Westinghouse Non-Proprietary Class 3

WCAP-16523-NP-A August 2007

Westinghouse Correlations WSSV and WSSV-T for Predicting Critical Heat Flux in Rod Bundles with Side-Supported Mixing Vanes

Westinghouse

WCAP-16523-NP-A

Westinghouse Correlations WSSV and WSSV-T for Predicting Critical Heat Flux in Rod Bundles with Side-Supported Mixing Vanes

Original Version: March 2006
Approved Version: August 2007

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Section A

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March 15, 2007

Mr. James A. Gresham, Manager
Regulatory Compliance and Plant Licensing
Westinghouse Electric Company
P.O. Box 355
Pittsburgh, PA 15230-0355

SUBJECT: FINAL SAFETY EVALUATION FOR WESTINGHOUSE ELECTRIC COMPANY (WESTINGHOUSE) TOPICAL REPORT (TR) WCAP-16523-P, "WESTINGHOUSE CORRELATIONS WSSV AND WSSV-T FOR PREDICTING CRITICAL HEAT FLUX IN ROD BUNDLES WITH SIDE-SUPPORTED MIXING VANES" (TAC NO. MD0561)

Dear Mr. Gresham:

By letter dated March 17, 2006, Westinghouse submitted TR WCAP-16523-P, "Westinghouse Correlations WSSV and WSSV-T for Predicting Critical Heat Flux in Rod Bundles with Side-supported Mixing Vanes," to the U.S. Nuclear Regulatory Commission (NRC) staff for review. By letter dated December 26, 2006, an NRC draft safety evaluation (SE) regarding our approval of TR WCAP-16523-P was provided for your review and comments. By letter dated January 17, 2007, Westinghouse commented on the draft SE. The NRC staff's disposition of Westinghouse's comments on the draft SE are discussed in the attachment to the final SE enclosed with this letter.

The NRC staff has found that TR WCAP-16523-P is acceptable for referencing in licensing applications for Combustion Engineering designed pressurized water reactors (CE-PWRs) to the extent specified and under the limitations delineated in the TR and in the enclosed final SE. The final SE defines the basis for our acceptance of the TR.

Our acceptance applies only to material provided in the subject TR. We do not intend to repeat our review of the acceptable material described in the TR. When the TR appears as a reference in license applications, our review will ensure that the material presented applies to the specific plant involved. License amendment requests that deviate from this TR will be subject to a plant-specific review in accordance with applicable review standards.

In accordance with the guidance provided on the NRC website, we request that Westinghouse publish accepted proprietary and non-proprietary versions of this TR within three months of receipt of this letter. The accepted versions shall incorporate this letter and the enclosed final SE after the title page. Also, they must contain historical review information, including NRC requests for additional information and your responses. The accepted versions shall include an "-A" (designating accepted) following the TR identification symbol.

If future changes to the NRC's regulatory requirements affect the acceptability of this TR, Westinghouse and/or licensees referencing it will be expected to revise the TR appropriately, or justify its continued applicability for subsequent referencing.

Sincerely,

/RA/

Jennifer M. Golder, Acting Deputy Director
Division of Policy and Rulemaking
Office of Nuclear Reactor Regulation

Project No. 700

Enclosure: Final SE

cc w/encl:
Mr. Gordon Bischoff, Manager
Owners Group Program Management Office
Westinghouse Electric Company
P.O. Box 355
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SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

TOPICAL REPORT WCAP-16523-P

"WESTINGHOUSE CORRELATIONS WSSV AND WSSV-T FOR PREDICTING CRITICAL HEAT FLUX IN ROD BUNDLES WITH SIDE-SUPPORTED MIXING VANES"

WESTINGHOUSE

PROJECT NO. 700

1.0 INTRODUCTION AND BACKGROUND

Topical Report (TR) WCAP-16523-P (Reference 1) describes the development of critical heat flux (CHF) correlations for pressurized water reactor (PWR) fuel designs containing structural mixing vane (MV) grids and intermediate flow mixer grids with side-supported vanes. The correlations, WSSV and WSSV-T, are for 14x14 and 16x16 fuel designs containing side-supported vane grids for Combustion Engineering designed PWRs (CE-PWRs). Both correlations utilize the same form, but with different coefficients. The WSSV correlation coefficients were derived with the Westinghouse version of the VIPRE-01 (VIPRE) (Reference 2) subchannel code. The WSSV-T correlation coefficients were derived with the CE TORC (Reference 3) subchannel code. The correlations were developed based on CHF test data obtained from the Heat Transfer Research Facility of Columbia University. The tests simulated 5x5 and 6x6 arrays of the fuel assembly geometry, side-supported mixing vane grids, uniform and non-uniform axial power shapes, non-uniform radial power distributions, with and without guide thimbles, varied heated lengths, and varied grid spacing.

The functional form of the CHF correlation is empirical and is based solely on experimental observations of the relationship between the measured CHF and the correlation variables. The correlation includes the following variables: pressure, local mass velocity, local quality, a grid spacing term, heated length from inlet to CHF location, and the heated hydraulic diameter ratio of the CHF channel.

In response to the U.S. Nuclear Regulatory Commission (NRC) staff's request for additional information, dated September 8, 2006 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML062430224), Westinghouse clarified the TR and addressed editorial comments by letter LTR-NRC-06-53, dated September 18, 2006 (ADAMS Accession No. ML062680154).

2.0 REGULATORY EVALUATION

Title 10 of the *Code of Federal Regulations* (10 CFR) Part 50, Section 34, "Contents of applications; technical information," requires that Safety Analysis Reports be submitted that analyze the design and performance of structures, systems, and components provided for the

prevention of accidents and the mitigation of the consequences of accidents. As part of the core reload design process, licensees (or vendors) perform reload safety evaluations to ensure that their safety analyses remain bounding for the design cycle. To confirm that the analyses remain bounding, licensees confirm those key inputs to the safety analyses (such as the CHF) are conservative with respect to the current design cycle. If key safety analysis parameters are not bounded, a re-analysis or a reevaluation of the affected transients or accidents is performed to ensure that the applicable acceptance criteria are satisfied.

The NRC staff's review was based on the evaluation of the technical merit of the submittal and compliance with any applicable regulations associated with reviews of topical reports.

3.0 TECHNICAL EVALUATION

Westinghouse has developed a new fuel design, with a 16x16 fuel lattice, for CE-PWRs. The design is described in WCAP-16500-P (Reference 4). The design has side-supported mixing vanes, similar to the 14x14 Turbo design described in CENPD-387-P-A (Reference 5).

Revised CHF correlations were developed for the following reasons:

1. New correlations were needed to model the thermal performance of the next generation fuel (NGF) design with the side-supported vane grids, the 16x16 fuel lattice, and multiple grid spacing for CE-PWRs.

2. New correlations should be applicable to a local quality higher than 30 percent in the hot channel.

Although CHF measured to code predicted (M/P) results with the TORC thermal hydraulic code, using the coefficients developed with the VIPRE code, were very close to the M/P values determined with the VIPRE code, Westinghouse decided to modify the coefficients for applications with the TORC and CETOP-D (Reference 6) thermal hydraulic codes to maintain the same departure from nucleate boiling ratio (DNBR) limit determined with the VIPRE code. This form of the correlation was identified as the WSSV-T correlation.

3.1 Database

CHF test data were taken with the NGF grid and fuel designs at the Heat Transfer Research Facility of Columbia University for use in developing the correlations for this design. Three of the tests were used in the development of the ABB-TV correlation (CENPD-387-P-A). Supplemental data, with a large range of grid spacing and data at high local qualities, were also used by Westinghouse to make the correlations robust. The supplemental tests included data for the 17x17 and 16x16 designs in Europe, the ABB-X2 correlation (Reference 7) and the side-supported vane data, including the 14x14 Turbo data.

The test data used in the correlation development and validation were from 5x5 and 6x6 rod bundles simulating the PWR fuel designs. Tests were performed with uniform and non-uniform axial power shapes for test arrays with, and without, guide thimbles. The supplemental data with mixing vane grids for the grid spacing term in the correlation form were obtained for test section heated lengths ranging from 96 to 168 inches, for grid spacing from 9.3 to 26 inches, for a rod diameter ranging from 0.374 to 0.423 inches and for a guide thimble diameter ranging

from 0.474 to 0.482 inches. For the development of the WSSV and WSSV-T correlations and validation database, additional data were obtained for test section heated lengths ranging from 118.1 to 150 inches, for grid spacing from 10.28 to 18.86 inches, for a rod diameter ranging from 0.374 to 0.440 inches, and for a guide thimble diameter ranging from 0.98 to 1.115 inches.

The correlation coefficients were based on a subset of the total test data, referred to as the correlation database, using 80 percent of the CHF test points. The remaining 20 percent of the test data were used as a validation database to evaluate the correlation. The NRC staff reviewed the correlation data tables and sub-channel data for accuracy and correspondence with the NGF design and sub-channel dimensions. The NRC staff also reviewed the axial geometries for discrepancies and nonconformities.

Westinghouse applied an outlier test (Reference 8) to check the database. The test was applied to the correlation database, and the combined correlation and validation database, after poolability was demonstrated. The test showed there were no outliers in either database.

The NRC staff finds there is reasonable assurance that the database used to develop the NGF CHF correlations for CE-PWRs was based on quality data representative of the design and that the statistical treatment of the database was based on previously accepted methods.

3.2 Correlation Form

The correlation form was based on the previously accepted form used for the ABB-NV and ABB-TV correlations in CENPD-387-P-A. The correlation form is empirical and is based solely on experimental observations of the relationship between the measured CHF and the correlation variables.

The initial correlation development for the NGF design was performed with the VIPRE code. Because both uniform and non-uniform axial power data were included in the database for the development of the NGF CHF correlation, the optimized non-uniform Tong shape factor, Fc, developed for the ABB-NV and ABB-TV correlations (CENPD-387-P-A) was applied. The local quality range proposed for the NGF CHF correlation was outside the range approved for the ABB-NV and ABB-TV correlations. The NRC staff requested that Westinghouse provide justification for its continued use.

The Westinghouse response pointed out that the local quality range as approved for the ABB-TV and ABB-NV correlations was based on data that did encompass the local quality range proposed for the NGF design WSSV and WSSV-T correlations. However, the extended quality range was not applied to the ABB-NV and ABB-TV correlations

The non-uniform Tong shape factor, F_c, described in CENPD-387-P-A was optimized by using the correlation form and coefficients from the uniform axial power data to evaluate the available non-uniform data. The non-uniform tests used to evaluate the empirical term "C" in CENPD-387-P-A had quality ranges covering the proposed range for the WSSV and WSSV-T correlations, from the beginning of subcooled boiling to the end of the heated assembly length. Therefore, in the region where the minimum DNBR could have occurred, the quality range in the non-uniform data was larger than the quality range for the final ABB-TV and ABB-NV correlations. Data from the supplemental non-uniform test were used to validate the use of the F_c coefficients determined in CENPD-387-P-A for the development of the WSSV and WSSV-T

correlations over the proposed local quality range. Scatter plots provided in Section 5 of WCAP-16523-P also showed no trend with quality or the value of F_c.

The NRC staff agrees with the Westinghouse conclusion that the results from the evaluation of the supplemental non-uniform power data, along with the evaluation of the non-uniform power data used in the original development of the ABB-NV and ABB-TV correlations, validates and justifies the use of the F_c empirical term "C," as determined in CENPD-387-P-A, for the new NGF correlations with the increased local quality range.

As stated in CENPD-387-NP-A (Reference 9), the original correlation form assumed that there was a linear relationship between the CHF and the local quality, up to the previously accepted local quality value of about 0.22. Based on visual observations made by Westinghouse, when considering the data at the high quality conditions, the heat flux did not continue to behave similarly with quality and an adjustment term was added to the correlation to account for the change in flow regimes observed with the mixing vane grids. The NRC staff requested that Westinghouse provide clarification on the selection of the local quality value above which the adjustment term would be applied to the CHF calculation (ADAMS Accession No. ML062080275).

The visual observations of the data when the higher quality data were included indicated a range in the local quality over which the trend change could be considered to begin. Different values for the local quality around the center of this range were evaluated by Westinghouse. The selected local quality value provided the lowest standard deviation and smoothest scatter plot for the CHF values evaluated for the proposed WSSV and WSSV-T correlations. As a further check, the statistical tests described in Section 5 of WCAP-16523-P were applied, by Westinghouse, to confirm the data with local quality greater than the selected point was poolable with the data with local quality less than the selected point.

The adjustment term and the selection of the local quality value, above which the adjustment term is applied to the CHF calculation, are based on an acceptable statistical treatment of the data. Further, the adjustment term adds conservatism to the NGF CHF correlation. Therefore, the NRC staff finds the local quality adjustment model to account for the observed heat flux at high qualities, developed for use in the WSSV and WSSV-T NGF CHF correlations, acceptable.

3.3 Statistical Evaluation

The following topics were considered by Westinghouse for the statistical treatment of the database: outliers, normality distribution, comparison of the various data groups, the homogeneity of variance, and the 95/95 DNBR limit. The means and standard deviation for the ratio of the M/P CHF were given for the total correlation database, for the individual tests in the correlation data set; for the total validation database and for the individual tests in the validation data set; and for the total combined database. The information was provided for both the WSSV and the WSSV-T correlations. A statistical evaluation was performed with the WSSV and the WSSV-T correlations for each test, bundle array, the correlation database, the validation database, and the combined correlation and validation database to determine the one-sided 95/95 DNBR limit applicable to each correlation. Standard statistical tests, the W and D' tests, were used to evaluate normality at the 95 percent confidence level: the W test for groups with less than 50 test points and the D' test for all other groups.

Each database was examined for outliers, and no points from the correlation or validation databases were eliminated.

Standard statistical tests were performed to determine if all or selected data groups belong to the same population in order to be combined for the evaluation of the 95/95 DNBR tolerance limit. In addition, scatter plots were generated for each variable in the correlation, for both the WSSV and the WSSV-T correlations, to examine the correlation for trends or regions of nonconservatism. The M/P CHF ratio was plotted as a function of the local mass flow rate, the system pressure, the local mass velocity, the local quality, the matrix heated hydraulic diameter (Dhm), the heated hydraulic diameter (Dh), the grid spacing term, the heated length from the bottom of the heated rod length to the location of CHF, and the non-uniform shape factor, F_c. The NRC staff examined these plots and determined that no trends or regions of nonconservatism were evident. The 95/95 DNBR limit was included on these plots to show the number of points that fall below the limit and the location of those points. The NRC staff examined all the plots and determined that the results were typical.

3.4 One-Sided 95/95 DNBR Limit

The computed 95/95 DNBR limit for the class of data provides 95 percent probability at the 95 percent confidence level that a rod in that class having that DNBR will not experience CHF.

All the data from the correlation and validation databases could be considered in the establishment of the one-sided 95/95 DNBR tolerance limit if the data could be pooled. Comparison tests were performed on the combined data sets prior to the determination of the 95/95 DNBR limit. For normally distributed groups, the Owen's one-sided tolerance limit factor (Reference 10) was used to compute the 95/95 DNBR limit. For groups that were not normally distributed, a distribution-free or non-parametric limit, from Chapter 2 of the National Bureau of Standards Handbook 91, was established. The most conservative limit determined for any group of data examined was then applied to the entire correlation data set. The 95/95 DNBR limit was determined to be 1.12 for both the WSSV and the WSSV-T correlations.

The statistical evaluation method has been previously reviewed and accepted by the NRC staff in CENPD-387-P-A. Therefore, the NRC staff finds the statistical evaluation performed by Westinghouse to develop the WSSV and the WSSV-T correlations and the 95/95 DNBR limit of 1.12 acceptable.

4.0 <u>LIMITATIONS AND CONDITIONS</u>

1. The WSSV correlation must be used in conjunction with the VIPRE code since the correlation was developed based on VIPRE and the associated VIPRE input specifications. Other uses of the WSSV correlation should reference this TR and be based on appropriate benchmarking with VIPRE.

2. The WSSV-T correlation must be used in conjunction with the TORC code since the correlation constants were developed based on TORC and the associated TORC input specifications. The correlations may also be used in the CETOP-D code in support of reload design calculations benchmarked by TORC.

3. The WSSV and WSSV-T correlations must also be used with the optimized Tong Fc shape factor for non-mixing and side-supported mixing vane grids to correct for non-uniform axial power shapes.

4. The range of applicability for both the WSSV and the WSSV-T correlations are:

Parameter	Units	Range
Pressure	psia	1,495 to 2,450
Local coolant quality	--	≤ 0.34
Local mass velocity	10^6 lbm/hr-ft^2	0.90 to 3.46
Matrix heated hydraulic diameter, Dhm	inches	0.4635 to 0.5334
Heated hydraulic diameter ratio, Dhm/Dh	--	0.679 to 1.00
Heated length, HL	inches	48* to 150
Grid spacing	inches	10.28 to 18.86
* Set as minimum HL value, applied at all elevations below 48 inches		

5.0 CONCLUSION

The WSSV and WSSV-T correlations indicate a minimum DNBR limit of 1.12 will provide a 95 percent probability with 95 percent confidence of not experiencing CHF on a rod showing the limiting value.

These correlations have been developed primarily for application to the new NGF 16x16 fuel design. However, since the correlations were developed with the 14x14 side-supported vane test data, they are also applicable to the 14x14 side-supported vane design with a large thimble (1.115 inch diameter) and 0.440 inch diameter rod. However, these new correlations do not supersede the existing correlations currently applied for this design. Westinghouse noted that the ABB-TV and WSSV or WSSV-T correlations have essentially the same performance for the 14x14 design, as expected.

The NRC staff has reviewed TR WCAP-16523-P and determined that it is approved for referencing in licensing applications for CE-PWRs to the extent specified and under the limitations and conditions listed in section 4.0 of this SE.

6.0 REFERENCES

1. Westinghouse Electric Company, letter LTR-NRC-06-9, dated March 17, 2006 (ADAMS Accession No. ML060880425), "Submittal of WCAP-16523-P/WCAP-16523-NP, 'Westinghouse Correlations WSSV and WSSV-T for Predicting Critical Heat Flux in Rod Bundles with Side-Supported Mixing Vanes,'" (Proprietary/Non-Proprietary).

2. WCAP-14565-P-A, "VIPRE-01 Modeling and Qualification for Pressurized Water Reactor Non-LOCA Thermal-Hydraulic Safety Analysis," October 1999.

3. CENPD-161-P-A, "TORC Code, A Computer Code for Determining the Thermal Margin of a Reactor Core," April 1986.

4. WCAP-16500-P, "CE 16x16 Next Generation Fuel Core Reference Report," February 2006.

5. CENPD-387-P-A, Rev.00, "ABB Critical Heat Flux Correlations for PWR Fuel," May 2000, CE Nuclear Power LLC, Windsor, Connecticut.

6. CETOP-D Reports: "CETOP-D Code Structure and Modeling Methods for Calvert Cliffs Units 1 and 2," CEN-191(B)-P, December 1981, "CETOP-D Code Structure and Modeling Methods for San Onofre Nuclear Generation Station Units 2 and 3," CEN-160(S)-P Rev. 1-P, September 1981, "CETOP-D Code Structure and Modeling Methods for Arkansas Nuclear One - Unit 2," CEN-214(A)-P, July 1982.

7. CE-NPSD-785-P, "ABB-X2 Critical Heat Flux Correlation for ABB 17x17 and 16x16 Standard and Intermediate Mixing Grid Fuel," Z. E. Karoutas, December 1994.

8. National Bureau of Standards Handbook 91, "Experimental Statistics," Chapter 17, Department of Commerce, August 1963.

9. CENPD-387-NP-A, REV.000, "ABB Critical Heat Flux Correlations for PWR Fuel," Section 3.0, Development of ABB-NV Correlation for Non-mixing Grids, page 3-1, May 2000, CE Nuclear Power LLC, Windsor, Connecticut.

10. SC-R-607, Sandia Corporation, "Factors for One-Sided Tolerance Limits and for Variable Sampling Plans," Owens, D. B., March 1963.

Attachment: Resolution of Comments

Principle Contributor: E. Throm

Date: March 15, 2007

RESOLUTION OF COMMENTS ON DRAFT SAFETY EVALUATION FOR

TOPICAL REPORT (TR) WCAP-16523-P, "WSSV AND WSSV-T FOR PREDICTING

CRITICAL HEAT FLUX IN ROD BUNDLES WITH SIDE-SUPPORTED MIXING VANES"

By letter dated January 17, 2007 (Agencywide Document Access and Management System Accession No. ML070230720), Westinghouse Electric Company (Westinghouse) provided comments on the draft safety evaluation (SE) for TR WCAP-16523, "WSSV and WSSV-T for Predicting Critical Heat Flux in Rod Bundles with Side-Supported Mixing Vanes." The following is the U.S. Nuclear Regulatory Commission (NRC) staff's resolution of those comments.

Westinghouse Comment:

Page 1, Line 23: change "request for addition" to "request for additional."

NRC Resolution:

The NRC staff agreed to this change.

Westinghouse Comment:

Page 2, Line 37: delete the phrase "from three additional tests."

NRC Resolution:

The NRC staff agreed to this change.

Westinghouse Comment:

Page 3, Line 31: change "ABB-NT" to "ABB-TV."

NRC Resolution:

The NRC staff agreed to this change.

Westinghouse Comment:

Page 3, Line 37: change "ABB-NT" to "ABB-TV."

NRC Resolution:

The NRC staff agreed to this change.

ATTACHMENT

Westinghouse Comment:

Page 4, Line 3: change "ABB-NT" to "ABB-TV."

NRC Resolution:

The NRC staff agreed to this change.

Westinghouse Comment:

Page 4, Line 12: change "mixing grids" to "mixing vane grids."

NRC Resolution:

The NRC staff agreed to this change.

Westinghouse Comment:

Page 6, Line 12: change this table from "Heated hydraulic diameter, Dh" in the Parameter column and "inches" in the Units column to "Heated hydraulic diameter ratio Dhm/Dh" in the Parameter column and leave the Units column unitless.

NRC Resolution:

The NRC staff agreed to this change.

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Section B

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Westinghouse

Westinghouse Electric Company
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e-mail: maurebf@westinghouse.com

Attention: F. M. Akstulewicz, Chief
Nuclear Performance & Code Review Branch
Division of Safety Systems

Our ref: LTR-NRC-06-9

March 17, 2006

Subject: Submittal of WCAP-16523-P/WCAP-16523-NP, "Westinghouse Correlations WSSV and WSSV-T for Predicting Critical Heat Flux in Rod Bundles with Side-Supported Mixing Vanes," (Proprietary/Non-Proprietary)

Dear Mr. Akstulewicz:

Enclosed are 5 Proprietary and 3 Non-Proprietary copies of WCAP-16523-P/WCAP-16523-NP, "Westinghouse Correlations WSSV and WSSV-T for Predicting Critical Heat Flux in Rod Bundles with Side-Supported Mixing Vanes," submitted to the NRC for review and approval. It is requested that the above topical be approved by March 2007. It is also requested that the NRC provide an estimate on the man-power resources required for the review and a tentative date for the acceptance meeting.

WCAP-16523-P/WCAP-16523-NP describes and presents the WSSV and WSSV-T Correlations for predicting critical heat flux for the CE 16x16 Next Generation Fuel (NGF) fuel design.

Also enclosed are:

1. One (1) copy of the Application for Withholding, AW-06-2115 with Proprietary Information Notice and Copyright Notice.
2. One (1) copy of Affidavit, AW-06-2115.

This submittal contains Westinghouse proprietary information of trade secrets, commercial or financial information which we consider privileged or confidential pursuant to 10 CFR Section 2.390. Therefore, it is requested that the Westinghouse proprietary information attached hereto be handled on a confidential basis and be withheld from public disclosure.

Correspondence with respect to the affidavit or Application for Withholding should reference AW-06-2115 and should be addressed to B. F. Maurer, Acting Manager, Regulatory Compliance and Plant Licensing, Westinghouse Electric Company LLC, P.O. Box 355, Pittsburgh, Pennsylvania 15230-0355.

Very truly yours,

B. F. Maurer, Acting Manager
Regulatory Compliance and Plant Licensing

Enclosures

cc: G. S. Shukla, NRR
L. M. Feizollahi, NRR

Westinghouse

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Attention: F. M. Akstulewicz, Chief
Nuclear Performance & Code Review Branch
Division of Safety Systems

Our ref: AW-06-2115

March 17, 2006

APPLICATION FOR WITHHOLDING PROPRIETARY INFORMATION FROM PUBLIC DISCLOSURE

Subject: Submittal of WCAP-16523-P, "Westinghouse Correlations WSSV and WSSV-T for Predicting Critical Heat Flux in Rod Bundles with Side-Supported Mixing Vanes," (Proprietary)

Reference: Letter from B. F. Maurer to F. M. Akstulewicz, LTR-NRC-06-9, dated March 17, 2006

Dear Mr. Akstulewicz:

The application for withholding is submitted by Westinghouse Electric Company LLC (Westinghouse) pursuant to the provisions of paragraph (b)(1) of Section 2.390 of the Commission's regulations. It contains commercial strategic information proprietary to Westinghouse and customarily held in confidence.

The proprietary material for which withholding is being requested is identified in the proprietary version of the subject report. In conformance with 10 CFR Section 2.390, Affidavit AW-06-2115 accompanies this application for withholding, setting forth the basis on which the identified proprietary information may be withheld from public disclosure.

Accordingly, it is respectfully requested that the subject information which is proprietary to Westinghouse be withheld from public disclosure in accordance with 10 CFR Section 2.390 of the Commission's regulations.

Correspondence with respect to this application for withholding or the accompanying affidavit should reference AW-06-2115 and should be addressed to B. F. Maurer, Acting Manager of Regulatory Compliance and Plant Licensing, Westinghouse Electric Company LLC, P. O. Box 355, Pittsburgh, Pennsylvania 15230-0355.

Very truly yours,

B. F. Maurer, Acting Manager
Regulatory Compliance and Plant Licensing

AW-06-2115

AFFIDAVIT

COMMONWEALTH OF PENNSYLVANIA:

ss

COUNTY OF ALLEGHENY:

Before me, the undersigned authority, personally appeared B. F. Maurer, who, being by me duly sworn according to law, deposes and says that he is authorized to execute this Affidavit on behalf of Westinghouse Electric Company LLC (Westinghouse) and that the averments of fact set forth in this Affidavit are true and correct to the best of his knowledge, information, and belief:

B. F. Maurer, Acting Manager
Regulatory Compliance and Plant Licensing

Sworn to and subscribed
before me this 17th day
of March, 2006

Notary Public

Notarial Seal
Sharon L. Fiori, Notary Public
Monroeville Boro, Allegheny County
My Commission Expires January 29, 2007
Member, Pennsylvania Association Of Notaries

(1) I am Acting Manager, Regulatory Compliance and Plant Licensing, in Nuclear Services, Westinghouse Electric Company LLC (Westinghouse) and as such, I have been specifically delegated the function of reviewing the proprietary information sought to be withheld from public disclosure in connection with nuclear power plant licensing and rulemaking proceedings, and am authorized to apply for its withholding on behalf of Westinghouse.

(2) I am making this Affidavit in conformance with the provisions of 10 CFR Section 2.390 of the Commission's regulations and in conjunction with the Westinghouse "Application for Withholding" accompanying this Affidavit.

(3) I have personal knowledge of the criteria and procedures utilized by Westinghouse in designating information as a trade secret, privileged or as confidential commercial or financial information.

(4) Pursuant to the provisions of paragraph (b)(4) of Section 2.390 of the Commission's regulations, the following is furnished for consideration by the Commission in determining whether the information sought to be withheld from public disclosure should be withheld.

(i) The information sought to be withheld from public disclosure is owned and has been held in confidence by Westinghouse.

(ii) The information is of a type customarily held in confidence by Westinghouse and not customarily disclosed to the public. Westinghouse has a rational basis for determining the types of information customarily held in confidence by it and, in that connection, utilizes a system to determine when and whether to hold certain types of information in confidence. The application of that system and the substance of that system constitutes Westinghouse policy and provides the rational basis required.

