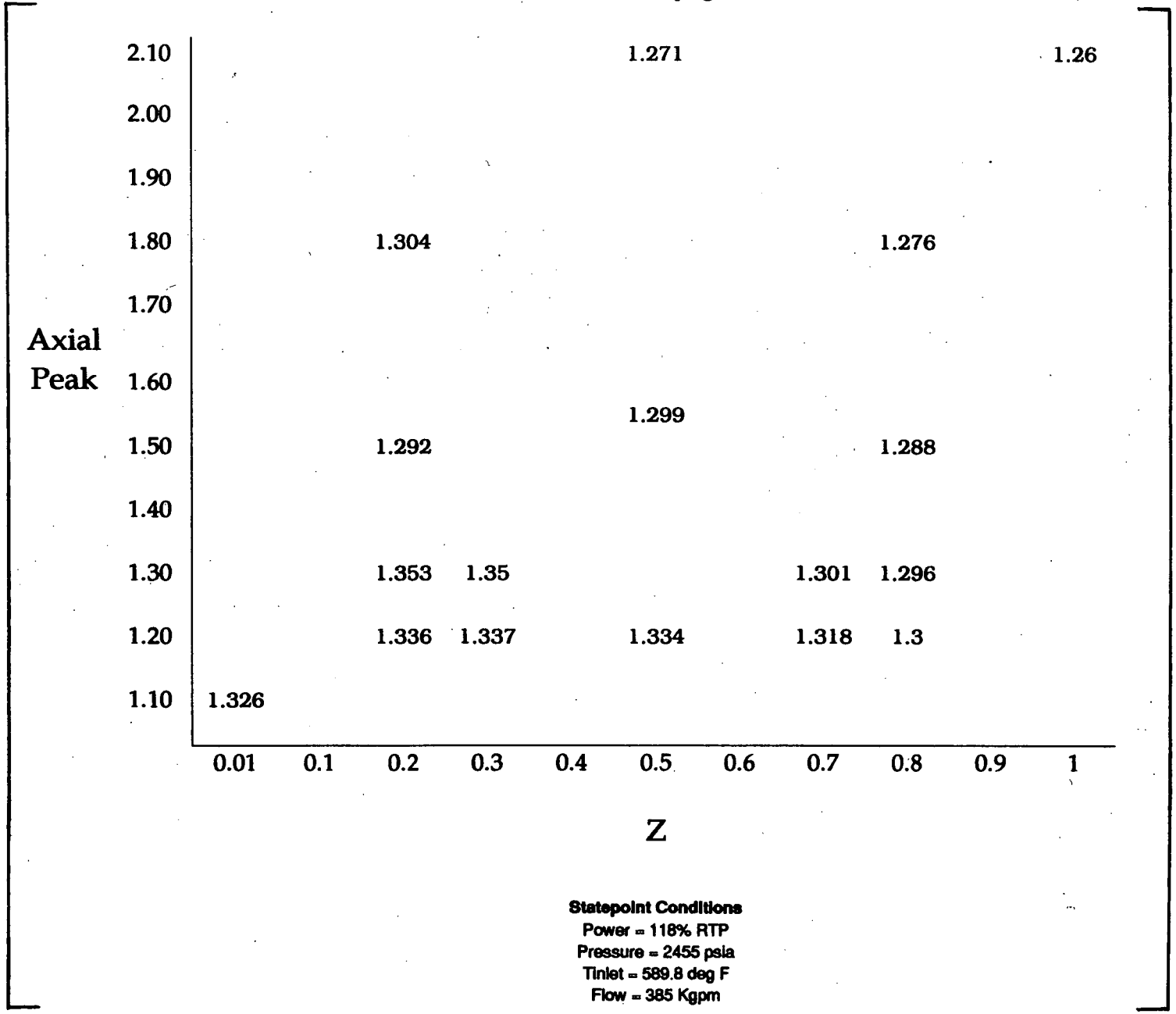
FIGURE 4C

M/C SDL Distribution At Constant Conditions, DCHF-1

500 Case Propagations



Statepoint Conditions
Power = 118% RTP
Pressure = 2455 psia
Tinlet = 589.8 deg F
Flow = 385 Kgpm

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FIGURE 5A
Oconee SDL's For 3000 Case Statepoints, BWC

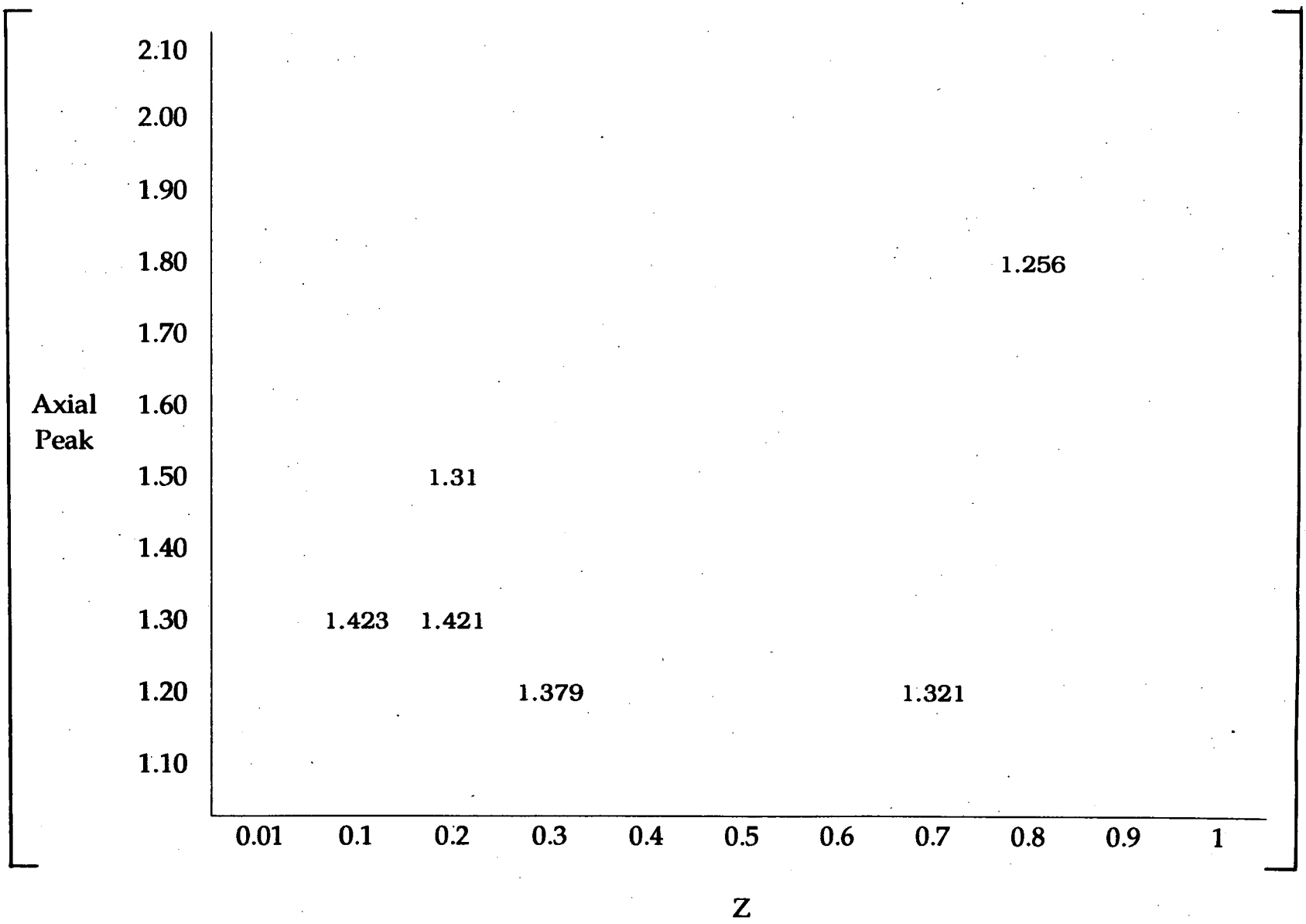

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FIGURE 5B
M/C SDL's For 3000 Case Statepoints, BWCMV

