Westinghouse Non-Proprietary Class 3

WCAP-16766-NP-A
Revision 0

February 2010

Westinghouse Next Generation Correlation (WNG-1) for Predicting Critical Heat Flux in Rod Bundles with Split Vane Mixing Grids

Westinghouse

WCAP-16766-NP-A
Revision 0

Westinghouse Next Generation Correlation (WNG-1) for Predicting Critical Heat Flux in Rod Bundles with Split Vane Mixing Grids

Approved Version: February 2010
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Section A

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NRC/RCPL-09-050

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

June 22, 2009

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

SUBJECT: WESTINGHOUSE ELECTRIC COMPANY - FINAL SAFETY EVALUATION RELATED TO REVIEW OF TOPICAL REPORT WCAP-16766-P, "WESTINGHOUSE NEXT GENERATION CORRELATION (WNG-1) FOR PREDICTING CRITICAL HEAT FLUX IN ROD BUNDLES WITH SPLIT VANE MIXING GRIDS" (TAC NO. MD7230)

Dear Mr. Gresham:

By letter dated October 26, 2007, Westinghouse Electric Company (Westinghouse) submitted Topical Report (TR) WCAP-16766-P, "Westinghouse Next Generation Correlation (WNG-1) for Predicting Critical Heat Flux in Rod Bundles with Split Vane Mixing Grids" to the U.S. Nuclear Regulatory Commission (NRC) staff for review and approval. By letter dated April 30, 2009, an NRC draft safety evaluation (SE) regarding our approval of TR WCAP-16766-P was provided for your review and comments. By e-mail dated May 19, 2009, Westinghouse commented on the draft SE and indicated that there is no Westinghouse Proprietary information included in 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 WCAP-16766-P is acceptable for referencing in licensing applications for Westinghouse designed fuel for pressurized water reactors 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,

Thomas B. Blount

Thomas B. Blount, Deputy Director
Division of Policy and Rulemaking
Office of Nuclear Reactor Regulation

Project No. 700

Enclosure: Final SE

cc w/encl:

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

FINAL SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

TOPICAL REPORT WCAP-16766-P, "WESTINGHOUSE NEXT GENERATION CORRELATION (WNG-1) FOR PREDICTING CRITICAL HEAT FLUX IN ROD BUNDLES WITH SPLIT VANE MIXING GRIDS"

WESTINGHOUSE ELECTRIC COMPANY

PROJECT NO. 700

1.0 INTRODUCTION

By letter dated October 26, 2007 (Reference 1), Westinghouse Electric Company (Westinghouse) submitted Topical Report (TR) WCAP-16766-P, "Westinghouse Next Generation Correlation (WNG-1) for Predicting Critical Heat Flux in Rod Bundles with Split Vane Mixing Grids" to the U.S. Nuclear Regulatory Commission (NRC) for review and approval. The purpose of this report was to identify and justify the use of the WNG-1 Critical Heat Flux (CHF) correlation for pressurized water reactor (PWR) fuel designs containing structural mixing vane (MV) grids and Intermediate Flow Mixer (IFM) grids. The WNG-1 correlation was developed for 17x17 Robust Fuel Assembly (RFA), 17x17 Next Generation Fuel (NGF), and 16x16 NGF fuel designs. The WNG-1 correlation's coefficients were derived with the Westinghouse version of the VIPRE-01 (VIPRE) (Reference 2) sub-channel code. The correlation was developed based on CHF test data obtained from the Heat Transfer Research Facility of Columbia University. The test data are from 5x5 and 6x6 rod bundles which simulated the Westinghouse PWR fuel designs with split mixing vane grids, with uniform and non-uniform axial power shapes, with non-uniform radial power distributions, with and without guide thimbles, with varied heated lengths, and with varied grid spacing.

In response to the NRC staff's request for additional information (RAI), dated May 6, 2008 (Reference 3), Westinghouse clarified the TR by LTR-NRC-08-37, dated July 25, 2008 (Reference 4). Further, in response to the NRC staff's additional RAI, dated November 25, 2008 (Reference 5), Westinghouse clarified the TR by LTR-NRC-09-11, dated February 12, 2009 (Reference 6). Where appropriate, the NRC staff commented on the responses to the RAIs in the Safety Evaluation (SE). Responses to RAIs not commented on in this SE were for NRC staff information or clarification and were found adequate (these include responses to RAI #2, #3, and #6 (Reference 4) and responses to further clarification on RAI #7e (Reference 6)).

2.0 REGULATORY EVALUATION

Section 50.34 of Title 10 of the *Code of Federal Regulations* (10 CFR), "Contents of construction permit and operating license applications; technical information", requires that Safety Analysis

ENCLOSURE

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 are responsible for 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 its compliance with the applicable regulations associated with the subject matter of this TR.

3.0 TECHNICAL EVALUATION

3.1 Background Information

Boiling crisis occurs when the boiling water flowing past a fuel rod transitions from nucleate boiling to film boiling. This transition decreases the heat transfer rate at the fuel rod surface, forcing the fuel rod surface temperature to dramatically increase in order to maintain the same total heat transfer. This large increase in fuel rod surface temperature may lead to fuel damage. The heat flux which causes this transition from nucleate boiling to film boiling is known as the CHF. To prevent possible fuel damage, boiling crisis is prevented via correlations used to predict the CHF. For normal reactor operations, thermal-hydraulic analysis is used to demonstrate that the peak heat flux in the core will remain below the CHF.

In Pressurized Water Reactors (PWR), CHF is primarily a local phenomenon caused by bubbles which crowd the surface of the fuel rod. If the bubbles prevent the cooling water from reaching the surface of the fuel rod, the flow can transition from nucleate boiling to film boiling. This form of CHF happens very quickly and is known as Departure from Nucleate Boiling (DNB). Keeping with common practice, the reviewers use DNB and CHF interchangeably. To prevent DNB, the Departure from Nucleate Boiling Ratio (DNBR) is used. DNBR is the ratio of the CHF at a location along the fuel rod divided by the current heat flux at that same location under the same coolant conditions.

Many parameters can impact DNB such as: flow pattern, bubble size and population, bubble layer thickness, wall superheat and flow memory, flow instability, local pressure, local enthalpy, mass velocity, inlet conditions, heated length, rod bundle shape, grid spacers, etc. (Reference 7). Due to the complex nature of the phenomenon of DNB, the functional form of DNB correlations are generally empirical and are often based solely on experimental observations of the relationship between the measured DNB and the measured DNB parameters.

The WNG-1 CHF correlation includes the following parameters: pressure, local mass velocity, local quality, heated length from the inlet to the CHF location, the distance between the grids, heated hydraulic diameter ratio as defined in response to RAI #1 (Reference 4), matrix heated hydraulic diameter as defined in response to RAI #1 (Reference 4), and a grid spacing term. The form of the correlation is essentially the same as that of the WSSV and WSSV-T CHF correlations (Reference 8).

Westinghouse has developed the WNG-1 correlation to accurately reflect thermal performance of NGF designs with split vane grids and with a wider parameter range than the existing CHF correlations in support of extended power uprates (local qualities higher than 30 percent). The WNG-1 correlation is applicable to the 16x16 NGF, 17x17 RFA, and 17x17 NGF fuel designs.

Initially, and reflected in the TR, Westinghouse intended to use the WNG-1 correlation for the 15x15 Upgrade fuel design. However, during the review the NRC staff raised questions on the data from the 15x15 Upgrade fuel design as well as the appropriate use of a DNBR generated from the combined database from all fuel designs for the 15x15 Upgrade fuel design. Westinghouse response in the further clarification to RAI #5 a, #7 b, d (Reference 6) and further discussion with the NRC staff demonstrated that there were issues which would need to be addressed if Westinghouse intended to use the WNG-1 correlation to analyze the 15x15 Upgrade fuel design. Westinghouse agreed that the 15x15 Upgrade fuel design would no longer be included as one of the fuel designs which could apply the WNG-1 correlation. The removal of the 15x15 Upgrade fuel design slightly changed the parameter range of the WNG-1 correlation as there were certain parameter values specific to the 15x15 Upgrade fuel design not found in the other three fuel designs. The WNG-1 correlation's range is limited to those parameter values found in the three fuel designs the correlation is applicable to: 16x16 NGF, 17x17 RFA, 17x17 NGF and as reiterated in Table 1 of this SE.

3.2 Database

CHF test data were taken with all four fuel designs. The test data used for development of the correlation were taken from nineteen test bundles with either 5x5 or 6x6 arrays with a split vane design mixing grid. Seven of the bundles had a uniform axial power shape and twelve had a non-uniform axial power shape. Sixteen of the bundles were representative of Westinghouse fuel with 0.374 inch outside diameter (O.D.) heated rods, 0.496 inch rod pitch, and 0.474 – 0.482 O.D. guide thimble. (Three of these sixteen bundles contained two IFM grids in each structural grid span to examine the impact of short grid spacing.) Two of the bundles were representative of Westinghouse fuel with 0.360 inch O.D. heated rods, 0.485 inch rod pitch, and 0.471 O.D. guide thimble. One of the bundles was representative of Westinghouse fuel with 0.423 inch O.D. heated rods and 0.563 inch rod pitch. These data were used to determine the coefficients of the WNG-1 correlation.

The test data used for validation of the correlation were taken from seven test bundles with either 4x4, 5x5 or 6x6 arrays with a split vane design mixing grid. Three of the bundles had a uniform axial power shape and four had a non-uniform axial power shape. Three of the bundles were also used in the development of the WRB-1 and WRB-2 correlations. Additional validation tests were split vane designs that are used outside the United States. Five of the bundles were representative of Westinghouse fuel with 0.374 inch O.D. heated rods, 0.496 inch rod pitch, and 0.474 – 0.482 O.D. guide thimble. Two of the bundles were representative of Westinghouse fuel with 0.422 inch O.D. heated rods and 0.555 – 0.563 inch rod pitch. The size of the validation database is 29 percent the size of the correlation database and was selected to demonstrate that the WNG-1 correlation was robust and predicts data well for conditions that are slightly outside the parameter range of the correlation database.

The test data used for development of the correlation and the test data used for the validation of the correlation were combined and used in generating the minimum allowable DNBR. Data from the 15x15 Upgrade fuel design were not taken out of the development or validation databases as including the data were conservative.

The correlation database is only valid if it is representative of the respective fuel types. The NRC staff asked if there were any anticipated changes in grid spacer location with reference to the tested assembly and the corresponding fuel design. Westinghouse responded to RAI #4 (Reference 4) stating that minor adjustments may be needed in mixed cores to ensure grid to grid overlap. The NRC staff agrees that minor adjustments should have little to no effect on the accuracy of the WNG-1 correlation.

The NRC staff reviewed the database and finds that the database used to develop the WNG-1 CHF correlation for Westinghouse was based on data representative of the fuel designs.

3.3 Trend Analysis

Westinghouse provided analysis which identify trends in the Measured to Predicted (M/P) values of CHF versus the variables of the WNG-1 correlation (pressure, local mass velocity, local quality, heated length from the inlet to the CHF location, the distance between the grids, heated hydraulic diameter ratio, matrix heated hydraulic diameter, and a grid spacing term). These plots were generated for the database as a whole and demonstrated that there were no significant trends in the WNG-1 prediction of CHF as a function of any variable.

The NRC staff reviewed the trend analysis and finds that there are no significant trends in the WNG-1 prediction of CHF as a function of any variable for any fuel type.

3.4 Application of the Correlation over the Intended Range

Because the functional form of WNG-1 correlations is empirical and was based on experimental observations of the relationship between the measured DNB and the correlation variables, the entire intended range of the correlation must be bounded by the test data. However, the WNG-1 correlation is also made up of test data from three separate fuel types and there were questions raised by the NRC staff requesting that Westinghouse justify the use of one correlation range for all the fuels when a correlation range for each of the three fuels could be more appropriate.

In their response to RAI #5 and #7 (Reference 4) and response to further clarification on RAI #5 b, c and #7 a, c (Reference 6), Westinghouse noted that the designs were similar according to key parameters (defined in Reference 9) and the data demonstrated similar performance over each of the three fuel types.

Specifically with reference to Westinghouse's response to further clarification on RAI #7c (Reference 6) about 16x16 NGF fuel, the NRC staff agrees with Westinghouse that the WNG-1 correlation is applicable over the entire mass flow range, even though there is a small portion of the range for which no 16x16 NGF data was available. The NRC staff agrees that the behavior of the 16x16 NGF fuel over this range will be conservatively bounded by the 17x17 NGF and 17x17 RFA fuel given the similarities between the key parameters of the fuel designs (defined in

Reference 9) and the small size of the portions of the range for which there was no 16x16 NGF data.