Under that system, information is held in confidence if it falls in one or more of several types, the release of which might result in the loss of an existing or potential competitive advantage, as follows:

(a) The information reveals the distinguishing aspects of a process (or component, structure, tool, method, etc.) where prevention of its use by any of Westinghouse's competitors without license from Westinghouse constitutes a competitive economic advantage over other companies.

(b) It consists of supporting data, including test data, relative to a process (or component, structure, tool, method, etc.), the application of which data secures a competitive economic advantage, e.g., by optimization or improved marketability.

(c) Its use by a competitor would reduce his expenditure of resources or improve his competitive position in the design, manufacture, shipment, installation, assurance of quality, or licensing a similar product.

(d) It reveals cost or price information, production capacities, budget levels, or commercial strategies of Westinghouse, its customers or suppliers.

(e) It reveals aspects of past, present, or future Westinghouse or customer funded development plans and programs of potential commercial value to Westinghouse.

(f) It contains patentable ideas, for which patent protection may be desirable.

There are sound policy reasons behind the Westinghouse system which include the following:

(a) The use of such information by Westinghouse gives Westinghouse a competitive advantage over its competitors. It is, therefore, withheld from disclosure to protect the Westinghouse competitive position.

b) It is information which is marketable in many ways. The extent to which such information is available to competitors diminishes the Westinghouse ability to sell products and services involving the use of the information.

c) Use by our competitor would put Westinghouse at a competitive disadvantage by reducing his expenditure of resources at our expense.

(d) Each component of proprietary information pertinent to a particular competitive advantage is potentially as valuable as the total competitive advantage. If competitors acquire components of proprietary information, any one component may be the key to the entire puzzle, thereby depriving Westinghouse of a competitive advantage.

(e) Unrestricted disclosure would jeopardize the position of prominence of Westinghouse in the world market, and thereby give a market advantage to the competition of those countries.

(f) The Westinghouse capacity to invest corporate assets in research and development depends upon the success in obtaining and maintaining a competitive advantage.

(iii) The information is being transmitted to the Commission in confidence and, under the provisions of 10 CFR Section 2.390, it is to be received in confidence by the Commission.

(iv) The information sought to be protected is not available in public sources or available information has not been previously employed in the same original manner or method to the best of our knowledge and belief.

(v) The proprietary information sought to be withheld in this submittal is that which is appropriately marked in Submittal of WCAP-16523-P, "Westinghouse Correlations WSSV and WSSV-T for Predicting Critical Heat Flux in Rod Bundles with Side-Supported Mixing Vanes," (Proprietary)," March 2006, for submittal to the Commission, being transmitted by Westinghouse letter (LTR-NRC-06-9) and Application for Withholding Proprietary Information from Public Disclosure, to the Document Control Desk. The proprietary information as submitted by Westinghouse Electric Company is for NRC review and approval.

This information is part of that which will enable Westinghouse to:

(a) Obtain generic NRC licensed approval for the Westinghouse WSSV and WSSV-T Correlations for the CE 16x16 NGF fuel assembly.

(b) Assist customers in improving their fuel performance (zero defects).

Further this information has substantial commercial value as follows:

(a) Westinghouse plans to continue to implement corrective actions to ensure the highest quality of fuel in order to meet the customer needs.

(b) Assist customers to obtain license changes.

Public disclosure of this proprietary information is likely to cause substantial harm to the competitive position of Westinghouse because it would enhance the ability of competitors to provide similar technical evaluation justifications and licensing defense services for commercial power reactors without commensurate expenses. Also, public disclosure of the information would enable others to use the information to meet NRC requirements for licensing documentation without purchasing the right to use the information.

The development of the technology described in part by the information is the result of applying the results of many years of experience in an intensive Westinghouse effort and the expenditure of a considerable sum of money.

In order for competitors of Westinghouse to duplicate this information, similar technical programs would have to be performed and a significant manpower effort, having the requisite talent and experience, would have to be expended for developing the enclosed improved core thermal performance methodology.

Further the deponent sayeth not.

PROPRIETARY INFORMATION NOTICE

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Abstract

This report describes the development of the Critical Heat Flux (CHF) correlations for Pressurized Water Reactor (PWR) fuel designs containing structural mixing vane (MV) grids and Intermediate Flow Mixer (IFM) grids with side-supported vanes. The WSSV correlation is for 14x14 and 16x16 fuel designs containing side-supported vane grids for Combustion Engineering designed PWRs (CE-PWR). The WSSV correlation coefficients were derived with Westinghouse version of the VIPRE-01 (VIPRE) subchannel code. The WSSV-T correlation is also for 14x14 and 16x16 fuel designs containing side-supported vane grids for Combustion Engineering designed PWRs (CE-PWR). The WSSV-T correlation coefficients were derived with the TORC subchannel code. Both correlations utilize the same form but with different constants. The correlations were developed based on CHF test data obtained from the Heat Transfer Research facility of Columbia University. The tests simulated 5x5 and 6x6 arrays of the fuel assembly geometry, side-supported mixing vane grids, uniform and non-uniform axial power shapes, non-uniform radial power distributions, with and without guide thimbles, varied heated lengths and grid spacing. The functional form of the CHF correlation is empirical and is based solely on experimental observations of the relationship between the measured CHF and the correlation variables. The correlation includes the following variables: pressure, local mass velocity, local quality, a grid spacing term, GST, heated length from inlet to CHF location and the heated hydraulic diameter ratio of the CHF channel. The grid spacing term, GST, is defined as the [

] [a, c]. The heated hydraulic diameter ratio is defined as the [

] [a, c]. Special geometry terms are applied to the correlation to correct CHF for grid spacing, heated length, cold wall and guide thimble effects. For the side-supported vane geometry with large guide thimble, the optimized non-uniform shape factor, F_C, developed in Reference 1 with no vane and side-supported vane non-uniform data, was used. The 95/95 DNBR limit for both the WSSV and WSSV-T CHF correlations is 1.12. The WSSV correlation is valid for use with Westinghouse version of the VIPRE code. The WSSV-T correlation is valid for use with the Westinghouse thermal hydraulic codes TORC and CETOP. The range of applicability for both correlations:

Parameter	WSSV and WSSV-T Range		
Pressure (psia)	1495	to	2450
Local mass velocity (Mlbm/hr-ft^2)	0.9	to	3.46
Local quality		≤	0.34
Heated length, inlet to CHF location (in)	48 [1]	to	150
Grid spacing (in)	10.28	to	18.86
Heated hydraulic diameter ratio, Dhm/Dh	0.679	to	1.00
Matrix Heated Hydraulic Diameter, Dhm (inches)	0.4635	to	0.5334

1 **Set as Minimum HL value, applied at all elevations below 48 inches.**

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1.0 Introduction

This report describes the development of the WSSV Critical Heat Flux (CHF) correlations for Pressurized Water Reactor (PWR) fuel designs containing structural mixing vane (MV) grids and Intermediate Flow Mixer (IFM) grids with side-supported vanes. A CHF correlation is also commonly referred to as a Departure from Nucleate Boiling (DNB) correlation. The WSSV correlation is for fuel designs containing side-supported vane grids to be used for Combustion Engineering designed PWRs (CE-PWR). Side-supported mixing vanes are illustrated in Figure 1-1. The WSSV correlation form is based on the ABB-TV correlation form(1). To account for the impact of grid spacing and to extend the correlation to higher local qualities, modifications to the ABB-TV correlation form are developed using the existing side-supported vane data and a supplemental broad uniform axial power test database with mixing vanes to make the correlation form robust. The correlation coefficients were derived with Westinghouse version of the VIPRE-01 (VIPRE) subchannel code(3)(4). The correlation for the side-supported vanes has also been implemented in the TORC and CETOP-D codes(5)(23). The TORC code is similar to VIPRE for application in the CE-PWR and the CETOP-D code is a fast running thermal-hydraulic tool used in reload design analyses and on-line monitoring. In order to maintain the same 95/95 departure from nucleate boiling ratio (DNBR) limit for the side-supported vane design when applied with the TORC and CETOP-D thermal hydraulic codes, the WSSV correlation constants were re-optimized with the TORC code without any change to the correlation form. To distinguish the correlations applied in the VIPRE and TORC thermal hydraulic codes, the correlation applied in TORC is identified as WSSV-T.

These correlations were developed based on CHF test data obtained from the Heat Transfer Research Facility of Columbia University. The test data used in the correlation development and validation are from 5x5 and 6x6 rod bundles simulating the PWR fuel designs. Tests were performed with uniform and non-uniform axial power shapes for test arrays with and without guide thimbles. The supplemental data with mixing vane grids for the grid spacing term in the correlation form were obtained for test section heated lengths ranging from 96 inches to 168 inches, grid spacing of 9.3 inches to 26 inches, rod diameter ranging from 0.374 inches to 0.423 inches and guide thimble diameter ranging from 0.474 inches to 0.482 inches. For the WSSV and WSSV-T correlation and validation database, data were obtained for test section heated lengths ranging from 118.1 inches to 150 inches, grid spacing of 10.28 inches to 18.86 inches, rod diameter ranging from 0.374 inches to 0.440 inches, and guide thimble diameter ranging from 0.98 to 1.115 inches.

The following sections describe the development of the new correlations and a brief summary of the contents of the report.

1.1 Need for New Correlations

The WSSV correlation was developed for the following reasons:

1. A new correlation is needed to accurately reflect thermal performance of the NGF design with the side-supported vane grids for CE-PWR with the 16x16 fuel lattice with multiple grid spacing.
2. The new correlation should be applicable to local quality higher than 30% in the hot channels.

Westinghouse has developed a new fuel design for the CE-PWR with 16x16 fuel lattice. The design is described in Reference 27. The design has side-supported mixing vanes, Figure 1-1, similar to the 14x14 Turbo design described in Reference 1. For the 16x16 side-supported vane design, data were obtained for grid spacing ranging from 10.28 inches to 15.72 inches.

To develop a correlation for this design, CHF test data were taken with the NGF grid and fuel designs at the Heat Transfer Research facility of Columbia University. In order to make the correlation robust for changes in grid spacing and the extension to higher qualities, supplemental data with a large range of grid spacing and data at high local qualities are examined as well as all side-supported mixing vane data. The supplemental data included the data for the 17x17 and 16x16 designs in Europe, ABB-X2 correlation[2] and side-supported vane data included the 14x14 Turbo data[1]. The initial correlation development was performed with the VIPRE code. Since both uniform and non-uniform axial power data were included in the database for the WSSV correlation, the optimized non-uniform shape factor developed for the ABB-NV and ABB-TV correlations[1] was applied. Although CHF measured to code predicted, M/P, results with the TORC thermal hydraulic code and the coefficients developed in VIPRE code were very close to the values determined with the VIPRE code, it was decided to modify the coefficients for applications with the TORC and CETOP-D thermal hydraulic codes to maintain the same DNBR limit determined with the VIPRE code. The correlation for TORC and CETOP applications benchmarked to TORC is identified as the WSSV-T correlation.

These correlations have been developed primarily for application for the new NGF 16x16 fuel design. However, since the correlation is developed with the 14x14 side-supported vane test data, it is applicable for the 14x14 side-supported vane design with large thimble (1.115 inch diameter) and 0.440 inch diameter rod, in addition to the 16x16 NGF design. These new correlations do not supersede the existing correlations[1][3] currently applied for this design. It is noted that the ABB-TV and WSSV or WSSV-T correlations have essentially the same performance for the 14x14 design, as expected.

1.2 New WSSV and WSSV-T PWR CHF Correlations for Side-Supported Mixing Vane Designs

The correlation form is based on the form used in Reference 1 for the ABB-NV and ABB-TV correlations. The form is empirical and is based solely on experimental observations of the relationship between the measured CHF and the correlation variables. The form assumes that there is a [

] ^{a,c}. The correlation includes the following variables: pressure, local mass velocity, local quality, a grid spacing term, heated length from inlet to CHF location and the heated hydraulic diameter ratio of the CHF channel. The modified grid spacing term, GST, is defined as the [

] ^{a,c}. Following Reference 1, the heated hydraulic diameter ratio is defined as the [

] ^{a,c}. Following Reference 1, special geometry terms are applied to the correlation to correct CHF for grid spacing, heated length, cold wall

and guide thimble effects. For the side-supported vane geometry with large guide thimble, the optimized non-uniform shape factor, F_C, developed in Reference 1 was used since the modified shape factor was developed with no vane and side-supported vane non-uniform data.

As described in Reference 1, the form of the ABB-NV and ABB-TV correlations was initially developed with the primary variables: pressure, local mass velocity, and local quality. [ ] $^{a, c}$ of the correlation, described in Section 3, use these primary variables. This [ ] $^{a, c}$ expression is based on a [ ] $^{a, c}$. This base form was modified to [ ] $^{a, c}$, as described in Section 3. The impact of geometry terms for heated length and heated hydraulic diameter are taken from Reference 1.

A description of the Westinghouse CHF tests supporting the WSSV correlation is summarized in Section 2. It is noted the same tests supporting the WSSV correlation developed in the VIPRE thermal hydraulic code are also used to support the version applied in the TORC thermal hydraulic code, WSSV-T. Section 3 describes the development of the correlation form applied to the side-supported vane data. Section 4 describes the optimization of the coefficients for the WSSV correlation and the validation of the correlation. All test data were evaluated by using the Westinghouse thermal hydraulic code, VIPRE(4). VIPRE was used to compute the local coolant conditions for the CHF test sections. A VIPRE model was prepared for each test section and appropriate empirical grid mixing factors for the split vane and side-supported vane designs were input into the model. Since the NRC-approved TORC thermal hydraulic code(5) is currently used for some plant licensing applications, the coefficients for the side-supported vane data, WSSV-T, were optimized to maintain the same 95/95 DNBR limit for the side-supported vane design when applied with the TORC and CETOP-D thermal hydraulic codes. The results of this optimization are also given in Section 4.

Section 5 summarizes the statistical evaluation for the WSSV and WSSV-T correlations. All the statistical tests are standard statistical methods that have been previously applied for other NRC-approved correlations. A statistical evaluation was performed with the correlation for each test section, the entire database and test subsets (groups of tests). Tests for normality were performed to check the hypothesis that the data are normally distributed. Statistical tests were performed to determine if all or selected data groups belong to the same population, in order to be combined for the evaluation of the 95/95 DNBR tolerance limit. Descriptions of the statistical tests applied are given in Section 5. The 95/95 DNBR limit is determined [ ] $^{a, c}$. The 95/95 DNBR limits for the WSSV and WSSV-T correlations were determined to be 1.12 Scatter plots of the ratio of measured to predicted (M/P) CHF versus correlation variables were also made to illustrate that the ratio does not show any significant trends relative to correlation variables.

Section 6 discusses how the new CHF correlations are applied in plant safety or reload analyses.

A detailed summary of the correlation and validation databases for the WSSV and WSSV-T correlations is given in Appendices A and C, respectively. The statistical output of the WSSV and WSSV-T correlations is given in Appendices B and D, respectively. A detailed summary of the test section radial and axial power distributions is given in Appendix E.

Figure 1-1
Illustration of Side-Supported Mixing Vane Design

a, c

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2.0 Description of CHF Test Program and Test Section Geometry

All the CHF experiments were conducted at Columbia University's Heat Transfer Research Facility. The WSSV database consists of CHF tests that spanned the period 1993 to 2003. A description of the test facility for the later tests, after 1990, can be found in Reference 1.

2.1 Description of WSSV Test Sections

The correlation form was based on the Reference 1 form, but modified to account for the effects of variable grid spacing associated with the intermediate mixing grids and to extend the quality range, as summarized in Section 3. The data used for the determination of the primary coefficients of the correlation and the evaluation of the WSSV correlation were obtained from six test bundles, four with a uniform axial power shape and two with a non-uniform axial power shape. It is noted that three of the test bundles were used in the development of the ABB-TV correlation(1). Three test sections simulate a 6x6 array of the Westinghouse 14x14 side-supported vane fuel assembly geometry (0.440 inch O.D. heated rods, 0.580 inch rod pitch and 1.115 inch O.D. guide thimble). Three test sections simulate a 5x5 or 6x6 array of the Westinghouse 16x16 side-supported vane fuel assembly geometry (0.374 inch O.D. heated rods, 0.506/0.496 inch rod pitch and 0.980 inch O.D. guide thimble). The 6x6 test array size was selected for the guide thimble tests to place the guide thimble in the center of the test section to reduce the thermal hydraulic impact of the cold wall on CHF measurements and to minimize the occurrence of CHF on peripheral rods. Peripheral rod CHF indications in the test section are not prototypical of in-core performance since there was a shroud wall in the test housing. Therefore, by increasing the array size it was expected that the number of primary peripheral rod CHF indications would be reduced and the CHF test would better simulate in-core performance. In addition, the geometry around the simulated guide thimble is a better representation of the reactor geometry.

Three of the tests were conducted with a simulated guide thimble. Typical radial geometries for the test sections with and without a guide thimble are shown in Figures 2-1, 2-2 and 2-3. The power split between the cold rods and hot rods for the WSSV tests ranged from [ ] a, b, c. The radial power distributions for the individual tests are given in Appendix F. The non-uniform axial power tests were conducted with cosine axial power shapes as shown in Figure 2-4. For the non-uniform axial power tests, the lower grids (two for 14x14 design and three for 16x16 design) in the test assemblies were non-mixing grids to simulate the reactor fuel assembly design. The axial locations of the test grids and rod thermocouples for the individual tests are given in Appendix F. A summary of the test section geometry for the six tests is shown in Table 2-1. The correlation coefficients were based upon a subset of the test data. The "correlation" database represents 80% of the CHF test points. The remaining 20% of the test data were used as a "validation" database for the evaluation of the correlation. The division of the data into correlation and validation databases was accomplished by sorting the data from each test as follows:

1. The data from the Columbia University data file were sorted by pressure, then inlet temperature and then mass velocity in descending order.
2. Every fifth point was then sorted out for use as a validation database.

In addition, repeat or duplicate points, defined as a point [ ]$^{a, c}$ are initially put into the validation database. Each point maintained in the validation database represents a unique test condition.

The side-supported vane data were then evaluated with the TORC thermal hydraulic code. The initial evaluation was performed using the coefficients developed with the VIPRE code. Although the results were very close to the results obtained with the VIPRE, the correlation coefficients were refit to provide the same DNBR limit established with the VIPRE code when the correlation is applied with the TORC and CETOP thermal hydraulic codes. Since a number of the correlation coefficients were modified, the correlation for the side-supported vane data is identified as WSSV-T.

The test grids for the Westinghouse tests are similar to a reactor design grid. Some tests were performed with zirconium alloy material. For the side-supported vane tests, the grid spacing was small enough to prevent excessive rod deflection due to electromagnetic forces without the use of simple support (ss) girds. The test grids for the 14x14 fuel assembly design and the test grids for the non-uniform axial power test for the 16x16 fuel assembly design were made of the stronger Inconel 600 material to prevent excessive rod deflection due to electromagnetic forces.

2.2 Test Procedure and Operation

Although the general test procedure has not changed from the 14x14 tests, described in Reference 1, a brief description of the test procedures and operation for the more recent 16x16 tests is provided below.

At the beginning of each test, cold flow pressure drop points were obtained over a range of flow conditions. At the start of each day of testing, a repeat pressure drop point is taken for comparison with earlier data. These data provide isothermal grid span pressure drop values to compare with prediction and establish a base for comparison in case of a malfunction of the rod bundle during the tests.

Heat balances were performed on the test section to check all loop and bundle instrumentation at high temperature and power and to check heat losses. These runs were accomplished at subcooled conditions before mixing or CHF data were obtained at the beginning of each day of operation. Mixing or CHF testing generally was not started until a test section heat loss was [ ]$^{a, c}$. Heat loss is defined as the fraction of heat generated by the rods that is lost to the test section shroud walls.

Subchannel mixing data were obtained at non-boiling conditions for a mixing test with a uniform axial power shape. Subchannel thermocouple data were recorded for each mixing test run after steady-state conditions were achieved for a constant pressure, inlet temperature, mass velocity and power. Power was determined for each test condition so the calculated outlet temperature in the hottest subchannel is close to the value specified in the mixing test matrix.

Critical Heat Flux experiments were performed by maintaining the following system conditions constant: test section outlet pressure, inlet temperature, and mass flow rate. The total power to the test section is

then increased until a temperature excursion is observed by one or more thermocouples positioned inside the heater rods. The amount of the excursion is approximately 10 to 30 °F and varies depending on system conditions. When the excursion is judged to be sufficient, the power to the test section is reduced. When the temperature excursion is minimal, confirmation of the validity of a CHF point is obtained by observing the temperature decay with power reduction. There is a characteristic temperature decay with time as the CHF zone is rewetted. This evidence is considered confirming in cases where the temperature decay pattern is typical. Otherwise, the experiment is repeated. When a CHF point is observed, the following measurements are recorded, while holding the test section power constant:

1. Recorded manually:
   - test section outlet pressure
   - pressure drop across the Venturi flow meter from a manometer
   - test section pressure drop from a manometer
   - rod(s) experiencing CHF

2. Recorded by the data acquisition system:
   - test section voltage
   - bus to bus voltage
   - generator amperages
   - inlet temperature
   - outlet temperature
   - outlet pressure transducers
   - turbine flow meter
   - Venturi flow meter transducer
   - test section pressure drop transducers
   - subchannel temperatures
   - heater rod temperatures

The test matrices were designed to cover a wide range of operating conditions and minimize peripheral rod indications.

Table 2-1
Geometric Characteristics of the WSSV Correlation and Validation Tests

Test No.	Test Array	Rod Diam. (in.)	Rod Pitch (in.)	Heated Length (in.)	Grid Spacing (in.)	Guide Thimble	GT Diam. (in.)	Axial Shape	Radial Split Cold/Hot	Shroud Clearance (in.)	SS Grid
Correlation Data											
Validation Data											

a, b, c

a, b, c

SS (Simple Support Grid): used to minimize rod bow.

Figure 2-1
Typical Radial Geometry
5x5 Matrix Test

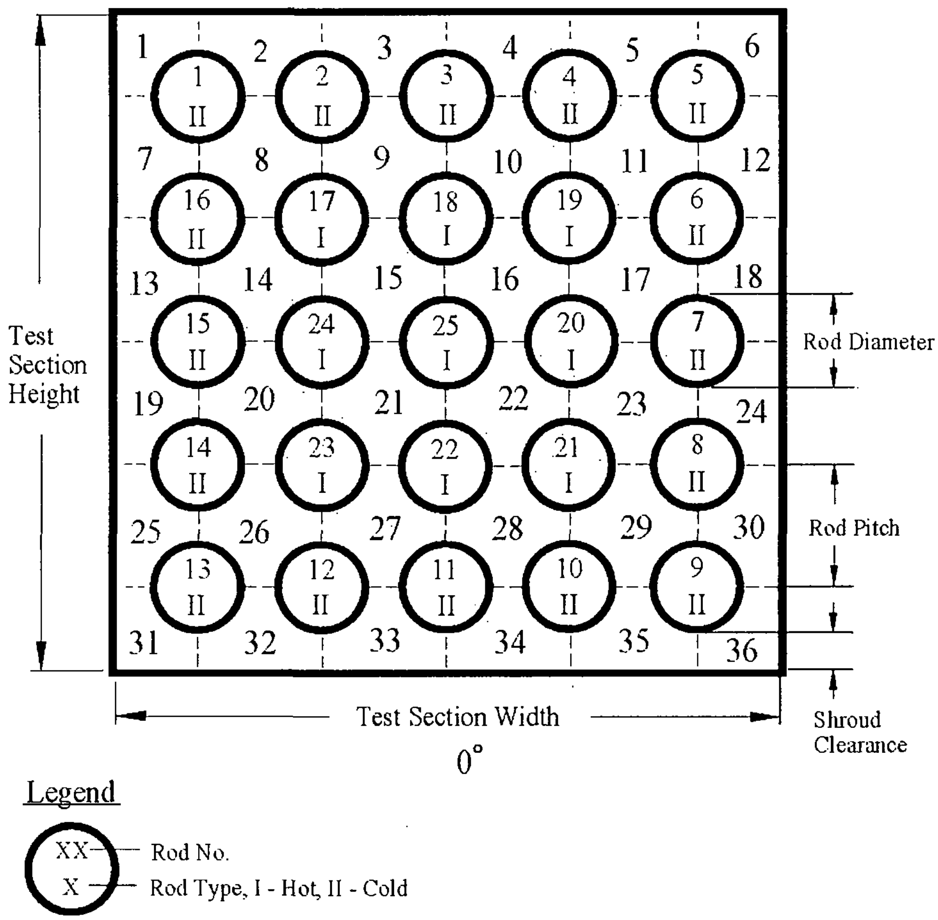

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Figure 2-2
Typical Radial Geometry
6x6 Matrix Test

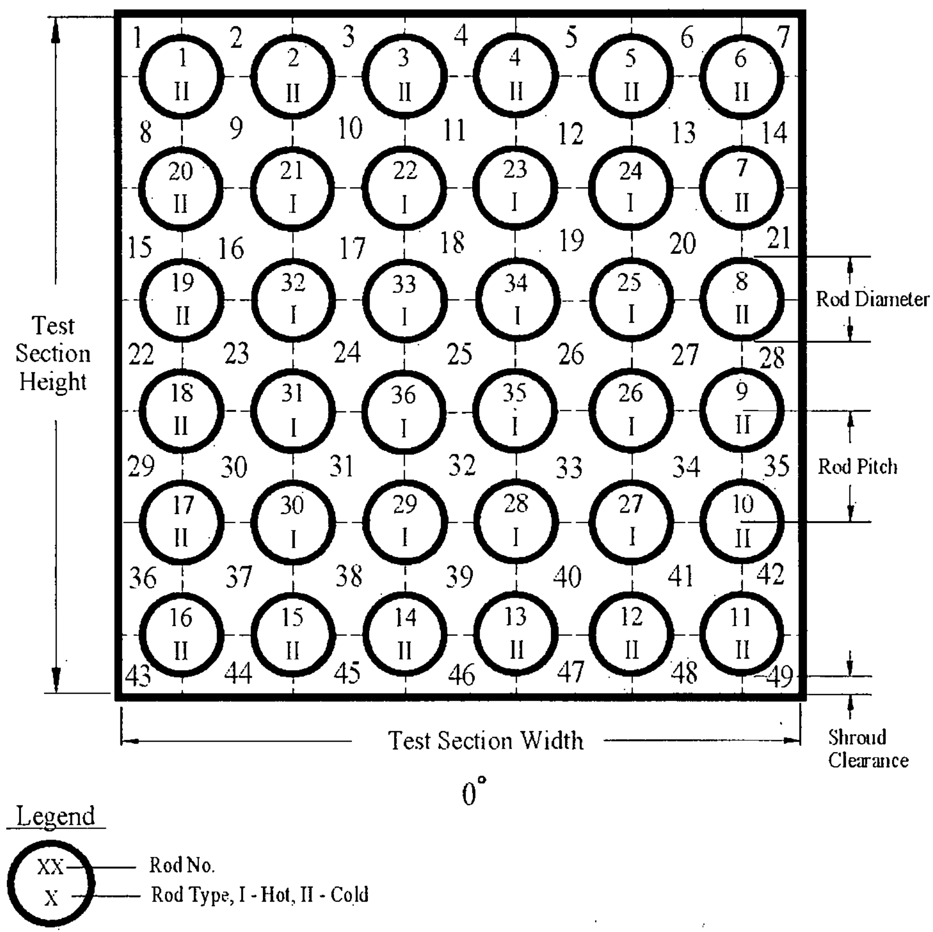

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Figure 2-3
Typical Radial Geometry
6x6 Guide Thimble Test, Large Thimble

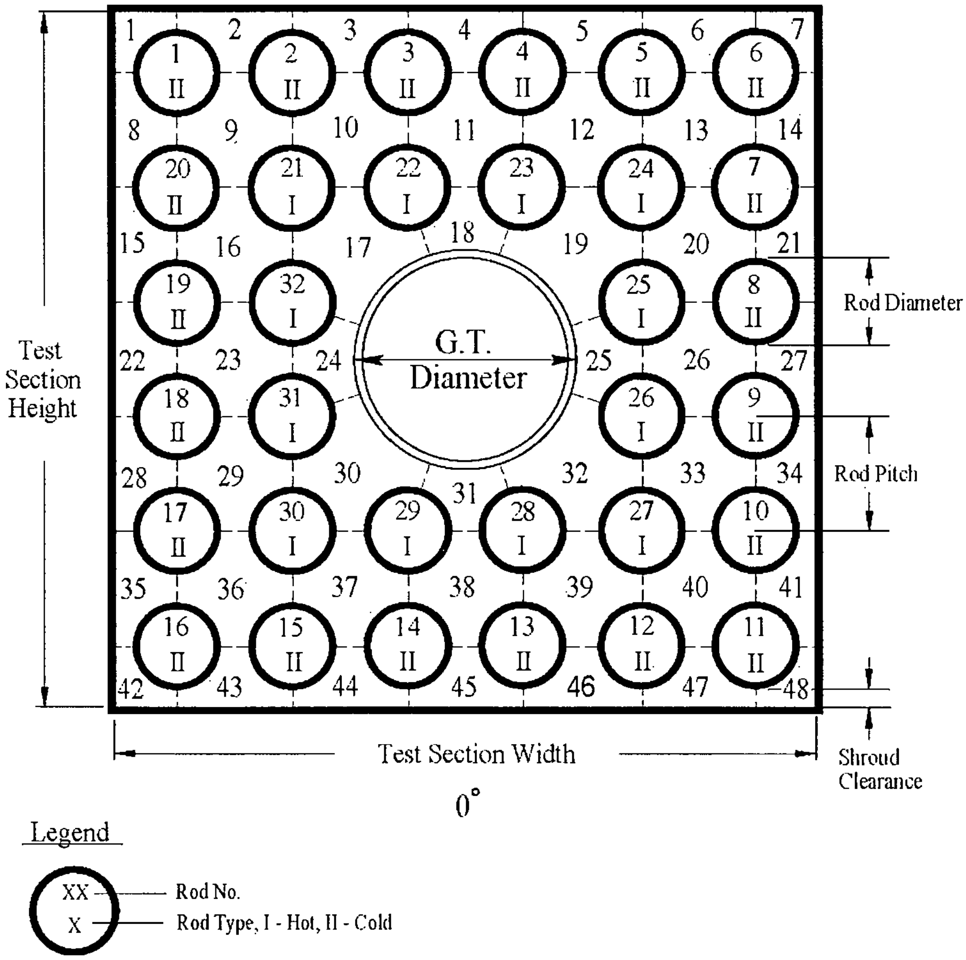

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Figure 2-4
Axial Heat Flux Distribution
WSSV Non-Uniform Axial Power Shape Tests

a, c

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3.0 Development of WSSV Correlation Form

The base form for WSSV is the same as used in the development of the ABB-NV and ABB-TV correlations, documented in Reference 1. As stated in Section 1, the form is modified to accurately reflect thermal performance of the NGF design with the side-supported vane grids for multiple grid spacing and to extend the local quality range in the hot channels. To account for these additional requirements, similar to the ABB-NV correlation in Reference 1, supplemental tests are employed to develop robust special geometry terms applied to the base form. The correlation form for the modified terms is developed with the support of split vane mixing grid data as well as the side-supported vane data. The supplemental tests were performed with simulated 5x5 and 6x6 arrays of the Westinghouse fuel assembly geometries for split vane mixing grids as shown in Table 3-1. The data used to determine the special geometry terms cover a wide range for grid spacing and local quality. The database used to develop the form for the grid spacing term includes tests with uniform axial power shapes with a range of radial power distributions, with and without guide thimbles, different guide thimble geometry, heated lengths from 96 to 168 inches and grid spacing ranging from 9.3 inches to 26 inches. The terms of the correlation form that are identical to the ABB-TV correlation[1] are also described briefly.

