Proj. 702

SIEMENS

July 18, 2000
NRC:00:031

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

Publication of EMF-92-081(P)(A) Revision 1, "Statistical Setpoint/Transient Methodology for Westinghouse Type Reactors"

Ref.: 1. Letter, Stuart A. Richards (NRC) to James F. Mallay (SPC), "Acceptance for Referencing of Licensing Topical Report EMF-92-081(P), Revision 1, *Statistical Setpoint/Transient Methodology for Westinghouse Type Reactors* (TAC NO. MA4593)," February 10, 2000.

Enclosed are 15 copies of the proprietary and 12 copies of the nonproprietary version of the topical report EMF-92-081(P)(A) Revision 1, *Statistical Setpoint/Transient Methodology for Westinghouse Type Reactors.* In Reference 1, the NRC accepted this report for referencing and requested that SPC publish accepted proprietary and nonproprietary versions of the report. The enclosed copies of the published report are constructed in accordance with procedures established in NUREG-0390.

The affidavit provided with the original submittal of this topical report satisfies the requirements of 10 CFR 2.790(b) to support the withholding of the proprietary version of the report from public disclosure.

Very truly yours,

[signature]

for James F. Mallay, Director
Regulatory Affairs

/arn

Enclosures

cc: N. Kalyanam
Project No. 702

AP01
1|15 prop.
1|12 non-prop.

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Richland, WA 99352

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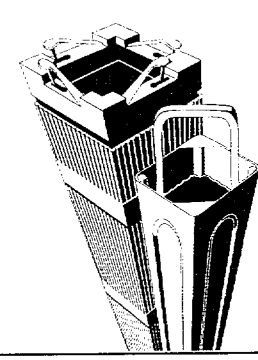
SIEMENS

EMF-92-081(NP)(A)
Revision 1

Statistical Setpoint/Transient Methodology for Westinghouse Type Reactors

February 2000



Siemens Power Corporation

Nuclear Division

Siemens Power Corporation

ISSUED IN SPC ON-LINE
DOCUMENT SYSTEM
DATE: 7/13/00

EMF-92-081(NP)
Revision 1

Issue Date:

Statistical Setpoint/Transient Methodology for Westinghouse Type Reactors

Prepared: ______________________ 12/22/98
W. T. Nutt Date
Safety Analysis Methods

/lmk

U.S. Nuclear Regulatory Commission
Report Disclaimer

Important Notice Regarding Contents and Use of This Document

Please Read Carefully

This technical report was derived through research and development programs sponsored by Siemens Power Corporation. It is being submitted by Siemens Power Corporation to the U.S. Nuclear Regulatory Commission as part of a technical contribution to facilitate safety analyses by licensees of the U.S. Nuclear Regulatory Commission which utilize Siemens Power Corporation fabricated reload fuel or technical services provided by Siemens Power Corporation for light water power reactors and it is true and correct to the best of Siemens Power Corporation's knowledge, information, and belief. The information contained herein may be used by the U.S. Nuclear Regulatory Commission in its review of this report and, under the terms of the respective agreements, by licensees or applicants before the U.S. Nuclear Regulatory Commission which are customers of Siemens Power Corporation in their demonstration of compliance with the U.S. Nuclear Regulatory Commission's regulations.

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Siemens Power Corporation

EMF-92-081(NP)
Revision 1

Statistical Setpoint/Transient Methodology for Westinghouse Type Reactors

Concurred: ____________________ 12/22/98
L. E. Hansen, Manager
Customer Projects
Date

Concurred: ____________________ 12/22/98
J. S. Holm, Manager
Product Licensing
Date

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

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

Approved: ____________________ 12/22/98
D. M. Brown, Manager
PWR Neutronics
Date

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

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

February 10, 2000

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

SUBJECT: ACCEPTANCE FOR REFERENCING OF LICENSING TOPICAL REPORT EMF-92-081, REVISION 1, "STATISTICAL SETPOINT/TRANSIENT METHODOLOGY FOR WESTINGHOUSE TYPE REACTORS," (TAC NO. MA4593)

Dear Mr. Mallay:

The staff has completed its review of the subject topical report submitted by Siemens Power Corporation (SPC) by letter dated December 21, 1998. On the basis of our review, the staff finds the subject report to be acceptable for referencing in license applications to the extent specified, and under the limitations delineated in the report, and in the enclosed safety evaluation (SE). The SE 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 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.

The staff will not repeat its 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, the NRC requests that SPC publish accepted versions of this report, including the safety evaluation, in proprietary and non-proprietary forms 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. The accepted versions shall also incorporate all communications between SPC and the staff during this review.

Should our criteria or regulations change so that our conclusions as to the acceptability of the report are no longer valid, 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 report 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

RELATING TO SIEMENS POWER CORPORATION LICENSING TOPICAL REPORT

EMF-92-081(P), REVISION 1,

"STATISTICAL SETPOINT/TRANSIENT METHODOLOGY

FOR WESTINGHOUSE TYPE REACTORS"

1.0 INTRODUCTION

By letter dated December 21, 1998, Siemens Power Corporation (SPC) proposed to revise the methodology used for statistical setpoint and transient analysis of Westinghouse type reactors (Ref. 1). The revised methodology incorporates new ways to statistically combine the uncertainties in the trip setpoints and limiting conditions of operation (LCOs). Additionally, a new methodology for calculating trip setpoints and verifying trip systems during transients is described. These changes to the setpoint methodology will facilitate automating the methodology, decreasing the user effect and the potential for introducing user errors.

This safety evaluation (SE) evaluates the changes incorporated into the methodology and will not reiterate the findings of the previous SE for the methodology that is unchanged.

2.0 METHODOLOGY CHANGES

The licensee requested approval for revising the statistical setpoint and transient analysis methodology previously approved for Westinghouse type reactors. The revision describes in greater detail how SPC confirms departure from nucleate boiling (DNB), fuel centerline melt (FCM), and hot-leg saturation protection, and incorporates new ways to combine the uncertainties of those calculations.

Overpower Delta Temperature (OPΔT) Reactor Trip Setpoint

The OPΔT setpoint provides 95 percent probability at a 95 percent confidence level that fuel melt will not occur during transients and anticipated operational occurrences (AOOs.) The form of the OPΔT setpoint trip is the same as used by Westinghouse (Ref. 2). The methodology used in determining coefficients K4 and K6 was not revised by this submittal.

To calculate the setpoint coefficients, a 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 linear heat generation rate (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 (Refs. 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. Revising the methodology facilitates automation of the calculation process and reducing the user effect on the calculation results.

The trip reset function is designed to accommodate events when the axial power shape distribution undergoes large changes resulting in core power distributions which have a total peaking in excess of Fq. This function is part of the OPΔT trip function. It compensates the setpoint value when the actual difference between the normalized fluxes from the top and bottom detectors of the power range nuclear ion chambers (ΔI) differs from the assumed value. Multiple axial shapes are used in determining the reset function so all potential axial shapes which could result in a peaking in excess of Fq are included in the calculation. Since the OPΔT trip equation is expressed in terms of core ΔT, the FCM power level probabilities for the axial shapes of interest are also converted into an expression for core ΔT. This calculation is performed at minimum pressure to maximize the core ΔT over the power level probability distribution. The minimum reset function can be expressed in terms of the core ΔT and the FCM core ΔT. A bounding reset function is determined which will prevent FCM for all axial shapes. This bounding reset function accounts for the uncertainties included in the calculation of the OPΔT reset function including the uncertainty in ΔI and protects against FCM with a 95/95 confidence protection.

The methods used to confirm the OPΔT trip are now included in the topical report. Previous versions stated that the confirmation had been performed but the methodology used for confirming the trip was not described. This confirmation methodology is used when the coefficients and reset function are known, i.e., when they are provided to SPC or are known from a previous calculation. It takes credit for the protection provided by the overtemperature delta temperature (OTΔT) trip function and main steam safety valves (MSSVs) by excluding operational areas where these actions protect from FCM. The confirmation is performed in two parts. First, the nominal margin is calculated, the difference between the trip and the limit using all variables at their nominal values. Then, the nominal margin is adjusted for uncertainties to obtain the statistically adjusted margin. The statistically adjusted margin between the trip power and the FCM power is verified to be positive with at least a 95 percent probability at a 95 percent confidence level.

Overtemperature Delta Temperature (OTΔT) Reactor Trip Setpoint

The OTΔT reactor trip setpoint provides 95/95 confidence that neither DNB nor hot-leg saturation will occur during normal operation, operational transients, and AOOs. The AOOs that the OTΔT trip protects against are uncontrolled power ascension and a core power redistribution. The form of the OTΔT setpoint trip is the same as used by Westinghouse. This revision does not include a change in the methodology used to determine the trip coefficients.

To confirm core safety limit lines (CSLLs), a set of OTΔT trip coefficients are calculated which bound the CSLLs. This determination is made by plotting the CSLLs as functions of core

average temperature and ΔT for each pressure and finding the trip coefficient values that will actuate the OTΔT trip before the CSLLs are reached.

The trip reset function is designed to protect against axial power shapes that are more limiting then design axial power shape. This function is part of the OTΔT trip function. It reduces the value of the trip point to reflect an increase in the hot channel factors which could result in localized DNB. Multiple axial shapes are considered for the determination of the reset function and the axial shapes that yield the minimum departure from nucleate boiling ratio (DNBR) are chosen for inclusion in the calculation. The response surface for the core ΔT most sensitive to uncertainties is determined from deterministic and nominal calculation results. The range of conditions considered in the calculation include those that are within the allowed pressure and are not excluded by the MSSV limit and saturation line curves. The margin at the most sensitive points is determined to define the statistical core ΔT penalty for DNB conditions. This penalty is shown as a ΔT uncertainty adjustment probability table in which each uncertainty parameter is explicitly modeled.

The methods used to confirm OTΔT DNB protection are described in the report. Previous topical reports stated that the confirmation could be performed but they did not provide the methodology for confirming OTΔT. This confirmation methodology is used when the coefficients and reset function are known, i.e., when they are provided to SPC or are known from a previous calculation. This methodology demonstrates that the margin between the power corresponding to DNB or hot-leg saturation and the trip is positive. To begin the calculation, the DNB-limiting axial power shapes are found and reduced to a representative group. Nominal and deterministic power cases corresponding to DNB are used to calculate the most sensitive point. This point is used to develop a probability distribution in power at DNB which includes uncertainties in the radial peaking factor, the engineering factor, and DNBR correlation, and the flow. In calculating the trip function, the uncertainties are all converted to power and combined to create a probability distribution in the trip margin. These uncertainties include the loop temperatures, the reactor coolant system (RCS) pressure, and the ΔI. The trip margin and power at DNB probability distributions are combined to create a probability distribution in the margin. This margin between the power corresponding to DNB or hot-leg saturation and the trip is verified to be positive with at least a 95 percent probability at a 95 percent confidence level and confirms that there is at least a 95/95 confidence of protection from DNB.

Statistical Transient Analysis Methodology

The statistical transient analysis provides 95 percent probability at a 95 percent confidence limit for protecting the specified acceptable fuel design limits (SAFDLs) and pressure limits.

The calculation of the trip setpoint follows a similar calculation path as the OPΔT and OTΔT trip setpoints. Transient analysis is 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 (Ref 5). 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 trip setpoint, the plant specific uncertainties from the trip uncertainty are included in the probability distribution. The combination of the two probability distributions can be performed by either of

two methods. The resultant probability distribution is compared to the results of the Monte Carlo run and the most limiting of the two calculations that will prevent transient limit violation with 95 percent probability at a 95 percent confidence level is selected at the technical specification (TS) limit. The statistical trip value is used as the TS limit in cases where the trip is either the OPΔT or OTΔT trip, and the setpoints were calculated based on the setpoint analysis. The trip setpoint calculation is performed using the same methodology for DNB, FCM, and system pressure to determine the 95/95 probability confidence trip setpoint.

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 method used to demonstrate that the overall probability distribution difference between the calculated setpoint parameter and the limit will protect the limit follows the same methodology scheme as confirming the OPΔT and OTΔT trips. For DNB, the parameters affecting the transient system behavior and minimum departure from nucleate boiling ration (MDNBR) are varied. The margin is obtained by subtracting the DNBR value that corresponds to DNB from the calculated MDNBR. This margin is verified to be positive with at least a 95/95 confidence and accounts for the uncertainties in the calculations. This methodology to confirm at least a 95/95 confidence between the calculated trip and the limit is performed for DNB, FCM, peak kW/ft 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.

Neutronics Analysis

This section has not been revised.

3.0 EVALUATION

The SPC revision to the methodology for the OPΔT and OTΔT trips, and the statistical analysis uses statistical and probabilistic methods that are standard textbook techniques that are applied in a consistent manner. These techniques use standard statistical techniques of combining 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 (Ref. 5.) The new techniques that are used, compared to the previously approved methodology, for combining the uncertainties incorporated into the setpoint methodology, are statistically valid applications which allow SPC to automate the methodology. This determination was made 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 confirms the core safety limit lines, and extends the transient methodology to postulated accidents and events which have no trip, and therefore,

adds additional safety verification to the overall methodology. Incorporating protection of the secondary system pressure limit into the transient methodology also adds conservatism.

4.0 CONCLUSIONS

Based on our 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 December 7, 1999 (Ref. 6):

1. 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.

2. The steam generator safety valve (SGSV) limit line provides an upper limit on the temperature range for setpoint verification. The upper limit on the temperature range should be adjusted to reflect the steam generator plugging level.

5.0 REFERENCES

1. Letter from James F. Mallay (SPC) to the U.S. Nuclear Regulatory Commission, submitting Topical Report EMF-92-081(P), Revision 1, "Statistical Setpoint/Transient Methodology for Westinghouse Type Reactors," December 21, 1998.

2. Siemans Power Corporation Topical Report, EMF-92-081(P), Revision 0 and Supplement 1, "Statistical Setpoint/Transient Methodology for Westinghouse Type Reactors," February 1994.

3. Exxon Nuclear Methodology for "RODEX2 Fuel Rod Thermal Mechanical Response Evaluation Model," XN-NF-81-58(P)(A), Revision 2 and Supplements 1 and 2, March 1984.

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

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

6. Letter from James F. Mallay (SPC) to the U.S. Nuclear Regulatory Commission, Conditions for Topical Report EMF-92-081(P), Revision 1, "Statistical Setpoint/Transient Methodology for Westinghouse Type Reactors," December 7, 1999.

Principal Contributor: U. Shoop

Date: February 10, 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

bc: (via e-mail)
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File/LB

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)

Siemens Power Corporation

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

September 28, 1999

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

SUBJECT: REQUEST FOR ADDITIONAL INFORMATION - SIEMENS TOPICAL REPORT, EMF-92-081 REVISION 1, "STATISTICAL SETPOINT/TRANSIENT METHODOLOGY FOR WESTINGHOUSE REACTORS" (TAC NO. MA4593)

Dear Mr. Mallay:

By letter dated December 21, 1998, the Siemens Power Corporation submitted Topical Report EMF-92-081, "Statistical Setpoint/Transient Methodology for Westinghouse 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

WESTINGHOUSE TYPE REACTORS

REQUEST FOR ADDITIONAL INFORMATION

1. Page 2-3, equation

   It is stated that K_6 becomes the adjustment for the nonlinear relationship between power and delta T. Please describe how K_6 provides the adjustment for nonlinear relationship and explain if the coefficient is calculated at each state point or if one value of the coefficient is determined.

2. Page 2-5, first paragraph

   Please define the parameters which feed into the peaking measurement uncertainty and engineering tolerance factors.

3. Page 2-7, Section 2.4

   Please describe the situation where the design value for the peaking can be exceeded and explain why the design value can be exceeded.

4. Page 2-9, last paragraph

   Please provide additional details on how the probability density for delta measurement is converted into a probability density in the reset function.

5. Page 2-10, Section 2.5

   It is stated that the dynamic compensation term is confirmed by transient analysis. Please describe the transient analysis performed to confirm the compensation term.

6. Page 2-11, fourth paragraph

   It is stated that in the confirmation of the OPΔT, a scan is performed to locate the minimum margin. Please describe how the scan is performed and if a matrix of the parameters used in the scan is generated, please provide it.

7. Page 2-12, Section 2.6.2

   Please explain (provide technical justification) how the scaling of the fuel centerline melt power is performed. Additionally, please explain how the peaking and engineering uncertainties were evaluated.

8. <u>Page 2-13, first paragraph</u>

Please provide details on how the trip channel uncertainty was obtained.

9. <u>Page 2-14, last paragraph</u>

Two methods of including the delta I uncertainty are described. Please provide details on which method is used in this analysis. Also, please provide details on what the bounding approximation is when it is used in calculations.

10. <u>Page 3-1, last paragraph</u>

The last sentence on the page references XCOBRA-IIIC. Please provide a reference for this approval and details of the uses this code was approved to perform.

11. <u>Page 3-7, third paragraph</u>

It is stated that a less conservative approach may be used if the conservatism resulting from the most sensitive point is unacceptably large. Please provide the definition of unacceptably large. Also, please quantify the frequency of the most sensitive point resulting in an unacceptably large conservatism.

12. <u>Page 3-9, fourth paragraph</u>

It is stated that in some cases the deterministic adjustment can be used instead of the statistical adjustment. Please provide additional details on the necessary criteria for using the deterministic method and quantify how frequently the deterministic adjustment is used. Since the statistical adjustment is the bounding adjustment, demonstrate how SPC ensures that using the deterministic adjustment will not violate the 95/95 confidence limit for avoiding DNB.

13. <u>Page 3-18, fourth paragraph</u>

It is stated that the hot leg saturation is no analog to the response surface uncertainties. Please explain what this statement means.

14. <u>Page 4-3/4-4, last paragraph continuing onto the next page</u>

It is stated that the 95/95 confidence uncertainty-adjusted trip is determined from the probability distribution described in the preceding paragraphs or taken from the Monte Carlo run. Please provide additional details or demonstrate when each method is used.

15. <u>Page 4-4, last paragraph</u>

Please present both methods of calculating the response surface; the method presented on page 4-4 and the more conservative (stated as unnecessary conservative assumption) method mentioned. Also, please explain how the more conservative method is unnecessary.

16. <u>Page 4-5, second paragraph</u>

It is stated that a set of nominal trips is selected for evaluation of the probability density based on each trip. Please explain how the set of nominal trips is selected.