Specifically with reference to Westinghouse's response to RAI #5 (Reference 4) and further clarification on RAI #5 b, c (Reference 6) about quality, the NRC staff agrees with Westinghouse that the WNG-1 correlation behaves conservatively in this range and also has a conservative trend with respect to available test data (both at CHF and non-CHF conditions). The NRC staff agrees that the WNG-1 correlation will accurately predict the CHF in this quality range.

The NRC staff reviewed the intended range of the correlation and finds that the behavior of the correlation is consistent among the fuel designs and supports one bounding range for all three fuels (given in Table 1).

3.5 Statistical Evaluation of DNBR

The following topics were considered by Westinghouse for the statistical treatment of the database: outliers, normal distribution, comparison of the various data groups, the homogeneity of variance, and the 95/95 DNBR limit. The means and standard deviations for the homogeneity of variance for the ratio of M/P CHF were given for the total correlation database, for the individual tests in the data set, for the total validation database, for the individual tests in the validation data set, and for the total combined database.

Standard statistical tests were used including the W-test for normality at the 95 percent confidence level for groups with less than 50 data points, the D' test for normality at the 95 percent confidence level for groups with more than 50 data points, and the Bartlett test for homogeneity of variance. The F-test analysis of variance (ANOVA) was applied to test for equality of means and Owen's method was applied to determine a one-sided 95/95 limit. For groups that did not pass the normality test, the Kruskal-Wallis One-Way Analysis of Variance by Ranks test was applied to check equality of the medians and the Summerville non-parametric one-sided 95/95 DNBR limit was determined.

Due to questions about the results of the poolability determination, in RAI #7 (Reference 3) the NRC staff requested that a 95/95 DNBR value be determined for each fuel type and the NRC staff requested Westinghouse provide justification for using the combined data from all fuel types to determine one 95/95 DNBR limit when it may be more appropriate to use the data from each fuel type to determine a 95/95 DNBR limit for that specific fuel type. This would result in three DNBR limits, one for each fuel type as outlined in the clarification to RAI #7a, d (Reference 5).

According to the Westinghouse Fuel Criteria Evaluation Process (FCEP) Section J (Reference 9), the ratios of the M/P critical heat fluxes are subject to the three aforementioned statistical tests to determine if they are from the same population (commonly referred to as poolability). Each CHF point represented one test run. All of the runs taken on a specific bundle represented a complete test; thus, in the development of the correlation there are nineteen tests corresponding to the nineteen bundles. Westinghouse combined the tests into groups and performed the three statistical tests comparing the groups to each other and determined the groups were poolable. The NRC requested that Westinghouse provide analysis to determine that the tests were poolable into the groups, acknowledging that if they were then the groups were poolable with each other in clarification to RAI #7e (Reference 5). Westinghouse's

response (Reference 6) indicated that if the tests were separated into groups which would pass the poolability requirements of the FCEP, the limiting group would have a conservative DNBR limit of 1.15.

The DNBR limit which meets the 95/95 acceptance criterion was determined using Owen's onesided tolerance limit method (Reference 10). Use of this method was approved by the NRC (Reference 9). The general equation for Owen's method is as follows:

$$95/95 \text{ DNBR limit} = \frac{1}{\overline{\frac{M}{P}} - K_{95/95} \cdot \sigma}$$

Where

$\overline{\frac{M}{P}}$ is the test population mean of measured to predicted CHF ratios.

σ is the effective standard deviation of all the M/P data.

$K_{95/95}$ is a tolerance multiplier which provides the 95/95 probability/confidence limit.

The constant $K_{95/95}$ is a function of the effective degrees of freedom in the test series.

Consistent with previous CHF correlations (Reference 11, 12) the standard deviation, shall be calculated from combined variance of the variance within the test series and the variance among the test series. The effective degrees of freedom shall also be calculated in a like manner.

Therefore, the NRC staff finds that with a DNBR limit of 1.15 the WNG-1 CHF correlation will conservatively predict the CHF behavior of the fuel designs described herein.

4.0 CONDITIONS AND LIMITATIONS

Based on the forgoing considerations, the NRC staff concludes that the use of the WNG-1 correlation with a DNBR limit of 1.15 is acceptable for plant safety analyses provided that the following conditions are met:

1. Because the WNG-1 correlation was developed from test assemblies designed to simulate 16x16 NGF, 17x17 RFA, and 17x17 NGF with split vane grids as described in the TR, the correlation may only be used to perform evaluations for those fuel designs without further justification. The WNG-1 correlation's range is limited to those parameter values found in these three fuel designs.

2. The WNG-1 correlation shall be used with a DNBR limit of 1.15 with the Westinghouse VIPRE-01 computer code. WNG-1 is dependent on calculated local fluid properties that shall be calculated by the Westinghouse version of

VIPRE-01 computer code which has been reviewed and approved by the NRC staff for that purpose.

3. The WNG-1 correlation can be used for PWR plant analyses of steady state and reactor transients other than loss of coolant accidents. The WNG-1 CHF correlation shall not be used for loss of coolant accident analysis unless additional justification is provided to the NRC which demonstrates that the applicable regulations are met and the computer code used to calculate local fuel element thermal/hydraulic properties has been approved for that purpose.

4. The correlation shall not be used outside its range of applicability defined by the range of the test data from which it was developed. This range is listed in Table 1.

Table 1: WNG-1 Applicability Range

Parameter	WNG-1 Applicability Range
Pressure (psia)	**1405 to 2495**
Local mass velocity (Mlbm/hr-ft2)	**0.79 to 3.72**
Local quality (fraction)	**≤ 0.43**
Heat length, inlet to CHF location (inches)	**48* to 168**
Grid spacing (inches)	**6.4 to 26**
Heated hydraulic diameter ratio	**0.85 to 1.00**
Matrix heated hydraulic diameter (inches)	**0.46 to 0.50**
Grid Spacing Term	**≥ 26.5**

* Set as minimum Heat length, applied at all elevations below 48 inches.

5. Modifications to the WNG-1 CHF correlation or modifications to the associated DNBR limit of 1.15 for the three associated fuel types (16x16 NGF, 17x17 NGF, and 17x17 RFA), would require additional NRC review and approval.

6. Use of the WNG-1 CHF correlation for fuel types other than those specified in this SE (16x16 NGF, 17x17 NGF, and 17x17 RFA) are considered by the NRC staff to constitute a departure from a method of evaluation in the safety analysis. Justification for a departure shall be provided to the NRC for review.

The NRC staff will require licensees referencing this TR in licensing applications to document how these conditions are met.

5.0 CONCLUSION

When exercised appropriately, the NRC staff has reasonable assurance that the use of the WNG-1 CHF Correlation, as documented in Reference 1, is acceptable in calculating the CHF for the specified fuel types. The NRC staff has reviewed the WNG-1 CHF Correlation, and does not intend to review the associated TR when referenced in licensing evaluations, but only finds the methods applicable when exercised in accordance with the conditions and limitations described in Section 4.0 of this SE.

If the NRC's criteria or regulations change so that its conclusions about the acceptability of the thermal-hydraulic methods or statistical analyses are invalidated, the licensee referencing the report (Reference 1) will be expected to revise and resubmit its respective documentation, or submit justification for the continued effective applicability of these methodologies without revision of the respective documentation.

6.0 REFERENCES

1. J.A. Gresham, Westinghouse Electric Company, letter to U.S. Nuclear Regulatory Commission (NRC), LTR-NRC-07-57, "Submittal of TR WCAP-16766-P, 'Westinghouse Next Generation Correlation (WNG-1) for Predicting Critical Heat Flux in Rod Bundles with Split Vane Mixing Grids'", October 26, 2007 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML073050397 (letter) / ML073050399 / ML073050398 (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 (ADAMS Accession No. ML993160153 / ML993160096 (Proprietary / Non-Proprietary)).

3. J. H. Thompson, U.S. NRC, letter to J. A. Gresham (Westinghouse) "Request for Additional Information Re: Westinghouse Electric Company (Westinghouse) Topical Report (TR) WCAP-16766-P 'Westinghouse Next Generation Correlation (WNG-1) for Predicting Critical Heat Flux in Rod Bundles with Split Vane Mixing Grids (TAC No. MD7230)'" dated May 6, 2008. (ADAMS Accession No. ML081200886 / ML081200872 (Proprietary / Non-Proprietary)).

4. J.A. Gresham, Westinghouse Electric Company, letter to U.S. NRC, LTR-NRC-08-37 "Response to NRC Request for Additional Information by the Office of Nuclear Reactor Regulation for Topical Report (TR) WCAP-16766-P, 'Westinghouse Next Generation Correlation (WNG-1) for Predicting Critical Heat Flux in Rod Bundles with Split Vane

Mixing Grids. (TAC No. MD7230)'" dated July 25, 2008. (ADAMS Accession No. ML082180031 / ML082180030 (Proprietary / Non-Proprietary)).

5. G. Bacuta, U.S. NRC, letter to James A. Gresham (Westinghouse) "Request for Additional Information Re: Westinghouse Electric Company (Westinghouse) Topical Report (TR) WCAP-16766-P 'Westinghouse Next Generation Correlation (WNG-1) for Predicting Critical Heat Flux in Rod Bundles with Split Vane Mixing Grids (TAC No. MD7230)'" dated November 25, 2008. (ADAMS Accession No. ML082971069 / ML082970996 (Proprietary / Non-Proprietary)).

6. J.A. Gresham, Westinghouse Electric Company, letter to U.S. NRC, LTR-NRC-09-11, "Further Clarifications on RAIs for Topical Report (TR) WCAP-16766-P, 'Westinghouse Next Generation Correlation (WNG-1) for Predicting Critical Heat Flux in Rod Bundles with Split Vane Mixing Grids.'" dated February 12, 2009. (ADAMS Accession No. ML090570514 / ML090570513 (Proprietary / Non-Proprietary)).

7. L.S. Tong, "Boiling Crisis and Critical Heat Flux," TID-25687, 1972.

8. WCAP-16523-P-A, "Westinghouse Correlation WSSV and WSSV-T for Predicting Critical Heat Flux in Rod Bundles with Side-Supported Mixing Vanes", August 2007 (ADAMS Accession No. ML072570633 / ML072570327 (Proprietary / Non-Proprietary)).

9. WCAP-12488-A, "Westinghouse Fuel Criteria Evaluation Process", October 1994 (ADAMS Accession No. ML020430107 (Proprietary)).

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

11. WCAP-10444-P-A, "Vantage 5 Fuel Assembly", September 1985 (ADAMS Accession No. ML080650257 (Proprietary)).

12. WCAP-15025-P-A, "Modified WRB-2 Correlation, WRB-2M, for Predicting Critical Heat Flux in 17x17 Rod Bundles with Modified LPD Mixing Vane Grids", April 1999 (ADAMS Accession No. ML081610106 (Proprietary)).

Principal Contributors: A. Attard
J. Kaizer

Date: June 22, 2009

RESOLUTION OF WESTINGHOUSE ELECTRIC COMPANY (WESTINGHOUSE)

COMMENTS ON DRAFT SAFETY EVALUATION FOR TOPICAL REPORT (TR)

WCAP-16766-P, "WESTINGHOUSE NEXT GENERATION CORRELATION (WNG-1)

FOR PREDICTING CRITICAL HEAT FLUX IN ROD BUNDLES WITH

SPLIT VANE MIXING GRIDS"

By e-mail dated May 19, 2009 (ADAMS Accession No. ML091400076), Westinghouse provided two (2) minor grammatical corrections on the draft safety evaluation (SE) for TR WCAP-16766-P, "Westinghouse Next Generation Correlation (WNG-1) for Predicting Critical Heat Flux in Rod Bundles with Split Vane Mixing Grids" to the U.S. Nuclear Regulatory Commission (NRC) staff for review and approval. In the same e-mail, Westinghouse also indicated that there is no Westinghouse Proprietary information included in the draft SE; therefore, the draft of this SE will be made publicly available. The following are the NRC staff's resolution of these comments:

Draft SE comments for TR WCAP-16766-P:

1. Page 2, Line 33: replace the word "flow" with the word "coolant", more accurante statement.

   NRC Resolution for Comment 1 on Draft SE:

   The staff reviewed the Westinghouse recommendation and found it acceptable because the change is a grammatical correction.

   On Page 2, Line 33 is changed to read "coolant conditions".

2. Page 7, Table 1: Matrix heated hydraulic diameter, should include the units (i.e., (inches)).

   NRC Resolution for Comment 2 on Draft SE:

   The staff has reviewed the Westinghouse suggestion and found it acceptable to include the units in inches.