The functional form of the CHF correlation is empirical and is based solely on experimental observations of the relationship between the measured CHF and the correlation variables. The base form of the correlation is essentially the same as the ABB-NV and ABB-TV correlations[1]. The correlation includes the following variables: pressure, local mass velocity, local quality, a grid spacing term, heated length from inlet to CHF location and the heated hydraulic diameter ratio of the CHF subchannel. Special geometry terms are applied to the correlation to correct CHF for grid, heated length, cold wall and guide thimble effects. The form assumes that there is a [

] $^{a, c}$. This differs from the ABB-NV and ABB-TV correlation form in Reference 1, which are limited to local quality below 22.5%. For the side-supported vane data, the optimized non-uniform shape factor developed in Reference 1 was utilized for the non-uniform tests. The effectiveness of the correlation form in fitting the side-supported vane data is demonstrated in Section 4 which examines the correlation fit to the side-supported vane CHF database.

3.1 Description of Tests Supporting Correlation Form Development

A summary description of the Westinghouse tests supporting the WSSV correlation is provided in Section 2. A summary description of the Westinghouse supplemental split vane data with [

] $^{a, c}$ used for the development of terms for grid spacing and higher quality is provided in Table 3-1. It is noted that many of these tests are the same tests used to develop and support previous correlations, such as the ABB-X2, WRB-1 and WRB-2 correlations[2][9][10]. These tests were selected to add data with different grid spacing, as well as data with a large range of local quality conditions. Similar to the correlations mentioned above, as well as the ABB-NV and ABB-TV correlations, the WSSV correlation is based upon a series of tests that provide a good representation of the thermal performance of

Westinghouse fuel assemblies for CE-PWRs. The tests were run with a shroud clearance designed to provide [

]$^{a, c}$.

3.2 Correlation Form

As stated earlier, the basic form for the WSSV correlation is based on the ABB-NV and ABB-TV correlations(1). As described in Reference 1, the base form of the WSSV correlation is developed with the primary variables: pressure, local mass velocity, and local quality. [ ]$^{a, c}$ of the correlation use these primary variables. This [ ]$^{a, c}$ expression is based on a [

]$^{a, c}$. The [ ]$^{a, c}$ expression used to develop the final correlation is given below:

[ ]$^{a, c}$

where:

$q''_{CHF,U}$	=	critical heat flux for uniform axial power, MBtu/hr-ft^2
P	=	Pressure, psia
GL	=	local mass velocity at CHF location, Mlbm/hr-ft^2
XL	=	local coolant quality at CHF location, decimal fraction

This base form can be used to correlate the data from any test section without variable grid spacing. Special terms are then developed to account for Grid Spacing (GS), Distance from Grid (DG), Heated Length (HL), Heated Hydraulic Diameter (Dhm) and proximity to the large guide thimble used in these designs. The supplemental split vane tests are used to provide the form for the grid spacing terms and to fit the higher quality data. The forms for these terms are determined by examining the data to ensure the form removes observed trends and provides the best fit for a large range of data. The required terms are then applied to the base form to account for variable grid spacing and to extend the quality range. The form change is then verified to be applicable with the side-supported vane database.

3.2.1 Heated Length, HL

During the development of the ABB-NV and ABB-TV correlations, the heated length term was developed with uniform axial power data with heated lengths of 48 inches, 84 inches and 150 inches(1). The heated length term developed was a multiplier to the main expression with an exponential form:

[ ]$^{a, c}$

where: HL = Distance from beginning of heated length (BOHL) to axial location of CHF

The heated length term was developed in Reference 1 with [ ]$^{a, c}$. This term was applied to the no vane and side-supported (or Turbo) vane data in Reference 1 since the [

]$^{a, c}$. Similar to the ABB-TV correlation in Reference 1, the [

] a, c. Similar to the ABB-NV and ABB-TV correlations, the heated length value of the correlation is constrained to be no less than 48 inches since there are no uniform CHF data available in this region.

3.2.2 Grid Spacing Terms

An [ ] a, c grid term was used in the ABB-NV and ABB-TV correlation's to correct CHF for different grid spacing. However, the grid spacing term was developed for non-mixing vane grids and conservatively applied for the side-supported Turbo mixing grids, Figure 3-1 of Reference 1. The purpose of this term is to account for the presence of the grid on CHF. This term results in lower CHF just upstream of a spacer grid, which produces better agreement with test results. The 16x16 NGF design was tested over a range of grid spacing to provide a more appropriate grid spacing term for the side-supported vane geometry.

To provide a robust form to account for multiple grid spacing and distance from grid over a wide range of grid spacing, the supplemental database were examined. The range of grid spacing values are shown in the table below. From the data it appears that the [ ] a, c.

This is similar to the grid spacing term applied in the WRB-2 correlation(10). To account for the effect of the [ ] a, c, a grid spacing term was developed, defined as:

[ ] a, c

[ ] a, c

Impact of Grid Spacing Database

Dhm	DG	Upstream Grid Spacing	GST

[ ] a, b, c

Based upon the fit of the data, it is concluded that the best [ ] a, c for the grid spacing term is shown below:

[ ]$^{a, c}$

where: A, B = Constants determined with nonlinear regression analysis code

Following the application of the grid spacing [ ]$^{a, c}$ the resultant M/P CHF ratio data were then examined for trends to determine if additional terms are needed to account for the grid spacing geometric effects. One noticeable trend was the [

]$^{a, c}$. The [ ]$^{a, c}$ with GST determined above accounted for the average effect of the grid spacing, but did not account for the [

]$^{a, c}$ of the correlation form. To examine the grid spacing term form with the side-supported vane data, the side-supported matrix data with variable grid spacing were fit with the grid spacing terms, for all tests points with the quality at 20% or below. The results are shown in the Table below.

Test	Rod Dia.	Dhm	DG	Upstream Grid Spacing	GST	Interim M/P
[						]$^{a, b, c}$

Based upon the good fit with the side-supported vane data with different values of GST, it is concluded that the grid spacing terms are applicable to the side-supported data.

3.2.3 Heated Hydraulic Diameter of CHF Channel

For the Westinghouse fuel assembly design with a large guide thimble, thimble replaces four fuel rods, it has been shown that there is a difference in performance for the matrix subchannels near the guide thimble and the guide thimble side and corner subchannels[1]. Channel 26 in Figure 2-3 is representative of a matrix channel near the guide thimble, channel 31 is representative of the guide thimble side channel and channel 32 is representative of the guide thimble corner channel. For the ABB-NV and ABB-TV correlations, the heated hydraulic diameter term to account for the difference in performance is:

[ ]$^{a, c}$

where: Dhm = Heated hydraulic diameter of a matrix subchannel with the same rod diameter and pitch, inches
Dh = Heated hydraulic diameter of the subchannel, inches
B = Constant fit with nonlinear regression analysis code

This same term is applied to the WSSV correlation since the geometry for the different channel types is the same.

3.2.4 Extension of Correlation to Higher Quality

The new database contains some data at qualities above the limits used for the ABB-TV correlation. A [

] a, c. The plot in Figure 3-2 for the side-supported data is an example of the observed trend. The supplementary split vane database with a larger variation in quality had similar trends. Based upon the [

] a, c. To account for the measured [
] a, c.

a, c

[ ]

Ref: LTR-NRC-06-53
Response to RAI #1

A plot of the supplemental data M/P ratio versus the quality with the form adjustment is shown in Figure 3-3. A plot of the side-supported vane data versus quality with the form adjustment is given in Figure 4-3. These plots demonstrate the adjustment conservatively accounts for [
] a, c.

3.2.5 Proximity of Matrix Subchannel to Guide Thimble

An examination of the CHF data for the matrix channels from both the ABB-NV and ABB-TV databases in Reference 1 indicated an improvement in performance in the matrix channels for tests without the guide thimble compared to data with the guide thimble. As documented in Reference 1, for the large guide thimble a set of terms were applied to account for the difference in performance in a matrix subchannel in a matrix test and a matrix subchannel in a guide thimble test. Since the geometry for the side-supported vane fuel assemblies is essentially the same as the fuel assembly geometries documented in Reference 1, it is expected that a similar adjustment is also required for the WSSV correlation. For the ABB-TV correlation, the guide thimble proximity factor was [ ] a, c the basic form. Since the factor included a [ ] a, c is more appropriate.

The guide thimble proximity term then has the form:

a, c

[ ]

Ref: LTR-NRC-06-53
Response to RAI #1

The value of [
] a, c. This is very similar to the term in Reference 1 except [
] a, c.

3.3 Final Correlation Form

Based upon the evaluation of the data, the following form is applied to the side-supported vane test data in Section 4. The final correlation form is specified below:

[ ] a, c

The Departure from Nucleate Boiling Ratio (DNBR) is defined as:

$$DNBR = q''_{CHF,U} / q''_{Channel} * F_C$$

where:	$q''_{CHF,U}$	=	Critical Heat Flux Based on Uniform Axial Power Shapes, MBtu/hr-ft^2
	P	=	Pressure, psia
	GL	=	Local Mass Velocity at CHF, Mlb/hr-ft^2
	XL	=	Local Coolant Quality at CHF, Decimal Fraction
	Dh	=	Heated Diameter of Subchannel, inches
	Dhm	=	Heated Diameter of Matrix Subchannel, inches
	DG	=	Distance from [ ]^{a,c} Grid to CHF Location, inches
	GS	=	Grid Span [ ]^{a,c} Grid Just Upstream of CHF Location, inches
	GST	=	Grid Spacing Term = [ ]^{a,c}
	HL	=	Heated Length From Beginning of Heated Length to CHF Location, inches
	CC	=	[ ]^{a,c}
	$q''_{Channel}$	=	Local Heat Flux, Mbtu/hr-ft^2
	F_C	=	Optimized F-Factor To Correct $q''_{CHF,U}$ For NU Shapes, from Reference 1

The value of F_C is determined with the expression:

$$F_C = \frac{C}{q''_{CHF,NU} * (1 - e^{-C\,l_{crit}})} \int_0^{l_{crit}} q''(z)\, e^{-C(l_{crit}-z)}\, dz$$

For Side-Supported Vane Data, F_C computed with the following empirical constants from Reference 1.

Ref: LTR-NRC-06-53 Response to RAI #3

$$C = [\quad]^{a,c} * (1 - XLcrit)^{[\quad]^{a,c}} / (GL/10^6)^{[\quad]^{a,c}}\ ft^{-1}$$

Ref: LTR-NRC-06-53 Response to RAI #2

where:	$q''_{CHF,NU}$	=	*non-uniform heat flux at CHF location l_{crit}, Mbtu/hr-ft^2*
	$q''(z)$	=	*local heat flux versus axial length, Mbtu/hr-ft^2*
	l_{crit}	=	*distance from inlet to CHF location, ft*
	z	=	*axial length, ft*
	XL_{crit}	=	*equilibrium quality at CHF locations*

Table 3-1
Geometric Characteristics of the Supplemental Split Vane Tests

Test No.	Test Array	Rod Diam. (in.)	Rod Pitch (in.)	Heated Length (in.)	Grid Spacing (in.)	Guide Thimble	GT Diam. (in.)	Axial Shape	Radial Split Cold/Hot	Shroud Clearance (in.)	SS Grid

a, b, c

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Figure 3-1
Supplemental Split Vane Uniform Matrix Data vs. GST

a, b, c

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Figure 3-2
Side-Supported Vane Uniform Matrix Test Data vs. XL
No Adjustment

[ ]a, b, c

This page intentionally left blank

Figure 3-3
Supplemental Split Vane Uniform Test Data vs. XL
With Adjustment in Section 3.2.5

a, b, c

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4.0 Development of WSSV Correlation for Side-Supported Mixing Grids

The WSSV correlation was developed based on Westinghouse CHF test data obtained from the Heat Transfer Research Facility of Columbia University. The tests were performed with simulated 5x5 and 6x6 arrays of Westinghouse 14x14 and 16x16 fuel assembly designs with large guide thimble and side-supported vane mixing grids (also referred to as Turbo mixing grids in Reference 1). The functional form of the correlation described in Section 3 was used to determine the coefficients with the correlation database. A validation database, approximately 20% of the correlation database, was then used to validate the correlation

4.1 Description of Tests Supporting Correlation

A summary description of the Westinghouse CHF tests supporting the WSSV correlation is provided in Section 2 of this report. The Westinghouse side-supported vane mixing grid tests used a 5x5 or 6x6 array of electrically heated rods with uniform and non-uniform axial power shapes, which simulated the geometry of the reactor fuel assembly. A 6x6 array was selected for the mixing vane grid tests with a guide thimble since it allowed the simulated thimble to be placed in the center of the test section and to minimize the number of peripheral rod primary indications, as described in Section 2. Figures showing the geometry for typical test sections are also shown in Section 2. The array of rods was placed in a square metal shroud lined with unheated ceramic walls. For the tests in the correlation database, the rod to wall gap was sized to [ ] a, c. The relative radial power split between cold and hot rods ranged from approximately [ ] a, b, c. The radial power split was created by using tubes with different wall thickness. The tubing was heated by passing DC current through the tube walls. Inconel 600 and 625 tubing was used in the construction of the heaters. The heaters were filled with alumina ceramic cylinders to maintain rod geometry, prevent deformation during testing, and to isolate the CHF detecting instrumentation from the tubing inner wall.

For uniform axial power shape tests, cold rods (relative power factor [ ] a, b, c) had a single thermocouple positioned 0.5 inches upstream of the end of heated length. Hot rods (relative power factor 1.00) had quadrant thermocouple instrumentation located 0.5 inches upstream of the end of heated length and a single thermocouple located near mid-span of the last structural grid span. For the non-uniform axial power shape test, non-directional type thermocouples were used in cold and hot rods at various axial levels. The location of the rods with quadrant thermocouple instrumentation and the axial locations of thermocouples for the specific tests are shown in Appendix F.

Mixing tests were also performed for test sections with a uniform axial power shape to determine the empirical mixing factors [ ] a, c for the side-supported vane grid. To evaluate the subcooled subchannel mixing, a thermocouple was installed in each subchannel at the end of the heated length to measure subchannel outlet temperature. A thermocouple support grid was used to locate these thermocouples in the center of

the subchannels.

A summary of the geometric characteristics for the tests in the WSSV database is given in Table 2-1. The Columbia data from the six side-supported vane tests were sorted prior to development of the correlation to form separate correlation and validation databases. The sorting technique is described in Section 2.1.2. Approximately 20% of the raw data were set aside for the validation of the correlation. The databases for both the correlation and validation data sets are given in Appendix A.

4.2 VIPRE Model

The test data from the Columbia University test facility were initially evaluated by using the Westinghouse VIPRE thermal hydraulic code[4]. The VIPRE code was used to predict local coolant conditions in each subchannel for the CHF test sections at multiple axial nodes based on bundle average data measurements. VIPRE models were prepared for each test section in the database based upon the test section axial and radial geometry and the test section axial and radial power distributions, Appendix F. The VIPRE calculations used the measured values of pressure, inlet temperature, bundle average mass velocity and bundle average heat flux, given in Appendix A.

The VIPRE decks are set up with [ ] a, c. The [ ] a, c is selected for the grid locations. The grid elevations are identified in Appendix F. Following the development of the ABB-NV and ABB-TV correlations[1], the [ ] a, c. It is noted that the code results for the local conditions are [ ] a, c used in the analysis. A summary table of the [ ] a, c for each test is provided in Table 4-1.

During the uniform test CHF test programs, approximately 30 mixing points were taken to evaluate the grid mixing factor. Mixing tests are described in detail in Reference 13. The tests were performed with the same test arrays used for the CHF tests. Since it is [ ] a, c, is used to assess the data, following Reference 1. The measured values for the mixing factor are given in Table 4-2. For all tests, the measured mixing factor is [ ] a, c, as expected. The mixing factor from [ ] a, c. Based upon the mixing factor comparisons from the matrix tests, this value is considered to be a conservative mixing factor for the 16x16 design.

The VIPRE two-phase flow and crossflow correlations are kept the same as that for Westinghouse PWR applications in Reference 4. The input specifications for the VIPRE model are summarized in Table 4-3.

4.3 Data Evaluation and Statistics

Following the same basic process used to determine the optimum coefficients for ABB-NV and ABB-TV in Reference 1, the following steps were performed for the optimization of the WSSV CHF correlation coefficients with the CHF "correlation" database:

1) The data from all the tests in the correlation database are reduced with the VIPRE code to obtain local mass flow and quality conditions for all subchannels and multiple axial nodes for each test run. For the matrix tests, the local conditions from the [ ]^{a,c} from the VIPRE code. For tests with a simulated guide thimble, the local conditions from the [ ]^{a,c} were selected to determine the coefficient for the heated hydraulic diameter term in the correlation form. The [ ]^{a,c} coefficients for the final correlation form, described in Section 3, were then determined from the [ ]^{a,c} using a non-linear regression analysis. As discussed in Section 3, the coefficients for the heated length term are taken from the ABB-NV and ABB-TV correlations[1]. Since these data contained [ ]^{a,c}. In addition, the coefficients for the grid spacing factor, [ ]^{a,c}. The optimized non-uniform shape factor documented in Reference 1 is applied for the non-uniform axial shape tests.

2) The data from the correlation database are then reduced with the correlation coefficients determined at the [ ]^{a,c}. The data from all the tests in the correlation database are [ ]^{a,c} with the VIPRE code to obtain local mass flow and quality conditions and DNBR calculations for all subchannels and multiple axial nodes for each test run. The local conditions were then [ ]^{a,c} for each test run. While maintaining the coefficients identified above fixed, the remaining [ ]^{a,c} coefficients of the correlation form were optimized using a non-linear regression analysis.

3) Step 2 was repeated with the WSSV correlation in VIPRE having the coefficients determined in step 2. The local conditions were then [ ]^{a,c} determined in step 2. The correlation statistics at the [ ]^{a,c} using the coefficients determined in step 2. The [ ]^{a,c} coefficients were then re-fit using a non-linear regression analysis and the correlation statistics were computed using the new coefficients. Since the [ ]^{a,c}, the coefficients determined in step 2 are considered to be final.

Following the same process described in Reference 1, a non-linear regression analysis code was also used to sort and fit the test data. The optimization of the constants was performed on data within the parameter ranges shown in Tables 4-4 and 4-5. The code was also used to [ ]^{a,c}. After the initial runs, the code could have been used to separate out outliers, following the procedure described in Section 5. No points

in the correlation database were rejected by this procedure as outliers.

The WSSV correlation with the final coefficients for application with the VIPRE code is shown on the following page. The means and standard deviations for the M/P CHF ratio for the correlation database and individual test sections are presented in Table 4-4, along with the range of the primary variables. As stated earlier, the statistics for the correlation database are based upon the [ ] a, c with the correlation application. The statistical output for the individual test points in the WSSV correlation database are provided in Appendix B. Further discussion of the statistical evaluation of the WSSV correlation is given in Section 5.

<u>**Final Correlation Form and Coefficients for WSSV for VIPRE Code**</u>

a, c

[ ]

4.4 Validation of Correlation

An independent validation database was generated from data excluded from the correlation database to verify performance of the WSSV correlation, as described in Section 5.1. Since the data were extracted

from the Columbia data for Tests [ ] a, c prior to the development of the correlation constants, the geometric characteristics for these data are identical to the correlation database, as summarized in Table 2-1. The validation database was generated in a manner similar to the process used to generate the correlation database [ ] a, c.

A VIPRE model was prepared for each validation test section based on the test section axial and radial geometry and test section axial and radial power distributions. The VIPRE calculation used the measured values of pressure, inlet temperature, bundle average mass velocity and bundle average heat flux at CHF, as given in Appendix A. The appropriate mixing factor was selected for the test geometry, from Table 4-2. The local conditions at the [ ] a, c, are used to evaluate the M/P CHF ratio.

The means and standard deviations for the M/P CHF ratio for the validation database and individual test sections are presented in Table 4-5, along with the range of the primary variables. The statistical output for the individual test points in the WSSV validation database are provided in Appendix B. Further discussion of the statistical evaluation of the WSSV correlation is given in Section 5.

4.5 Side-Supported Vane Data Evaluation with TORC Thermal Hydraulic Code

The side-supported vane data were also evaluated with the TORC thermal Hydraulic code[5]. Based upon evaluations done to date[3], correlations developed in TORC could be applied in VIPRE without change of coefficients and/or the 95/95 DNBR limit. However, it is not clear that correlations developed in VIPRE can be applied in TORC without any change. To evaluate this, side-supported vane data were input into the TORC thermal hydraulic code with the WSSV correlation and constants developed in VIPRE. The TORC database was generated in a manner similar to the process used to generate the VIPRE correlation database at the [ ] a, c.

A TORC model was prepared for each test section based on the test section axial and radial geometry and test section axial and radial power distributions. The TORC calculation used the measured values of pressure, inlet temperature, bundle average mass velocity and bundle average heat flux at CHF, as given in Appendix C. The appropriate mixing factor was selected for the test geometry, from Table 4-2. The local conditions at the [ ] a, c, were used to evaluate the M/P CHF ratio. A comparison of the TORC and VIPRE models is shown in Table 4-6. The input specifications for the TORC model are summarized in Table 4-7.

Accuracy of CHF prediction is measured as the ratio of measured CHF to predicted CHF (M/P). Table 4-8 shows means and standard deviations of TORC M/P values for each test section, for the correlation database, the validation database and the entire database, as compared to the VIPRE WSSV results shown in Tables 4-4 and 4-5. It is noted that the TORC model utilized the ABB-NV correlation to cover the [

] a, c from the beginning of heated length. [

]^{a,c} from the comparison. There is no bias in the CHF predictions observed in the scatter plots of TORC M/P versus pressure, local mass velocity and local quality when the VIPRE developed constants are applied, Figures 4-1 through 4-3.

In general, the VIPRE developed coefficients provide a good fit when applied in TORC. However, the results in TORC do produce a slightly higher 95/95 DNBR limit than the results in VIPRE when the statistical methods in Section 5 are applied. Since the data had similar standard deviations when applied in both codes and there were no non-conservative trends observed, the constants of the same correlation form were re-fit for application with the TORC code with a nonlinear regression analysis code. Since the constants are re-fit to maintain the same 95/95 DNBR limit when applied with the VIPRE and TORC thermal hydraulic code, the correlation for the side-supported vane mixing grids for TORC is identified as WSSV-T. The constants were re-fit following Steps 2 and 3 described in Section 4.3. As stated in Step 2, the constants for [ ]^{a,c} are held fixed. The remaining [ ]^{a,c} are re-fit using the local conditions from TORC at the [ ]^{a,c}. The TORC correlation database is shown in Appendix C. The non-linear regression analysis code was used to fit and sort the test data. The optimization of the constants was performed on data within the parameter ranges shown in Table 4-9. The code was also used to separate out [ ]^{a,c}. After the initial runs, the code could have been used to separate out outliers, following the procedure described in Section 5. No points in the correlation database were rejected by this procedure as outliers.

The WSSV-T correlation with the final coefficients for application with the TORC code is shown on the following page. The means and standard deviations for the M/P CHF ratio for the entire side-supported vane database individual test sections are presented in Table 4-9, along with the range of the primary variables. As stated earlier, the statistics for the correlation database are based upon the MDNBR subchannel data only. The statistical output for the individual test points in the WSSV-T correlation database are provided in Appendix D. A comparison of the statistics from VIPRE with WSSV and TORC with WSSV-T for the entire database is given in Table 4-10. The difference of one point is due to the [ ]^{a,c}. It is noted that the statistics for the individual tests, as well as the entire database, are extremely close. Further discussion of the statistical evaluation of the WSSV-T correlation is given in Section 5.

<u>**Final Correlation Form and Coefficients for WSSV-T for TORC Code**</u>

a, c

[ ]

[ ]a,c

Table 4-1
Loss Coefficients Input to Thermal Hydraulic Codes
$$Kgrid = A * Re^{B} + C$$

Test	Grid	A	B	C

a, b, c

Table 4-2
Measured Mixing Factor Input to Thermal Hydraulic Codes

Test	Array Size	Rod Diam (in)	Heated Length (in)	Grid Spacing (in)	Guide Thimbles	Radial Split Cold/Hot	Number of Points	TDC Mean	Inverse Peclet # Mean

a, b, c

Table 4-3

Input Specifications for Side-Supported Vane Test VIPRE Model

1. Supplementary DNBRS output file selected: IDNBRS set to 2 or 3 in CONT.6
2. Single phase friction factor: f = [ ] a, b, c
3. Two-phase flow friction multiplier: [ ] a, c
4. Two Phase Flow: [ ] a, c
5. Axial Power Distribution:
   Uniform Test, uniform axial power distribution
   Non-uniform Test, non-uniform axial power distribution specific to test
6. Loss coefficient used: See Table 4-1
7. The crossflow resistance factor, [ ] a, b, c
   [ ] a, b, c
8. The turbulent momentum factor: [ ] a, b, c
9. The traverse momentum parameter [ ] a, c
10. The axial flow convergence for external iteration, FERROR set to [ ] a, b, c
11. Turbulent Mixing: [ ] a, c, Table 4-2. Value from [ ] a, c. This applies to both single and two-phase conditions.
12. Uniform mass velocity was used as the inlet flow option.
13. [ ] a, c for non-uniform tests.

