EMF-1961 (NP)(A)
Revision 0

Statistical Setpoint/Transient Methodology for Combustion Engineering Type Reactors

July 2000

Siemens Power Corporation

ISSUED IN SPC ON-LINE
DOCUMENT SYSTEM
DATE: 9/16/00

EMF-1961(NP)
Revision 0

Statistical Setpoint/Transient Methodology for Combustion Engineering Type Reactors

Concurred: ANR by RL
L. E. Hansen, Manager
Customer Projects
12/22/98
Date

Concurred: ANR by RL
J. S. Holm, Manager
Product Licensing
12/22/98
Date

Approved: R E Collingham
R. E. Collingham, Manager
Safety Analysis Methods
12/22/98
Date

Approved: ANR by RL
R. C. Gottula, Manager
PWR Safety Analysis
12/22/98
Date

Approved: ANR by RL
D. M. Brown, Manager
PWR Neutronics
12/22/98
Date

Approved: ANR by RL
R. G. Grummer, Manager
Neutronic Analysis Methods
12/22/98
Date

U.S. Nuclear Regulatory Commission
Report Disclaimer

Important Notice Regarding Contents and Use of This Document

Please Read Carefully

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

July 12, 2000

Mr. James F. Mallay
Director, Nuclear Regulatory Affairs
Siemens Power Corporation
2101 Horn Rapids Road
Richland, WA 99352-0130

SUBJECT: ACCEPTANCE FOR REFERENCING OF LICENSING TOPICAL REPORT EMF-1961(P), REVISION 0, "STATISTICAL SETPOINT/TRANSIENT METHODOLOGY FOR COMBUSTION ENGINEERING TYPE REACTORS" (TAC NO. MA4659)

Dear Mr. Mallay:

The Nuclear Regulatory Commission (NRC) has completed the review of the subject topical report submitted by the Siemens Power Corporation (SPC) by letter dated December 21, 1998. The report is acceptable for referencing in licensing applications to the extent specified, and under the limitations delineated in the report, and in the associated NRC safety evaluation (SE) which is enclosed. The safety evaluation defines the basis for NRC acceptance of the report.

Pursuant to 10 CFR 2.790, we have determined that the enclosed SE does not contain proprietary information. However, we will delay placing the SE in the public document room and delay adding it to the Agencywide Documents Access and Management Systems Publicly Available Records System (ADAMS PARS) Library for a period of ten (10) working days from the date of this letter to provide you with the opportunity to comment on the proprietary aspects only. If you believe that any information in the enclosure is proprietary, please identify such information line by line and define the basis pursuant to the criteria of 10 CFR 2.790.

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 ensure 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, we request that SPC publish accepted versions of this report, proprietary and non-proprietary, within 3 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 so that our conclusions about acceptability of the report are invalidated, SPC and the licensees referencing the topical report will be expected to revise and resubmit their respective documentation, or to submit justification for the continued effective applicability of the topical reports without revision of their respective documentation.

Sincerely,

Stuart A. Richards, Director
Project Directorate IV and Decommissioning
Division of Licensing Project Management
Office of Nuclear Reactor Regulation

Project No. 702

Enclosure: Safety Evaluation

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

SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

TOPICAL REPORT EMF-1961(P), REVISION 0,

"STATISTICAL SETPOINT/TRANSIENT METHODOLOGY

FOR COMBUSTION ENGINEERING TYPE REACTORS"

SIEMENS POWER CORPORATION

1.0 INTRODUCTION

By letter dated December 21, 1998, Siemens Power Corporation (SPC) submitted Topical Report EMF-1961(P), Revision 0, "Statistical Setpoint/Transient Methodology for Combustion Engineering Type Reactors" that described a new methodology for statistical setpoint and transient analysis of Combustion Engineering (CE) type reactors (Reference 1). The methodology includes ways to statistically combine the uncertainties for analyzing limiting conditions of operation (LCOs), limiting safety system settings (LSSSs), and transients. The new methodology uses SPC's previously approved generic statistical uncertainty analysis methodology (GSUAM) (Reference 2); a methodology to statistically combine uncertainties and create response surfaces which are used to determine the probability of conservatively remaining below the limiting parameter. The methodology is based on CE plants with thermal margin/low pressure (TM/LP) LSSS, local power density (LPD) LSSS, LPD LCO, and departure from nucleate boiling (DNB) LCO. The new statistical methodology will facilitate automating the methodology, decreasing the user effect and the potential for introducing user errors.

2.0 METHODOLOGY

The vendor requested approval to use a new statistical setpoint and transient analysis methodology for CE type reactors. The topical report describes how SPC extends their previously approved statistical method (Reference 3) to include additional transients and incorporate new techniques for combining the uncertainties.

2.1 LCOs and LSSSs

The LCOs and LSSSs protect against fuel failure in loss-of-coolant accidents (LOCAs), prevent DNB, and meet specified acceptable fuel design limits (SAFDLs) for fuel centerline melt (FCM). LOCA limits are based on the linear heat generation rate (LHGR) used in the LOCA analysis, DNB limits are based on correlations approved by the NRC, and FCM limits are calculated for each reload cycle and fuel design. In determining the LCO and LSSS limits, a deterministic method with values set at the most limiting conservative values or the statistical method can be utilized.

2.2 LPD LCO and LPD LSSS

The LPD LCO and LSSS protect against FCM. The LPD LSSS monitors the power level of the reactor and trips the reactor when the power level exceeds the setpoint corresponding to the axial shape index (ASI). The LPD LCO prevents the LPD from exceeding the LHGR limit of the LOCA analysis. In developing the limits, both functions use the worst axial power distribution and the technical specification radial power distribution for a given ASI (an augmented radial power distribution is used for cases when the control elements are inserted). To provide additional conservatism to the LPD LCO and LSSS calculations, the most limiting axial power distribution for a given ASI is used in setting the limit.

To calculate the LPD LSSS and LCO, an FCM limit based on the operating cycle and core design is needed. This FCM limit is expressed in terms of KW/ft; thus, the FCM limit is expressed as a function of a limit on LHGR. The FCM limit is a cycle specific parameter which is calculated for each reload using the RODEX2 code, a quasi-static fuel rod performance code used by SPC (References 3 and 4). The calculation of the FCM limit accounts for the gadolinia concentration, burnup history, axial power shape, and periodic power spikes (to account for the scram delay time). To correlate the FCM limit to a LHGR limit, melt curves for the fuel rods are generated. These melt curves provide a relationship between melt power and the rod burnup and gadolinia concentration. Thus, the power at which FCM begins for each rod type is identified and through a relationship is converted into a LHGR. The FCM limit is the minimum LHGR for all fuel types divided by the fraction of power generated in the rod. Including the method to calculate the FCM limit in the statistical setpoint/transient methodology for CE type reactors is a new addition to the topical report. The FCM limit methodology facilitates automation of the calculation process, reducing the user effect on the calculation results.

The LPD LSSS calculation is performed over a series of axial power shapes. For each shape, the FCM power is calculated. The difference between the trip power and the FCM power is calculated to determine the margin between the two. This margin between the two powers must be positive for all values of ASI considered to confirm that the LPD LSSS protects against FCM with a 95 percent confidence level at a 95 percent probability. During the calculation of the trip power, the uncertainties from measurements and calculational uncertainties are included. These uncertainties are included using standard statistical methods to combine them into the calculated margin. This calculation is an iterative process. If the initial estimate of the LPD LSSS does not provide 95/95 confidence protection, then it is made more restrictive until the power margin provides 95/95 confidence protection.

The LPD LCO is performed in the same manner as the LPD LSSS; however, the LPD LCO prevents the plant from exceeding a reduced LHGR during operation. The LPD LCO is used when the in-core detectors are not in service. Therefore, the LHGR value used for developing the LPD LCO is equal to or less than the LHGR value used in the LOCA analysis.

2.3 TM/LP LSSS and DNB LCO

The TM/LP LSSS and DNB LCO protects against DNB. The TM/LP LSSS provides a reactor trip when the limiting fuel pin approaches DNB and the DNB LCO provides protection from DNB during anticipated operational occurrences. These protective functions are determined using an iterative process which provides protection with at least a 95 percent probability at a 95 percent confidence level.

The TM/LP LSSS provides protection by tripping the reactor at a pressure which will preclude DNB and hot-leg saturation. Calculating the LSSS begins with the development of axial power shapes for the operating cycle and then the reduction of the number of shapes by a deterministic method, resulting in a set of bounding axial power shapes for each ASI used for setting the limit. This set of axial power shapes is used to perform sensitivity studies to obtain the most sensitive point, the point that shows the greatest change in the calculated pressure. A response surface is developed around the most sensitive point providing the pressure at DNB. The response surface is comprised of all parametric variations statistically combined and includes the appropriate uncertainties. Using the response surface calculation, a table of parametric variation with the corresponding DNB pressure is obtained.

The trip margin is defined as the 95 percent lower limit at a 95 percent confidence level of the difference between the DNB pressure (or hot-leg saturation pressure) to the trip pressure. Demonstrating that the trip margin is positive confirms that there is 95/95 confidence of protection from DNB. Calculation of the margin takes credit for the protection provided by the LPD LSSS and main steam safety valves (MSSVs) by excluding operational areas where these actions provide protection. The confirmation of positive trip margin is performed for the hot-leg saturation and DNB pressures. The confirmation of the hot-leg saturation pressure margin is performed in two steps. First, the nominal margin is calculated. This is defined as the difference between the trip pressure and the saturation pressure corresponding to the temperature points of the vessel exit and inlet. Then, the nominal margin is adjusted for uncertainties to obtain the statistically adjusted margin. Similarly, for the confirmation of DNB pressure, the nominal margin is calculated for the difference between the DNB pressure and the trip pressure and then the margin is statistically adjusted to account for the uncertainties. These statistically adjusted margins are verified to be positive with at least a 95 percent probability at a 95 percent confidence level to demonstrate that they adequately protect against DNB.

The DNB LCO is performed in the same manner as the TM/LP LSSS; however, the DNB LCO iterates on power instead of pressure. Additionally, no credit is taken for the protection provided by the LPD LSSS and MSSVs.

2.4 Transient Analysis Methodology

The statistical transient analysis provides 95 percent probability at a 95 percent confidence limit that the reactor protection system, in conjunction with the LCOs and LSSSs, will ensure that the SAFDLs and pressure limits will not be exceeded.

The calculation of the trip setpoint follows a similar calculation path as that for establishing the LPD, DNB and TM/LP, LSSSs and LCOs. Transient analyses are performed using nominal and deterministic values to develop the most sensitive point and the corresponding response surface for the point. This portion is performed using SPC's approved GSUAM methodology (Reference 2). GSUAM is a methodology to statistically combine uncertainties and create response surfaces which are used to determine the probability of conservatively remaining below the limiting parameter. In determining the response surfaces, the parameter uncertainties are included in the probability distribution. The trip setpoint is performed using the same methodology for DNB, FCM, and system pressure to demonstrate the 95/95 probability confidence of protection.

When transient analysis involves multiple trips, the probability distributions for each trip can be evaluated independently and the overall probability for the respective parameter of interest (DNB, FCM, or system pressure limit) can be determined. This is shown through probabilistic techniques to provide 95/95 confidence.

The methods used to confirm margin demonstrate that the overall probability distribution difference between the calculated setpoint parameter and the limit will protect the limit. For DNB, the parameters affecting the transient system behavior and minimum departure from nucleate boiling ratio (MDNBR) are varied. The margin is obtained by subtracting the DNBR value that corresponds to DNB from the calculated MDNBR. This margin is confirmed for 95/95 confidence and accounts for the uncertainties. This confirmation methodology is performed for DNB, FCM, and system pressure. In the simplified DNB method, the parameters affecting the transient system behavior are set to their deterministic limit while the parameters for MDNBR calculation are still varied. The simplified FCM margin confirmation is similar although the uncertainty in the peak LHGR is directly calculated and a deterministic approach is used to determine the FCM limit.

2.5 Neutronics Analysis

Core average axial power distributions and the corresponding internal and external ASIs are used in the setpoint and transient analysis. These ordered pairs of axial power distributions and ASIs are cycle-specific parameters generated from core simulation techniques. The original core simulation calculations provide the design total peaking and radial peaking factors. Therefore, they are modified to bound reactor operation by using the technical specification limit values.

3.0 EVALUATION

The SPC methodology for the LPD, DNB, and TM/LP, LSSSs and LCOs, uses statistical and probabilistic analytical methods that are standard textbook techniques and are applied in a consistent manner. These methods use standard statistical techniques to combine the uncertainties to create a response surface for determining the probability of remaining below or above the limit value which was previously approved for use by SPC (Reference 2). The new techniques that are used, compared to the previously approved methodology, for combining the uncertainties incorporated into the setpoint methodology, are statically valid applications which allow SPC to automate the methodology. The staff made this determination by comparing SPC's methods to methods in statistics books and verifying the statistical applications with the NRC statistical expert. The subsets of variables treated statistically were reviewed and determined to be properly treated, combined based on dependence or independence, and incorporated in the methodology. In the confirmation of margin calculation, treating the one variable subset at their conservative deterministic values results in a conservative confirmation of the margin. The new methodology extends the transient methodology to postulated accidents and events which have no trip, and therefore, adds additional safety verification to the overall methodology.

4.0 CONCLUSIONS

Based on its review, the staff concludes that the proposed topical report is acceptable. This acceptance is subject to the following conditions which SPC agreed to by letter dated March 3, 2000 (Reference 4):

1. This methodology is approved only for CE type reactors which use protection systems as described in the topical report.

2. The methodology includes a statistical treatment of specific variables in the analysis; therefore, if additional variables are treated statistically SPC should re-evaluate the methodology and document the changes in the treatment of the variables. The documentation will be maintained by SPC and will be available for NRC audit.

5.0 REFERENCES

1. Letter from James F. Mallay (SPC) to the U.S. Nuclear Regulatory Commission, submitting Topical Report EMF-1961(P), Revision 0, "Statistical Setpoint/Transient Methodology for Combustion Engineering Type Reactors," December 21, 1998.

2. Exxon Nuclear Methodology for "Generic Statistical Uncertainty Analysis Methodology," XN-NF-22(P)(A), November 1983.

3. Exxon Nuclear Company Topical Report XN-NF-507(P)(A), Supplements 1 and 2, "ENC Setpoint Methodology for C.E. Reactors: Statistical Setpoint Methodology," September 1986.

4. Letter from James F. Mallay (SPC) to the U.S. Nuclear Regulatory Commission, accepting to the Conditions in Topical Report EMF-1961(P), "SER Conditions for EMF-1961(P), "Statistical Setpoint/ Transient Methodology for Combustion Engineering Type Reactors,"" March 3, 2000.

Principal Contributor: Undine Schoop

Date: July 12, 2000

SIEMENS

December 21, 1998
NRC:98:086

Document Control Desk
ATTN: Chief, Planning, Program and Management Support Branch
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

Request for Review of EMF-92-081(P) Revision 1, "Statistical Setpoint/Transient Methodology for Westinghouse Type Reactors" and EMF-1961(P) Revision 0, "Statistical Setpoint/Transient Methodology for Combustion Engineering Type Reactors"

Enclosed are fifteen (15) copies of the proprietary (NOTE: Three copies have been forwarded to Mr. Egan Wang) and twelve (12) copies of the non-proprietary version of the reports EMF-92-081 Revision 1, "Statistical Setpoint/Transient Methodology for Westinghouse Type Reactors" and EMF-1961(P) Revision 0, "Statistical Setpoint/Transient Methodology for Combustion Engineering Type Reactors." It is requested that the NRC review these reports to support plant analyses performed by Siemens for its PWR customers.

Some of the information contained in the enclosed topical reports are considered to be proprietary to Siemens Power Corporation. As required by 10 CFR 2.790(b), an affidavit is enclosed to support the withholding of this information from public disclosure.

If you have any questions or if I can be of further assistance, please call me at (509) 375-8757.

Very truly yours,

James F. Mallay, Director
Regulatory Affairs

/arn

Enclosures

cc: Mr. T. E. Collins (USNRC)
Mr. R. Caruso (USNRC)
Mr. E. Y. Wang (USNRC) (3 proprietary copies of each report)
Project No. 702 (12 proprietary/12 non-proprietary copies of each report)

bc: (via e-mail)
R. E. Collingham
H. D. Curet
D. J. Denver
R. L. Feuerbacher
R. C. Gottula
L. E. Hansen
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Siemens Power Corporation

2101 Horn Rapids Road
Richland, WA 99352

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AFFIDAVIT

STATE OF WASHINGTON)
) ss.
COUNTY OF BENTON)

I, James F. Mallay, being duly sworn, hereby say and depose:

1. I am Director, Regulatory Affairs, for Siemens Power Corporation ("SPC"), and as such I am authorized to execute this Affidavit.

2. I am familiar with SPC's detailed document control system and policies which govern the protection and control of information.

3. I am familiar with the SPC information presented in the enclosures to letter NRC:98:086 referred to as "Documents." Information contained in these Documents has been classified by SPC as proprietary in accordance with the control system and policies established by SPC for the control and protection of proprietary and confidential information.

4. These Documents contain information of a proprietary and confidential nature and is of the type customarily held in confidence by SPC and not made available to the public. Based on my experience, I am aware that other companies regard information of the kind contained in these Documents as proprietary and confidential.

5. These Documents have been made available to the U.S. Nuclear Regulatory Commission in confidence, with the request that the information contained in the Documents will not be disclosed or divulged.

6. These Documents contain information which is vital to a competitive advantage of SPC and would be helpful to competitors of SPC when competing with SPC.

7. The information contained in these Documents is considered to be proprietary by SPC because it reveals certain distinguishing aspects of SPC licensing methodology which secure competitive advantage to SPC for fuel design optimization and marketability, and includes information utilized by SPC in its business which affords SPC an opportunity to obtain a competitive advantage over its competitors who do not or may not know or use the information contained in these Documents.

8. The disclosure of the proprietary information contained in these Documents to a competitor would permit the competitor to reduce its expenditure of money and manpower and to improve its competitive position by giving it valuable insights into SPC licensing methodology and would result in substantial harm to the competitive position of SPC.

9. These Documents contain proprietary information which is held in confidence by SPC and is not available in public sources.

10. In accordance with SPC's policies governing the protection and control of information, proprietary information contained in these Documents has been made available, on a limited basis, to others outside SPC only as required and under suitable agreement providing for nondisclosure and limited use of the information.

11. SPC policy requires that proprietary information be kept in a secured file or area and distributed on a need-to-know basis.

12. Information in these Documents provides insight into SPC licensing methodology developed by SPC. SPC has invested significant resources in developing the methodology as well as the strategy for this applicaticn.

Assuming a competitor had available the same background data and incentives as SPC, the competitor might, at a minimum, develop the information for the same expenditure of manpower and money as SPC.

13. The foregoing statements are true and correct to the best of my knowledge, information, and belief.

SUBSCRIBED before me this 22nd day of December, 1998.

SUE M. GALPIN
COMMISSION EXPIRES
NOTARY PUBLIC
FEB. 27, 2000
STATE OF WASHINGTON

Sue M. Galpin

Sue M. Galpin
NOTARY PUBLIC, STATE OF WASHINGTON
MY COMMISSION EXPIRES: 02/27/00

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

September 28, 1999

Mr. James F. Mallay
Director, Regulatory Nuclear Affairs
Siemens Power Corporation
2101 Horn Rapids Road
Richland, WA 99352

SUBJECT: REQUEST FOR ADDITIONAL INFORMATION - SIEMENS TOPICAL REPORT, EMF-1961, "STATISTICAL SETPOINT/TRANSIENT METHODOLOGY FOR COMBUSTION ENGINEERING (CE) REACTORS" (TAC NO. MA4659)

Dear Mr. Mallay:

By letter dated December 21, 1998, the Siemens Power Corporation submitted Topical Report EMF-1961, "Statistical Setpoint/Transient Methodology for CE Reactors" for staff review. The staff is reviewing the Topical Report and additional information, as discussed in the enclosure is requested, in order for the staff to complete its review.

The enclosed request was discussed with your staff on September 22, 1999. A mutually agreeable target date of within 30 days of the date of this letter for your response was established. If circumstances result in the need to revise the target date, please call me at the earliest opportunity at 301-415-1480.

Sincerely,

N. Kalyanam, Project Manager, Section 2
Project Directorate IV & Decommissioning
Division of Licensing Project Management
Office of Nuclear Reactor Regulation

Project No. 702

Enclosure: Request for Additional Information

GENERAL QUESTIONS PERTAINING TO BOTH

THE WESTINGHOUSE AND COMBUSTION ENGINEERING

STATISTICAL SETPOINT/TRANSIENT METHODOLOGY

1. Please provide flowcharts of overall methodology for arriving at the statistical setpoint/transient analysis.

2. Please confirm the use of textbook statistical methods throughout.

3. Please explain if the applied methodology is in accordance with the methodology described in GSUAM.

4. Please provide details on why the methodologies for the two reactor types differs.

Enclosure

STATISTICAL SETPOINT/TRANSIENT METHODOLOGY FOR

COMBUSTION ENGINEERING TYPE REACTORS

REQUEST FOR ADDITIONAL INFORMATION

1. Page 2-8, Section 2.2.1

   The general form of the TM/LP trip is given. Please detail how the alpha, beta, and gamma terms for the equation were determined.

2. Page 2-9, fifth paragraph

   The iterative scheme for obtaining the DNB portion of the P_{VAR} is described. Please provide additional details or a demonstration of this iterative scheme.

3. Page 2-10, second paragraph

   Please specify how the adjustment of the cold temperature is set for each plant? Also, please provide further explanation on why it is not part of SPC's statistical methodology.

4. Page 2-22, Section 2.2.4.1

   It is stated that significant parameters are treated statistically while the remaining parameters may be set to their conservative limits. Please explain how SPC determines which parameters are significant.

5. Page 2-23, Section 2.3

   It is stated that Tables 2.4 and 2.5 contain typical plant values that will be used in the proposed methodology which are in publicly available documents. Please provide the references for where these values can be obtained.

6. Page 2-23, second paragraph under 2.3

   It is stated that the values currently in Tables 2.4 and 2.5 for power distribution peaking factor uncertainties are typical. Please provide additional details on which power distribution factor uncertainties are used in the analysis, the typical ones in Tables 2.4 and 2.5 or plant specific uncertainties. Also, if the power distribution factor uncertainties from Tables 2.4 and 2.5 are used, please explain (provide technical justification) for using them.

7. Page 2-30, Table 2.6

   Please provide the bases for the pump coastdown rate.

8. Page 3-2, second paragraph

The text mentions that the minor variations are caused by the limitations of the output file print format. Please describe these limitations and quantify the impact of the limitations on the results.

9. Page 3-3, fourth paragraph

Please demonstrate how the probability density for the LCO power was generated.

10. Page 3-6, third paragraph

Please provide further explanation or demonstrate how the QA and QR1 functions were calculated.

11. Page 3-6, fifth paragraph

The margin calculation is stated. Please provide further explanation or demonstrate how this margin is calculated.

12. Page 3-8, Section 3.4.2

Please provide additional details or demonstrate how the LOCF confirmation is performed.

13. Page 4-3, third paragraph

It is stated that the target-specific uncertainties are included in the calculation of the probability distribution of the margin. Please describe these uncertainties, explain how these uncertainties are included, and how the probability distribution is calculated.

14. Page 4-4, fifth paragraph

The text states that the DNB value is uncertain so a probability of DNB is calculated. Please explain how this calculation is performed.

15. Page 4-7, first paragraph

It is stated that an adjustment for the size of the data base is required. Please provide additional details on how this adjustment is performed.

SIEMENS

October 4, 1999
NRC:99:044

Document Control Desk
ATTN: Chief, Planning, Program and Management Support Branch
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555-0001

Request for Additional Information to the Topical Report EMF-1961(P) Revision 0, "Statistical Setpoint/Transient Methodology for Combustion Engineering Type Reactors"

Ref.: 1. Letter, N. Kalyanam (NRC) to James F. Mallay (SPC), "Request for Additional Information – Siemens Topical Report, EMF-1961, "Statistical Setpoint/Transient Methodology for Combustion Engineering (CE) Reactors (TAC NO. MA4659)," September 28, 1999.

Ref.: 2. Letter, James F. Mallay (SPC) to Document Control Desk, "Request for Review of Topical Report EMF-92-081(P) Revision 1, 'Statistical Setpoint/Transient Methodology for Westinghouse Type Reactors' and EMF-1961(P) Revision 0, 'Statistical Setpoint/Transient Methodology for Combustion Engineering Type Reactors,'" NRC:98:086, December 21, 1998.

Reference 1 requests additional information relevant to one of the topical reports submitted by Reference 2. The responses to the RAI are provided in the attachment to this letter.

Siemens Power Corporation considers some of the information contained in the attachment to this letter to be proprietary. This information has been noted as such by enclosing it within brackets. The affidavit provided with the original submittal of the reference topical report satisfies the requirements of 10 CFR 2.790(b) to support the withholding of this information from public disclosure.

Very truly yours,

James F. Mallay

James F. Mallay, Director
Regulatory Affairs

/arn

Attachment

cc: Mr. N. Kalyanam (2 copies w/attachment)
Project No. 702 (w/attachment)

Siemens Power Corporation

2101 Horn Rapids Road
Richland, WA 99352

Tel: (509) 375-8100
Fax: (509) 375-8402

Responses to General Questions pertaining to both the Westinghouse and Combustion Engineering Statistical Setpoint/Transient Methodologies

1. ***Please provide flowcharts of overall methodology for arriving at the statistical setpoint/transient analysis.***

See charts on page 4 through page 11 of this attachment.

2. ***Please confirm the use of textbook statistical methods throughout.***

There are three "textbook" methods used in the methodology. Two are from probability theory and one is a statistical method. The two from probability theory are used extensively. The statistical adjustment is used in two areas.

The first standard probabilistic tool is used to convert the probability density for one random variable to that for another random variable when the relationship between the two random variables is known. This particular tool can be found expressed in any text on probability. The relationship is derived from the definition of the probability distribution and the requirement that probability be preserved, even when expressed in terms of another variable.

When y is related to x by a function g, y = g(x), the probability density for y can be expressed in terms of x (or vice versa). [

]

The second standard probabilistic tool is based on the definition of [

] It represents an extension of the first tool to treat multidimensional dependencies. The probability distribution for a random variable, Z, can be written as

$$F_Z(z) = \int_{-\infty}^{z} f_Z(z)dz$$

If z is related to several other variables by some function, $G(x_1,x_2,\ldots x_n)$, the probability distribution can be written [

]

where the domain is defined by the relationship between z and the other random variables. The meaning of $F_z(z)$ is that it is the probability that z is greater than a random variable, Z. Therefore the domain of the integration is defined as [

]

In the cases discussed in the methodology, the random variables are independent and the [

]

is determined by the functional relationship between the random variables.