   On Page 7, Row 8 of Table 1 is changed to read "Matrix heated hydraulic diameter (inches)".

ATTACHMENT

Section B

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Westinghouse

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Nuclear Services
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U.S. Nuclear Regulatory Commission
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Our ref: LTR-NRC-07-57
October 26, 2007

Subject: Submittal of WCAP-16766-P/WCAP-16766-NP, "Westinghouse Next Generation Correlation (WNG-1) for Predicting Critical Heat Flux in Rod Bundles with Split Vane Mixing Grids," (Proprietary/Non-proprietary)

Enclosed are Proprietary and Non-Proprietary copies of WCAP-16766-P/WCAP-16766-NP, "Westinghouse Next Generation Correlation (WNG-1) for Predicting Critical Heat Flux in Rod Bundles with Split Vane Mixing Grids," submitted to the NRC for review and approval. It is requested that the above topicals be approved by November 2008. 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.

Also enclosed is:

1. One (1) copy of the Application for Withholding, AW-07-2348 (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 the affidavit or Application for Withholding should reference AW-07-2348 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,

R. M. Spaan / FOR

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

Enclosures
cc: A. Mendiola, NRR
J. Thompson, NRR

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Our ref: AW-07-2348
October 26, 2007

APPLICATION FOR WITHHOLDING PROPRIETARY
INFORMATION FROM PUBLIC DISCLOSURE

Subject: Submittal of WCAP-16766-P, "Westinghouse Next Generation Correlation (WNG-1) for Predicting Critical Heat Flux in Rod Bundles with Split Vane Mixing Grids," (Proprietary)

Reference: Letter from J. A. Gresham to Document Control Desk, LTR-NRC-07-57, dated October 26, 2007

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-07-2348 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-07-2348 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,

R. M. Spanfor

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

Cc: A. Mendiola, NRR
J. Thompson, NRR

AW-07-2348

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, Principal Engineer
Regulatory Compliance and Plant Licensing

Sworn to and subscribed
before me this 29th day
of October, 2007.

Sharon L. Markle
Notary Public

COMMONWEALTH OF PENNSYLVANIA
Notarial Seal
Sharon L. Markle, Notary Public
Monroeville Boro, Allegheny County
My Commission Expires Jan. 29, 2011
Member, Pennsylvania Association of Notaries

(1) I am Principal Engineer, 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 "Submittal of WCAP-16766-P, "Westinghouse Next Generation Correlation (WNG-1) for Predicting Critical Heat Flux in Rod Bundles with Split Vane Mixing Grids," (Proprietary), for submittal to the Commission, being transmitted by Westinghouse letter (LTR-NRC-07-57) 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 Next Generation Correlation (WNG-1) for Predicting Critical Heat Flux in Rod Bundles with Split Vane Mixing Grids for Westinghouse fuel designs.

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

Further this information has substantial commercial value as follows:

(a) Westinghouse can use this 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 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

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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Abstract

This report describes the development of Westinghouse Next Generation Critical Heat Flux (CHF) correlation (WNG-1) for Pressurized Water Reactor (PWR) fuel designs containing structural mixing vane (MV) grids and Intermediate Flow Mixer (IFM) grids with split vanes. The WNG-1 correlation was developed for the Westinghouse Next Generation Fuel, but can be used for current fuel designs containing split vane grids that are enveloped by the database. The WNG-1 correlation coefficients were derived with the Westinghouse version of the VIPRE-01 (VIPRE) subchannel code. The correlation was developed based on CHF test data obtained from the Heat Transfer Research facility of Columbia University. The tests simulated 4x4, 5x5 and 6x6 arrays of the fuel assembly geometry, split vane mixing 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 same correlation form has been previously used for other PWR fuel designs. 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 account for grid spacing, heated length, and cold wall effects. Based upon the uniform and non-uniform data [

] [a,c], an optimized non-uniform shape factor, F_C, is developed for the split vane mixing grid geometries covered by the correlation. The ***proposed*** 95/95 DNBR limit for the WNG-1 CHF correlation is 1.14. ***The final NRC-approved 95/95 DNBR limit for the WNG-1 CHF correlation is 1.15.*** The WNG-1 correlation will be used with Westinghouse version of the VIPRE code. The range of applicability for the WNG-1 correlations is summarized as follows:

Refer to final SE

Parameter	WNG-1 Correlation Parameter Range
Pressure (psia)	1405 to 2495
Local mass velocity (Mlbm/hr-ft^2)	0.79 to 3.72
Local quality (fraction)	≤ 0.43
Heated length, inlet to CHF location (inches)	48* to 168
Grid spacing (inches)	6.4 to 26
Heated hydraulic diameter ratio, [ ] [a,c]	0.85 to 1.00
Matrix Heated Hydraulic Diameter, Dhm (inches)	0.46 to ***0.50***
Grid Spacing Term, GST [ ] [a,c]	≥ 26.5

Refer to final SE

* 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 Westinghouse Next Generation Critical Heat Flux (CHF) correlation (WNG-1) for Pressurized Water Reactor (PWR) fuel designs containing structural mixing vane (MV) grids and Intermediate Flow Mixer (IFM) grids. A CHF correlation is also commonly referred to as a Departure from Nucleate Boiling (DNB) correlation. The WNG-1 correlation was developed for the Westinghouse Next Generation Fuel, but can be used for current designs containing split vane grids that are enveloped by the database. The split vane designs, included in the WNG-1 correlation database, are illustrated in Figure 1-1. The WNG-1 correlation form is essentially the same as the WSSV and WSSV-T correlations for Combustion Engineering PWR (CEPWR) fuel designs containing grids with side-supported vanes, Reference 1. Adjustments to the correlation form are due to the differences in the grid mixing vane design and the thimble tube geometry. The correlation coefficients were derived with Westinghouse version of the VIPRE-01 (VIPRE) subchannel code, Reference 2.

This correlation was developed based on Westinghouse Critical Heat Flux (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 4x4, 5x5 and 6x6 rod bundles simulating the Westinghouse PWR (W-PWR) fuel designs. The Westinghouse Next Generation Fuel (NGF) 17x17 design may contain 2 IFM grids located consecutively in a grid span between two MV grids. To provide sufficient data to cover different grid spacings, the WNG-1 database also contains previous CHF tests for existing fuel designs. Tests were performed with uniform and non-uniform axial power shapes for test arrays with and without guide thimbles. The test sections have heated lengths ranging from 96 inches to 168 inches, grid spacing of 6.4 inches to 26 inches, and rod diameter ranging from 0.360 inches to 0.423 inches.

The following sections describe why the new correlation was developed and a brief summary of the contents of the report.

1.1 Need for New Correlation

The WNG-1 correlation was developed for the following reasons:

1) A new correlation is needed to accurately reflect thermal performance of the Next Generation Fuel (NGF) designs with the split vane grids. The NGF design may have up to three grid span values over the length of the bundle. For example, for the 17x17 NGF 5-IFM design with a nominal heated length of 12 feet, the lower region has 20.55 inch grid spacing, the center region has 10.28 inch grid spacing and the upper region has grid spacing as low as 6.4 inches.
2) The new correlation should be applicable to a wider parameter range than the existing correlation (e.g., local quality higher than 30%), in support of extended power uprate.

Westinghouse has developed several new fuel designs, collectively identified as the Next Generation Fuel Design in 16x16 and 17x17 lattices. [ ] [a, c] shown in Figure 1-1 are covered by the WNG-1 correlation database. For the NGF designs, grid spacing varies depending on number of IFM grids in a grid span. A new DNB correlation is needed to accurately reflect thermal margin of the NGF design.

To develop a correlation for these designs, CHF test data were taken with the NGF grid and fuel designs at the Heat Transfer Research Facility of Columbia University. Since the correlation needed to cover a large range of grid spacing, mixing grid data from previous testing were included in the development of the final correlation form and constants to make the correlation robust and to cover the W-PWR fuel designs with the 0.422 inch rod diameter. The database also included the data for the 17x17 Robust Fuel Assembly (RFA) design, Reference 3, and the data for the 17x17 and 16x16 designs in Europe as documented in Reference 4. All of those fuel designs use grids with split vanes.

Both uniform and non-uniform axial power data were included in the database for the WNG-1 correlation. This provided the data required to develop an optimized non-uniform shape factor, F_C, for the correlation. The data at the measured elevation [ ] [a, c] the single tube and annular geometry used in the development of the Tong non-uniform shape factor, Reference 5. The data at the measured elevation were then used to optimize the non-uniform shape factor for the split vane data with small thimble tubes.

The WNG-1 correlation has been developed primarily for application for the new NGF fuel designs. The WNG-1 correlation also has a wider parameter range than an existing DNB correlation for fuel designs covered by its database. Since the correlation is developed with multiple fuel designs, it is considered to be applicable for the designs that fall within the parameter range. The WNG-1 correlation is considered to be applicable to the following designs:

- W-PWR Next Generation Fuel (NGF) or Upgrade designs with 0.360, 0.374 and 0.422-inch diameter rods and split vane mid-grid designs.
- Westinghouse 17x17 Robust Fuel Assembly (RFA) designs at high quality and/or low flow (outside the range of the WRB-2M correlation, Reference 3).

However, the WNG-1 correlation does not supersede any existing correlations, Reference 3, 6 or 7, applied for the current fuel designs.

1.2 The WNG-1 PWR CHF Correlation

Similar to the WSSV correlation for the CE-PWR NGF fuel design, Reference 1, the WNG-1 correlation is based on the ABB-NV correlation form. To account for effects of the smaller guide thimble geometry

and variable grid spacing on the non-uniform shape factor, modifications to the WSSV correlation form are made. A description of the Westinghouse CHF tests supporting the WNG-1 correlation is summarized in Section 2 of this report. The database contains test data to support the special geometry terms, especially grid spacing, for the correlation form and for validation.

Section 3 describes the modification of the WSSV correlation form for application with split vanes with a small guide thimble and the optimization of the coefficients for the WNG-1 correlation and the validation of the correlation. As stated above, the correlation form is based on the form used in References 1 and 8 for the ABB-NV, ABB-TV and WSSV correlations. The form is empirical and is based solely on experimental observations of the relationship between the measured CHF and the correlation variables. Similar to the WSSV correlation, the correlation form assumes that there is a linear relationship between CHF and local quality [

] [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 grid spacing term, GST, is defined as the [

] [a, c]. The heated hydraulic diameter ratio is defined as the [ ] [a, c]. The F_C non-uniform shape factor is also optimized for the split vane data with the small thimble fuel geometry and applied to the correlation to account for the effects of non-uniform axial power shapes [ ] [a, c]. Refer RAI 1 in LTR-NRC-08-37

All test data were evaluated by using the Westinghouse thermal hydraulic code, VIPRE-01 (or VIPRE), Reference 2. 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 designs were input into the model.

Section 4 summarizes the statistical evaluation for the WNG-1 correlation and determination of the 95/95 DNBR limit. All the statistical tests are standard statistical methods that have been previously applied for other NRC-approved correlations. 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 4. The 95/95 DNBR limit is determined [ ] [a, c]. Since all data grouped by geometry could be pooled, based on the applied statistical tests, the ***proposed*** 95/95 DNBR limit for the WNG-1 correlation was based on the final database and determined to be 1.14. ***The final NRC-approved 95/95 DNBR limit for the WNG-1 CHF correlation is 1.15.*** 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 trends relative to correlation variables. Refer to final SE

Section 5 discusses how the WNG-1 correlation is to be applied in plant safety analyses or reload analyses. Conclusions are presented in Section 6 and References are given in Section 7.

A detailed summary of the correlation and validation databases for the WNG-1 correlation is given in Appendix A. The statistical output of the WNG-1 correlation is given in Appendix B. A detailed summary of the test section radial and axial power distributions is given in Appendix C.

Figure 1-1
Description of Split Vane Designs

a, c

[ ]

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 WNG-1 correlation is based upon a re-evaluation of CHF data from tests that spanned the period from 1990 to 1996 and new data from tests performed in the period 1998 to 2003. The validation tests for the WNG-1 correlation were performed over the period of 1970 to 2001. A description of the test facility for the later tests, after 1990, can be found in Reference 8. A detailed description of the facility for the tests performed in the 1970's is given in Reference 9.