Table 4-4
CHF Test Statistics for WSSV Correlation Database with VIPRE Code

Test No.	Rod Diam. (in.)	Rod Pitch (in.)	Dhm (in.)	Heated Length (in.)	GST	Axial Shape	Guide Thimble	WSSV N	WSSV M/P μ	WSSV M/P Std. Dev.
ALL								395	1.0012	0.0522

a, b, c

Parameter Range of Data:

Pressure, psi:	Min.	1495	Max.	2450
Local Mass Velocity, Mlb/hr-ft^2:	Min.	0.90	Max.	3.46
Local Quality	Min.	- 0.15	Max.	0.34

Table 4-5
CHF Test Statistics for WSSV Validation Database with VIPRE Code

Test No.	Rod Diam. (in.)	Rod Pitch (in.)	Dhm (in.)	Heated Length (in.)	GST	Axial Shape	Guide Thimble	WSSV N	WSSV M/P μ	WSSV M/P Std. Dev.
ALL								105	1.0033	0.0473

a, b, c

Parameter Range of Data:

Pressure, psi:	Min.	1495	Max.	2415
Local Mass Velocity, Mlb/hr-ft^2:	Min.	0.90	Max.	3.40
Local Quality	Min.	- 0.07	Max.	0.30

Table 4-6
Summary of TORC Model with WSSV in Comparison with VIPRE Model

Input Parameter	VIPRE	TORC
Radial Channels	Appendix F	Same
Axial Nodes	[ ]a, c Dependent on Test	[ ]a, c
[ ]a, c for Turbulent Mixing	Table 4-2	Same
Turbulent Momentum Factor	[ ]a, b, c	[ ]a, b, c
Axial Friction Factor, f	[ ]a, b, c	[ ]a, b, c
Crossflow Momentum Parameter	[ ]a, c	[ ]a, b, c
Crossflow Resistance Factor, K	[ ]a, b, c [ ]a, b, c	[ ]a, b, c
Average Grid Loss Coefficient, K	Table 4-1	Same
Two-Phase Flow	[ ]a, c	[ ]a, c
Two-Phase Flow Friction Multiplier	[ ]a, c	[ ]a, c

Table 4-7
Input Specifications for Side-Supported Vane Test TORC Model

1. Supplementary output file selected: N7=1 in Card Group 1.
2. Single phase friction factor: f = [ ] $^{a, b, c}$
3. Two-phase pressure drop predicted by the [ ] $^{a, c}$.
4. There is no forced flow diversion.
5. Uniform Test, uniform axial power distribution.
   Non-uniform Test, non-uniform axial power distribution specific to test.
6. Average grid loss coefficient used: Table 4-1
7. The COBRA III-C crossflow resistance relationship is used.
8. The diversion crossflow resistance factor [ ] $^{a, b, c}$.
9. The turbulent momentum factor: [ ] $^{a, b, c}$.
10. The traverse momentum parameter [ ] $^{a, b, c}$.
11. The number of axial nodes: Uniform test – [ ] $^{a, b, c}$.
    Non-Uniform Test, same as VIPRE Model.
12. The allowable fractional error in flow convergence: [ ] $^{a, b, c.}$
13. Interchannel energy transfer due to turbulent interchange and flow scattering is described by an [ ] $^{a, c}$, Table 4-2.
14. Thermal conduction in the coolant is neglected.
15. [ ] $^{a, c}$ was used for two-phase flow.
16. Uniform mass velocity was used as the inlet flow option.
17. [ ] $^{a, c}$ for non-uniform tests.

Table 4-8
VIPRE and TORC M/P Comparison for WSSV Correlation with VIPRE Coefficients

a, b, c

Test Number	VIPRE			TORC		
	N	M/P Mean	Std. Dev.	N	M/P Mean	Std. Dev.
Entire Database	500	1.0017	0.0512	497	0.9892	0.0506

Table 4-9
CHF Test Statistics for WSSV-T Correlation Database with TORC Code

Test No.	Rod Diam. (in.)	Rod Pitch (in.)	Dhm (in.)	Heated Length (in.)	GST	Axial Shape	Guide Thimble	WSSV-T N	WSSV-T M/P μ	WSSV-T M/P Std. Dev.
	ALL							499	1.0027	0.0511

a, b, c

Parameter Range of Data:

Pressure, psi:	Min.	1495	Max.	2450
Local Mass Velocity, Mlb/hr-ft^2:	Min.	0.86	Max.	3.48
Local Quality	Min.	– 0.15	Max.	0.35

Table 4-10
Side-Supported Vane Data M/P Comparison for VIPRE with WSSV Correlation and TORC with WSSV-T Correlation

Test Number	VIPRE			TORC		
	N	M/P Mean	Std. Dev.	N	M/P Mean	Std. Dev.
Entire Database	500	1.0017	0.0512	499	1.0027	0.0511

a, b, c

Figure 4-1
TORC M/P CHF Ratio with VIPRE WSSV Constants vs. Pressure

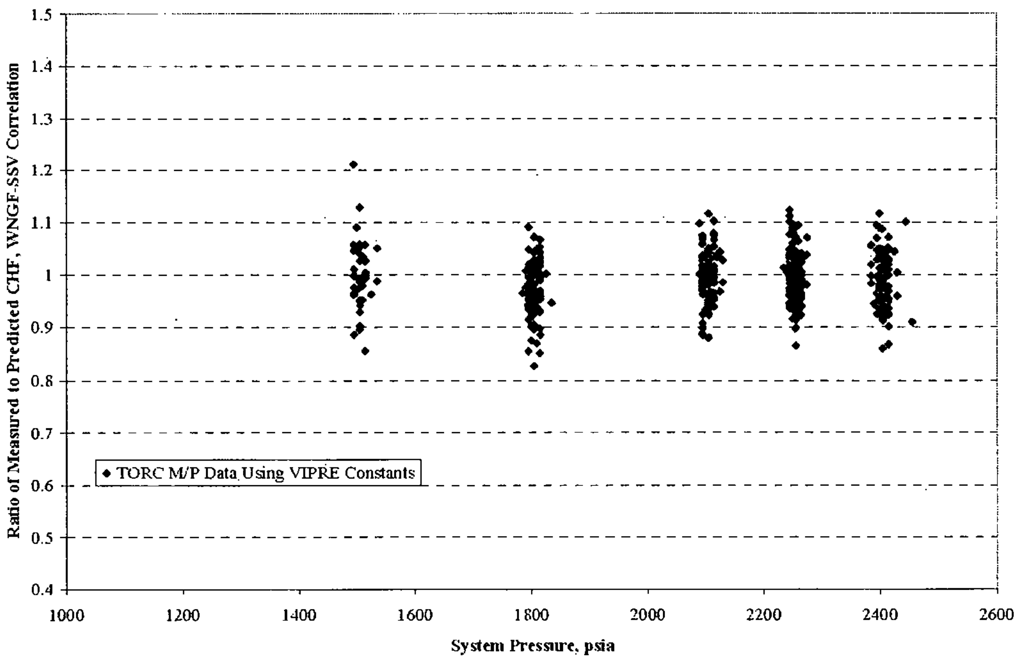

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Figure 4-2

TORC M/P CHF Ratio with VIPRE WSSV Constants vs. Local Mass Velocity

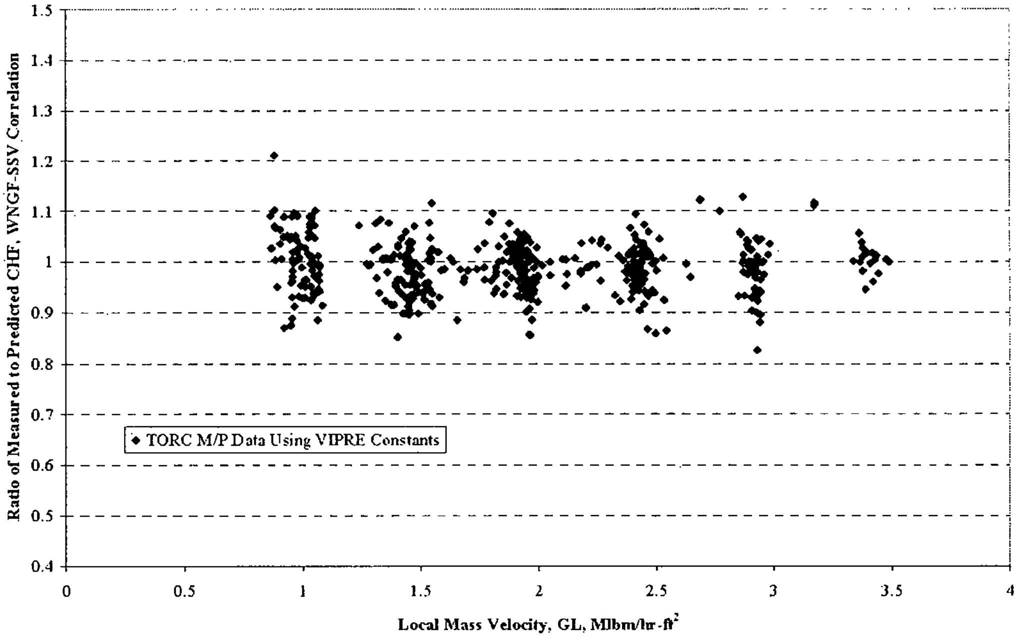

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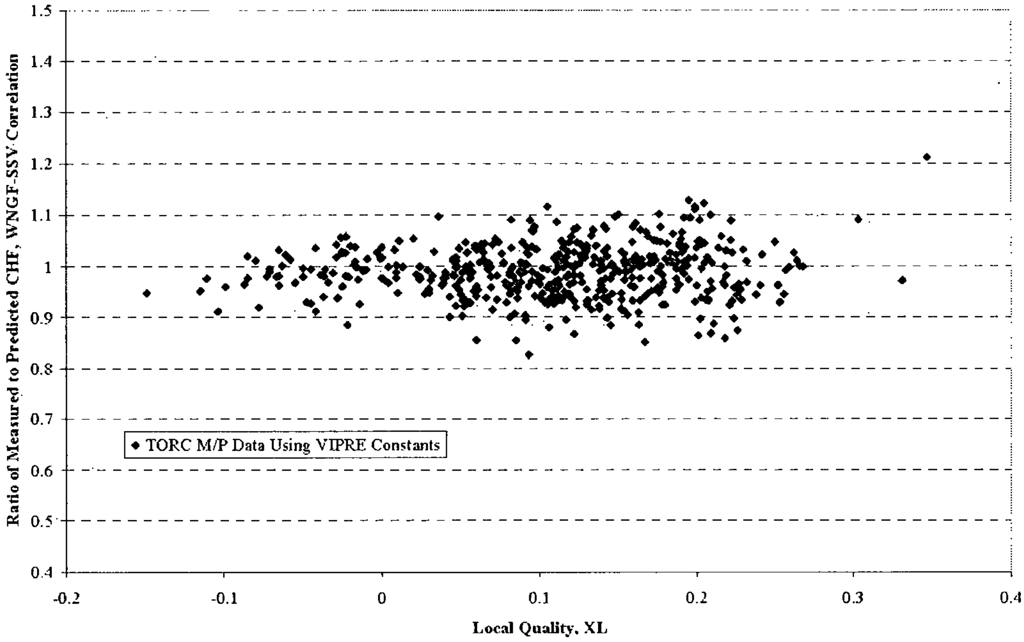
Figure 4-3
TORC M/P CHF Ratio with VIPRE WSSV Constants vs. Local Quality



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5.0 Statistical Evaluation

The mean and standard deviation for the ratio of measured to WSSV predicted CHF with the VIPRE code are given in Table 4-4 for the correlation database and individual test sections and Table 4-5 for the validation database and individual test sections. The mean and standard deviation for the ratio of measured to WSSV-T predicted CHF with the TORC thermal hydraulic code are given in Table 4-9 for the entire side-supported vane database and individual test sections. A statistical evaluation is performed with the WSSV correlation for [ ] a, c, the correlation database, the validation database and a combined correlation and validation database to determine the one-sided 95/95 DNBR limit applicable to each correlation. A statistical evaluation is performed with the WSSV-T correlation for [ ] a, c, and the correlation database to determine the one-sided 95/95 DNBR limit applicable to the side-supported vane correlation with the TORC code. The statistical tests applied are the same tests applied in Reference 1 for the ABB-NV and ABB-TV correlations. *No* points for WSSV or WSSV-T correlation databases were eliminated as outliers per the procedure given in Chapter 17 of Reference 7, a rigorous outlier test applied in Reference 1. Tests for normality at the 95% confidence level were performed on the above data sets to determine the proper statistical methods to be used for the data. The W and D' tests[14] were used to evaluate normality. The W test is applied to tests with less than 50 test points and the D' test is applied to all other test groups.

Ref: LTR-NRC-06-53 Response to RAI #6

Statistical tests were performed to determine if all or selected data groups belong to the same population, in order to be combined for the evaluation of the 95/95 DNBR tolerance limit. For normally distributed groups, homogeneity of variance was examined using Bartlett's test and homogeneity of the means was examined with the t-test or general F-test. The t-test was applied for testing the combinability of two groups and the F-test was applied to multiple groups. For groups that did not pass the normality test, the Wilcoxon-Mann-Whitney test or the Kruskal-Wallis One-Way Analysis of Variance by Ranks test is used to test the null hypotheses that the medians, or averages, of the tests or groups are the same. The Wilcoxon-Mann-Whitney test was applied for testing the poolability of two groups and the Kruskal-Wallis One-Way Analysis of Variance by Ranks test was applied to multiple groups. Since the groups that failed the D' normality test, passed other normality tests, such as the Kolmogorov-Smirnov test, the Bartlett and F-tests were initially applied to check for poolability of these groups. Data that did not pass any of these tests were not combined. Since it is proper to utilize all data in the evaluation of the correlation, the one-sided 95/95 DNBR tolerance limit is calculated for a combined correlation and validation database, if the data are poolable, or for the limiting subsets of data if not all of the data are poolable. The poolability tests were performed on the correlation and validation databases. For normally distributed groups, Owen's one-sided tolerance limit factor[6] is used to compute the 95/95 DNBR limit. For groups that are not normally distributed, a distribution-free or non-parametric limit, from Chapter 2 of Reference 7, is established. To cover all regions with the 95/95 limit, the most conservative limit for any subset examined is applied to the entire set of data.

Scatter plots were then generated for each of the variables in the correlation to examine the correlation for trends or regions of non-conservatism. The measured to correlation predicted CHF ratio is plotted as a

function of pressure, local mass velocity, local quality, matrix heated hydraulic diameter, Dhm, heated hydraulic diameter, Dh, the grid spacing term, GST, heated length from BOHL to location of CHF, and the optimized non-uniform shape factor, F_C. The DNBR limit is also shown on these plots to show the number of test points that fall below the limit and the location of those points. The total number of test points that fall below the limit is also identified.

5.1 Statistical Tests

5.1.1 Treatment of Outliers

Each database is examined for outliers by the following method:

The probability of rejecting an observation when all data belong to the same group, α, was selected to be 0.05. The term $\alpha' = 1 - (1-\alpha)^{1/n}$ is computed. The value of $(1 - \alpha'/2)$ is the normal cumulative distribution value, P, and the value of $z_{1-\alpha'/2}$ is calculated or taken from cumulative normal distribution tables. For a mean value of m, the values of a and b are computed where:

$$a = m - \sigma * z_{1-\alpha'/2}$$
$$b = m + \sigma * z_{1-\alpha'/2}$$

Any observation that does not lie in the interval a to b is rejected. The method does assume a normal distribution and the values of μ, mean of the data, and s, standard deviation of the data, are reasonable estimates of m and σ. Therefore, care must be taken to ensure the elimination of outliers is justifiable.

Ref: LTR-NRC-06-53 Response to RAI #6

The test was applied to the correlation database and the combined correlation database and validation database after poolability was demonstrated. No points from the correlation or validation databases were eliminated.

5.1.2 Normality Tests

The W and D' tests[14] were used to evaluate the assumption of a normal distribution. For individual tests with less than 50 test points, the W test is applied. The test statistic W is computed as:

Ref: LTR-NRC-06-53 Response to RAI #7

$$W = b^2 / S^2$$

where:

$$S^2 = \sum_{i=1}^{n} (x_i - \bar{x})^2$$

$$b = \sum_{i=1}^{k} a_{n-i+1} (x_{n-i+1} - x_i) \qquad x_i \textit{ in ascending order}$$

ai from Table 1[14]

k = n/2 if n is even and k = (n-1)/2 if n is odd.

The value of W is compared with percentage points of the distribution of W for P set to 0.05 from Table 2 of Reference 14. Small values of W indicate non-normality. For combined tests or individual tests with $n \geq 50$, the D' normality test is applied. The test statistic D' is computed as:

$$D' = T / S$$

where:

$$S = \left[\sum_{i=1}^{n} (x_i - \bar{x})^2 \right]^{0.5}$$

$$T = \sum_{i=1}^{n} \{i - (n+1)/2\} x_i \qquad x_i \textit{ in ascending order}$$

The calculated value of D' is compared with the percentage points values of the distribution of D' from Table 5 of Reference 14. The D' test indicates non-normality if the calculated value of D' falls outside of the range established from Table 5 for P set to 0.025 and 0.975. These tests were selected since they are considered to be more rigorous compared to other normality tests such as the Kolmogorov-Smirnov test. Furthermore, the D' and W tests are the ANSI standard tests that have been used in previous data analyses reviewed and approved by the NRC.

5.1.3 Statistical Tests for Comparison of Data Groups

Statistical tests were performed to determine whether data groups could be considered to come from one population. The Bartlett test for homogeneity of variances and the t-test, for 2 groups, or the F-test, for multiple groups are applied to determine if data groups can be combined. If the data groups fail the normality test or the homogeneity of variances test, the Mann-Whitney Rank Sum test or the Kruskal-Wallis One-Way Analysis of Variance by Ranks test is used to check the null hypotheses that the medians, or averages, of the tests or groups are the same. For the groups that pass the equality of means tests or the non-parametric tests for the null hypothesis that the samples are from the same population, the normality tests are applied to the combined groups to check the assumption of normality. If the combined group passes the normality test, Owen's one-sided tolerance limit factor[6] is used to compute the 95/95 DNBR limit. If the combined group fails the normality test, a distribution-free one-sided 95/95 limit is determined, Chapter 2 of Reference 7. A brief description of the comparison tests is given below:

5.1.3.1 Homogeneity of Variances

One of the most used tests for examining the homogeneity of a set of variances is Bartlett's test[15]. Bartlett showed that for a set of variances estimated from K independent samples from normal distributions having a common variance σ^2, a quantity M/C would have a distribution satisfactorily approximated by the χ^2 distribution. Specifically:

$$M = N \ln\left\{N^{-1} * \sum_{t=1}^{K} \nu_t s_t^2\right\} - \sum_{t=1}^{K} \nu_t \ln s_t^2$$

$$C = 1 + \frac{1}{3(K-1)}\left\{\sum_{t=1}^{K} \frac{1}{\nu_t} - \frac{1}{N}\right\}$$

where:

s_t^2 Is an estimate of variance for test section t based on degrees of freedom ν_t, K is the number of test sections.

$$N = \sum_{t=1}^{K} \nu_t$$

and the quantity M/C is distributed approximately as χ^2 with K-1 degrees of freedom.

5.1.3.2 Test for Equality of Means for Two Data Groups - Unpaired t-Test

When data from two groups passed the test for homogeneity of variances, the t-Test was employed to test the hypothesis that $\mu_1 - \mu_2 = 0.0$ or that $\mu_1 = \mu_2$, where μ_1 is the mean from data group 1 and μ_2 is the mean from data group 2. The test statistic t is calculated with the expression:

$$t = \frac{\mu_1 - \mu_2}{s_\upsilon \left(\frac{1}{n1} + \frac{1}{n2}\right)^{0.5}}$$

where:

$$s_\upsilon^2 = \frac{\sum_{j=1}^{n1}(x_{1j} - \mu_1)^2 + \sum_{j=1}^{n2}(x_{2j} - \mu_2)^2}{n1 + n2 - 2}$$ is a "pooled" estimate

The computed value of t is compared with the value $t_{\alpha/2, n1+n2-2}$ in a table of percentiles of the t distribution for α set to 0.05. The hypothesis that $\mu_1 = \mu_2$ is rejected, if the computed value of t is larger then the value of $t_{\alpha/2, n1+n2-2}$.

5.1.3.3 Test for Equality of Means for Multiple Data Groups – Analysis of Variance, F-Test

An analysis of variance test was performed to test the equality of means and determine whether the data from multiple tests or groups could be pooled. One of the usual techniques for examining the equality of means determined in an experimental study is a particular form of the F-test. In this technique, two mean squares are found, call them S_1, the between test section mean square and S_2, the within test section mean square. If K is the number of test sections, n_t the number of data for test section t and n is the total number of data,

$$S_1 = \frac{\sum_{t=1}^{K} n_t \left(\overline{X}_t - \overline{\overline{X}}\right)^2}{K-1} \text{, and}$$

$$S_2 = \frac{\sum_{t=1}^{K} \left\{ \sum_{i=1}^{n_t} \left(X_{ti} - \overline{X}_t\right)^2 \right\}}{n-K}$$

In these expressions X_{ti} is an individual datum for test section t, $\overline{X}_t$ is the mean value of X for test section t and $\overline{\overline{X}}$ is the grand mean for all data. Under the hypotheses of normality, homogeneity of variance and equality of means, S_1 and S_2 are independent estimates of the variance, σ^2, due to random deviation from the true grand mean. Therefore the ratio:

$F = S_1 / S_2$ should follow the F distribution with degrees of freedom, $\nu_1 = K - 1$ and $\nu_2 = n - K$.

The calculated value of F is compared with the value of $F_{1-\alpha(\upsilon_1,\upsilon_2)}$ for α set to 0.05. Should the test section means not be equal, S_1 will contain additional components of variance. Therefore, large values of F require the rejection of the hypothesis of equality among the means of the tests or groups.

5.1.3.4 Distribution Free Comparison of Average Performance

For combinations that have one or both tests fail the normality test, the Wilcoxon-Mann-Whitney Test(7)(16) is used to compare two groups. To apply this test when one of the samples has n > 10, all groups considered, the data are combined. The number of points in the smaller sample is m; the number from the larger group is n. The M/P CHF values from the two groups are ranked from 1 to m+n = N with tied ranks being assigned the average. The value of T is computed by summing the ranks in the smaller group. The value of z is then computed with the expression:

$$z = \frac{T \pm 0.5 - m*(N+1)/2}{\left[m*n*(N+1)/12\right]^{0.5}}$$

The significance of z is assessed from cumulative normal distribution table. The value of z must fall between -1.645 to +1.645 for the two groups to pass the null hypotheses that the groups are drawn from the same population for P equal 0.950 for the left and right tails of the distribution.

For comparison of tests or multiple groups that failed the Bartlett test for equal variance or the D' test for normality, the Kruskal-Wallis One-Way Analysis of Variance by Ranks test(7)(16) is used. The level of significance of the test, α, is selected to be 0.05. The $\chi^2_{1-\alpha}$ value for K - 1 = degrees of freedom is taken from a table of the percentiles of the χ^2 distribution. The data from all tests or groups are ranked from lowest to highest. The H statistic is then calculated with the equation:

$$H = \frac{12}{N(N+1)} * \sum_{i=1}^{K} \frac{R_i^2}{n_i} - 3*(N-1)$$

where R_i is the sum of the ranks for the ith test, n_i is the number of points in test i and N is the total number of points. If $H > \chi^2_{1-\alpha}$, one rejects the hypothesis that the averages are the same.

5.1.4 One-sided 95/95 DNBR Limit

All data from the correlation and validation databases could be considered in the establishment of the one-sided 95/95 DNBR tolerance limit if the data can be pooled. Therefore, the comparison tests are performed on the combined data sets prior to the determination of the 95/95 DNBR limit. If not all of the data passed the analysis of variance tests, the data were grouped into subsets based on geometry or by test and the 95/95 DNBR limit was established for the different groups of pooled data. The computed 95/95 DNBR limit for the class of data provides 95% probability at the 95% confidence level that a rod in that class having that DNBR will not experience CHF. The most conservative limit determined for any group of data examined is then applied to the entire correlation data set. For normally distributed groups, Owen's one-sided tolerance limit factor[6] is used to compute the 95/95 DNBR limit. For groups that are not normally distributed, a distribution-free or non-parametric limit, from Chapter 2 of Reference 7, is established.

5.1.4.1 Normally Distributed 95/95 DNBR Limit

The mean and standard deviation of the ratio of measured to predicted CHF for the WSSV or WSSV-T correlations are computed for each data group or class of data that pass the comparison tests and D' normality test. This group can include all data from the correlation database and validation database or a subset of that data. A 95/95 DNBR limit is evaluated for each group based on the following formulas:

$$DNBR_{95/95} = \frac{1}{\overline{X} - KS}$$

$$K = \frac{1.645 + 1.645[1-(1-\frac{2.706}{2(n-1)})\bullet(1-\frac{1}{n})]^{\frac{1}{2}}}{1-\frac{2.706}{2(n-1)}}$$

where:

- $\overline{X}$ = mean of ratio of measured to predicted CHF
- S = standard deviation of measured to predicted CHF
- K = 95/95 confidence multiplier (Expression given in Reference 25, practically equivalent to Owen's tables in Reference 6)
- n = number of data points

5.1.4.2 Distribution Free 95/95 Limit

For data groups that do not pass the D' normality test, a distribution free one-sided 95/95 limit is established. Table A-31 of Reference 7 gives the largest value of m such that one can assert with 95% confidence that 95% of the population lies above the mth smallest value of X_i, where X_i is an individual test run value of the ratio of measured to correlation predicted CHF in the non-normally distributed group.

As stated earlier, if all of the data in the combined correlation and validation database could not be pooled, the most conservative 95/95 limit for any subset of that data is the specified limit for the correlation. As a check on the limit, the total number and percentage of test points that fall below the specified limit are also identified. In addition, the limit computed for the entire database is computed using the total variance approach applied in References 9 and 10. Also, the limit for the entire database is computed using the distribution free method if the entire database is not normally distributed.

5.1.5 Graphical Verification

After the determination of the 95/95 DNBR limit for the correlation, scatter plots are then generated for each of the variables in the correlation to examine the correlation for trends or regions of non-conservatism. The M/P CHF ratio is plotted as a function of pressure, local mass velocity, local quality, matrix heated hydraulic diameter (Dhm), heated hydraulic diameter (Dh), the grid spacing term (GST), heated length from BOHL to location of CHF, and the optimized non-uniform shape factor (F_C). The DNBR limit is also shown on these plots to show the number of test points that fall below the limit and the location of those points.