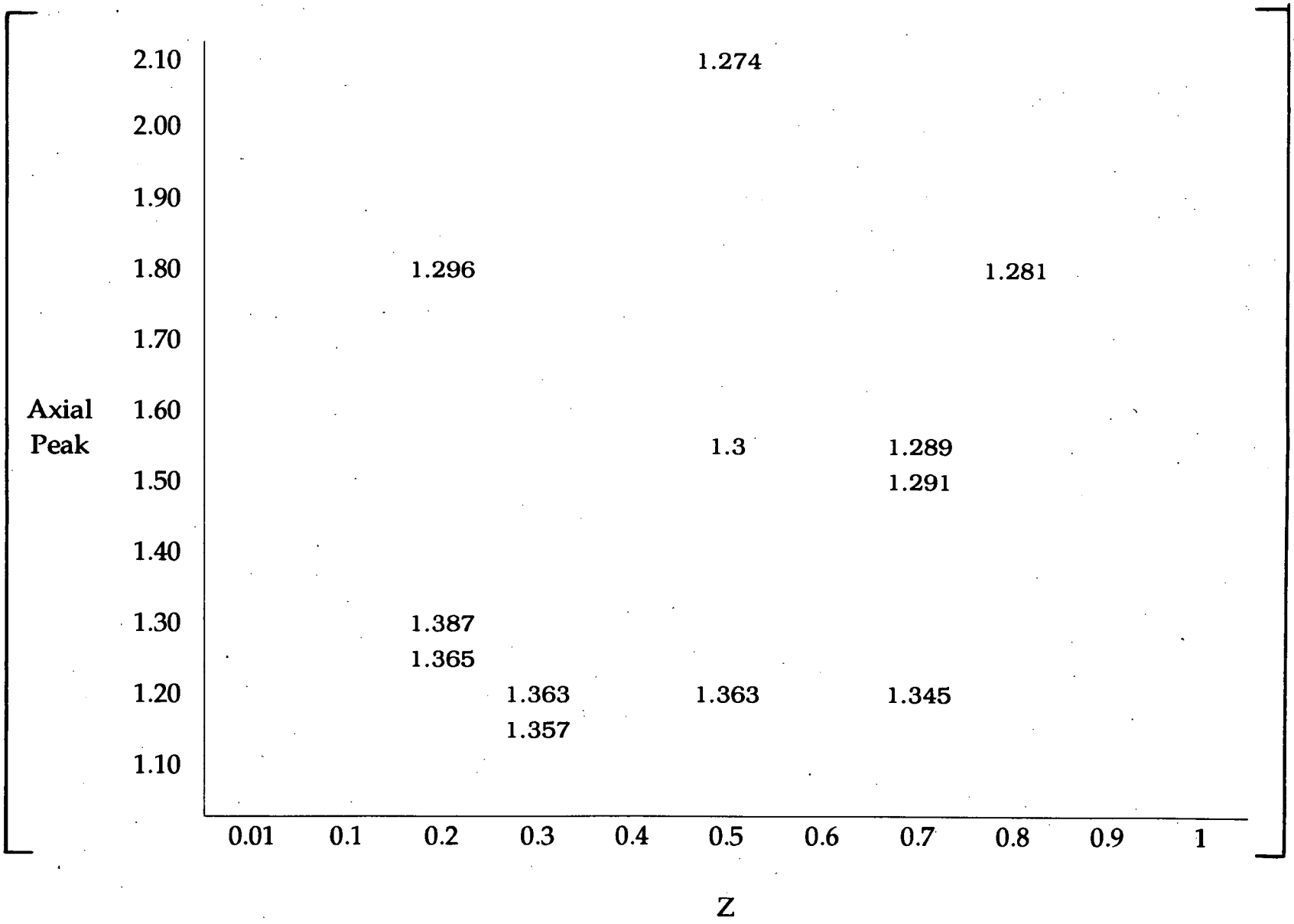

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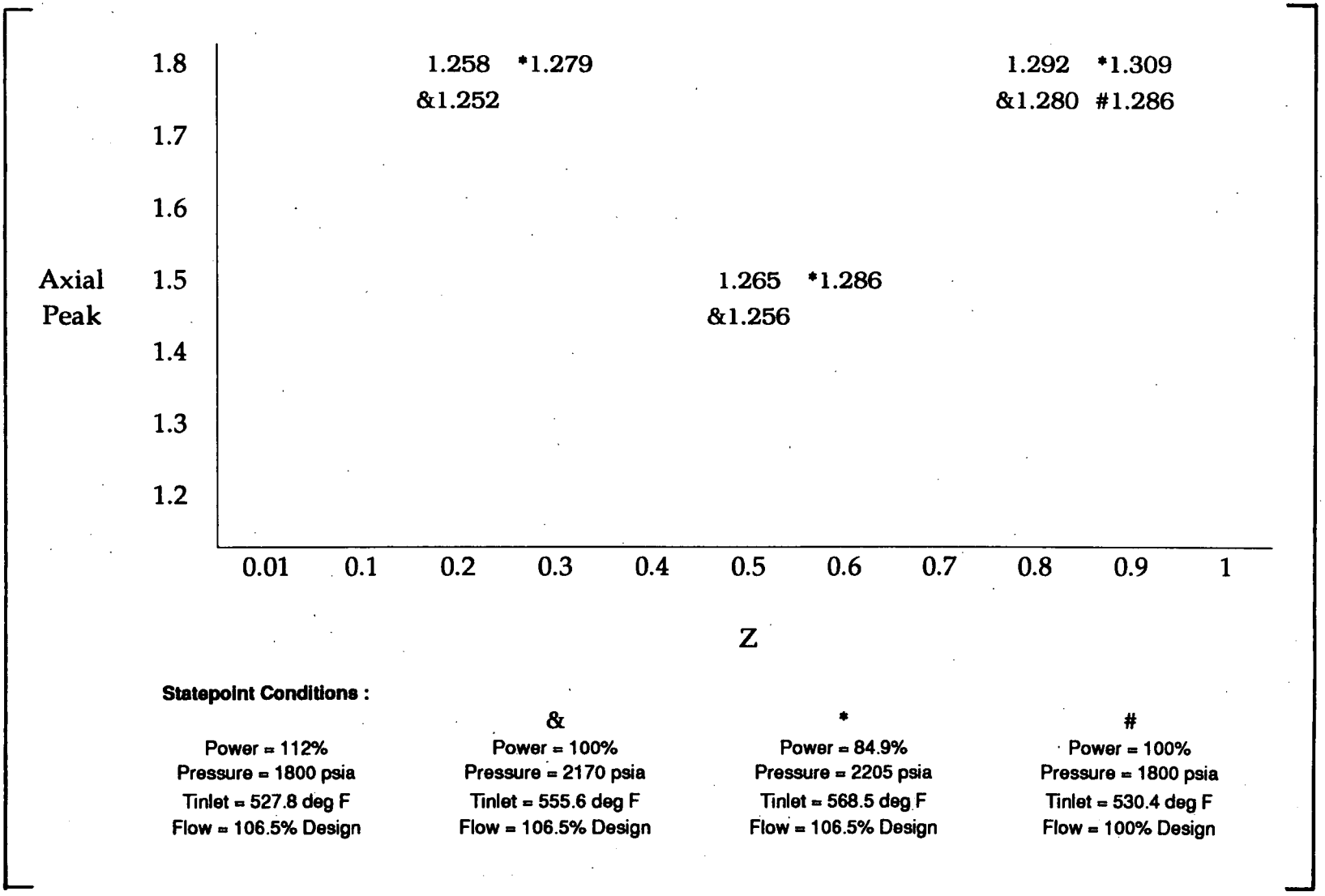
FIGURE 6A
Oconee SDL's For Various Conditions



Statepoint Conditions :

	&	*	#
Power = 112%	Power = 100%	Power = 84.9%	Power = 100%
Pressure = 1800 psia	Pressure = 2170 psia	Pressure = 2205 psia	Pressure = 1800 psia
Tinlet = 527.8 deg F	Tinlet = 555.6 deg F	Tinlet = 568.5 deg F	Tinlet = 530.4 deg F
Flow = 106.5% Design	Flow = 106.5% Design	Flow = 106.5% Design	Flow = 100% Design

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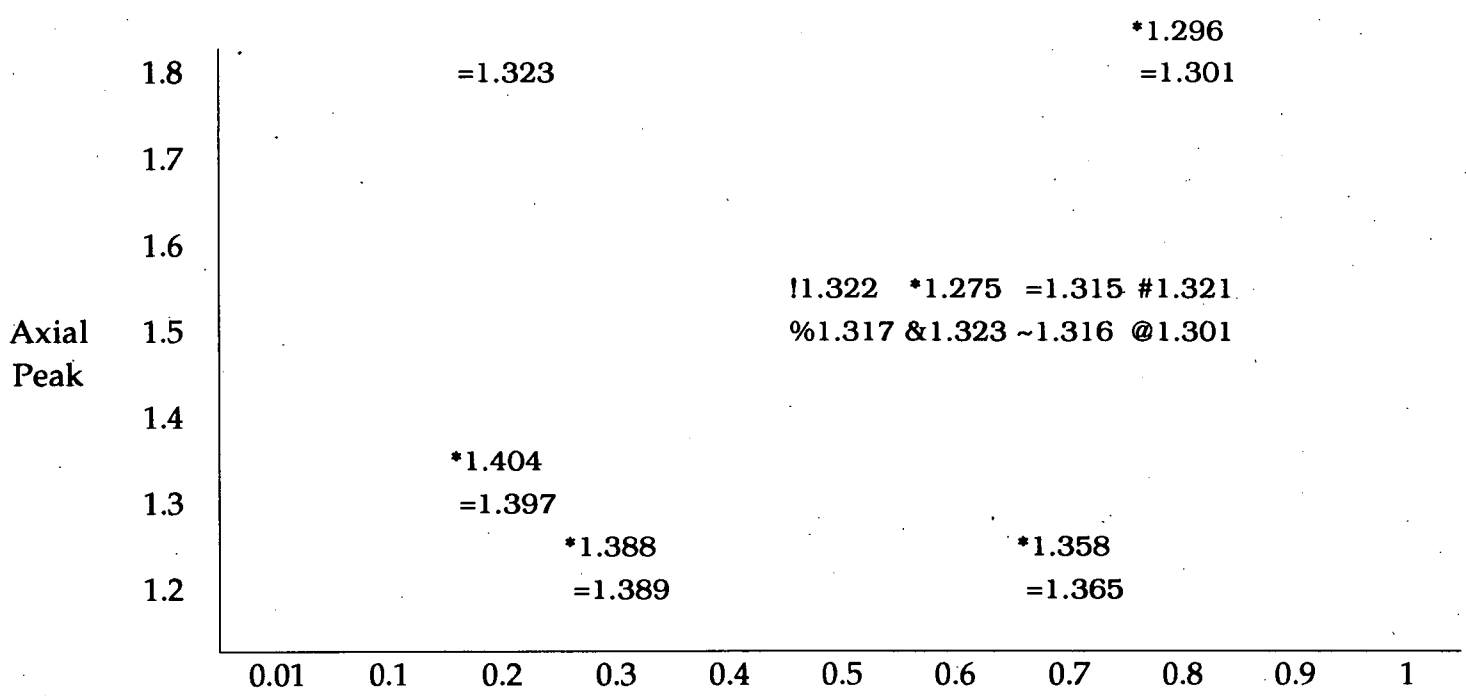
FIGURE 6B
M/C SDL's For Various Conditions