17. <u>Page 4-5, fourth paragraph</u>

It is stated that to confirm the margin to DNB, the experimental design can vary the system parameters, trips, and LCOs. Please provide additional details.

18. <u>Page 4-13, third paragraph</u>

It is stated that the probability of having no margin to DNB is about 1.86 percent and therefore, no fuel failure by DNB is predicted. Please explain or demonstrate the calculation for this probability.

19. <u>Page B-19, Figure B.8</u>

Please explain the method used to generate this figure.

SIEMENS

October 4, 1999
NRC:99:043

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-92-081(P) Revision 1, "Statistical Setpoint/Transient Methodology for Westinghouse Type Reactors"

Ref.: 1. Letter, N. Kalyanam (NRC) to James F. Mallay (SPC), "Request for Additional Information – Siemens Topical Report, EMF-92-081 Revision 1, "Statistical Setpoint/Transient Methodology for Westinghouse Reactors (TAC NO. MA4593)," 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, Director
Regulatory Affairs

/arn

Attachment

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

Siemens Power Corporation

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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 [

]

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.

[

]

LPD LCO – 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.

DNB LCO – 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.

TM/LP – 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 Westinghouse Type Reactors

1. Pg. 2-3, equation,

It is stated that K_6 becomes the adjustment for the nonlinear relationship between power and delta T. Please describe how K_6 provides the adjustment for nonlinear relationship and explain if the coefficient is calculated at each state point or if one value of the coefficient is determined.

The note was provided as a way of clarifying the constants. The trip protects against FCM. FCM is determined by the power and the F_Q. When using the technical specification limit for F_Q, the power is the principal determinant of the peak LHGR, and thereby the FCM. Power is not proportional to ΔT. It is proportional to the change in enthalpy. Temperature changes are not proportional to enthalpy changes, they behave more like enthalpy carried to the 0.4 power. As the average temperature rises, the ΔT corresponding to a specific power decreases. By subtracting a term proportional to the average temperature, the OPΔT can produce a better representation of power. Multiplying K_6 by the change in average temperature accounts for the non-linear relationship between power and ΔT. There is only one value determined for K_6.

2. Pg. 2-5, first paragraph,

Please define the parameters which feed into the peaking measurement uncertainty and engineering tolerance factors.

Peaking measurement uncertainties were determined based on a series of core measurements and predictions. This value is a part of the neutronics methodology and the value is reported as a part of that submittal: EMF-96-029(P)(A). The values of the uncertainties can change if changes are made in the neutronics methodology.

The engineering tolerance uncertainty is made up of the following components:

3. **Pg. 2-7, Section 2.4,**

Please describe the situation where the design value for the peaking can be exceeded and explain why the design value can be exceeded.

The OPΔT trip without the reset function can protect against FCM for any shape not resulting in an F_Q which exceeds the design value. During a xenon oscillation, the axial power shapes can change dramatically and can result in shapes that, even though they do not exceed the radial peaking limits, can exceed the total peaking limit. The reset function was designed to modify the trip ΔT to account for this potential. Since this is a trip designed to intervene when the plant is operating outside of the normal LCOs (including the F_Q limit), it cannot rely on the total peaking factor to remain within the Technical Specification limits. This trip function does not cover cases for which the radial peaking factor exceeds the Technical Specification limits. These need to be addressed by transient analysis.

4. **Pg. 2-9, last paragraph,**

Please provide additional details on how the probability density for delta measurement is converted into a probability density in the reset function.

The axial offset of the shape being considered is multiplied by the nominal (measured) power at the trip to convert it to the correct ΔI value. The reset function typically has a value of zero over a range of ΔI from −20% to 20%. Outside that range, it changes at the rate of about 2% per 1% change in ΔI outside this central "deadband." The conversion of the uncertainty in ΔI to an uncertainty in the reset function is relatively simple.

[

]

5. **Pg. 2-10, Section 2.5,**

It is stated that the dynamic compensation term is confirmed by transient analysis. Please describe the transient analysis performed to confirm the compensation term.

The transient used to check dynamic compensation term is a linear power ramp. The overall trip performance is also tested during events like a slow, uncontrolled, bank withdrawal. The linear ramp case simulates a slow heatup of the primary caused a linear power excursion. The RTD responses are simulated and used to drive a full, dynamically-compensated trip. As the transient proceeds, the trip setpoint decreases in response to the changes in temperature and the dynamic compensation term until it is less than or equal to the measured ΔT.

The heat flux in the core is used to calculate a static ΔT and a T_{AVE} corresponding to the power. The T_{AVE} is used to calculate a "static" trip value, which is compared to the static ΔT. As the transient proceeds, the setpoint moves slightly and the static ΔT moves up until it matches the trip setpoint.

If the dynamically-compensated trip occurs before the static trip, the dynamic compensation is sufficient to provide protection.

6. **Pg. 2-11, fourth paragraph,**

It is stated that in the confirmation of the OPΔT, a scan is performed to locate the minimum margin. Please describe how the scan is performed and if a matrix of the parameters used in the scan is generated, please provide it.

[

]

7. **Pg. 2-12, Section 2.6.2,**

Please explain (provide technical justification) how the scaling of the fuel centerline melt power is performed. Additionally, please explain how the peaking and engineering uncertainties were evaluated.

The peaking factor and engineering factor uncertainties are applied to F_Q as multiplicative factors.

$$F_{Q,adj} = f_Q \cdot (1 + f_{pk}) \cdot (1 + f_{eng})$$

The power at FCM is given by the following expression

$$Q_{FCM} \equiv \frac{LHGR_{FCM} \cdot Q_{Rated}}{LHGR_{RATED}^{AVERAGE} \cdot F_{Q,adj}}$$

Defining the nominal power at FCM as

$$Q_{FCM,nom} \equiv \frac{LHGR_{FCM} \cdot Q_{Rated}}{LHGR_{RATED}^{AVERAGE} \cdot F_Q}$$

yields the expression in Section 2.6.2,

$$Q_{FCM} = \frac{Q_{FCM,nom}}{(1+f_{pk}) \cdot (1+f_{eng})}$$

The nominal power at FCM will not vary if the value of F_Q is fixed at the Technical Specification limit. When the axial power shapes are being processed to confirm the reset function, the power at FCM varies. To simplify the effort, [

]

8. Pg. 2-13, first paragraph,

Please provide details on how the trip channel uncertainty was obtained.

Trip channel uncertainty can be composed of contributions from the variations in the average temperature, the uncertainty from the calorimetric for power, uncertainties from the trip channel hardware, reproducibility/drift uncertainties in the trip channel hardware and ΔI measurement uncertainties. Generally, Westinghouse combines all of these sources in a single, overall channel uncertainty using the Z-R-S methodology. The uncertainty is applied directly to the K_4. When this latter form is available, it is used directly.

9. Pg. 2-14, last paragraph,

Two methods of including the delta I uncertainty are described. Please provide details on which method is used in this analysis. Also, please provide details on what the bounding approximation is when it is used in calculations.

When ΔI measurement uncertainty is included as a constant value in the overall channel uncertainty, it has to be a bounding value. One way to do this is to use the maximum slope (absolute value) of the reset function to convert the ΔI measurement uncertainty to an uncertainty in K_4. The method shown on page 2-15 is an "exact" method for including the ΔI measurement uncertainty. It still potentially suffers from the limitations inherent in the knowledge of the ΔI measurement uncertainty and its distribution and it is a numerical integration.

10. Pg. 3-1, last paragraph,

The last sentence on the page references XCOBRA-IIIC. Please provide a reference for this approval and details of the uses this code was approved to perform.

XCOBRA-IIIC has been approved for use in evaluating core flow distributions and calculating DNBRs. Its use in statistical setpoints was approved for C-E plants and for Westinghouse plants. The following documents relate to the use of XCOBRA-IIIC in setpoints and transients and have been reviewed and approved for use by the NRC.

"Application of Exxon Nuclear Company PWR Thermal Margin Methodology to Mixed Core Configurations," XN-NF-82-21(P)(A), Revision 1, September 1983.

This submittal described the use of a detailed, two-pass model to calculate MDNBR.

"ENC Setpoint Methodology for C. E. Reactors: Statistical Setpoint Methodology," XN-NF-507(P)(A) & Supplements 1&2, September 1986.

This submittal described the use of XCOBRA-IIIC in an iterative mode for determining the power, pressure or temperature corresponding to DNB. The application to the TM/LP, the CEA drop and the Loss-of-Coolant-Flow accident was described.

"Statistical Setpoint/Transient Methodology for Westinghouse Type Reactors," EMF-92-081(P)(A) & Supplement 1, February 1994.

The submittal described the use of XCOBRA-IIIC in the analysis of the OTΔT trip for a Westinghouse plant and in the statistical analysis of transients.

11. Pg. 3-7, third paragraph,

It is stated that a less conservative approach may be used if the conservatism resulting from the most sensitive point is unacceptably large. Please provide the definition of unacceptably large. Also, please quantify the frequency of the most sensitive point resulting in an unacceptably large conservatism.

Unacceptably large means that for one or more cases, margin cannot be demonstrated using the conservative response surface. As noted, the choice of using a single response surface that would produce the most conservative statistics was made to save work. It is bounding. The

intent of this paragraph was to make clear that doing the full analysis was always an option and that describing the simplification of using the most bounding response surface did not preclude use of multiple response surfaces.

Since SPC started using this approach for C-E plants in 1982, the need to evaluate a point separately has occurred quite infrequently.

12. Pg. 3-9, fourth paragraph,

It is stated that in some cases the deterministic adjustment can be used instead of the statistical adjustment. Please provide additional details on the necessary criteria for using the deterministic method and quantify how frequently the deterministic adjustment is used. Since the statistical adjustment is the bounding adjustment, demonstrate how SPC ensures that using the deterministic adjustment will not violate the 95/95 confidence limit for avoiding DNB.

This paragraph reserves the option to limit the maximum statistical adjustment to a point to be less than the deterministic adjustment to that point. If the deterministic adjustment is less than the statistical adjustment it would be used. This has never happened.

The deterministic adjustment will always be greater than the 95/95 limit simply because all of the uncertainties are "stacked." It will also be larger than the statistical adjustment, provided the statistical adjustment does not have too many conservatisms added. The use of a bounding response surface could potentially result in a statistical adjustment to the nominal value that is larger than the deterministic value.

13. Pg. 3-18, fourth paragraph,

It is stated that the hot leg saturation is no analog to the response surface uncertainties. Please explain what this statement means.

This should read "...has no analog ...." The statement means that the point of hot-leg saturation does not have to be treated statistically.

14. Pg. 4-3/4-4, last paragraph continuing onto the next page,

It is stated that the 95/95 confidence uncertainty-adjusted trip is determined from the probability distribution described in the preceding paragraphs or taken from the Monte Carlo run. Please provide additional details or demonstrate when each method is used.

In cases where a code is available to perform the numerical integration, it would be used. In other cases, a Monte Carlo simulation would be used. At present, computer codes are not available to do this portion of the analysis and Monte Carlo simulation will be used in the near term. As computer codes are written and verified against the Monte Carlo method, they may replace the Monte Carlo simulations.

15. Pg. 4-4, last paragraph,

Please present both methods of calculating the response surface; the method presented on page 4-4 and the more conservative (stated as unnecessary conservative assumption) method mentioned. Also, please explain how the more conservative method is unnecessary.

The conservative method is not unnecessary. The assumption that other trips cannot intervene is unnecessarily conservative to demonstrate the efficacy of the trip system and LCOs.

If an event is being analyzed to set a specific trip, the other trips should be ignored. If the analysis is being performed to satisfy the requirements of the Standard Review Plan, the ensemble of trips available may be considered. Transient analysis is usually performed to demonstrate acceptable performance for the entire Reactor Protection System and LCOs. The last paragraph describes the general approach for taking more than one trip into consideration. The discussion in the preceding section (Section 4.1) focussed on calculating the value of a setpoint such that it would provide protection by itself. The section on multiple trip setpoints addresses calculating setpoints for multiple trips at the same time. The issue of multiple trips is considered because for many transients, several trips may be candidates for trip protection. Each of these could be set to provide the protection individually. Since limit protection is provided in the aggregate, setting each trip to provide the protection by itself provides a higher probability of protection than required.

[

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16. Pg. 4-5, second paragraph,

It is stated that a set of nominal trips is selected for evaluation of the probability density based on each trip. Please explain how the set of nominal trips is selected.

The process for selecting nominal trips is iterative. A set is selected and the probability calculated for each trip using the probability distribution created for that trip from the response surface calculation. These probabilities are combined to determine the probability of a trip. Other preferences and/or criteria would be used to select the set. As an example, the licensee may not want the high flux trip to be greater than 109% of rated power. Thus, when searching for the correct set of trips, nominal high flux trips greater than 109% would not be considered. Since there are an infinite number of sets of trips that will provide protection at the 95/95 limit, the final set will be a semi-optimized set, reflecting the best set for plant operation that still provides the required protection.

In addition, one or more of the trips may enter into other events. The nominal trip setting would be set to provide the protection for all events.

17. Pg. 4-5, fourth paragraph,

It is stated that to confirm the margin to DNB, the experimental design can vary the system parameters, trips, and LCOs. Please provide additional details.

The first step in this process is to create a set of input files for the transient code. Each of these files simulates the same event but each has a different set of assumptions regarding the system parameters (e.g. pressure, pressurizer level, primary temperature, safety and relief valve setpoints and capacities), the trips (OTΔT, OPΔT, high flux, low flow, pressurizer pressure, etc.) and the LCOs (e.g. flow). The pattern of variation (experiment design) depends on the number of input parameters being varied. The variations in each parameter cover a range (around $\pm 2\sigma$) with several points.

Each of the cases is run and the figure of merit extracted. For DNB, there are four values extracted: heat flux, exit pressure, core flow and inlet temperature. For FCM, the power is the figure of merit. For over-pressurization, the figures of merit are the primary or secondary pressures and the pressurizer level.

For over-pressurization, the upper 95/95 limit can be calculated directly by fitting the calculated points (pressure or level) with a polynomial in the parameters that were varied and evaluating the resulting fit using a Monte Carlos code. This process is described in GSUAM and has been used by SPC for calculating probability distributions of margins in pressure and power for C-E plants.

For FCM, the fit process is the same (except the fit variable is power, not pressure) and the Monte Carlo simulation combines the peaking and engineering uncertainties with the response surface for power.

[

]

18. Pg. 4-13, third paragraph,

It is stated that the probability of having no margin to DNB is about 1.86 percent and therefore, no fuel failure by DNB is predicted. Please explain or demonstrate the calculation for this probability.

The formulation described in Section 4.4.1 was used for the sample case. [

]

19. Pg. B-19, Figure B.8,

Please explain the method used to generate this figure.

The description of the transformation of temperature and power uncertainties is given on page B-3. The curve in Figure B.8 is $f_{Q,T}$. The subscript denotes the uncertainty in power coming from the uncertainty in temperature. [

]

[

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SIEMENS

December 7, 1999
NRC:99:051

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-92-081(P) Revision 1, "Statistical Setpoint/Transient Methodology for Westinghouse Type Reactors"

Ref.: 1. Letter, James F. Mallay (SPC) to Document Control Desk, "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,'" NRC:98:086, December 21, 1998.

The attachment to this letter provides a list of conditions proposed for the approved application of statistical setpoint/transient methodology for Westinghouse type plants described in the topical report submitted to the NRC by Reference 1. Siemens Power Corporation finds these conditions acceptable and appropriate.

Very truly yours,

James F. Mallay, Director
Regulatory Affairs

/arn

Attachment

cc: U. S. Shoop (w/attachment)
N. Kalyanam (w/attachment)
Project No. 702

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Proposed SER Conditions for EMF-92-081(P) Revision 1, "Statistical Setpoint/Transient Methodology for Westinghouse Type Reactors"

1. 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.

2. The steam generator safety valve (SGSV) provides an upper limit on the temperature range for setpoint verification. The upper limit on the temperature range should be adjusted to reflect the steam generator plugging level.

EMF-92-081(NP)(A)
Revision 1

Statistical Setpoint/Transient Methodology for Westinghouse Type Reactors

December 1998

Nature of Changes

Item	Paragraph or Page(s)	Description and Justification
1.	None	This is a complete revision of an existing document.

Contents

Tables

Figures

Distribution

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R. E. Collingham
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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 report describes Siemens Power Corporation's (SPC's) methodology for statistical setpoint and transient analyses. SPC's methodology consists of statistical development and confirmation of the reactor trips used in Westinghouse-type pressurized water reactors (PWRs). The statistical treatment is an extension of the Generic Statistical Uncertainty Analysis Methodology (GSUAM) described in Reference 1 and in Appendix A to Supplement 1 of Reference 4.

The document describes the statistical methodology used for setting trips and Limiting Conditions of Operation (LCOs) and for confirming existing trips and LCOs. The overpower ΔT (OPΔT) and the overtemperature ΔT (OTΔT) trip functions are set or confirmed using steady-state methods. The processes involved in setting the coefficients for both trip functions and in confirming existing trip coefficients are discussed in Sections 2 and 3, respectively. The setting and confirmation of other trips and LCOs using statistical methods are discussed in Section 4. The descriptions in Section 4 are based on a statistical treatment of transients.

This methodology is used to calculate trip setpoints and to verify trip systems and LCOs. Sections 2 through 4 include sample cases illustrating how existing trip functions are confirmed. Section 5 describes the methods used to generate the core power distributions employed in verifying the trip reset functions. Appendix A describes a deterministic calculation of the linear heat generation (LHGR) limit corresponding to fuel centerline melt (FCM) and includes a sample case showing the calculation of the limit. Appendix B describes the confirmation of Core Safety Limit Lines (CSLLs) using statistical methods and gives a sample case illustrating the process.

SPC approved statistical setpoint and transient methodology for Westinghouse-type reactors is described in Reference 2. This revision documents the methodology in a more detailed manner and provides new sample cases which cover the scope of the methodology. It incorporates the following changes to the description provided in the approved methodology:

1. [

]

2. The acceptance criterion based on joint probabilities of ΔI and power are replaced by a conversion of ΔI uncertainties into power uncertainties.
3. The emphasis is moved from calculating trip setpoints and coefficients to confirming the margin to the setpoint.
4. The confirmation of margin to hot-leg saturation is performed when the DNB margin is confirmed.
5. The emphasis in statistical transient analysis is moved from calculating the trip setpoint necessary to provide protection of a limit to confirming the margin to the limit.
6. The transient methodology is extended to postulated accidents and to events which have no trip.
7. The limits protected by the transient methodology now include secondary system pressure.
8. The confirmation of Core Safety Limit Lines is added.