5.2 WSSV Side-Supported Vane Correlation with VIPRE Code: Statistical Evaluation and 95/95 DNBR Limit

The W and D' normality tests and comparison tests were performed to determine if the WSSV correlation and validation data were random samples from one or more populations and whether the data from individual tests and the combination of tests were normally distributed. As stated in Section 5.1, parametric comparison tests were performed to determine if data from the tests were poolable, then normality tests were performed on the pooled data and if the data failed the normality test, non-parametric tests were performed to check the hypothesis that the averages for the pooled tests are the same. For the WSSV correlation, since the correlation and validation data were taken from the same test series, if it is shown the data can be pooled, the data are combined for the determination of the one-sided 95/95 DNBR limit. Therefore, the initial evaluation was performed to determine whether the correlation and validation data were from the same population. The mean and standard deviation for the ratio of measured to predicted CHF for the WSSV correlation with the VIPRE thermal hydraulic code are shown in Table 4-4 for the correlation database and Table 4-5 for the validation database. The correlation database has 395 points and the validation database has 105 points or 21% of the total points within the range of applicability. The Bartlett test and t-Test were applied to the data in the correlation database and validation database to verify that these data came from the same population(s). The results from the tests

are summarized in Table 5.2-1. Since the validation data failed the D' normality test at the 5% significance level, Table 5.2-3, the results of the non-parametric analysis is also given in Table 5.2-1. It is noted the same tests were applied to the correlation and validation data test section by test section and all test sections passed the comparison tests and could be pooled. Since no bias is observed between the correlation database and verification database, a multiple data analysis was performed on all of the test section data. The results of the comparison tests are given in Table 5.2-2. Based upon the results of the parametric tests, one would conclude that all test sections have [ ] a, c. Multiple comparison tests are performed to [ ] a, c with the application of the statistical tests identified in Section 5.1. The data were initially examined by test section geometry. Since the side-supported vane design and tests have been performed with two fuel designs, the 14x14 and 16x16 designs with large thimbles, the data are examined by [ ] a, c. Based upon this analysis, it was determined that the WSSV data could be separated into two subsets of data, based on the [ ] a, c. As seen in Table 5.2-2, the database has [ ] a, c. These two subsets are identified as G-1 and G-2 for geometry 1 and geometry 2.

In addition, following Reference 1, multiple comparison tests are also performed to identify [ ] a, c with the application of the statistical tests identified in Section 5.1. This approach treats [ ] a, c. The tests in the most limiting subsets are identified below:

a, b, c

Subset	Tests Included	No. Points	Mean	Std. Dev.

It is noted that due to the [ ] a, c. The W and D' normality tests were then applied to the data from each test section and each set of data, as shown in Table 5.2-3. The results of the group comparison tests are shown in Table 5.2-4.

Since the combined 14x14 database [ ] a, c was applied to evaluate the data grouped by bundle array. The data [ ] a, c. Based upon the results, presented in Table 5.2-4, the one-sided 95/95 DNBR limit is evaluated with [ ] a, c. Since the combined database [ ] a, c is based on the parametric method

described in Section 5.1. The non-parametric method is only applied to the [ ] ^{a,c}. The one-sided 95/95 DNBR limits for the different identified groups are shown in Table 5.2-5.

The one-sided 95/95 DNBR tolerance limit for the combined data is provided in Table 5.2-5. Based upon the data presented in this table, the 95/95 DNBR limit is based upon the data pooled by test, or 1.12. This compares to a limit of 1.11 computed based on the worst subset when pooling the data based on geometry. The DNBR limit of 1.12 for the most non-conservative data will be applied to the entire database. A plot of the measured CHF versus the WSSV predicted CHF for all the test data is given in Figure 5.2-1, along with the DNBR limit curve. The DNBR limit of 1.12 is equivalent to a value of 0.893 for the M/P CHF ratio. It is noted that for the entire database, twelve test points, or 2.4% of the data fall below the M/P 95/95 limit of 0.893.

The data are then examined graphically in order to check for any deviation as a function of the correlation variables. The plots of the M/P CHF ratio as a function of pressure, local mass velocity, local quality, matrix heated hydraulic diameter (Dhm), heated hydraulic diameter (Dh), the grid spacing term (GST), the heated length from BOHL to location of CHF, and the optimized non-uniform shape factor (F_C), are shown in Figures 5.2-2 through 5.2-9. The DNBR limit is also shown on these plots to show the number of test points that fall below the limit and the location of those points. There are no observed adverse trends on any of the plots.

Based upon the results of the statistical tests applied to the WSSV VIPRE database and the scatter plot analysis, the one-sided 95/95 DNBR limit is determined to be 1.12. The applicable parameter ranges for the WSSV correlation are given in Table 5.2-6.

Table 5.2-1
Comaprison Tests
WSSV VIPRE Correlation and Validation Database

Bartlett Test Results

Database	N	Mean	s	K	M	C	M/C	χ^2_{95}	Pass Test
Combined	500	1.0017	0.0512	2	1.543	1.0034	1.538	3.84	Yes

a, b, c

t-Test Results

Database	N	Mean	s	$\mu_1 - \mu_2$	s_p	t	$t_{975,498}$	Pass Test
Combined	500	1.0017	0.0512	-0.0021	0.0513	-0.366	-1.96	Yes

a, b, c

Wilcoxon-Mann-Whitney Rank Sum Test Results

Database	N	Mean	s	T	z	z_{95}	Pass Test
Combined	500	1.0017	0.0512	26876	0.436	1.645	Yes

a, b, c

Table 5.2-2
Comparison Tests
Combined Correlation and Validation WSSV VIPRE Database

Test No.	Rod Diam. (in.)	Rod Pitch (in.)	Dhm (in.)	Heated Length (in.)	GST	Axial Shape	Guide Thimble	WSSV N	WSSV M/P µ	WSSV M/P Std. Dev.
ALL								500	1.0017	0.0512

a, b, c

Bartlett Test Results – WSSV VIPRE Data

Database	N	Mean	s	K	M	C	M/C	χ^2_{95}	Pass Test
ALL	500	1.0017	0.0512	6	7.808	1.0061	7.760	11.07	Yes

F-Test Results – WSSV VIPRE Data

Database	v_1	v_2	S_1	S_2	S_1 / S_2	$F_{95(v1, v2)}$	Pass Test
ALL	5	494	0.01540	0.00249	6.1747	2.21	No

Kruskal-Wallis Variance By Ranks Test Results – WSSV VIPRE Data

Database	K	H	χ^2_{95}	Pass Test
ALL	6	37.69	11.07	No

Table 5.2-3
W and D' Normality Tests WSSV VIPRE Database

Data	N	Mean	D' Calculated	D' P=.025	D' P=.975	Pass Test
[						] a, b, c

Data	N	Mean	W Calculated	W P=.05	Pass Test
[					] a, b, c

Subset G1 – [ ] a, c

Subset G2 – [ ] a, c

Subset T1 – [ ] a, c

Subset T2 – [ ] a, c

Table 5.2-4
Comparison Tests for Pooled Subsets WSSV VIPRE Database

Bartlett Test Results – WSSV Data

Database	N	Mean	s	K	M	C	M/C	χ^2_{95}	Pass Test
Subset G1	395	0.9971	0.0513	2	2.225	1.0048	2.215	3.84	Yes
Subset G2	105	1.0188	0.0472	1					
Subset T1	178	0.9875	0.0497	3	6.496	1.0099	6.432	5.99	No
Subset T2	254	1.0039	0.0529	3	2.285	1.0071	2.269	5.99	Yes

t-Test Results

Database	N	Mean	S	$\mu_1 - \mu_2$	S_p	t	$t_{975,393}$	Pass Test
Subset G1	395	0.9971	0.0513	.0089	.0513	1.348	1.96	Yes

F-Test Results – WNGF-SSV VIPRE – Subset T2

Database	v_1	v_2	S_1	S_2	S_1 / S_2	$F_{95(v1, v2)}$	Pass Test
Subset T2	2	251	0.00232	0.00280	0.829	3.00	Yes

Wilcoxon-Mann-Whitney Rank Sum Test Results – 14x14 and 16x16 Data

Database	N	Mean	S	m	n	z	z_{975}	Pass Test
14x14 & 16x16	500	1.0017	0.0512	179	321	2.257	1.96	No

Kruskal-Wallis Variance By Ranks Test Results - Subset T1

Database	K	H	χ^2_{95}	Pass Test
Subset T1	3	3.851	5.99	Yes

Subset G1 – [ ]^a, c
Subset G2 – [ ]^a, c
Subset T1 – [ ]^a, c
Subset T2 – [ ]^a, c

Table 5.2-5
Determination of $DNBR_{95}$ Limit for Pooled Data
WSSV VIPRE Database

Calculation of $DNBR_{95}$ Limit Calculation for Parametric Data

Database	Mean	S	N	K	$DNBR_{95}$

a, b, c

Calculation of $DNBR_{95}$ Limit Calculation for Nonparametric Data

Database	γ	P	n	M	Value	$DNBR_{95}$

a, b, c

Partial Ranking of Data from 14x14 Data

a, b, c

Table 5.2-6
Parameter Ranges for the Final WSSV VIPRE Correlation Database

Parameter	Minimum	Maximum
Pressure (psia)	1495	2450
Local Coolant Quality	-0.15	0.34
Local Mass velocity (Mlb/hr-ft^2)	0.90	3.46
Matrix Heated Hydraulic Diameter, Dhm (inches)	0.4635	0.5334
Heated Hydraulic Diameter Ratio, Dhm/Dh	0.679	1.00
Heated Length, HL (inches)	48*	150
Grid Spacing, GS (inches)	10.28	18.86

*Set as minimum HL value, applied at all elevations below 48 inches

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Figure 5.2-1
Measured and Predicted Critical Heat Fluxes
WSSV Correlation with VIPRE Code

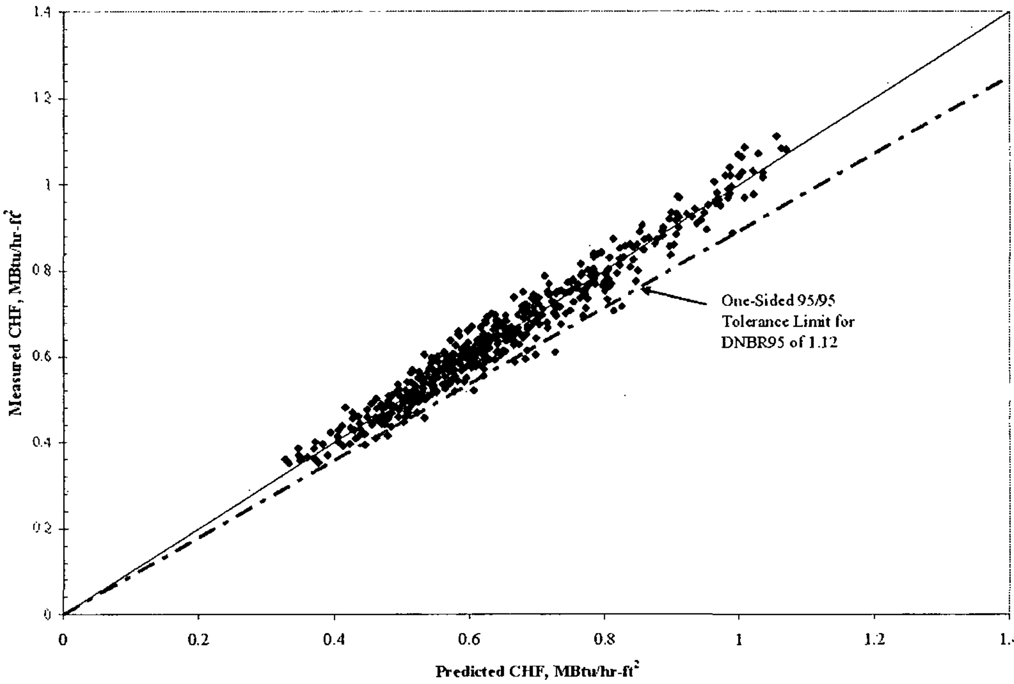

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Figure 5.2-2
Plot of M/P CHF Ratio vs. Pressure
WSSV Correlation with VIPRE Code

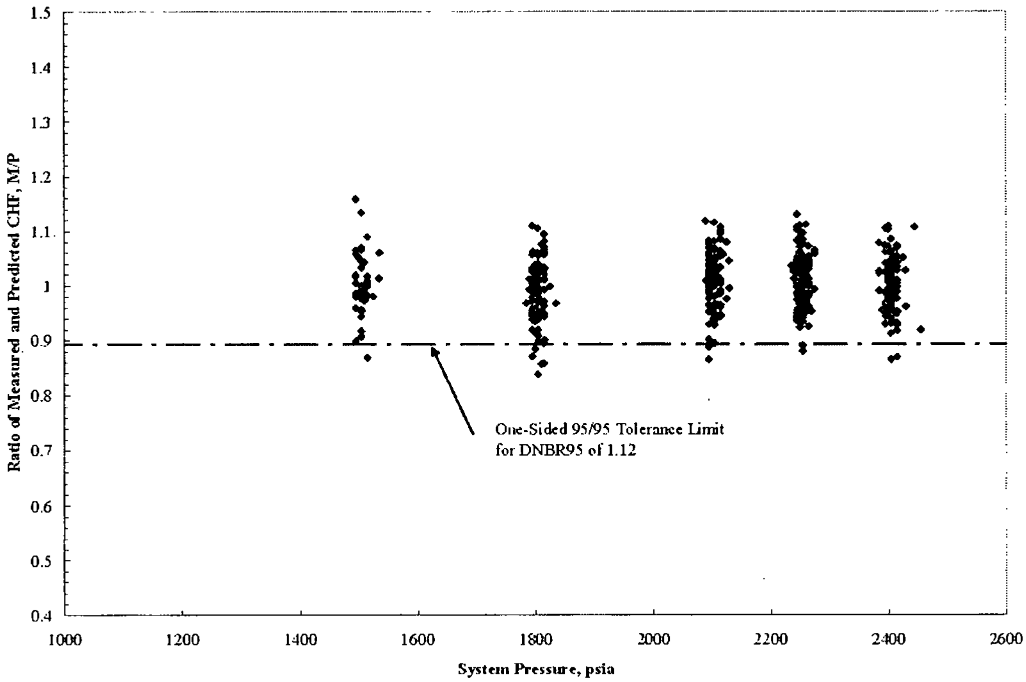

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Figure 5.2-3
Plot of M/P CHF Ratio vs. Local Mass Velocity
WSSV Correlation with VIPRE Code

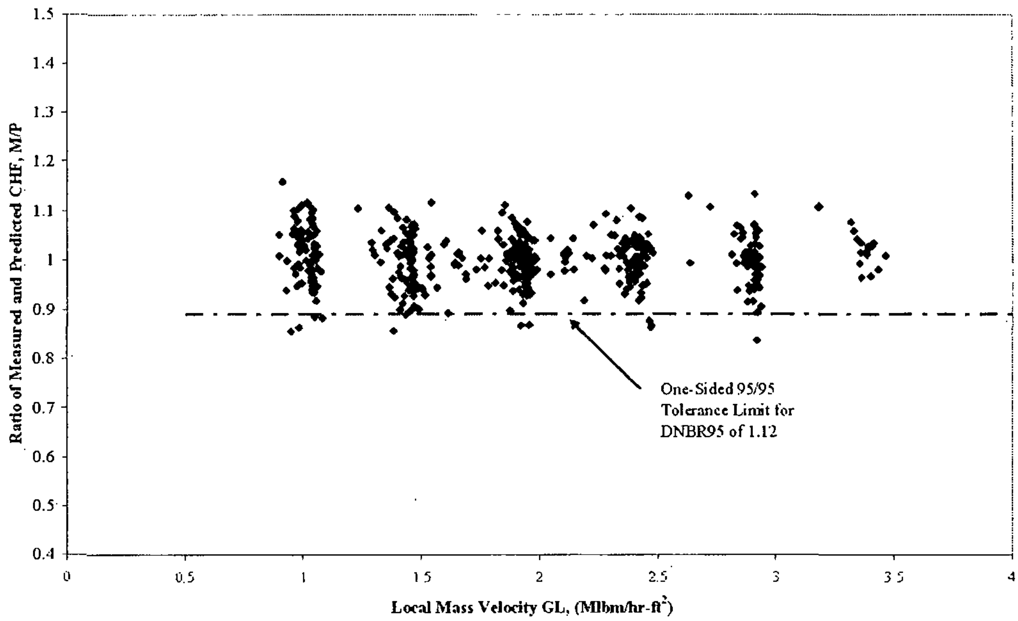

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Figure 5.2-4
Plot of M/P CHF Ratio vs. Local Quality
WSSV Correlation with VIPRE Code

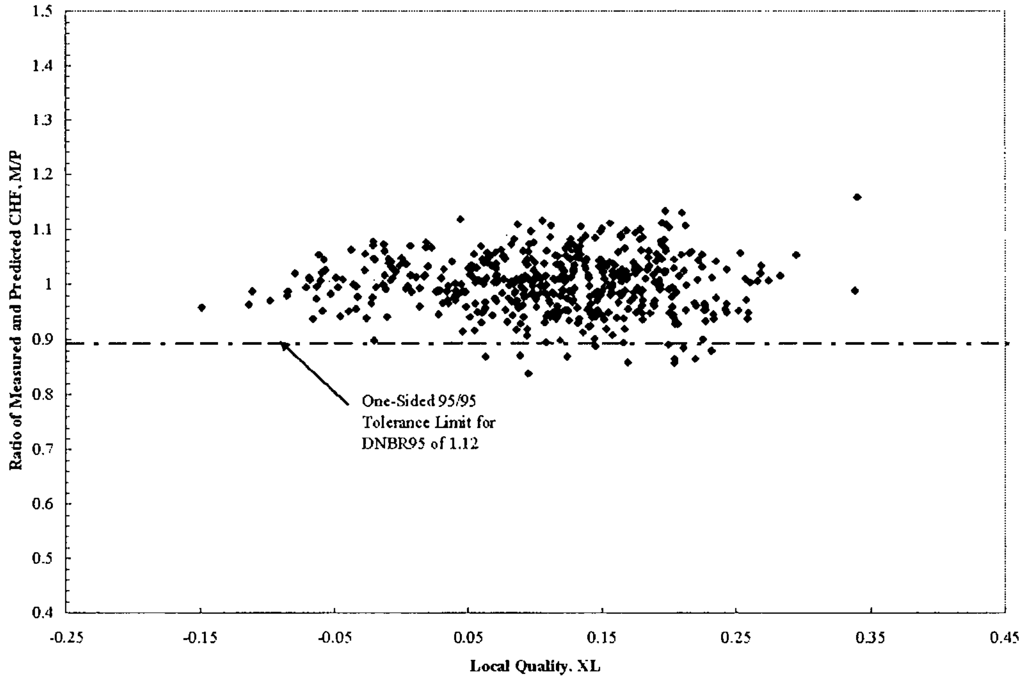

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Figure 5.2-5
Plot of M/P CHF Ratio vs. Matrix Heated Diameter, Dhm
WSSV Correlation with VIPRE Code

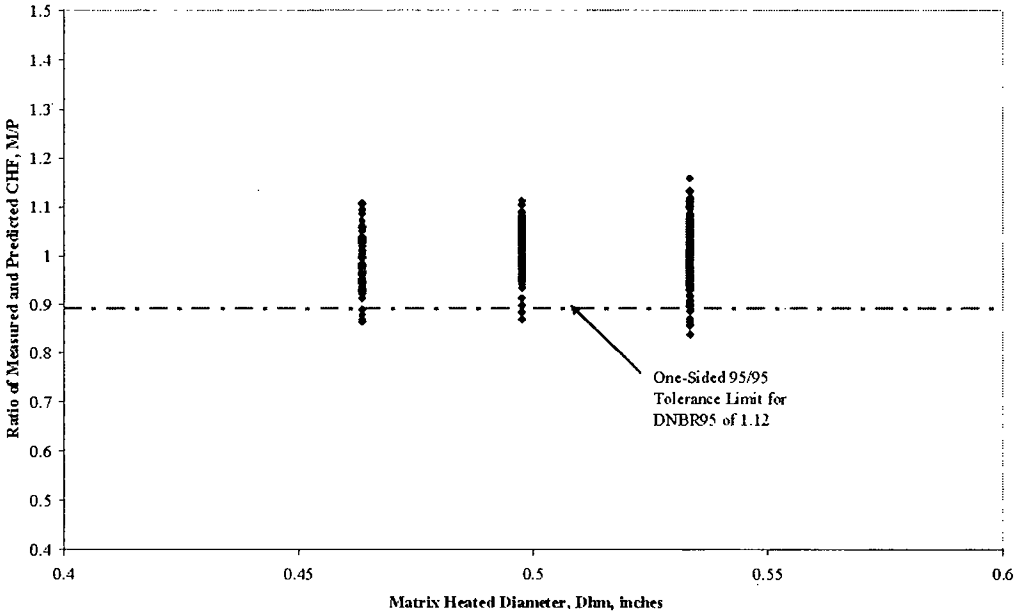

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Figure 5.2-6
Plot of M/P CHF Ratio vs. Heated Hydraulic Diameter, Dh
WSSV Correlation with VIPRE Code

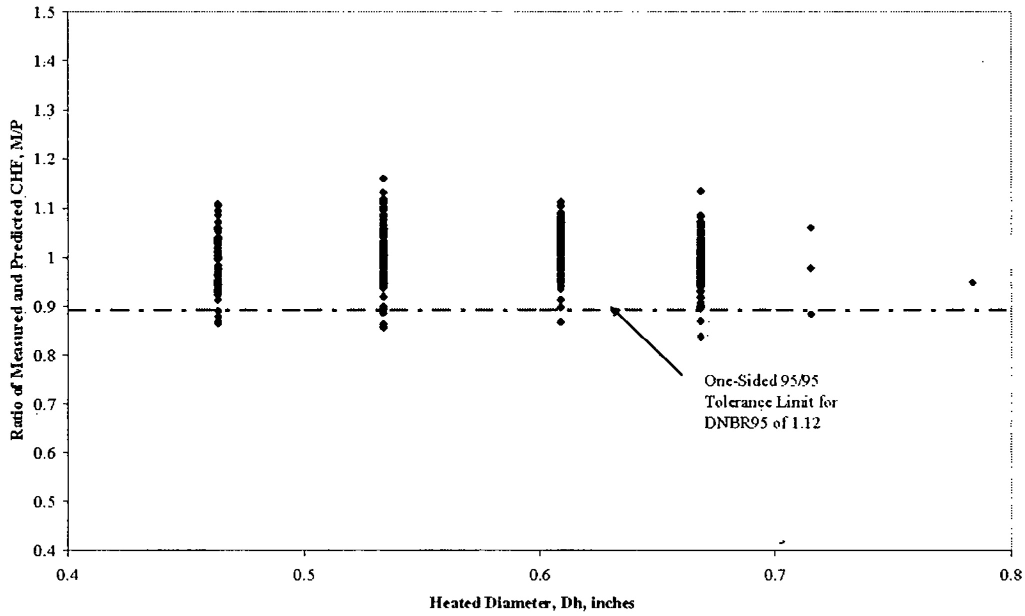

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Figure 5.2-7
Plot of M/P CHF Ratio vs. Grid Spacing Term, GST
WSSV Correlation with VIPRE Code

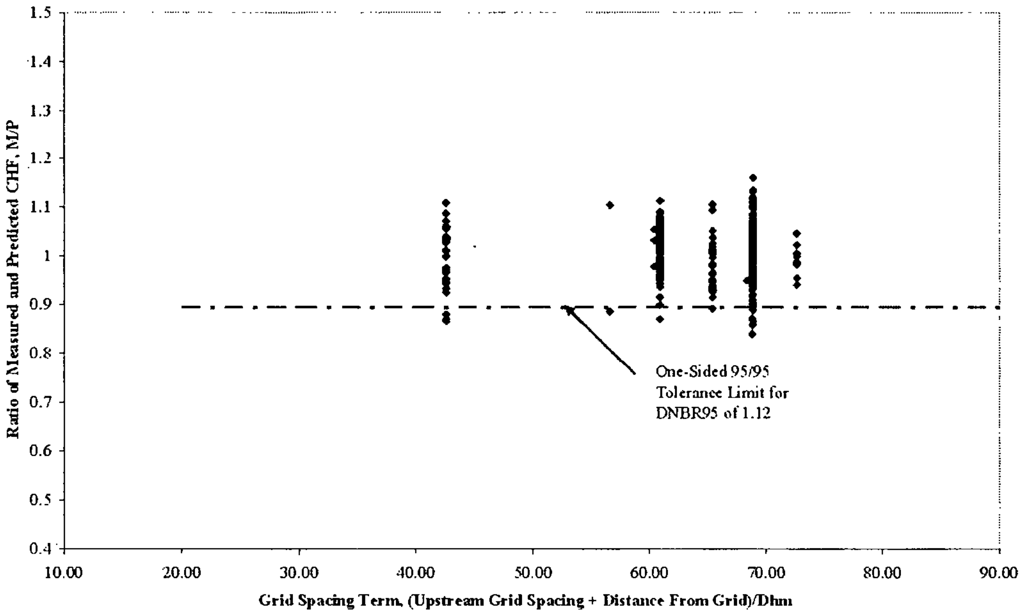

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Figure 5.2-8
Plot of M/P CHF Ratio vs. Heated Length, HL
WSSV Correlation with VIPRE Code

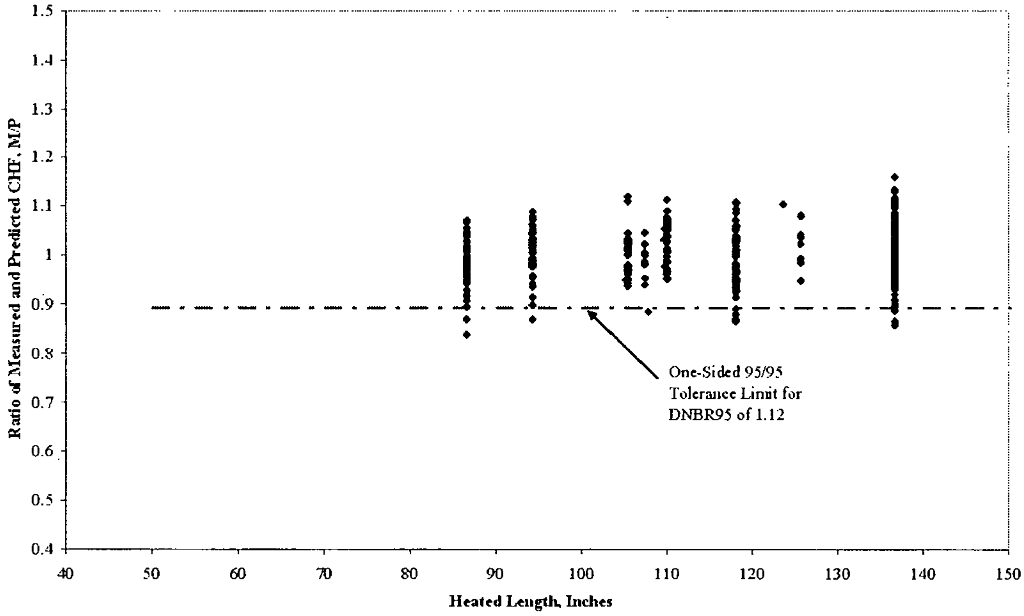

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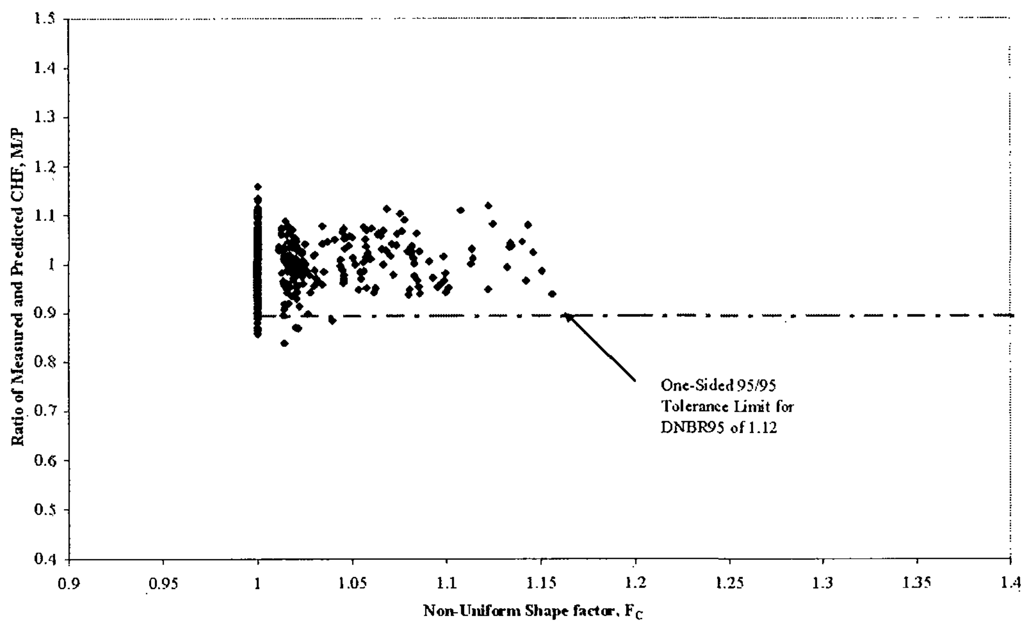
Figure 5.2-9
Plot of M/P CHF Ratio vs. Non-Uniform Shape Factor, F_C
WSSV Correlation with VIPRE Code



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5.3 WSSV-T Side-Supported Vane Correlation with TORC Code: Statistical Evaluation and 95/95 DNBR Limit

Based upon the comparison of the correlation and validation database in Section 5.2 and the very close similarity in the results with the VIPRE and TORC thermal hydraulic codes, the correlation and validation databases were combined to determine the one-sided 95/95 DNBR limit with the modified coefficients for the TORC code. As noted in Section 4, the results with TORC, when the VIPRE developed constants were applied, gave very similar results, but the one-sided 95/95 DNBR limit for the most conservative subset was slightly higher. As shown in Table 4-10, the results with the modified coefficients for application with TORC were extremely close to the VIPRE results. Although very close, the process used to compare tests and determine the one-sided 95/95 DNBR limit is repeated for the data obtained from the TORC code. The results of the comparison tests for all are given in Table 5.3-1. It is noted that there is one less point since the MDNBR location for Run 126 of [ ] a, b, c, so this point was not included in the database. Based upon the results of the parametric tests, one would conclude that all test sections have the [ ] a, c. Similar to Section 5.2, multiple comparison tests are performed to identify data groups that can be pooled with the application of the statistical tests identified in Section 5.1. The data were initially examined by test section geometry. Since the side-supported vane design and tests have been performed with two fuel designs, the 14x14 and 16x16 designs with large thimbles, the data are examined by [ ] a, c. Based upon this analysis, it was determined the WSSV-T data could be separated into two subsets of data, based on the [ ] a, c. As seen in Table 5.3-1, the database has [ ] a, c. These two subsets are identified as G-1 and G-2 for geometry 1 and geometry 2.