2.1 Description of Typical Test Sections

The correlation form was based on the WSSV form in Reference 1, but was modified to account for the effects of the split vanes and small thimble, as summarized in Section 3. The data used for the determination of the primary coefficients during development of the WNG-1 correlation were obtained from nineteen test bundles, seven with a uniform axial power shape and twelve with non-uniform axial power shapes. Nine of these test bundles were also used in existing correlations such as the WRB-2M, Reference 3, and the ABB-X2 for European application, Reference 4. The test sections in the correlation database simulate a 5x5 or 6x6 array of the Westinghouse fuel assembly geometry with split vane mixing grids. Sixteen of these test sections are representative of the Westinghouse fuel assembly with 0.374 inch O.D. heated rods, 0.496 inch rod pitch, and 0.474 – 0.482 inch O.D. guide thimble. Two test sections are representative of the Westinghouse fuel assembly geometry with 0.360 inch. O.D. heated rods, 0.485 inch rod pitch and 0.471 inch O.D. guide thimble. One test section is representative of the Westinghouse fuel assembly geometry with a 0.423 inch O.D. heated rod and 0.563 inch rod pitch. One test was performed to examine the impact of short grid spacing, two IFM grids in each structural grid span, with the Westinghouse assembly geometry of 0.374 inch O.D. heated rods, 0.496 inch rod pitch and 0.482 inch O.D. guide thimble.

The data used to validate the WNG-1 correlation were obtained from seven test bundles, three with a uniform axial power shape and four with non-uniform axial power shapes. The validation database test sections simulate a 4x4, 5x5 or 6x6 array of the Westinghouse fuel assembly geometry with a split vane design, [ ] [a, c], mixing grids. The validation database is approximately 29% of the correlation database. The validation database was selected to demonstrate the WNG-1 correlation is robust and predicts data well for conditions that are slightly outside the parameter range in the correlation database. Three of these test bundles were used in the development of the WRB-1 and WRB-2 correlations, References 6 and 7, and have an older Inconel grid design. Additional validation tests (Tests 83 and 102) are split vane designs that are used outside the United States. Five of these test sections are representative of the Westinghouse fuel assembly with 0.374 inch O.D. heated rods, 0.496 inch rod pitch, and 0.474 – 0.482 inch O.D. guide thimble. Two of the test sections are representative of the Westinghouse fuel assembly geometry with 0.422 inch O.D. heated rods and 0.555-0.563 inch rod pitch.

From the total of twenty-six tests examined, twelve of the tests were conducted with a simulated guide thimble and fourteen tests were conducted with simulated matrix subchannels. Typical radial geometries for the 5x5 test sections, with and without a guide thimble, are shown in Figures 2-1 and 2-2. Typical radial geometries for the 6x6 test sections with the small thimble, with and without a guide thimble, are shown in Figures 2-3 and 2-4. A typical radial geometry for the 4x4 test sections, without a guide thimble, is shown in Figure 2-5. The power split between the cold rods and hot rods ranged from [ ] [a,c]. The radial power distributions for the individual tests are given in Appendix C. The non-uniform tests were conducted with multiple axial power shapes, as shown in Figure 2-6. The test section heated length for the tests ranged from 96 inches to 168 inches. The upstream grid spacing in the tests ranged from 6.4 inches to 26 inches. The axial locations of the test grids and rod thermocouples for the individual tests are given in Appendix A. A summary of the test section geometry for the twenty-six tests is shown in Table 2-1. The data from the "correlation" test sections were used to develop the coefficients for the WNG-1 correlation. The data from the "validation" test sections were used to validate the correlation. Since Tests 100-102 provided additional data with the larger rod diameter and larger rod pitch, producing increased values of the matrix heated hydraulic diameter, Dhm, these tests were added to the correlation database for the correlation statistical evaluation.

The test grids for all the Westinghouse tests are similar to the production grids of actual fuel designs. Some tests were performed with Zircaloy-4 or ZIRLO™ material and intermediate simple support (SS) grids were used to prevent excessive rod deflection due to electromagnetic forces. Some test grids were made of the stronger Inconel 625 material and the intermediate SS grids were not necessary for minimizing rod bow and deflection.

2.2 Test Procedure and Operation

Although the general test procedure has not changed from earlier tests, a brief description of the test procedures and operation for the more recent tests, after 2001, 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 each 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 for a CHF data point, 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 WNG-1 Correlation and Validation Tests

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

a, b, c

a, b, c

* EPRI Test #, Reference 10, used for Test Identification, Data from References 6 and 7 Applied

Grid Spacing Definitions:

x / y	-	Two grid spacings, x and y in test
x – y	-	Multiple grid spacing from x to y. For tests 108 and 109, grid spacings were [ ]a, b, c
xE/y	-	Generally grid spacing of y, but last grid is x inches from end of heated length (EOHL) for uniform test