2. Overpower ΔTemperature Reactor Trip Setpoint

The OPΔT trip setpoint is designed to protect the Specified Acceptable Fuel Design Limit (SAFDL) on FCM during normal operation, operational transients and Anticipated Operational Occurrences (AOOs). The OPΔT ensures that, at a 95% probability with a 95% confidence level, no location in the core experiences FCM. AOOs that may challenge the SAFDL are those that result in a slow, uncontrolled power ascension or axial core power redistribution. Typical events to be considered include, but are not limited to, the following:

- Uncontrolled RCCA Withdrawal
- Uncontrolled Boron Dilution
- Increased Feedwater Flow
- Decreased Feedwater Heating
- Excessive Load Increase

The adequacy of the OPΔT trip is confirmed by showing that the power at which the FCM limit would be reached exceeds that at which the trip occurs with a 95% probability with at least 95% confidence. The confirmation takes into account all applicable uncertainties.

Sections 2.1 through 2.4 describe the OPΔT trip function and the calculation of the trip coefficients and reset function (see discussion below). Section 2.5 covers confirmation of the dynamic compensation terms; Section 2.6 covers the process of confirming an existing trip function.

2.1 Description of the Trip Function

The OPΔT trip function is based on hot leg and cold leg temperatures and on the relative power readings from the ex-core detectors. The general form of the trip function is the following:

$$\Delta T \frac{(1+\tau_1 S)}{(1+\tau_2 S)(1+\tau_3 S)} = \Delta T_0 \left[K_4 - K_5 \frac{\tau_7 S}{(1+\tau_7 S)(1+\tau_6 S)} T - K_6 \{ T \frac{1}{1+\tau_6 S} - T' \} - F(\Delta I) \right]$$

where

ΔT	=	maximum measured ΔT, °F
ΔT_0	=	indicated ΔT at rated thermal power, °F
T	=	indicated average reactor coolant temperature, °F
T'	=	indicated average reactor coolant temperature at rated thermal power, °F
K_4	=	a preset, manually adjustable bias
K_6	=	a constant that accounts for the effects of coolant density and heat capacity on the relationship between ΔT and thermal power, 1 /°F. This coefficient is typically set to zero when $T < T'$, so that it never causes the trip ΔT to increase.

Compensation for axial power shape changes is provided by the trip reset function, $F(\Delta I)$, where,

ΔI	=	the difference between the normalized fluxes from the top and bottom detectors of the power range nuclear ion chambers.

Dynamic compensation is included to account for transport delays and delays in the resistance thermal detectors (RTDs) in the hot and cold legs. The terms in the trip that perform this function are the following:

K_5	=	a constant that compensates for piping and thermal delays, 1 /°F
S	=	Laplace transform operator, 1/sec
$(1 + \tau_1 S)/(1 + \tau_2 S)$	=	Lead-lag compensator on measured ΔT
$1/(1 + \tau_3 S)$	=	Lag compensator on measured ΔT

$1/(1+\tau_6 S)$ = Lag compensator on measured average coolant temperature

$\tau_7 S/(1+\tau_7 S)$ = the function generated by the rate-lag controller for average coolant temperature dynamic compensation.

The function of the OPΔT can be demonstrated by considering the trip function in a steady state and removing the compensation from the reset function. The trip function becomes

$$T = T_0[K_4 - K_6(T - T')]$$

which can be written as

$$\frac{\Delta T}{\Delta T_0} = K_4 - K_6(T - T')$$

The meaning of the constants becomes clearer using this arrangement. The system parameter that determines FCM is the power. The left side of the equation needs to be a good, or conservative, surrogate for normalized reactor power corresponding to FCM. K_4 becomes the normalized power at which FCM would occur and K_6 becomes the adjustment for the nonlinear relationship between power and ΔT.

2.2 Setpoint Calculation Overview

The procedure for calculating a set of coefficients (K_4, K_5 and K_6) for the OPΔT setpoint equation consists of the following steps:

2.3 Calculation of Trip Coefficients

For simplicity, the dynamic compensation terms and the reset function are removed from the trip function. The verification of these terms is discussed in Sections 2.4 and 2.5. The simplified trip equation becomes

$$\Delta T = \Delta T_0 [K_4 - K_6 \{T - T'\}]$$

K_4 and K_6 trip coefficients that limit the core power level such that FCM will not occur are calculated. These coefficients include the uncertainties associated with peaking.

The FCM limit is specified for the fuel design in terms of the local LHGR. Given the design F_Q, the nominal core power level ($Q_{FCM,nom}$) that corresponds to the LHGR limit for FCM is determined.

$$Q_{FCM,nom} = \left\{ \frac{LHGR_{FCM,nom}}{LHGR_{ave} x F_Q} \right\} x Rated Power$$

where

$Q_{FCM,nom}$	=	nominal FCM power
$LHGR_{FCM,nom}$	=	lowest LHGR at which FCM can occur
$LHGR_{ave}$	=	average LHGR at rated power.

The enthalpy change across the core is proportional to power with fixed flow. The core ΔT decreases for a fixed power and flow as the hot leg temperature approaches saturation. This is because the specific heat capacity of water varies with the temperature and pressure. The methodology accounts for this effect.

The coefficient on the average temperature, K_6, reduces the trip setpoint to provide more protection. As a conservative simplification, the K_4 coefficient is calculated assuming that the average temperature compensation does not exist. Solving the simplified trip equation for K_4 at the uncertainty-adjusted CPL power yields

$$K_4 = \frac{\Delta T_{CPL}}{\Delta T_0}$$

where the subscript, CPL, indicates the core ΔT at the core protection power limit. The value of ΔT_{CPL} is set to the smallest value pressures between the high and low trip setpoints for pressurizer pressure. This occurs at the minimum allowable pressure.

The K_6 term of the OPΔT equation accounts for the effects of the increasing average temperature on the relationship between ΔT and core power. At constant pressure and power, an increased average temperature results in a smaller ΔT. The OPΔT setpoint must be reduced at average temperatures above the nominal average temperature to account for this effect.

The value of K_6 is calculated using the following equation:

$$K_6 = \frac{K_4 - \frac{\Delta T^*}{\Delta T_0}}{T^* - T'}$$

where

ΔT^*	=	core temperature rise at the core protection limit
T^*	=	average core temperature at the core protection limit and with a core temperature rise of ΔT^*.

To ensure that the OPΔT setpoint is conservative, the K_6 coefficient is maximized. To maximize K_6, ΔT and T are calculated with the pressure set to the high pressurizer pressure trip setpoint and with the hot leg temperature set to the corresponding saturation temperature.

The K_4 coefficient calculated is then adjusted

Table 2.1 lists typical uncertainty parameters included in the OPΔT setpoint analysis. [

]

To determine the statistical adjustment, the probability distribution for K_4 is calculated by explicitly modeling the assumed distribution of each parameter. The K_4 distribution is calculated using a Monte Carlo simulation, or by direct integration of the probability densities for each uncertainty. When a direct integration is used, it is benchmarked against a Monte Carlo simulation.

The 95/95 bounding value of K_4 and K_6 are the final coefficient values.

2.4 Trip Reset Function

The values for the trip coefficients, K_4 and K_6, are calculated using a design limit of total peaking, F_Q. For events undergoing large changes in the axial power shape distribution, the peaking can exceed this design value. The trip reset function is designed to account for the effects of core power distributions having total peaking in excess of F_Q. The process is iterative and requires a confirmation of margin for the calculated reset function to complete the process. Section 5 describes the method of creating the axial distributions used in the analysis of the reset function.

Statistical development of the reset trip function consists of the following steps:

[ ]

Steps 5 through 7 are repeated until the reset function shape assumed to convert the ΔI uncertainties to K_4 uncertainties provides sufficient compensation in Step 7. These steps in the statistical analysis of the reset function are described in the following paragraphs.

A large number of axial power shapes is used to confirm the reset function. For each axial shape, the FCM power is determined, ignoring the effects of the uncertainties. The nominal power level at which FCM is precluded for a given axial power shape is given by

$$Q^{reset}_{FCM,nom} = \left\{ \frac{LHGR_{FCM}}{LHGR_{ave} x F_Q x F_{AUG}} \right\} x Rated Power$$

where

F_{AUG} = ratio of the total peaking corresponding to an axial power shape with the design peaking.

All axial shapes with a value of F_{AUG} less than unity (total peaking less than the design F_Q) are discarded.

The probability distributions around each nominal FCM power are generated. Accounting for uncertainties, the core power level at which fuel melt is precluded is specified by

[

] these are the same equations that were solved for K_4 and K_6. In this case, the probability distribution is expressed in power.

The OPΔT trip equation is expressed in terms of core ΔT. The FCM core ΔT's are calculated for each of the power levels in the probability distribution for FCM power and the system plant pressure is set to the minimum allowed.

The static form of the OPΔT setpoint equation, with the reset function, is

$$\Delta T = \Delta T_0 \left[K_4 - K_6 \{ T - T' \} - F(\Delta I) \right]$$

In operation, the core ΔT must remain below the right-hand side of the equation.

Expressing this in terms of the ΔT at FCM, the minimum required value for the reset function corresponding to shape is

$$F(\Delta I) = K_4 - \frac{\Delta T_{FCM}}{\Delta T_0}$$

The required F(ΔI) correction is calculated for each ΔT_{FCM} value. A bounding F(ΔI) correction is determined to prevent FCM for all axial power shapes.

The reset function depends on the variable ΔI, which is obtained from the excore neutron flux detectors that measure the relative power in the top (P_t) and bottom (P_b) of the core. ΔI is defined as (P_t - P_b). The axial offset (AO) is defined in terms of ex-core readings and is related to ΔI as follows:

$$AO \equiv \frac{(P_t - P_b)}{(P_t + P_b)} = \frac{\Delta I}{(P_t + P_b)}$$

Each core average axial power shape has an average axial offset, AO. Multiplying this AO by the power at which the trip needs to occur results in a ΔI value that corresponds to the indicated ΔI at which FCM can occur.

[ ]

The probability distribution for [ ] This is achieved by iterating on the reset function until an acceptable result is obtained.

2.5 Dynamic Compensation

The calculation of the trip setpoint coefficients was a static calculation that ignored the transient effects on the measured temperatures. The dynamic compensation time constants (τ_1 through τ_7) and the K_5 coefficients are set such that during a transient event, the trip will protect against FCM with at least 95% probability at a 95% confidence level. The dynamic compensations term is confirmed by transient analysis and by simulating a range of power ascension rates. In this simulation, the core inlet conditions, power and system pressure are used as input to the static version of the uncertainty-adjusted OPΔT trip as determined earlier. In the same simulation, the sensed hot and cold leg temperatures are used as input to the dynamically-compensated trip. The combination of time constants and trip coefficients must be such that the dynamically compensated trip will be reached before the static trip occurs.

2.6 Confirmation of OPΔT

In many cases, the trip coefficients and reset function are known and only a confirmation of OPΔT is required. This process is somewhat simpler than calculating the trip coefficients. The flow for the confirmation calculations for this trip is shown in Figure 2.1.

The trip confirmation takes into account its function of protecting against FCM and takes credit for the action of the OTΔT trip and the main steam safety valves (MSSVs) in precluding certain areas of operation. Table 2.1 lists uncertainties considered in the confirmation of the OPΔT trip.

The confirmation of the trip function uses the same general equations as does the calculation of the trip coefficients and the reset function. The steps in the calculation are described in the following paragraphs.

As a first step in the confirmation of the OPΔT trip, the inlet temperature and pressure is [ ] The nominal power margin is calculated and then a statistical adjustment is made to reduce the margin. The [ ] uses the Technical Specification local peaking limit, F_Q, to calculate the power at FCM.

The reset function is confirmed using the [ ] This confirmation is similar to the [ ] but uses the total peaking corresponding to each axial power shape rather than the Technical Specification limit.

2.6.1 Nominal Margin

Given a local peaking factor, the nominal power at FCM is given by

$$Q_{FCM,nom} = \left\{ \frac{LHGR_{FCM}}{LHGR_{ave} x F_Q} \right\} x Rated Power$$

where

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

The local peaking is allowed to have a part-power augmentation program and F_Q may be a function of the trip power.

The ability of the OPΔT trip to protect against FCM in a static mode is confirmed by calculating the power at which the trip would occur; given an axial power shape, a system pressure and an inlet temperature; and comparing the trip power to the power at which FCM would occur for the same axial power shape, inlet temperature and system pressure.

The nominal margin is calculated by subtracting the nominal trip power from the nominal melt power.

2.6.2 Statistically Adjusted Margin

The final margin is obtained by making a statistical adjustment to the margin. [

]

[

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[

]

2.6.3 Action of the MSSV

When the MSSV opens, the reactor primary loop can not heat up any more for a given power. The temperature in the secondary side of the steam generator is calculated as follows:

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

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 operation (about 700 to 800 psia) and xcof is adjusted to make $T_{S.G.}$ the saturation temperature corresponding to the primary coolant system (PCS) average temperature at full power.

The MSSVs will open at some setpoint around 1,000 psia. An offset of 3% - 6% will be 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.

2.7 Sample Case

The sample case presented in this section summarizes an example how the OPΔT trip is confirmed. The input used for the sample case, shown in Table 2.2, is typical for a Westinghouse reactor. The reset function is a part of the input. Figure 2.2 shows the reset function used in the sample case.

The first step in the confirmation is to calculate [

]

The statistical analysis is performed for a large number of axial power shapes. Some details for the first axial power shape are discussed in the following paragraphs to help demonstrate the confirmation process.

The OPΔT margin was calculated over [

] using the nominal F_Q of 2.34. This corresponds to a limit of 2.52, given the peaking and engineering factor uncertainties. The case with the [

] The nominal trip power, ignoring the reset function, is 3,022 MWt and the nominal melt power is 4,366 MWt.

Figure 2.4 shows [

]

[

] The final margin is 1,039 MWt.

The reset function is confirmed [

] using the nominal peaking limit. A set of axial power shapes is used to confirm the reset function. In this case, the axial power shapes have the F_Q given by multiplying the maximum axial peaking times the $F_{\Delta H}$ limit. Only 4 axial power shapes were evaluated for margin to trip. The remaining axial power shapes were eliminated because they were generated at a power below the melt power on a deterministic basis. One of the cases for which the margin was evaluated is in the following paragraphs.

The axial power shape has an ex-core axial offset of -36% and an F_Q of 3.05. This corresponds to a nominal FCM power of 3,350 MWt, or 121% of rated power. The nominal trip power is 2,357 MWt, or 85% of rated power.

The probability distribution shown in Figure 2.3 [

] Figure 2.5 shows the probability distribution for the FCM power, [

]

Figure 2.6 shows the [

]

[

] Figure 2.7 shows [

] The lower 5% limit of the FCM power is about 110% of rated power and the nominal trip is at 85% of rated power. The margin is about 25% of rated power, or about 690 MWt.

[

] The resulting margins are shown in Figure 2.8. All of the margins are positive at the 95% probability limit, which confirms the coefficients and the reset function of the OPΔT trip.

Table 2.1 Description of OPΔT Uncertainties

Table 2.2 Typical Input for OPΔT Verification

Table 2.2 Input for OPΔT Verification - continued

Figure 2.1 Calculational Flow for OPΔT Confirmation

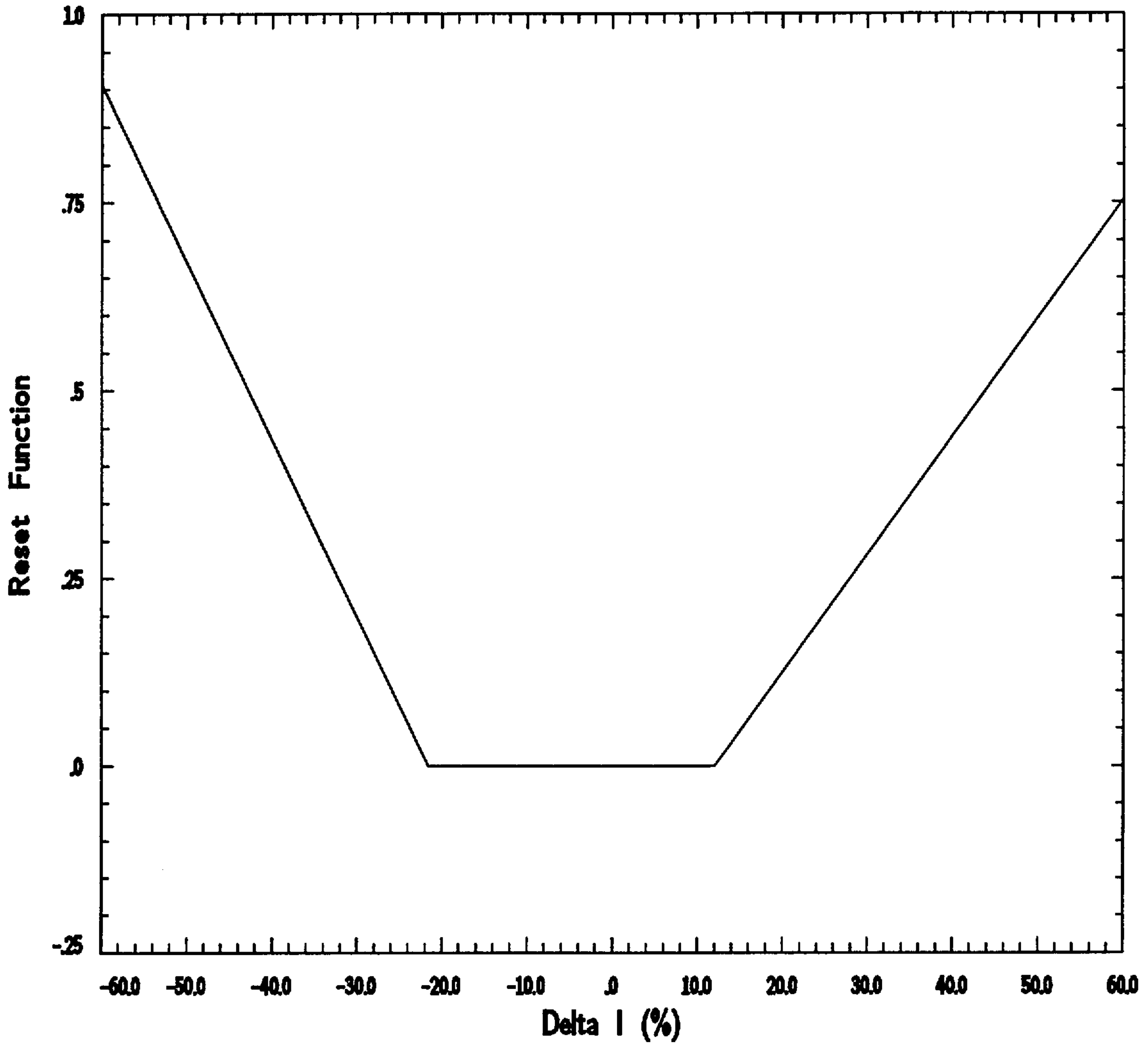

Figure 2.2 Reset Function for Sample Case

Figure 2.3 Probability Distribution for FCM Multiplicative Factor

Figure 2.4 Probability Distribution of FCM Power for Limiting Point in Scan

Figure 2.5 Probability Distribution for FCM Power for Reset Function Verification