The statistical method used is an adjustment of the mean and the standard deviation based on a limited sample size. This approach is based on D.B. Owens' "Factors for One-Sided Tolerance Limits and Variable Sampling Plans." The principle assumptions are that the mean of the distribution behaves like a studentized t-distribution and that the standard deviation behaves according to a χ^2 distribution. The resulting non-central t-distribution is used to adjust statistics to account for limited sample sizes. The two places it is used are for the calculation of the statistical relation between the [

]

3. ***Please explain if the applied methodology is in accordance with the methodology described in GSUAM.***

GSUAM methods are used in creating response surfaces and fitting them. For transient analyses, the analysis used the response surface techniques and can use Monte Carlo methods to combine probabilities.

4. ***Please provide details on why the methodologies for the two reactor types differs.***

The transient methodologies for the two reactor types are the same. The setpoint methodologies differ because the types of setpoints differ and because the forms are significantly different.

<u>LPD LSSS</u> – This function protects against fuel centerline melt (FCM) in Combustion Engineering (C-E) plants. In a Westinghouse reactor, the analogous trip is the Over Power ΔT trip (OPΔT).

The LPD LSSS is a curve constituting a boundary for allowed power as a function of ASI. Since the power, which is one of the main factors in FCM, is measured directly, the verification of margin is straightforward.

The OPΔT trip measures temperatures and the axial flux difference (ΔI) and trips the reactor based on the ΔT. Since temperature rises across the core are related to power through other variables and since the measurements are made at locations somewhat removed from the core itself, the trip includes a set of dynamic compensation terms to account for loop transit delays and RTD time constants. The task of verifying the OPΔT involves first verifying that a static version of the trip would protect against fuel centerline melt and then verifying that the dynamic compensation terms can produce a trip before the static conditions would require a trip.

Because of the differences, the LPD LSSS simply includes an overshoot delay in power to account for transient effects, but the OPΔT is evaluated in a transient simulation. In addition, the OPΔT margin is evaluated over a range of pressures and temperatures to confirm that the functional form can protect against FCM.

[

]

<u>LPD LCO</u> – The LPD LCO provides protection against the LOCA limit when the in-core measurement system is not functioning in C-E plants. This LCO is not a part of the Westinghouse system, and there is no direct analog.

<u>DNB LCO</u> – For a C-E plant, operating within this LCO (and all of the others) will result in not penetrating DNB for any AOO. Since the most limiting challenges are either a dropped rod (usually has no trip) and the loss of power to the RCPs, these two events are evaluated statistically to confirm this LCO. This LCO is not a part of the Westinghouse system, and there is no direct analog.

<u>TM/LP</u> – This trip protects against hot-leg saturation and DNB in a C-E plant and is analogous to the Over Temperature ΔT (OTΔT) trip in a Westinghouse plant. The TM/LP trips on pressure and the OTΔT trips on the difference between the hot and cold leg RTD readings. Since the TM/LP measures power, pressure, ASI and inlet temperature directly, the effects of transient overshoot can be included directly as a bias. The OTΔT is confirmed statically and then the dynamic compensation terms are evaluated separately.

Figure 1 Flow of FCM Calculations

Figure 2 Flow of LPD LSSS Confirmation

Figure 3 Flow of TM/LP Confirmation

Figure 4 Flow of DNB LCO Confirmation

Figure 5 Flow of OPΔT Confirmation

Figure 6 Flow of OTΔT Confirmation

Figure 7 Flow of CSLL Confirmation

Figure 8 Flow of Statistical MDNBR Calculations

Responses to Request for Additional Information on the Statistical Setpoint/Transient Methodology for Combustion Engineering Type Reactors

1. Pg. 2-8, Section 2.2.1,

The general form of the TM/LP trip is given. Please detail how the alpha, beta, and gamma terms for the equation were determined.

The coefficients for the TM/LP trip; α, β and γ; are determined such that they prevent the occurrence of hot leg saturation or DNB. The traditional method of determining the values makes use of the Core Safety Limit Lines (CSLLs) and finds a set that conservatively bounds the CSLLs. When a confirmation of the trip is performed, the values selected for the trip are checked to confirm that they provide the protection for DNB and hot leg saturation. Whether SPC created the values from the CSLLs or modified existing values in some way, the ultimate test of the acceptability of the values is the confirmation process.

2. Pg. 2-9, fifth paragraph,

The iterative scheme for obtaining the DNB portion of the P_{VAR} is described. Please provide additional details or a demonstration of this iterative scheme.

The iterative process seeks to determine the pressure at which DNB would occur. When uncertainties are ignored, DNB occurs at the mean value of the correlation [

] The iterative process is repeated for a range of values in power and T_{inlet} that cover the range over which the TM/LP would need to provide protection. In addition to the power and T_{inlet}, the axial power shape is considered as a variable, too. These three inputs are varied because they represent the parameters that are input to the TM/LP.

Thus, the process is to select an axial power shape (corresponds to an ASI), a power and an inlet temperature and to calculate the MDNBR, using XCOBRA-IIIC. [

]

3. Pg. 2-10, second paragraph,

Please specify how the adjustment of the cold temperature is set for each plant? Also, please provide further explanation on why it is not part of SPC's statistical methodology.

The correction to the cold leg temperature was created by C-E to help reduce the effects of thermal striping (stratification) in the cold leg that caused the cold leg RTD readings to develop a bias as a function of power. The form developed consisted of an adjustment term proportional to the normalized power. SPC has not included the setting of the coefficient for the normalized power term in the setpoint methodology. The value of the coefficient need be derived only once as it is a function of the geometry of the cold leg and the steam generator outlet. The uncertainties associated with the cold leg temperature measurement are treated by SPC as representing the presence, or lack, of the cold leg compensation term.

For many operating plants, this additional compensation has been disabled.

4. Pg. 2-22, Section 2.2.4.1,

It is stated that significant parameters are treated statistically while the remaining parameters may be set to their conservative limits. Please explain how SPC determines which parameters are significant.

The phenomenology of the LOCF event was evaluated to determine what affects the calculated MDNBR for the event. The LOCF is initiated by a complete loss of power to the four Reactor Coolant Pumps (RCPs). They begin to coast down as a result of the torque mismatch. As the flow reduces, the local conditions within the core begin to deteriorate as the power-to-flow ratio increases. The MDNBR begins to fall. When the sensed flow reaches the low flow setpoint, a reactor trip signal is generated and, after a short delay, the reactor scrams. The power reduces rapidly and the MDNBR recovers. The phenomena determining the challenge to DNB are the rate of flow reduction and the time required to introduce sufficient negative reactivity to shut the reactor down.

The significant parameters are those which are a part of the phenomena determining the challenge to DNB. [

]

5. Pg. 2-23, Section 2.3,

It is stated that tables 2.4 and 2.5 contain typical plant values that will be used in the proposed methodology which are in publicly available documents. Please provide the references for where these values can be obtained.

The values presented in the tables came from the SAR for St. Lucie Unit 1 and "St. Lucie Unit 1 Stretch Power Application Cycle 4, Docket #50-335 – Safety Evaluation."

6. Pg. 2-23, second paragraph under 2.3,

It is stated that the values currently in Tables 2.4 and 2.5 for power distribution peaking factor uncertainties are typical. Please provide additional details on which power distribution factor uncertainties are used in the analysis, the typical ones in Tables 2.4 and 2.5 or plant specific uncertainties. Also, if the power distribution factor uncertainties from Table 2.4 and 2.5 are used, please explain (provide technical justification) for using them.

As a part of implementing neutronics methods, SPC calculates the uncertainty in the measured peaking factors. The current uncertainties supported by SPC's methodologies are a one-side 95/95 uncertainty of 6% on radial peaking and 7% on total peaking. These values were obtained by comparing a large number of predicted power distributions with measurements, EMF-96-029(P)(A).

7. Pg. 2-30, Table 2.6,

Please provide the bases for the pump coastdown rate.

Pump coast downs were performed during startup testing at a plant at Hot Zero Power and at 40% power. These data were fit and the pump coastdown coefficient extracted.

8. Pg. 3-2, second paragraph,

The text mentions that the minor variations are caused by the limitations of the output file print format. Please describe these limitations and quantify the impact of the limitations on the results.

This figure is an intermediate result used to illustrate the components of the statistical calculation. It is created within the computer code and used there as a part of the margin calculation. It is also printed to the output file as a part of the summary of the calculation. The values printed in the output file were used to create the plot. The format of the print to the output file limited the number of significant digits and resulted in small oscillations in the plotted figure. These format limitations have no effect on the results.

9. Pg. 3-3, fourth paragraph,

Please demonstrate how the probability density for the LCO power was generated.

The probability density was calculated by transforming the ASI uncertainty into power uncertainty using the DNB LCO. This LCO is given in the following table:

DNB LCO	
ASI	Allowed Power (%)
-0.5	45.0
-0.08	85.0
0.08	85.0
0.5	45.0

The ASI of the case described in the subject paragraph is 0.091. Over the range −0.08 < ASI < 0.08, variations in ASI do not contribute to a variation in the power. All randomly selected ASIs in this range return a power of 85% of rated. In the region ASI > 0.08, a 1% change in ASI corresponds to a 0.9524% change in power. Thus the relationship between power and ASI for this latter region can be defined as

$$\text{Power} = 0.45 - 0.9524 * (\text{ASI} - 0.5)$$

for ASI >0.08.

Using the standard form for transforming a probability, the probability density for power over this region is given by

[

]

When the ASI is less than 0.08, the value of the power is unaffected by changes in ASI. [

]

The values in Figure 3.8 have been scaled such that the integral over all powers becomes 100 rather than 1. The scaling reflects the manner in which the density is used within the computer code.

10. Pg. 3-6, third paragraph,

Please provide further explanation or demonstrate how the QA and QR1 functions were calculated.

The probability densities for these functions were calculated. The functions themselves were being confirmed as a part of the TM/LP trip verification. These probability densities themselves were calculated by transforming the ASI to obtain the uncertainty in QA and the power for the uncertainty in QR1.

The QA function is given as

QA Function for TM/LP		
ASI	*QA*	*dQA/dASI*
-0.6	*1.4*	
0.0	*1.1*	*-0.5*
0.2	*1.0*	*-0.5*
0.6	*1.2*	*0.5*

The probability density for QA is given by

The ASI value for this case is 0.211, which places the nominal point near the minimum of the QA function. The function is double-valued and the probability density will have contributions from ASI>0.2 and from ASI<0.2 which correspond to the same value of QA.

When ASI > 0.2, the relationship between ASI and QA is given by

$$QA = 1.0 + 0.5 * (ASI - 0.2)$$

When ASI < 0.2, the relationship is

$$QA = 1.0 - 0.5 * (ASI - 0.2)$$

The QR1 function is given by

QR1 Function for TM/LP		
Power	*QR1*	*DQR1/dPOWER*
0	*.235*	
.781	*.836*	*1*
.972	*.972*	*0.712*
1.2	*1.2*	*1*

For the case in question, the power was about 107% of rated and the transformation became a 1. Thus, the probability density for the QR1 function was just the probability density for power.

11. Pg. 3-6, fifth paragraph,

The margin calculation is stated. Please provide further explanation or demonstrate how this margin is calculated.

A large number of cases are considered in the confirmation of the TM/LP trip. The margin is expressed as the difference between the pressure at which DNB would occur (a statistical variable) and the trip pressure (another statistical variable). The probability distribution for the DNB pressure is based on a fit to the response surface and is usually done [ ] The uncertainty in the TM/LP pressure from the ASI uncertainty, power uncertainty and T_{inlet} uncertainty are combined to obtain the uncertainty in the calculated trip pressure. The difference between the two pressures is calculated statistically and combined with the uncertainty in the pressure measurement (separate from the uncertainty in the calculated trip uncertainty). This distribution is shifted by any pressure biases necessary to reflect transient overshoot in pressure (trip delays, scram delays, etc.). The DNB pressure is the core exit pressure (XCOBRA-IIIC calculates the core exit pressure), which is usually about 20 psi higher than the pressurizer pressure. This adjustment is added to the mean of the distribution and the lower 95% limit in pressure margin is calculated from the distribution.

12. Pg. 3-8, Section 3.4.2,

Please provide additional details or demonstrate how the LOCF confirmation is performed.

The confirmation of the DNB LCO for LOCF is very similar to the confirmation for CEAD. A set of [ ] using nominal assumptions. [ ] XCOBRA-IIIC is then used to calculate the response surface points. Using the nominal points from XCOBRA-IIIC and the response surface points, the margin between the initial power corresponding to DNB (a statistical variable) and the DNB LCO is calculated for each nominal point.

13. Pg. 4-3, third paragraph,

It is stated that the target-specific uncertainties are included in the calculation of the probability distribution of the margin. Please describe these uncertainties, explain how these uncertainties are included, and how the probability distribution is calculated.

The generic terminology used in this section was used so that calculations to protect DNB, FCM, primary over-pressurization and secondary over-pressurization could be discussed in the same manner. For each transient, a subset of parameters is selected for variation. All other parameters are biased in a manner consistent with the plant transient methodology. Generally the subset selected for statistical variation is comprised of parameters which affect the result and for which uncertainties can be established. The transient runs are repeated multiple times, varying one or more of the selected parameters for each run. This process is an application of techniques described in the GSUAM methodology. For each of the events considered, the factors that can produce the largest mitigation or exacerbation of the results are the most likely candidates for statistical variation. Trip setpoints, scram curves, pump coastdowns, safety valve actuation, etc. are examples of these factors.

For DNB, the parameters affecting heat flux, inlet enthalpy, flow and pressure are considered in the plant transient analysis. Since the DNBR is calculated by XCOBRA-IIIC, the response surface input varies the peaking factor for each case calculated. [ ]

[ ] This approach provides slightly more DNB margin than the simplified method because it treats a larger set of parameters statistically.

For FCM, the parameters affecting the power are the only significant parameters. Similar to the DNB calculation, the parameters that affect power are varied to create the response surface. To calculate the margin, the response surface is [ ]

For events with primary or secondary pressurization, the response surface in the respective pressure is converted directly to a probability distribution and the 95/95 margin calculated directly. The parameters varied for these cases are selected using the same general criteria: impact on the pressure and quantifiable uncertainties.

14. Pg. 4-4, fifth paragraph,

The text states that the DNB value is uncertain so a probability of DNB is calculated. Please explain how this calculation is performed.

The calculation of the probability of the DNB margin is described on pages 4-5 and 4-6. The final result is [ ]

The DNB value is uncertain, even given the MDNBR. The correlation really gives a conditional probability. The probability distribution is the probability of DNB, given a value for MDNBR. The problem can be approached in the manner described on pages 4-5 and 4-6, or a Bayesian argument can be used, which says that [ ]

This will lead to the same expression as given on page 4-6 for the margin, except that Z will be zero.

The probability of a specific MDNBR is obtained using a response surface calculation with XCOBRA-IIIC in which [ ] This is described on page 4-5. [ ] to get the probability for MDNBR. Finally, [ ]

15. Pg. 4-7, first paragraph,

It is stated that an adjustment for the size of the data base is required. Please provide additional details on how this adjustment is performed.

The adjustment is described in the succeeding paragraphs. This is one of the two places where statistical methods are applied. The statistics of the DNBR correlation are adjusted for the size of the underlying database. There are several methods used, including non-parametric (distribution-free) methods. Parametric methods will result in a smaller adjustment to the raw statistical parameters (mean and standard deviation). This produces a more conservative estimate of the underlying data, since the assumed adjustment from raw data to the correlation parameters is smaller and the inferred raw data are much closer to the bounding numbers used in the correlation. Some of the conservatism inherent in this approach is removed because the effective MDNBR is calculated using the same parametric methods. It should be noted that the effective MDNBR is provided as an aid in assessing the results. The real measurement of success or failure is the [ ]

The parametric method used in this work is a standard technique described in D.B. Owens' "Factors for One-Sided Tolerance Limits and Variable Sampling Plans." This method assumes that the distribution has a mean behaving like a Student's t-distribution and that a standard deviation behaving like a χ^2 distribution. The calculated mean and standard deviation of data are used with an appropriate tolerance factor to correspond to the desired one-sided probability.

In a probabilistic analysis of a DNB event the probability that DNB occurs is calculated. The MDNBR, based on an applicable correlation, is calculated. However, the values known for the correlation are usually the mean and the 95/95 limit. These values have been adjusted to reflect the sample size. In order to connect the calculated probability of DNB to the test data supporting the correlation directly, the mean and standard deviation of the test data corresponding to the approved limit for the correlation are calculated, based on the sample size. This is done by calculating the k-factors corresponding to the mean and approved limit. Using the same method, the k-factor for the probability of DNB at a 95% confidence level is calculated based on the size of the data base. The effective MDNBR is just the mean of the test data plus this k-factor times the standard deviation.

SIEMENS

March 3, 2000
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Document Control Desk
ATTN: Chief, Planning, Program and Management Support Branch
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555-0001

SER Conditions for EMF-1961(P), "Statistical Setpoint/Transient Methodology for Combustion Engineering Type Reactors"

Two conditions have been proposed for inclusion in the safety evaluation report for EMF-1961(P). These conditions are:

1. This methodology is approved only for CE type reactors which use protection systems as described in the topical report.

2. The methodology includes a statistical treatment of specific variables in the analysis; therefore, if additional variables are treated statistically SPC should re-evaluate the methodology and document the changes in the treatment of the variables. The documentation will be maintained by SPC and will be available for NRC audit.

Siemens Power Corporation discussed these conditions with the NRC and agrees they are acceptable and appropriate.

Very truly yours,

James F. Mallay

James F. Mallay, Director
Regulatory Affairs

/arn

cc: N. Kalyanam
U. S. Shoop
Project No. 702

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EMF-1961(NP)(A)
Revision 0

Statistical Setpoint/Transient Methodology for Combustion Engineering Type Reactors

December 1998

Nature of Changes

Item	Paragraph or Page(s)	Description and Justification
1.	None	This is a new document.

Contents

Tables

Figures

Distribution

D. M. Brown
R. E. Collingham
R. L. Feuerbacher
R. C. Gottula
R. G. Grummer
L. E. Hansen
J. R. Hartman
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PWR Safety Analysis
R. S. Reynolds
Safety Analysis Methods
R. I. Wescott

Proprietary Version – 15 (for NRC)
Non-Proprietary Version – 12 (for NRC)

1. Introduction

This document describes Siemens Power Corporation's (SPC's) methodology for statistically analyzing Limiting Conditions of Operation (LCOs), Limiting Safety System Settings (LSSSs) and transients for Combustion Engineering (C-E) pressurized water reactors. The statistical combination of uncertainties used in this methodology uses SPC's approved Generic Statistic Uncertainty Analysis Methodology (GSUAM) described in Reference 1 and in Appendix A to Supplement 1 in Reference 2. The methodology described herein is based on C-E plants with Thermal Margin/Low Pressure (TM/LP) and Local Power Density (LPD) LSSSs and LPD and departure from nucleate boiling (DNB) LCOs.

Statistically combining the uncertainties involved in calculating LCOs and LSSSs establishes conservative and meaningful values for those settings. The statistical analysis of plant transients shares the statistical techniques used for the LSSSs and LCOs and incorporates a plant transient model to propagate uncertainties.

Section 2 describes the procedures used in statistically determining LCOs and LSSSs for C-E reactors and for statistically confirming the LCOs and LSSSs. Section 3 gives sample cases for each setpoint described in Section 2. Section 4 describes the statistical transient analysis. Section 5 describes the setpoint axial power shapes used for the analysis. Appendices A and B describe the calculation of a fuel centerline melt (FCM) limit and confirmation of the Core Safety Limit Lines (CSLLs), respectively.

SPC approved statistical setpoint and transient methodology for Combustion Engineering reactors is described in Reference 2. This report documents that methodology in a more detailed manner, extends the scope to include additional transients and provides new sample cases which cover the scope of the methodology better. It incorporates the following changes to the description provided in the approved methodology:

1. [

]

2. The acceptance criterion based on joint probabilities of ASI and power are replaced by a conversion of ASI uncertainties into power uncertainties.
3. The confirmation of the margin to hot-leg saturation is performed when the DNB margin is confirmed.
4. A description of the calculation of fuel center line melt limits is added.
5. The analysis of statistical transients is extended from the two limiting DNB events, Loss of Coolant Flow and Control-Element-Assembly Drop, to include other events.
6. The limits protected by the transient methodology include fuel center line melt and secondary system pressure.
7. The confirmation of Core Safety Limit Lines is added.

2. Limits on Operating Conditions and Safety System Settings

LCOs and LSSSs are determined or confirmed based on meeting Specified Acceptable Fuel Design Limits (SAFDLs) for FCM, preventing DNB and protecting against fuel failure in Loss-of-Coolant Accidents (LOCAs). DNB limits are based on DNB correlations which have been approved by the U.S. Nuclear Regulatory Commission (NRC). Both FCM and the LOCA limits are based on the linear heat generation rate (LHGR). The LHGR limit for LOCAs is the value used in the LOCA analyses. Appendix A describes the calculation of the FCM limit.

In all cases, the comparisons to limits include compensation for uncertainties. Historically, uncertainties have been included in a "deterministic" fashion; that is, the value for each uncertain parameter has always been selected to be at its most unfavorable limit. This approach compensated for uncertainties in a very conservative fashion and required only a single analysis. The methods described in this section may be applied to treat all uncertainties deterministically.

In the statistical analyses, the uncertainties are accounted for by statistical combination. GSUAM, along with other standard probabilistic techniques, is used to statistically combine the uncertainties. This approach provides an accurate method for accounting for uncertainties and can require a large number of calculations.

SPC uses a bounding approach to reduce the number of calculations for some cases. This approach is used for cases that have many nominal cases. The uncertainties could be combined at each nominal point and a margin defined. In general, the number of calculations used in the analysis can be reduced by statistically combining the bulk of the uncertainties at a single nominal point and applying this calculational uncertainty to every nominal point. The nominal point used is conservatively chosen to provide the greatest uncertainty in the calculated results and, therefore, a conservative estimate at all other points.

The nominal point is chosen by finding the location where the difference between the nominal point and the deterministic calculation is maximum. SPC has chosen to use this approach in deriving and confirming the setpoints, because it provides a selection criterion that is both workable and heuristically sound. The point selected by this criterion will result in a conservative estimate of the uncertainties in the calculated result for all applicable points.

Deriving an LCO or LSSS is somewhat more difficult than confirming an existing setpoint, because the power uncertainty coming from the axial shape index (ASI) uncertainty depends on the functional form and the process becomes iterative. The methods Sections 2.1.2, 2.1.3, 2.2.2 and 2.2.4 to confirm a setpoint can be used in an iterative manner to derive a setpoint.

Sections 2.1 through 2.3 describe the application of SPC's statistical methods in the calculation and confirmation of LCOs and LSSSs.

2.1 Local Power Densities

Protection against FCM is provided by the LPD LSSS and the LPD LCO. The LPD LSSS protects against FCM by monitoring the power level of the reactor and tripping the reactor when the power level exceeds the trip setpoint corresponding to the ASI. The LPD LCO limits power operation based on the ASI. The function of the LPD LCO is to protect against the LPD exceeding the LHGR limit set by the LOCA analysis.

These functions are based on the worst axial (F_z) and radial (F_r) power distributions for a given ASI. Radial power distribution does not effect the ASI directly. Therefore, the radial peaking factor assumed for all values of ASI is the Technical Specification value. If the technical specification value of F_r does not apply to a core with control elements inserted, the F_r is augmented to account for the increased peaking from the control elements.

Each axial power distribution has a value for ASI. However, several axial power distributions can correspond to the same ASI. In determining the LPD LSSS and LCO, the most limiting axial distribution for a given ASI sets the limit.

Sections 2.1.1 through 2.1.3 describe the procedure for establishing the setpoint, first without considering uncertainties then including appropriate adjustments for uncertainties.

2.1.1 Local Power Density Limiting Safety System Settings Without Uncertainties

This section describes the generation of the LPD LSSS using all nominal or "best estimate" values. The calculational procedure consists of determining the power at which FCM would be predicted to occur. Given a total peaking factor, the maximum allowed power is given by

$$POWER = \left\{ \frac{LHGR_{FCM}}{LHGR_{ave} x F_Q} \right\} x Rated Power$$

where

$$LHGR_{ave}\ (kw/ft) = \frac{\text{Rated Power (MWt) x 1000}}{\text{Number of Assemblies x Fuel Rods per Assembly x Active Length (ft)}}$$

$LHGR_{FCM}$ is the FCM limit and F_Q is the total peaking factor.

A comprehensive set of axial shapes is prepared for the operating cycle (see Section 5). Each shape has an ASI and an F_Q. The percent allowed power for each axial power shape is calculated. The resulting power and ASI points can be plotted and a simple curve drawn that does not pass above any of the points. This curve would be the LPD LSSS for the case where uncertainties are not accounted for. The interpretation of this curve is that, for any axial shape corresponding to some ASI, FCM would not be predicted below the curve.

2.1.2 Local Power Density Limiting Safety System Settings With Uncertainties

Calculation of the LPD LSSS statistically is an iterative process and involves selecting a guess for the LPD LSSS and then evaluating the power margin provided by the trip. The LPD LSSS calculated in the preceding section, which does not include the effects of uncertainties, can be adjusted to provide a first guess for the LPD LSSS. If the guess does not provide protection, it is made more restrictive and the power margin evaluated. This process is repeated until the power margin is confirmed for the LPD LSSS. The LPD LSSS is then determined.

Figure 2.1 shows the flow of the process for confirming the LPD LSSS. To confirm the LPD LSSS, a series of calculations is performed using each axial power shape. Those shapes for which the melt power exceeds the power at which the shape was generated by the offset of the Variable High Power (VHP) trip, adjusted for uncertainties, are not considered.

For the remaining shapes, the nominal margin between the trip power and the FCM power is calculated, then adjusted for uncertainties. This adjustment is made by calculating the probability distribution in margin between the trip power and the power at which FCM would occur. Using the one-sided, lower 95% of the margin from the distribution, a table of margin versus ASI is created. For the LPD LSSS to be confirmed, all of the margin values in the table must be positive.

The uncertainties that must be accounted for are basically from two sources: measurement and calculational uncertainties. Calculational uncertainties include model structural deficiencies and parameter uncertainties. Table 2.1 lists the uncertainties included in the LPD LSSS. Section 2.3 briefly describes these parameter uncertainties.

[

]

2.1.2.1 Axial Power Shape Rejection Criterion

[

]

2.1.2.2 Statistical Calculation of Margin

FCM power margin is calculated statistically in two steps. [

]

2.1.2.3 Statistical Calculation of ASI Contribution to Power

The contribution to the power uncertainty from the ASI uncertainty is defined in terms of the barn, $\Phi(ASI)$, where $\Phi(ASI)$ denotes the trip power as a function of ASI. The probability density in barn power is defined based on the [

] This transformation of the probability density needs to be evaluated over the whole range of the LSSS.

[

]

[

]

2.1.2.4 Statistical Margin

[

]

2.1.3 Local Power Density Limiting Conditions of Operation

The LPD LCO is similar in form to the LPD LSSS and is based on preventing the plant from exceeding a reduced LHGR during operation. The value of the reduced LHGR is no greater than the value used in the LOCA analysis. The LPD LCO has no trip associated with it. It comes into effect only when the in-core detectors are not in service. Besides the target value for LHGR and the shape of the LPD LCO, the major difference in its treatment is the difference in the uncertainties associated with the reactor power required to meet the limit. It has no trip delays, biases or uncertainties. The flow of the calculation is the same as that for the LPD LSSS confirmation shown in Figure 2.1.