Figure 2-1
Typical Radial Geometry
5x5 Matrix Test

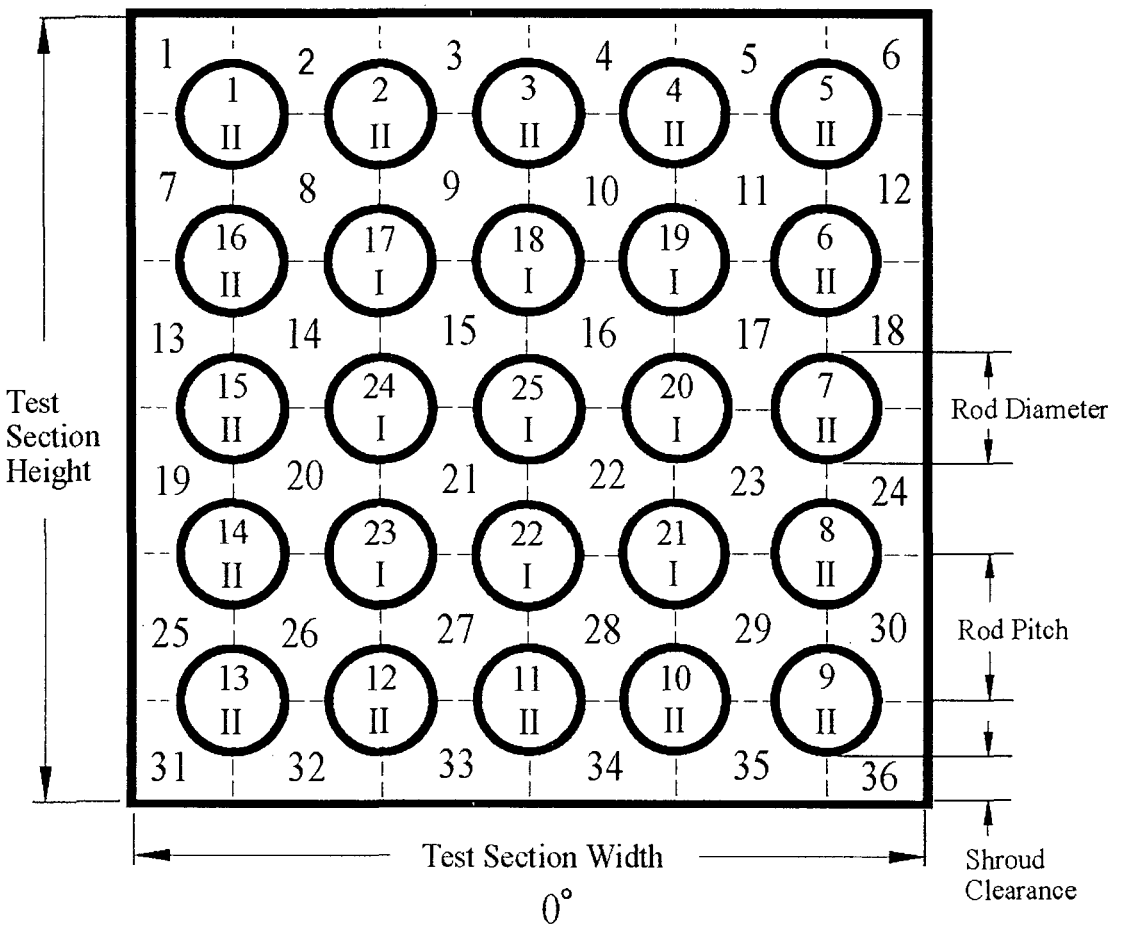


Figure 2-2
Typical Radial Geometry
5x5 Guide Thimble Test

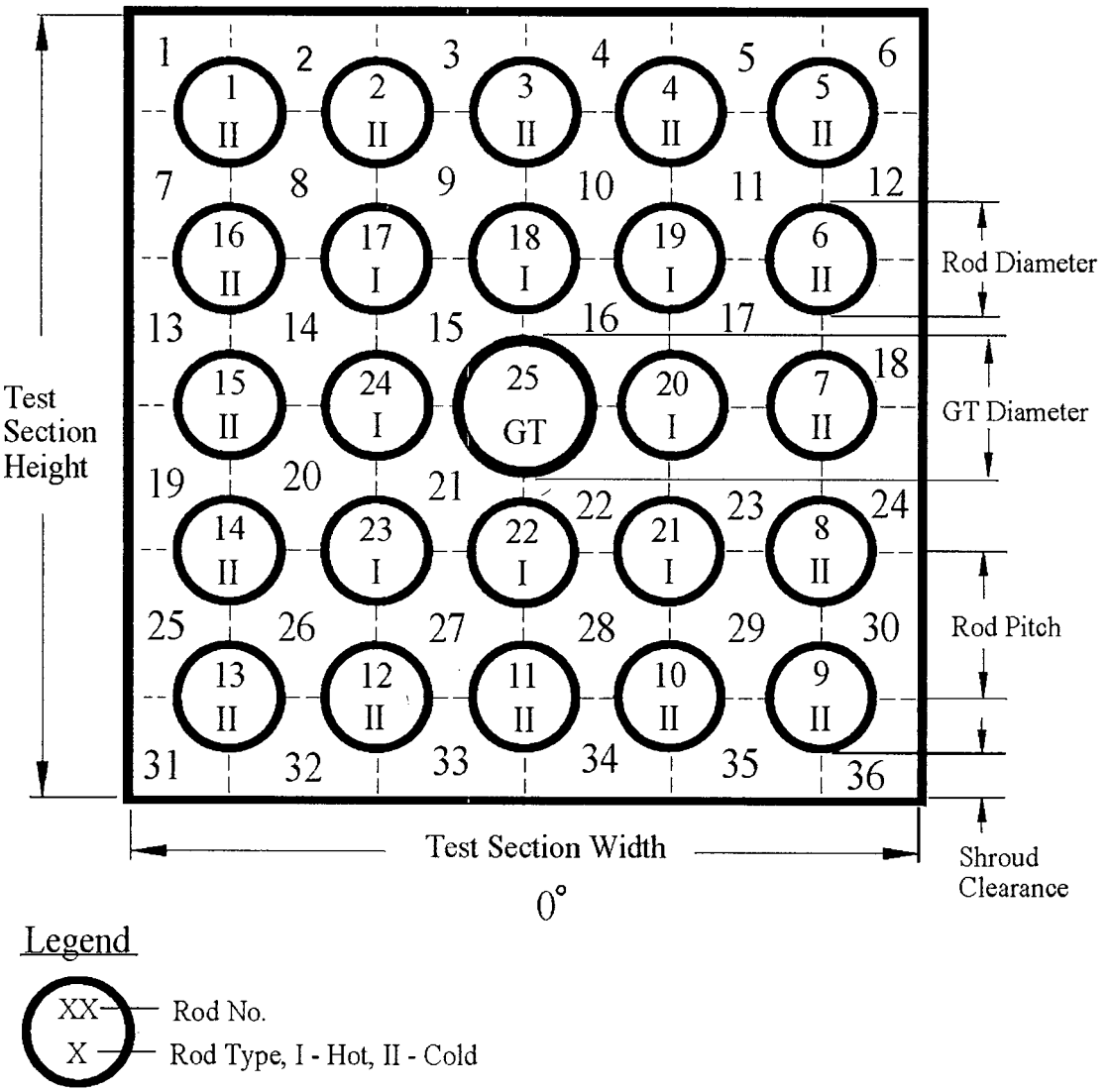


Figure 2-3
Typical Radial Geometry
6x6 Matrix Test

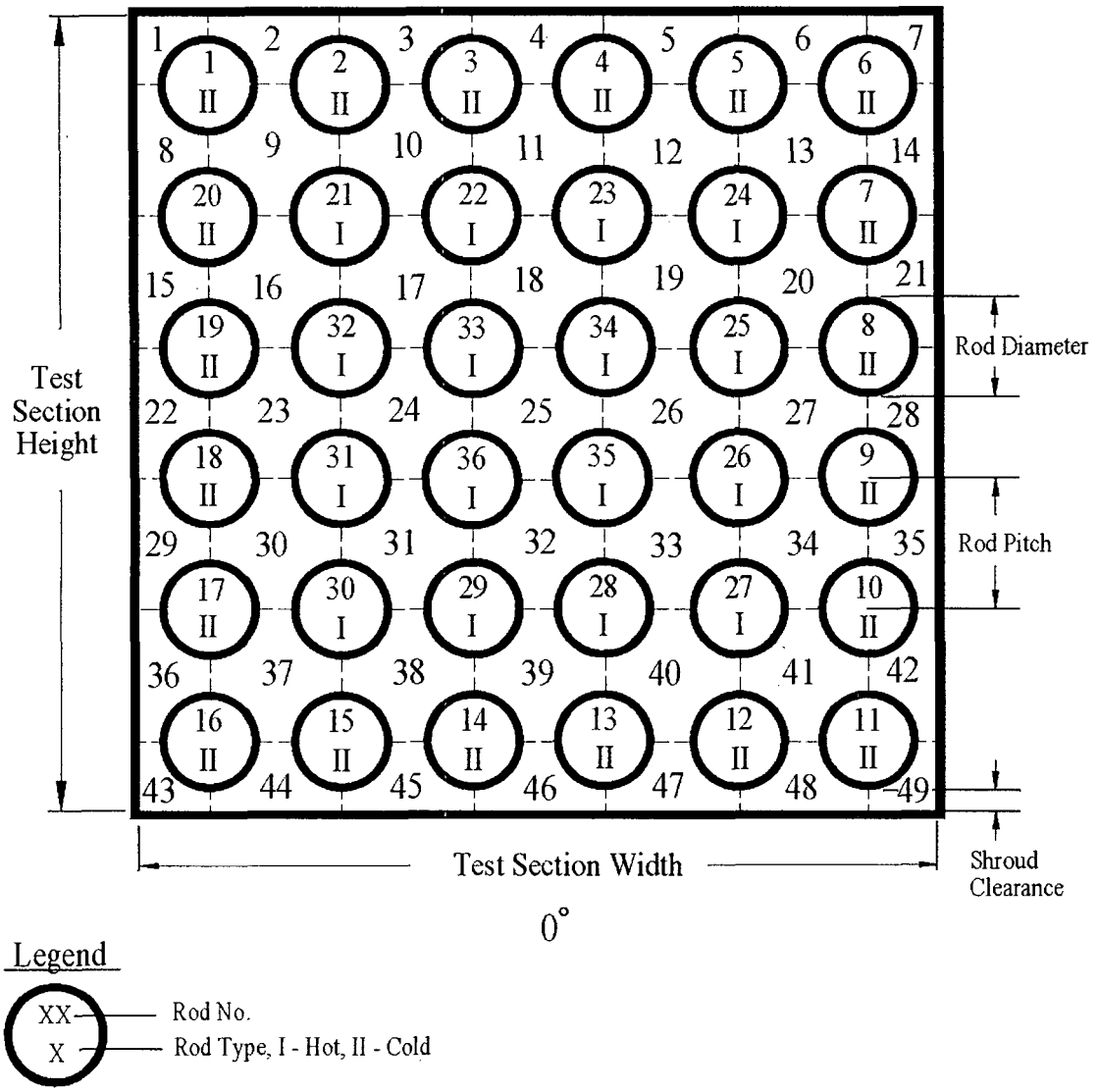


Figure 2-4
Typical Radial Geometry
6x6 Guide Thimble Test

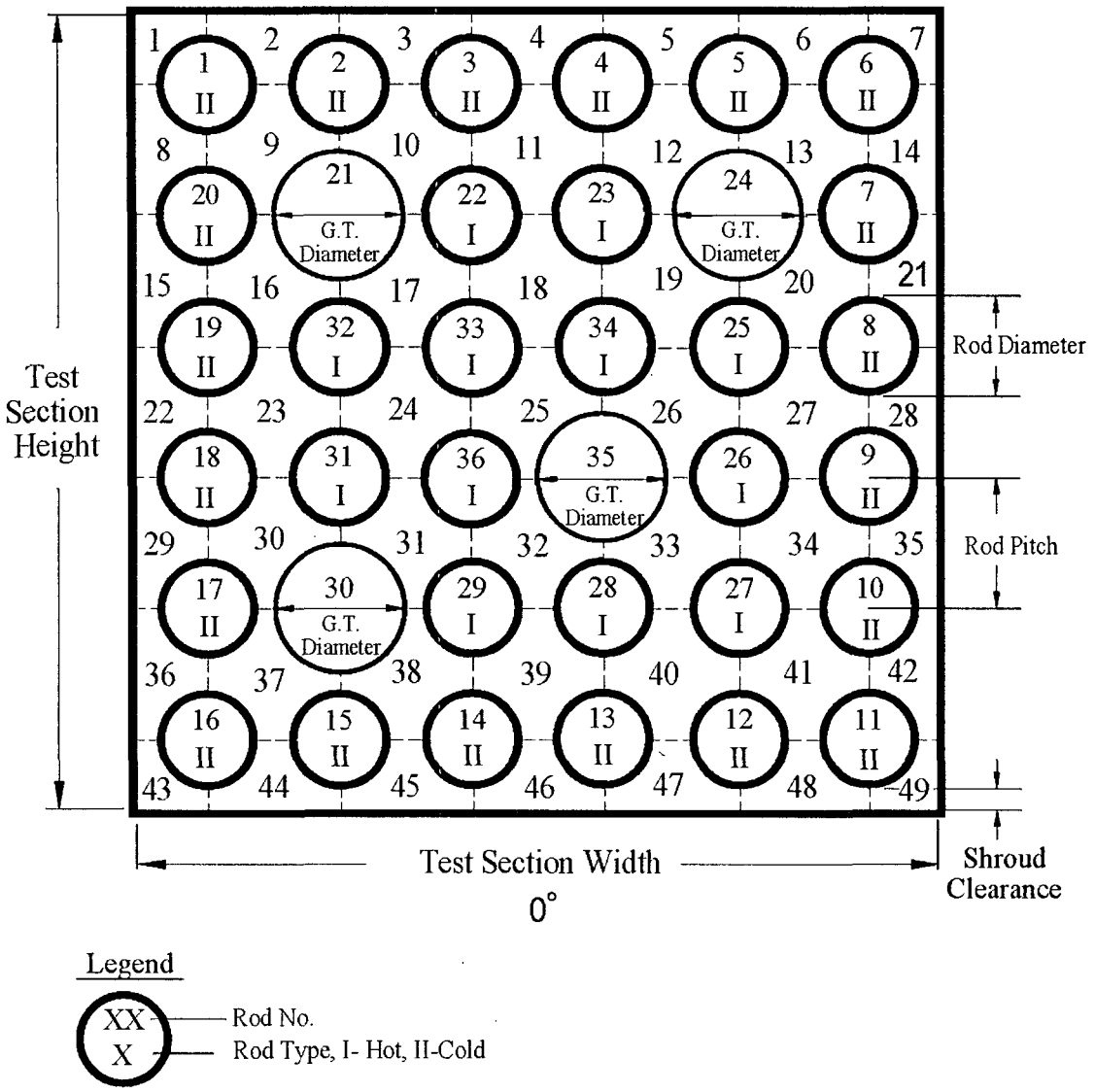
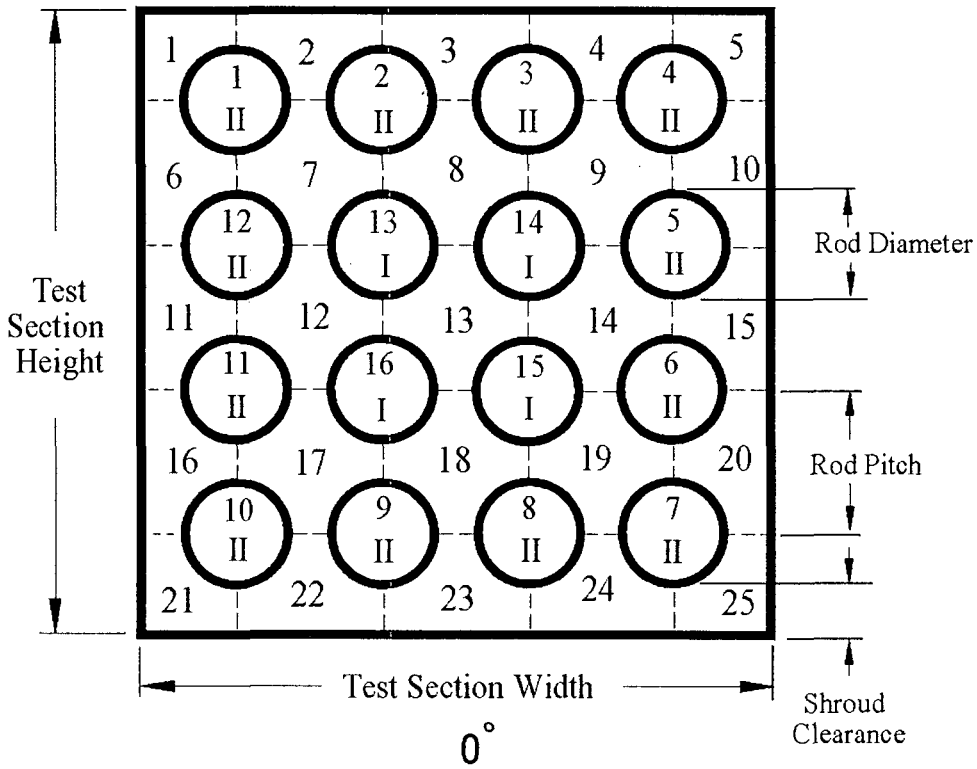


Figure 2-5
Typical Radial Geometry
4x4 Matrix Test



Legend

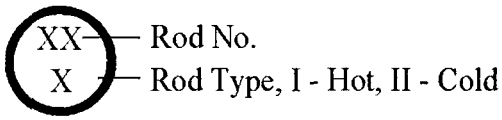


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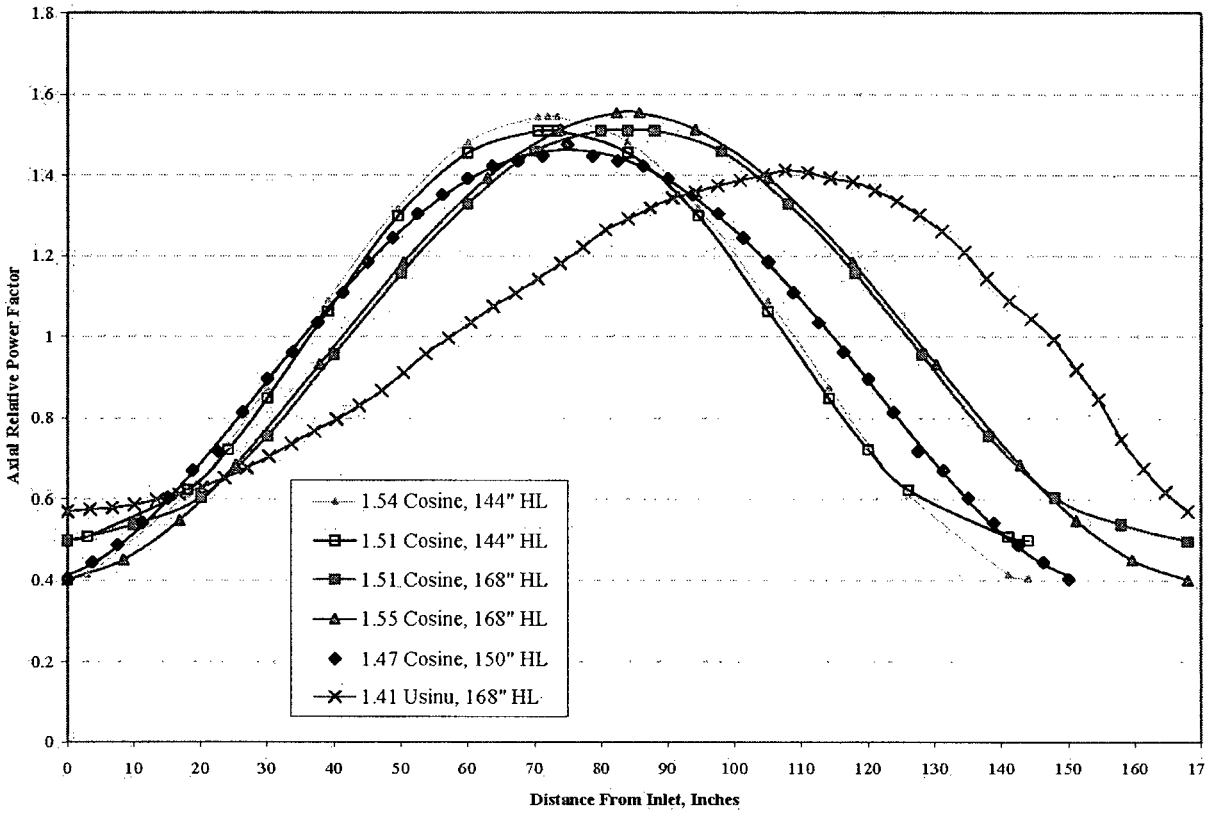
Figure 2-6
Axial Heat Flux Distribution
Non-Uniform Axial Power Shapes in WNG-1 Database



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3.0 Development of WNG-1 Correlation for Split Vane Mixing Grids

The WNG-1 correlation form was developed based on Westinghouse Critical Heat Flux (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 fuel designs containing 0 to 2 Intermediate Flow Mixing grids (IFM grids) between the structural mixing grids. All the grids used for the CHF tests contain a split vane mixing grid design, [ ] a, c, in Figure 1-1. The correlation database includes tests with uniform and non-uniform axial power distributions, with and without guide thimbles, heated lengths from 118.1 to 168 inches and grid spacing from 6.4 to 21.1 inches. A validation database, approximately 29% of the correlation database, was then used to validate robustness of the correlation. The validation database includes tests with uniform and non-uniform axial power distributions, with and without guide thimbles, heated lengths from 96 to 168 inches and grid spacing from 10 to 26 inches.