Figure 2.6 Probability Density for Power from ΔI Uncertainty

Figure 2.7 Overall Probability Distribution for FCM Power for Reset Function Verification

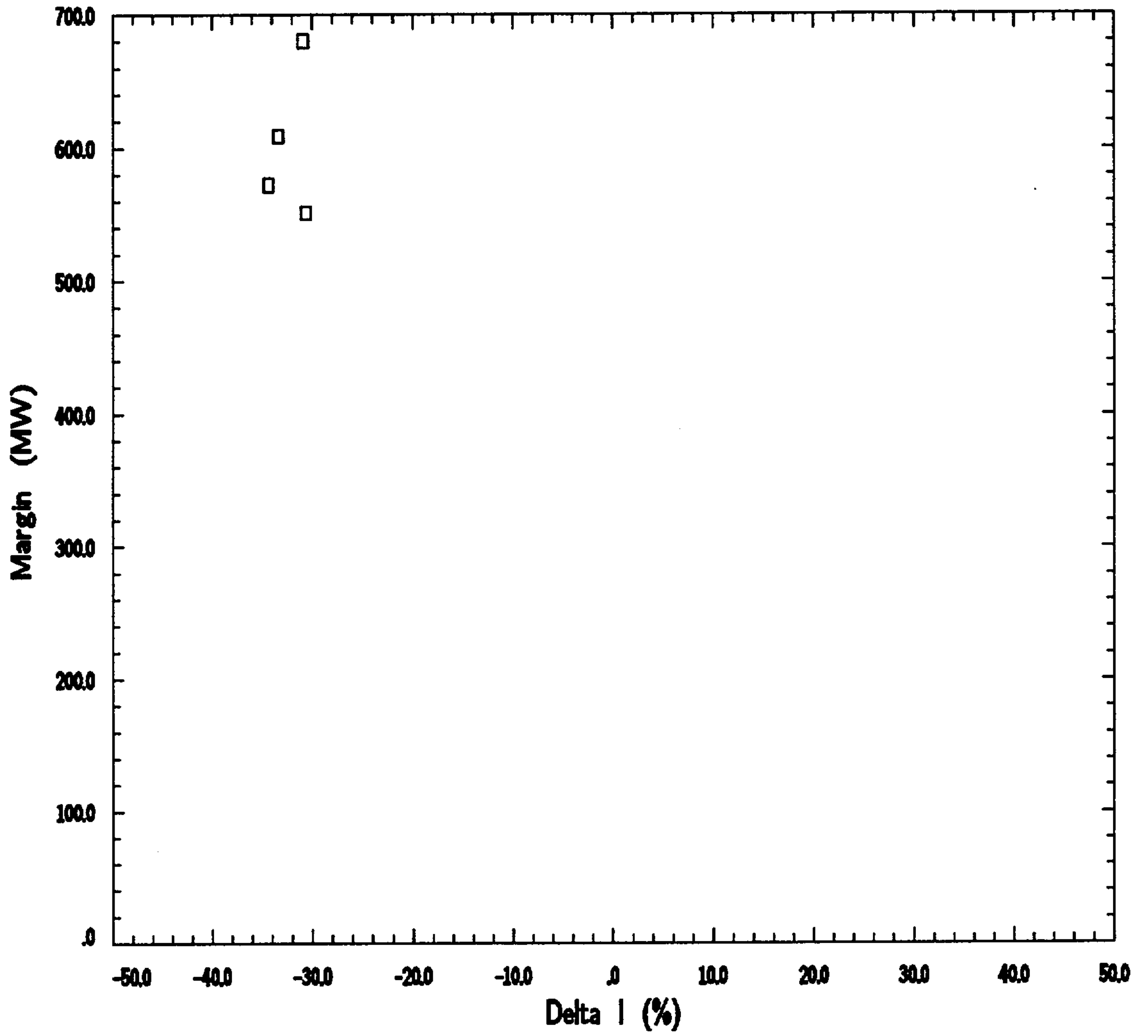

Figure 2.8 Overall Margin for OPΔT for Sample Case

3. Overtemperature ΔTemperature Reactor Trip Setpoint

The OTΔT trip is designed to protect the SAFDL on Departure from Nucleate Boiling (DNB) and prevent boiling in the vessel hot legs during normal operation, operational transients and AOOs. The trip is set such that with 95% probability and 95% confidence, neither DNB nor hot leg saturation will occur. Preventing boiling in the hot legs permits the measured temperature differences across the vessel to be used to calculate power for use in the protection system. AOOs that may challenge the OTΔT trip are those that result in an uncontrolled power ascension or a core power redistribution. Typical events to be considered include, but are not limited to, the following:

- Uncontrolled RCCA Withdrawal
- Uncontrolled Boron Dilution
- Increased Feedwater Flow
- Decreased Feedwater Heating
- Excessive Load Increase.

The onset of DNB in the core or boiling in the hot legs depends on the average coolant temperature, primary system pressure, core flow and core thermal power. Coolant temperature limits imposed by the MSSVs are used in setting the trip coefficients. Corrections to the trip setpoint are made to compensate for highly peaked power distributions, changes in coolant density and heat capacity with temperature, transient delays in vessel temperature measurements and trip channel uncertainties.

In general, the discussion of the OTΔT trip given in this section will follow that of the OPΔT in Section 2. The major differences will arise from the need to set the limit based on DNB protection, not FCM protection. Minimum DNB ratio (MDNBR) values are calculated using NRC-approved correlations and codes (XCOBRA-IIIC).

3.1 Description of the Trip Function

The OTΔT trip function is similar to the OPΔT trip function, except for the addition of a pressure compensation term. The trip function is written in its general form as

$$\Delta T \frac{(1+\tau_1 S)}{(1+\tau_2 S)(1+\tau_3 S)} = \Delta T_0 \left[K_1 - K_2 \frac{(1+\tau_4 S)}{(1+\tau_5 S)} \{T \frac{1}{1+\tau_6 S} - T'\} + K_3 (P - P') - F(\Delta I) \right]$$

where

ΔT	=	maximum measured ΔT, °F
ΔT_0	=	indicated ΔT at rated thermal power, °F
T	=	indicated average reactor coolant temperature, °F
T'	=	indicated average reactor coolant temperature at rated thermal power, °F
P	=	indicated pressurizer pressure, psia
P'	=	indicated pressurizer pressure at rated power conditions, psia
K_1	=	a preset, manually adjustable bias
K_2	=	a constant that accounts for the effects of coolant density and heat capacity on the relationship between ΔT and thermal power, 1 /°F
K_3	=	a constant that compensates for changes in pressurizer pressure, 1/psi.

The compensation for axial power shapes is provided by the reset function, $F(\Delta I)$.

Dynamic compensation is provided in the trip by the following terms:

S	=	Laplace transform operator, 1/sec

$(1+\tau_1 S)/(1+\tau_2 S)$	=	Lead-lag compensator on measured ΔT
$1/(1+\tau_3 S)$	=	Lag compensator on measured ΔT
$(1+\tau_4 S)/(1+\tau_5 S)$	=	Lead-lag compensator on measured coolant average temperature
$1/(1+\tau_6 S)$	=	Lag compensator on measured average coolant temperature

The method by which this trip protects against DNB and hot leg saturation is more clearly shown by considering the static case and removing the compensation for axial power shapes. The function simplifies to the following:

$$\Delta T = \Delta T_0\left[K_1 - K_2\{T - T'\} + K_3(P - P')\right]$$

Rearranging the equation helps clarify the function of the trip setpoint.

$$\frac{\Delta T}{\Delta T_0} = K_1 - K_2(T - T') + K_3(P - P')$$

The left side represents the normalized power which will protect against DNB and hot leg saturation. K_1 is the normalized power at nominal average temperature and pressure that corresponds to DNB. Unlike FCM, DNB and hot leg saturation depend on the thermal-hydraulic conditions. The additional terms adjust the constant to reflect two other phenomena: the change in relationship between power and ΔT as the core exit approaches saturation, and the behavior of DNB and saturation as a function of the other system parameters.

3.2 Setpoint Calculation Overview

The statistical development of an OTΔT setpoint equation has two main parts. These are the calculation of the OTΔT trip coefficients, K_1, K_2 and K_3, (Section 3.3) and the determination of the reset function (Section 3.4). The trip coefficients must be set to protect against both DNB and hot leg saturation for a design axial power shape.

The statistical OTΔT setpoint calculations are performed on a static basis. The dynamic compensation terms, described in Section 3.5, are verified in a separate calculation.

3.3 Calculation of Trip Coefficients

This section describes for the calculation of the trip coefficients, K_1, K_2 and K_3, and the adjustment to K_1 to account for uncertainties.

The static form of the OTΔT setpoint equation is

$$\Delta T = \Delta T_0\left[K_1 - K_2\{T - T'\} + K_3(P - P') - F(\Delta I)\right]$$

Because the reset function is treated separately, this equation can be reduced to

$$\Delta T = \Delta T_0\left[K_1 - K_2\{T - T'\} + K_3(P - P')\right]$$

The calculation of the trip coefficients uses a design axial power shape that will bound the deadband region of the reset function (the region in which the reset function has no effect on the trip value). This axial can be selected by calculating the MDNBR at an elevated power level for each axial power shape over the selected range for the deadband. The choice of design shapes establishes the deadband and can be changed if the reset function obtained is unsatisfactory.

The trip coefficients are calculated using the following steps:

[

]

[

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In the NOMSCAN step, the average coolant temperature and core ΔT are varied to yield a target MDNBR (typically the mean of the MDNBR correlation) for a number of pressure conditions. In this step, all uncertainties are set to zero. The OTΔT trip is part of the overall reactor system and the range of average coolant temperatures and core ΔTs over which the OTΔT must provide protection is limited. The range over which the trip coefficients are calculated is limited by the OPΔT trip, by the high flux trip and by the setpoint of the first bank of MSSVs.

For each pressure, two average coolant temperature/core ΔT points are determined. These two points are set by the intersection of the OPΔT setpoint line

$$\Delta T = \Delta T_0 \left[K_4 - K_6 \{T - T'\} \right],$$

with the MSSV line

$$T_{sat}(P_{MSSV}) = T - \frac{xcof}{Q}$$

where

P_{MSSV} = pressure setpoint of first bank of MSSVs, psia

$T_{sat}(P_{MSSV})$	=	saturation temperature corresponding to the pressure setpoint of the first bank of MSSVs, °F
xcof	=	total heat transfer coefficient from primary to secondary, MWt/°F
Q	=	total primary power, MWt

and with the hot leg saturation line

$$T_{SAT}(P) = T + \frac{\Delta T}{2}$$

or the line at which DNB occurs.

The first point is the intersection of the OPΔT setpoint line with the DNB line or saturation line, whichever occurs at a lower average temperature. The second point is the intersection of the MSSV line and the DNB line or the hot leg saturation line, whichever occurs at a lower average temperature.

Those parameters not treated statistically are set to their respective deterministic values in the NOMSCAN analysis. Table 3.1 lists typical parameters considered statistically in setting the trip coefficients for OTΔT.

In the NOMSCAN calculation, all input parameters other than MDNBR are at their respective nominal values. The target MDNBR is the nominal value adjusted for calculated biases such as rod bow and mixed core penalties. Radial peaking is adjusted as a function of power level, as specified by the plant Technical Specifications. The axial distribution assumed is bounding for a desired ΔI band.

In the DETSCAN portion of the OTΔT statistical setpoint development, all uncertain parameters are adjusted to their respective deterministic limits. The DETSCAN portion, which uses the same set of pressures and average coolant temperatures, is similar to the NOMSCAN except for the treatment of uncertainties. The core ΔT that yields the deterministic MDNBR, as adjusted for biases, is determined for each case. The change in ΔT between the NOMSCAN calculation and the DETSCAN calculation is calculated. The nominal average coolant temperature and pressure

state that has the greatest change in core ΔT is the point most sensitive to uncertainties.

A response surface for core ΔT is generated with the nominal values set to the most sensitive point. The uncertainty variation methods for the generation of the response surface are given in SPC's approved GSUAM methodology (Reference 1).

The response surface generated at the most sensitive point will result in conservative statistics. The choice to limit the calculation to the most sensitive point was made to limit the number of response surfaces required. A less conservative but still valid approach would be to generate response surfaces around several nominal points, up to and including all nominal points. This approach may be used if the conservatism resulting from the selection of the most sensitive point is unacceptably large. If response surfaces are generated for all nominal points, the DETSCAN portion of the analysis would not be performed.

To determine the statistical core ΔT penalty for DNB conditions, a Monte Carlo simulation of the margin at the most sensitive point is performed using the following expression for margin:

The difference between the hot leg saturation NOMSCAN calculation and the DNB NOMSCAN calculation is that the target value is hot leg saturation. At each pressure for which hot leg saturation occurs at an average temperature lower than that for which the MSSV would open, the effect of uncertainties on the ΔT corresponding to hot leg saturation is determined. At the pressures and average coolant temperatures determined in the NOMSCAN sequence, the deterministic, uncertainty-adjusted core ΔT of hot leg saturation is determined for the DETSCAN. The nominal average coolant temperature and pressure with the largest difference between the NOMSCAN and DETSCAN ΔT values is the most sensitive point.

A response surface for core ΔT is generated with the nominal values set to the most sensitive point. The uncertainty variation methods for generating the response surface are given in SPC's approved GSUAM methodology. The variables used in the hot leg saturation simulation are listed in Table 3.1. [

]

To determine the statistical core ΔT penalty for hot leg saturation conditions, a Monte Carlo simulation of the margin at the most sensitive point is performed using the following expression for margin:

The statistical DNB and hot leg saturation ΔT adjustments determined from the Monte Carlo simulations described in the preceding paragraphs are applied to the respective nominal condition points determined in the NOMSCAN calculational sequence. Using the uncertainty-adjusted points a set of CSLLs is determined. Each CSLL consists of a set of curves that protect against hot leg saturation or DNB, whichever is more limiting, at a series of pressures ranging from the low to the high pressure settings on the pressurizer pressure.

These adjusted limit lines specify the conditions that protect against DNB and hot leg saturation with at least 95% probability at a 95% confidence level. Because the statistical adjustments were determined from the points most sensitive to uncertainties, a nominal point could have a deterministic uncertainty adjustment smaller than the bounding statistical uncertainty adjustment. In these cases, the deterministic adjustment may be used instead.

A set of OTΔT trip coefficients are determined that will bound the uncertainty-adjusted CSLLs. This is done by plotting the CSLLs as a function of core average temperature and ΔT for each pressure and selecting values of the trip coefficients that will result in an OTΔT trip before the CSLL is reached.

The coefficients calculated by this process are compared with the trip coefficients supported by the transient analyses. The set of coefficients that is most restrictive is used in setting the Technical Specification OTΔT equation.

3.4 Trip Reset Function

The trip coefficients are calculated to protect against DNB with 95% probability at a 95% confidence level for a design axial power shape. The purpose of the trip reset function is to compensate for axial power shapes that are more limiting than this design axial shape.

The process for evaluating the reset trip function consists of the following steps:

[

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[

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Steps 6 through 11 are repeated until the reset function shape assumed to convert the ΔI uncertainties to ΔT uncertainties provide sufficient compensation in Step 9.

Section 5 describes the generation of the axial power shapes. A large number of axial power shapes result from this process. The total range of ΔI values is broken up into several smaller "bins" and a nominal ΔI value is assigned to that bin. The axial power shapes used in the calculation of the reset trip function are those axials that result in the lowest MDNBR for each bin. To determine these limiting axial shapes, each axial shape generated at a power level is analyzed using a consistent set of conditions. The axial shape that results in the lowest MDNBR for a bin is retained and used in the subsequent setpoint calculations.

In the NOMSCAN portion of the statistical reset trip function procedure, the average coolant temperature and core ΔT for which a given axial will yield a target MDNBR are determined. The pressure range considered is the nominal allowed pressure range of the plant. This range of conditions is further limited by the saturation lines and MSSV limit curves. All input parameters other than MDNBR are set to their respective nominal values. The target MDNBR is the mean of the DNB correlation adjusted for rod bow and mixed core penalties. Radial peaking is adjusted as a function of power level as specified by the plant Technical Specifications. In the determination of the NOMSCAN conditions, the power level corresponds to the power used in generating the axial power shape.

The average coolant temperature is varied to achieve the target MDNBR. The range of average coolant temperatures and core ΔT is limited by the OPΔT trip. At lower pressures, hot leg saturation may be more limiting and these cases need not be considered. At low power, the MSSV can open before the target MDNBR is reached. These cases are not considered.

In the DETSCAN portion of the statistical method, all uncertainty parameters are adjusted to their respective deterministic limits. The core ΔT which yields the target MDNBR is determined at each of the pressures and average coolant temperatures determined by the NOMSCAN calculations for each axial power

shape. The NOMSCAN average coolant temperature, pressure and axial shape combination with the greatest change in ΔT between the NOMSCAN and DETSCAN calculations is the most sensitive point. The only difference between this process and the calculation of the trip coefficients is that the DETSCAN process considers a number of axial power shapes. The calculation of the trip coefficients uses only the design axial.

A response surface in core ΔT is created around the most sensitive point in pressure and average coolant temperature. The only difference the process used to generate this response surface and the one for calculating the trip coefficients is that the axial power shape is the shape corresponding to the most sensitive point rather than the design axial. The uncertainty variation methods for generating the response surface are given in SPC's approved GSUAM methodology. Table 3.1 lists typical uncertainty parameters considered in the analysis.