2.2 Departure from Nucleate Boiling

The TM/LP LSSS and the DNB LCO are designed to protect the DNB SAFDL. The TM/LP LSSS trips the reactor when conditions approach a 95% probability that the limiting pin undergoes DNB. The DNB LCO ensures that Anticipated Operational Occurrences (AOOs) will not result in DNB with at least 95% probability at a 95% confidence level. As with the LPD LSSS and LCO, the TM/LP and DNB LCO are determined by an iterative process which is converged when DNB protection is confirmed.

Sections 2.2.2 and 2.2.4 describe the SPC methodology for combining uncertainties in the determination of these two limit curves. As with FCM protection functions discussed earlier, the determination of the limit curves without uncertainties is treated first, then the statistical method for conservatively accounting for uncertainties is shown.

2.2.1 Thermal Margin/Low Pressure Limiting Safety System Settings Without Uncertainties

The TM/LP trip is actuated when a measured pressure falls below a calculated limit, P_{VAR}. The calculated limit is based on analysis of the DNBR as a function of pressure, ASI, power and inlet temperature. The general form of the TM/LP trip is

$$P_{VAR} = \alpha \times Q_{DNB} + \beta \times T_{CAL} + \gamma$$

where

$$Q_{DNB} \equiv QR_1 \times QA$$

and

$$T_{CAL} \equiv T_{inlet} + K_c \times B$$

The TM/LP has a minimum pressure (P_{floor}) that will result in a trip. The TM/LP trip pressure is the maximum of the calculated trip pressure and the floor.

QA adjusts the normalized power depending on the ASI. Its function is to correct for axial power shapes. QR_1 depends on the measured power and corrects for radial peaking increases due to part-power rodding configurations.

The power used in the TM/LP is the maximum of that calculated by two different methods: the excore (neutron) detectors and a simple calorimetric (thermal) calculation.

Thermal power is calculated from temperature readings from the resistance thermal detectors (RTDs) in the hot and cold legs.

$$B = \Delta T\ (K_\alpha + K_\beta \times T_{inlet} + K_\gamma \times \Delta T) + Bias$$

The variable, T_{cal}, adjusts the inlet temperature using the thermal power calculation in an attempt to account for potential thermal stratification in the cold leg.

The nominal trip pressure is the pressure at a combination of power, ASI and inlet temperature and is the maximum of the following choices:

- The pressure at which DNBR equals the DNBR mean, adjusted for the effects of rod bow and the mixed core penalties,
- The hot leg saturation pressure,
- The floor pressure in the trip.

To obtain the DNB portion of P_{VAR} for a selected value of ASI, Q and T_{inlet}, the following iterative scheme is used. The axial power shape that produces the worst DNBR for a range of ASI values centered around a selected ASI is selected from the file of axial power shapes and used to calculate the pressure corresponding to DNB. Values of power which are not permitted by the LPD LSSS or the main steam safety valve (MSSV) settings are not considered in this analysis. The radial peaking factor is set at its nominal value. Flow is fixed at the thermal design limit and the DNBR target is set to the DNBR mean, adjusted for rod bow and mixed core penalties. Power and T_{inlet} are chosen and the pressure corresponding to DNB is calculated. The iteration provides a single point for DNB pressure.

This process is repeated for a set of ASI values ranging from -0.6 to 0.6 and over a large range of powers and T_{inlet}. When enough points to span the range in which DNB protection is required of the TM/LP have been found, a conservative fit for pressure as a function of power, ASI and T_{inlet} is performed, and the required nominal TM/LP trip thus established.

The adjustment of the cold leg temperature based on the thermal power is set independently for each plant and the impact of the adjustment is considered in setting the TM/LP. The calculation of the adjustment is not a part of SPC's statistical methodology.

The results of the nominal calculation provide a series of pressures as a function of power, ASI and T_{inlet} at which the critical heat flux calculated by the NRC-approved DNBR correlation and corrected for rod bow and mixed core penalties, is equal to the calculated heat flux.

Hot leg saturation pressures are calculated by calculating the hot leg temperature corresponding to the power and inlet temperature and then looking up the saturation pressure in the steam tables.

2.2.2 Thermal Margin/Low Pressure Limiting Safety System Settings With Uncertainties

This LSSS protects against hot-leg saturation and DNB during slow transients. The TM/LP LSSS provides this protection by calculating a pressure at which the reactor will scram. The calculated pressure depends on the neutron power, the thermal power, the ASI and the inlet temperature. The trip setpoint is confirmed by showing that the LSSS, as adjusted for all uncertainties and transient biases, will still produce a reactor scram before DNB or hot leg saturation is challenged for all slow transients. Figure 2.2 shows the flow of the calculations performed to confirm the TM/LP.

2.2.2.1 DNB Calculations

The statistical analysis provides a conservative distribution of trip pressures around the nominal curves that will protect the limiting pin from DNB at a probability level of at least 95% at a confidence level of 95%. The number of statistical analyses of the TM/LP trip pressure over the range of all ASI, power and T_{inlet} is sufficient that a bounding choice of statistics is made.

Confirmation of DNB protection uses a large collection of axial power shapes that correspond to the operating cycle being analyzed. The method for calculating these shapes is discussed in Section 5. MDNBR calculations are based on an XCOBRA-IIIC model appropriate for the cycle.

The first step in the process is a conservative simplification that reduces the number of axial power shapes to approximately 20. The MDNBR for all of the axial power shapes is evaluated at 140% of nominal power to produce very low values of MDNBR. The shapes are sorted into bins based on their ASI in 20 bins 0.06 ASI units wide ranging from 0.6 to -0.6 ASI units. This part of the setpoint confirmation process is deterministic and produces bounding axial power shapes for each final ASI. The only aspect of axial power shapes treated statistically is [

]

The limiting axial power shapes are used to calculate both nominal and deterministic powers or temperatures corresponding to DNB. [

]

Deterministic cases use a high value ($\sim 2\sigma$ above the correlation mean) of DNBR as the point of DNB and change the values of the variables so that less power is required to reach DNB. This calculation is used only to reduce the number of potential cases to be used in calculating the uncertainty of the DNB point to a single case. The case (axial power shape, nominal system conditions, etc.) that shows the greatest change in the calculated variable (pressure) is the most sensitive point.

The next step is to calculate response surface points. This calculation uses the most sensitive point as the nominal point. The response surface points will be the pressure at DNB for a large number (~100) of cases. Each case represents a variation in one or more of the parameters to be combined statistically by this process. In general, the parameters that are varied in the response surface are not measured as a part of the trip or used as a measure of the margin.

The response surface calculation results in a table of parameter variations with the corresponding pressure at DNB.

2.2.2.2 Hot Leg Saturation Calculations

Hot-leg saturation is confirmed for the TM/LP trip. This confirmation does not require the process described in Section 2.2.2.1 to determine the pressure uncertainty for DNB. The hot leg temperature can be calculated using the design flow, the nominal power and the inlet temperature. The pressure that corresponds to hot leg saturation comes from the steam tables.

2.2.2.3 Response Surface Uncertainties

The response surface includes [

]

2.2.2.4 Calculation of Trip Margin

The trip margin is defined by the 95% lower limit of the difference between the DNB (or hot-leg saturation) pressure at a 95% confidence level to the trip pressure. The nominal points at which DNB occurs come from the nominal calculation used to find the most sensitive point. The hot-leg saturation pressure is obtained by calculating the vessel exit temperature for a series of powers and inlet temperature points and looking up the saturation pressure.

The DNBR calculations are performed for all of the limiting axial power shapes over a range of power and inlet temperature to find the nominal conditions at which DNB would occur with 50% probability. These nominal points are a series of cases at different powers, pressures and inlet temperatures for a variety of axial power shapes that produce an MDNBR at the adjusted DNB correlation mean value. The nominal margin is the difference between the nominal pressure at DNB and the TM/LP trip pressure calculated using the nominal power and inlet temperature.

The pressure at which saturation occurs is calculated using steam tables to find the exit temperature from the vessel and the saturation temperature for the hot leg. The nominal pressure for the TM/LP trip is calculated and the nominal margin between the trip and the saturation pressure is determined.

The nominal margins are adjusted for uncertainties to obtain the power margin provided by the trip.

2.2.2.5 Trip Pressure

The uncertainty in the TM/LP trip function can be determined by examining each term in the trip equation and establishing a probability density for it, then combining the densities.

2.2.2.6 [ ]

The contributors to the uncertainty in ASI include [

] The use of the limiting shape in each ASI bin is a conservatism to bound the DNBR calculation.

[

]

[

]

2.2.2.7 Combination of Pressure Uncertainties

Pressure uncertainty has [

] This is done by determining the margin that has a 5% probability of exceeding the true margin.

2.2.2.8 Interaction with LPD LSSS

The TM/LP is confirmed only for cases that will not trip on the LPD LSSS. The LPD LSSS is checked by confirming that the probability of getting a trip on this function is at least 95%. [

]

2.2.2.9 Interaction with the MSSV

The TM/LP is not confirmed for primary conditions that would result in the MSSV lifting. When the MSSV opens, the reactor primary loop is unable to heat up any more for a given power. The temperature of the secondary side of the steam generator is given by

$$T_{S.G.} = T_{ave} - \frac{xcof}{Q}$$

The secondary side of the steam generator is assumed to be at saturation. Thus, $T_{S.G.}$ at normal operation corresponds to the saturation temperature for full-power (about 700 to 800 psia) and xcof is adjusted to make the $T_{S.G.}$ be the saturation temperature, given the average temperature of the primary system at full power.

The MSSVs will open at some setpoint around 1,000 psia and will have an offset of 3% to 6% associated with the setpoint. The saturation temperature for the setpoint with offsets becomes the discriminant for excluding certain reactor state points. If, when $T_{S.G.}$ is calculated for a state point, the value is greater than the saturation temperature for the opening of the MSSVs, the case is not considered.

2.2.3 Departure from Nucleate Boiling Limiting Conditions of Operation Without Uncertainties

The DNB LCO is designed to protect the DNBR SAFDL during an AOO. It is set and confirmed by the limiting transient events. The limiting transients are those that produce the largest decrease in DNBR from an initial steady state power and ASI. The DNB LCO is plotted as a "barn" on a percent-allowed-power versus ASI plot.

Operation of the reactor within this barn, disregarding uncertainties, means no AOO would result in a DNBR less than or equal to the adjusted mean (shifted by rod bow and mixed core penalties) of the applicable DNBR correlation.

2.2.3.1 CEA Drop

One of the most common limiting AOOs is the inadvertent insertion of a single full-length Control Element Assembly (CEA). No reactor trip occurs for this AOO and the only DNB protection is provided by the DNB LCO. In this event, the turbine control system restores the reactor to the initial power level using the moderator feedback. The final steady-state condition differs principally from the original operating condition in that the radial power distribution is increased. Often a loss of pressurizer control is assumed to accompany the rod drop, resulting in a lower pressure.

An iterative XCOBRA-IIIC calculation similar to that for the TM/LP LSSS is performed. The DNB LCO calculation differs from the TM/LP LSSS calculation in that the iteration is on power rather than pressure. The radial power distribution used in the calculation is the distribution that corresponds to a core with a dropped CEA. The iteration for the power corresponding to DNBR equal to the adjusted correlation mean is performed for each ASI using the worst axial shape for DNBR, points corresponding to percent allowed power and ASI generated and a DNB LCO barn drawn below the points.

2.2.3.2 Loss-of-Coolant-Flow

Another common limiting AOOs is the loss of power to all reactor coolant pumps. On initiation of the loss-of-coolant-flow (LOCF) transient, the flow begins to decrease rapidly and the reactor is tripped on a low-coolant-flow signal. Following reactor trip, the CEAs are inserted and the reactor is shut down. During the transient, DNBR falls rapidly because of the decreasing flow until the heat flux in the reactor begins to fall as a result of the scram. Beyond that time in the transient, DNBR rises as the heat flux falls rapidly.

To determine the percent allowed power for a specific value of ASI, the transient is simulated for the worst axial power shape (the shape that produces the minimum initial DNBR) corresponding to the ASI. The scram curve is adjusted to correspond to the axial shape. The transient simulation is iteratively repeated, varying the initial power, until a DNBR equal to the adjusted correlation mean is obtained. This procedure defines the percent allowed power at one particular ASI. The process is repeated for each value of ASI and a curve can be drawn under these points. This curve defines the DNB LCO.

2.2.4 Departure from Nucleate Boiling Limiting Conditions of Operation With Uncertainties

To account for uncertainties in the parameters and model structure, a more restrictive DNB LCO than the one defined in Section 2.2.3 must be established. Although the effect of uncertainties could be evaluated using each axial power shape, uncertainties are conservatively treated by using the probability distribution in DNB power at the most sensitive point for simplicity. This point corresponds to the axial power shape that produces the greatest difference between the nominal and the deterministic percent allowed power. The distribution at the most sensitive point is used to adjust each nominal value of ASI.

2.2.4.1 CEA Drop

Figure 2.3 shows the flow of the confirmation calculations for the DNB LCO. Protection against DNB is provided by limiting the reactor power based on the peripheral (external) ASI such that the probability of DNB for a CEA Drop (CEAD) is less than 5% with 95% confidence. The shape of the DNB LCO barn, in conjunction with the radial power peaking limits and other LCOs, protects against DNB.

Table 2.3 lists uncertainties considered in the confirmation of the DNB LCO. Including the effects of these uncertainties uses a fit to the response surface for the DNB target power and [ ] to combine the various contributors to the uncertainty. The response surface provides the variation in power required to produce the target MDNBR when [ ]

The nominal power corresponding to DNB is calculated for each limiting axial power shape using the conditions corresponding to the conditions at the time of MDNBR for the transient. These calculations are performed to find the nominal conditions at which DNB would occur with a 50% probability. These nominal points are a series of cases that produce an MDNBR at the [ ] The most limiting axial power shape is determined by setting the parameters most conservatively and finding the axial power shape that produces the largest change in power (deterministic calculation).

The nominal margin for each axial power shape is the difference between the nominal power for DNB and the DNB LCO power corresponding to the peripheral ASI for the axial power shape. The nominal margins do not include the effects of the uncertainties. The final margins are adjusted for uncertainties to obtain the 95% lower limit on the power margin provided by the trip. [ ] are then applied to the nominal cases to produce an allowed-power-versus-ASI plot. The DNB LCO is established such that all points are above the barn,

Uncertainty from Response Surface

The response surface is used in calculating the uncertainty in the power at which DNB occurs and is expressed in terms of standard deviations in the independent variables (the DNBR limit, F_r, inlet temperature and flow) and the dependent variable (power). The response surface is fit with a second order polynomial of the form

Combining Power Uncertainties

The uncertainty of the difference between the [ ]

[ ]

A factor which must be considered is the impact of [ ] on ASI uncertainty. [ ]

Combination of Power and ASI Uncertainties.

The uncertainty in power margin is combined with the uncertainty in ASI in a manner similar to that used to combine the other probabilities. The probability distribution for the combined powers is expressed as

2.2.4.1 Loss of Coolant Flow

The setting or confirmation of the DNB LCO based on the Loss-of-Coolant-Flow (LOCF) event is very similar to the process described for the CEAD. Table 2.3 lists the parameter uncertainties treated in this analysis. The transient is particularly sensitive to flow coastdown, reactor trip setpoint, and reactivity insertion following the scram. Other parameters can vary, but the effect of such variation is significantly less than the flow dynamics and low-flow trip performance. Hence, the significant parameters are those effecting flow coastdown and reactor shutdown. As in the nominal and deterministic cases, the scram curve depends on the worst axial shape, which is limited by the choice of ASI.

In analyzing the effects of uncertainties, significant parameters are treated statistically and the remaining parameters may be set to their respective conservative limits. The resulting lower limit for percent allowed power at the selected value of ASI is conservative (i.e., lower than the actual limit). When the difference between the statistically determined and nominally determined percent allowed power at the selected ASI is applied to the nominal calculation at each ASI, DNB LCO confirmation is conservative.

The DNB LCO is confirmed to protect against DNB occurring for LOCF. The process is similar to that used for confirming the DNB LCO for the CEAD and the discussion in Section 2.2.4.1 applies to this event with the following exceptions:

2.3 Parameter Uncertainties

Tables 2.4 and 2.5 identify parameter uncertainties and some of their typical values that will be handled with the proposed methodology. The parameters for which uncertainties are identified generally are C-E plant system parameters, and the uncertainty values correspond to those appearing in publicly available documents.

The power distribution peaking factor uncertainties are supported by SPC's analysis of the neutronics computer codes. The values currently in Tables 2.4 and 2.5 for power distribution peaking factor uncertainties are typical. Plant instrument calibration procedures and related specification requirements are designed so these uncertainties applicable in the past do not increase, If any uncertainties change, the revised values will be used.

Some of the uncertainties identified in Tables 2.4 and 2.5 have not been assigned uncertainty values. The basis by which these uncertainties will be quantified by SPC is summarized in Table 2.6.

Table 2.1 Uncertainties in LPD LSSS or LCO Confirmation

Table 2.2 Uncertainties in TM/LP Confirmation

Table 2.3 Uncertainties in DNB LCO Confirmation

Table 2.4 Uncertainty Sources for Fuel Centerline Melt Calculations

Table 2.5 Uncertainty Sources for DNBR Calculations

Table 2.6 Uncertainty Quantification Bases

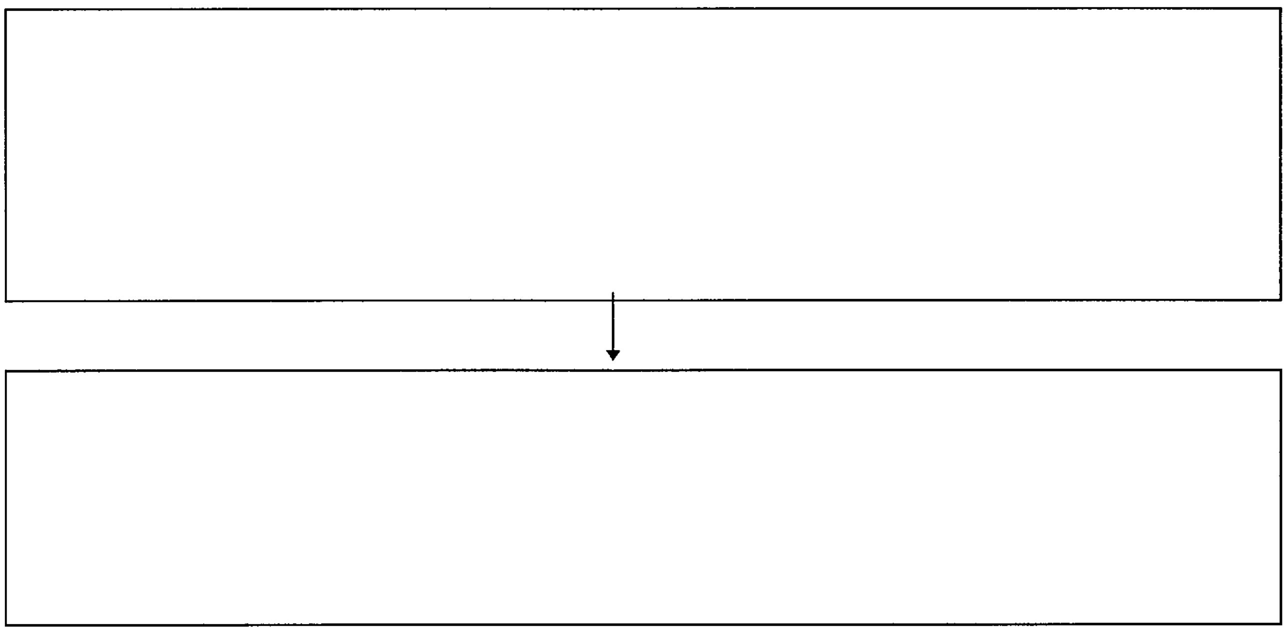

Figure 2.1 Flow of LPD LSSS or LCO Confirmation

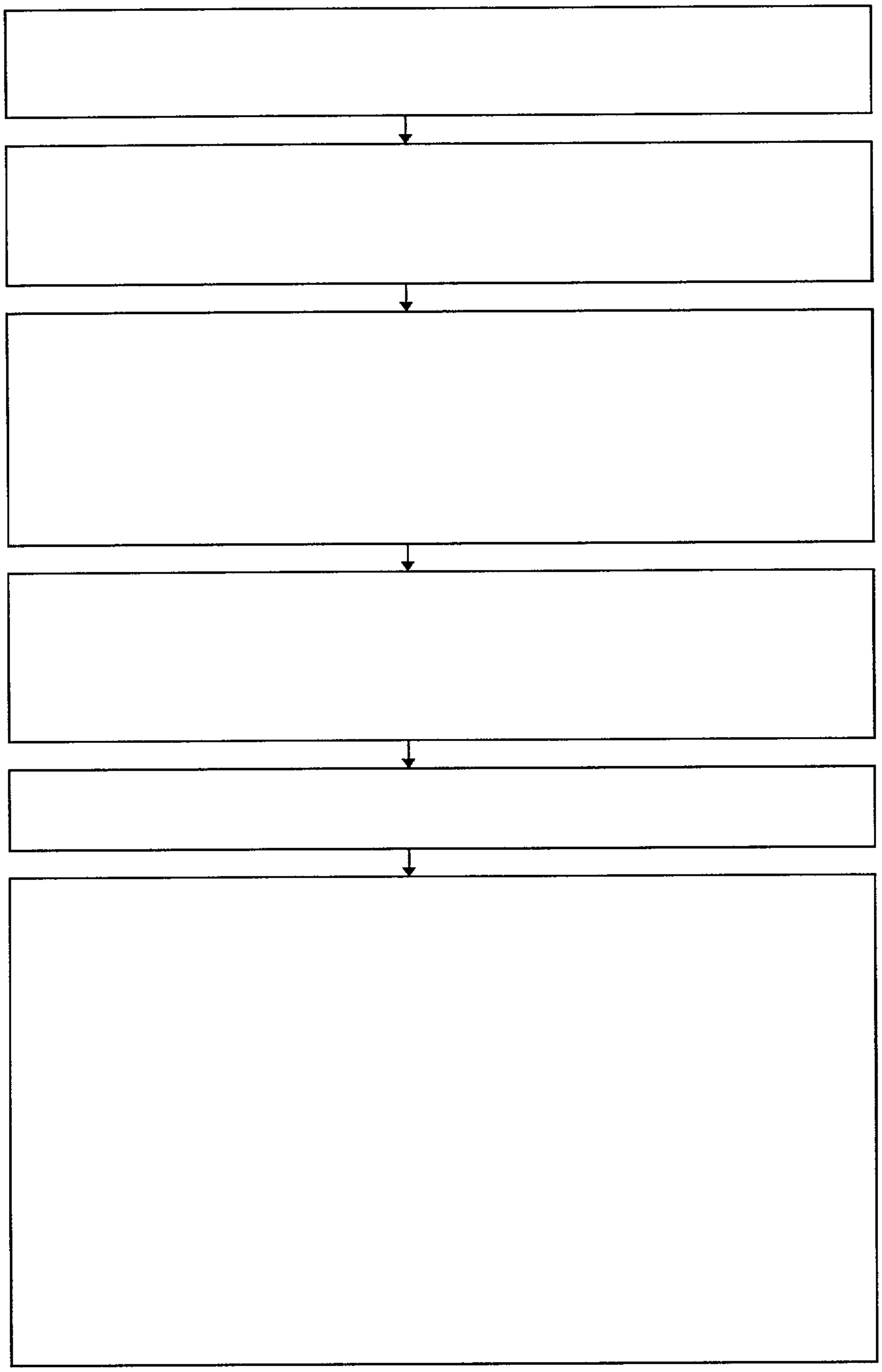

Figure 2.2 Flow of TM/LP Confirmation

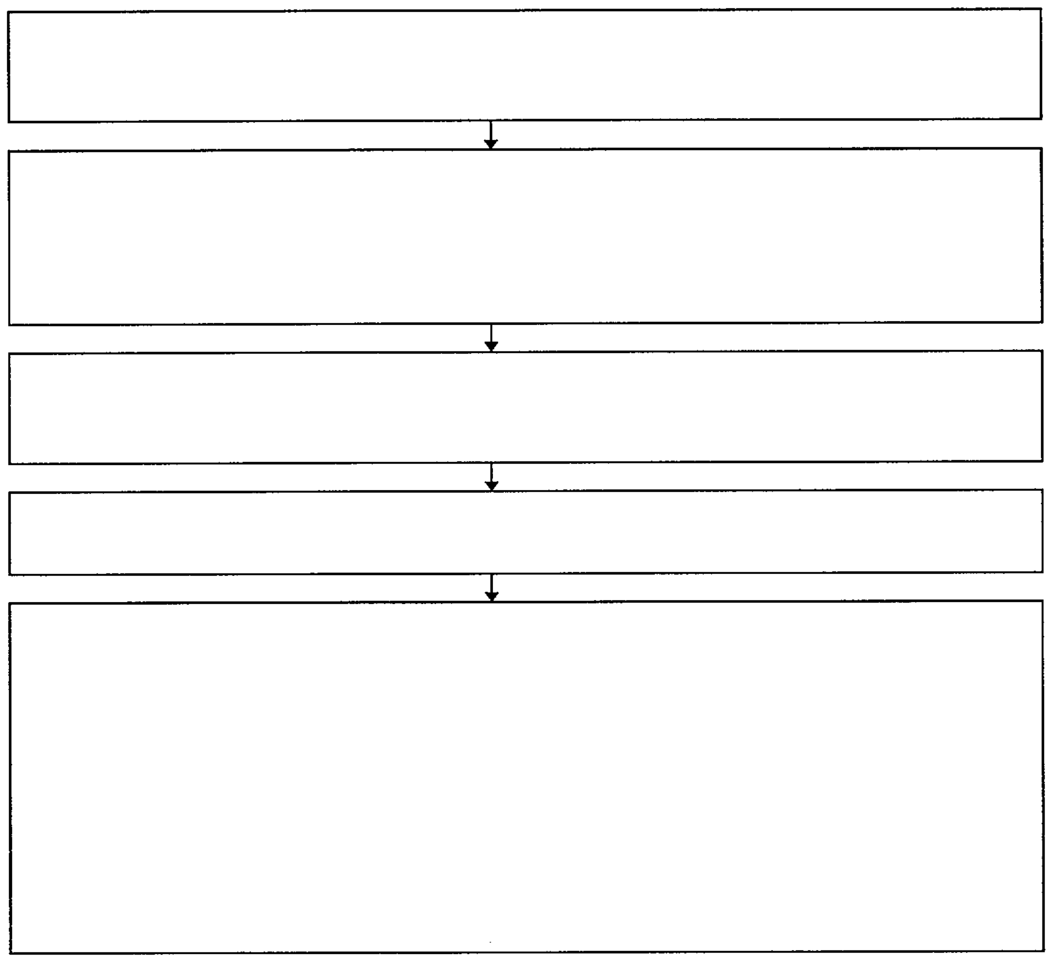

Figure 2.3 Flow of DNB LCO Confirmation

3. Sample Calculations

This section presents a series of sample cases demonstrating the confirmation of the margin to each of the four functions using the statistical methods described in Section 2. Only the confirmation is shown, because developing a trip is an iterative process with the confirmation as the key step.