Statepoint Conditions :

=	#	*	~
Power = 96.1%	Power = 49.1%	Power = 100%	Power = 115%
Pressure = 2285.9 psia	Pressure = 2283 psia	Pressure = 2250 psia	Pressure = 2230 psia
Tinlet = 575.3 deg F	Tinlet = 558.5 deg F	Tinlet = 561.6 deg F	Tinlet = 575.0 deg F
Flow = 309.54 Kgpm	Flow = 261.03 Kgpm	Flow = 385.0 Kgpm	Flow = 381.1 Kgpm

%	&	@	!
Power = 120%	Power = 75%	Power = 80.8%	Power = 95.7%
Pressure = 1945 psia	Pressure = 2455 psia	Pressure = 2444 psia	Pressure = 2320 psia
Tinlet = 561.4 deg F	Tinlet = 629.4 deg F	Tinlet = 558.4 deg F	Tinlet = 561.9 deg F
Flow = 385.0 Kgpm	Flow = 385.0 Kgpm	Flow = 250.6 Kgpm	Flow = 274.1 Kgpm

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FIGURE 7A Sensitivity of DNBR to Axial Power Distribution, BWC

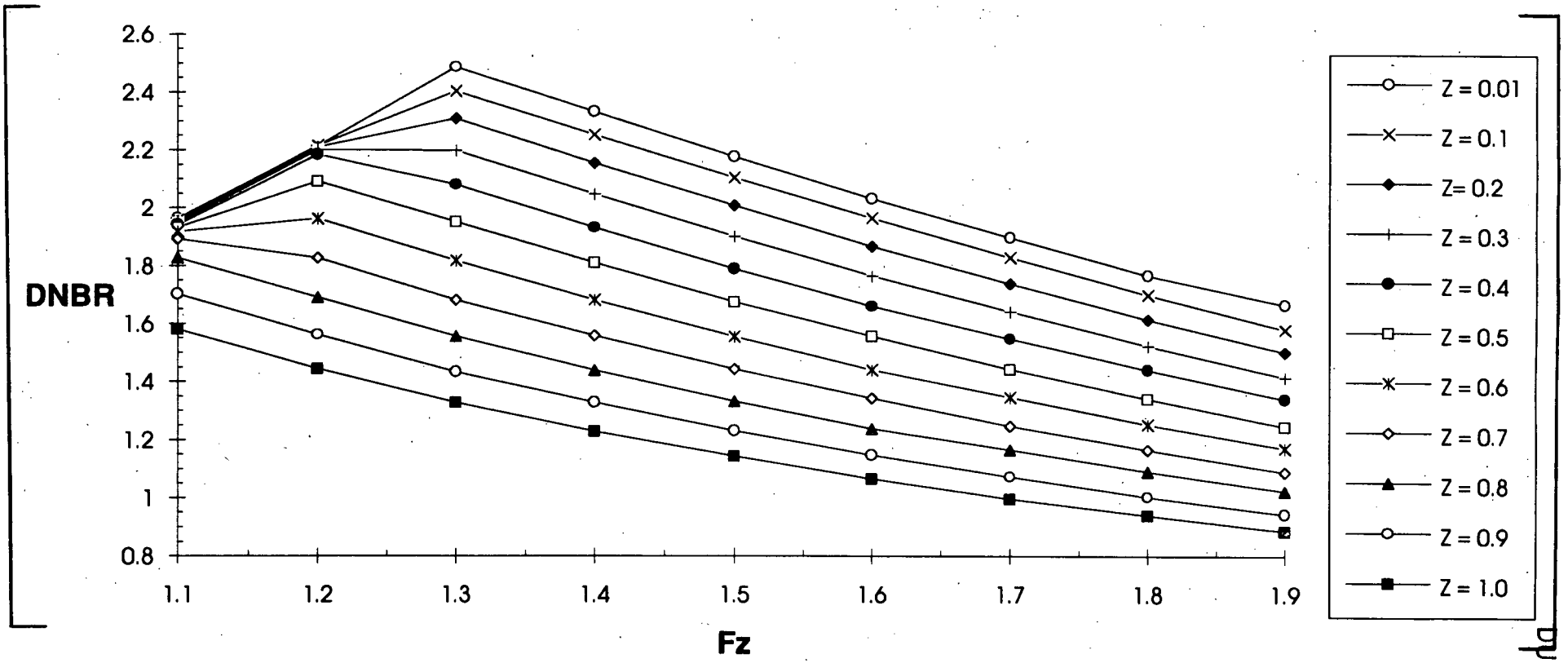

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FIGURE 7B Sensitivity of DNBR to Axial Power Distribution, BWCMV