The response surface generated at the most sensitive point will result in conservative statistics. A less conservative but still valid approach would be to generate a response surface around several of the nominal points. This approach may be used for selected points if the conservatism resulting from the selection of the most sensitive point is unacceptably large.

The result of the Monte Carlo calculation is a ΔT uncertainty adjustment probability table. In this calculation, the distribution of each uncertainty parameter is explicitly modeled. If more than one response surface were generated to cover the operational range, this calculation would be performed for each response surface.

3.5 Dynamic Compensation

The calculation of the trip setpoint coefficients ignored the transient effects on the measured temperatures. The dynamic compensation time constants (τ_1 through τ_6) should be set such that, during a transient event, the trip will protect against DNB or hot leg saturation with at least 95% probability at a 95% confidence level. The dynamic compensation terms are confirmed by transient analysis and by simulating a range of power ascension rates. In this simulation, the core inlet, power and pressure are used as input to the static version of the uncertainty-adjusted OTΔT trip. In the same simulation, the sensed hot and cold leg temperatures are used as input to the dynamically-compensated trip. The combination of time constants and trip coefficients must be such that the dynamically compensated trip will be reached before the static trip would occur.

3.6 Confirmation of OTΔT

Confirmation of DNB protection is based on showing that margin between the power corresponding to DNB or hot leg saturation and the trip is positive. The process uses a large collection of axial power shapes corresponding to the operating cycle being analyzed. Section 5 describes the process of creating these axial power shapes. Figure 3.1 gives a schematic of the confirmation process. As in the earlier discussions, MDNBR calculations are based on XCOBRA-IIIC.

The first step in the process is to determine the DNB-limiting axial power shapes to limit the number of axial power shapes considered. This is done by calculating the MDNBR for all axial power shapes at [ ] The most limiting shape in each range (bin) of internal AO is retained. There are 20 bins in AO which cover the range of AO values from -0.6 to +0.6. This part of the setpoint confirmation process is deterministic and produces bounding axial power shapes for each AO bin. The only aspect of axial power shapes that is treated statistically [ ]

Each axial power shape has an internal and an external AO. The relationship between the internal and external AO varies somewhat between each of the shapes. However, from the original collection of shapes only about 20 are retained. [ ]

The limiting axial power shapes are used to calculate both nominal and deterministic powers corresponding to DNB. Nominal cases assume that DNB occurs at the mean of the correlation [ ] The nominal cases treat all variables as nominal. Deterministic cases use a high value ($\sim 2\sigma$ above the correlation mean) of DNB ratio (DNBR) as the point of DNB and change the values of all variables such that the power to reach DNB is reduced. 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 power is the most sensitive point.

The next step is to calculate the response surface points. This calculation is performed using the nominal conditions identified as the most sensitive point. Each of the points represents a variation in one or more of the parameters that are to be combined statistically by this process. [ ]

[

]

A fit to the response surface points produces the response surface. This response surface is used to get the probability distribution of the DNB power.

Hot leg saturation is confirmed for the OTΔT trip. This confirmation does not require this process to determine the power for DNB. Saturation properties come from the steam tables.

3.6.1 Nominal Margins

The nominal power at which DNB occurs is calculated for the limiting axial power shapes over a range of power and inlet using nominal conditions. These nominal points are a series of cases at different powers, pressures and inlet temperatures and for a variety of axial power shapes that produce an MDNBR that is at the adjusted DNBR correlation mean value.

The power at which the OTΔT trip ΔT matches the reactor ΔT is the nominal trip power. The difference between the nominal DNB power and the nominal OTΔT trip power is the nominal margin.

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. The nominal power for the OTΔT trip is calculated and the nominal margin between the OTΔT trip and the saturation power is determined.

3.6.2 Statistically Adjusted Margin

Table 3.1 lists uncertainties considered in the confirmation of the OTΔT trip. The nominal margin is adjusted to reflect these uncertainties. Inclusion of the effects of these uncertainties makes use of [

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[

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The response surface is used in [

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[

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[

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3.6.3 Action of the MSSV

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 calculated using

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

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 $T_{S.G.}$ the saturation temperature, given the PCS 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.

3.7 Sample Case

This sample case demonstrates the confirmation of the power margin for an example of a typical Westinghouse plant. Table 3.2 lists the input for the sample case. This case forces the part-power peaking using a power-dependent peaking table. Table 3.3 shows this table of $F_{\Delta H}$ as a function of power. The maximum radial peaking factor at each power level was extracted for each power level and compared to the value from the limit table (Table 3.3). The maximum of the two was selected in each case and used for all DNBR calculations at part power. Table 3.4 shows the power-dependent radial peaking factors for this sample case. These are the "forced" limiting values adjusted to the nominal value.

The [ ] were extracted from the collection of axial power shapes created by the neutronics calculations described in Section 5. Table 3.5 lists the power-dependent rod shadowing statistics extracted from the axial power shapes.

The axial power shapes were scanned to determine the 20 shapes that were most limiting over the range from -0.6 to 0.6. Table 3.6 summarizes the results of this scan. The first column gives the mean AO for each bin. The AO is used here because ΔI is proportional to the power. The second column is a case identifier. This identifier will be carried with the shape through to the final margin calculation, however, it is modified by adding two trailing digits to will identify the pressure and the inlet temperature, thereby specifying the nominal case. The third column is the MDNBR for a 40% overpower condition. 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. Most of the limiting shapes correspond to powers that are well below full power.

The nominal cases consisted of 36 different pressure and power combinations for each axial power shape. Of the possible 720 nominal cases that could be constructed from the 20 axial power shapes and 36 pressure and power combinations, 6 failed to converge on an inlet temperature for DNB during the scan for the nominal cases. This left 714 nominal cases.

Case #27723 had the most negative power difference between the deterministic and nominal cases. The value is -18% RTP. Axial power shape #277 was used for the analysis and the response surface used 2.11 Mlbm/hr-ft^2, 2355 psia, 620 °F and 99% as the nominal point for the flow, pressure, inlet temperature and power, respectively.

The response surface was fit to 91 points covering the range from about 75% RTP to about 110% RTP.

The OTΔT verification was performed using the nominal inputs, [

] and general input for the sample OTΔT verification case in Table 3.2.

The first step in checking the OTΔT is to confirm that it protects against hot leg saturation. This check was performed over a range of pressures ranging from 1,700 psia to 2,550 psia and inlet temperatures ranging from 520°F to 625°F. The

minimum margin, 240 MWt, was found at 1,700 psia and 580°F. This confirms that the OTΔT trip function will protect against hot leg saturation.

Next, the response surface points were fit with [

] Figures 3.2 and 3.3 show the fit and the [ ], respectively, for the DNB power. The [

]

The intermediate steps for processing nominal case #27419 are described below. This case has an inlet temperature of 578°F, a pressurizer pressure of 1,935 psia, a nominal DNB power of 2,742 MWt, a nominal trip power of 1,343 MWt and a ΔI at the trip power of -23%. This case was chosen because the ΔI falls on a point near the edge of the deadband for the reset function and shows the [

]

Cases were first tested to ensure that they would not trip on the OPΔT trip or on the High Flux trip and that the MSSVs would not open.

[

]

The overall margin was calculated by subtracting the nominal OTΔT trip power from the adjusted DNB power. Figure 3.6 shows the [

] from this case.

This process was repeated for all 714 nominal points. The margins for the 115 cases that avoided tripping on the OPΔT or the High Flux trip and that did not open the MSSVs were calculated. Figure 3.7 shows the margins.

In all cases, the OTΔT trip provided a positive margin, confirming its protection.

Table 3.1 Description of OTΔT Uncertainties

Source	Description

Table 3.2 Typical Input for OTΔT Verification

Variable	Value

Table 3.3 Power-Dependent Radial Peaking Factors

Power, % RTP	$F_{\Delta H}$ Limit
0.0	2.34
100.0	1.73
125.0	1.73

Table 3.4 Nominal $F_{\Delta H}$ From TP9SCAN

Power, % RTP	$F_{\Delta H}$
50.0	1.953
60.0	1.894
70.0	1.836
80.0	1.777
90.0	1.719
100.0	1.660
110.0	1.660
120.0	1.660

Table 3.5 Rod-Shadowing Statistics for Sample Case

Table 3.6 Limiting DNB Shapes for Sample OTΔT Confirmation Case

Case Number	AO	Axial Shape Number	MDNBR	Power, % RTP
1	0.60	31	0.728	50.0
2	0.54	29	0.768	60.0
3	0.48	47	0.831	50.0
4	0.42	45	0.884	60.0
5	0.36	43	0.941	70.0
6	0.30	240	0.982	50.0
7	0.24	63	1.000	50.0
8	0.18	238	1.132	60.0
9	0.12	271	1.136	50.0
10	0.06	269	1.259	60.0
11	-0.00	256	1.308	50.0
12	-0.06	287	1.354	50.0
13	-0.12	285	1.496	60.0
14	-0.18	261	1.443	100.0
15	-0.24	279	1.303	90.0
16	-0.30	277	1.231	100.0
17	-0.36	273	1.114	120.0
18	-0.42	278	1.101	100.0
19	-0.48	274	1.019	120.0
20	-0.54	288	0.988	50.0

Figure 3.1 Flow of OTΔT Confirmation

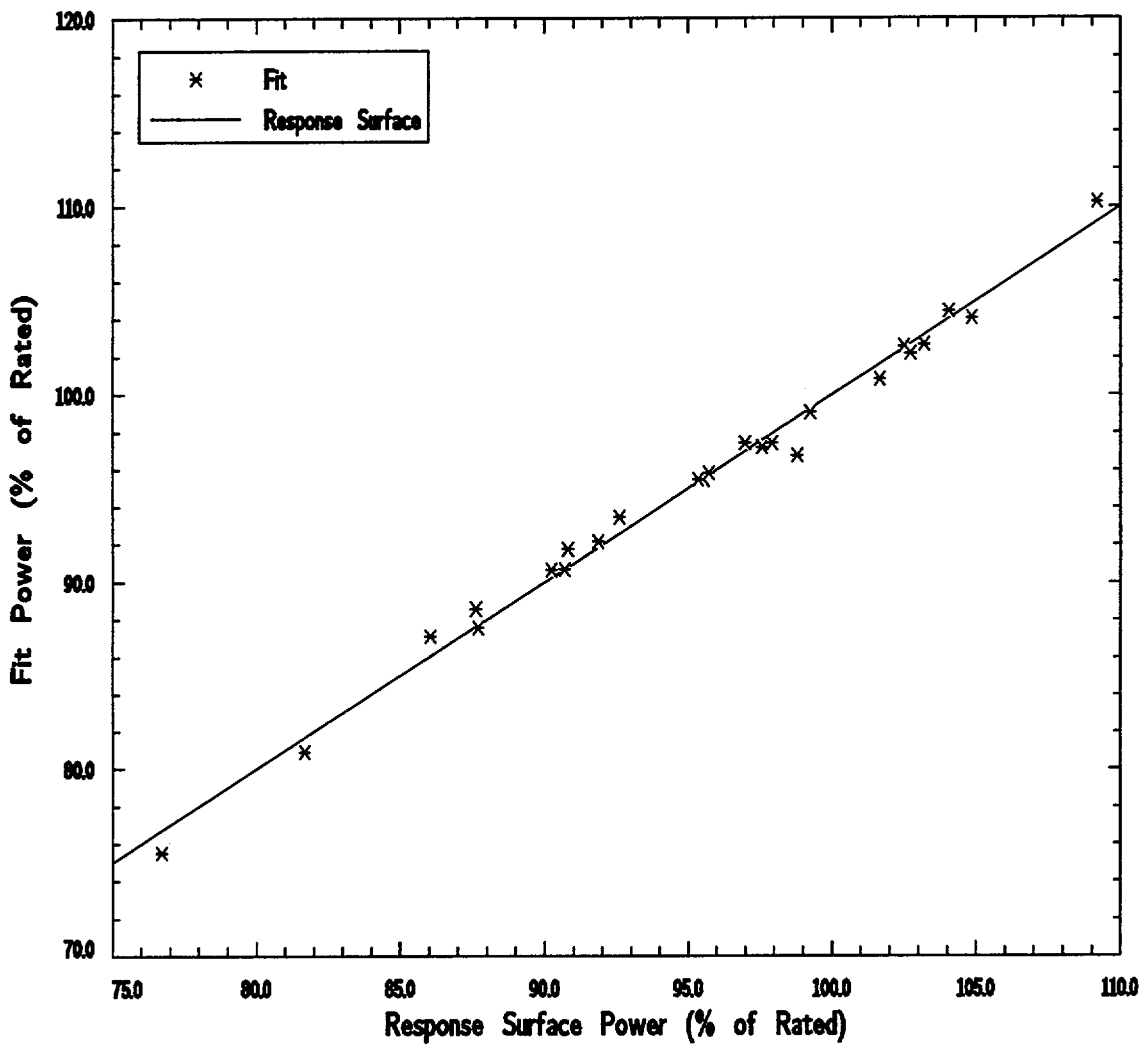

Figure 3.2 Fit to Response Surface for OTΔT Confirmation

Figure 3.3 Probability Distribution for DNB Power

Figure 3.4 Probability Distribution of Adjusted DNB Power

Figure 3.5 Probability Density for Power From ΔI Uncertainty

Figure 3.6 Overall Probability Distribution for Margin to OTΔT

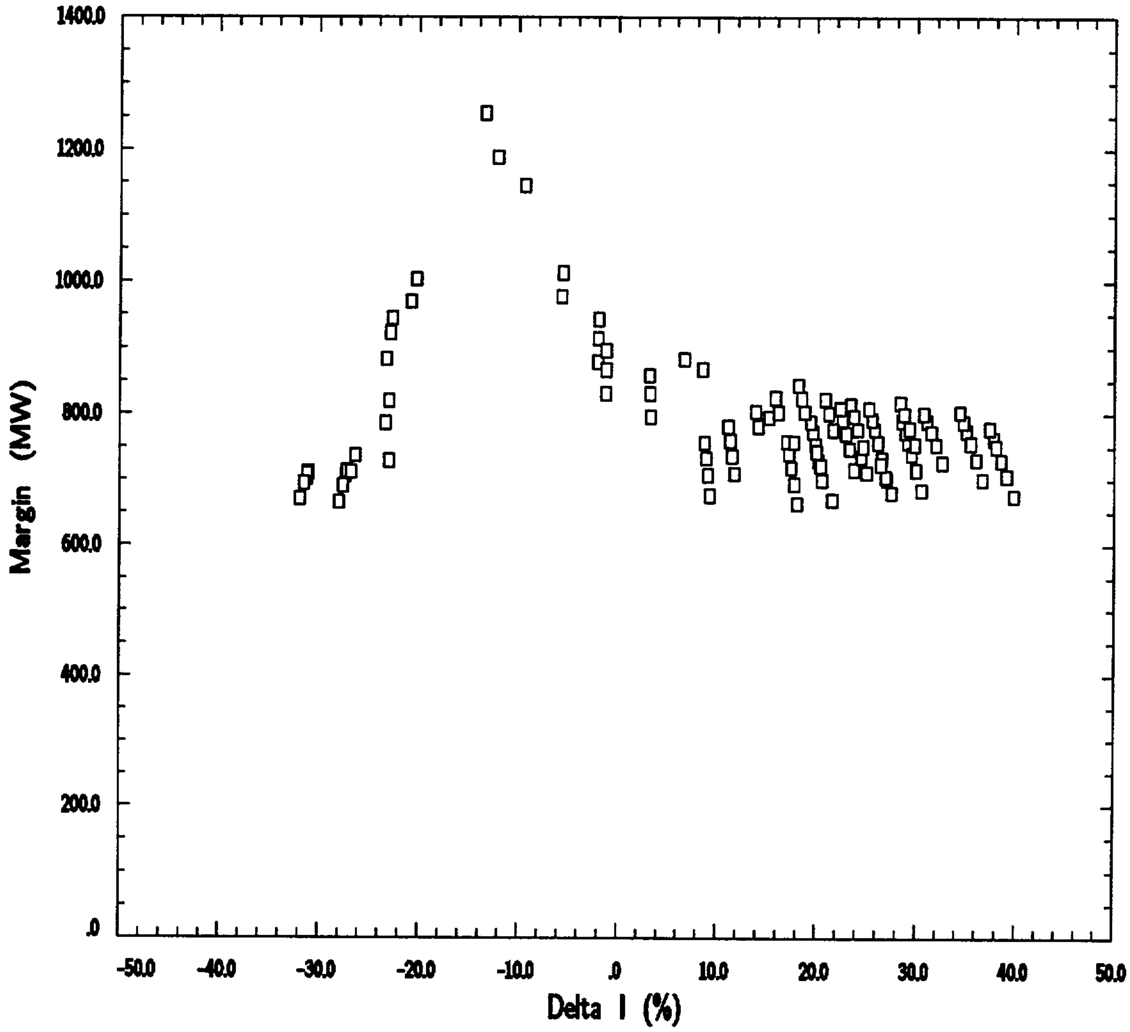

Figure 3.7 Overall Margin

4. Statistical Transient Analysis Methodology

The Westinghouse-type plant statistical transient analyses are performed in a manner that results in the reactor protective system (RPS), in conjunction with the LCOs, protecting the SAFDLs and pressure limits with a 95% probability at a 95% confidence limit. This can be done by determining the required setpoint or confirming the margin when the trip setpoint is specified or for a case in which no trip occurs.

For slow transients, the OTΔT and OPΔT trips are designed to protect against DNB, hot leg saturation and FCM. For a class of events characterized by more rapid power excursion, confirming that the trip system protects or setting the trips to protect the SAFDLs.

Events such as a statically misaligned rod or misloaded assembly would not result in a trip and the margin to DNB would be confirmed. Sections 4.3 through 4.6 cover setting trips and confirming margin.

The description of a statistical treatment of uncertainties in the following section does not preclude the deterministic treatment of any, or all, of the uncertain parameters.

4.1 Calculation of the Trip Setpoint

This method would be used to set a trip that provided the only active protection for SAFDLs or pressure limits. The product from this process is a trip setpoint (or trip coefficients) that protects against the SAFDLs or pressure limits with 95% probability at a 95% confidence.