The functional form of the correlation is based upon the WSSV correlation form developed in Reference 1. To account for some geometric differences in vane design and guide thimble size, the development of the form and application for the WNG-1 correlation are provided in section 3.1. 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. Similar to the WSSV correlation, the correlation form assumes that there is a linear relationship between CHF and local quality [

] a, c.

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. The F_C non-uniform shape factor is also optimized for the split vane data with the small thimble and applied to the correlation to account for the effects of non-uniform axial power shapes [ ] a, c.

Refer RAI 1 in LTR-NRC-08-37

3.1 Description of Tests Supporting Correlation

A summary of the Westinghouse CHF tests supporting the WNG-1 correlation is provided in Section 2 of this report. Figures showing the geometry of typical 4x4, 5x5 and 6x6 test sections are also shown in Section 2. The array of rods was placed in a square metal shroud lined with unheated ceramic walls. Similar to previous correlations, the WNG-1 correlation is based upon a series of tests that provide a good representation of the thermal performance of Westinghouse fuel assemblies. The tests were run with grids made of Zircaloy material with simple support grids placed between the test grids or with test grids made with the stronger Inconel 600, or 625, material to minimize the rod deformation. Both of these changes provided a good representation of the thermal performance of Westinghouse fuel assembly in the reactor. For the tests in the correlation database, the rod to wall gap was sized to minimize the risk of DNB occurring on peripheral rods that are not representative of the fuel assembly, while maintaining similar

hydraulic resistance in the grid region for peripheral and interior subchannels. The relative radial power split between cold and hot rods ranged from approximately [ ] [a, c] to minimize the risk of DNB occurring on peripheral rods. 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 [ ] [a, 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 C.

Mixing tests were also performed for test sections with a uniform axial power shape to determine the empirical mixing factors (inverse Peclet number, Pe, or equivalent Thermal Diffusion Coefficient, TDC) for the split 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.

Since the WNG-1 correlation needed to cover fuel designs with grid spans having 0 to 2 IFM grids, CHF test data for split vane fuel assembly designs from previous testing were included in the correlation database, Table 2-1, to make the correlation robust. The database contains the data from the WRB-2M correlation, Reference 3, and data for the 17x17 and 16x16 designs in Europe, ABB-X2 correlation, Reference 4. The correlation database for the WNG-1 (Westinghouse NGF) correlation was selected from Westinghouse CHF tests based on several criteria:

1. Correlation database includes all data taken with simulated 5x5 arrays for the 17x17 and 16x16 NGF split vane fuel assembly designs.
2. Correlation database should include CHF data from tests that are used to evaluate the split vane mixing data.
3. Correlation database should include CHF data with different rod and hydraulic diameters and guide thimble sizes to expand geometric range.
4. Correlation database should include cosine data for 0.374" rod with one IFM between structural grids to appropriately cover range of 0 to 2 IFM grids per nominal grid span for the 17x17 designs.
5. Correlation should include different heated lengths for uniform axial data to expand quality range.

The correlation database for the NGF split vane correlation, WNG-1, is given in Table 2-1.

The primary intent of the validation was to demonstrate the correlation is robust. To develop a separate validation database for the WNG-1 correlation, validation tests are selected to:

1. Provide additional data for geometry with 0.422 in diameter rod.
2. Provide confirmation that data for the RFA-2 fuel fits the correlation.
3. Provide confirmation that the modification to the non-uniform shape factor is applicable to data from non-uniform tests with a $\mu \sin \mu$ axial power shape.
4. Provide confirmation that data from uniform axial power tests with 96" heated length are applicable with the heated length term applied for the correlation.
5. Provide confirmation that correlation can be extended to grid spacing of 22 in and pressure to near 1400 psia.
6. Provide at least 300 data points, or approximately 20% of the correlation database.

To meet these conditions, the seven tests listed in Table 2-1 were selected for the validation database. It is noted that some of the tests are for older grid designs no longer used and for grid designs used only outside of the United States. As stated above, the validation database was selected to demonstrate the correlation is robust. The applicable designs (Section 1.1) are a subset of the correlation database.

3.2 Correlation Form

As stated earlier, the basic form for the WNG-1 correlations is similar to the WSSV correlation developed in Reference 1. Following the development of the WSSV correlation form, the base form of the WNG-1 correlations 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] 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 rod bundle test sections without variable grid spacing. Fuel dependent special terms are then developed for Grid Spacing (GS), Distance from Grid (DG), Heated Length (HL) and Heated Hydraulic Diameter (Dhm). As noted in Reference 1, split vane test data were used to provide the form for the grid spacing terms and to fit higher quality data for the WSSV correlation form development. The required terms are then applied to the base form to account for variable grid spacing. The terms are discussed in brief for the application for the WNG-1 correlation. It is noted that the WSSV correlation had a set of terms to account for different performance in a matrix channel adjacent to the large guide thimble and a matrix channel [ ] [a, c] in the CE-PWR fuel. For the relatively smaller thimble (replaces one rod) geometry in

Westinghouse fuel designs, the impact of the thimble is sufficiently small that the set of correlation terms in the WSSV correlation (Reference 1) to account for the proximity of the matrix channel to the guide thimble are not required, simplifying the correlation.

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, Reference 8. 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

Similar to the WSSV correlation in Reference 1, the [

] a, c. Therefore, the expression and range determined in Reference 8 are also applicable for the WNG-1 correlation. Similar to the WSSV correlation, the heated length value is constrained to be no less than 48 inches since that are no CHF data available below this elevation.

3.2.2 Grid Spacing Terms

The form for the grid spacing terms for the WSSV correlation was developed using the larger split vane database, Reference 1. Therefore, the same form is applied for the WNG-1 correlation. The purpose of the grid spacing terms is to account for the effect of the grid on CHF. This term results in lower CHF just upstream of a spacer grid, which produces better agreement with test results. As described in Reference 1, to account for [ ] a, c was developed, defined as:

[ ]a, c

where: [ ]a, c

As noted in Reference 1, this is similar to the grid spacing term in the WRB-2 correlation, Reference 6. 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

As described in Reference 1, following the application of the grid spacing [ ] a, c to the supplemental split vane data, the resultant M/P CHF ratio data were then examined for trends to determine if any additional term is 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. Since this term was originally developed with split vane data in Reference 1, this additional term is also applied for the WNG-1 correlation. New coefficients are required to properly account for the split vane mixing grid performance.

3.2.3 Heated Hydraulic Diameter of CHF Channel

For the Westinghouse CE-PWR fuel assembly design, a large guide 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. For the ABB-NV, ABB-TV, WSSV and WSSV-T correlations, References 1 and 8, the heated hydraulic diameter term was developed to account for the difference in performance:

[ ] a, c

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

To evaluate whether the same form can be applied to the split vane small thimble geometry, the available data at the maximum quality channel at the measured elevation were examined. The data with a non-uniform shape factor near 1.0 were sorted based on test geometry. The average values of M/P CHF ratio for different grid spacing and different subchannel geometry are computed using a correlation with the developed form for the measured elevation data. The data are summarized in the table below. From the data, it appears the form does properly account for the difference in performance between the matrix channel and the thimble channel. Based upon these results, it is concluded that the [ ] a, c can be used to account for the thimble effect for fuel designs with the small thimble.

[

Test	Rod Diameter	Dhm	GST	Measured Elevation M/P

] a, c

3.2.4 Extension of Correlation to Higher Quality

As stated in Reference 1, a [

] [a, c]. The plot in Figure 3-1 is an example of the observed trend with split vane data. Based upon the [

] [a, c] value provided the lowest standard deviation for the split vane data. As a further check, the statistical tests described in Section 4.0 are applied to confirm [

] [a, c].

Following Reference 1, to account for the measured [

] [a, c]. Based upon the split vane data at higher mass velocities, the form used for the WSSV correlation in Reference 1 was [

] [a, c] is shown below:

[ ] [a, c]

The value of [ ] [a, c]

[ ] [a, c]

Plots of the WNG-1 correlation M/P CHF ratio versus the quality with the form adjustment are shown in Section 4. These plots demonstrate that the adjustment adequately accounts for the flow regime effects at higher qualities.

3.2.5 Optimization of Tong F_C Shape Factor for Non-Uniform Axial Power Shapes

A number of non-uniform tests are included in the split-vane correlation database, Table 2-1. The axial power shapes are shown in Figure 2-6. The data at the measured elevations were examined with correlations developed with uniform axial power shape data and the correlation form:

[ ] [a, c]

The matrix test data and the guide thimble test data were examined separately to determine whether the same trend is observed in both data sets. The non-uniform data based on local conditions at the measured elevations were examined with the non-uniform shape factor, F_C, set to 1.0 and with the standard Tong non-uniform shape factor with the Tong empirical constants, Reference 5. For the case when the non-uniform shape factor is applied, the predicted CHF is computed with the expression:

$$q''_{CHF,NU} = q''_{CHF,U} / F_C$$

where: $q''_{CHF,U}$ = local critical heat flux in channel predicted by the correlation
F_C = Non-uniform heat flux factor

The value of F_C is determined with the expression:

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

The Tong empirically determined coefficient, C, is evaluated with the expression:

$$C = 1.8 * (1-XL_{crit})^{4.31} / (GL/10^6)^{0.478} \ ft^{-1}$$

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
GL = mass velocity, Mlbm/hr-ft^2

The overall results for the guide thimble tests are shown in the table below:

a, c

[ ]

Based upon this data, it appears that the non-uniform shape factor required for the non-uniform data to fit the expression developed from uniform data is [ ] a, c. Plots of the average measured/predicted (M/P) CHF ratio using a measured elevation correlation developed from uniform guide thimble data [ ] a, c are shown in Figure 3-2. These plots indicate the required non-uniform shape factor value required [

] [a,c], as shown in Figure 3-2.

The same process applied to the thimble non-uniform test data was followed with the matrix non-uniform data. The matrix data shows a similar trend as the guide thimble data with F_C set to 1.0. Trend plots of the M/P CHF ratio based on the measured elevation correlations versus values of the non-uniform shape factor computed with the Tong empirical coefficients, F_T, are shown in Figure 3-3. Both plots, guide thimble test data and matrix test data, show a very similar trend of M/P close to 1 for F_T close to 1.0 and M/P about 1.2 for F_T near 1.5. This indicates the value of the non-uniform shape factor computed with the Tong empirical coefficients is too large for the split vane data in the WNG-1 correlation database. Consideration was given to modifying the constants in the equation for C, similar to the optimization performed for the side-supported and non-mixing vane data in Reference 8. However, there was no direct allowance for the [

] [a,c]. Therefore, the values of F_C are computed with the expression:

[ ] [a,c]

where: F_C = Non-uniform shape factor applied to non-uniform axial shape data
F_T = Non-uniform shape factor computed with Tong empirical coefficients
B = Constant fit with nonlinear regression analysis
[ ] [a,c]

The thimble and matrix channel data were initially correlated separately, and both sets of data had essentially the same value for the constant B, again indicating the same trend for the two test geometries. Based on the lack of trend, as shown in plots in Section 4, the optimization of the non-uniform shape factor [

] [a,c].