3.1 LPD LSSS

The input for the LPD LSSS sample case is given in Table 3.1. In this case, the optional azimuthal tilt allowance was not used, but the power-dependent power uncertainty option was used. The LPD LSSS is given as a part of the input; Figure 3.1 shows the LPD LSSS used in the sample case.

The first step in the confirmation is to calculate the [ ] for the FCM power. This is shown in Figure 3.2. [ ] This would give values of 1.07 and 0.93 at the [ ] limit. However, the [ ] shown in Figure 3.2 has a slight skew to higher powers and the two [ ] limits are more like 1.08 and 0.93.

The statistical analysis is performed for a large number of axial power shapes. Some details for the first case will be discussed to help demonstrate the confirmation process.

The first axial power shape has an F_Q of 2.12. This corresponds to a nominal FCM power of 4,320 MWt, or 160% of rated power. The peripheral ASI for this shape is 0.092 and the corresponding trip power from the LPD LSSS in Figure 3.1 is 2,951 MWt, or 109% of rated power. The nominal margin is more than 50% of rated power.

The [ ] in Figure 3.2 is first multiplied by the nominal FCM power; [ ]

Figure 3.4 shows the [ ]

[ ] The nominal trip power is subtracted to produce the margin. Figure 3.5 shows the [ ] The mean value of the [ ] The lower 5% limit is about [ ]

This process of calculating the power distribution for FCM, adjusting it [ ] is repeated until each acceptable axial power shape has been used. The resulting margins are shown in Figure 3.6 and are typical of the confirmation process.

3.2 LPD LCO

The input for the LPD LCO sample case is given in Table 3.2. The input is similar to the input for the LPD LSSS sample case, except that the FCM limit is replaced with a LOCA LHGR limit of 15 kW/ft, the trip uncertainty and bias are set to zero and the LPD LSSS barn is replaced with the LPD LCO barn. Figure 3.7 shows the LPD LCO.

The confirmation process for the LPD LCO is exactly the same as that for the LPD LSSS, and, [ ] the [ ] is the same and is given in Figure 3.2.

The same set of axial power shapes is used in the confirmation and the first case, which has a peripheral ASI of 0.091 and an F_Q of 2.12, has a power at the LOCA LHGR limit of 3,086 MWt, or 114% of rated. The LCO on power is 2,268 MWt, or 84% power.

One difference that effects the probability density for the LCO power is that the barn is flat, instead of having a peak like the LPD LSSS has. Figure 3.8 shows the [ ]

The confirmation process is repeated for a large number of cases. Figure 3.9 shows a plot of the final margin as a function of peripheral ASI. Again, the confirmation has protected the most limiting axial power shape and understated the margin.

3.3 *TM/LP*

The setpoint axial file for this sample case contained 2,604 axial power shapes. These shapes were generated at power levels from 50% to 100% of rated power. They were converted to XCOBRA-IIIC input shapes and the rod shadowing statistics were extracted. The DNB portion of the TM/LP is really at higher powers so limiting the power at which shapes were generated so they could be applied to the power ranges being verified for DNB protection would be acceptable. The use of all power levels is a conservative simplification which is often used in DNB calculations.

Table 3.3 summarizes the [ ] extracted from the axial power shapes. The maximum radial peaking factor at each power level is extracted and used to adjust [ ] to be consistent with power. Table 3.4 shows the power-dependent [ ] used for this sample case.

The axial power shapes were scanned and the DNB limiting shapes with ASIs that cover the range from -0.6 to 0.6 determined. Table 3.5 summarizes the results of the scan. The first column gives the mean ASI for each bin. Although searches were done on the entire range in ASI, the absolute value of the bin ASI for the shapes does not exceed 0.36. The second column is a case identifier. This identifier will be carried with the shape through to the final margin calculation; however, it will be modified by adding two trailing digits which will identify the power and the inlet temperature, thereby specifying the nominal case. The third column is the MDNBR for a 40% overpower condition for each shape. As the axial shapes move from top-peaked to bottom peaked, the MDNBR gets larger. The last column is the power at which the axial power shape was generated, expressed as a percent of rated thermal power. Note that most of the limiting shapes correspond to powers which are well below full power.

The nominal cases consist of a large number of different pressure and power combinations for each axial power shape. The cases span the ranges of power and T_{inlet} and thoroughly test the TM/LP.

When the search for the pressure for DNB for the deterministic cases was complete, Case 118438 had a ΔP between the deterministic and nominal Cases of 409 psi. This is the largest difference. Axial power shape #1184 was used for the analysis and the response surface used 2.14 Mlbm/hr-ft^2, 1960 psia, 597 °F and 95% for the flow, pressure, inlet temperature and power, respectively.

The response surface points consisted of 99 points covering the range from 1,960 psia to about 2,350 psia.

The TM/LP confirmation was performed using the nominal inputs, the [ ] and the general input for the sample TM/LP verification case in Table 3.6.

The first step in checking the TM/LP is to confirm that it protects against hot leg saturation. This is performed over a range of powers and temperatures. The minimum power is the power which produces the floor trip pressure for the TM/LP at the maximum inlet temperature. The scan range for the sample case was from 2,160 MWt to the VHP trip ceiling and from 530°F to 580°F. The minimum margin, 124 psi, was found at 2,160 MWt and 570°F.

Next, the response surface points were fit and the [ ] was calculated. Figures 3.10 and 3.11 show the [ ] for the DNB power. The [ ]

The intermediate steps for processing nominal case #25776 are described in the following paragraphs. This case has an inlet temperature of 602°F, a pressurizer pressure of 2,180 psia, a nominal power of 2,902 MWt and an internal ASI of 21.1%. This case was chosen because it falls on the point where the slope changes sign for the QA function and will show the transformation of ASI uncertainty into QA uncertainty.

Cases are first tested to be sure they will not trip on the LPD LSSS or on the VHP trip and that the MSSVs will not open. For this case, the [ ] trip on the LPD LSSS was [ ] Cases are rejected only when the [ ] The power was well below the VHP trip ceiling and the MSSVs would not have opened.

The thermal power, B, was calculated. Total power was calculated by auctioneering between the nuclear (ex-core) power and B. The [ ]

Figure 3.13 shows the [ ] of the power provided to the trip. In this particular case, the auctioneering did not have much effect on the probability, because the mean value of the thermal power is 2713 MWt (~100% RTP) and the mean value of the nuclear power is 2,902 MWt (107.5% RTP).

The [ ] for the QA and QR1 functions were calculated. Figures 3.14 and 3.15 show these two [ ] The QA function was evaluated in a region with a minimum. The [ ] The QR1 was evaluated in the region around 107.5% of rated power. In this region, the QR1 function is equal to the power (See Table 3.6).

The uncertainty in the trip pressure (P_{VAR}) was calculated using the trip equation. The resulting [ ] is shown in Figure 3.16. Because the margin is just the difference between the DNB pressure and the trip pressure, [ ] Figure 3.17 shows the [ ] for the trip, including the uncertainties in [ ]

The overall margin was calculated by subtracting the trip pressure from the DNB pressure, adjusting for transient biases and for the difference between the core exit pressure and the pressurizer pressure and including the pressure measurement error. The transient biases, which are listed in Table 3.1, are included to account for the transient difference between the cold leg RTD reading and the core inlet, the bias in the pressurizer pressure caused by transient lags in the sensor, a [ ] decalibration of the flux measurements. Figure 3.18 shows the [ ] for the margin from this first case.

This process was repeated for all of the nominal points in the file.

The margins for 297 cases were calculated. These were sorted in ascending order in margin and printed as a summary. Table 3.7 lists the most limiting cases. In all cases, the margin is positive, confirming the TM/LP trip.

3.4 DNB LCO

The DNB LCO is confirmed for the CEAD and the LOCF. The limiting axial power shapes were selected from the same set of axial power shapes used for the TM/LP verification. Because both the CEAD and LOCF have a known initial condition, the total number of nominal cases and deterministic cases is just the number of limiting axial power shapes.

The general input for the DNB LCO confirmation, given in Table 3.8, is the same for both events. The DNB LCO is shown pictorially in Figure 3.19.

3.4.1 CEAD Confirmation

The set of CEAD axial power shapes is the same set selected for the TM/LP verification and is summarized in Table 3.5. The conditions selected for the CEAD correspond to a core exit pressure of 2,113 psia and a T_{inlet} of 528°F.

Because there are only 13 limiting shapes covering the range $-0.36 \leq ASI \leq 0.36$, there are 13 nominal cases and 13 deterministic cases. A search of the axial shapes shows that shape #2594, which has an ASI of 34.6% and a DNB power of 158% RTP gives the largest change in power. This shape and power were used to calculate the response surface points.

The response surface points are fit with a polynomial. Figure 3.20 compares the power corresponding to the fit to the response surface points. Using this fit, the [ ] in the DNB power was calculated.

This [ ] is shown in Figure 3.21. The power uncertainty from the [ ] was combined with the [ ] Except for the contribution from the [ ] this is the uncertainty in the power margin. The distribution is shown in Figure 3.22.

The ASI [ ] was adjusted for [ ] then used to calculated the [ ] for the LCO power. Figure 3.23 shows the [ ] for the DNB LCO barn power coming from the [ ] The case selected (ASI = 0.195) has the ASI is near the upper corner of the DNB LCO barn with a nominal allowed power of 100% RTP. [ ]

The uncertainty in the [ ] was combined with the uncertainty from the [ ] to get an overall margin distribution. Figure 3.24 shows this distribution. The margin at the lower 5% probability is 989 MW.

Figure 3.25 shows the final margins for each ASI. The minimum margin occurs at the minimum ASI for which full-power operation is allowed. Finding no negative margins confirms that DNB is protected for the CEAD event.

3.4.2 LOCF Confirmation

The set of limiting axial power shapes used for the LOCF verification was selected from the same axial power shapes by calculating the MDNBR using 125% of rated power and 70% flow rather than 140% of rated power, as was used for the TM/LP and the CEAD. Reduced flow is used here because this is a low-flow event. The set of cases used for LOCF verification is summarized in Table 3.9. The first column gives the mean ASI for each bin. The second column is a case identifier. This identifier will be carried with the shape through to the final margin calculation;

however, it will be modified by adding two trailing digits that will identify the power and the inlet temperature, thereby specifying the nominal case. The third column is the MDNBR for a 25% overpower condition and 30% flow reduction for each shape. The last column is the power at which the axial power shape was generated, expressed as a percent of rated thermal power. This set of shapes is similar to the set for the CEAD and for TM/LP given in Table 3.4. The initial conditions for the LOCF event are a T_{inlet} of 550°F and a core exit pressure of 2,450 psia.

As with the CEAD confirmation, there are13 limiting shapes covering the range -0.36 ≤ ASI ≤ 0.36, and there are 13 nominal cases and 13 deterministic cases. A search of these shapes showed that the most sensitive shape is #1361, which has an ASI of 27.3% and a DNB power of 140 % RTP. A set of response surface points was created using this shape.

The response surface points are fit with a polynomial. Figure 3.26 compares the power corresponding to the fit to the response surface point. Using this fit, the [ ] in the DNB power was calculated. This [ ] is shown in Figure 3.27. The power uncertainty from the [ ] was combined with the [ ] Except for the contribution from the [ ] this is the uncertainty in the power margin. The distribution is shown in Figure 3.28.

The ASI [ ] was adjusted for [ ] then used to calculated the [ ] for the LCO power. Figure 3.29 shows the [ ] for the DNB LCO barn power coming from the [ ] For the case selected (ASI = 0.259) the ASI is near the upper corner of the DNB LCO barn and the allowed power is 91% RTP. [ ]

The uncertainty in the [ ] was combined with the uncertainty from the [ ] to get an overall margin distribution. Figure 3.30 shows this distribution. The margin at the lower 5% probability is 975 MW.

Figure 3.31 shows the final margins for each ASI. The minimum margin occurs at the minimum ASI for which full-power operation is allowed. Finding no negative margins confirms that DNB is protected for the LOCF event.

Table 3.1 Input for LPD LSSS Test Case

Table 3.2 Input for LPD LCO Test Case

Table 3.3 Rod-Shadowing Statistics

Table 3.4 Power-Dependent Radial Power Peaking

Power, % RTP	Radial Power Peaking
100	1.741
90	1.803
80	1.804
70	1.824
60	1.849
50	1.855

Table 3.5 Limiting Axial Power Shapes for Sample CEAD and TM/LP Cases

ASI	Case No.	MDNBR	Core Power, % RTP
-0.36	2551	0.760	50
-0.30	1456	0.790	50
-0.24	1432	0.853	70
-0.18	1440	0.909	50
-0.12	1188	0.942	50
-0.06	1184	1.027	60
0.00	1307	1.092	70
0.06	1170	1.168	50
0.12	1166	1.276	60
0.18	425	1.363	70
0.24	257	1.458	90
0.30	1485	1.578	80
0.36	2594	1.572	100

Table 3.6 Input for TM/LP Test Case

Table 3.6 Input for TM/LP Test Case - continued

Table 3.7 Margin Summary for TM/LP Sample Case

Case Number	Power (MW)	T_{inlet} (°F)	Flow (Mlbm/hr)	ASI	Pressure (psia)	Margin (psi)
145641	2,565.0	590.53	134.40	-0.327	2,290.0	242.39
42529	2,970.0	602.48	131.43	0.153	2,290.0	248.79
145640	2,565.0	583.98	135.93	-0.327	2,180.0	249.38
255116	2,430.0	586.92	135.25	-0.361	2,180.0	251.97
25776	2,902.5	602.13	131.52	0.211	2,180.0	258.24
144053	2,667.6	597.25	132.76	-0.181	2,290.0	264.67
145639	2,565.0	578.15	137.23	-0.327	2,070.0	267.46
144066	2,835.0	594.97	133.33	-0.181	2,400.0	268.25
144059	2,735.1	593.89	133.59	-0.181	2,290.0	268.65
144065	2,835.0	587.91	135.02	-0.181	2,290.0	269.16
145616	2,430.0	590.09	134.50	-0.327	2,180.0	269.87
144023	2,700.0	596.03	133.06	-0.181	2,290.0	270.19
255115	2,430.0	581.11	136.58	-0.361	2,070.0	270.26
144072	2,870.1	592.99	133.81	-0.181	2,400.0	270.27
144071	2,870.1	585.83	135.50	-0.181	2,290.0	270.67
118866	2,835.0	597.38	132.73	-0.149	2,400.0	271.81
144077	2,902.5	583.89	135.95	-0.181	2,290.0	272.45
143247	2,632.5	593.88	133.59	-0.265	2,290.0	272.45
144078	2,902.5	591.17	134.25	-0.181	2,400.0	272.49
42570	2,870.1	602.06	131.54	0.153	2,180.0	272.52

Table 3.8 Input Data for DNB LCO Sample Case

Table 3.9 Limiting Axial Power Shapes for Sample LOCF Case

ASI	Case No.	MDNBR	Core Power, % RTP
-0.36	2551	0.530	50
-0.30	2460	0.549	50
-0.24	1432	0.593	70
-0.18	2279	0.629	50
-0.12	1188	0.652	50
-0.06	1184	0.707	60
0.00	1307	0.754	70
0.06	1170	0.799	50
0.12	50	0.852	60
0.18	296	0.901	80
0.24	257	0.959	90
0.30	1361	1.087	70
0.36	1482	1.213	90