In addition, following Section 5.2, multiple comparison tests are also performed to identify [ ] a, c with the application of the statistical tests identified in Section 5.1. This approach treats [ ] a, c. For the TORC data, all data fall into two subsets. The tests in the two subsets are identified below:

Subset	Tests Included	No. Points	Mean	Std. Dev.
[				]

a, b, c

It is noted that the data from [ ] a, c. The W and D' normality tests were then applied to the data from each test section and each set of data, as shown in Table 5.3-2. It is noted that all tests [ ] a, c passed the test and all

pooled groups passed the normality tests. The results of the group comparison tests are shown in Table 5.3-3.

Since the combined 14x14 database with TORC passed the D' normality test, the unpaired t-Test was applied to evaluate the data grouped by bundle array. The data passed this test, so the one-sided DNBR limit was based on the combined data-set. This is not surprising since the data with the VIPRE code also passed the Bartlett test and t-test. Based upon the results, presented in Table 5.3-3, the one-sided 95/95 DNBR limit is evaluated with four groups and the entire database. Since the pooled groups all passed the normality tests, the limit for the combined database is based on the parametric method described in Section 5.1. The one-sided 95/95 DNBR limits for the different identified groups are shown in Table 5.3-4.

Based upon the data presented in Table 5.3-4, the most conservative 95/95 DNBR limit is based upon the data pooled by test, subset T1, or 1.12. This is the same established with the same subset for the side-supported vane correlation with the VIPRE code, WSSV. The DNBR limit of 1.12 for the most non-conservative data is applicable for the entire database. A plot of the measured CHF versus the WSSV-T predicted CHF for all the test data is given in Figure 5.3-1, along with the DNBR limit curve. The DNBR limit of 1.12 is equivalent to a value of 0.893 for the M/P CHF ratio. It is noted that for the entire database, eleven test points, or 2.2% of the data fall below the M/P 95/95 limit of 0.893.

The data are then examined graphically in order to check for any deviation as a function of the correlation variables. The plots of the M/P CHF ratio as a function of pressure, local mass velocity, local quality, matrix heated hydraulic diameter (Dhm), heated hydraulic diameter (Dh), the grid spacing term (GST), the heated length from BOHL to location of CHF, and the optimized non-uniform shape factor (F_C), are shown in Figures 5.3-2 through 5.3-9. The DNBR limit is also shown on these plots to show the number of test points that fall below the limit and the location of those points. There are no observed adverse trends on any of the plots.

Based upon the results of the statistical tests applied to the WSSV-T TORC database and the scatter plot analysis, the one-sided 95/95 DNBR limit is determined to be 1.12. The applicable parameter ranges for the WSSV-T correlation are given in Table 5.3-5.

Table 5.3-1
Comparison Tests
Combined Correlation and Validation WSSV-T TORC Database

Test No.	Rod Diam. (in.)	Rod Pitch (in.)	Dhm (in.)	Heated Length (in.)	GST	Axial Shape	Guide Thimble	WSSV-T N	WSSV-T M/P μ	WSSV-T M/P Std. Dev.
ALL								499	1.0027	0.0511

a, b, c

Bartlett Test Results – WSSV-T TORC Data

Database	N	Mean	S	K	M	C	M/C	χ^2_{95}	Pass Test
ALL	499	1.0026	0.0511	5	9.396	1.0061	9.339	11.07	Yes

F-Test Results – WSSV-T TORC Data

Database	v_1	v_2	S_1	S_2	S_1 / S_2	$F_{95(v1, v2)}$	Pass Test
ALL	5	493	0.01434	0.00249	5.749	2.21	No

Kruskal-Wallis Variance By Ranks Test Results – WSSV-T TORC Data

Database	K	H	χ^2_{95}	Pass Test
ALL	6	34.826	11.07	No

Table 5.3-2
W and D' Normality Tests
WSSV-T TORC Database

Data	N	Mean	D' Calculated	D' P=.025	D' P=.975	Pass Test

[ ] a, b, c

Data	N	Mean	W Calculated	W P=.05	Pass Test

[ ] a, b, c

Subset G1 – [ ] a, c

Subset G2 – [ ] a, c

Subset T1 – [ ] a, c

Subset T2 – [ ] a, c

Table 5.3-3
Comparison Tests for Pooled Subsets WSSV-T TORC Database

Bartlett Test Results – WNGF-SPV Data

Database	N	Mean	s	K	M	C	M/C	χ^2_{95}	Pass Test
14x14 & 16x16	499	1.0027	0.0511	2	0.907	1.0022	0.905	3.84	Yes
Subset G1	395	0.9994	0.0527	2	0.219	1.0048	0.218	3.84	Yes
Subset G2	104	1.0151	0.0428	1					
Subset T1	178	0.9884	0.0511	3	3.092	1.0099	3.062	5.99	Yes
Subset T2	358	1.0100	0.0506	4	8.729	1.0059	8.678	7.81	No

t-Test Results

Database	N	Mean	s	$\mu_1 - \mu_2$	s_p	t	$t_{975,713}$	Pass Test
14x14 & 16x16	499	1.0027	0.0511	0.0051	0.0511	1.077	1.96	Yes
Subset G1	395	0.9994	0.0527	.0075	.0527	1.106	1.96	Yes

F-Test Results – WSSV-T TORC – Subsets T1 & T2

Database	v_1	v_2	S_1	S_2	S_1 / S_2	$F_{95(v1, v2)}$	Pass Test
Subset T1	2	175	0.00637	0.00256	2.486	3.00	Yes
Subset T2	3	354	0.00139	0.00257	0.542	2.60	Yes

Kruskal-Wallis Variance By Ranks Test Results - Subset T1

Database	K	H	χ^2_{95}	Pass Test
Subset T2	4	2.798	7.81	Yes

Subset G1 – [ ] [a, c]

Subset G2 – [ ] [a, c]

Subset T1 – [ ] [a, c]

Subset T2 – [ ] [a, c]

Table 5.3-4
Determination of $DNBR_{95}$ Limit for Pooled Data
WSSV-T TORC Database

Calculation of $DNBR_{95}$ Limit Calculation for Parametric Data

Database	Mean	S	N	K	$DNBR_{95}$

a, b, c

Table 5.3-5

Parameter Ranges for the Final WSSV-T TORC Correlation Database

Parameter	Minimum	Maximum
Pressure (psia)	1495	2450
Local Coolant Quality	-0.15	0.34
Local Mass velocity ($Mlb/hr\text{-}ft^2$)	0.90	3.46
Matrix Heated Hydraulic Diameter, Dhm (inches)	0.4635	0.5334
Heated Hydraulic Diameter Ratio, Dhm/Dh	0.679	1.00
Heated Length, HL (inches)	48*	150
Grid Spacing	10.28	18.86

*Set as minimum HL value, applied at all elevations below 48 inches

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Figure 5.3-1
Measured and Predicted Critical Heat Fluxes
WSSV-T Correlation with TORC Code

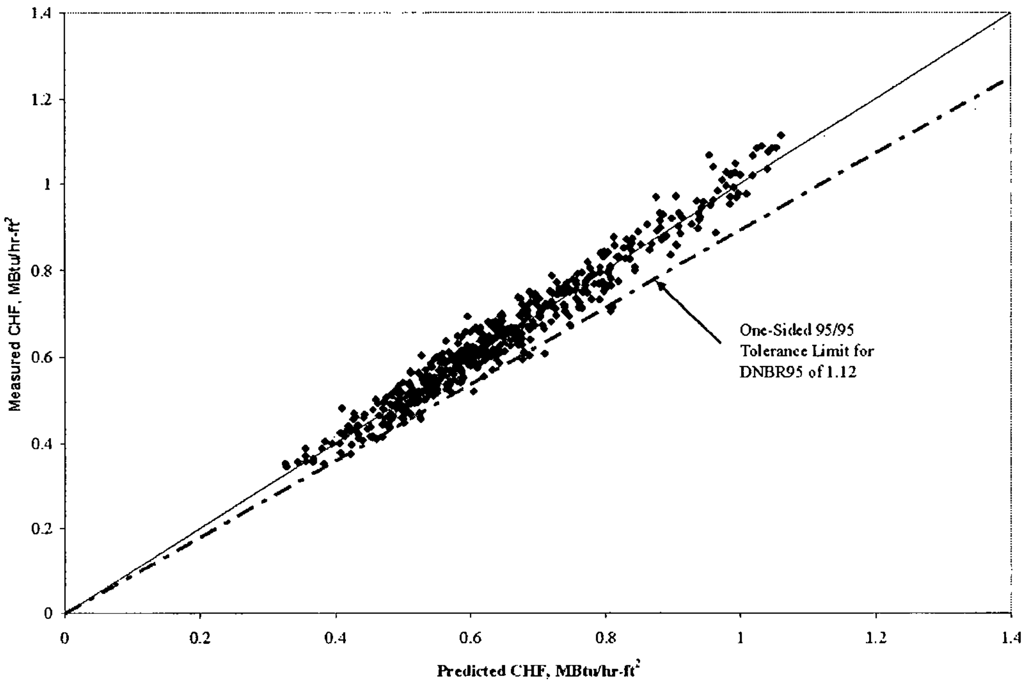

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Figure 5.3-2
Plot of M/P CHF Ratio vs. Pressure
WSSV-T Correlation with TORC Code

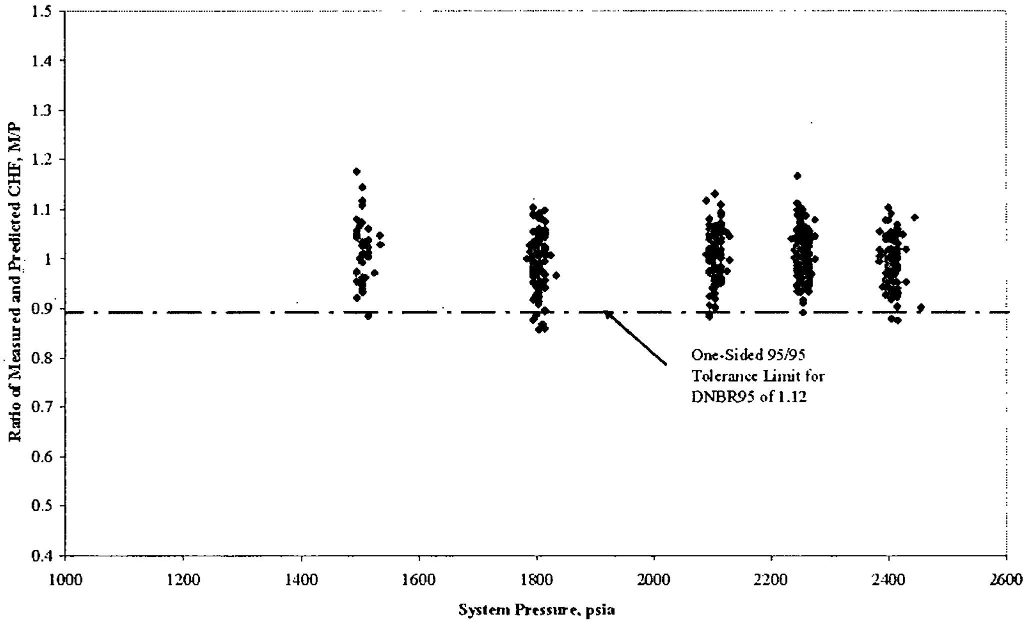

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Figure 5.3-3
Plot of M/P CHF Ratio vs. Local Mass Velocity
WSSV-T Correlation with TORC Code

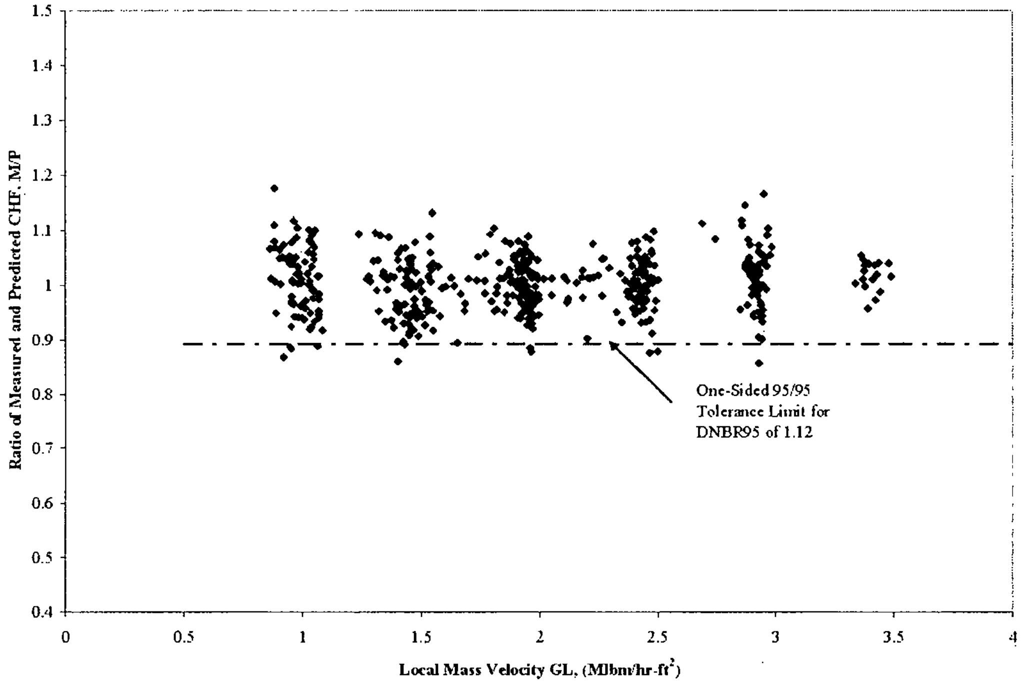

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Figure 5.3-4
Plot of M/P CHF Ratio vs. Local Quality
WSSV-T Correlation with TORC Code

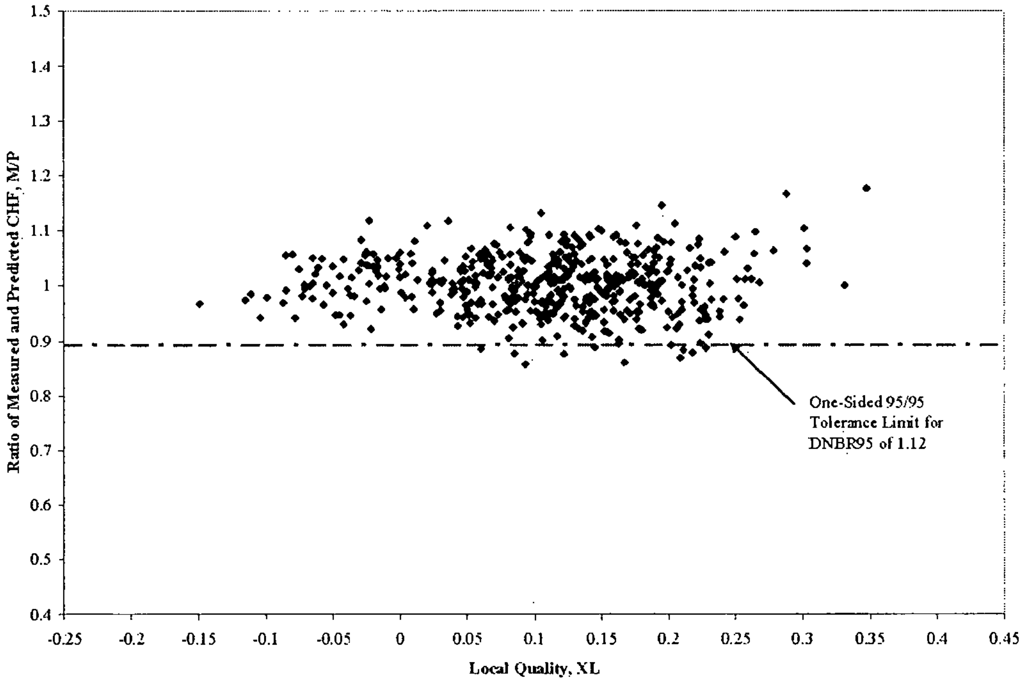

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Figure 5.3-5
Plot of M/P CHF Ratio vs. Matrix Heated Diameter, Dhm
WSSV-T Correlation with TORC Code

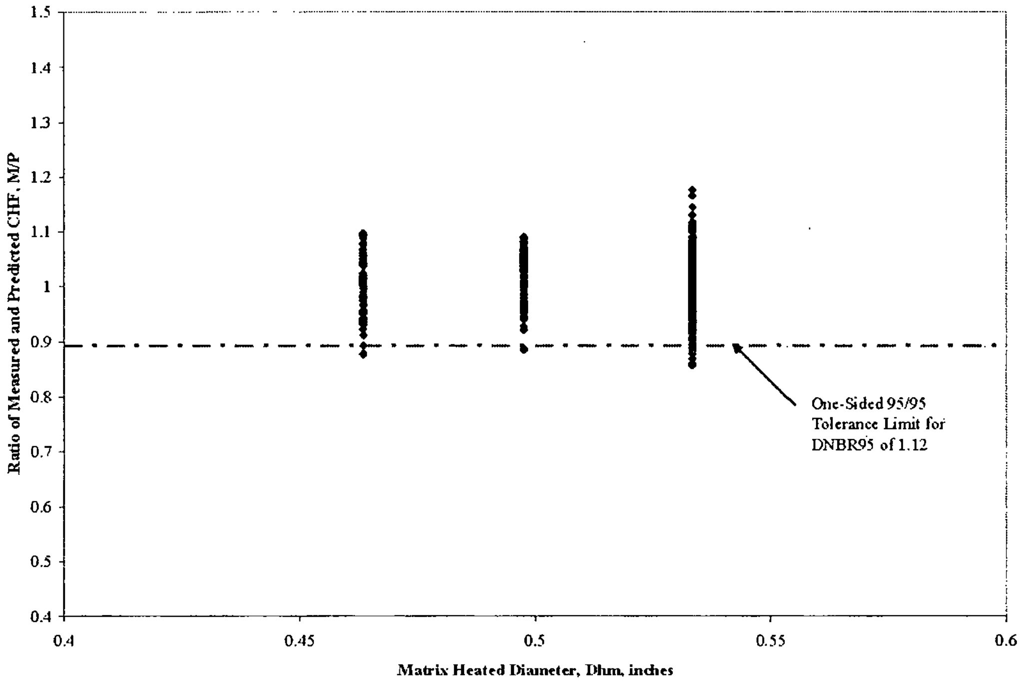

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Figure 5.3-6
Plot of M/P CHF Ratio vs. Heated Hydraulic Diameter, Dh
WSSV-T Correlation with TORC Code

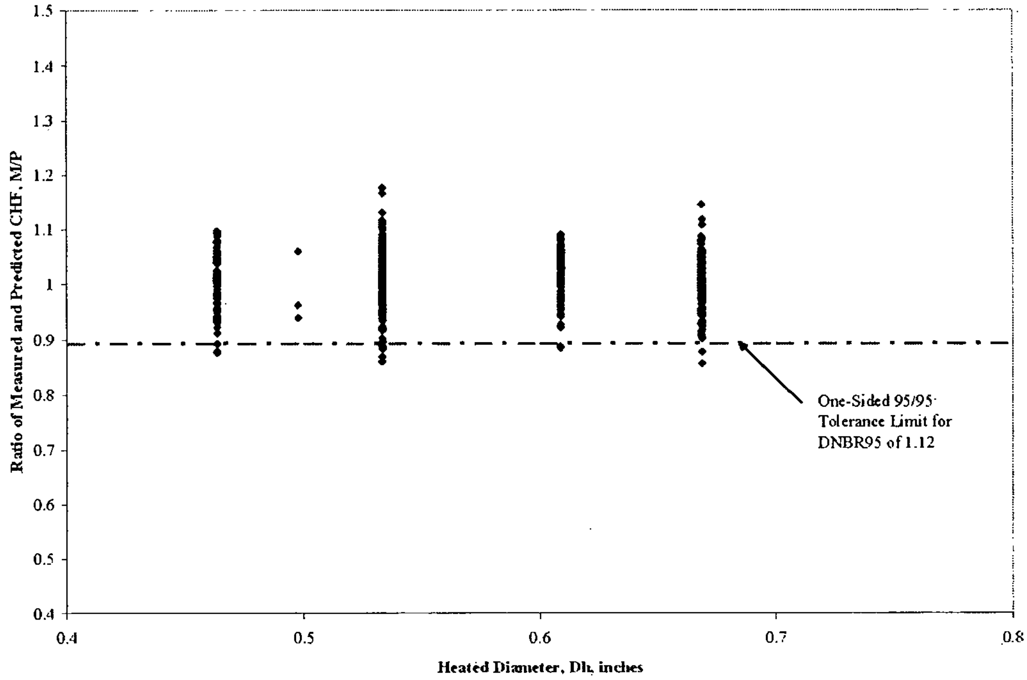

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Figure 5.3-7
Plot of M/P CHF Ratio vs. Grid Spacing Term, GST
WSSV-T Correlation with TORC Code

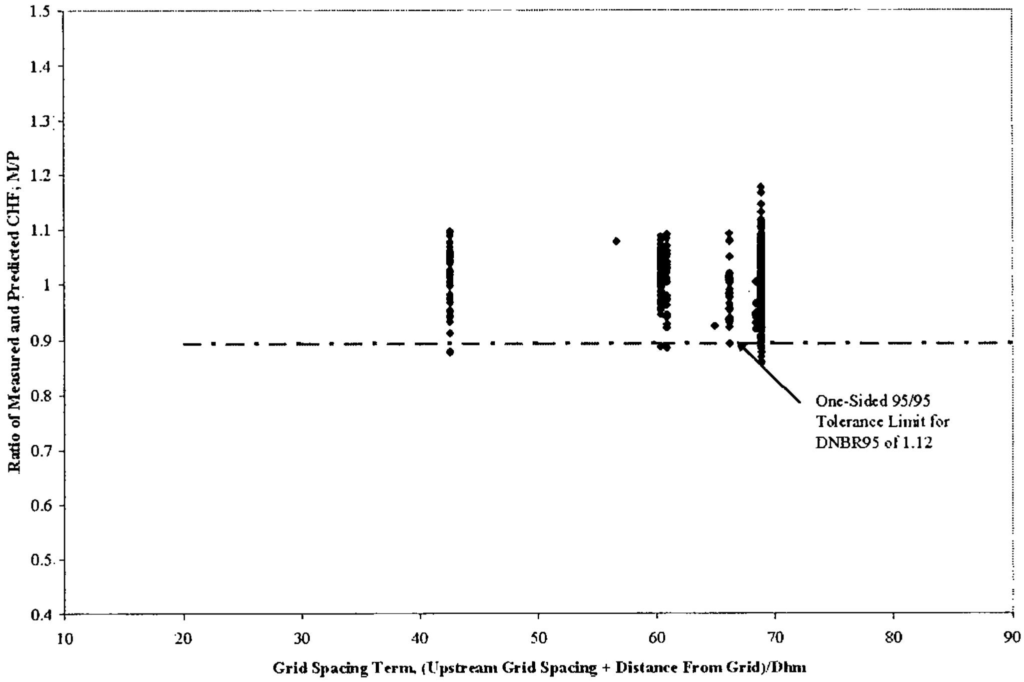

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Figure 5.3-8
Plot of M/P CHF Ratio vs. Heated Length, HL
WSSV-T Correlation with TORC Code

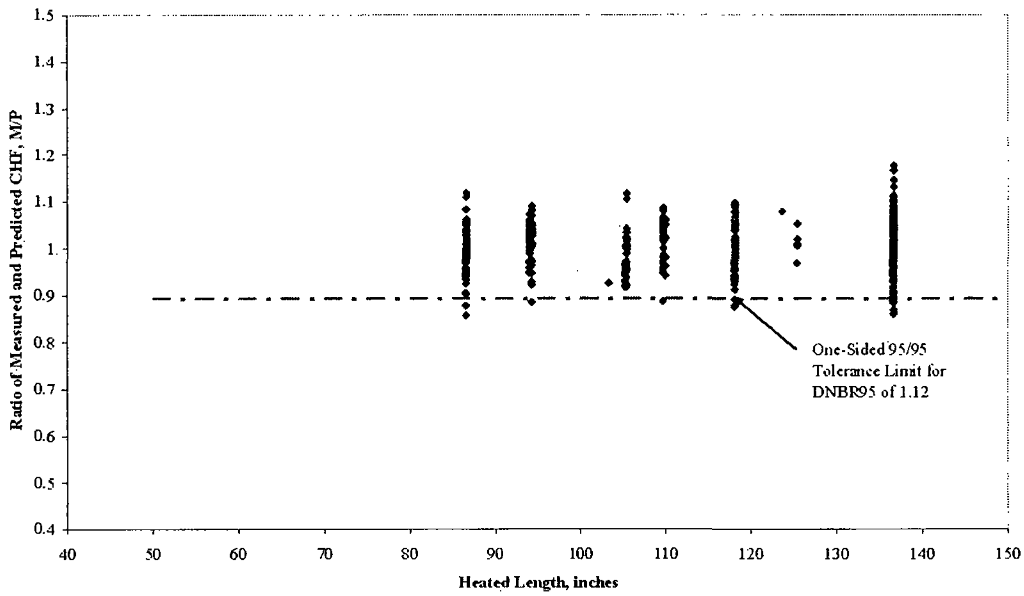

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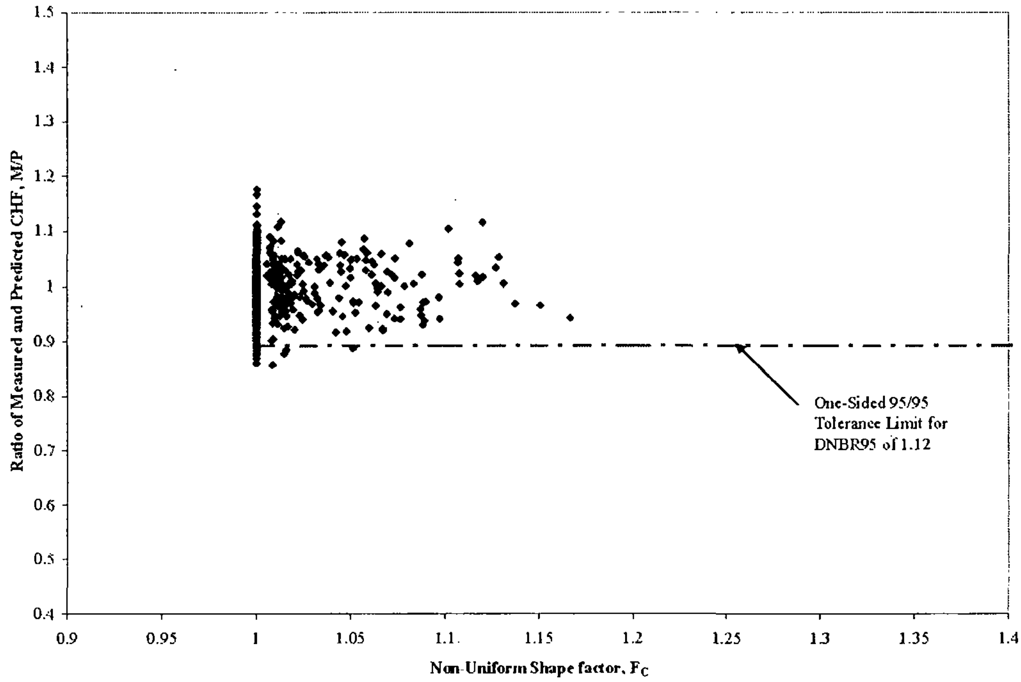
Figure 5.3-9
Plot of M/P CHF Ratio vs. Non-Uniform Shape Factor, F_C
WSSV-T Correlation with TORC Code



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6.0 Correlation Applications

Westinghouse intends to use the WSSV and WSSV-T correlations for evaluating T/H design of the fuel assembly and the reactor core of CE-PWRs in accordance with the CHF or DNB acceptance criterion defined in the Standard Review Plan (SRP)[17]. SRP Sections 4.2 and 4.4 states that the DNB acceptance criterion provides assurance that there be at least a 95% probability at a 95% confidence level that the hot fuel rod in the core does not experience a DNB during Condition I or II events. The acceptance criterion is met in T/H design when the minimum DNBR of the hot rod in the hot channel is above the 95/95 DNBR limit of the correlation. Derivation of the WSSV and WSSV-T 95/95 DNBR limits was presented in Section 5. The correlations will be used only with a computer code that has been used for the correlation development and has been qualified with the 95/95 DNBR limit. Technology transfer of the WSSV or WSSV-T correlation(s) will follow a process that meets the requirements specified in Generic Letter (GL) 83.11 Supplement 1, "Qualification for Performing Safety Analyses."