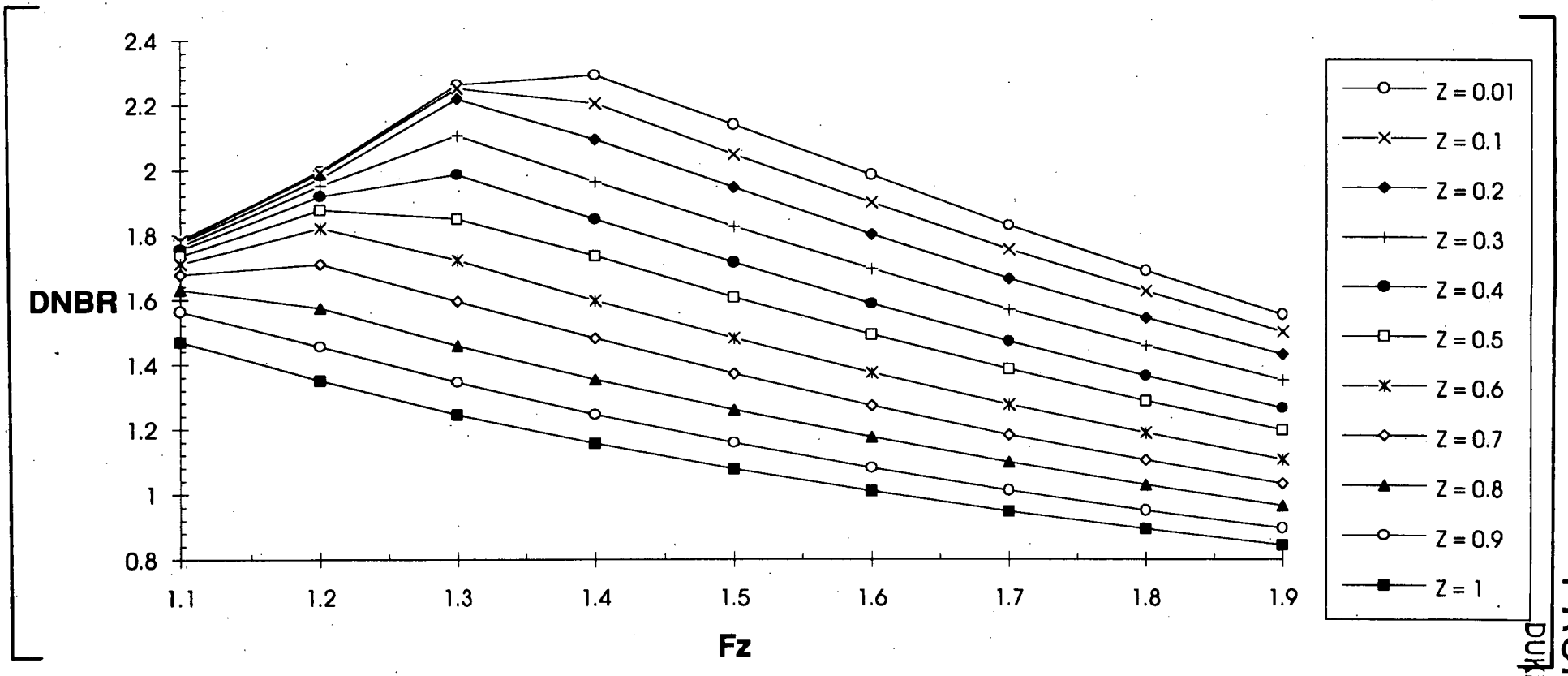

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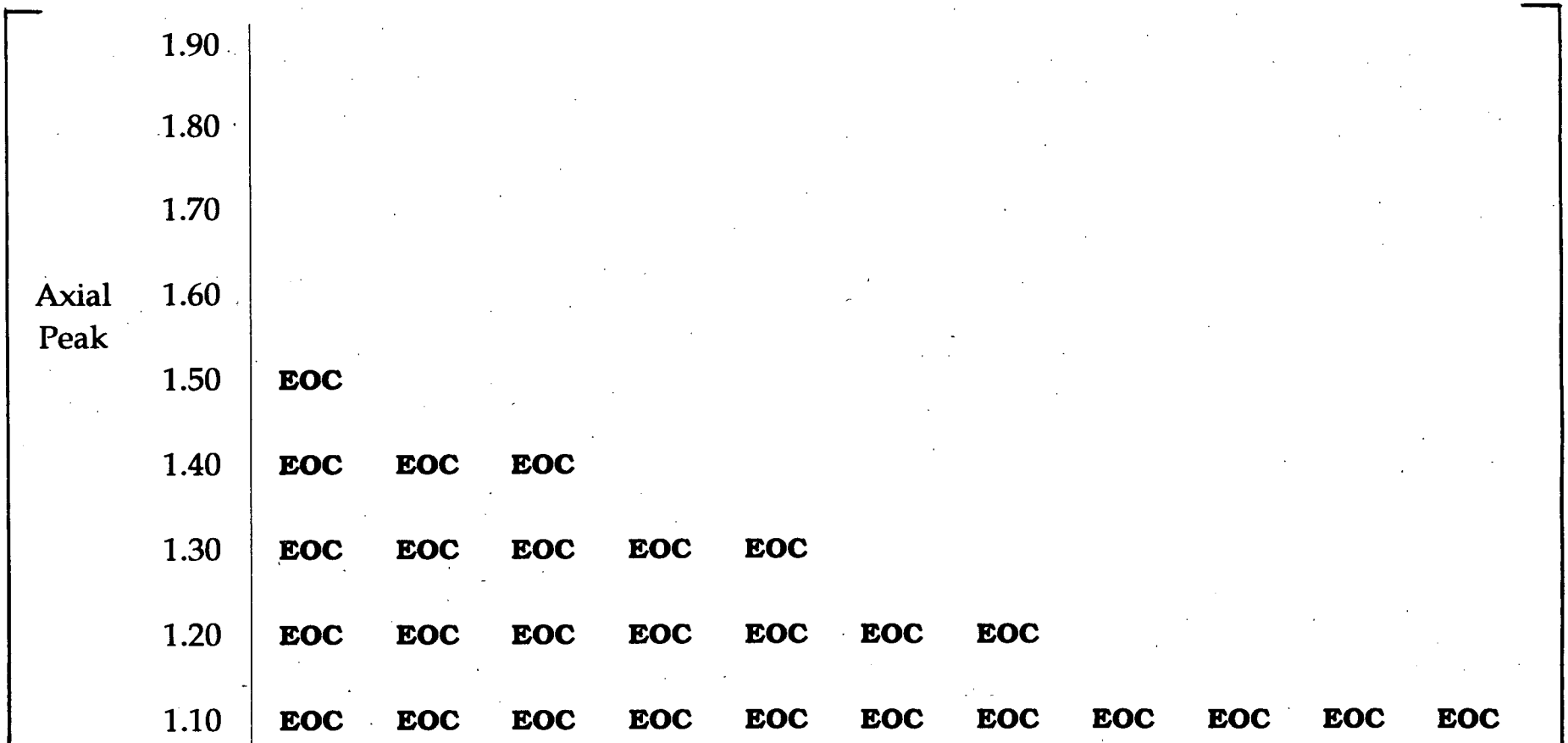
FIGURE 8A

Axial Power Distributions With EOC MDNBR, BWC



EOC - Denotes MDNBR location at the end of the heated length (last heated node).

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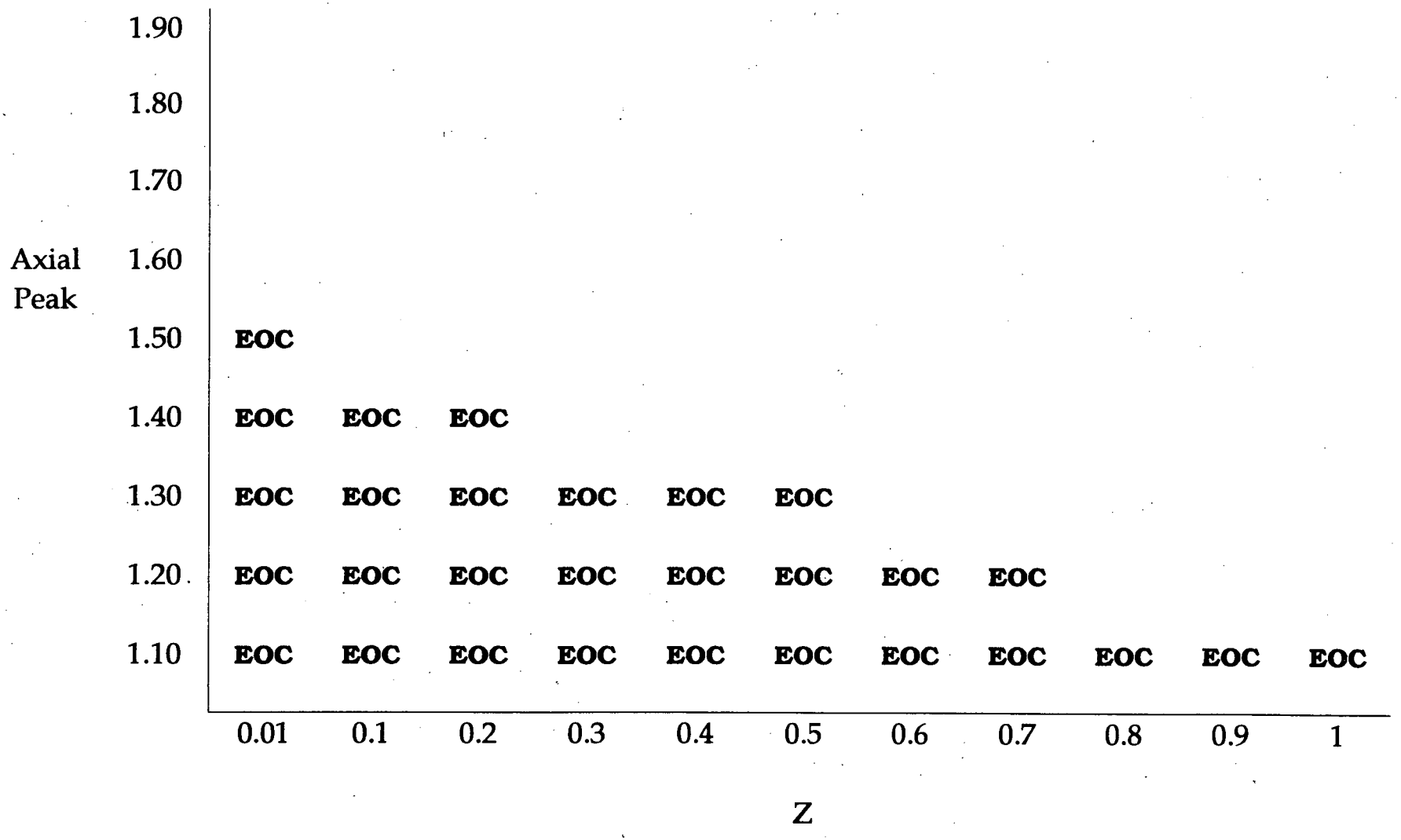
FIGURE 8B
Axial Power Distributions With EOC MDNBR, BWCMV



EOC - Denotes MDNBR location at the end of the heated length (last heated node).

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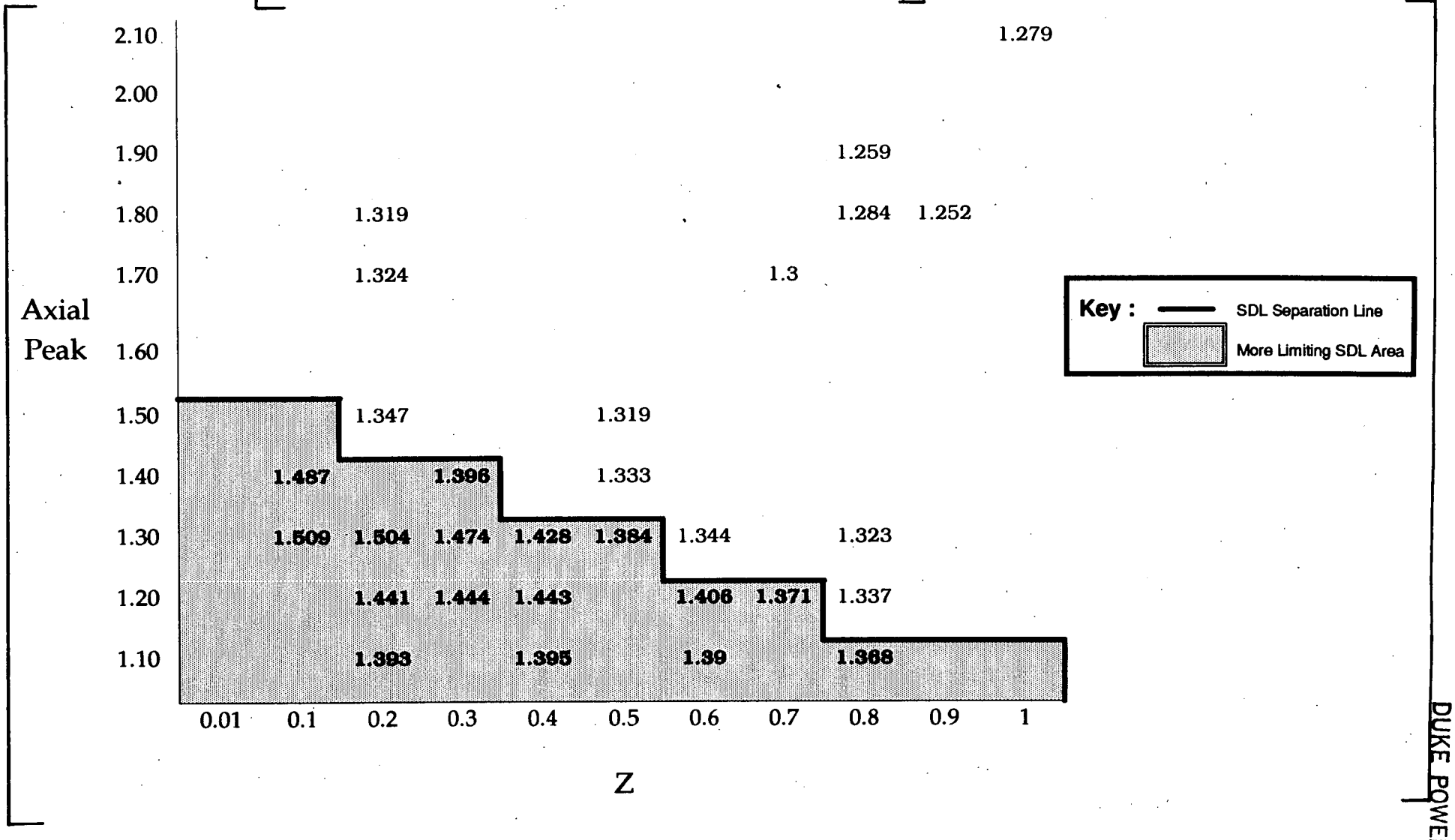
FIGURE 9
Example of a Split Statistical DNB Limit Application



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APPENDIX A

Oconee Plant Specific Data

This Appendix contains the plant specific data and limits for the Oconee Nuclear Station. The thermal hydraulic statistical core design was performed as described in the main body of this report.