3.3 Final Correlation Form

Based upon the evaluation of the uniform and non-uniform data, the following form is applied to the split vane test data.

Final WNG-1 Correlation Form

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 Upstream of 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
$q''_{Channel}$ = Local Heat Flux, Mbtu/hr-ft^2
F_C = Optimized F-Factor To Correct $Q''_{CHF,U}$ for NU Shapes
F_T = Standard Tong Non-Uniform Shape Factor

The Tong non-uniform shape factor, F_T is computed with the empirically determined coefficient, C,

$$C = 1.8 * (1 - XL_{crit})^{4.31} / (GL/10^6)^{0.478} \ ft^{-1}$$

3.4 VIPRE Model

The test data from Columbia were evaluated by using the Westinghouse version of VIPRE-01 (VIPRE) thermal hydraulic code, Reference 2. The VIPRE code was used to predict local coolant conditions in each subchannel for the CHF test sections at multiple axial nodes. 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. The VIPRE calculations were based on the measured values of pressure, inlet temperature, bundle average mass velocity and bundle average heat flux.

The VIPRE decks are set up with [ ] a, c for the non-uniform tests. The [ ] a, c is selected to define the grid locations [ ] a, c. Following

the development of the WRB-1, WRB-2 and WRB-2M correlations, References 3, 6 and 7, calculated [

] a, c.

For the uniform axial power shape CHF test programs, approximately 30 mixing points were taken to evaluate the grid mixing factor. Mixing test procedures are described in detail in Reference 11. The tests were performed with the same test arrays used for the CHF tests. The subchannel mixing data were then reduced to evaluate the thermal mixing factor. Since it is [

] a, c.

[ ] a, c

The VIPRE two-phase flow and cross-flow correlations are kept the same as that for Westinghouse fuel design applications in Reference 2. The input specifications for the VIPRE model are summarized in Table 3-2.

3.5 Data Evaluation and Statistics

The following steps were performed for the optimization of the WNG-1 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. A utility code was then used to select the local conditions from the [ ] a, c from the VIPRE code. This was a [ ] a, c. The [ ] a, c coefficients for the final correlation form, provided in Section 3.3, were then determined from the [ ] a, c using a nonlinear regression analysis. As discussed in Section 3.2, the coefficients for the heated length term are to be the same as the ABB-NV, ABB-TV and WSSV correlations, References 1 and 8. To provide optimization of the non-uniform shape factor [ ] a, c.

2.) The data from the correlation database are then reduced in a version of VIPRE that has 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 [
] [a,c] of the correlation form were optimized using a non-linear regression analysis.

3.) Step 2 was repeated with the WNG-1 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 MDNBR elevation were evaluated 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 3-3 and 3-4. The code was also used to [
] [a,c]. The repeat runs were identified in the Columbia database. To be considered as duplicate data, the [

] [a,c]. After the initial runs, the code could have been used to separate out outliers, following the procedure described in Section 4. No points in the correlation database were rejected by this procedure as outliers.

The WNG-1 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 3-3, 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 WNG-1 correlation database are provided in Appendix B. Further discussion of the statistical evaluation of the WNG-1 correlation is given in Section 4.

Final Correlation Form and Coefficients for WNG-1 for VIPRE Code

a, b, c

[ ]

Nomenclature:

$q''_{CHF,U}$ = 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 to CHF Location, inches
GS = Grid Span Upstream of 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
F_C = Optimized F-Factor to Correct $q''_{CHF,U}$ for NU Shapes,
F_T = Standard Tong Non-Uniform Shape Factor

3.6 Validation of Correlation

An independent validation database was generated from tests excluded from the correlation database to verify performance of the WNG-1 correlation, as described in Section 3.1. Due to the large size of the correlation database, the primary purpose of the validation database is to demonstrate the correlation is sufficiently robust that the correlation provides good agreement with parameters somewhat outside the original correlation database. The geometric characteristics for these tests are 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 calculations were based on the measured values of pressure, inlet temperature, bundle average mass velocity and bundle average heat flux

at CHF, as given in Appendix A. For tests documented in References 6 and 7, the [

] [a, c]. The local conditions at the [

] [a, c], are used to determine the M/P CHF ratio. For non-uniform tests, the calculated DNB ratio is modified with the [ ] [a, c] for the axial shape factor, F_C.

The means and standard deviations for the M/P CHF ratio for the validation database and individual test sections are presented in Table 3-4, along with the range of the primary variables. It is noted that no points were eliminated as an outlier by the procedure described in Section 4 in the validation database. The statistical output for the individual test points in the WNG-1 validation database is provided in Appendix B. Further discussion of the statistical evaluation of the WNG-1 correlation is given in Section 4.

Table 3-1

[ ] [a, c] Input to VIPRE

a, b, c

[ ]

Table 3-2
Input Specifications for WNG-1 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, 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. Grid loss coefficients used: See Table 3-1
7. The crossflow resistance factor: [ ] a, b, c
   [ ] a, b, c
8. The turbulent momentum factor: [ ] a, 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 (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 3-3
CHF Test Statistics for WNG-1 Correlation Database

Test No.	Rod Diameter (~ in)	Rod Pitch (~ in)	Dhm (~ in)	Heated Length (~ in)	GST	Axial Shape	Guide Thimble	WNG-1 N	WNG-1 M/P Mean, μ	WNG-1 M/P Std. Dev.

a, b, c

Parameter Range of Data:

Pressure, psi:	Min.	1485	Max.	2495
Local Mass Velocity, Mlb/hr-ft^2:	Min.	0.79	Max.	3.60
Local Quality:	Min.	-0.21	Max.	0.43

Table 3-4
CHF Test Statistics for WNG-1 Validation Database

Test No.	Rod Diameter (~in)	Rod Pitch (~in)	Dhm (~in)	Heated Length (~in)	GST	Axial Shape	Guide Thimble	WNG-1 N	WNG-1 M/P Mean, μ	WNG-1 S Std. Dev.

a, b, c

Parameter Range of Data:

Pressure, psi:	Min.	1405	Max.	2495
Local Mass Velocity, Mlb/hr-ft^2:	Min.	0.86	Max.	3.72
Local Quality:	Min.	−0.14	Max.	0.33

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Figure 3-1
Split Vane Uniform Matrix Test Data vs. XL
[ ] a, c

a,b,c

[ ]

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Figure 3-2

Non-Uniform Guide Thimble Data [ ]a,c

for Correlation Based on Guide Thimble Uniform Data

a,b,c

[ ]

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Figure 3-3
Non-Uniform Data Trend with Non-Uniform Shape Factor
Computed with Tong Coefficients, F_T

a,b,c

[ ]

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Figure 3-4

TDC [ ] a,c, Split Vane Designs

a,b,c

[ ]

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4.0 Statistical Evaluation

The mean and standard deviation for the ratio of measured to WNG-1 predicted CHF are shown in Table 3-3 for the correlation database and the individual test sections and Table 3-4 for the validation database and individual test sections. A statistical evaluation is performed with the WNG-1 correlation for [ ] [a, c], the correlation database, the validation database, and a combined database. To demonstrate that the correlation is robust, [ ] [a, c] the final combined database. The statistical tests applied are the same tests applied in References 1 and 8 for the ABB-NV, ABB-TV, and WSSV correlations. The data in the correlation database, validation database, and final combined database were examined to determine whether any data would be eliminated as an outlier per the procedure given in Chapter 17 of Reference 12, the same rigorous outlier test applied in References 1 and 8. No points from either the WNG-1 correlation database or the validation database were eliminated by this test.

Section 4.1 describes statistical test methods and procedures, similar to those in References 1 and 8, used for evaluation of the WNG-1 correlation. Section 4.2 provides results of the statistical evaluation and the correlation 95/95 DNBR limit.

4.1 Statistical Tests

Statistical tests were performed to determine if all or selected data groups belong to the same population, for the evaluation of the 95/95 DNBR 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 with equal variances, Reference 14, was applied for testing the equality of means of two groups that passed both the normality tests and the homogeneity of variance test. The t-Test with unequal variances, Reference 15, was applied for testing the equality of means of two groups that passed the normality tests but failed the homogeneity of variance test. The ANOVA F-Test was applied to multiple groups that passed the normality tests. 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 combine-ability of two groups and the Kruskal-Wallis One-Way Analysis of Variance by Ranks Test was applied to multiple groups. For groups that failed the D' Normality Test but passed other normality tests such as the Kolmogorov-Smirnov Test, the Bartlett and F-Tests were applied to check for poolability of these groups. Data that did not pass any of these tests were not combined.

The one-sided 95/95 limits were calculated for a combined correlation and validation database using data for current grid designs, after the data sets in the database were evaluated to be poolable. The poolability tests were performed on the correlation and validation databases. The poolability tests were then applied [ ] [a, c] for the tests in the combined database. For normally distributed groups, Owen's one-sided tolerance limit factor, Reference 16, 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 12, 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 as measured to correlation predicted CHF ratio versus each of the variables in the correlation to examine the correlation for trends or regions of non-conservatism. 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.

4.1.1 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:

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

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. Based upon the application of this test to the correlation database, validation database and final combined database, no points were eliminated by this test.

4.1.2 Normality Tests

The W and D' tests, Reference 13, 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:

$$\mathbf{W} = \mathbf{b}^2 / \mathbf{S}^2$$

where:

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

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

a_i from Table 1, Reference 13
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 13. Small values of W indicate non-normality. For combined tests or individual tests with n ≥ 50, the D' normality test is applied. The test statistic D' is computed as:

$$D' = T / S$$

where:

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

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

The calculated value of D' is compared with the percentage points of the distribution of D' from Table 5 of Reference 13. 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.

4.1.3 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, 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. The Kruskal-Wallis One-Way Analysis of Variance by Ranks test is also used to check the null hypotheses that the medians, or averages, of the tests or groups are the same for multiple groups that pass the normality test, but fail the homogeneity of variance test. 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, Reference 16, 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 12. A brief description of the comparison tests is given below:

4.1.3.1 Homogeneity of Variances

One of the most used tests for examining the homogeneity of a set of variances is Bartlett's test (Reference 17). 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:

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

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

where: s^2_t is an estimate of variance for test section t based on degrees of freedom v_t , K is the number of test sections,

$N = \sum_{t=1}^{K} v_t$,

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

4.1.3.2 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:

$$t = \frac{\mu_1 - \mu_2}{s_0\,(1/n1 + 1/n2)^{0.5}}$$

where: $s_0^2 = \dfrac{\sum_{j=1}^{n1}(x_{1j} - \mu_1)^2 + \sum_{j=1}^{n2}(x_{2j} - \mu_2)^2}{n1 + n2 - 2}$ is a "pooled" estimate

The computed value of t is compared with the value $t_{\alpha/2,\, n1+n1-2}$ 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 $t_{\alpha/2,\, n1+n1-2}$.

When data from two groups passed the test for normality, but not the test for homogeneity of variances, a t-Test with unequal variances described below 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. From Reference 15, the test statistic t is calculated with the expression:

$$t = \frac{\mu_1 - \mu_2}{(S_1^2/n1 + S_2^2/n2)^{0.5}}$$

where: S_i^2 = Variance of sample i
ni = Number of data, sample i

4.1.3.3 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.

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

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

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 $F_{1-\alpha}(\nu_1, \nu_2)$ 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.

4.1.3.4 Distribution Free Comparison of Average Performance

For combinations that have one or both tests fail the normality test, the Wilcoxon-Mann-Whitney Test, References 12 and 18, 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:

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

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, References 12 and 18 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.

4.1.4 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 and grouped data based on geometry prior to the determination of the 95/95 DNBR limit. If not all of the data could be pooled, the data were separated into subsets that could be pooled 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, Reference 16, 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 12, is established.

4.1.4.1 Normally Distributed 95/95 DNBR Limit

The mean and standard deviation of the ratio of measured to WNG-1 predicted CHF 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:

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

$$K = \frac{1.645 + 1.645[1-(1-\frac{2.706}{2(n-1)})\bullet(1-\frac{1}{n})]^{0.5}}{1-\frac{2.706}{2(n-1)}}$$

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 14, practically equivalent to Owen's tables in Reference 16)
n = number of data points

4.1.4.2 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 12 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 6 and 7. Also, the limit for the entire database is computed using the distribution free method if the entire database is not normally distributed.

4.1.5 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.