Each correlation application is discussed further below.

6.1 WSSV Correlation Application

The WSSV correlation 95/95 DNBR limit with the Westinghouse version of the VIPRE-01 code (VIPRE) is 1.12. The range of applicability for the WSSV correlation, based on its database, is summarized in Table 6-1.

The WSSV correlation is applicable to fuel designs for which test data have been included in the correlation database. Specifically, the correlation will be applied to the following fuel designs:

- CE-PWR 16x16 NGF design with the side-supported vane grids
- CE-PWR 14x14 Turbo design with the side-supported vane grids.

For the non-mixing vane region, the ABB-NV correlation[1] is used to calculate DNBR values in the hot channels. The application of the WSSV and ABB-NV correlations with VIPRE are in full compliance with the conditions of the Safety Evaluation Report (SER) on the VIPRE code and modeling for CE-PWRs[3]. Although empirical mixing factors were used in VIPRE models for correlation development, the reactor analysis is to be performed with the design Inverse Peclet number of [ ] a, c, the same as was done for ABB-TV[1]. The correlations will be used only with USNRC-approved methodology for PWR safety analysis. Currently, the methodology includes the Revised Thermal Design Procedure (RTDP)[18], the transition core evaluation method[19], and the reload evaluation method[20], as well as the approved uncertainty analysis methods of Extended Statistical Combination of Uncertainties (ESCU)[21], and Modified SCU (MSCU)[22], for CE-PWRs. In addition, [ ] a, c. The plant analysis will account for uncertainties in plant operating parameters, nuclear and thermal parameters, and fuel fabrication parameters in addition to uncertainty in the DNB correlations.

6.2 WSSV-T Correlation Application

The WSSV-T correlation 95/95 DNBR limit and its supporting M/P statistics with the TORC code is also 1.12. The range of applicability for the WSSV-T correlation, based on its database, is summarized in Table 6-1, which is the same as the WSSV correlation range.

The WSSV-T correlation is applicable to fuel designs for which test data have been included in the correlation data base. Specifically, the correlation will be applied to the following fuel designs, similar to the WSSV correlation:

- CE-PWR 16x16 NGF design with the side-supported vane grids
- CE-PWR 14x14 Turbo design with the side-supported vane grids.

For the non-mixing vane region, the ABB-NV correlation[1] is used to calculate DNBR values in the hot channels. The application of the WSSV-T and ABB-NV correlations with TORC are in full compliance with the conditions of the Safety Evaluation Report (SER) on the TORC code and modeling for CE-PWRs[5].

The TORC code is used in reloads to perform detailed modeling of the core and hot assembly and to determine minimum DNBR in the hot assembly. The CETOP-D code[23] is a fast running tool, which is used in reload analyses to calculate the minimum DNBR in the hot subchannel. While the TORC code can be applied directly in the reload analyses[26], typically the TORC code is used to benchmark the CETOP-D DNBR results such that the CETOP-D results are conservative relative to TORC. The WSSV-T and ABB-NV correlations are in both TORC and CETOP-D. Therefore, the application of WSSV-T and ABB-NV correlations with CETOP-D for PWRs is equivalent to their application with TORC.

Although the empirical mixing factors were used in TORC models for correlation development, the reactor analysis is to be performed with the design Inverse Peclet number of [ ] a, c or the equivalent TDC, the same as ABB-TV[1].

The WSSV-T correlation will be used with USNRC-approved methodology for PWR safety and setpoint analyses, including the approved uncertainty analysis methods of Extended Statistical Combination of Uncertainties (ESCU)[21], and Modified SCU (MSCU)[22]. In addition, [

] a, c. The impact of the WSSV-T on all other reports is the same as specified for the ABB-TV correlation in section 7 of Reference 1.

Table 6-1
Applicable Range of WSSV and WSSV-T CHF Correlations

Parameter	Applicable Range
Pressure (psia)	1495 to 2450
Local Coolant Quality	≤ 0.34
Local Mass velocity (Mlb/hr-ft^2)	0.90 to 3.46
Matrix Heated Hydraulic Diameter, Dhm (inches)	0.4635 to 0.5334
Heated Hydraulic Diameter Ratio, Dhm/Dh	0.679 to 1.00
Heated Length, HL (inches)	48* to 150
Grid spacing (inches)	10.28 to 18.86

* Set as minimum HL value, applied at all elevations below 48 inches

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7.0 Conclusions

The following conclusions and restrictions apply for the WSSV and WSSV-T CHF correlations:

1. Analysis of the WSSV and WSSV-T correlations and the source and validation data indicates the correlations accurately reflect the test results of the CE 16x16 NGF fuel design as well as the Westinghouse current side-supported vane design (14x14 Turbo).

2. Analysis of the WSSV and WSSV-T correlations and the source and validation data indicates that a minimum DNBR limit of 1.12 for the WSSV and WSSV-T correlations will provide a 95% probability with 95% confidence of not experiencing CHF on a rod showing the limiting value.

3. Statistical tests support the evaluation of the 95/95 DNBR limit of the WSSV and WSSV-T correlations.

4. The WSSV correlation must be used in conjunction with the VIPRE code since the correlation was developed based on VIPRE and the associated VIPRE input specifications. [

   ]$^{a, c}$.

5. The WSSV-T correlation must be used in conjunction with the TORC code since the correlation constants were developed based on TORC and the associated TORC input specifications. The correlations may also be used in the CETOP-D code in support of reload design calculations benchmarked by TORC.

6. The WSSV and WSSV-T correlations must also be used with the optimized F_C shape factor developed in Reference 1 for non-mixing and side-supported mixing vane grids to correct for non-uniform axial power shapes.

7. The range of applicability for each of the correlations is provided in Section 6.0.

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8.0 References

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Appendix A
WSSV Database

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Appendix A: WSSV Database

A detailed summary of the WSSV correlation database is shown in Table A-1 and the validation database is shown in Table A-2. The tables in this appendix summarize the raw data from Columbia data files, the test geometry information needed for the correlation development, the predicted local coolant conditions taken from the VIPRE runs. The tabulation presented here gives the data from all CHF experiments with test sections described in Table 2-1 for which the system pressure was greater than 1490 psia and the test section average mass velocity was greater than 0.89 Mlbm/hr-ft^2. Repeat runs and runs with only cold rods indicating DNB in the correlation or validation database, identified in bold italics, were eliminated in the correlation codes along with points outside the correlation parameter limits. Nomenclature for heading abbreviations in Appendices A, C and E are defined below:

TS	=	Test section number
TD	=	Test section type (UM is uniform shape without guide thimble, UT is uniform shape with guide thimble, NT is non-uniform shape with guide thimble)
Press	=	Test section pressure (psia)
Tin	=	Test section inlet temperature (°F)
Gavg	=	Average test section mass velocity (Mlbm/hr-ft^2)
Qavg	=	Test section critical bundle average heat flux (MBtu/hr-ft^2)
DROD	=	Primary DNB rod thermocouple number
DCH	=	VIPRE subchannel number where local coolant conditions are selected
GL	=	Local mass velocity in CHF channel (Mlbm/hr-ft^2)
XL	=	Local quality in CHF channel
CHFm	=	Measured CHF (MBtu/hr-ft^2)
F_C	=	Non-uniform shape factor = 1.00 for uniform axial power shape based on COPT from Reference 1 for non-uniform axial power shape
GS	=	Nominal upstream grid spacing from [ ]$^{a, c}$ (in)
HL	=	Heated length to CHF site (in)
DG	=	Distance from [ ]$^{a, c}$ grid to CHF site (in)
De	=	Wetted hydraulic diameter of CHF channel (in)
Dh	=	Heated hydraulic diameter of CHF channel (in)
Dhm	=	Heated hydraulic diameter of matrix channel (in)

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Table A-1
WSSV Correlation Database

TS TD	Run	Press.	Tin	Gavg	Qavg	DROD	DCH	GL	XL	CHFm	FC	GS	HL	DG	De	Dh	Dhm

a, b, c

Table A-1 (continued)
WSSV Correlation Database

TS TD	Run	Press.	Tin	Gavg	Qavg	DROD	DCH	GL	XL	CHFm	FC	GS	HL	DG	De	Dh	Dhm

a, b, c

Table A-1 (continued)
WSSV Correlation Database

a, b, c

TS TD	Run	Press.	Tin	Gavg	Qavg	DROD	DCH	GL	XL	CHFm	FC	GS	HL	DG	De	Dh	Dhm

Table A-1 (continued)
WSSV Correlation Database

TS TD	Run	Press.	Tin	Gavg	Qavg	DROD	DCH	GL	XL	CHFm	FC	GS	HL	DG	De	Dh	Dhm

a, b, c

Table A-1 (continued)
WSSV Correlation Database

TS TD	Run	Press.	Tin	Gavg	Qavg	DROD	DCH	GL	XL	CHFm	FC	GS	HL	DG	De	Dh	Dhm

a, b, c

Table A-1 (continued)
WSSV Correlation Database

TS TD	Run	Press.	Tin	Gavg	Qavg	DROD	DCH	GL	XL	CHFm	FC	GS	HL	DG	De	Dh	Dhm

a, b, c

Table A-1 (continued)
WSSV Correlation Database

a, b, c

TS TD	Run	Press.	Tin	Gavg	Qavg	DROD	DCH	GL	XL	CHFm	FC	GS	HL	DG	De	Dh	Dhm

Table A-1 (continued)
WSSV Correlation Database

a, b, c

TS TD	Run	Press.	Tin	Gavg	Qavg	DROD	DCH	GL	XL	CHFm	FC	GS	HL	DG	De	Dh	Dhm

Table A-1 (continued)
WSSV Correlation Database

TS TD	Run	Press.	Tin	Gavg	Qavg	DROD	DCH	GL	XL	CHFm	FC	GS	HL	DG	De	Dh	Dhm

a, b, c

Table A-1 (continued)
WSSV Correlation Database

a, b, c

TS TD	Run	Press.	Tin	Gavg	Qavg	DROD	DCH	GL	XL	CHFm	FC	GS	HL	DG	De	Dh	Dhm

Table A-1 (continued)
WSSV Correlation Database

a, b, c

TS TD	Run	Press.	Tin	Gavg	Qavg	DROD	DCH	GL	XL	CHFm	FC	GS	HL	DG	De	Dh	Dhm

Table A-1 (continued)
WSSV Correlation Database

a, b, c

TS TD	Run	Press.	Tin	Gavg	Qavg	DROD	DCH	GL	XL	CHFm	FC	GS	HL	DG	De	Dh	Dhm

Table A-1 (continued)
WSSV Correlation Database

TS TD	Run	Press.	Tin	Gavg	Qavg	DROD	DCH	GL	XL	CHFm	FC	GS	HL	DG	De	Dh	Dhm

a, b, c

Table A-1 (continued)
WSSV Correlation Database

a, b, c

TS TD	Run	Press.	Tin	Gavg	Qavg	DROD	DCH	GL	XL	CHFm	FC	GS	HL	DG	De	Dh	Dhm

Table A-1 (continued)
WSSV Correlation Database

a, b, c

TS TD	Run	Press.	Tin	Gavg	Qavg	DROD	DCH	GL	XL	CHFm	FC	GS	HL	DG	De	Dh	Dhm

Table A-1 (continued)
WSSV Correlation Database

a, b, c

TS TD	Run	Press.	Tin	Gavg	Qavg	DROD	DCH	GL	XL	CHFm	FC	GS	HL	DG	De	Dh	Dhm

Table A-2
WSSV Validation Database

a, b, c

TS TD	Run	Press.	Tin	Gavg	Qavg	DROD	DCH	GL	XL	CHFm	FC	GS	HL	DG	De	Dh	Dhm

Table A-2 (continued)
WSSV Validation Database

a, b, c

TS TD	Run	Press.	Tin	Gavg	Qavg	DROD	DCH	GL	XL	CHFm	FC	GS	HL	DG	De	Dh	Dhm

Table A-2 (continued)
WSSV Validation Database

a, b, c

TS TD	Run	Press.	Tin	Gavg	Qavg	DROD	DCH	GL	XL	CHFm	FC	GS	HL	DG	De	Dh	Dhm

Table A-2 (continued)
WSSV Validation Database

TS TD	Run	Press.	Tin	Gavg	Qavg	DROD	DCH	GL	XL	CHFm	FC	GS	HL	DG	De	Dh	Dhm

a, b, c

Table A-2 (continued)
WSSV Validation Database

a, b, c

TS TD	Run	Press.	Tin	Gavg	Qavg	DROD	DCH	GL	XL	CHFm	FC	GS	HL	DG	De	Dh	Dhm

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Appendix B
WSSV VIPRE Statistical Output

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Appendix B: WSSV VIPRE Statistical Output

A detailed summary of the statistical output of the WSSV correlation is given in Table B-1. For each test run in Table B-1, the values for the correlation variables, the measured CHF and WSSV predicted CHF with the VIPRE code are given, along with the value for the M/P CHF ratio. Data from the correlation database are identified with the letter C and data from the validation database are identified with the letter V. The repeat test runs and any test runs with variables outside the correlation parameter range are removed from Table B-1. The individual test section, database, subset, and overall statistics are given at the end of the output in Table B-1. Nomenclature for heading abbreviations in Appendices B and D are defined below:

TS	=	Test section number
TD	=	Test section type (UM is uniform shape without guide thimble, UT is uniform shape with guide thimble, NT is non-uniform shape with guide thimble)
Press	=	Test section pressure (psia)
GL	=	Local mass velocity in CHF channel (Mlbm/hr-ft^2)
XL	=	Local quality in CHF channel
F_C	=	Non-uniform shape factor = 1.00 for uniform axial power shape based on COPT from Reference 1 for non-uniform axial power shape
GS	=	Upstream nominal grid spacing, [ ]$^{a, c}$ (in)
HL	=	Heated length to CHF site (in)
DG	=	Distance from [ ]$^{a, c}$ grid to CHF site (in)
Dh	=	Heated hydraulic diameter of CHF channel (in)
Dhm	=	Heated hydraulic diameter of matrix channel (in)
GST	=	Grid spacing term, [ ]$^{a, c}$
CHFm	=	Measured CHF (MBtu/hr-ft^2)
CHFp	=	WSSV predicted CHF divided by F_C, Appendix B (MBtu/hr-ft^2), WSSV-T predicted CHF divided by F_C, Appendix D (MBtu/hr-ft^2)

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Table B-1
Statistical Output of WSSV Correlation VIPRE Database

a, b, c

TS TD	Run	Press.	GL	XL	FC	GS	HL	DG	Dh	Dhm	GST	CHFm	CHFp	M/P-1	M/P

Table B-1 (continued)
Statistical Output of WSSV Correlation VIPRE Database

TS.TD	Run	Press.	GL	XL	FC	GS	HL	DG	Dh	Dhm	GST	CHFm	CHFp	M/P-1	M/P

a, b, c

Table B-1 (continued)
Statistical Output of WSSV Correlation VIPRE Database

a, b, c

TS TD	Run	Press.	GL	XL	FC	GS	HL	DG	Dh	Dhm	GST	CHFm	CHFp	M/P-1	M/P

Table B-1 (continued)
Statistical Output of WSSV Correlation VIPRE Database

TS TD	Run	Press.	GL	XL	FC	GS	HL	DG	Dh	Dhm	GST	CHFm	CHFp	M/P-1	M/P

a, b, c

Table B-1 (continued)
Statistical Output of WSSV Correlation VIPRE Database

a, b, c

TS TD	Run	Press.	GL	XL	FC	GS	HL	DG	Dh	Dhm	GST	CHFm	CHFp	M/P-1	M/P

Table B-1 (continued)
Statistical Output of WSSV Correlation VIPRE Database

TS TD	Run	Press.	GL	XL	FC	GS	HL	DG	Dh	Dhm	GST	CHFm	CHFp	M/P-1	M/P

a, b, c

Table B-1 (continued)
Statistical Output of WSSV Correlation VIPRE Database

a, b, c

TS TD	Run	Press.	GL	XL	FC	GS	HL	DG	Dh	Dhm	GST	CHFm	CHFp	M/P-1	M/P

Table B-1 (continued)
Statistical Output of WSSV Correlation VIPRE Database

a, b, c

TS TD	Run	Press.	GL	XL	FC	GS	HL	DG	Dh	Dhm	GST	CHFm	CHFp	M/P-1	M/P

Table B-1 (continued)
Statistical Output of WSSV Correlation VIPRE Database

a, b, c

TS TD	Run	Press.	GL	XL	FC	GS	HL	DG	Dh	Dhm	GST	CHFm	CHFp	M/P-1	M/P

Table B-1 (continued)
Statistical Output of WSSV Correlation VIPRE Database

a, b, c

TS TD	Run	Press.	GL	XL	FC	GS	HL	DG	Dh	Dhm	GST	CHFm	CHFp	M/P-1	M/P

Table B-1 (continued)
Statistical Output of WSSV Correlation VIPRE Database

TS TD	Run	Press.	GL	XL	FC	GS	HL	DG	Dh	Dhm	GST	CHFm	CHFp	M/P-1	M/P

a, b, c

Table B-1 (continued)
Statistical Output of WSSV Correlation VIPRE Database

a, b, c

TS TD	Run	Press.	GL	XL	FC	GS	HL	DG	Dh	Dhm	GST	CHFm	CHFp	M/P-1	M/P

Table B-1 (continued)
Statistical Output of WSSV Correlation VIPRE Database

a, b, c

TS TD	Run	Press.	GL	XL	FC	GS	HL	DG	Dh	Dhm	GST	CHFm	CHFp	M/P-1	M/P

Table B-1 (continued)
Statistical Output of WSSV Correlation VIPRE Database

TS TD	Run	Press.	GL	XL	FC	GS	HL	DG	Dh	Dhm	GST	CHFm	CHFp	M/P-1	M/P

a, b, c

Table B-1 (continued)
Statistical Output of WSSV Correlation VIPRE Database

TS.TD	Run	Press.	GL	XL	FC	GS	HL	DG	Dh	Dhm	GST	CHFm	CHFp	M/P-1	M/P

a, b, c

Table B-1 (continued)
Statistical Output of WSSV Correlation VIPRE Database

a, b, c

TS TD	Run	Press.	GL	XL	FC	GS	HL	DG	Dh	Dhm	GST	CHFm	CHFp	M/P-1	M/P

Table B-1 (continued)
Statistical Output of WSSV Correlation VIPRE Database

a, b, c

TS TD	Run	Press.	GL	XL	FC	GS	HL	DG	Dh	Dhm	GST	CHFm	CHFp	M/P-1	M/P

Table B-1 (continued)
Statistical Output of WSSV Correlation VIPRE Database

TS TD	Run	Press.	GL	XL	FC	GS	HL	DG	Dh	Dhm	GST	CHFm	CHFp	M/P-1	M/P

a, b, c

Table B-1 (continued)
Statistical Output of WSSV Correlation VIPRE Database

TS TD	Run	Press.	GL	XL	FC	GS	HL	DG	Dh	Dhm	GST	CHFm	CHFp	M/P-1	M/P

a, b, c

Table B-1 (continued)

Statistical Output of WSSV Correlation VIPRE Database

TS TD	Run	Press.	GL	XL	FC	GS	HL	DG	Dh	Dhm	GST	CHFm	CHFp	M/P-1	M/P

[ ]a, b, c

Correlation Database

[ ]a, b, c

Validation Database

[ ]a, b, c

Combined Database

a, b, c

[ ]

a, b, c

[ ]

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Appendix C
WSSV-T Database

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Appendix C: WSSV-T Database

A detailed summary of the WSSV-T Database is shown in Table C-1. The table in this appendix summarizes the raw data from Columbia data files, the test geometry information needed for the correlation development, the predicted local coolant conditions taken from the TORC runs.. The tabulation presented here gives the data from all CHF experiments with test sections described in Table 2-1. Repeat runs in the correlation database and runs with only cold rods indicating DNB, identified in bold Italics, were eliminated in the correlation codes along with points outside the correlation parameter limits. Nomenclature for heading abbreviations is defined in Appendix A:

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Table C-1
WSSV-T Correlation Database

TS TD	Run	Press.	Tin	Gavg	Qavg	DROD	DCH	GL	XL	CHFm	FC	GS	HL	DG	De	Dh	Dhm

a, b, c

Table C-1 (continued)
WSSV-T Correlation Database

a, b, c

TS TD	Run	Press.	Tin	Gavg	Qavg	DROD	DCH	GL	XL	CHFm	FC	GS	HL	DG	De	Dh	Dhm

Table C-1 (continued)
WSSV-T Correlation Database

a, b, c

TS TD	Run	Press.	Tin	Gavg	Qavg	DROD	DCH	GL	XL	CHFm	FC	GS	HL	DG	De	Dh	Dhm

Table C-1 (continued)
WSSV-T Correlation Database

a, b, c

TS TD	Run	Press.	Tin	Gavg	Qavg	DROD	DCH	GL	XL	CHFm	FC	GS	HL	DG	De	Dh	Dhm

Table C-1 (continued)
WSSV-T Correlation Database

a, b, c

TS TD	Run	Press.	Tin	Gavg	Qavg	DROD	DCH	GL	XL	CHFm	FC	GS	HL	DG	De	Dh	Dhm

Table C-1 (continued)
WSSV-T Correlation Database

a, b, c

TS TD	Run	Press.	Tin	Gavg	Qavg	DROD	DCH	GL	XL	CHFm	FC	GS	HL	DG	De	Dh	Dhm

Table C-1 (continued)
WSSV-T Correlation Database

a, b, c

TS TD	Run	Press.	Tin	Gavg	Qavg	DROD	DCH	GL	XL	CHFm	FC	GS	HL	DG	De	Dh	Dhm

Table C-1 (continued)
WSSV-T Correlation Database

a, b, c

TS TD	Run	Press.	Tin	Gavg	Qavg	DROD	DCH	GL	XL	CHFm	FC	GS	HL	DG	De	Dh	Dhm

Table C-1 (continued)
WSSV-T Correlation Database

a, b, c

TS TD	Run	Press.	Tin	Gavg	Qavg	DROD	DCH	GL	XL	CHFm	FC	GS	HL	DG	De	Dh	Dhm

Table C-1 (continued)
WSSV-T Correlation Database

a, b, c

TS TD	Run	Press.	Tin	Gavg	Qavg	DROD	DCH	GL	XL	CHFm	FC	GS	HL	DG	De	Dh	Dhm

Table C-1 (continued)
WSSV-T Correlation Database

a, b, c

TS TD	Run	Press.	Tin	Gavg	Qavg	DROD	DCH	GL	XL	CHFm	FC	GS	HL	DG	De	Dh	Dhm

Table C-1 (continued)
WSSV-T Correlation Database

a, b, c

TS TD	Run	Press.	Tin	Gavg	Qavg	DROD	DCH	GL	XL	CHFm	FC	GS	HL	DG	De	Dh	Dhm

Table C-1 (continued)
WSSV-T Correlation Database

a, b, c

TS TD	Run	Press.	Tin	Gavg	Qavg	DROD	DCH	GL	XL	CHFm	FC	GS	HL	DG	De	Dh	Dhm

Table C-1 (continued)
WSSV-T Correlation Database

a, b, c

TS TD	Run	Press.	Tin	Gavg	Qavg	DROD	DCH	GL	XL	CHFm	FC	GS	HL	DG	De	Dh	Dhm

Table C-1 (continued)
WSSV-T Correlation Database

a, b, c

TS TD	Run	Press.	Tin	Gavg	Qavg	DROD	DCH	GL	XL	CHFm	FC	GS	HL	DG	De	Dh	Dhm

Table C-1 (continued)
WSSV-T Correlation Database

a, b, c

TS TD	Run	Press.	Tin	Gavg	Qavg	DROD	DCH	GL	XL	CHFm	FC	GS	HL	DG	De	Dh	Dhm

Table C-1 (continued)
WSSV-T Correlation Database

a, b, c

TS TD	Run	Press.	Tin	Gavg	Qavg	DROD	DCH	GL	XL	CHFm	FC	GS	HL	DG	De	Dh	Dhm

Table C-1 (continued)
WSSV-T Correlation Database

a, b, c

TS	TD	Run	Press.	Tin	Gavg	Qavg	DROD	DCH	GL	XL	CHFm	FC	GS	HL	DG	De	Dh	Dhm

Table C-1 (continued)
WSSV-T Correlation Database

a, b, c

TS TD	Run	Press.	Tin	Gavg	Qavg	DROD	DCH	GL	XL	CHFm	FC	GS	HL	DG	De	Dh	Dhm

Table C-1 (continued)
WSSV-T Correlation Database

a, b, c

TS TD	Run	Press.	Tin	Gavg	Qavg	DROD	DCH	GL	XL	CHFm	FC	GS	HL	DG	De	Dh	Dhm

Table C-1 (continued)
WSSV-T Correlation Database

a, b, c

TS TD	Run	Press.	Tin	Gavg	Qavg	DROD	DCH	GL	XL	CHFm	FC	GS	HL	DG	De	Dh	Dhm

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Appendix D
WSSV-T TORC Statistical Output

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Appendix D: WSSV-T TORC Statistical Output

A detailed summary of the statistical output of the WSSV-T correlation is given in Table D-1. For each test run in Table D-1, the values for the correlation variables, the measured CHF and WSSV-T predicted CHF with the TORC code are given, along with the value for the M/P CHF ratio. The repeat test runs and any test runs with variables outside the correlation parameter range are removed from Table D-1. The individual test section, database, subset, and overall statistics are given at the end of the output in Table D-1. Nomenclatures for table heading abbreviations are given in Appendix B.