Plant Specific Data

This analysis is for the Oconee plant (two loop B&W PWR) with Mark-B fuel assemblies detailed in Reference 2. The BWC critical heat flux correlation described in Reference 9 is used.

Thermal Hydraulic Code and Model

The VIPRE-01 thermal hydraulic computer code (Reference 1) and the Oconee eight channel model approved in Reference 2 are used in this analysis.

Statepoints

The statepoint conditions evaluated in this analysis are listed in Table A-1.

Key Parameters and Uncertainties

The key parameters and their uncertainty magnitude and associated distribution used in this analysis are listed on Table A-2. The range of key parameter values is listed on Table A-4.

DNB Statistical Design Limits

The statistical design limit for each statepoint evaluated is listed on Table A-3. Section 1 of Table A-3 contains the 500 case runs and Section 2 contains the 3000 case runs. All statepoint SDL values reported in this analysis are normally distributed. The statistical design limit using the BWC CHF correlation for Oconee was determined to be [1.43 for end-of-channel (EOC) limited axial power distributions and 1.36 for the remaining power distributions.] Figure A-1 graphically depicts the application [of these limits.]

TABLE A-1. Oconee SCD Statepoints

STPT No.	Pres psia	Tin °F	Q %FP	Flow %Design	FΔh	F_z	z	COMMENTS
1	2235	569.1	112	106.5	1.714	1.2	0.2	Base
2						1.2	0.8	Statepoint-
3						1.5	0.5	High Temp
4						1.5	0.2	Safety
5						1.8	0.2	Limit
6						1.8	0.8	
7						1.3	0.7	
8						1.3	0.3	
9						1.7	0.7	
10						1.7	0.8	
11						1.5	0.8	
12						1.3	0.8	
13						1.2	0.5	
14						1.5	0.3	
15						1.5	0.7	
16	2235	569.1	112	106.5	1.5	1.8	0.2	Low FΔh
17						1.8	0.8	
18						1.5	0.2	
19						1.5	0.5	
20						1.5	0.8	
21						1.2	0.2	
22						1.2	0.8	
23	2235	565.8	112	100	1.714	1.8	0.2	Low Flow
24						1.8	0.8	
25						1.5	0.5	
26						1.2	0.2	
27						1.2	0.8	
28	2235	574.6	100	106.5	1.714	1.8	0.2	Low Power
29						1.8	0.8	
30						1.5	0.5	
31						1.2	0.2	
32						1.2	0.8	
33	2170	555.6	100	106.5	1.714	1.8	0.2	Normal
34						1.8	0.8	Operation
35						1.5	0.5	Tave=579.0
36						1.2	0.2	
37						1.2	0.8	
38	2205	568.5	84.9	106.5	1.714	1.8	0.2	NOTE (2)
39						1.8	0.8	3-Pump
40						1.5	0.5	Operation
41						1.2	0.2	Hi Temp
42						1.2	0.8	Safety Limit
43	1800	527.8	112	106.5	1.714	1.8	0.2	NOTE (1)
44						1.8	0.8	Low Pressure
45						1.5	0.5	Safety Limit

TABLE A-1 Continued Oconee SCD Statepoints

STPT No.	Pres psia	Tin °F	Q %FP	Flow %design	FΔh	F_z	z	Comments
46	1800	527.8	112	106.5	1.714	1.2	0.2	
47						1.2	0.8	
48	1800	530.4	100	100	1.714	1.8	0.8	Note(1) Low Pres,Q,Flow
49						1.2	0.8	
50	2235	569.1	112	106.5	1.9	1.8	0.2	Hi FΔh
52						1.5	0.5	
53						1.2	0.2	
54						1.2	0.8	
55	2235	569.1	112	106.5	2.0303	1.1	0.2	High Temperature Maximum Allowable Peaking Limits
56					2.0233	1.1	0.4	
57					2.0102	1.1	0.6	
58					2.0923	1.2	0.2	
59					2.0856	1.2	0.3	
60					2.0773	1.2	0.4	
61					2.0498	1.2	0.6	
62					2.1604	1.3	0.1	
63					2.1505	1.3	0.2	
64					2.1380	1.3	0.3	
65					2.1227	1.3	0.4	
66					2.2176	1.4	0.1	
67					1.7390	1.7	0.7	
68					1.6326	1.8	0.8	
69					1.5759	1.8	0.9	
70					1.5857	1.9	0.8	
71					1.9854	1.1	0.8	
72					2.0292	1.2	0.7	
73					1.9653	1.2	0.8	
74					2.0481	1.3	0.6	
75					1.9124	1.3	0.8	
76					2.1801	1.4	0.3	
77					2.0573	1.4	0.5	
78					2.1877	1.5	0.2	
79					1.9926	1.5	0.5	
80					2.0432	1.7	0.2	
81					1.9726	1.8	0.2	
82					2.1042	1.3	0.5	

NOTES:

- 100% design flow is equal to four times 88,000 gpm/pump or 352,000 gpm total system flow.

- 100% Full Power (FP) is equal to 2568 MWth.

(1) Outlet temperature equals 581.0 °F.

(2) The core flow is reduced to 79.8 % (0.749 x 1.065) of the 4-pump value to model 3-pump operation.

TABLE A-2. Oconee Statistically Treated Uncertainties

Parameter	Type of Uncertainty	Type of Distribution	Uncertainty	Standard Deviation
Reactor System				
Power	Measurement	Normal	± 2.0 %FP	± 1.0 %FP
Temperature	Measurement	Normal	± 2.0 °F	± 1.0 °F
Pressure	Measurement	Normal	± 30.0 psi	± 15.0 psi
Core Flow	Measurement	Normal	± 2.0 %design	± 1.0 %design
Nuclear				
$F\Delta h$	Calculation	Normal	----------	± 2.84 %
F_z	Calculation	Normal	----------	± 2.91 %
z	Calculation	Uniform	± 6.0 in.	----------
Fq"	Calculation	Normal	[+ 2.08 %	+ 1.26 %]
Fq	Calculation	Normal	[+ 2.27 %	+ 1.38 %]
Hot Channel Flow Area	Measurement	Uniform	[- 3.00 %]	----------
DNBR	Correlation	Normal	----------	± 8.88 %
DNBR	Code	Normal	[± 5.0 %	± 3.04 %]

TABLE A-2 Continued Oconee Statistically Treated Uncertainties

Parameter	Justification
System Pressure	This uncertainty accounts for random uncertainties in various instrumentation components. Since the random uncertainties are normally distributed, the square root of the sum of the squares (SRSS) that results in the pressure uncertainty is also normally distributed.
Inlet Temperature	Same approach as System Pressure uncertainty.
Core Power	The core power uncertainty was calculated by statistically combining the various random uncertainties associated with the measurement of core power. Since the random uncertainties are normally distributed, the srss of them that results in the core power uncertainty is also normally distributed.
Core Flow	Same approach as Core Power uncertainty.
Radial Power, $F\Delta h$	This uncertainty accounts for the error associated in the physics code's calculation of radial assembly power and the measurement of the assembly power. This uncertainty distribution is normal.
Axial Peak Power, Fz	This uncertainty accounts for the axial peak prediction uncertainty of the physics codes. The uncertainty is normally distributed.
Axial Peak Location, z	This uncertainty accounts for the possible error in interpolating on axial peak location in the maneuvering analysis. The uncertainty is one half of the physics code's axial node. The uncertainty distribution is conservatively applied as uniform.

TABLE A-2 Continued Oconee Statistically Treated Uncertainties

Parameter	Justification
Local Heat Flux HCF, Fq"	This uncertainty accounts for the decrease in DNBR at the point of MDNBR due to engineering tolerances. This uncertainty is also increased to account for flux depression at the spacer grids. The uncertainty is normally distributed and conservatively applied as one-sided in the analysis to ensure the MDNBR channel location is consistent for all cases.
Rod Power HCF, Fq	This uncertainty accounts for the increase in rod power due to manufacturing tolerances. The uncertainty in calculating the peak pin from assembly radial peak is also statistically combined with the manufacturing tolerance uncertainty to arrive at the correct value. The uncertainty is normally distributed and conservatively applied as one-sided in the analysis to ensure the MDNBR channel location is consistent for all cases.
Hot Channel Flow Area	This uncertainty accounts for manufacturing variations in the instrument guide tube sub-channel flow area. This uncertainty is uniformly distributed and is conservatively applied as one-sided in the analysis to ensure the MDNBR channel location is consistent for all cases.
DNBR - Correlation	This uncertainty accounts for the CHF correlation's ability to predict DNB. The uncertainty is normally distributed.
DNBR - Code/Model	This uncertainty accounts for the thermal-hydraulic code uncertainties and offsetting conservatism's. This uncertainty also accounts for the small DNB prediction differences between various model sizes. This uncertainty is normally distributed.