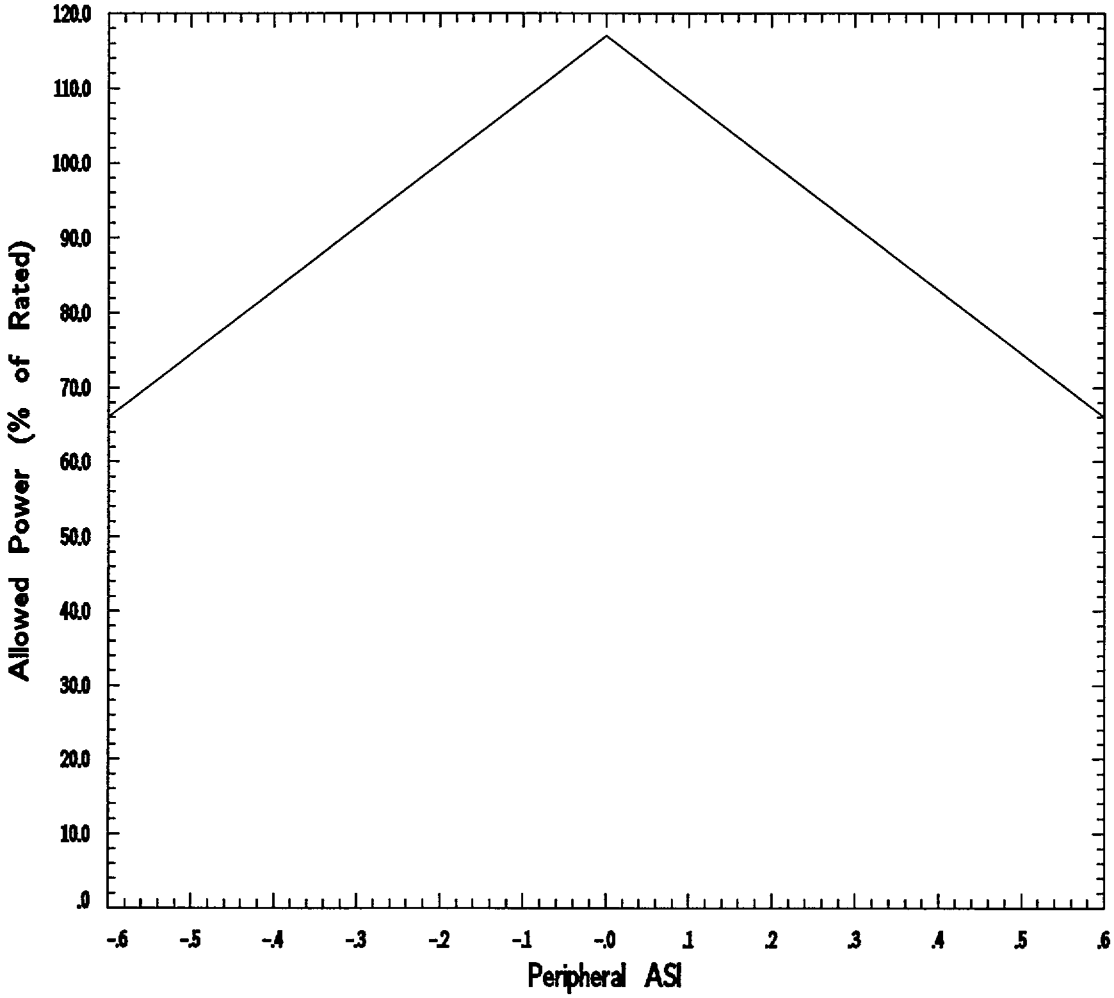

Figure 3.1 LPD LSSS for Sample Case

Figure 3.2 Uncertainty From Peaking and Engineering Factors for LPD LSSS

Figure 3.3 Uncertainty in Melt Power

Figure 3.4 Uncertainty in Trip Power From ASI Uncertainty

Figure 3.5 Probabilistic Margin

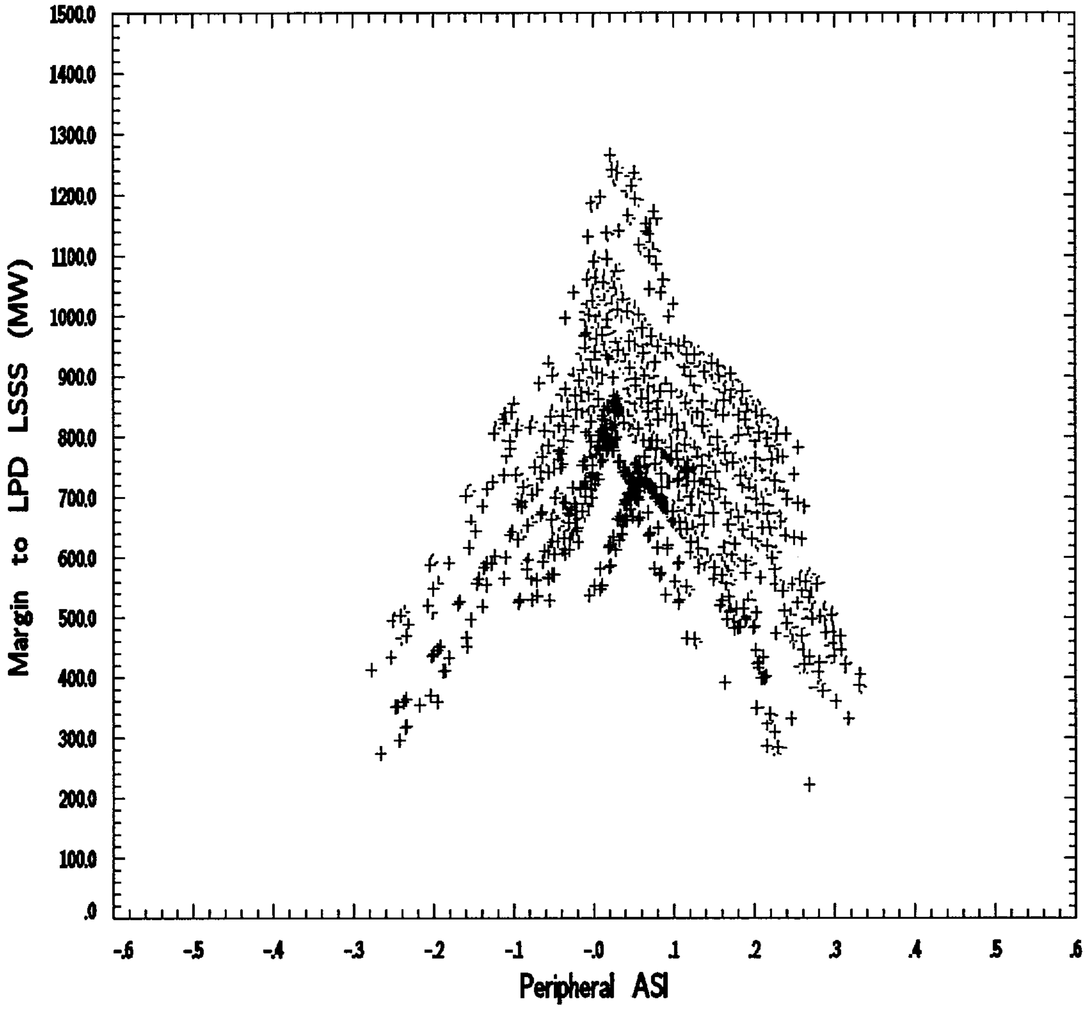

Figure 3.6 Margin to LPD LSSS for Sample Case

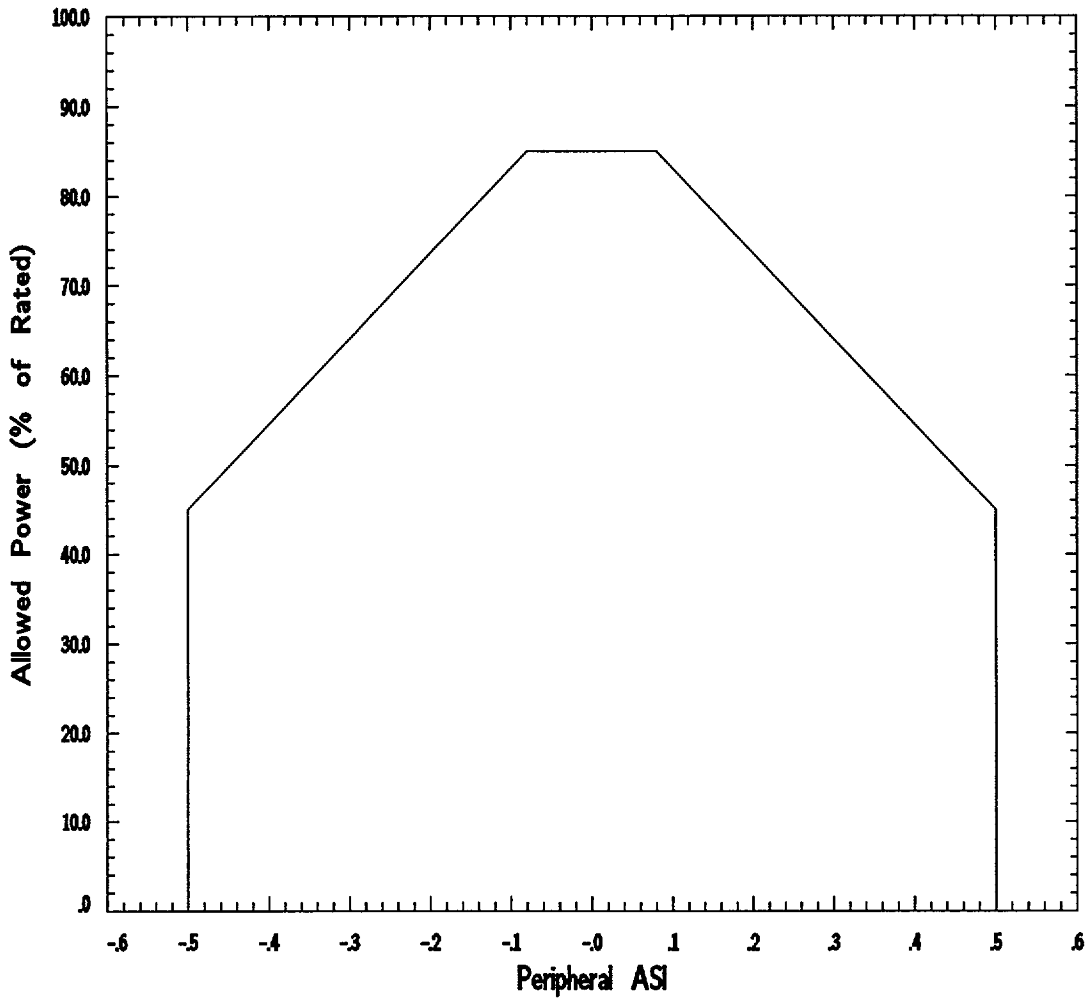

Figure 3.7 LPD LCO for Sample Case

Figure 3.8 Uncertainty in Barn Power From ASI Uncertainty

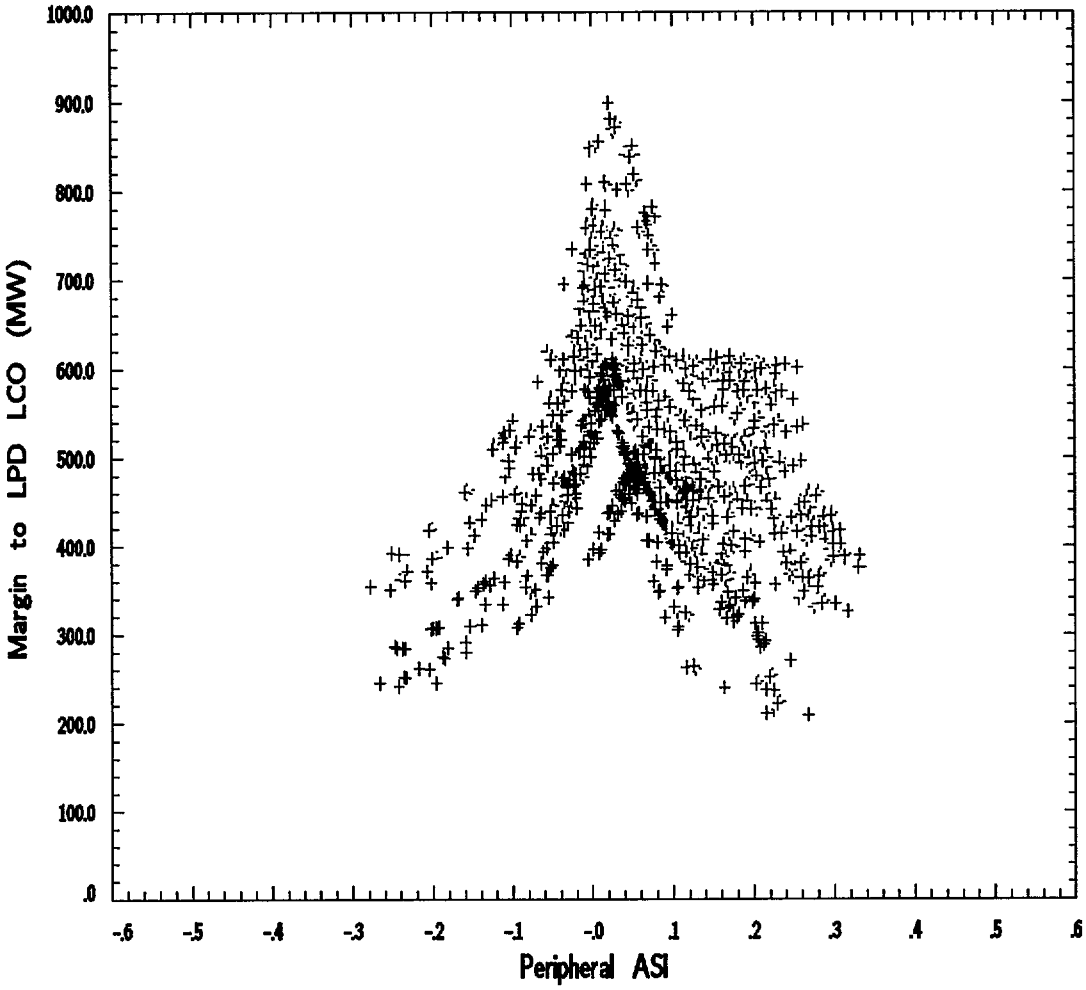

Figure 3.9 Margin to LPD LCO for Sample Case

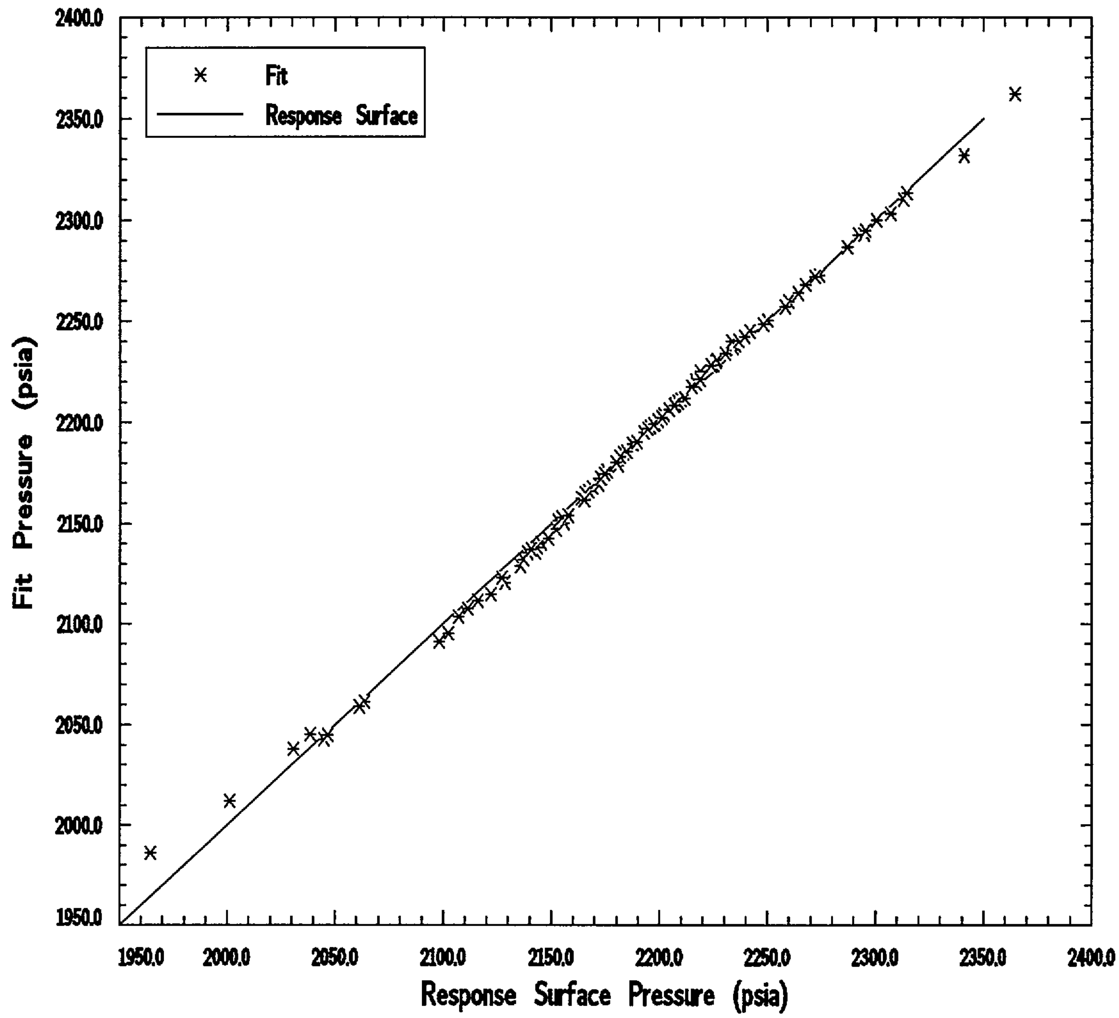

Figure 3.10 Fit to Response Surface for TM/LP Sample Case

Figure 3.11 Uncertainty in DNB Pressure

Figure 3.12 Uncertainty in Thermal Power

Figure 3.13 Uncertainty in Auctioneered (TRIP) Power

Figure 3.14 Uncertainty in QA Function

Figure 3.15 Uncertainty in QR1 Function

Figure 3.16 Uncertainty in Trip Pressure

Figure 3.17 Uncertainty in PVAR

Figure 3.18 Overall Margin for TM/LP

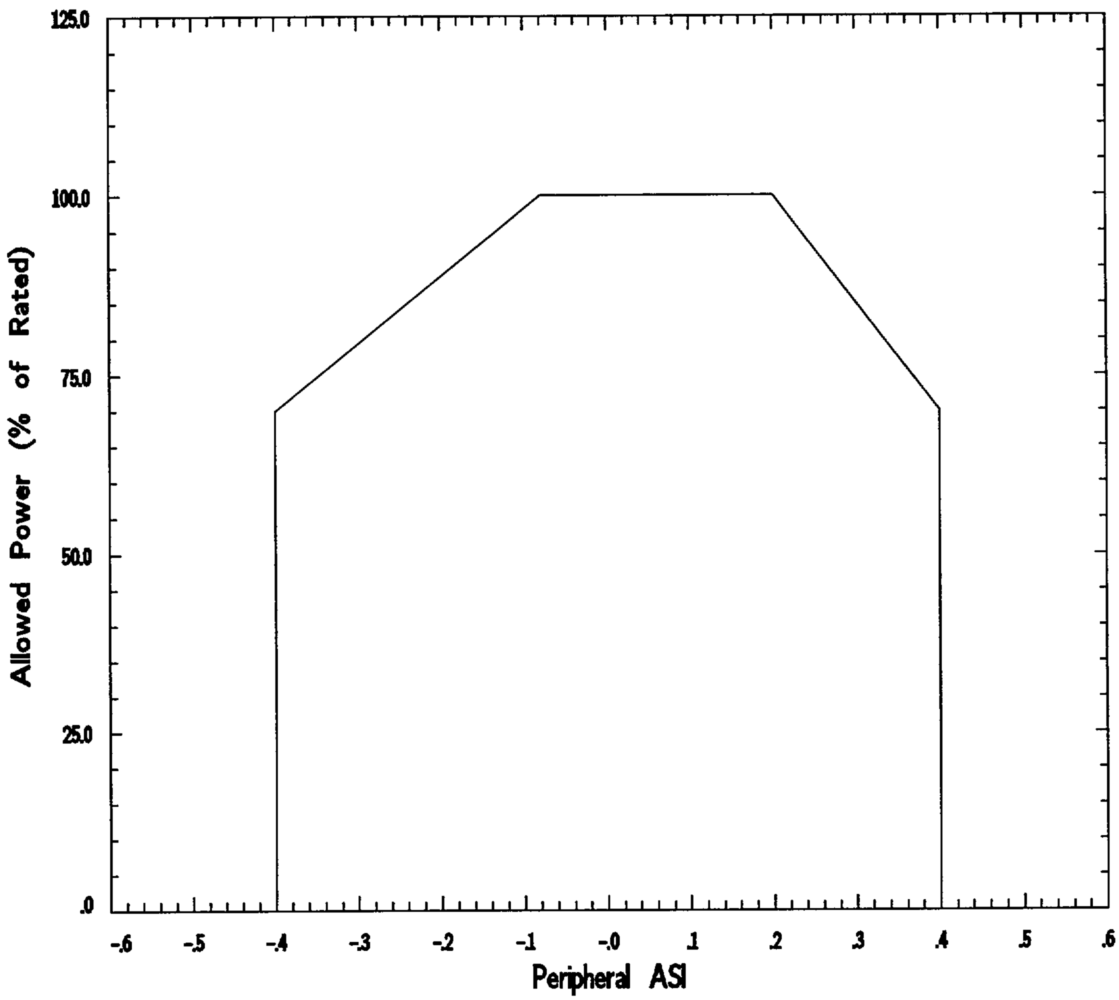

Figure 3.19 DNB LCO for Sample Case

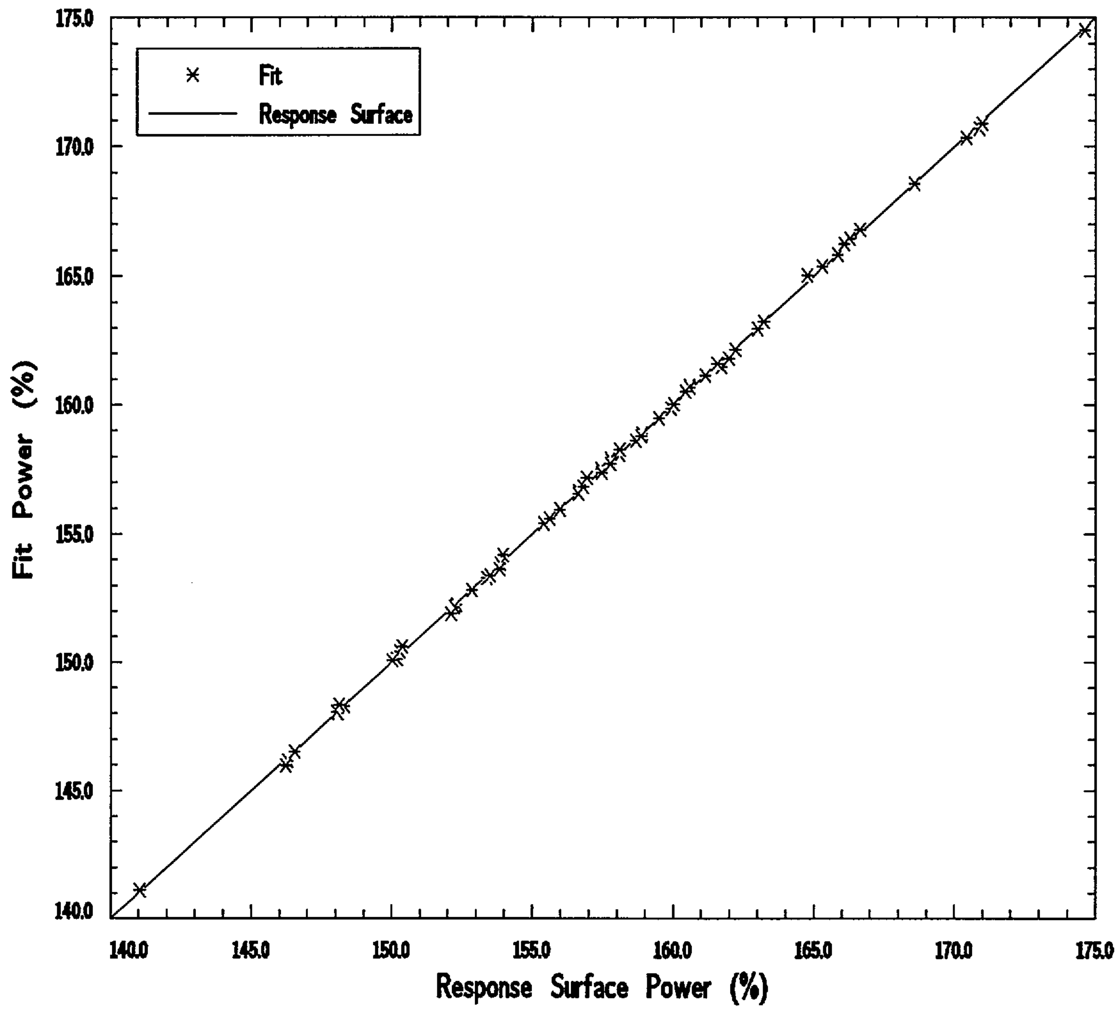

Figure 3.20 Fit to Response Surface for CEAD

Figure 3.21 Uncertainty From Response Surface for CEAD

Figure 3.22 Uncertainty in Power From RS and Calorimetric for CEAD

Figure 3.23 Uncertainty in Power From ASI for CEAD

Figure 3.24 Power Margin to DNB LCO for CEAD

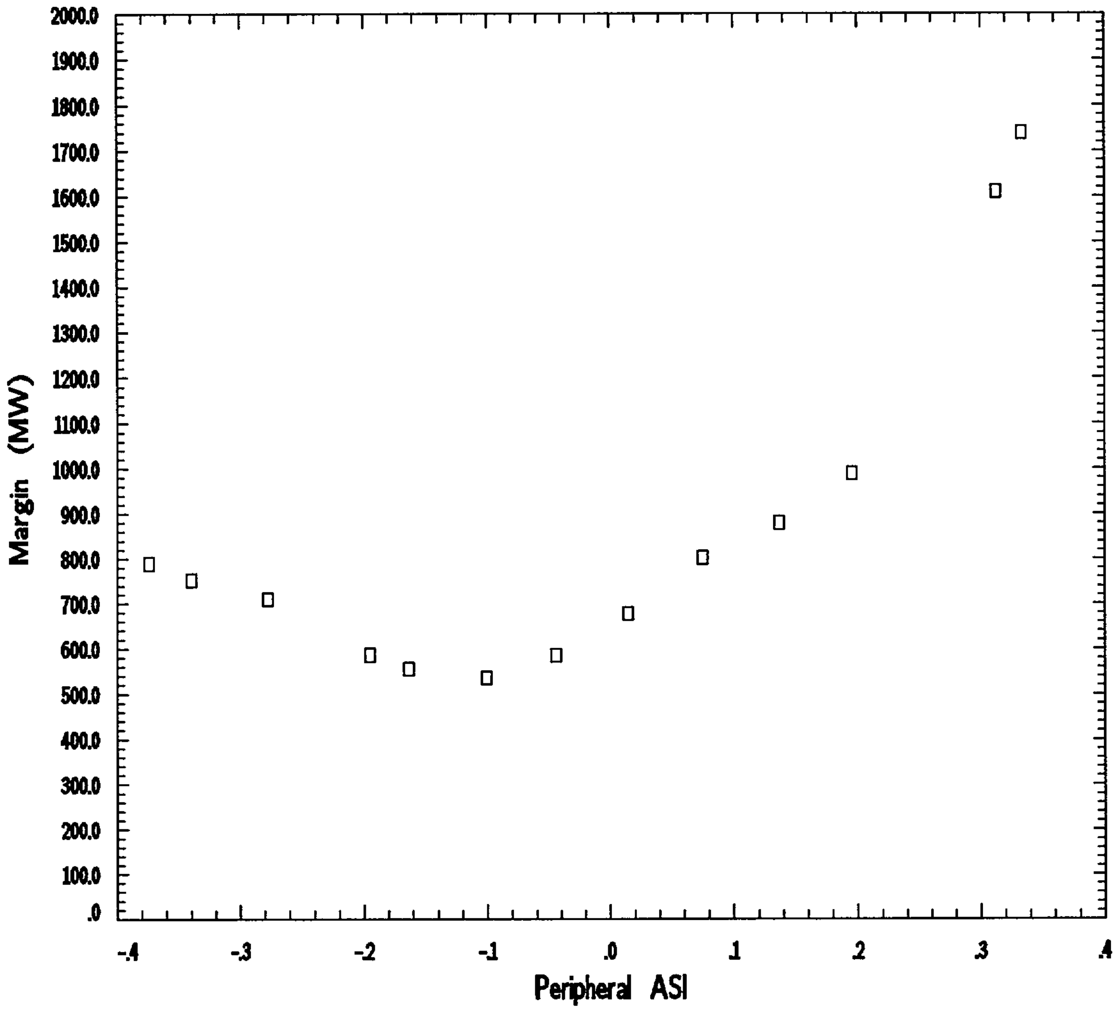

Figure 3.25 Overall Margin to DNB LCO for CEAD

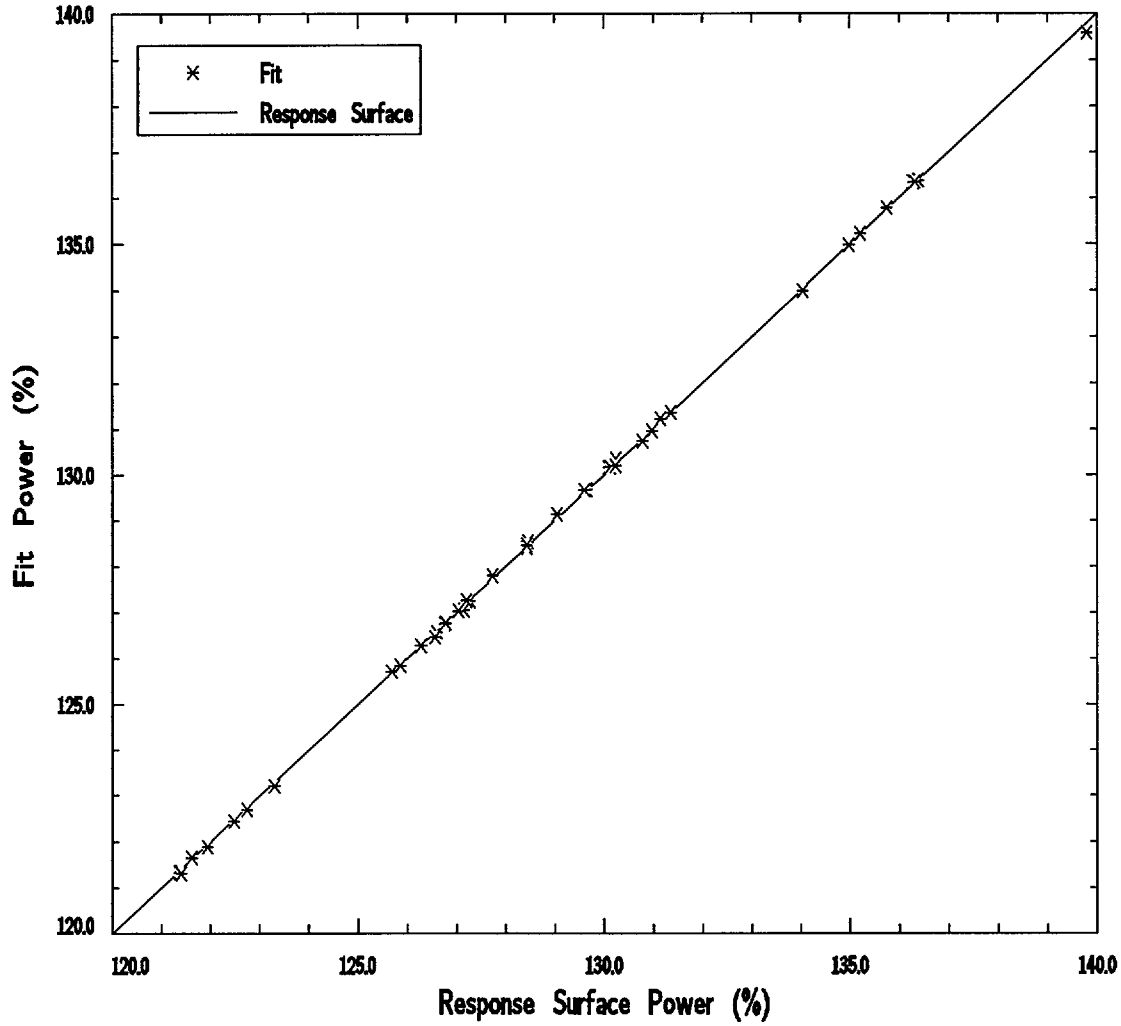

Figure 3.26 Fit to Response Surface for LOCF

Figure 3.27 Uncertainty From Response Surface for LOCF

Figure 3.28 Uncertainty in Power From RS and Calorimetric for LOCF

Figure 3.29 Uncertainty in Power From ASI for LOCF

Figure 3.30 Power Margin to DNB LCO for LOCF

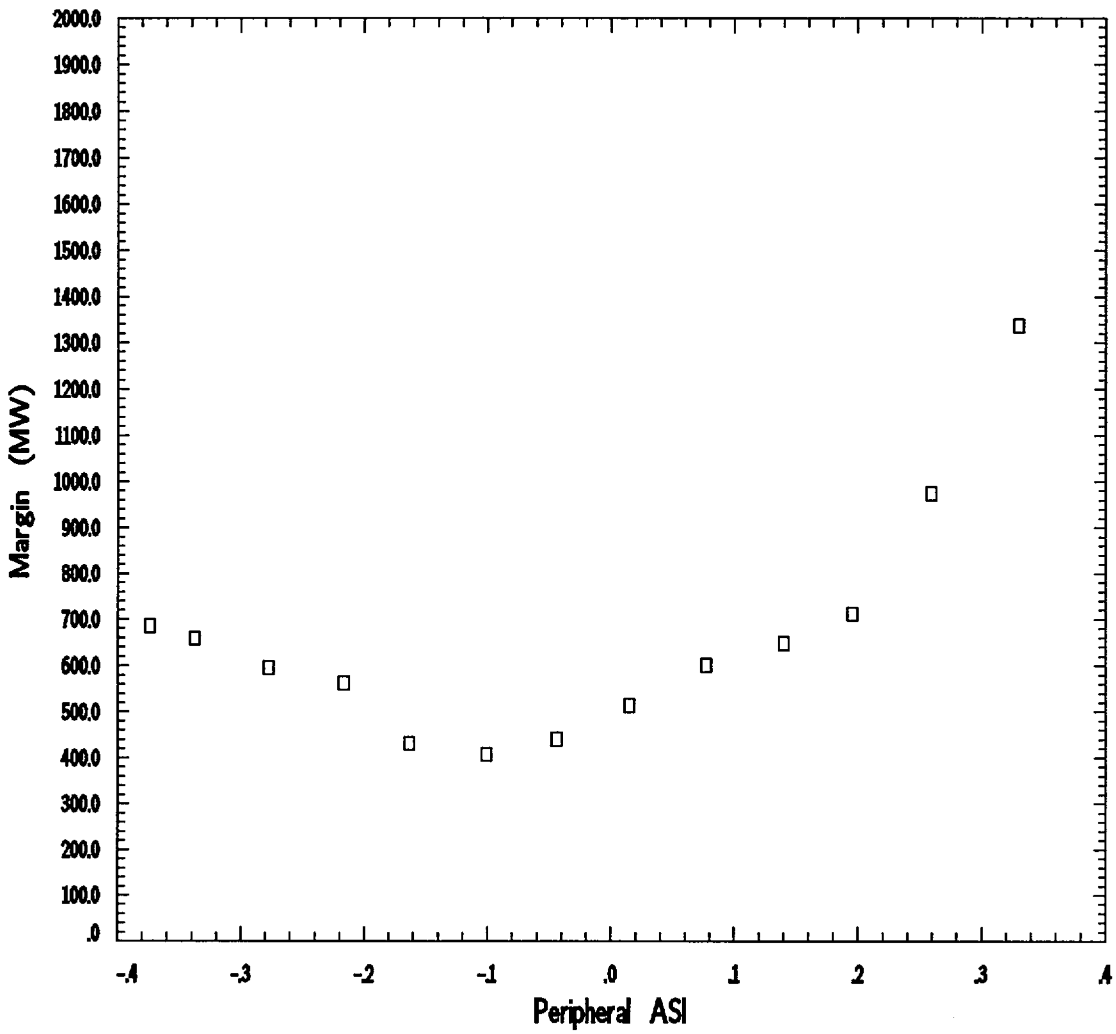

Figure 3.31 Overall Margin to DNB LCO for LOCF

4. Transient Analysis

The statistical transient analyses are performed in a manner that results in the protective system, in conjunction with the LCOs and LSSSs, protecting the SAFDLs and pressure limits with 95% probability at a 95% confidence limit. For slow transients that do not undergo significant changes in the radial power distribution, the LPD LSSS is designed to protect against FCM and the TM/LP trip is designed to protect against DNB or hot leg saturation.

For events characterized by more rapid power excursion or a radial power redistribution, confirming that the LCOs and LSSSs, in conjunction with the remainder of the reactor protection system (RPS), protect against FCM, DNB, hot leg saturation and pressurization of the primary and secondary systems is necessary. The confirmation of margin is discussed in the Section 4.1. As with the other setpoints, setting a trip setpoint is an iterative process in most cases. Thus, a methodology for confirming the margin is sufficient to set a setpoint.

4.1 Confirmation of Margin

Transient analysis confirms that the system, as configured for the cycle of operation, will not exceed SAFDLs and system pressurization limits. The confirmation of trip values is based on their ability to protect against violation of these limits with a prescribed level of certainty (95% probability at a 95% confidence level). To confirm the margin based on the LCOs and RPS, the margin to the limit is the statistically varied parameter. The tools used in this process are similar to those used in the confirmation of the LSSSs and LCOs discussed in Section 2. A transient model is used to propagate the uncertainties in the initial conditions, the RPS actions and plant response so they can be combined with the uncertainty in the margin to the acceptance limit. To confirm the margin, the calculated margin must be positive with 95% probability at a 95% confidence level.