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Table D-1
Statistical Output of WSSV-T Correlation TORC Database

TS TD	Run	Press.	GL	XL	FC	GS	HL	DG	Dh	Dhm	GST	CHFm	CHFp	M/P-1	M/P

a, b, c

Table D-1 (continued)
Statistical Output of WSSV-T Correlation TORC Database

a, b, c

TS TD	Run	Press.	GL	XL	FC	GS	HL	DG	Dh	Dhm	GST	CHFm	CHFp	M/P-1	M/P

Table D-1 (continued)
Statistical Output of WSSV-T Correlation TORC Database

a, b, c

TS TD	Run	Press.	GL	XL	FC	GS	HL	DG	Dh	Dhm	GST	CHFm	CHFp	M/P-1	M/P

Table D-1 (continued)
Statistical Output of WSSV-T Correlation TORC Database

TS TD	Run	Press.	GL	XL	FC	GS	HL	DG	Dh	Dhm	GST	CHFm	CHFp	M/P-1	M/P

a, b, c

Table D-1 (continued)
Statistical Output of WSSV-T Correlation TORC Database

a, b, c

TS TD	Run	Press.	GL	XL	FC	GS	HL	DG	Dh	Dhm	GST	CHFm	CHFp	M/P-1	M/P

Table D-1 (continued)
Statistical Output of WSSV-T Correlation TORC Database

a, b, c

TS TD	Run	Press.	GL	XL	FC	GS	HL	DG	Dh	Dhm	GST	CHFm	CHFp	M/P-1	M/P

Table D-1 (continued)
Statistical Output of WSSV-T Correlation TORC Database

a, b, c

TS TD	Run	Press.	GL	XL	FC	GS	HL	DG	Dh	Dhm	GST	CHFm	CHFp	M/P-1	M/P

Table D-1 (continued)
Statistical Output of WSSV-T Correlation TORC Database

a, b, c

TS TD	Run	Press.	GL	XL	FC	GS	HL	DG	Dh	Dhm	GST	CHFm	CHFp	M/P-1	M/P

Table D-1 (continued)
Statistical Output of WSSV-T Correlation TORC Database

TS TD	Run	Press.	GL	XL	FC	GS	HL	DG	Dh	Dhm	GST	CHFm	CHFp	M/P-1	M/P

a, b, c

Table D-1 (continued)
Statistical Output of WSSV-T Correlation TORC Database

TS TD	Run	Press.	GL	XL	FC	GS	HL	DG	Dh	Dhm	GST	CHFm	CHFp	M/P-1	M/P

a, b, c

Table D-1 (continued)
Statistical Output of WSSV-T Correlation TORC Database

a, b, c

TS TD	Run	Press.	GL	XL	FC	GS	HL	DG	Dh	Dhm	GST	CHFm	CHFp	M/P-1	M/P

Table D-1 (continued)
Statistical Output of WSSV-T Correlation TORC Database

TS TD	Run	Press.	GL	XL	FC	GS	HL	DG	Dh	Dhm	GST	CHFm	CHFp	M/P-1	M/P

a, b, c

Table D-1 (continued)
Statistical Output of WSSV-T Correlation TORC Database

a, b, c

TS TD	Run	Press.	GL	XL	FC	GS	HL	DG	Dh	Dhm	GST	CHFm	CHFp	M/P-1	M/P

Table D-1 (continued)
Statistical Output of WSSV-T Correlation TORC Database

TS TD	Run	Press.	GL	XL	FC	GS	HL	DG	Dh	Dhm	GST	CHFm	CHFp	M/P-1	M/P

a, b, c

Table D-1 (continued)
Statistical Output of WSSV-T Correlation TORC Database

a, b, c

TS TD	Run	Press.	GL	XL	FC	GS	HL	DG	Dh	Dhm	GST	CHFm	CHFp	M/P-1	M/P

Table D-1 (continued)
Statistical Output of WSSV-T Correlation TORC Database

a, b, c

TS TD	Run	Press.	GL	XL	FC	GS	HL	DG	Dh	Dhm	GST	CHFm	CHFp	M/P-1	M/P

Table D-1 (continued)
Statistical Output of WSSV-T Correlation TORC Database

a, b, c

TS TD	Run	Press.	GL	XL	FC	GS	HL	DG	Dh	Dhm	GST	CHFm	CHFp	M/P-1	M/P

a, b, c

Appendix E
WSSV and WSSV-T CHF Test Geometries

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Appendix E WSSV and WSSV-T CHF Test Geometries

The test section radial and axial geometries for the tests used in the development and validation of the WSSV and WSSV-T correlations are shown in Figures E-1 through E-11. The axial relative power input into the VIPRE and TORC codes for the non-uniform tests are shown in Table E-1.

Table E-1
VIPRE/TORC Axial Power Distribution Input
for WSSV and WSSV-T Non-uniform Tests

Test 93		Test 114		
x/L	Relative Power	x/L	Relative Power	a, b, c

Figure E-1
Radial Geometry Test 91

a, b, c

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Figure E-2
Axial Geometry Tests 91 and 92

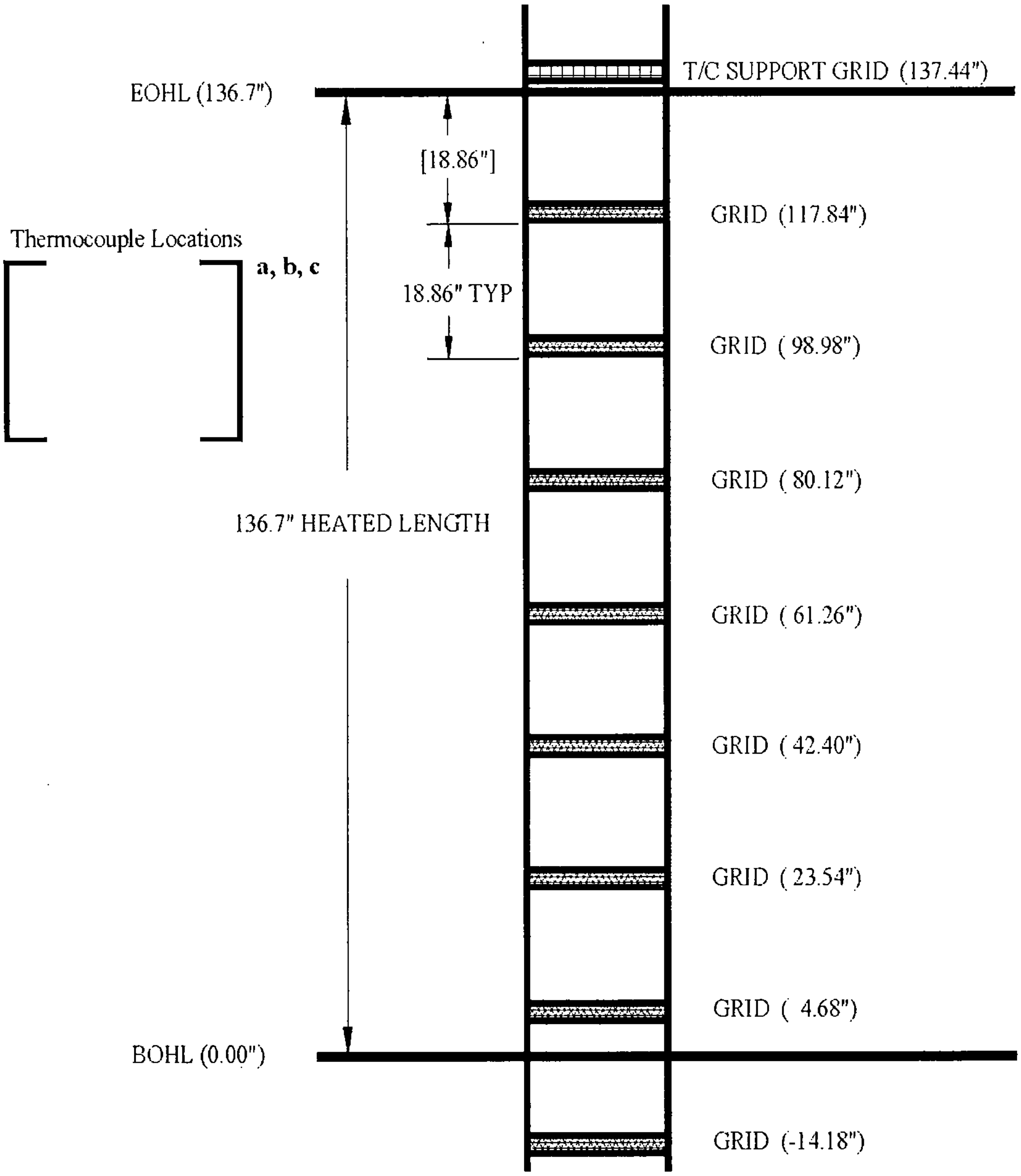

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Figure E-3
Radial Geometry Test 92

[ ] a, b, c

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Figure E-4
Radial Geometry Test 93

[ ]a, b, c

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Figure E-5
Axial Geometry Test 93

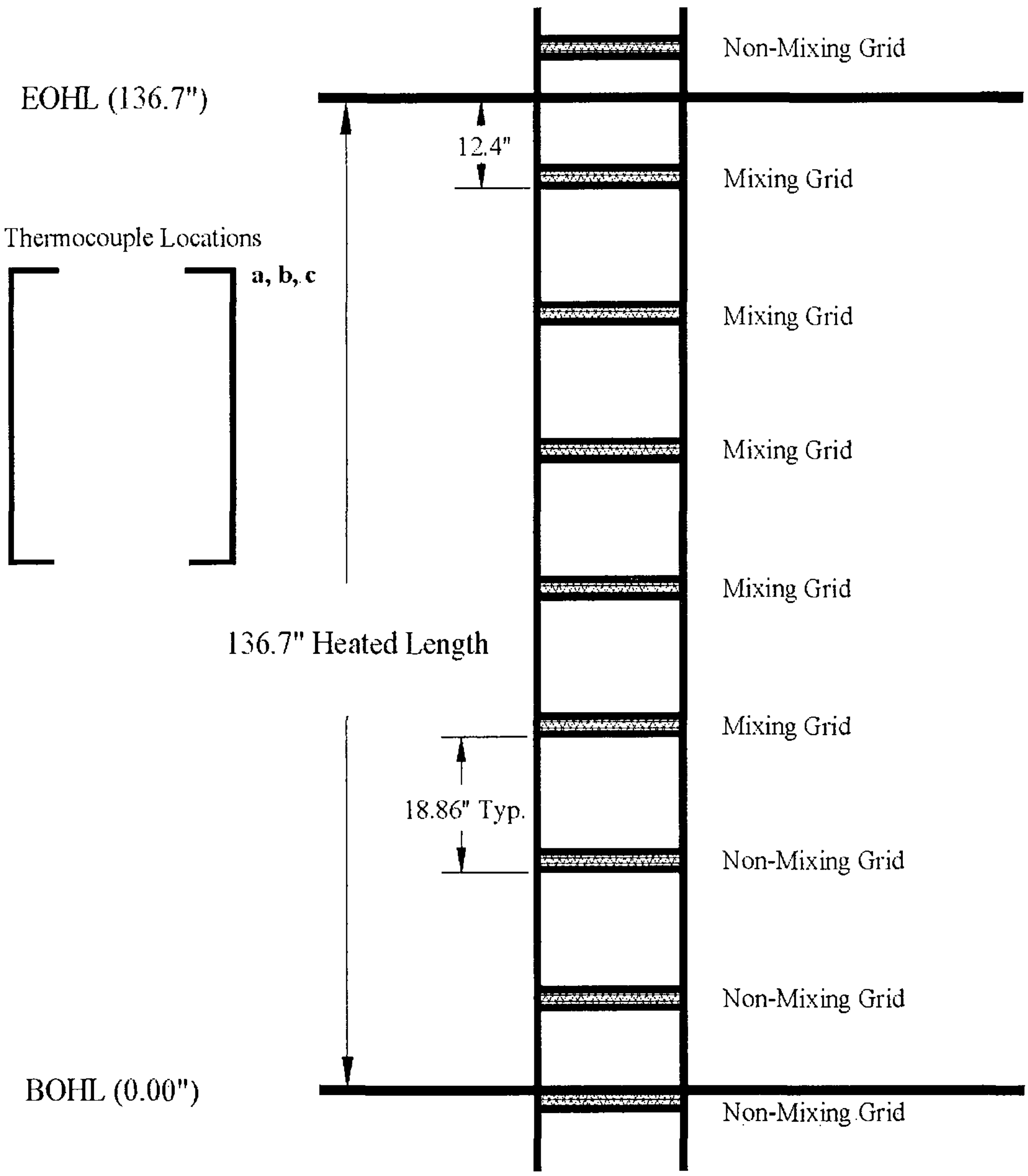

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Figure E-6
Radial Geometry Test 106

a, b, c

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Figure E-7
Axial Geometry Test 106

a, b, c

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Figure E-8
Radial Geometry Test 111

[ ]a, b, c

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Figure E-9
Axial Geometry Test 111

a, b, c

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Figure E-10
Radial Geometry Test 114

[ ] a, b, c

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Figure E-11
Axial Geometry Test 114

a, b, c

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Section C

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Our ref: LTR-NRC-06-53

September 18, 2006

Subject: Response to NRC's Request for Additional Information By the Office Of Nuclear Reactor Regulation Topical Report WCAP-16523-P, "Westinghouse Correlations WSSV and WSSV-T for Predicting Critical Heat Flux in Rod Bundles with Side-Supported Mixing Vanes" (TAC No. MD0561) (Proprietary/Non-Proprietary)

Enclosed are copies of the Proprietary and Non-Proprietary responses for NRC's Request for Additional Information for WCAP-16523-P/WCAP-16523-NP "Westinghouse Correlations WSSV and WSSV-T for Predicting Critical Heat Flux in Rod Bundles with Side-Supported Mixing Vanes".

Also enclosed is:

1. One (1) copy of the Application for Withholding, AW-06-2200 (Non-proprietary) with Proprietary Information Notice.
2. One (1) copy of Affidavit (Non-proprietary).

This submittal contains proprietary information of Westinghouse Electric Company, LLC. In conformance with the requirements of 10 CFR Section 2.390, as amended, of the Commission's regulations, we are enclosing with this submittal an Application for Withholding from Public Disclosure and an affidavit. The affidavit sets forth the basis on which the information identified as proprietary may be withheld from public disclosure by the Commission.

Correspondence with respect to this affidavit or Application for Withholding should reference AW-06-2200 and should be addressed to J. A. Gresham, Manager, Regulatory Compliance and Plant Licensing, Westinghouse Electric Company LLC, P.O. Box 355, Pittsburgh, Pennsylvania 15230-0355.

Very truly yours,

J. A. Gresham, Manager
Regulatory Compliance and Plant Licensing

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Our ref: AW-06-2200

September 18, 2006

APPLICATION FOR WITHHOLDING PROPRIETARY INFORMATION FROM PUBLIC DISCLOSURE

Subject: Response to NRC's Request for Additional Information By the Office Of Nuclear Reactor Regulation Topical Report WCAP-16523-P, "Westinghouse Correlations WSSV and WSSV-T for Predicting Critical Heat Flux in Rod Bundles with Side-Supported Mixing Vanes" (TAC No. MD0561) (Proprietary)

Reference: Letter from J. A. Gresham to NRC, LTR-NRC-06-53, dated September 18, 2006

The application for withholding is submitted by Westinghouse Electric Company LLC (Westinghouse) pursuant to the provisions of paragraph (b)(1) of Section 2.390 of the Commission's regulations. It contains commercial strategic information proprietary to Westinghouse and customarily held in confidence.

The proprietary material for which withholding is being requested is identified in the proprietary version of the subject report. In conformance with 10 CFR Section 2.390, Affidavit AW-06-2200 accompanies this application for withholding, setting forth the basis on which the identified proprietary information may be withheld from public disclosure.

Accordingly, it is respectfully requested that the subject information which is proprietary to Westinghouse be withheld from public disclosure in accordance with 10 CFR Section 2.390 of the Commission's regulations.

Correspondence with respect to this application for withholding or the accompanying affidavit should reference AW-06-2200 and should be addressed to J. A. Gresham, Manager of Regulatory Compliance and Plant Licensing, Westinghouse Electric Company LLC, P. O. Box 355, Pittsburgh, Pennsylvania 15230-0355.

Very truly yours,

J. A. Gresham, Manager
Regulatory Compliance and Plant Licensing

AW-06-2200

AFFIDAVIT

COMMONWEALTH OF PENNSYLVANIA:

ss

COUNTY OF ALLEGHENY:

Before me, the undersigned authority, personally appeared J. A. Gresham, who, being by me duly sworn according to law, deposes and says that he is authorized to execute this Affidavit on behalf of Westinghouse Electric Company LLC (Westinghouse) and that the averments of fact set forth in this Affidavit are true and correct to the best of his knowledge, information, and belief:

J. A. Gresham, Manager
Regulatory Compliance and Plant Licensing

Sworn to and subscribed
before me this 18th day
of September, 2006.

Notary Public

Notarial Seal
Sharon L. Fiori, Notary Public
Monroeville Boro, Allegheny County
My Commission Expires January 29, 2007
Member, Pennsylvania Association Of Notaries

(1) I am Manager, Regulatory Compliance and Plant Licensing, in Nuclear Services, Westinghouse Electric Company LLC (Westinghouse) and as such, I have been specifically delegated the function of reviewing the proprietary information sought to be withheld from public disclosure in connection with nuclear power plant licensing and rulemaking proceedings, and am authorized to apply for its withholding on behalf of Westinghouse.

(2) I am making this Affidavit in conformance with the provisions of 10 CFR Section 2.390 of the Commission's regulations and in conjunction with the Westinghouse "Application for Withholding" accompanying this Affidavit.

(3) I have personal knowledge of the criteria and procedures utilized by Westinghouse in designating information as a trade secret, privileged or as confidential commercial or financial information.

(4) Pursuant to the provisions of paragraph (b)(4) of Section 2.390 of the Commission's regulations, the following is furnished for consideration by the Commission in determining whether the information sought to be withheld from public disclosure should be withheld.

(i) The information sought to be withheld from public disclosure is owned and has been held in confidence by Westinghouse.

(ii) The information is of a type customarily held in confidence by Westinghouse and not customarily disclosed to the public. Westinghouse has a rational basis for determining the types of information customarily held in confidence by it and, in that connection, utilizes a system to determine when and whether to hold certain types of information in confidence. The application of that system and the substance of that system constitutes Westinghouse policy and provides the rational basis required.

Under that system, information is held in confidence if it falls in one or more of several types, the release of which might result in the loss of an existing or potential competitive advantage, as follows:

(a) The information reveals the distinguishing aspects of a process (or component, structure, tool, method, etc.) where prevention of its use by any of Westinghouse's competitors without license from Westinghouse constitutes a competitive economic advantage over other companies.

(b) It consists of supporting data, including test data, relative to a process (or component, structure, tool, method, etc.), the application of which data secures a competitive economic advantage, e.g., by optimization or improved marketability.

(c) Its use by a competitor would reduce his expenditure of resources or improve his competitive position in the design, manufacture, shipment, installation, assurance of quality, or licensing a similar product.

(d) It reveals cost or price information, production capacities, budget levels, or commercial strategies of Westinghouse, its customers or suppliers.

(e) It reveals aspects of past, present, or future Westinghouse or customer funded development plans and programs of potential commercial value to Westinghouse.

(f) It contains patentable ideas, for which patent protection may be desirable.

There are sound policy reasons behind the Westinghouse system which include the following:

(a) The use of such information by Westinghouse gives Westinghouse a competitive advantage over its competitors. It is, therefore, withheld from disclosure to protect the Westinghouse competitive position.

b) It is information which is marketable in many ways. The extent to which such information is available to competitors diminishes the Westinghouse ability to sell products and services involving the use of the information.

c) Use by our competitor would put Westinghouse at a competitive disadvantage by reducing his expenditure of resources at our expense.

(d) Each component of proprietary information pertinent to a particular competitive advantage is potentially as valuable as the total competitive advantage. If competitors acquire components of proprietary information, any one component may be the key to the entire puzzle, thereby depriving Westinghouse of a competitive advantage.

(e) Unrestricted disclosure would jeopardize the position of prominence of Westinghouse in the world market, and thereby give a market advantage to the competition of those countries.

(f) The Westinghouse capacity to invest corporate assets in research and development depends upon the success in obtaining and maintaining a competitive advantage.

(iii) The information is being transmitted to the Commission in confidence and, under the provisions of 10 CFR Section 2.390, it is to be received in confidence by the Commission.

(iv) The information sought to be protected is not available in public sources or available information has not been previously employed in the same original manner or method to the best of our knowledge and belief.

(v) The proprietary information sought to be withheld in this submittal is that which is appropriately marked in LTR-NRC-06-53 P-Attachment, Response to NRC's Request for Additional Information By the Office Of Nuclear Reactor Regulation Topical Report WCAP-16523-P, "Westinghouse Correlations WSSV and WSSV-T for Predicting Critical Heat Flux in Rod Bundles with Side-Supported Mixing Vanes" (TAC No. MD0561) (Proprietary), for submittal to the Commission, being transmitted by Westinghouse letter (LTR-NRC-06-53) and Application for Withholding Proprietary Information from Public Disclosure, to the Document Control Desk. The proprietary information as submitted by Westinghouse Electric Company is responses to NRC's Request for Additional Information.

This information is part of that which will enable Westinghouse to:

(a) Demonstrate the acceptability of the CE 16x16 Next Generation Fuel and corresponding correlation.

(b) Assist customers in implementing an improved fuel product.

Further this information has substantial commercial value as follows:

(a) Westinghouse can use this fuel design with its associated correlation to further enhance their licensing position over their competitors.

(b) Assist customers to obtain license changes.

Public disclosure of this proprietary information is likely to cause substantial harm to the competitive position of Westinghouse because it would enhance the ability of competitors to provide similar fuel design and licensing defense services for commercial power reactors without commensurate expenses. Also, public disclosure of the information would enable others to use the information to meet NRC requirements for licensing documentation without purchasing the right to use the information.

The development of the technology described in part by the information is the result of applying the results of many years of experience in an intensive Westinghouse effort and the expenditure of a considerable sum of money.

In order for competitors of Westinghouse to duplicate this information, similar technical programs would have to be performed and a significant manpower effort, having the requisite talent and experience, would have to be expended for developing the enclosed improved core thermal performance methodology.

Further the deponent sayeth not.

PROPRIETARY INFORMATION NOTICE

Transmitted herewith are proprietary and/or non-proprietary versions of documents furnished to the NRC in connection with requests for generic and/or plant-specific review and approval.

In order to conform to the requirements of 10 CFR 2.390 of the Commission's regulations concerning the protection of proprietary information so submitted to the NRC, the information which is proprietary in the proprietary versions is contained within brackets, and where the proprietary information has been deleted in the non-proprietary versions, only the brackets remain (the information that was contained within the brackets in the proprietary versions having been deleted). The justification for claiming the information so designated as proprietary is indicated in both versions by means of lower case letters (a) through (f) located as a superscript immediately following the brackets enclosing each item of information being identified as proprietary or in the margin opposite such information. These lower case letters refer to the types of information Westinghouse customarily holds in confidence identified in Sections (4)(ii)(a) through (4)(ii)(f) of the affidavit accompanying this transmittal pursuant to 10 CFR 2.390(b)(1).

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Response to NRC's Request for Additional Information By the Office Of Nuclear Reactor Regulation Topical Report WCAP-16523-P, "Westinghouse Correlations WSSV and WSSV-T for Predicting Critical Heat Flux in Rod Bundles with Side-Supported Mixing Vanes" (TAC No. MD0561) (Non-Proprietary)

Westinghouse Electric Company
P.O. Box 355
Pittsburgh, Pennsylvania 15230-0355

**Response to NRC's Request for Additional Information
By the Office Of Nuclear Reactor Regulation
Topical Report WCAP-16523-P, "Westinghouse Correlations WSSV and WSSV-T for Predicting Critical Heat Flux in Rod Bundles with Side-Supported Mixing Vanes" (TAC No. MD0561) (Non-Proprietary)**

Question 1: **On page 23 of 124, the B-array index shown in the top equation is not consistent with the index value for the same equation elsewhere in the report. Correct as appropriate.**

Response 1: *The B-array indices shown on page 23 will be corrected to be consistent with the final equation form shown on page 24 of 124 in the final approved report.*

Question 2: **On page 24 of 124, define the following terms in the equation for F_C:**

$q''_{CHF,NU}$ (not defined until page 36 of 124)

l_{crit}

z

Response 2: *The terms in the equation for F_C will be defined following the equation given on page 24 of 124 in the final approved report.*

Question 3: **On page 24 of 124, the only parts of the last equation previously considered proprietary are the leading coefficient and the exponents, see for example page 5-5 in CENPD-387-NP-A, Rev. 000, "ABB Critical Heat Flux Correlations for PWR Fuel." Correct as appropriate, and define any new terms.**

Response 3: *The proprietary brackets will be moved to cover just the leading coefficient and the exponents, consistent with CENPD-387-P-A in the final approved report. Terms are defined following the equation for F_C.*

Question 4: **The term F_C, to correct for non-uniform shapes, includes an empirical term "C" taken from CENPD-387-P-A, "ABB Critical Heat Flux Correlations for PWR Fuel." The parameter ranges have been expanded in the current proposal as compared to the previous study, most notably in the local coolant quality. Provide an explanation, or re-evaluate the empirical term "C" to cover the new parameter range, justifying the use of this term for cases outside the original parameter ranges used to develop "C."**

Response 4: *As described in Section 5 of CENPD-387-P-A, the non-uniform shape factor was optimized based upon the application of the correlation form and coefficients from uniform axial power data to the available non-uniform data. The non-uniform tests used*

to evaluate the empirical term "C" in CENPD-387-P-A had quality ranges from [ ]$^{a, b, c}$ from the beginning of subcooled boiling to the end of heated length. Therefore, in the region where minimum DNBR could have occurred, the quality range in the non-uniform data was larger than the quality range for the final correlation. In CENPD-387-P-A, the coefficients were determined with the data from five tests with five non-uniform shapes and were validated with the data from three additional tests. As shown in Figure 5-7 of CENPD-387-P-A, the results [ ]$^{a, c}$ for the entire range of quality at the MDNBR locations. For the WSSV and WSSVT correlations, the data from Test 114 is used to validate the use of the coefficients determined in CENPD-387-P-A for the current correlation. Test 114 has a large quality range from [ ]$^{a, b, c}$ from the beginning of subcooled boiling to end of heated length. As stated in Section 5, the mean for Test 114 is [ ]$^{a, b, c}$ with VIPRE for WSSV and [ ]$^{a, b, c}$ with TORC for WSSV-T with standard deviations less than [ ]$^{a, b, c}$. The scatter plots in Section 5 show no trend with quality or the value of F_C. Therefore, the results for Test 114, along with Test 93, validate and justify the use of the empirical term "C", determined in CENPD-387-P-A for the new correlations with the increased local coolant quality range.

Question 5: **The base ABB-NV and ABB-TV correlations (CENPD-387) did not include a factor to extend the correlation to higher qualities. The break point selected overlaps the previous data. Provide a discussion for how the break point was selected.**

Response 5: *Visual observations of the data when the higher quality data are included indicated the [ ]$^{a, c}$ value provided the lowest standard deviation and smoothest scatter plot for the values evaluated for the WSSV and WSSV-T correlations. As a further check, the statistical tests described in Section 5 were applied to confirm the [ ]$^{a, c}$.*

Question 6: **On page 38 of 124, it is stated "After the initial runs, the code could {emphasis added} have been used to separate out outliers, following the procedure described in Section 5. No points in the correlation database were rejected by this procedure as outliers." In Section 5, page 56 of 124, it is stated "As stated in Section 4, no points from the correlation or validation databases were eliminated." Clarify the actual procedure used to determine that no points in the data base were identified as outliers.**

Response 6: *The procedure used was the application of the outlier test given in Chapter 17 of Reference 7 that is described in Section 5.1.1. The test was applied to the correlation database and the combined correlation and validation database, after poolability was demonstrated. The test showed there were no outliers in either database. This*

description of the procedure will be added to Section 5.1.1 in the final approved report. Also, the words, "As stated in Section 4", will be removed from page 55 to eliminate the cross-reference.

Question 7: **On page 56 of 124, should the equation for W be b^2/S^2 (b-squared divided by s-squared)?**

Response 7: *The expression W = b2/S2 will be corrected to* $W = b^2/S^2$ *in the final approved report.*