TABLE A-3. Oconee Statepoint Statistical Results

500 Case Runs

Statepoint #	Mean	σ	Coefficient of Variation	Statistical DNBR	EOC
1	2.688	0.325	0.121	1.289	Yes
2	2.057	0.249	0.121	1.292	No
3	1.992	0.229	0.115	1.272	No
4	2.295	0.252	0.110	1.257	No
5	1.890	0.212	0.112	1.265	No
6	1.332	0.167	0.125	1.303	No
7	2.037	0.242	0.119	1.283	No
8	2.526	0.278	0.110	1.256	Yes
9	1.523	0.184	0.121	1.292	No
10	1.421	0.176	0.124	1.301	No
11	1.631	0.201	0.123	1.297	No
12	1.898	0.232	0.122	1.294	No
13	2.462	0.281	0.114	1.268	Yes
14	2.200	0.244	0.111	1.259	No
15	1.751	0.196	0.112	1.287	No
16	2.077	0.206	0.099	1.227	No
17	1.559	0.159	0.102	1.235	No
18	2.515	0.249	0.099	1.225	No
19	2.225	0.223	0.100	1.227	No
20	1.890	0.193	0.102	1.233	No
21	3.043	0.301	0.099	1.225	Yes
22	2.371	0.239	0.101	1.231	No
23	1.718	0.203	0.118	1.282	No
24	1.155	0.151	0.131	1.322	No
25	1.785	0.216	0.121	1.290	No
26	2.334	0.322	0.138	1.344	Yes
27	1.794	0.226	0.126	1.231	No
28	2.007	0.225	0.112	1.265	No
29	1.437	0.177	0.123	1.296	No
30	2.122	0.244	0.115	1.271	No
31	2.893	0.338	0.117	1.280	Yes
32	2.212	0.265	0.120	1.288	No
33	2.230	0.241	0.108	1.252	No
34	1.695	0.200	0.118	1.280	No
35	2.402	0.262	0.109	1.256	No
36	3.286	0.358	0.109	1.254	Yes
37	2.599	0.296	0.114	1.268	No
38	2.093	0.245	0.117	1.279	No
39	1.445	0.184	0.127	1.309	No
40	2.185	0.260	0.119	1.286	No
41	2.896	0.385	0.133	1.323	Yes

TABLE A-3 Continued Oconee Statepoint Statistical Results

500 Case Runs

Statepoint #	Mean	σ	Coefficient of Variation	Statistical DNBR	EOC
42	2.224	0.276	0.124	1.300	No
43	1.957	0.215	0.110	1.258	No
44	1.417	0.173	0.122	1.292	No
45	2.079	0.235	0.113	1.265	No
46	2.820	0.327	0.116	1.276	Yes
47	2.174	0.259	0.119	1.283	No
48	1.603	0.192	0.120	1.286	No
49	2.453	0.287	0.117	1.279	No
50	1.593	0.191	0.120	1.287	No
52	1.648	0.203	0.123	1.296	No
53	2.144	0.298	0.139	1.350	Yes
54	1.639	0.210	0.128	1.314	No
55	1.385	0.211	0.152	1.393	Yes
56	1.382	0.210	0.152	1.395	Yes
57	1.399	0.208	0.151	1.390	Yes
58	1.394	0.229	0.164	1.441	Yes
59	1.389	0.229	0.165	1.444	Yes
60	1.381	0.227	0.165	1.443	Yes
61	1.359	0.210	0.155	1.406	Yes
62	1.404	0.254	0.181	1.509	Yes
63	1.392	0.250	0.180	1.504	Yes
64	1.376	0.237	0.172	1.474	Yes
65	1.358	0.218	0.161	1.428	Yes
66	1.377	0.241	0.175	1.487	Yes
67	1.357	0.168	0.124	1.300	No
68	1.355	0.161	0.119	1.284	No
69	1.340	0.145	0.108	1.252	No
70	1.340	0.148	0.111	1.259	No
71	1.358	0.196	0.145	1.368	Yes
72	1.328	0.193	0.145	1.371	Yes
73	1.349	0.183	0.136	1.337	No
74	1.334	0.183	0.137	1.344	No
75	1.345	0.176	0.131	1.323	No
76	1.321	0.200	0.152	1.396	Yes
77	1.336	0.179	0.134	1.333	No
78	1.333	0.184	0.138	1.347	No
79	1.342	0.174	0.130	1.319	No
80	1.342	0.177	0.132	1.324	No
81	1.343	0.174	0.130	1.319	No
82	1.323	0.197	0.149	1.384	Yes

TABLE A-3 continued Oconee Statepoint Statistical Results

3000 Case Runs

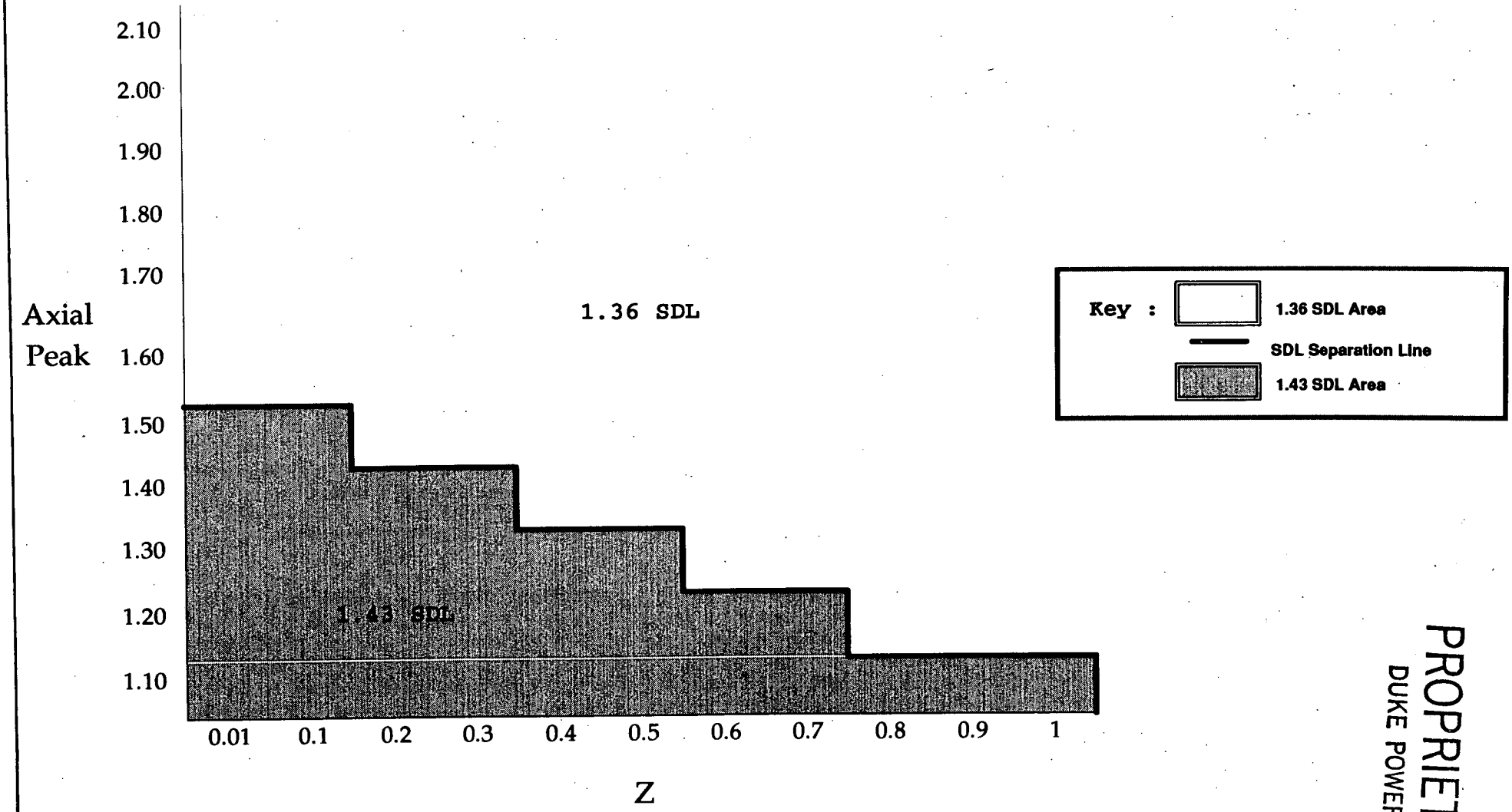
Statepoint #	Mean	σ	Coefficient of Variation	Statistical DNBR	EOC
2-T	1.887	0.230	0.122	1.267	No
3-T	1.859	0.128	0.118	1.255	No
6-T	1.222	0.153	0.126	1.277	No
20-T	1.744	0.184	0.106	1.224	No
24-T	1.199	0.152	0.127	1.281	No
26-T	2.430	0.308	0.127	1.281	Yes
29-T	1.441	0.175	0.121	1.265	No
34-T	1.697	0.197	0.116	1.255	No
39-T	1.702	0.117	0.117	1.251	No
41-T	2.908	0.369	0.127	1.281	Yes
44-T	1.421	0.170	0.120	1.261	No
53-T	2.214	0.294	0.133	1.297	Yes
54-T	1.692	0.212	0.126	1.277	No
59-T	1.396	0.221	0.159	1.379	Yes
62-T	1.330	0.228	0.171	1.423	Yes
63-T	1.321	0.225	0.171	1.421	Yes
68-T	1.355	0.160	0.118	1.256	No
72-T	1.336	0.187	0.141	1.321	No
78-T	1.339	0.183	0.136	1.310	No

TABLE A-4 Oconee Key Parameter Ranges

Parameter	Maximum	Minimum
Core Power (% FP)	112	84.9
Pressure (psia)	2235	1800
T inlet (deg. F)	574.9	527.8
RCS Flow (Percent Design)	106.5	100.0
FΔH	2.2176	1.500
Fz, Z	All Maximum Allowable Peaking Limit Space	

All values listed in this table are based on the currently analyzed Statepoints. Ranges are subject to change based on future statepoint conditions.