Table 4.1 lists the typical parameters varied in confirming the margin to different limits. Treating a subset of variables deterministically will result in calculational simplification and a conservative confirmation of margin. Sections 4.3 and 4.4 describe simplified confirmation of margins for DNB and FCM in more detail.

The confirmation of margin for all limits can be summarized as the following series of steps, which assume multiple possible initial system conditions or transient initiators, ("points"):

[

]

Many transients have only one point to evaluate. For these transients, Steps 2 through 5 can be eliminated and the nominal point treated as the most sensitive point. Steps 3 and 4 determine the conditions that produce the greatest change in the margin. When only a single set of conditions exists, the nominal calculations and response surface calculations are performed at this point. When multiple points exist, the most sensitive point is determined by finding the point that results in the largest change in the margin (DNBR, FCM, or pressure).

In the nominal transient analysis, the parameters to be treated statistically are set to their respective nominal values. All parameters not being treated statistically are set in accordance with an approved deterministic transient analysis methodology.

In the deterministic transient analysis, the parameters are set to the deterministic values. The most sensitive point is the point with the largest reduction in margin between the deterministic and nominal transient results.

Response surface points in the target (MDNBR, LHGR or pressure) are calculated around the most sensitive point, fit with a polynomial and the [ ] in margin determined. These steps are based on SPC's approved GSUAM methodology.

The [ ] is calculated based on the response surface. The target-specific uncertainties are included in the calculation of the [ ] This is done for DNB using a response surface in DNBR that corresponds to the uncertainties in [ ] The parameter uncertainties and their respective distributions are explicitly modeled in the calculation of the probability distribution for the margin. For simplicity, any or all of the statistical variables can be treated deterministically. The values and distributions of the various uncertainty plant parameters are justified on a plant specific basis.

The difference between the nominal margin and the lower, one-sided 95/95 margin from the calculation of the probability distribution is a statistical penalty and is used to adjust the other nominal margins (if any exist) to complete the confirmation.

FCM margin and the system pressure margin are calculated in a similar manner and they differ from the DNB margin calculation in that the target value is calculated more directly from the transient analysis. The calculation of the [ ] to FCM is performed in the same manner as the system pressure. The uncertainties associated with FCM include [ ] The system uncertainties are the same as those used for the DNB confirmation.

For DNB, a separate response surface can be created in MDNBR based on variables such as the [

] The two response surfaces are combined to produce the final probability distribution. The probability of DNB can be converted to an effective MDNBR as described in Section 4.2 below.

Treating a subset of variables deterministically will result in calculational simplification and a conservative confirmation of margin. Sections 4.2 and 4.3 describe simplified confirmation of margins for DNB and FCM in more detail.

4.2 Simplified DNB Margin Confirmation

DNB margin can be confirmed by comparing the MDNBR to the value of DNBR that corresponds to DNB. In the fully statistical methodology, this is done by calculating the MDNBR with all parameters treated statistically. In the simplified statistical methodology, some of the parameters are treated deterministically. The set treated deterministically contains those parameters that effect the system transient. The flow for confirming the DNB margin when the system transient is treated deterministically is summarized in Figure 4.1.

In the simplified confirmation, the parameters that effect the system response are treated deterministically. The uncertainties treated statistically are the [

]

A response surface calculation in MDNBR captures the variation in MDNBR [

] The margin to DNB is calculated by subtracting the DNBR that corresponds to DNB from the MDNBR. Because both values are uncertain, a probability of DNB is calculated and the effective MDNBR (based on the correlation statistics) is calculated. The confirmation is based on the probability of DNB. The calculation of the effective MDNBR allows the event results to be summarized in a more familiar form that still captures the statistical results.

A series of MDNBR calculations is performed with [ ] varied around the nominal values. These variations in [ ] are based on SPC's approved GSUAM methodology and are response surface points.

A fit to the MDNBRs that make up the response surface points is performed. This fit is then used to combine the [ ] uncertainties to determine the probability of DNB and calculate the effective MDNBR from the correlation statistics. In all of the statistical combination of uncertainties discussed in the following paragraphs, each variable is treated as being characterized by a normal distribution.

[

]

4.3 Simplified FCM Margin Confirmation

FCM margin is calculated in a manner similar to that described for the DNB margin with the simplification that the uncertainty in the peak LHGR is calculated directly and the FCM limit is not uncertain.

Each axial power shape has a local peaking factor. Based on this peaking factor, the LHGR at FCM is given by

$$Q_{FCM,i} = \{ \frac{\text{LHGR Limit}}{\text{LHGR}_{ave} \times F_{Q,i}} \} \times \text{Rated Power}$$

where

$$\text{LHGR}_{ave}(\text{kW / ft}) = \frac{\text{Rated Power (MWt)} \times 1000}{\text{Number of Assemblies} \times \text{Fuel Rods per Assembly} \times \text{Active Length (ft)}}$$

and $F_{Q,i}$ is the total peaking factor for the i^{th} axial power shape.

The power corresponding to the fuel centerline temperature is proportional to the heat flux. The effective power for FCM calculations is given by the [

]

The margin is defined by the 95% lower limit of the difference between the FCM point and the effective power for the event, Q_{event}. This margin is calculated for all axial power shapes in the setpoint file.

The statistical calculation of the power is performed in two steps. The [ ] then multiplied by the nominal FCM power for the axial power shape being considered. The [ ] is combined with the uncertainty from the first step to get the uncertainty in the margin to FCM.

The final power margin is obtained by subtracting the event power, Q_{event}, from the FCM power. Positive margins confirm that FCM is protected.

4.4 DNB Margin - Sample Case

Table 4.3 gives the input for the sample case. This sample case has reduced flow and increased power, somewhat like a loss of coolant flow event. The power was increased so that the MDNBR produced was 1.038.

The experimental design used nine points (two variables, three levels), which corresponds to Option 1 in Table 4.2. This option varies the power and the peaking from - 1-96 standard deviations to + 1-96 standard deviations in three levels. The other options vary the same parameters over the same range, but have additional intermediate levels. Table 4.4 lists the response surface points created by this experimental design. The response surface points were then fit using a [

] Figure 4.2 compares the fit to the calculated MDNBR. The [ ] for MDNBR from the response surface was calculated and is shown in Figure 4.3. Because MDNBR is always adjusted to account for the engineering factor, the [

]

[

]

4.5 FCM Margin - Sample Case

The input for the FCM sample case is given in Table 4.5. The nominal event power is based on the relative heat flux for the case being evaluated then reduced by 2% RTP to account for the 2% calorimetric bias in the transient analysis.

The first step is to calculate the [

] The[ ] is shown in Figure 4.6. For each axial power shape in the shape file, the FCM power is calculated [

] The lower 5% limit of margin is retained from each case.

The case that produced the minimum margin for this sample has an F_Q of 2.78 and a melt limit of 2,797 MWt, which is about 121% of rated power. The probability distribution for the melt power for this case is given in Figure 4.7.

[

]

This process is repeated for all axial power shapes with peripheral ASIs between -8% and +16%, which is the range of full-power operation allowed by the DNB LCO. The final margin, which is positive for all ASIs (minimum margin is about 15 MWt) and confirms the protection against FCM, is shown in Figure 4.9.

Table 4.1 Parameters Typically Treated Statistically in Transient Analyses

Table 4.2 Optional Experiment Designs for Statistical Evaluation of MDNBR

Variation in units of σ	Variations in Power and $F_{\{\Delta H,r\}}$ Included by Option		
	1	2	3
0.00	x	x	x
1.96	x	x	x
-1.96	x	x	x
1.00		x	x
-1.00		x	x
0.50			x
-0.50			x

Table 4.3 Input for Statistical MDNBR Sample Case

Table 4.4 Response Surface for Statistical MDNBR Sample Case

Power	Peaking	MDNBR
0.00	0.00	1.240
0.00	1.96	1.121
0.00	-1.96	1.372
1.96	0.00	1.169
1.96	1.96	1.049
1.96	-1.96	1.294
-1.96	0.00	1.317
-1.96	1.96	1.193
-1.96	-1.96	1.452

Table 4.5 Input for FCM Sample Case

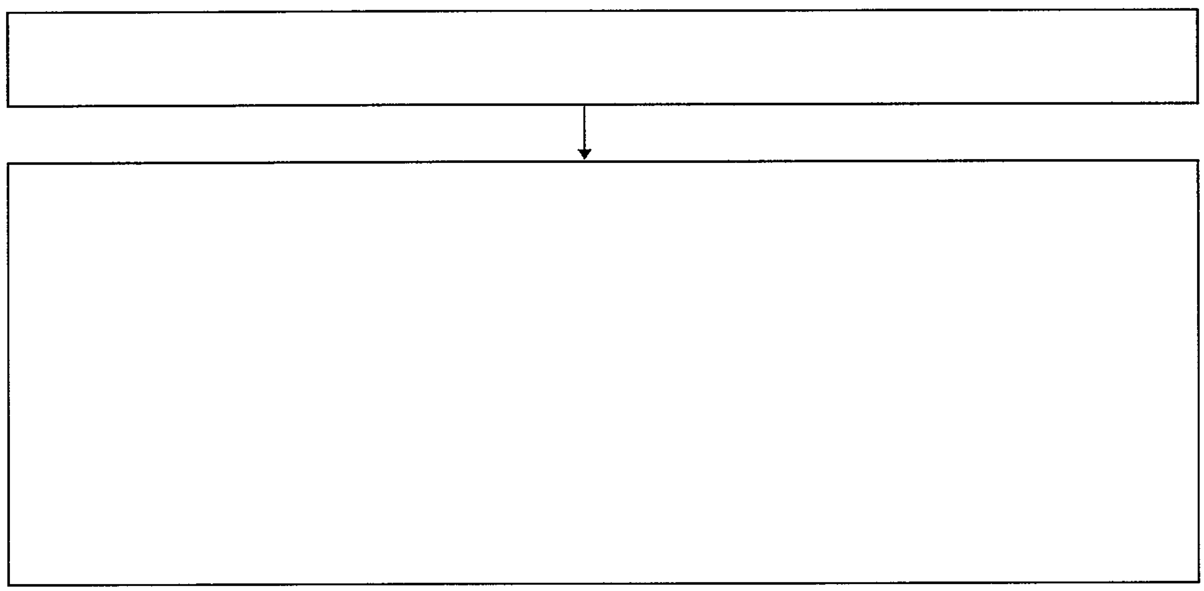

Figure 4.1 Flow of Statistical MDNBR Calculations

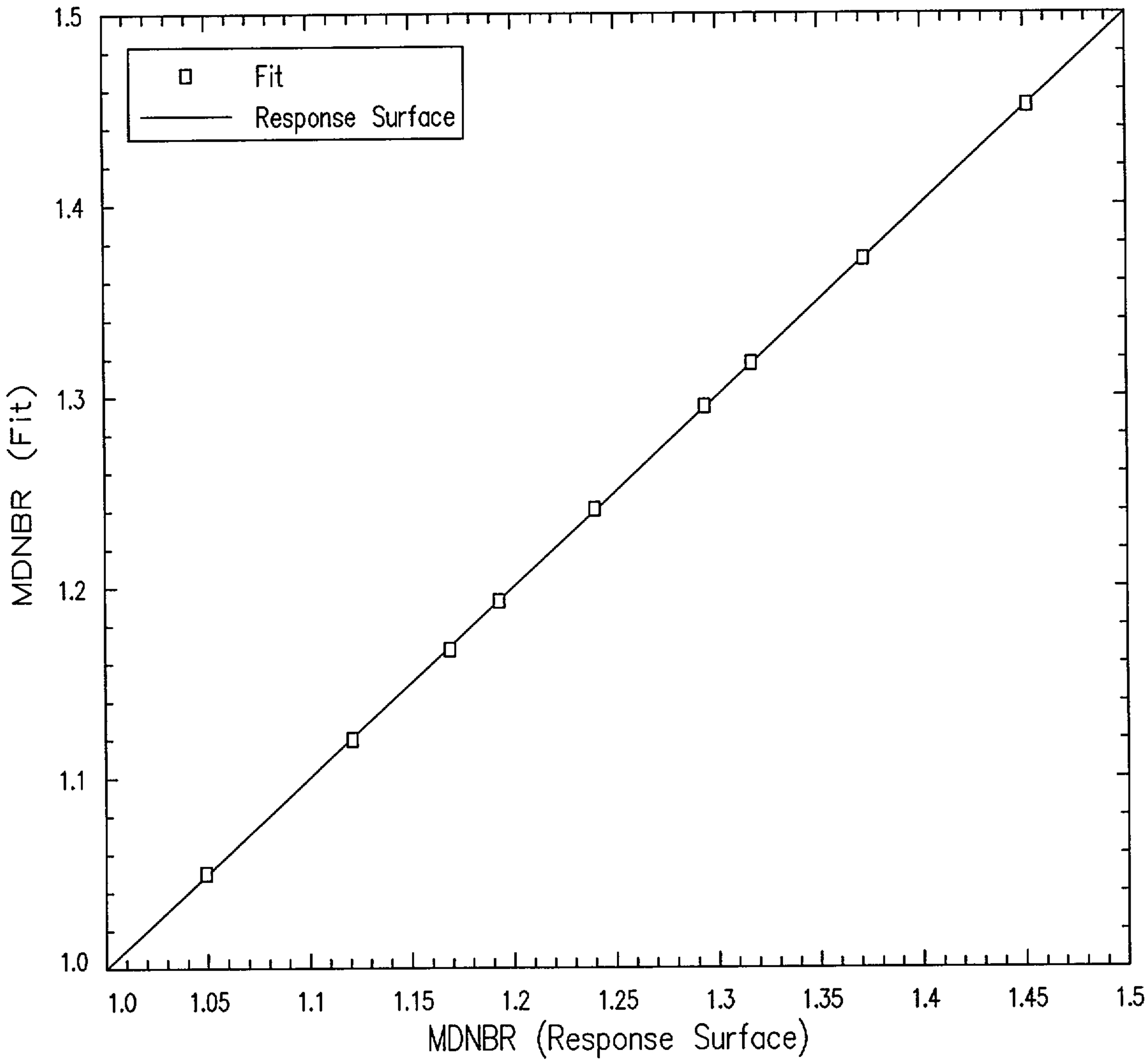

Figure 4.2 Fit to MDNBR Response Surface for Sample Case

Figure 4.3 Probability Density for MDNBR Response Surface

Figure 4.4 Probability Density for MDNBR

Figure 4.5 Probability Distribution for Margin to DNB

Figure 4.6 Probability Distribution for FCM Multiplicative Factor

Figure 4.7 Probability Distribution for Melt Power

Figure 4.8 Probability Distribution for Margin to FCM

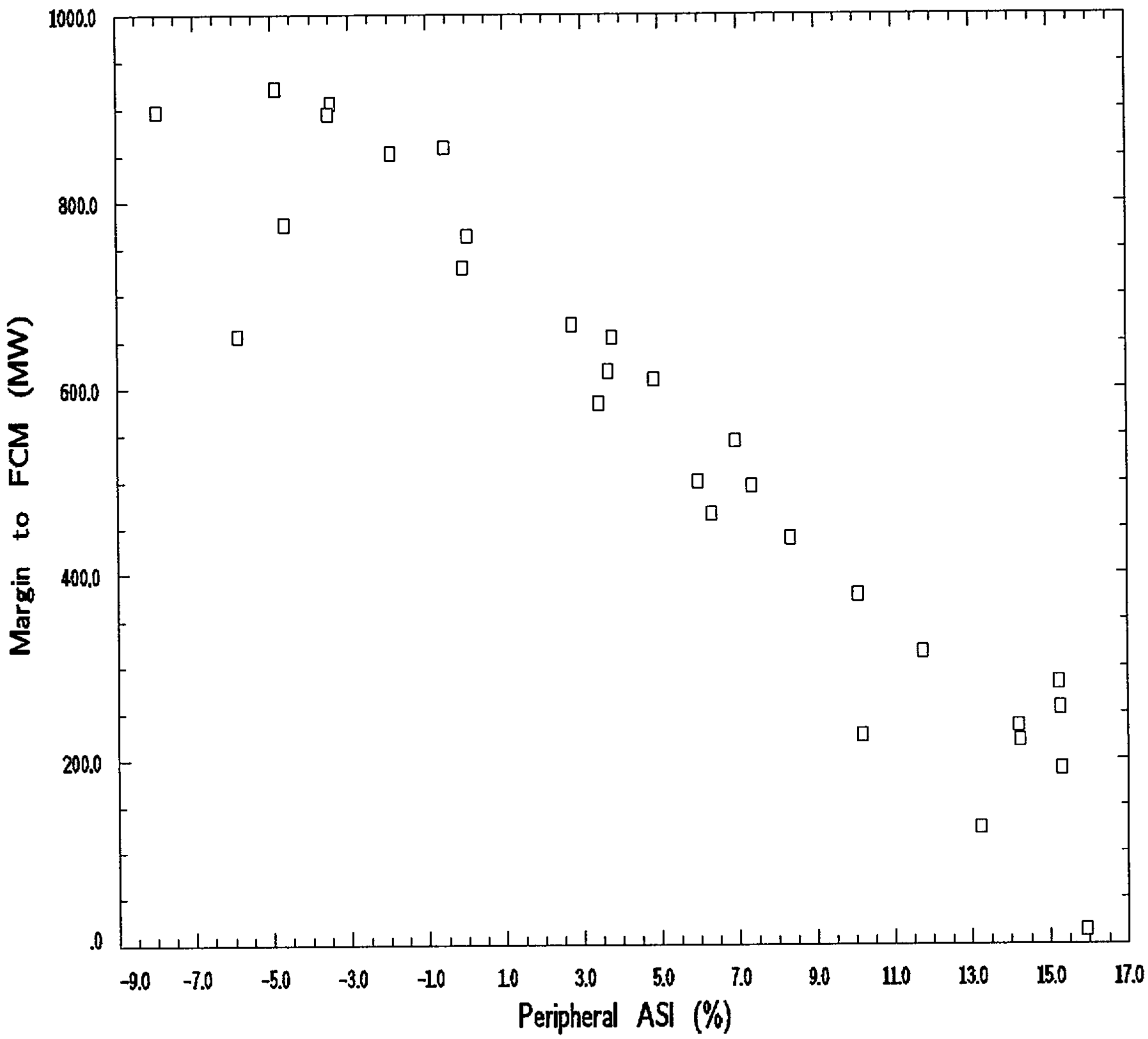

Figure 4.9 Margin to FCM for Sample Case

5. Neutronics Analysis

The core average axial power distributions and the corresponding internal and external ASIs are calculated for each cycle to support the setpoint and transient analyses.

Ordered pairs of axial power distributions and ASIs are used in both the determination of the LSSSs and LCOs. The following description of the axial power distribution generation is used to obtain input for both the LSSS and LCO setpoint analyses

5.1 Simulator Model Development Description

The following steps describe the procedure used in establishing the reactor core model that generates the axial power distributions used in the setpoint analyses.

1. [

]

[

]

5.2 *Modifications to Calculated Peaking Factors*

In the procedure described in 5.1 the nominal values of $F_{r,max}$ and $F_{Q,max}$ represent the design values for the core being analyzed. Because of this, the nominal peaking factors calculated by the procedure are modified to ensure that they will bound reactor operation by using peaking factor data at the Technical Specification limits.

5.2.1 Radial Peaking Factor

A radial peaking factor (F_r) will be calculated for each axial shape. At the simulated all rods out (ARO) core conditions, the value used in the setpoint methodology is the Technical Specification value. However, at CEA-insertion core conditions this value may increase beyond the Technical Specification value. The values to be used in the setpoint analysis are defined as

$$F_r' = \frac{F_r(Q, CEA)}{F_r(Q, ARO)} F_{r,TS}$$

where F_r' is the radial peaking factor used in the setpoint analysis, $F_r(Q,CEA)$ is the core maximum F_r value for the power level, Q, under CEA insertion conditions for the case analyzed, calculated by the three-dimensional simulation code. F_r (Q,ARO) is the core maximum value of F_r at the power level, Q, and ARO conditions and $F_{r,TS}$ is the Technical Specification limit of F_r.

5.2.2 Total Peaking Factor

A total peaking factor, F_Q', is used for the LPD LSSS and LPD LCO calculations. The values to be used are defined as

$$F_Q' = F_{Q,MAX}(Q)\frac{F_{r,TS}}{F_r(Q,ARO)}$$

where F_Q' is the total peaking factor used in the setpoint analysis and $F_{Q,MAX}(Q)$ is the core maximum F_Q calculated by the core simulation code for the case analyzed.

The values of F_Q' calculated this way bound those values that may occur in the core. Therefore, adherence to the F_r Technical Specification limit effectively limits core F_Q'.

6. References

1. *Generic Statistical Uncertainty Analysis Methodology*, XN-NF-22(P)(A), November 1983.
2. *ENC Setpoint Methodology for C. E. Reactors: Statistical Setpoint Methodology*, XN-NF-507(P)(A), Supplement 1 & 2, September 1986.
3. *Factors for One-Sided Tolerance Limits and Variable Sampling Plans*, SCR-607, U.S. Department of Commerce, National Technical Information Services, March 1963.

APPENDIX A - FUEL CENTERLINE MELT

The fuel centerline melt (FCM) limit is expressed as a function of a limit on linear heat generation rate (LHGR). This Appendix describes Siemens Power Corporation's (SPC's) method of calculating this limit.

The fuel centerline temperature is calculated as a function of [

] This calculation is performed using RODEX2 (References A.1 and A.2), which is a quasi-static fuel rod performance code used by SPC. The [

] is used to convert the RODEX2 result to the LHGR at which FCM would occur as a [

]

To find the limit on the peak UO_2 rod, the [

] are used. This limit is set by finding the maximum of:

Because gadolinia-bearing rods become more reactive later in the cycle, the limit on the UO_2 rod may be set by the high concentration gadolinia-bearing rods. The difference between the uranium enrichment in the UO_2 rods and the gadolinia-bearing rods is the determining factor. Very large differences will keep the UO_2 rods limiting.

This analysis makes use of deterministic design values and bounding assumptions and as burnup and power shapes to address uncertainties. The melt power calculated from this process is a bounding value.

A.1 RODEX2 Runs

The FCM limit calculation makes use of five RODEX2 runs to calculate the fuel temperature for a series of short-term power spikes to various levels. These are combined with the [ ] to calculate a peak LHGR limit for any UO_2 rod. Figure A.1 is a schematic of the flow of the calculation.

Five RODEX2 runs are made, one for each gadolinia concentration from 0 (UO_2) rod to 8 w/o, steps of 2 w/o. In addition to these design parameters, a generic set of power histories is used. These shapes are designed to produce a conservative (high) estimate of the ratio of the [ ] This results in a higher peak fuel centerline temperature for a fixed rod power and lower melt temperature for a fixed rod burnup. The axial power shapes used to produce this conservative history are interpolated between the three shapes for beginning, middle and end of the cycle (BOC, MOC and EOC, respectively) shown in Figure A.2. The BOC power shape is a chopped cosine that meets the overall peaking limit when the hot rod is placed at the radial peaking limit. The default shapes result in a set of power shapes that produce conservative burnups, especially for high burnup cores that flatten more than the default core does.

The UO_2 rod is modeled at the radial peaking limit throughout the cycle. The rod powers for the gadolinia rods are reduced initially compared to the UO_2 rod power; then allowed to return nearly to the UO_2 rod power as the cycle progresses. This results in power histories for these rods that are similar to the power histories they might experience in operation. Figure A.3 shows the relative power (gadolinia rod over peak UO_2 rod) curves for each of the four gadolinia concentrations considered.

Periodically throughout the cycle, the rod power is spiked for a few seconds to the values given in Table A.1 to allow RODEX2 to calculate the fuel temperature as a function of rod power at different burnups. The axial power shape used for these spikes is shown in Figure A.4. The power histories force the peak burnup to be in the central spiked region.

This ensures that peak relative burnup and power occurs at the same axial node on the rod.

A.2 Fuel Centerline Melt LHGR

The calculation of the LHGR for FCM can be divided into two steps: 1) calculation of the melt curves for UO_2 rods and fuel rods with gadolinia concentrations from 2% to 8% and 2) calculation of the LHGR on a UO_2 rod which precludes FCM for any rod in the assembly.

The RODEX2 outputs are searched for the power spikes. The power history in the RODEX2 runs consists of a pattern of one operating point for accumulating burnup followed by six power spikes. The nodal structure from the default RODEX2 input is 13 axial nodes with nodes 3, 6, 7, 8 and 11 at the spike limit. The fuel centerline temperatures and burnups are read from the RODEX2 output files for each of these six powers. The melt temperature (T_{melt}) for each of the five nodes, denoted by i, is calculated at each spike, denoted by j, and a relationship (Reference A.3) between spike power at the node and the fuel centerline temperature is used to determine the melt power for the fuel rod ($P_{melt,\ rod}$), which satisfies

$$T_{i,j}(P_{rod})|P_{rod} = P_{melt,rod} = T_{melt}(B_{i,j}, C_{gad}))$$

where $B_{i,j}$ is the burnup and $T_{i,j}(P)$ is the fuel centerline temperature of the i^{th} node at the j^{th} power spike (P_{rod}) and C_{gad} is the gadolinia concentration of the rod in percent. The melt temperature [

] of the rod

[ ] and for each rod burnup and gadolinia concentration, the minimum melt power is selected from all of the $P_{melt,\ rod}$. The relationship between rod burnup and this minimum melt power is called the melt curve. A typical set of melt curves is shown in Figure A.5.

The fuel melt curves provide a relationship between melt power and the rod burnup and gadolinia concentration. The melt limit is determined by searching through the [ ] and calculating the power limitation on each rod. The ultimate limit at each assembly burnup level is set for the UO_2 rod with the highest power. This limit is set by finding the [ ]

The minimum FCM power for a UO_2 rod is determined for each rod type (gadolinia concentration) at a series of assembly burnups, up to the maximum burnup for any assembly in the fresh fuel for the cycle of operation. The FCM limit is the minimum LHGR for all the fuel types divided by the fraction of power generated in the rod. This last step is necessary because RODEX2 uses only the power deposited in the rod to calculate LHGR and the normal operational definition of LHGR uses the total power.

A.3 FCM LHGR - Sample Case

The sample case is for a fuel design with all four gadolinia concentrations. The deduction in enrichment for the gadolinia-bearing rods is such that they become limiting by mid-cycle. The maximum rod burnup was set to 31,000 MWd/MTU. Tables A.2 through A.6 show the rod power as a function of rod burnup for each of the five fuel rod types. These are obtained by extracting the fuel centerline temperature from the RODEX2 runs for all six power spikes at each burnup point in the RODEX2 runs. Then the FCM temperature for the [ ] and the rod LHGR corresponding to FCM were calculated.

Table A.7 shows the minimum UO_2 rod powers at FCM for each gadolinia concentration at a series of assembly burnups. These were created by combining the [

] for eight different fuel assembly designs at a series of assembly burnups with the melt curves for each gadolinia concentration as a function of the rod burnup. In this case, the eight fuel designs were analyzed using CASMO-2E. The LHGRs given in Table A.7 are the minimum LHGRs from all eight assembly designs for each gadolinia concentration at each assembly burnup. The blank cells in the table are assembly burnups for which the CASMO-2E runs were not available.