The statistical transient process for calculating trip setpoints is similar to the process outlined for the OTΔT and OPΔT trip setpoints. The steps, which assume that multiple points are required for the transient, are as follows:

[

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[

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When the transient really has only one point, the DETSCAN portion can be eliminated and the single point is the most sensitive point.

The NOMSCAN and DETSCAN calculations determine the conditions that produce the greatest change in the required trip setpoint. When a single set of conditions exists, the nominal calculations and response surface calculations are performed at this single point. Most transients represent a single point. In the case of bank withdrawals at power, the spectrum of withdrawal rates can be considered as a set of conditions and the each withdrawal rate treated as a separate point. When multiple points exist, the most sensitive point is determined by finding the set of conditions that results in the largest change in the trip setpoint corresponding to the limit (DNBR, FCM, or pressure) between the calculation with nominal values (including the limits) and the calculation with deterministic values.

A response surface in the trip setpoint is created at either the single point or at the most sensitive point using those variables that are not a part of the trip uncertainty. The resulting data are fit with a polynomial to create a response surface in the trip setpoint. This process is performed in accordance with SPC's approved GSUAM methodology.

[

] The values

and distributions of the various uncertainty plant parameters are justified on a plant-specific basis.

[

]

The 95% probability/95% confidence uncertainty-adjusted trip is determined from the probability distribution described in the preceding paragraphs or taken from the

Monte Carlo run. [

] The most limiting of the resulting trip setpoints is the setpoint that will prevent the transient from violating the respective limit with 95% probability at a 95% confidence level and is used in setting the Technical specification value.

If the trip being considered is either the OPΔT or OTΔT, and if the trip coefficients were calculated based on the setpoint analysis discussed in Sections 2 and 3, the more limiting statistical trip value is used in the setting of the Technical Specifications.

The calculation of the probability distribution for the trip setpoint corresponding to FCM is performed in the same manner as the system pressure calculations, except that the trip is adjusted in each case to produce the FCM. [

]

4.2 Multiple Trip Setpoints

In some cases multiple trips may be involved. As an example, bank withdrawal from power may be terminated by OTΔT or a High Flux trip. In the most limiting cases, more than one trip would be expected to be reached. This makes the confirmation of a single trip much more complicated, unless the other trips are assumed to be nonfunctional.

Rather than take the unnecessary conservative assumption that the other trips cannot intervene, the probability distributions for each trip can be evaluated independently, assuming the other trips do not intervene, and the overall probability of DNB (or FCM on system pressure limit) calculated for the ensemble of trips available. [

]

[

]

This process is somewhat cumbersome compared to the direct confirmation of the complete trip system described in the Section 4.3. However, after the DNB (or FCM on system pressure) probability distributions for each trip have been determined, evaluating a large number of combinations of trip setpoints in order to determine an optimum combination that still provides the protection is relatively simple. Since the major calculational task is determining the probability density based on each trip. This is done by selecting a set of nominal trips, evaluating the probability distribution for each trip and calculating the overall probability of failure, P_{TRIP}, for each combination.

4.3 Confirmation of Margin

The purpose of transient analysis is to confirm that the RPS and LCOs, as configured for the operating cycle, will meet the SAFDLs and system pressurization limits. The confirmation of these values is based on their ability to protect against violation of all acceptance limits with a prescribed level of uncertainty, generally 95% probability at a 95% confidence level.

To confirm the margin to DNB (or FCM or the system pressure limit), the experimental design can vary the system parameters, trips and LCOs. The overall probability distribution of the margin between the MDNBR (or peak kW/ft or system pressure) and the limit can be created and the probability that the system will protect the limit determined.

The calculation of the MDNBR would involve first creating a response surface for the parameter being tested using the transient system code and XCOBRA-IIIC, if

needed. This response surface in calculated MDNBR would be fit with a polynomial, which would be used to combine the uncertainties in the transient response with other uncertainties. The probability of exceeding the limit would be calculated from this overall margin distribution. If this probability were less than 5%, the event consequences would be acceptable.

For DNB, a separate response surface can be created in MDNBR based on variable uncertainties that are unaffected by the transient, [

] The two response surfaces would then be combined to produce the final probability distribution. The probability can be converted to an effective MDNBR as described in Section 4.4 below.

Treating a subset of variables deterministically will result in simplified calculation and a conservative confirmation of margin.

4.4 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 deterministic method, this is done by calculating the MDNBR with all parameters treated deterministically. In the simplified statistical method, some of the parameters are treated statistically. The flow for confirming the DNB margin when the system transient is not treated statistically is summarized in Figure 4.1.

In the simplified confirmation, the parameters affecting the system response are treated deterministically. The uncertainties, treated statistically are the those corresponding [

]

[

]

4.4.1 Margin to DNB

A response surface calculation is performed using XCOBRA-IIIC to capture the variation in MDNBR with power and peaking. [

] The margin to DNB is calculated by subtracting the DNBR that corresponds to DNB from the MDNBR. Because both of these values are uncertain, a probability of DNB and the effective MDNBR (based on the correlation statistics) are calculated.

A base, deterministic XCOBRA-IIIC deck is modified to produce a large number of altered input decks for XCOBRA-IIIC. [

]

The statistical calculation of the DNB margin uses a series of MDNBR calculations performed by XCOBRA-IIIC to quantify the variation caused [

]

[

]

4.4.2 Effective MDNBR

[

]

4.5 Simplified FCM Margin Confirmation

The FCM margin is calculated similarly to the DNB margin. However, the calculation is simpler because the uncertainty in the peak LHGR is calculated

directly and the FCM limit has been calculated using a deterministic process (Appendix A).

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

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

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 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 final power margin is obtained by subtracting the event power, Q_{event}, from the FCM power.

The margin is calculated for a wide range of shapes and each margin is associated with an axial offset (AO). To convert the AO to ΔI margin, the relative power for the event (not the effective power, but the ex-core detector power divided by the rated power) is multiplied by the AO and the sign is changed. Cases with ΔI values outside of the deadband of the reset function are rejected.

4.6 Sample Case - DNB Margin

Table 4.3 contains 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. Table 4.4 lists the response surface points created by this experimental design. The response surface points were then fit [ ]. 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 [ ] was combined with the response surface uncertainty to give the [ ] for MDNBR shown in Figure 4.4.

[ ] an effective MDNBR [ ] was calculated. The resulting MDNBR is 1.185.

4.7 Sample Case - FCM Margin

The input for the FCM sample case is given in Table 4.5. [ ]

[ ] 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. [ ] for this case is given in Figure 4.7.

Combining [ ] gives the overall [ ] shown in Figure 4.8. At the 5% level, the margin is about 15 MWt (~0.65% RTP).

This process is repeated for all axial power shapes. Each axial power shape corresponds to a specific AO, which is converted to ΔI using the High Flux Trip power. This power was selected, because the event tripped on the High Flux Trip and, therefore, the ex-cores were reading the nominal High Flux Trip power. The allowable range for the cases to be considered is the deadband of the reset function adjusted by the ΔI uncertainty (3%). In this case, the range is from -20% to +15%. The margin is shown in Figure 4.9. In all cases, the margin is positive and no fuel failure by FCM is predicted.

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 $F_{(\Delta H,r)}$ - 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

Variable	Value

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

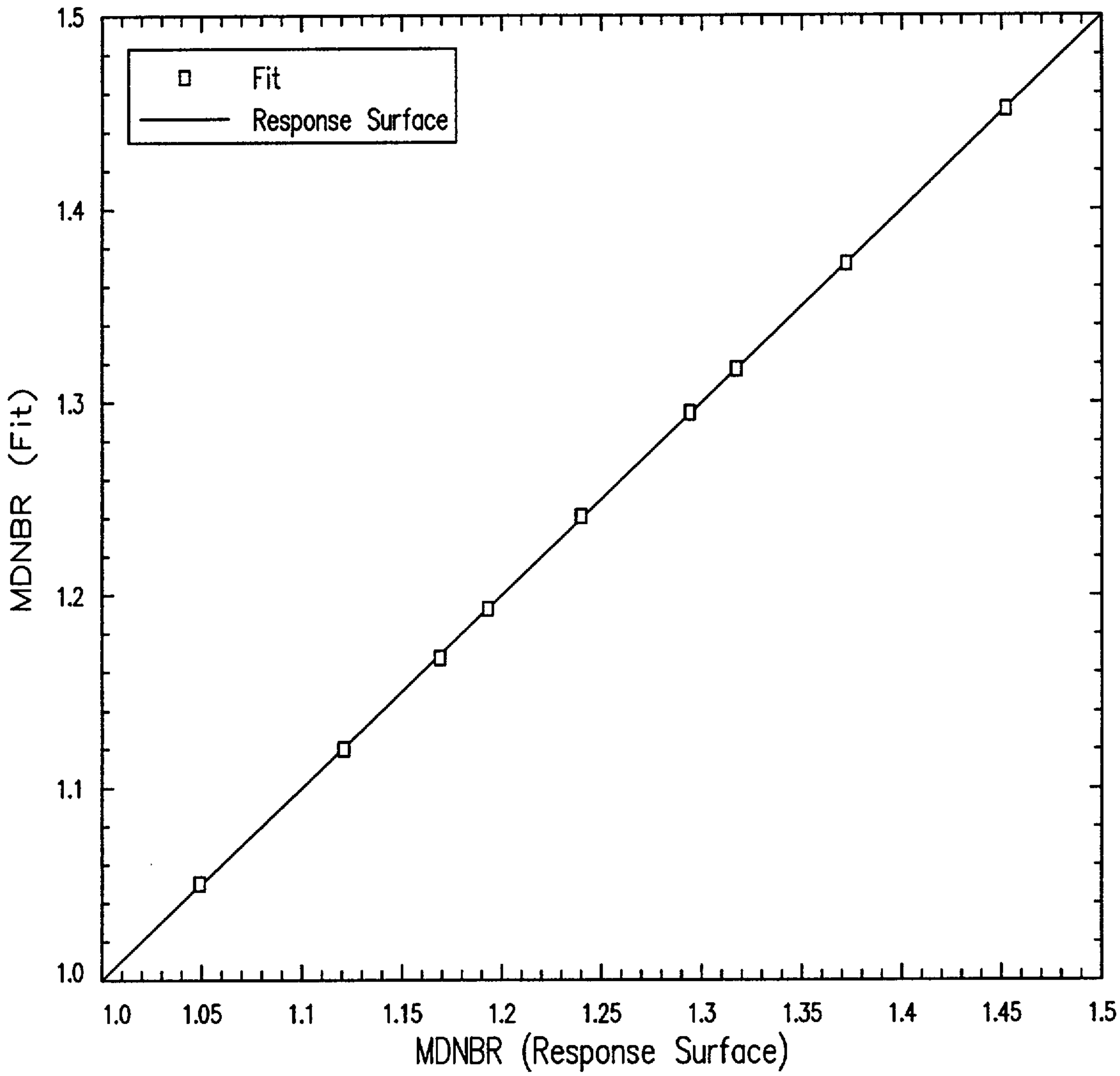

Figure 4.2 Fit to MDNBR Response Surface for Sample Case

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

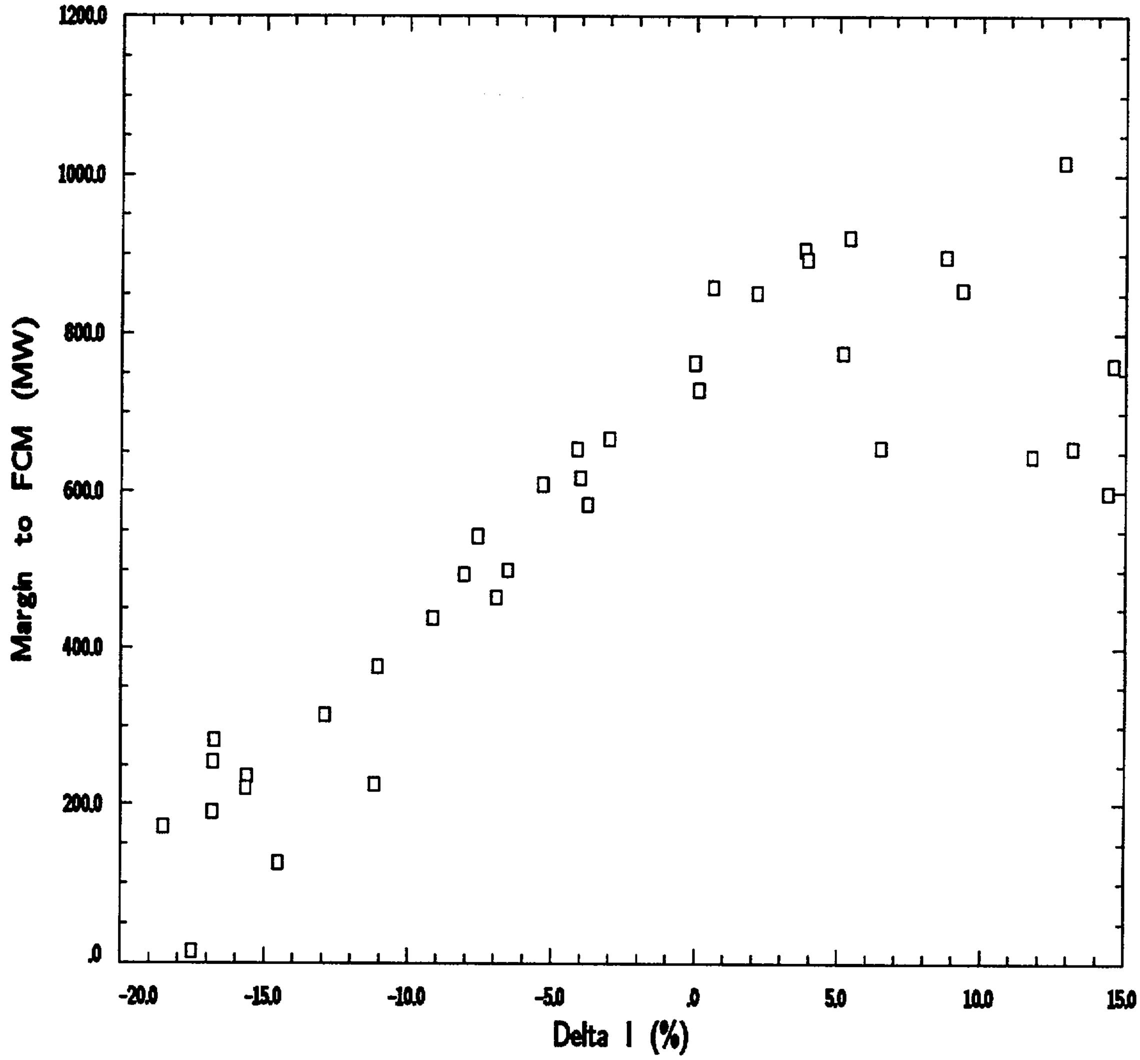

Figure 4.9 Margin to FCM for Sample Case

5. Neutronics Analysis

This section describes the generation of the axial power shapes used in determining the F(ΔI) portion of the reactor trip functions. An F(ΔI) adjustment is used in the OPΔT and OTΔT trips to account for the effect of variations in the core axial power distribution on the margin to FCM and DNB, respectively.

The following procedure establishes the reactor core model that generates the axial power shapes used in the setpoint analyses.

[

]

[

]

The radial peaking factor for each axial shape is augmented to the Technical Specification limit at the corresponding power level. The total peaking factor for each axial shape is also increased by this augmentation factor.

6. References

1. *Generic Statistical Uncertainty Analysis Methodology*, XN-NF-22(P)(A), November 1983.

2. *Statistical Setpoint/Transient Methodology for Westinghouse Type Reactors*, EMF-92-081(P)(A) and Supplement 1, February 1994.

3. *Factors for One-Sided Tolerance Limits and Variable Sampling Plans*, SCR-607, U.S. Department of Commerce, National Technical Information Services, March 1963.

4. *ENC Setpoint Methodology for C. E. Reactors: Statistical Setpoint Methodology*, XN-NF-507(P)(A), Supplements 1 and 2, September 1986.

APPENDIX A - FUEL MELT LIMIT

The fuel centerline melt (FCM) limit is expressed as a function of a limit on linear heat generation rate (LHGR). This Appendix describes 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 is generally set by the highest concentration gadolinia-bearing rod at the highest burnup achieved for the cycle.

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

A.1 *RODEX2 Runs*

The FCM limit calculation uses several 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. A schematic of the flow of the calculation is given in Figure A.1.

A number of RODEX2 runs are made, one for each gadolinia concentration. 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 the beginning, middle and end of the cycle (BOC, MOC and EOC) 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 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 to nearly 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 an example of 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 very short time 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 calculations which result in the LHGR for FCM consists of two steps: 1) calculation of the melt curves for UO_2 rods and fuel rods with gadolinia concentrations 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 being 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 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:

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

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 expressed as a percent. The melt temperature [

] of the rod (Reference A.3).

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. An example of a set of typical melt curves is given 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 operating cycle. The FCM limit is the minimum LHGR for all 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 17x17 Westinghouse fuel design containing all gadolinia concentrations in the design. 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 calculated.

Table A.7 shows the minimum UO_2 rod powers at FCM for each gadolinia concentration at a series of assembly burnups. These rod powers 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. 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 assembly analyses 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 begins 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

RODEX2 Calculations				
UO_2 Rod	2 w/o Gad Rod	4 w/o Gad Rod	6 w/o Gad Rod	8 w/o Gad Rod

↓ ↓ ↓ ↓ ↓

Calculate the FCM LHGR

- Calculate the fuel melt curves based on rod power and burnup from the RODEX2 output for each gadolinia concentration.
- Use the [ ] to convert the fuel melt curves to UO_2 rod limits based on protecting all rods
- Find the most limiting value for the first cycle of operation.