FIGURE A-1
Oconee Split Statistical DNB Limits



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APPENDIX B

McGuire/Catawba Plant Specific Data

This Appendix contains the plant specific data and limits for the McGuire and Catawba Nuclear Stations. The thermal hydraulic statistical core design was performed as described in the main body of this report.

Plant Specific Data

This analysis is for the McGuire and Catawba plants (four loop Westinghouse PWR's) with either Mark-BW or Optimized Fuel Assemblies as described in Reference 3. The BWCMV critical heat flux correlation described in Reference 9 is used for analyzing both fuel types.

Thermal Hydraulic Code and Model

The VIPRE-01 thermal hydraulic computer code (Reference 1) and the McGuire/Catawba eight channel model approved in Reference 3 are used in this analysis.

Statepoints

The statepoint conditions evaluated in this analysis are listed in Table B-1.

Key Parameters and Uncertainties

The key parameters and their uncertainty magnitude and associated distribution used in this analysis are listed on Table B-2. The range of key parameter values is listed on Table B-4.

DNB Statistical Design Limits

The statistical design limit for each statepoint evaluated is listed on Table B-3. Section 1 of Table B-3 contains the 500 case runs and Section 2 contains the 3000 case runs. All statepoint SDL values listed in this analysis are normally distributed. The statistical design limit using the BWCMV CHF correlation for McGuire/Catawba was determined to be [1.40 for end-of-channel (EOC) limited axial power distributions and 1.33 for the remaining power distributions.] Figure B-1 graphically depicts the application [of these limits.]

TABLE B-1. McGuire/Catawba SCD Statepoints

Stpt #	Power	Pressure	Temperature	Flow	Axial Peak	Radial Peak
1	118%	2455 psia	589.8 deg F	385 Kgpm	1.20 @ 0.2	1.610
2	118%	2455 psia	589.8 deg F	385 Kgpm	1.20 @ 0.3	1.604
3	118%	2455 psia	589.8 deg F	385 Kgpm	1.20 @ 0.5	1.582
4	118%	2455 psia	589.8 deg F	385 Kgpm	1.20 @ 0.7	1.554
5	118%	2455 psia	589.8 deg F	385 Kgpm	1.20 @ 0.8	1.509
6	118%	2455 psia	589.8 deg F	385 Kgpm	1.30 @ 0.2	1.650
7	118%	2455 psia	589.8 deg F	385 Kgpm	1.30 @ 0.3	1.637
8	118%	2455 psia	589.8 deg F	385 Kgpm	1.30 @ 0.7	1.521
9	118%	2455 psia	589.8 deg F	385 Kgpm	1.30 @ 0.8	1.470
10	118%	2455 psia	589.8 deg F	385 Kgpm	1.50 @ 0.2	1.666
11	118%	2455 psia	589.8 deg F	385 Kgpm	1.50 @ 0.8	1.387
12	118%	2455 psia	589.8 deg F	385 Kgpm	1.55 @ 0.5	1.500
13	118%	2455 psia	589.8 deg F	385 Kgpm	1.80 @ 0.2	1.498
14	118%	2455 psia	589.8 deg F	385 Kgpm	1.80 @ 0.8	1.265
15	96.1%	2286 psia	575.3 deg F	309.5 Kgpm	1.55 @ 0.7	1.500
16	100%	2250 psia	561.6 deg F	385 Kgpm	1.30 @ 0.2	2.103
17	120%	1945 psia	561.4 deg F	385 Kgpm	1.55 @ 0.5	1.500
18	100%	2250 psia	561.6 deg F	385 Kgpm	1.20 @ 0.7	2.022
19	100%	2250 psia	561.6 deg F	385 Kgpm	1.80 @ 0.8	1.641
20	96.1%	2286 psia	575.3 deg F	309.5 Kgpm	1.30 @ 0.2	1.687
21	96.1%	2286 psia	575.3 deg F	309.5 Kgpm	1.80 @ 0.2	1.606
22	96.1%	2286 psia	575.3 deg F	309.5 Kgpm	1.20 @ 0.7	1.628
23	96.1%	2286 psia	575.3 deg F	309.5 Kgpm	1.80 @ 0.8	1.349

TABLE B-1 - Continued McGuire/Catawba SCD Statepoints

Stpt #	Power	Pressure	Temperature	Flow	Axial Peak	Radial Peak
24	96.1%	2286 psia	575.3 deg F	309.5 Kgpm	1.20 @ 0.3	1.641
25	100%	2250 psia	561.6 deg F	385 Kgpm	1.20 @ 0.3	2.042
26	75%	2455 psia	629.4 deg F	385 Kgpm	1.55 @ 0.5	1.710
27	100%	2280 psia	561.6 deg F	385 Kgpm	1.55 @ 0.7	1.500
28	115%	2230 psia	575.0 deg F	381.2 Kgpm	1.55 @ 0.7	1.500
29	49.1%	2283 psia	558.5 deg F	261 Kgpm	1.55 @ 0.7	2.798
30	81%	2215 psia	558.5 deg F	269.5 Kgpm	1.55 @ 0.7	1.725
31	118%	2455 psia	589.8 deg F	385 Kgpm	1.10 @ 0.01	1.568
32	118%	2455 psia	589.8 deg F	385 Kgpm	2.10 @ 1.0	1.115
33	80.8%	2444 psia	558.4 deg F	250.6 Kgpm	1.55 @ 0.7	1.725
34	80.8%	2444 psia	558.4 deg F	250.6 Kgpm	1.55 @ 0.7	1.725
35	95.7%	2320 psia	561.9 deg F	274.1 Kgpm	1.55 @ 0.7	1.500
36	95.7%	2302 psia	571.7 deg F	300.5 Kgpm	1.55 @ 0.7	1.500
37	80.8%	2444 psia	558.4 deg F	270.9 Kgpm	1.55 @ 0.7	1.725
38	80.8%	2444 psia	558.4 deg F	270.9 Kgpm	1.55 @ 0.7	1.725
39	118%	2455 psia	589.8 deg F	385 Kgpm	2.10 @ 0.5	1.268
40	118%	2455 psia	589.8 deg F	385 Kgpm	1.30 @ 0.2	1.650
41	118%	2455 psia	589.8 deg F	385 Kgpm	1.55 @ 0.5	1.500
42	118%	2455 psia	589.8 deg F	385 Kgpm	1.80 @ 0.8	1.265
43	100%	2250 psia	561.6 deg F	385 Kgpm	1.30 @ 0.2	2.103

TABLE B-2. McGuire/Catawba Statistically Treated Uncertainties

Parameter	Uncertainty / Standard Deviation	Type of Distribution
Core Power	+/- 2% / +/- 1.22%	Normal
Core Flow		
Measurement	+/- 2.2% / +/- 1.34%	Normal
Bypass Flow	+/- 1.5%	Uniform
Pressure	+/- 30 psi	Uniform
Temperature	+/- 4 deg F	Uniform
$F^N_{\Delta H}$		
Measurement	+/- 3.25% / 1.98%	Normal
$F^E_{\Delta H}$	+/- 3.0% / 1.82%	Normal
Spacing	+/- 2.0% / 1.22%	Normal
F_Z	+/- 4.41% / 2.68%	Normal
Z	+/- 6 inches	Uniform
DNBR		
Correlation	+/- 16.78% / 10.2%	Normal
Code/Model	[+/- 5.0% / 3.04%]	Normal

TABLE B-2 Continued McGuire/Catawba Statistically Treated Uncertainties

Parameter	Justification
Core Power	The core power uncertainty was calculated by statistically combining the uncertainties of the process indication and control channels. The uncertainty is calculated from normally distributed random error terms such as sensor calibration accuracy, rack drift, sensor drift, etc combined by the square root sum of squares method (SRSS). Since the uncertainty is calculated from normally distributed values, the parameter distribution is also normal.
Core Flow Measurement	Same approach as Core Power.
Bypass Flow	The core bypass flow is the parallel core flow paths in the reactor vessel (guide thimble cooling flow, head cooling flow, fuel assembly/baffle gap leakage, and hot leg outlet nozzle gap leakage) and is dependent on the driving pressure drop. Parameterizations of the key factors that control ΔP, dimensions, loss coefficient correlations, and the effect of the uncertainty in the driving ΔP on the flow rate in each flow path, was performed. The dimensional tolerance changes were combined with the SRSS method and the loss coefficient and driving ΔP uncertainties were conservatively added to obtain the combined uncertainty. This uncertainty was conservatively applied with a uniform distribution.
Pressure	The pressure uncertainty was calculated by statistically combining the uncertainties of the process indication and control channels. The uncertainty is calculated from random error terms such as sensor calibration accuracy, rack drift, sensor drift, etc combined by the square root sum of squares method. The uncertainty distribution was conservatively applied as uniform.
Temperature	Same approach as Pressure.