At very low burnup, the gadolinia-bearing rods place a very high limitation on the UO_2 rods LHGR. The gadolinia-bearing rod has so little power at the beginning of the cycle, the UO_2 rod would have to reach very high powers to cause melt in the gadolinia-bearing rod. As the burnup increases and the power in the gadolinia-bearing rods begin to approach that of the peak UO_2 rod, the higher concentration gadolinia-bearing rods begin to determine the FCM power. At the highest burnup, the 8 w/o rod produces a UO_2 rod power of 20.011 kW/ft.

Because the minimum value in Table A.7 is still the LHGR based on the power generated in the fuel rod, it should be divided by the fraction of power generated in the rod (0.974) to give the normal LHGR limit, 20.546 kW/ft.

Table A.1 Power Spikes for Fuel Centerline Melt Calculations

Number	Power (kW/ft)
1	18.5
2	20.0
3	21.0
4	22.0
5	23.0
6	24.5

Table A.2 Fuel Centerline Melt Power Versus Burnup for a UO_2 Rod

Rod Burnup (MWd/MTU)	Rod Power at FCM (kW/ft)
2.87	25.28
2383	25.49
4763	25.11
7142	24.97
9522	24.82
11900	24.65
14280	24.49
16660	24.32
19040	24.15
21420	23.95
23800	23.73
26180	23.48
28560	23.23
30940	22.98

Table A.3 Fuel Centerline Melt Power Versus Burnup for 2 w/o Gad Rod

Rod Burnup (MWd/MTU)	Rod Power at FCM (kW/ft)
1.22	23.67
1479	23.90
3434	23.75
5682	23.43
8004	23.26
10340	23.11
12670	22.96
15000	22.81
17330	22.65
19670	22.48
22000	22.29
24330	22.08
26660	21.87
28990	21.66

Table A.4 Fuel Centerline Melt Power Versus Burnup for 4 w/o Gad Rod

Rod Burnup (MWd/MTU)	Rod Power at FCM (kW/ft)
1.05	22.20
1222	22.42
2807	22.41
4653	22.21
6704	21.96
8888	21.80
11140	21.68
13400	21.54
15660	21.40
17920	21.25
20180	21.08
22440	20.90
24700	20.71
26970	20.52

Table A.5 Fuel Centerline Melt Power Versus Burnup for 6 w/o Gad Rod

Rod Burnup (MWd/MTU)	Rod Power at FCM (kW/ft)
0.88	20.88
965.2	21.09
2180	21.11
3645	21.06
5335	20.92
7270	20.70
9370	20.51
11540	20.38
13750	20.24
15960	20.11
18170	19.96
20390	19.82
22600	19.65
24820	19.48

Table A.6 Fuel Centerline Melt Power Versus Burnup for 8 w/o Gad Rod

Rod Burnup (MWd/MTU)	Rod Power at FCM (kW/ft)
0.82	19.68
826.6	19.87
1812	19.90
3018	19.87
4408	19.83
6033	19.71
7892	19.52
9947	19.30
12110	19.14
14310	19.01
16510	18.88
18730	18.74
20940	18.59
23160	18.42

Table A.7 FCM Power Versus Assembly Burnup by Gadolinia Concentration

Rod LHGR (kW/ft) at FCM for Various Gadolinia Concentrations

Assembly Burnup (MWd/MTU)	0 w/o	2 w/o	6 w/o	8 w/o
0	25.279	54.613	65.808	67.580
500	25.327	51.144	62.981	65.221
1000	25.374	47.717	60.184	63.070
1500	25.421	44.113	57.483	61.057
2000	25.468	40.912	54.836	58.969
2500	25.400	38.021	52.353	56.750
3000	25.307	35.450	49.970	54.759
3500	25.215	33.193	47.762	52.811
4000	25.123	31.232	45.596	50.851
4500	25.081	29.596	43.724	48.859
5000	25.046	28.356	42.002	46.934
5500	25.012	27.438	40.299	45.227
6000	24.977	26.710	38.756	43.497
6500	24.942	26.148	37.288	41.843
7000	24.905	25.781	35.867	40.256
7500	24.870	25.457	34.516	38.942
8000	24.834	25.237	33.206	37.542
8500	24.796	25.047	31.998	36.229
9000	24.758	24.932	30.822	35.003
9500	24.719	24.819	29.679	33.867
10000	24.680	24.711	28.598	32.773
10500	24.642	24.652	27.614	31.709
11000	24.606	24.570	26.651	30.720
11500	24.570	24.536	25.877	29.745
12000	24.534	24.454	25.253	28.883
12500	24.498	24.418	24.662	27.999
13000	24.459	24.360	24.148	27.216
13500	24.419	24.461	23.708	26.472
14000	24.380	24.406	23.341	25.693
14500	24.341	24.352	23.035	24.950
15000	24.302	24.150	22.783	24.247
15500	24.263	24.221	22.605	23.622
16000	24.224	24.189	22.452	23.085
16500	24.185	24.107	22.326	22.596
17000	24.147	24.048	22.221	22.191
17500	24.102	23.902	22.141	21.800
18000	24.058	23.929	22.062	21.535
18500	24.014	23.915		21.341
19000	23.971	23.877		21.171
19500	23.924	23.840		21.028
20000	23.897	23.620	21.837	20.928
20500	23.871	23.741		20.852
21000	23.844	23.697		20.796
22500	23.711			
25000	23.439	23.057	21.354	20.398
27500	23.165			
30000	22.988	22.531	20.854	20.011

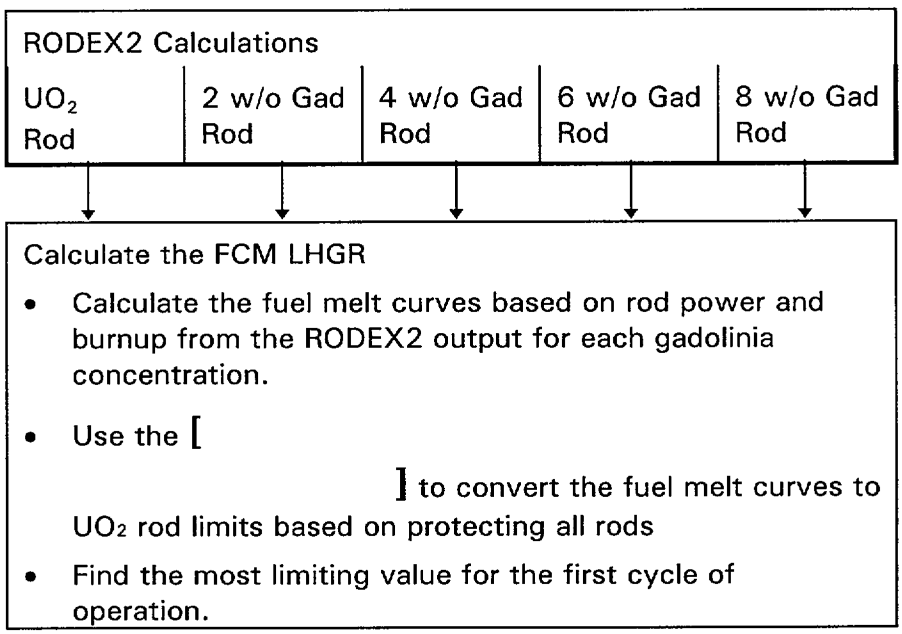

Figure A.1 Flow of FCM Calculations

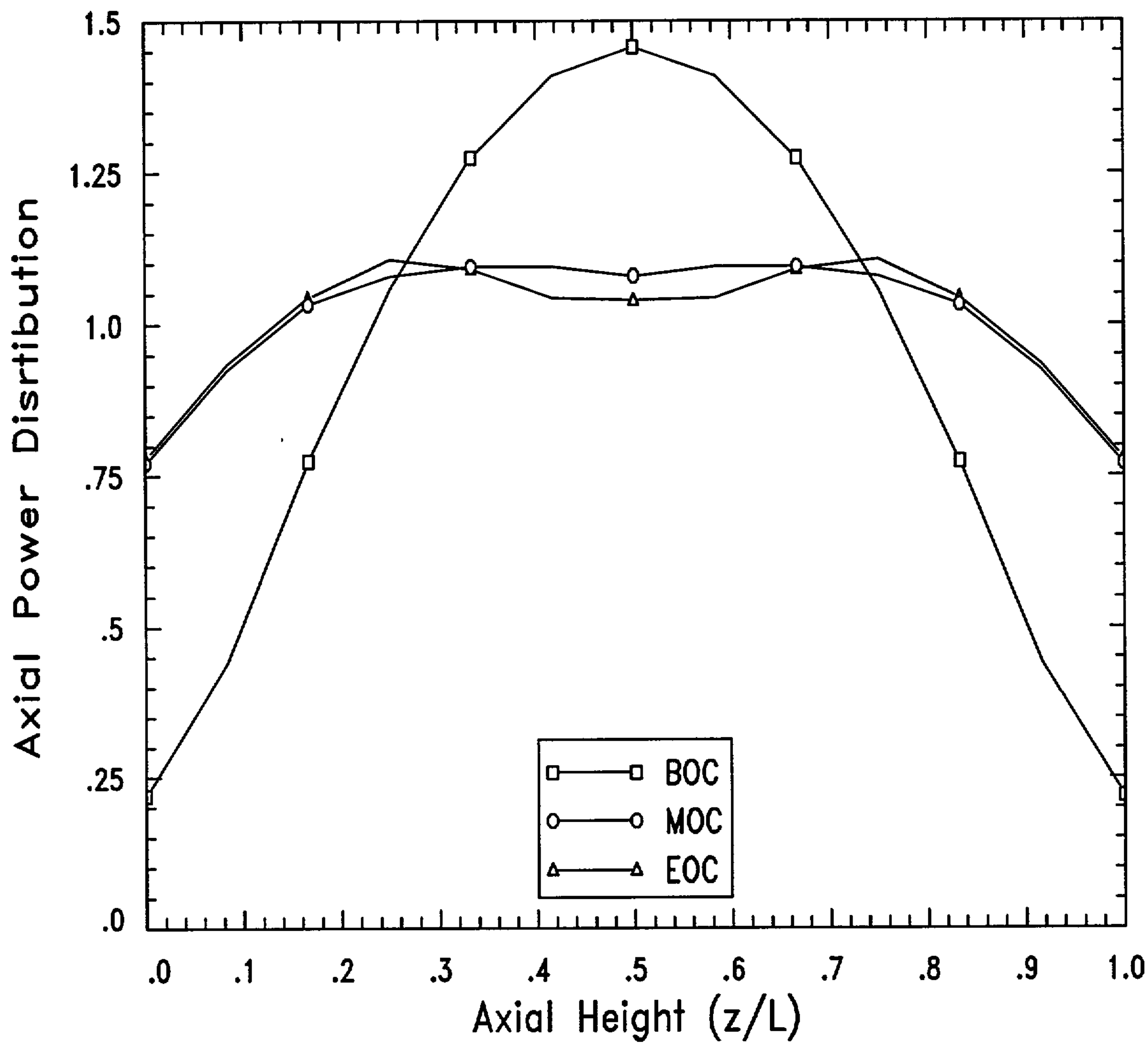

Figure A.2 Axial Power Shapes (BOC Shape uses $F_Q/F_{\Delta H}$ - 1.46)

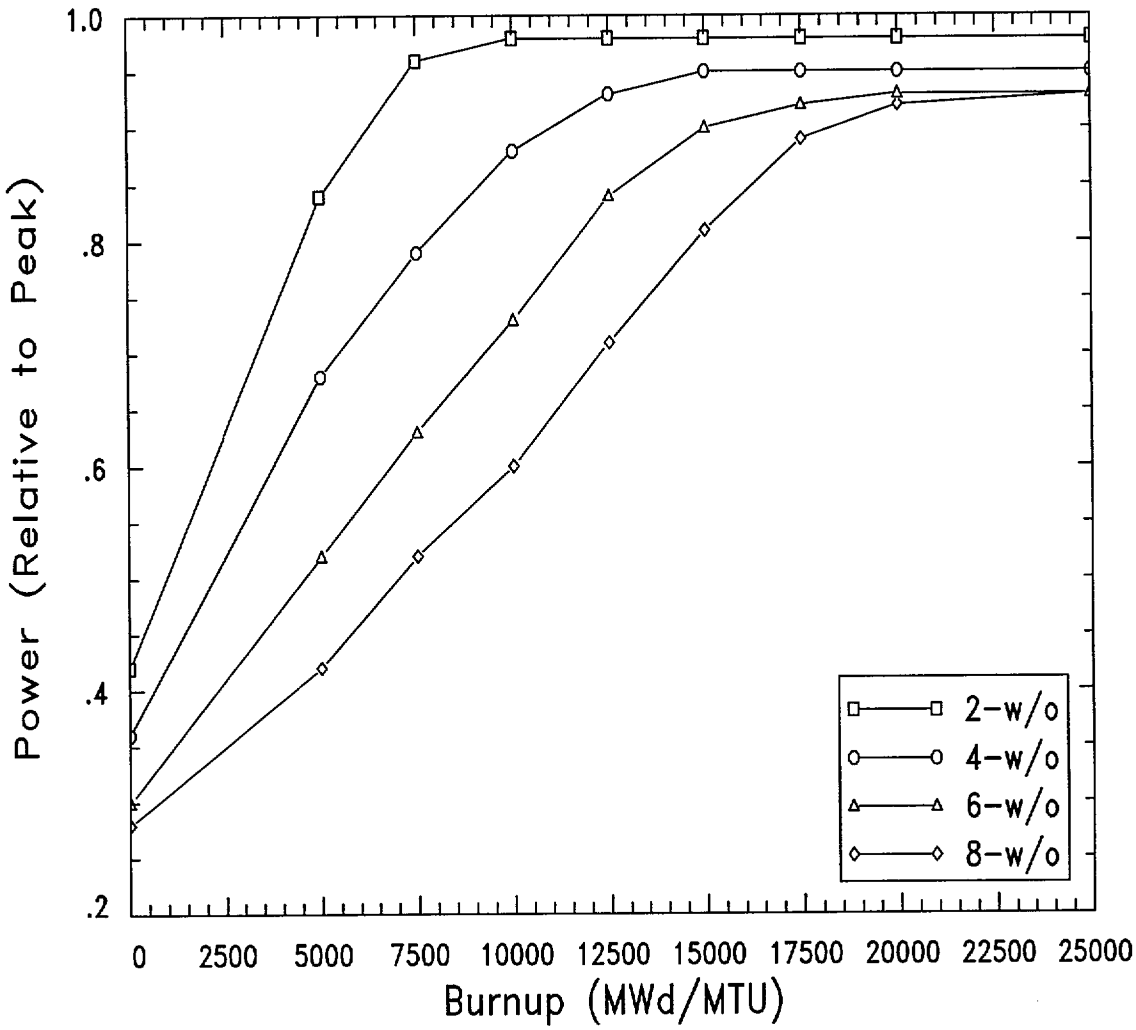

Figure A.3 Power Levels (Relative to High Powered UO_2 Rod) for Gadolinia Rods

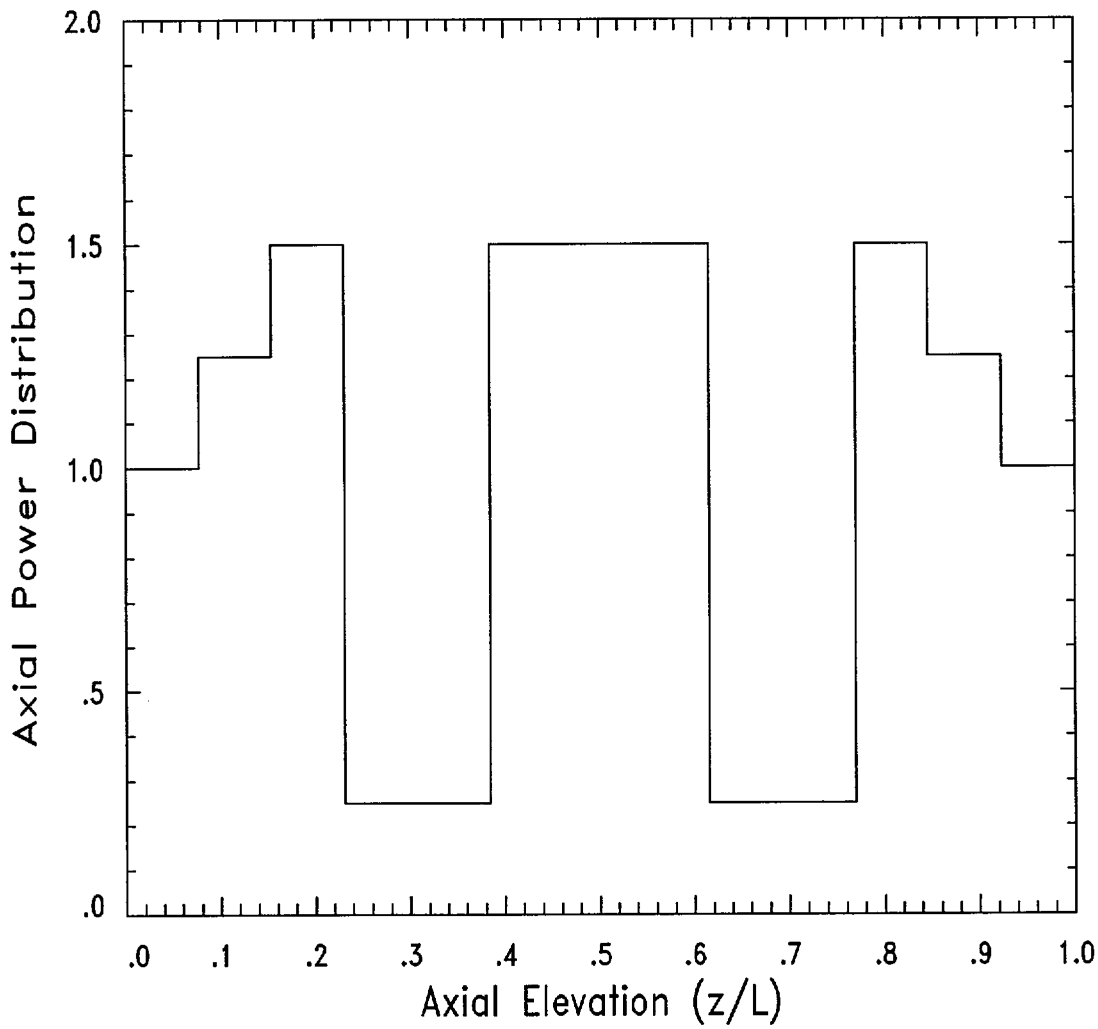

Figure A.4 Axial Power Shape Used Spiking to Melt

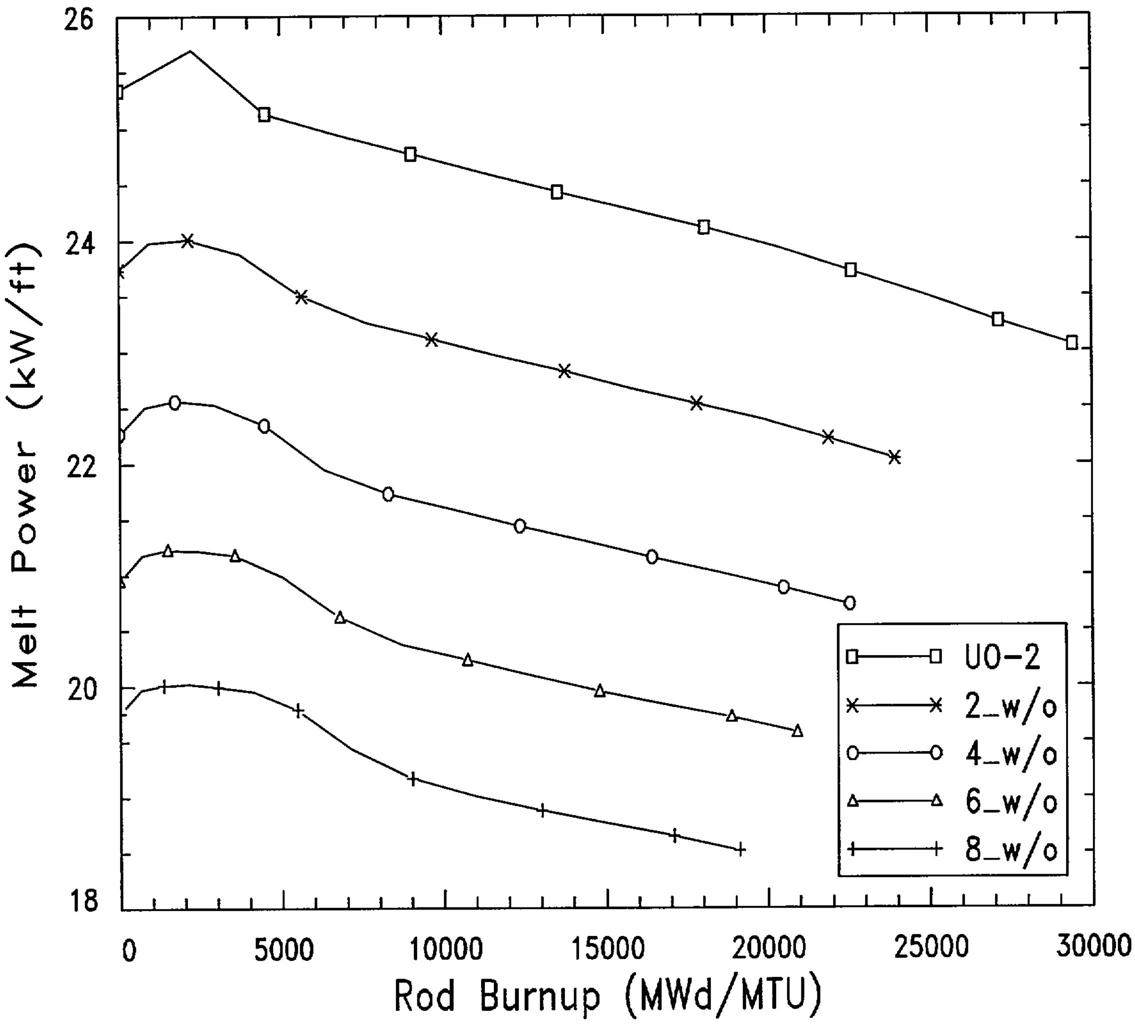

Figure A.5 Typical Fuel Rod Melt Curve

A.4 References

A.1 *RODEX2 Fuel Rod Thermal-Mechanical Response Evaluation Model*, XN-NF-81-58(P)(A), Revision 2 and Supplements 1 and 2, March 1984.

A.2 *RODEX2 Fuel Rod Thermal-Mechanical Response Evaluation Model*, ANF-81-58(P)(A), Revision 2, Supplements 3 and 4, June 1990.

A.3 Gadolinia Fuel Properties for LWR Fuel Safety Evaluation, XN-NF-79-56, Revision 1, November 1981.

APPENDIX B - CORE SAFETY LIMIT LINES

For a statistical confirmation, the Core Safety Limit Lines (CSLLs) are treated as a series of isobars in power and temperature (inlet or loop average) that establish the operating frontiers in power and temperature at each pressure such that departure from nucleate boiling (DNB) in the core and hot leg saturation are both avoided with at least a 95% probability at a 95% confidence level. Each isobar is made up of two regions. The first, flatter region is established by hot leg saturation and the second, steeper portion is established by DNB. When plant conditions change (uncertainties, flows, radial peakings or DNB correlations), the CSLLs, which are the basis for the Thermal Margin/Low Pressure trip, are confirmed.

B.1 Confirmation of CSLLs

The confirmation of CSLLs is similar to the confirmation of the TM/LP trip. The main difference is that only one axial power shape is used in the confirmation of the CSLLs. The axial power shape, taken from the setpoint axial power shapes, which produces the lowest minimum DNB ratio (MDNBR), while still allowing full power operation, is used as a design axial shape.

Nominal power margins are calculated, based on the nominal DNB power for a pressure and temperature and the CSLL power corresponding to the same pressure and temperature. The overall flow of the confirmation process is shown in Figure B.1. The effect of uncertainties (See Table B.1) is then incorporated to reduce the nominal margin.

DNBR calculations are performed over a range of power and inlet temperature to find the nominal conditions at which DNB would occur with 50% probability. The nominal DNB points are a series of cases at different powers, pressures and inlet temperatures that produce an MDNBR at the adjusted DNB correlation mean value. Adjustment to the mean value of the correlation can come from a rod bow penalty or a mixed core penalty. The power from the CSLL corresponding to the inlet temperature and pressure is the nominal CSLL power. The nominal DNBR power is used to calculate the nominal margin between the CSLL and the conditions at which DNB occurs. The cases evaluated for DNB are determined by the nominal XCOBRA-IIIC conditions for DNB.

The power at which saturation occurs is calculated using steam tables to find the exit temperature from the vessel and the saturation temperature for the hot leg. Powers from

25% to 100% of rated are used to determine the temperature from each isobar and confirm that hot leg saturation is protected. The nominal power for the CSLL is calculated and the nominal margin between the CSLL and the saturation power is determined.

The nominal margins are adjusted for uncertainties to obtain the power margin provided by the trip. The overall margin is given by the nominal margin adjusted by the lower 95% limit of the margin distribution

$$\text{Margin}_{\text{overall}} = \text{Margin}_{\text{nominal}} + Q_{5\%}$$

where $Q_{5\%}$ denotes the power corresponding to the one-sided lower 95% limit of the margin uncertainty distribution.

The uncertainty in the margin provided by the CSLLs is determined by combining [ ]

When the limit is set by saturation in the hot leg, the uncertainty is the [ ]

[

]

The CSLLs are not confirmed for primary conditions that would result in a main steam safety valve (MSSV) lifting. When the MSSV opens, the reactor primary loop is unable to heat up any more for a given power. The temperature of the secondary side of the steam generator is given by

$$T_{S.G.} = T_{ave} - \frac{xcof}{Q}$$

The secondary side of the steam generator is assumed to be at saturation. Thus, $T_{S.G.}$ at normal operation corresponds to the saturation temperature for full-power (about 700 to 800 psia) and xcof is adjusted to make the $T_{S.G.}$ the saturation temperature, given the primary system average temperature at full power.

The MSSVs will open at some setpoint around 1,000 psia and will have an offset of 3% to 6% associated with this setpoint. The saturation temperature for the setpoint with offsets becomes the discriminant for excluding certain reactor state points. If, when $T_{S.G.}$ is calculated for a state point, the value is greater than the saturation temperature for the opening of the MSSVs, the case is not considered.

B.2 Sample Case

The input for this CSLL confirmation case is given in Tables B.2 and B.3. The CSLLs used for this sample case are listed in Table B.3 and shown in Figure B.2[1]. The CSLLs can be based on inlet temperature or average temperature. The confirmation of the CSLLs is similar to that for the TM/LP, except that a single axial power shape is used. The design axial shape used for this sample case is shown in Figure B.3.