Figure A.1 Flow of FCM Calculations

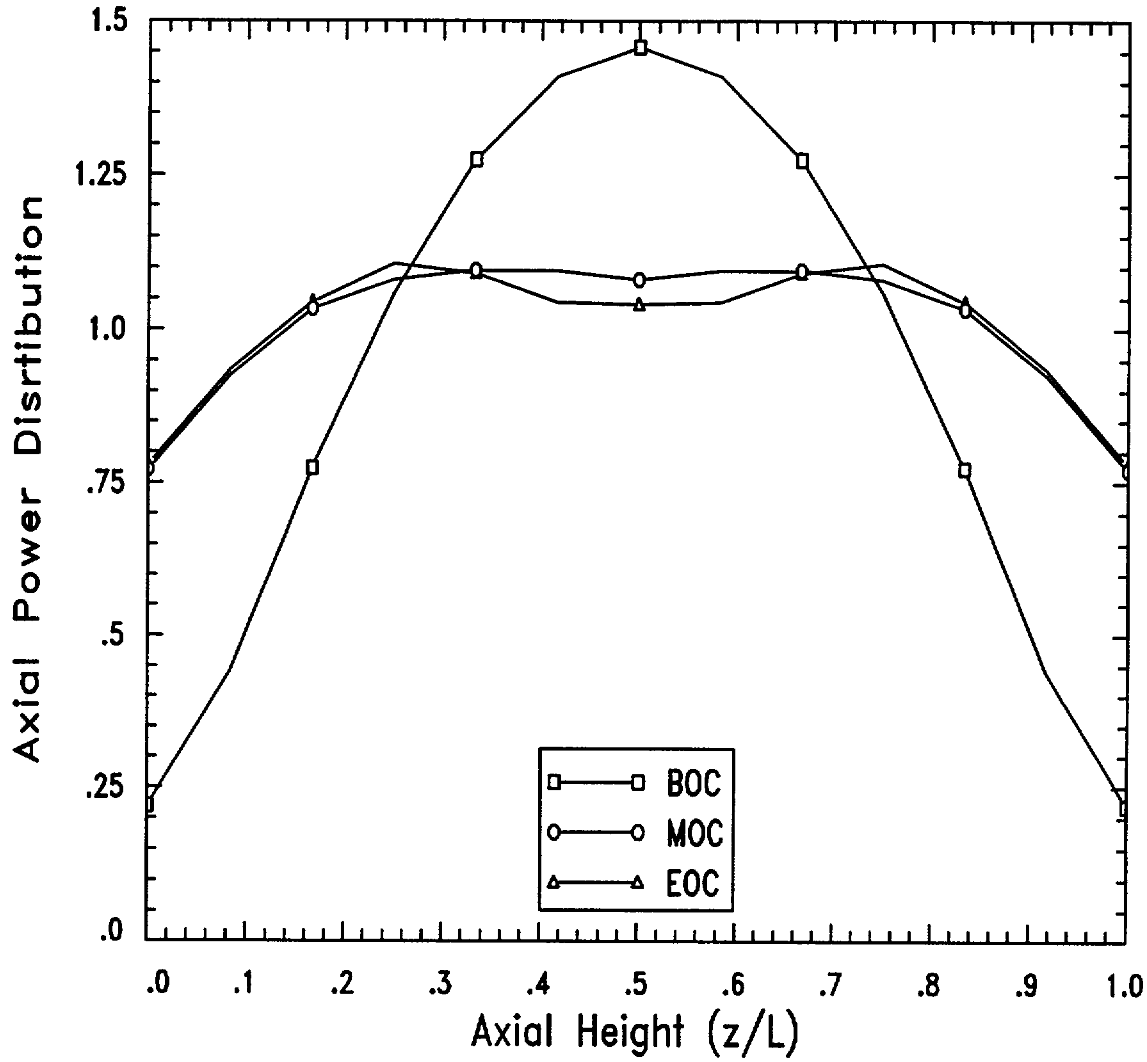

Figure A.2 Axial Power Shapes (BOC Shape uses $F_Q/F_{\Delta H}$ - 1.46)

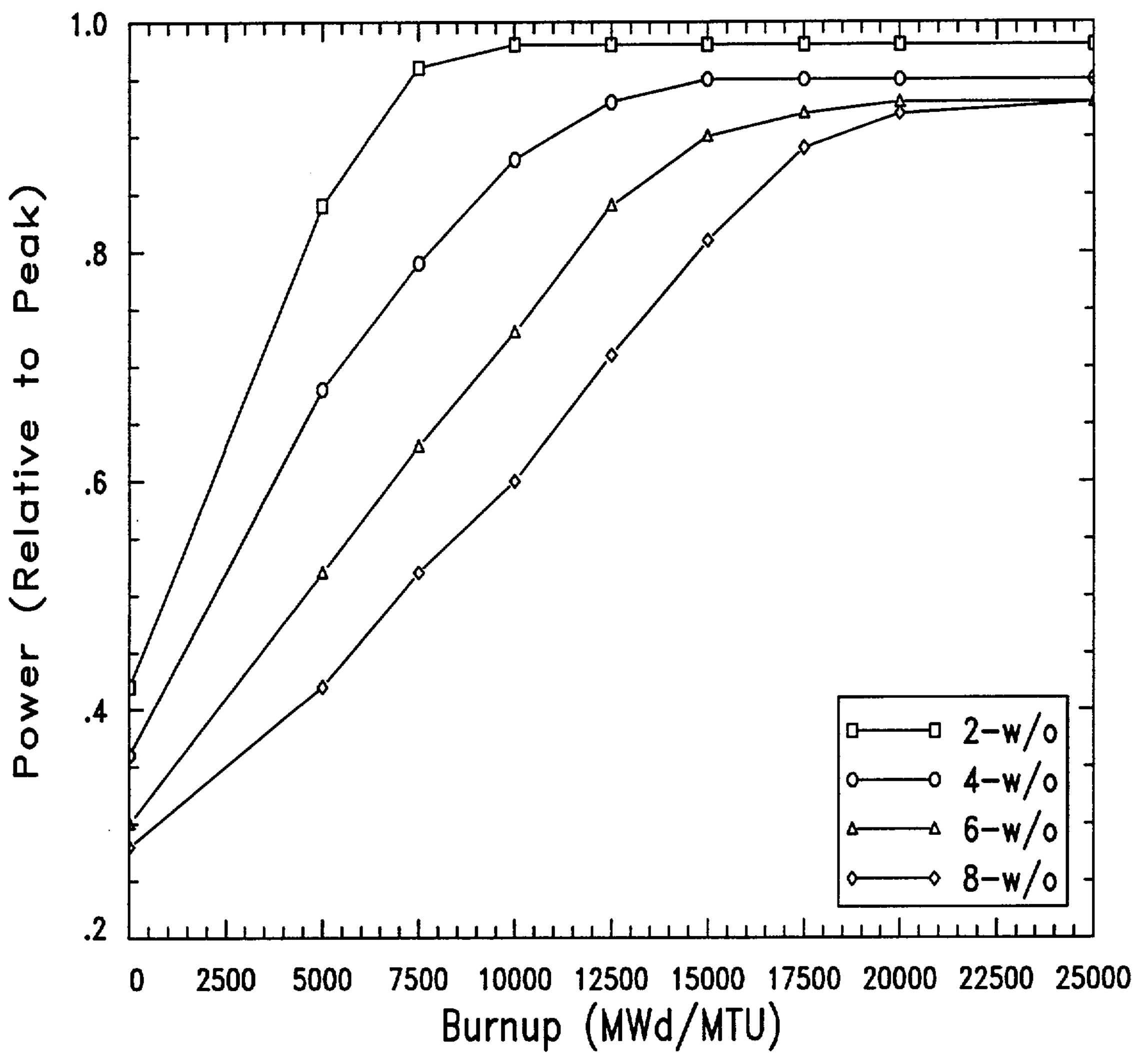

Figure A.3 Power Levels (Relative to High Powered UO_2 Rod) for Gadolinia Rods

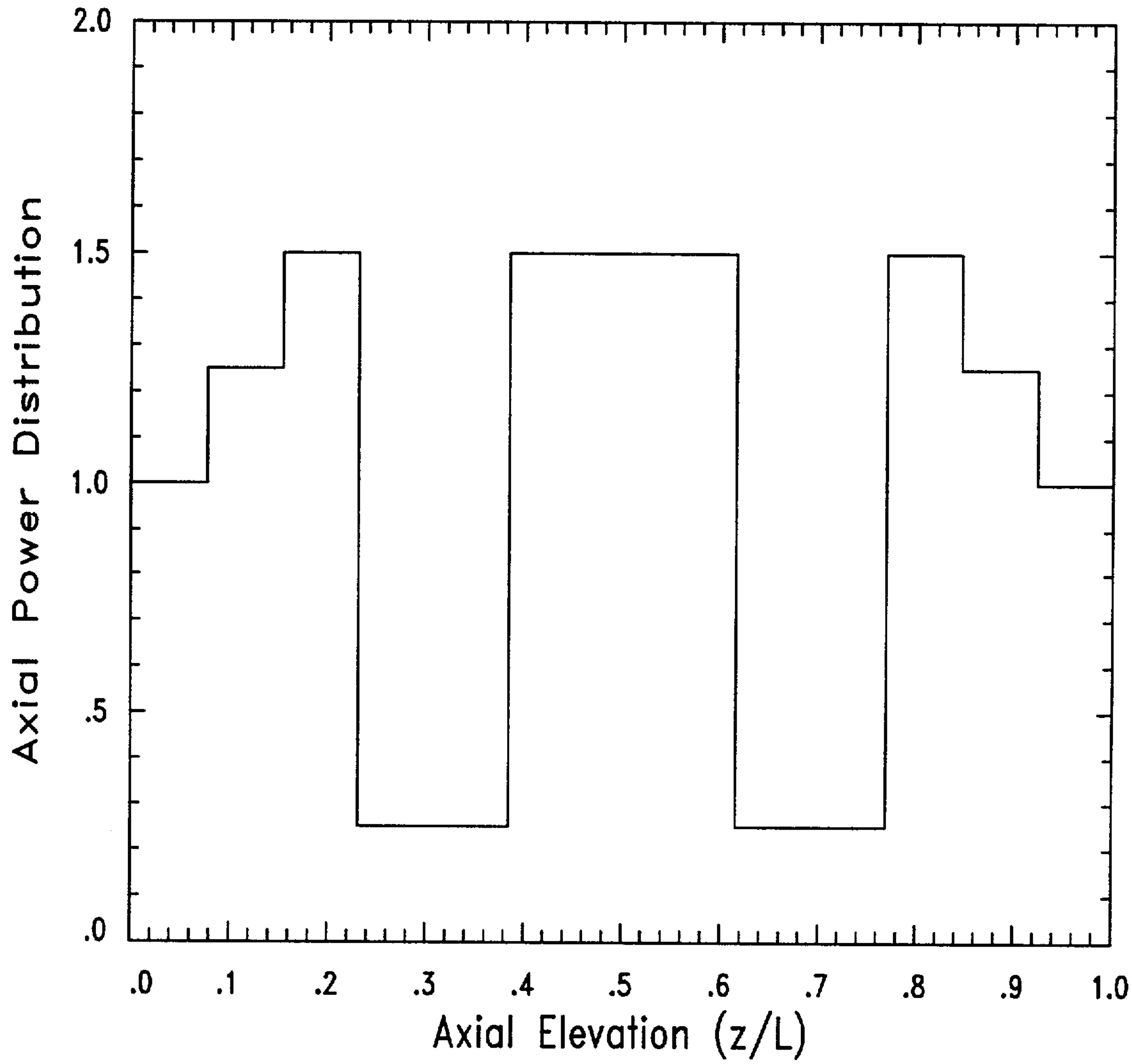

Figure A.4 Axial Power Shape Used in Spiking the LHGR to Melt

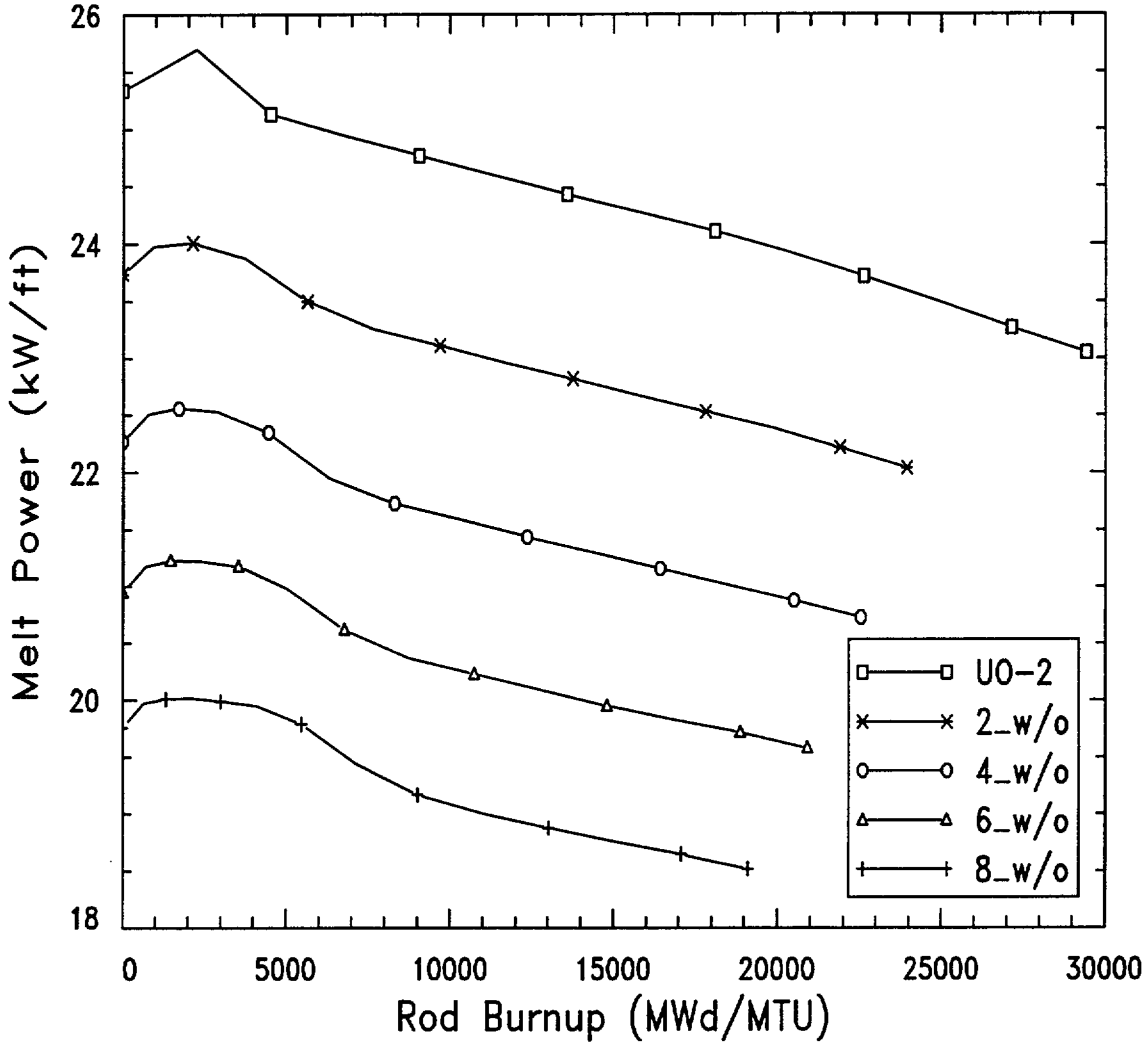

Figure A.5 Fuel Melt Curves

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

The Core Safety Limit Lines (CSLLs) are 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 MDNR 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 Departure from Nucleate Boiling (DNB). These CSLLs can be created by plotting the curves for hot leg saturation and deterministic DNB and then using the confirmation process to iterate until the desired margins are obtained. When plant conditions change (uncertainties, flows, radial peakings or DNB correlations), the CSLLs, which are the basis for the OTΔT trip for Westinghouse plants, are confirmed.

B.1 Confirmation of CSLLs

The confirmation of CSLLs is similar to the confirmation of DNB and hot-leg saturation for the OTΔT trip. The main difference is that only one axial power shape is used in the confirmation. A design axial shape is used, if available. If none exists, the cycle-specific axial power shape that produces the lowest DNBR and that has a ΔI within the deadband of the reset function is used.

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 incorporated to reduce the nominal margin.

The DNBR calculations are performed by XCOBRA-IIIC. These calculations are performed for a single axial power shape over a range of power and inlet temperature to find the nominal conditions at which DNB would occur with a 50% probability. The nominal DNB points are a series of cases at different powers, pressures and inlet temperatures that produce an MDNBR that is at the DNB correlation mean value. 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 get 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 margin is adjusted for uncertainties in order to obtain the power margin provided by the CSLLs.

The overall margin is given by the nominal margin adjusted by the lower 95% limit of the margin distribution

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

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, this is just the calorimetric uncertainty in power, f_{cal}. When it is set by DNB, this power is the combination of the [

]

The CSLLs are 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 as

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

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 axial shape is shown in Figure B.3.

[1] Except for 2,400 psia line.

The nominal cases consist of 66 different pressure and power combinations for the design axial. These cases are listed in Table B.4. All nominal cases converged on an inlet temperature for DNB during the scan. The case with the largest change in power between the nominal case and the deterministic case was at 100% power and had an inlet temperature of 619 °F and a core exit pressure of 2,460 psia. This nominal case was used as the input for the response surface calculation.

The response surface output had 91 points covering the range from about 75% RTP to about 110% RTP. 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 CSLL verification was performed.

Cases were first tested to be sure that the MSSVs would not open. This test eliminated 46 cases in the hot-leg saturation scan and the nominal case scan, together

The CSLL was checked 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 66 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 CSLL was checked to confirm that it protects against DNB. The DNB response surface points were fit with a [

] was calculated. Figures B.4 and B.5 show the [

] 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 in a region where the transition between the hot-leg saturation portion of the CSLL and the isotherm for the inlet temperature can effect the shape of the probability densities.

[

]

This process was repeated for all 66 nominal points in the file of nominal cases and for 28 hot-leg saturation cases. Statistically adjusted margins for the 48 cases that avoided opening the MSSVs were calculated. These ranged between 520 MWt and 2,232 MWt, confirming that the CSLLs would protect against DNB and hot leg saturation.