TABLE B-2 Continued McGuire/Catawba Statistically Treated Uncertainties

Parameter	Justification
$F^N_{\Delta H}$ Measurement	This uncertainty is the measurement uncertainty for the movable incore instruments. A measurement uncertainty can arise from instrumentation drift or reproducibility error, integration and location error, error associated with the burnup history of the core, and the error associated with the conversion of instrument readings to rod power. The uncertainty distribution is normal.
$F^E_{\Delta H}$	This uncertainty accounts for the manufacturing variations in the variables affecting the heat generation rate along the flow channel. This conservatively accounts for possible variations in the pellet diameter, density, and U_{235} enrichment. This uncertainty distribution is normal and was conservatively applied as one-sided in the analysis to ensure the MDNBR channel location was consistent for all cases.
Spacing	This uncertainty accounts for the effect on peaking of reduced hot channel flow area and spacing between assemblies. The power peaking gradient becomes steeper across the assembly due to reduced flow area and spacing. This uncertainty distribution is normal and was conservatively applied as one-sided to ensure consistent MDNBR channel location.
F_Z	This uncertainty accounts for the axial peak prediction uncertainty of the physics codes. The uncertainty distribution is applied as normal.
Z	This uncertainty accounts for the possible error in interpolating on axial peak location in the maneuvering analysis. The uncertainty is one half of the physics code's axial node. The uncertainty distribution is conservatively applied as uniform.
DNBR Correlation	This uncertainty accounts for the CHF correlation's ability to predict DNB. The uncertainty distribution is applied as normal.

TABLE B-2 Continued McGuire/Catawba Statistically Treated Uncertainties

Parameter	Justification
DNBR	
Code/Model	This uncertainty accounts for the thermal-hydraulic code uncertainties and offsetting conservatisms. This uncertainty also accounts for the small DNB prediction differences between the various model sizes. The uncertainty distribution is applied as normal.

TABLE B-3. McGuire/Catawba Statepoint Statistical Results

500 Case Runs

Statepoint #	Mean	σ	Coefficient of Variation	Statistical DNBR	EOC
1	1.537	0.229	0.1492	1.397	Yes
2	1.582	0.237	0.1500	1.388	Yes
3	1.572	0.231	0.1469	1.376	Yes
4	1.517	0.210	0.1387	1.348	Yes
5	1.521	0.202	0.1331	1.329	Yes
6	1.637	0.244	0.1489	1.385	Yes
7	1.625	0.234	0.1441	1.368	Yes
8	1.515	0.200	0.1320	1.326	No
9	1.505	0.199	0.1319	1.325	No
10	1.554	0.194	0.1256	1.308	No
11	1.505	0.191	0.1266	1.308	No
12	1.517	0.194	0.1279	1.312	No
13	1.523	0.194	0.1271	1.310	No
14	1.508	0.184	0.1222	1.294	No
15	1.625	0.209	0.1289	1.315	No
16	1.660	0.257	0.1546	1.404	Yes
17	1.520	0.196	0.1292	1.317	No
18	1.509	0.214	0.1417	1.358	Yes
19	1.511	0.186	0.1229	1.296	No
20	1.856	0.282	0.1518	1.397	Yes
21	1.642	0.215	0.1311	1.323	No
22	1.641	0.235	0.1435	1.365	Yes
23	1.625	0.202	0.1242	1.301	No
24	1.797	0.270	0.1501	1.389	Yes
25	1.631	0.245	0.1501	1.388	Yes
26	1.595	0.209	0.1313	1.323	No
27	2.245	0.260	0.1160	1.275	No
28	1.435	0.185	0.1292	1.316	No
29	1.702	0.222	0.1305	1.321	No
30	1.686	0.220	0.1305	1.321	No
31	1.531	0.224	0.1462	1.375	Yes
32	1.507	0.177	0.1173	1.279	No
33	1.914	0.238	0.1244	1.301	No
34	1.931	0.237	0.1226	1.295	No
35	1.619	0.212	0.1309	1.322	No
36	1.623	0.211	0.1300	1.319	No
37	1.914	0.238	0.1244	1.301	No
38	1.859	0.233	0.1256	1.305	No
39	1.499	0.179	0.1197	1.286	No
40	1.599	0.243	0.1518	1.397	Yes
41	1.506	0.189	0.1258	1.306	No
42	1.491	0.181	0.1212	1.291	No
43	1.716	0.259	0.1512	1.391	Yes

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TABLE B-3 Continued McGuire/Catawba Statepoint Statistical Results

3000 Case Runs

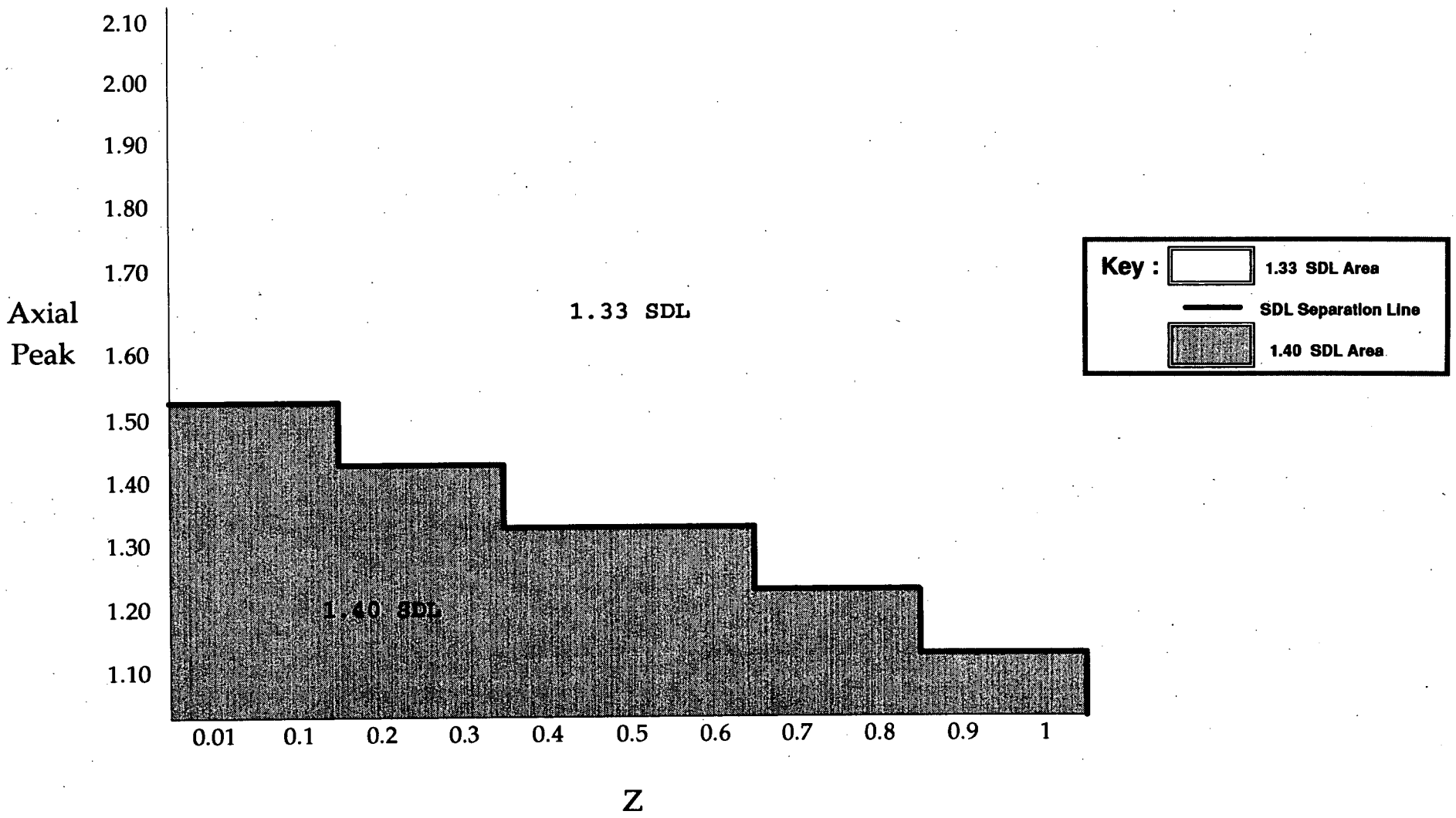
Statepoint #	Mean	σ	Coefficient of Variation	Statistical DNBR	EOC
2-T	1.526	0.235	0.1537	1.363	Yes
3-T	1.524	0.235	0.1540	1.363	Yes
4-T	1.485	0.220	0.1484	1.345	Yes
12-T	1.508	0.201	0.1335	1.300	No
13-T	1.516	0.200	0.1320	1.296	No
14-T	1.503	0.191	0.1269	1.281	No
16-T	1.659	0.268	0.1613	1.387	Yes
20-T	1.862	0.287	0.1542	1.365	Yes
37-T	1.901	0.246	0.1293	1.289	No
38-T	1.846	0.241	0.1305	1.291	No
39-T	1.500	0.187	0.1244	1.274	No

TABLE B-4 McGuire/Catawba Key Parameter Ranges

Parameter	Maximum	Minimum
Core Power (% RTP)	120	49.1
Pressure (psia)	2455	1945
T inlet (deg. F)	629.4	558.4
RCS Flow (Thousand GPM)	385.0	250.6
FΔH	2.7983	1.1152
Fz, Z	All Maximum Allowable Peaking Limit Space	

All values listed in this table are based on the currently analyzed Statepoints. Ranges are subject to change based on future statepoint conditions.

FIGURE B-1
McGuire/Catawba Split Statistical DNB Limits



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