The nominal cases consist of combinations of pressure and power for the design axial. These cases are listed in Table B.4. The case with the largest change in power between the nominal case and the deterministic case was at 100% power, had an inlet temperature

[1] Except for 2,400 psia line.

of 619°F and a core exit pressure of 2,460 psia. This nominal case was used as the mean for the response surface calculation.

The response surface points covered the range from about 75% RTP to about 110% RTP.

The CSLL verification was performed using the nominal inputs, the rod shadowing statistics, the response surface output and the general input for the sample CSLL verification case in Tables B.2 and B.3.

The first step in checking the CSLL is to confirm that it protects against hot leg saturation. This check was performed over a range of powers from 25% RTP to 100% RTP, because this is the region where hot leg saturation is limiting. The temperature for the confirmation was extracted from the CSLL isobar corresponding to the pressure. In addition, in the course of checking the nominal cases, the power to DNB was compared to the power for hot leg saturation and the lower of the two was used to test the CSLLs.

The DNB response surface points were fit with a [

] was calculated. Figures B.4 and B.5 show the fit and the probability distribution for the DNB power,] respectively. The [

]

The intermediate steps for the processing of nominal case #69 are described below. This case has an inlet temperature of 577°F, a core exit pressure of 2,145 psia, a nominal DNB power of 3.274 MWt and a nominal CSLL power of 2,076 MWt. This case was chosen because it is limited by DNB and occurs in a region where the transition between the hot leg saturation and DNB portions of the CSLL can effect the shape of the probability densities, as can the isotherm for the inlet temperature.

[

]

[

]

Cases were tested to be sure that the MSSVs would not open. The margins for the cases that avoided opening the MSSVs were calculated. These ranged between 520 MWt and 2,232 MWt, demonstrating that the CSLLs would protect against DNB and hot leg saturation.

Table B.1 Uncertainties in CSLL Confirmation

Table B.2 Input for CSLL Confirmation: Sample Case

Table B.3 CSLLs for Sample Case

P=2400.0		P=2300.0		P=2200.0		P=2100.0		P=2000.0		P=1900.0		P=1800.0	
Q	T_{ave}	Q	T_{ave}	Q	T_{ave}	Q	T_{ave}	Q	T_{ave}	Q	T_{ave}	Q	T_{ave}
0.00	662	0.00	656	0.00	649	0.00	643	0.00	636	0.00	629	0.00	621
0.70	625	0.70	618	0.71	609	0.74	600	0.76	592	0.84	581	0.87	570
1.18	563	1.18	554	1.18	546	1.18	539	1.18	534	1.18	525	1.18	521

Table B.4 Nominal Cases for CSLL Confirmation

T_{inlet} (°F)	Pressure (psia)	Power (MWt)
619.01	2,460.0	2,775.0
613.18	2,355.0	2,775.0
607.65	2,250.0	2,775.0
602.13	2,145.0	2,775.0
596.63	2,040.0	2,775.0
590.99	1,935.0	2,775.0
616.56	2,460.0	2,824.9
610.74	2,355.0	2,824.9
605.17	2,250.0	2,824.9
599.60	2,145.0	2,824.9
593.95	2,040.0	2,824.9
588.27	1,935.0	2,824.9
614.05	2,460.0	2,874.9
608.21	2,355.0	2,874.9
591.35	2,040.0	2,874.9
597.03	2,145.0	2,874.9
602.63	2,250.0	2,874.9
585.54	1,935.0	2,874.9
611.70	2,460.0	2,924.8
605.81	2,355.0	2,924.8
594.43	2,145.0	2,924.8
588.65	2,040.0	2,924.8
600.14	2,250.0	2,924.8
582.83	1,935.0	2,924.8
609.31	2,460.0	2,974.7
603.40	2,355.0	2,974.7
591.90	2,145.0	2,974.7
597.70	2,250.0	2,974.7
586.06	2,040.0	2,974.7
580.09	1,935.0	2,974.7
594.97	2,460.0	3,274.4

Table B.4 Nominal Cases for CSLL Confirmation - continued

T_{inlet} (°F)	Pressure (psia)	Power (MWt)
597.38	2,460.0	3,224.4
588.84	2,355.0	3,274.4
606.88	2,460.0	3,024.7
599.75	2,460.0	3,174.5
602.09	2,460.0	3,124.6
591.24	2,355.0	3,224.4
564.31	1,935.0	3,274.4
582.89	2,250.0	3,274.4
570.57	2,040.0	3,274.4
576.72	2,145.0	3,274.4
593.67	2,355.0	3,174.5
604.48	2,460.0	3,074.6
600.93	2,355.0	3,024.7
573.11	2,040.0	3,224.4
566.88	1,935.0	3,224.4
579.24	2,145.0	3,224.4
585.29	2,250.0	3,224.4
596.09	2,355.0	3,124.6
581.79	2,145.0	3,174.5
575.69	2,040.0	3,174.5
587.76	2,250.0	3,174.5
569.47	1,935.0	3,174.5
590.27	2,250.0	3,124.6
598.53	2,355.0	3,074.6
584.28	2,145.0	3,124.6
595.21	2,250.0	3,024.7
583.47	2,040.0	3,024.7
578.22	2,040.0	3,124.6
572.07	1,935.0	3,124.6
586.78	2,145.0	3,074.6
592.70	2,250.0	3,074.6
580.83	2,040.0	3,074.6
589.32	2,145.0	3,024.7
574.73	1,935.0	3,074.6
577.39	1,935.0	3,024.7

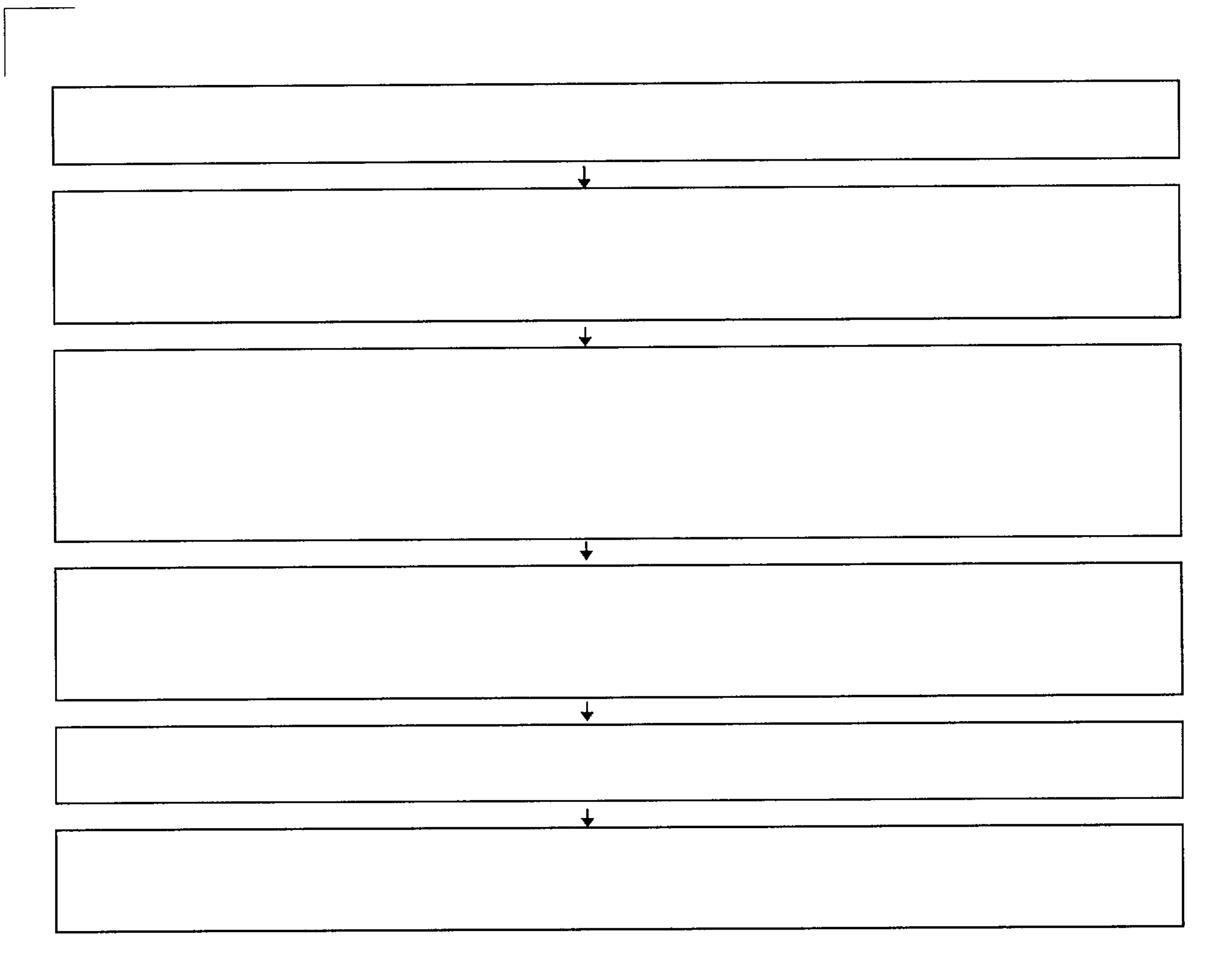

Figure B.1 Flow of CSLL Confirmation

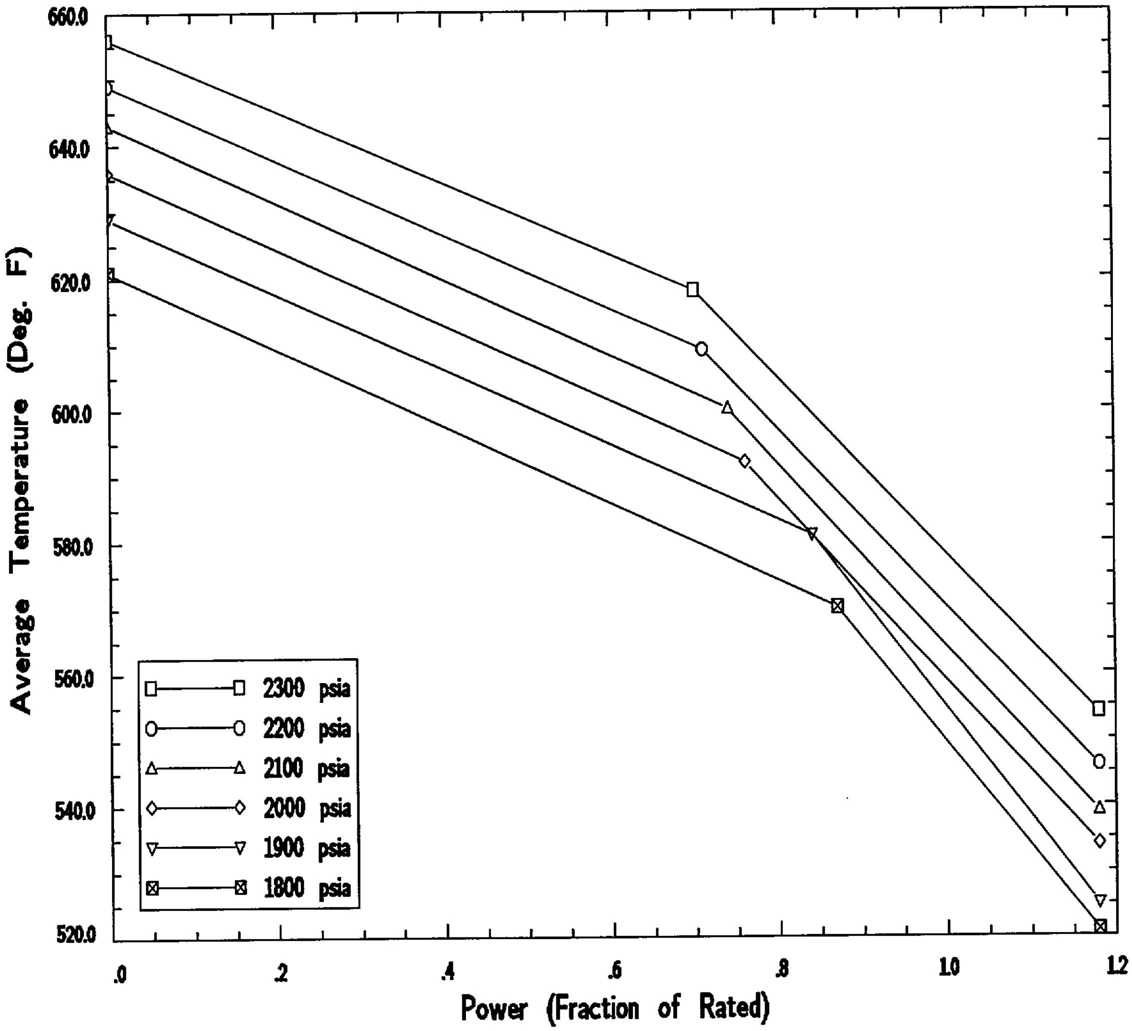

Figure B.2 CSLLs for Sample Case

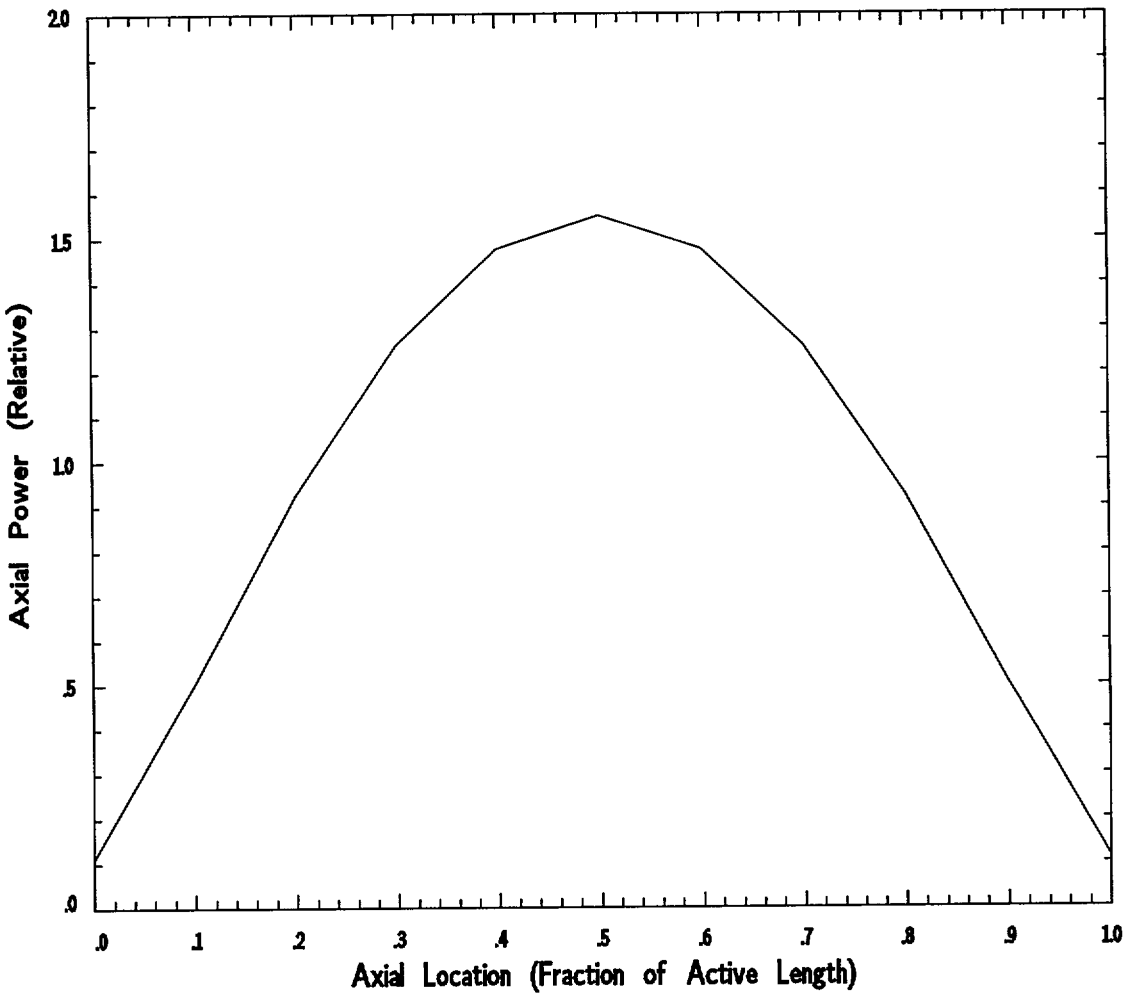

Figure B.3 Design Axial Power Shape for CSLL Confirmation - Sample Case

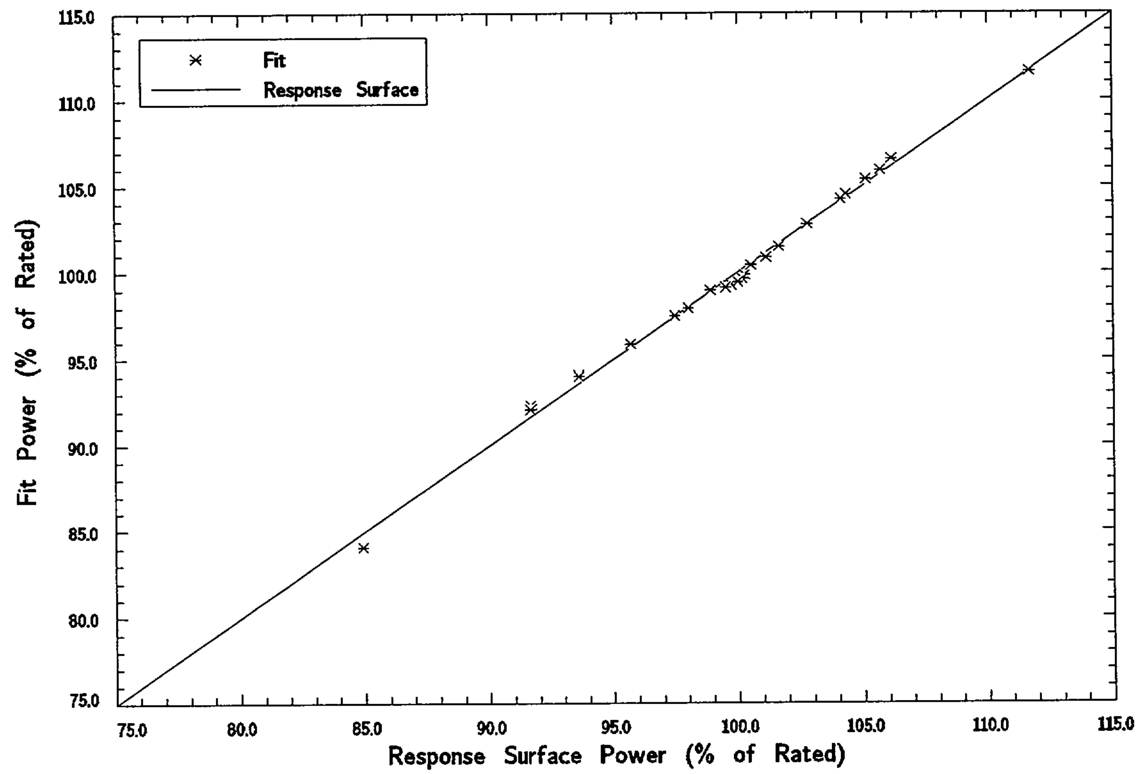

Figure B.4 Fit to DNB Response Surface for Sample Case

Figure B.5 Probability Distribution for Power From Response Surface

Figure B.6 Probability Distribution for Power

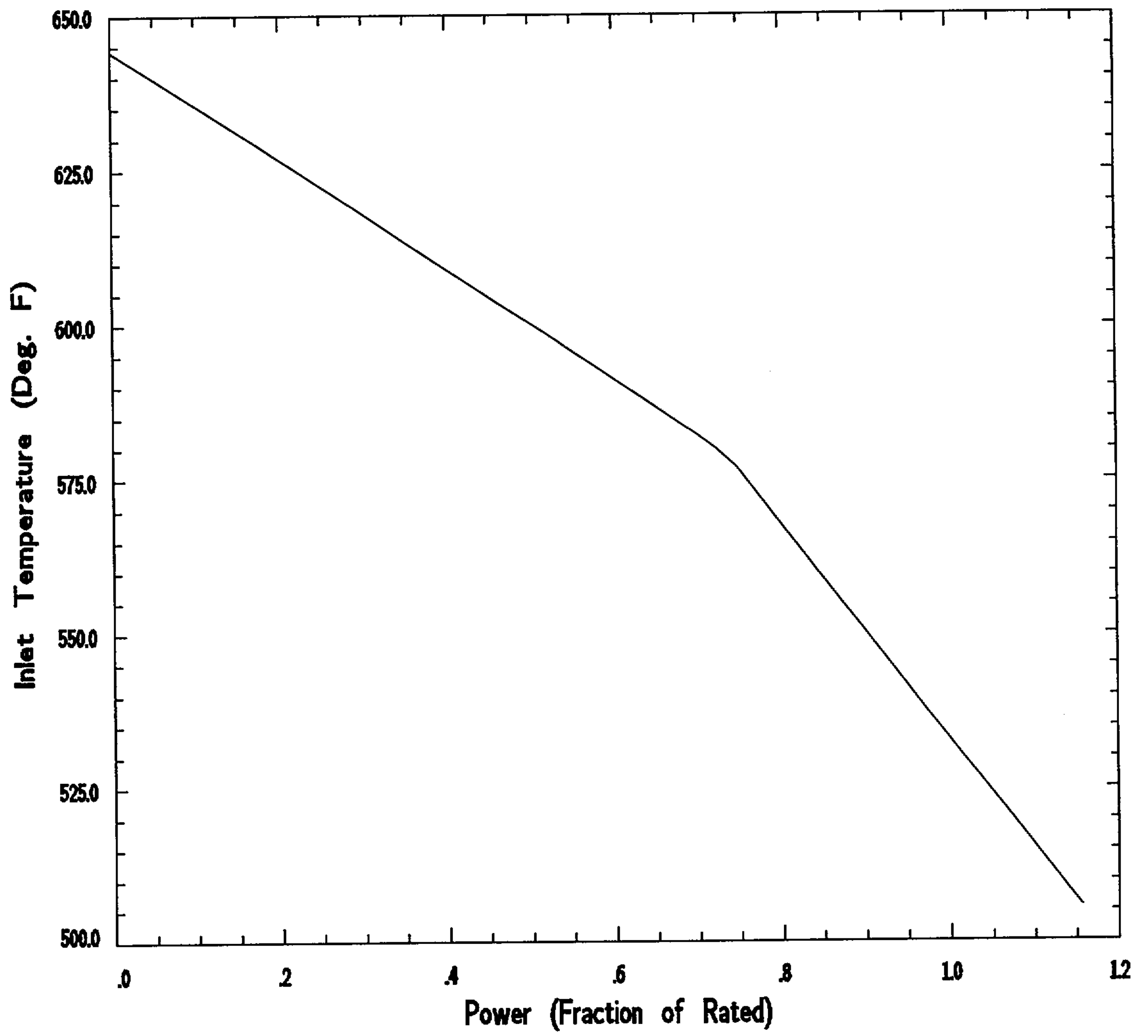

Figure B.7 Isobar at 2,120 psia

Figure B.8 Probability Density for Power From Temperature Uncertainty

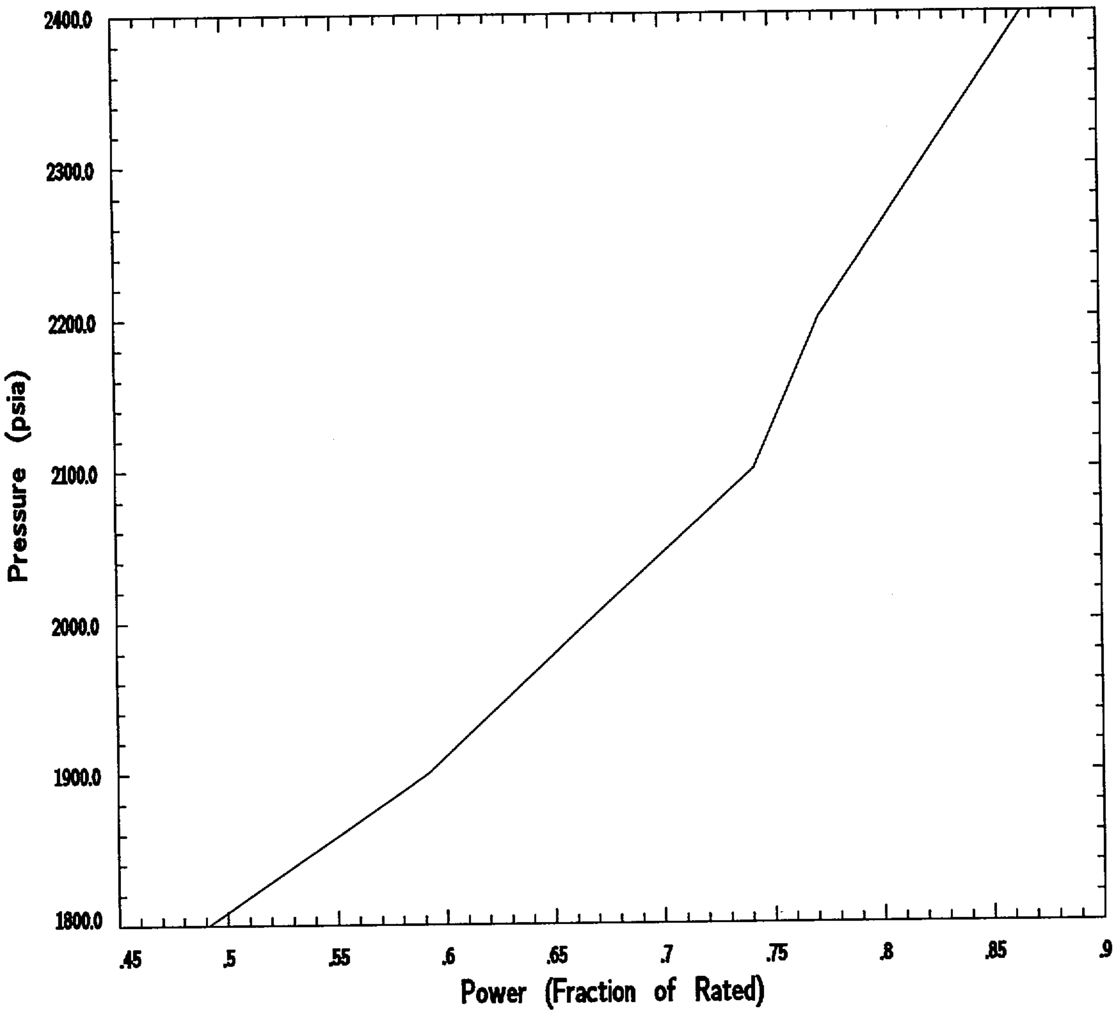

Figure B.9 Isotherm for 577°F

Figure B.10 Probability Density for Power From Pressure Uncertainty

Figure B.11 Overall Margin Adjustment for Sample Case