Table B.1 Uncertainties in CSLL Confirmation

Index	Variable	Description of Uncertainties

Table B.2 Input for CSLL Confirmation: Sample Case

Variable	Value

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

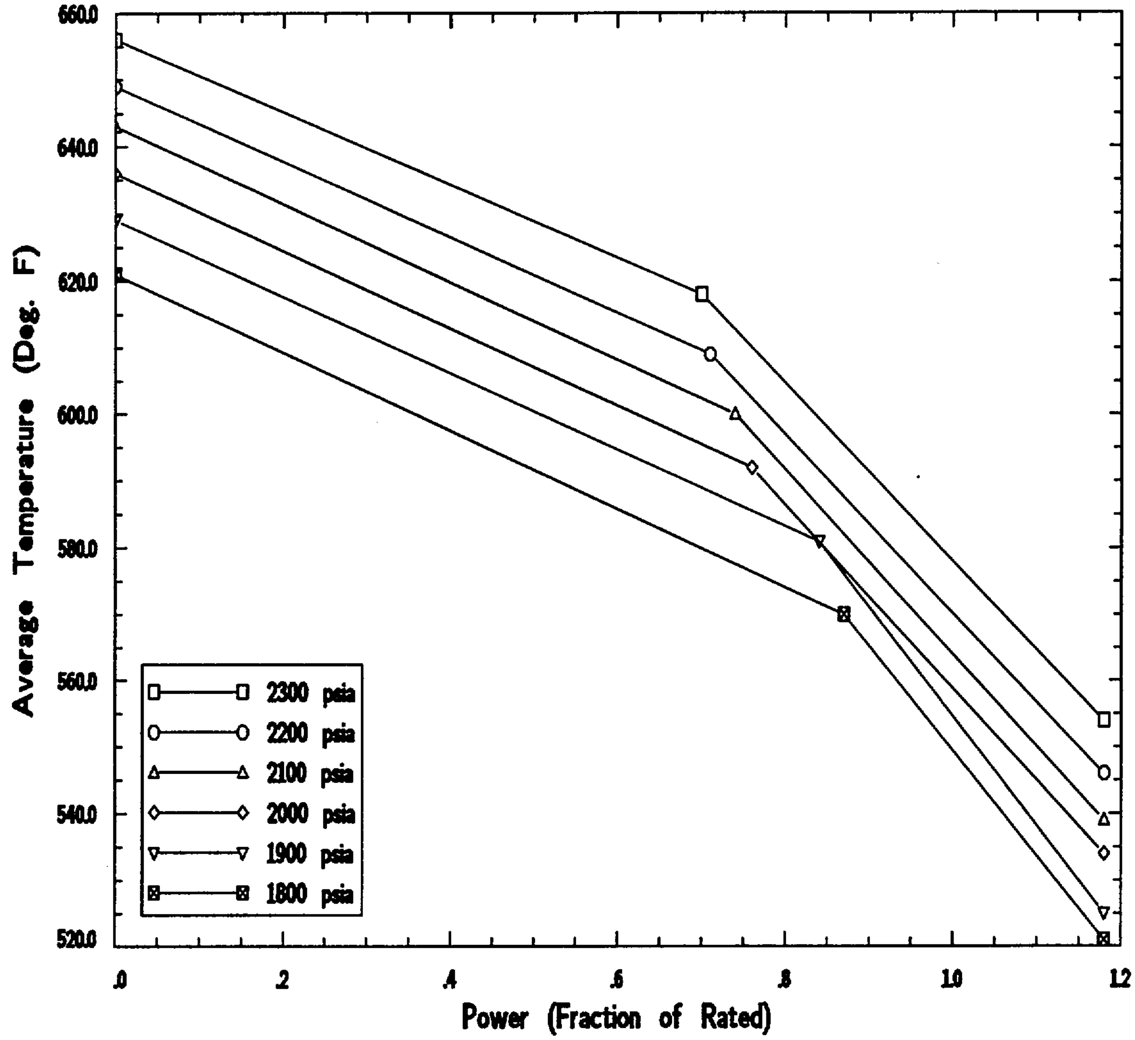

Figure B.2 CSLLs for Sample Case

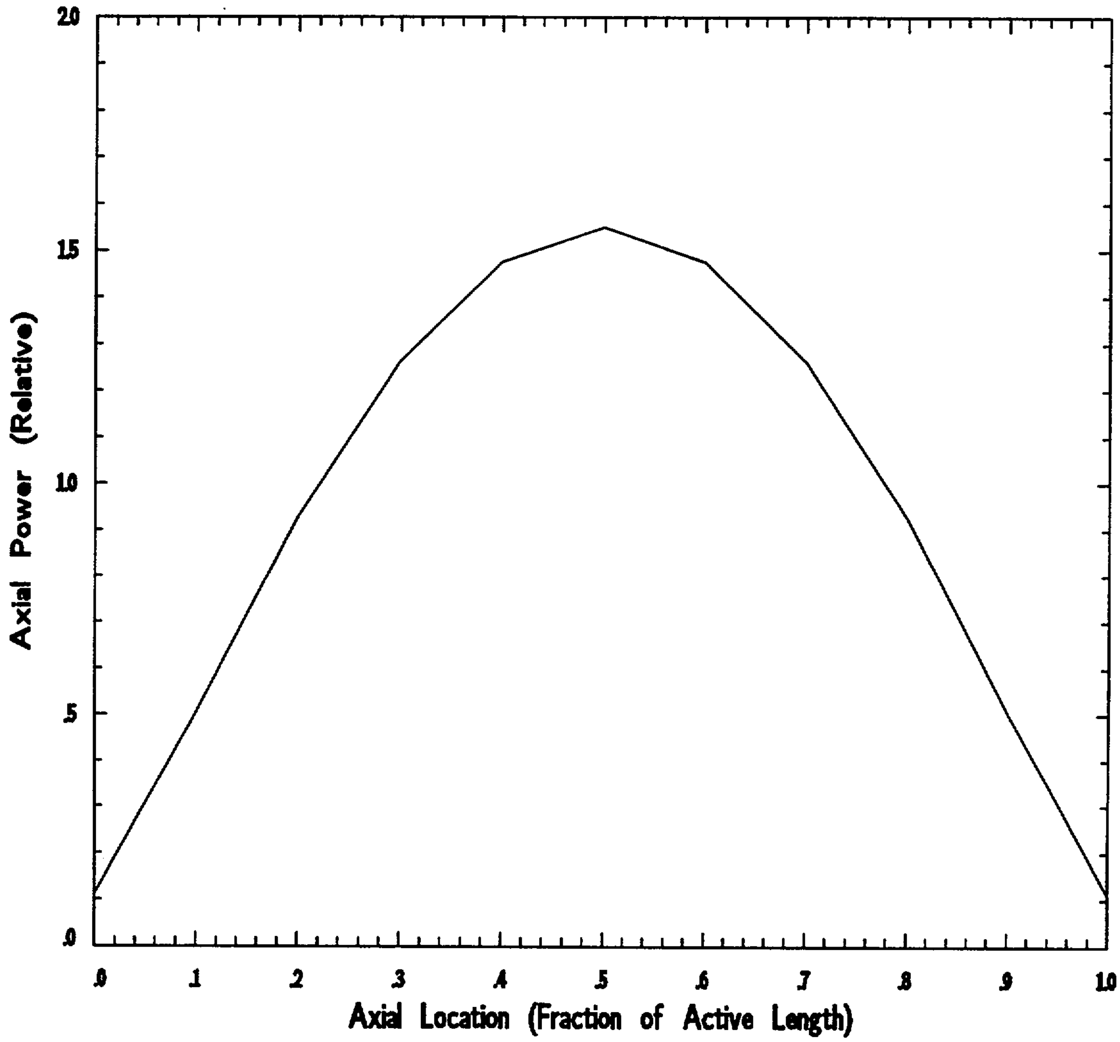

Figure B.3 Design Axial Power Shape for CSLL Confirmation

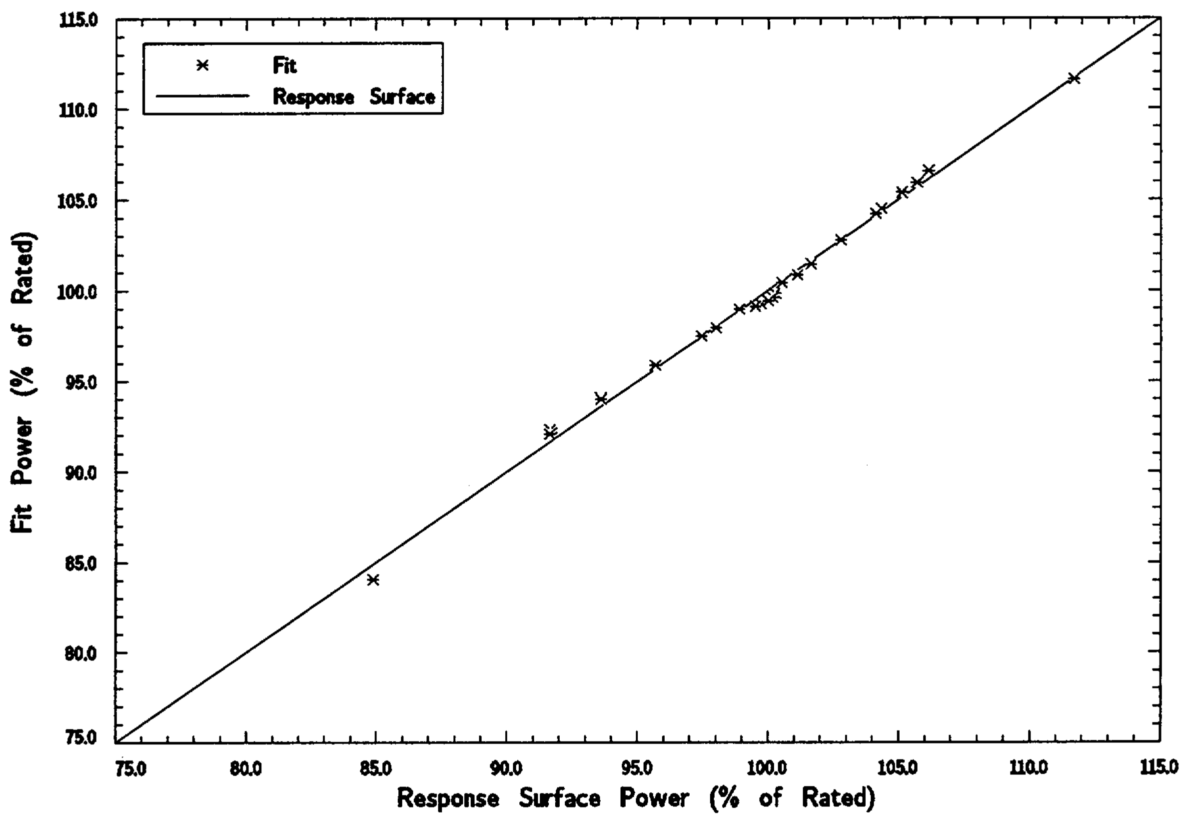

Figure B.4 Fit to DNB Response Surface

Figure B.5 Probability Distribution for Power From Response Surface

Figure B.6 Probability Distribution for Power

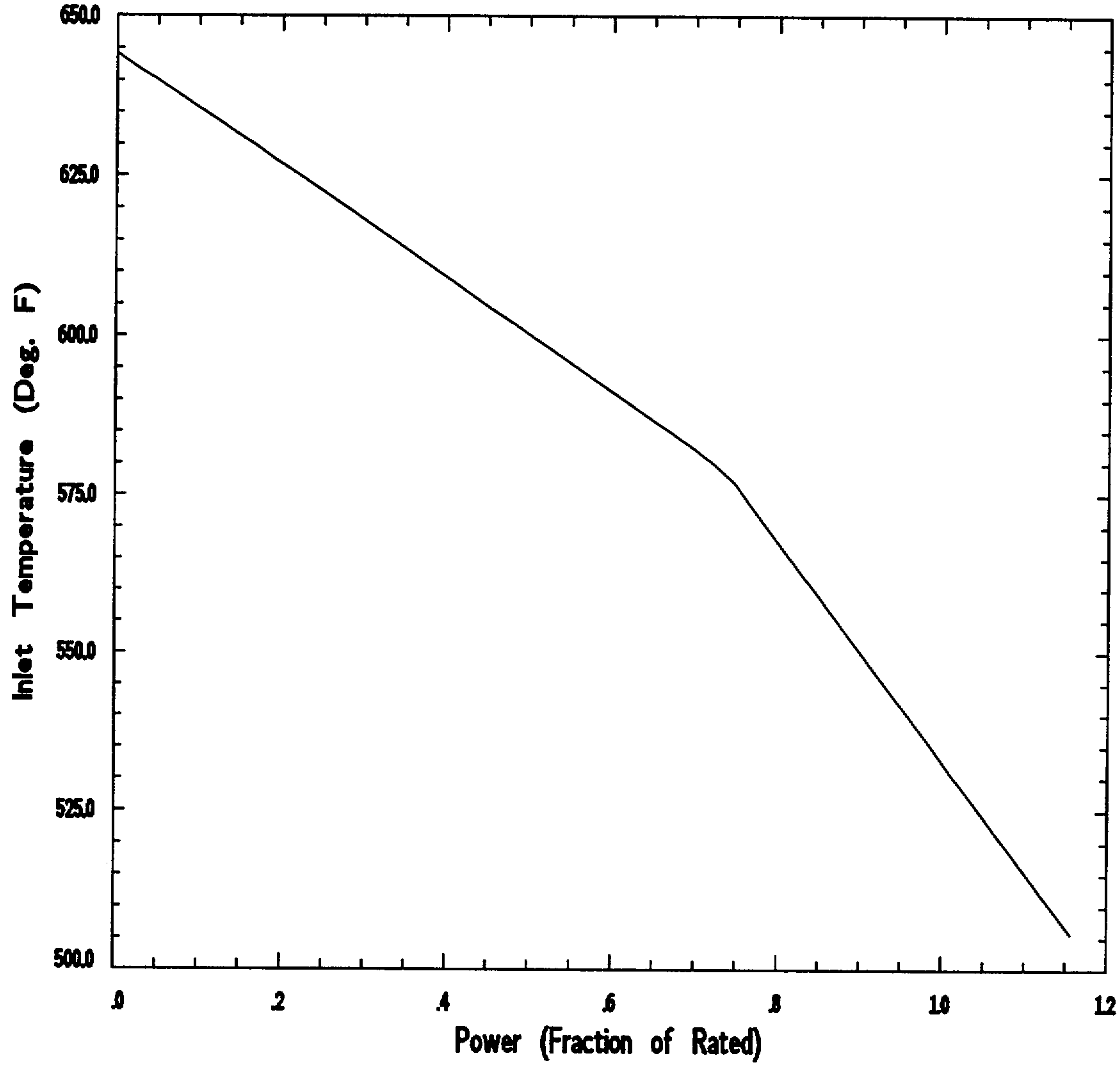

Figure B.7 Isobar at 2,120 psia

Figure B.8 Probability Density for Power From Temperature Uncertainty

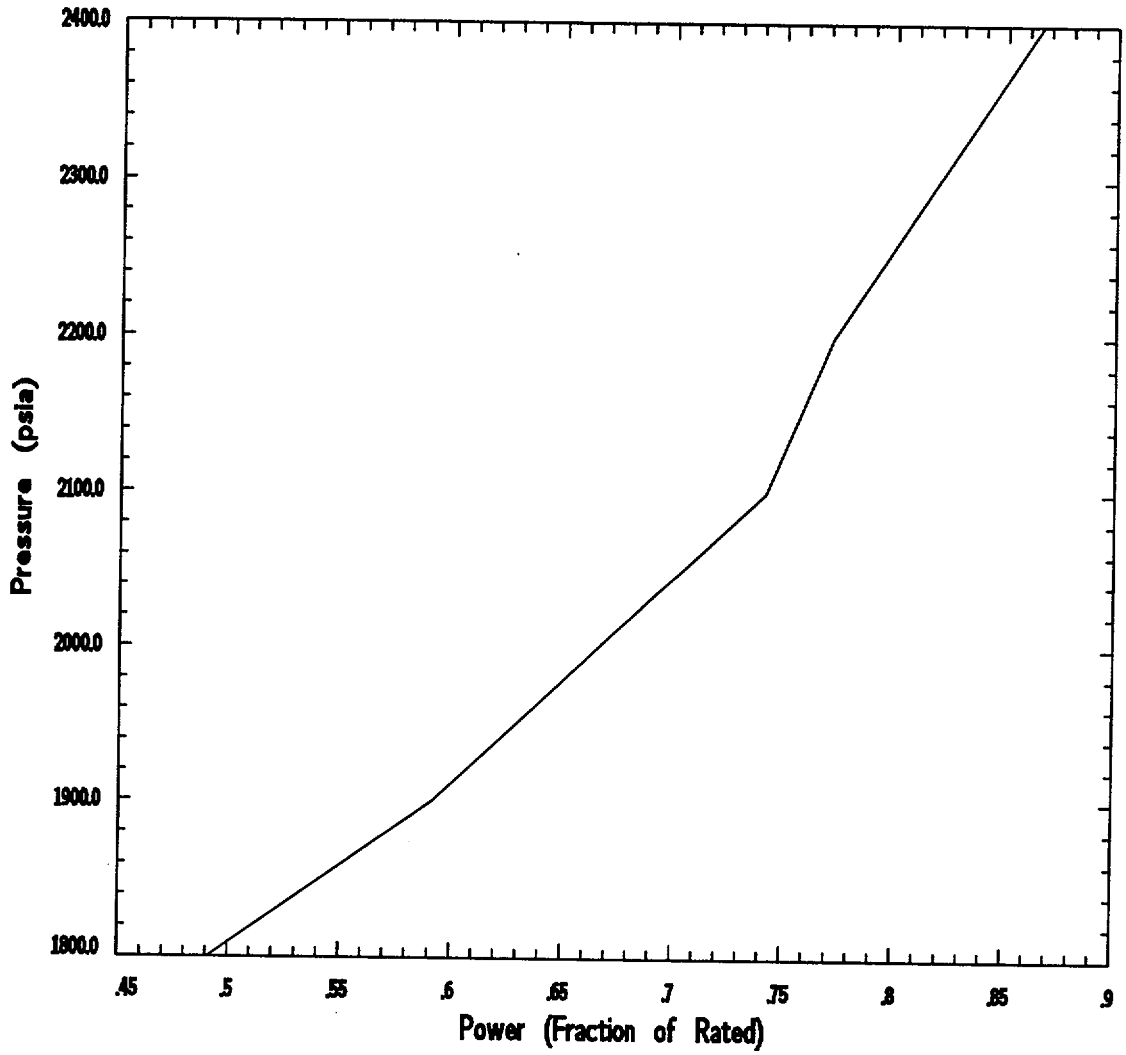

Figure B.9 Isotherm for 577°F

Figure B.10 Probability Density for Power From Pressure Uncertainty

Figure B.11 Probability Distribution for Statistical Adjustment to Power Margin