4.2 WNG-1 Correlation Statistical Evaluation and 95/95 DNBR Limit

Following References 1 and 8, the W and D' Normality tests and comparison tests described in Section 4.1 were performed to determine if the WNG-1 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. The initial evaluation was performed to determine whether the correlation and validation data were from the same population to determine whether the validation database did validate the correlation. If the data are from the same population, this allows some or all of

the validation database to be combined with the correlation database prior to further examinations for bias and the one-sided 95/95 DNBR limit. The mean and standard deviation for the ratio of measured to WNG-1 predicted CHF are shown in Table 3-3 for the correlation database and Table 3-4 for the validation database. The correlation database has 1,412 points and the validation database has 412 points or 29% of the correlation database. Test for normality of the data for the correlation and validation databases were performed and the results are given in Table 4.2-1. Although the correlation database did not pass the normality test, the Bartlett Test and t-Test were applied to the correlation and validation data along with the distribution free Wilcoxon-Mann-Whitney Test for group comparisons since the correlation data passed other normality tests such as the Kolmogorov-Smirnov Test. The results from the comparison tests are summarized in Table 4.2-2. When correlation and validation tests passed the normality test but failed the Bartlett test, the t-Test with unequal variances was used to test for equality of means. The Wilcoxon-Mann-Whitney Test was also used to test the hypothesis that the two groups could have the same average performance. Based upon this evaluation, it is concluded that the validation database does validate the correlation.

As stated previously, to check the robustness of the correlation, some of the data in the validation database are from tests with [ ]^{a,c}. The WNG-1 correlation 95/95 DNBR limit is determined [ ]^{a,c}. Therefore, the validation data [ ]^{a,c} are added to the correlation database to produce the combined database used to determine the 95/95 DNBR limit. [ ]^{a,c} to the correlation database to determine the 95/95 DNBR limit.

The results of the parametric comparison tests for the combined database used to determine the 95/95 DNBR limit for the correlation are given in Table 4.2-3. The results indicate that [ ]^{a,c}. Additional statistical tests were then performed with the test data grouped by test geometry. The database has data from guide thimble tests and matrix tests; so test section geometry is one variable examined. The database has data for tests sections with [ ]^{a,c} is another variable examined. The database has data for [ ]^{a,c} that is examined. Multiple comparison tests are performed to identify data groups that can be pooled with the application of the statistical tests identified in Section 4.1.

The first step was to examine each geometric group in the database with the normality tests. The results from these normality tests are given in Table 4.2-4. The next step was to examine equality of variance for the groups. The data for the [ ] [a, c]. There were three sets examined, the [ ] [a, c]. The results of the Bartlett test are given in Table 4.2-5. Based upon this test, the data grouped by [ ] [a, c] the Bartlett test for equality of variances, [ ] [a, c]. Since the data grouped [ ] [a, c] was applied to test the equality of means. Since the data grouped by [ ] [a, c] was applied for the comparison of means test. This test was also applied to the data grouped by [ ] [a, c]. The data grouped by [ ] [a, c]. The results of the comparison tests are given in Table 4.2-7. Based upon these tests, the data grouped by [ ] [a, c] could all be pooled. Therefore, for each [ ] [a, c], the 95/95 DNBR limit is based on the entire database of 1581 points in Table 4.2-3.

Since the combined database [ ] [a, c] is based on the parametric method described in Section 4.1. The one-sided 95/95 DNBR limit for the WNG-1 correlation is computed to be 1.139, as shown in Table 4.2-8. Therefore, the 95/95 DNBR limit is set to 1.14. A plot of the measured CHF versus the WNG-1 predicted CHF for all the test data is given in Figure 4.2-1, along with the DNBR limit curve. The DNBR limit of 1.14 is equivalent to a value of 0.8772 for the M/P CHF ratio. It is noted that for the entire database, fifty-six test points, or 3.5% of the data fall below the $M/P_{95/95}$ limit of 0.8772.

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 4.2-2 through 4.2-9. 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 WNG-1 VIPRE database and the scatter plot analysis, the one-sided 95/95 DNBR limit is determined to be 1.14. The applicable parameter ranges for the WNG-1 correlation are given in Table 4.2-9.

Table 4.2-1
W and D' Normality Tests
WNG-1 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

Table 4.2-2
Comparison Tests
WNG-1 Correlation and Validation Database

Bartlett Test Results – WNG-1 Data

Database	N	Mean	s	K	M	C	M/C	$\chi^2_{.95}$	Pass Test

a, b, c

Table 4.2-3
Parametric Comparison Tests
Combined Correlation and Validation WNG-1 Database

Test No.	Rod Diameter (~ in)	Rod Pitch (~ in)	Dhm (~ in)	Heated Length (~ in)	GST	Axial Shape	Guide Thimble	WNG-1 N	WNG-1 M/P Mean, μ	WNG-1 M/P Std. Dev.

a, b, c

Bartlett Test Results – WNG-1

Database	N	Mean	s	K	M	C	M/C	$\chi^2_{.95}$	Pass Test
ALL	1,581	1.0027	0.0730	22	122.86	1.0069	122.01	32.6	No

F-Test Results – WNG-1 Data

Database	n_1	n_2	S_1	S_2	S_1 / S_2	$F_{.95}(n_1, n_2)$	Pass Test
ALL	21	1559	0.0290	0.00501	5.792	1.57	No

Table 4.2-4
WNG-1 Final Database [ ] [a, c] Normality Test Results

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

a, b, c

Table 4.2-5
Bartlett Equality of Variance Test Results, WNG-1

Tests	df	M	C	M/C	$\chi^2_{.95}$	Pass Test

a, b, c

Table 4.2-6
Parametric Comparison Tests for Pooled [ ] [a, c] Subsets
WNG-1 Database

t-Test Results with Unequal Variance Data Grouped by Test Geometry

Geometry	n_1	n_2	S_1^2	S_2^2	t	$t_{.025,1579}$	Pass Test

a, b, c

Table 4.2-7
Distribution Free Comparison Tests for Pooled [ ] [a, c] Subsets
WNG-1 Database

Check of H Statistic From Kruskal-Wallis Variance By Ranks Test

Test	n_t	R_i	R_i^2/n_i	H	$\chi^2_{.95}$

a, b, c

Table 4.2-8
Determination of 95/95 DNBR Limit for Pooled Data
WNG-1 Database

Database	N	Mean	S	K	$DNBR_{95}$
[					] a, b, c

Table 4.2-9
Parameter Ranges for the WNG-1 Database

Parameter	Applicable Range
Pressure (psia)	1405 to 2495
Local Coolant Quality	≤ 0.43
Local Mass velocity (Mlb/hr-ft^2)	0.79 to 3.72
Matrix Heated Hydraulic Diameter, Dhm (inches)	0.46 to 0.53
Heated Hydraulic Diameter Ratio, [ ]^{a,c}	0.85 to 1.00
Heated Length, HL (inches)	48* to 168
Grid spacing (inches)	6.4 to 26
Grid Spacing Term, GST [ ]^{a,c}	≥ 26.5**

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

** If Grid is in next node and GST < 26.5, set GST to 26.5
Note: This does not apply to [ ]^{a,c}

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Figure 4.2-1
Measured and Predicted Critical Heat Fluxes
WNG-1 Correlation

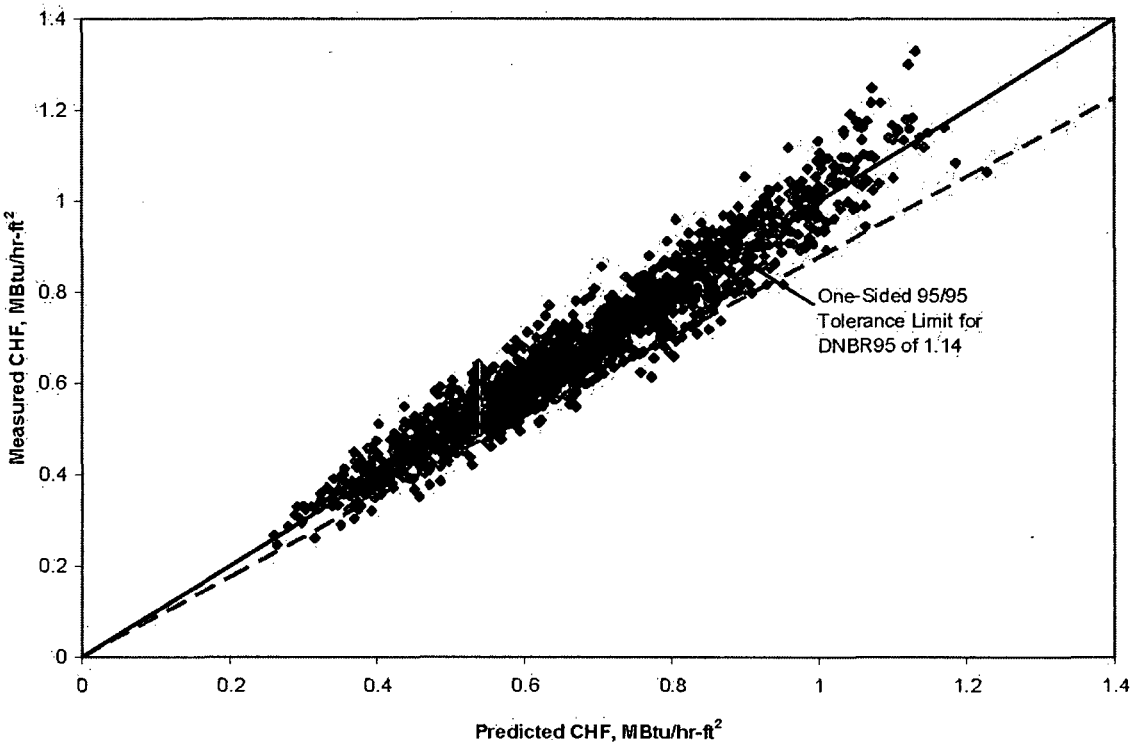

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Figure 4.2-2
Plot of M/P CHF Ratio vs. Pressure
WNG-1 Correlation

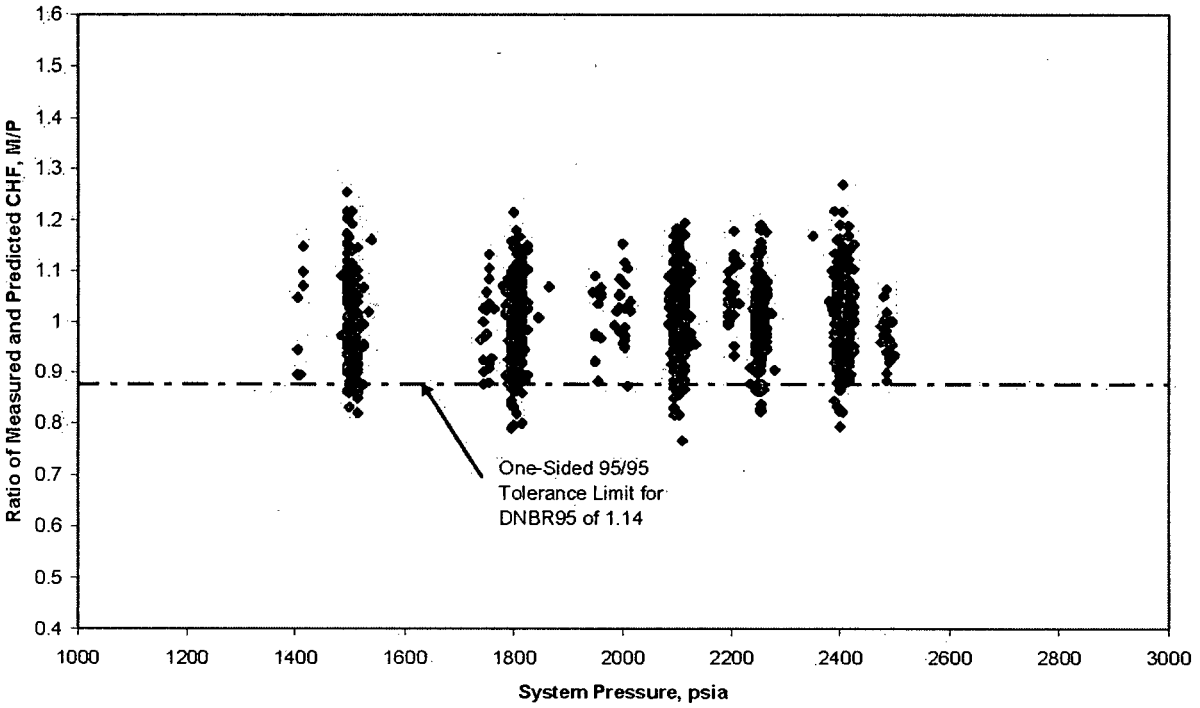

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Figure 4.2-3
Plot of M/P CHF Ratio vs. Local Mass Velocity
WNG-1 Correlation

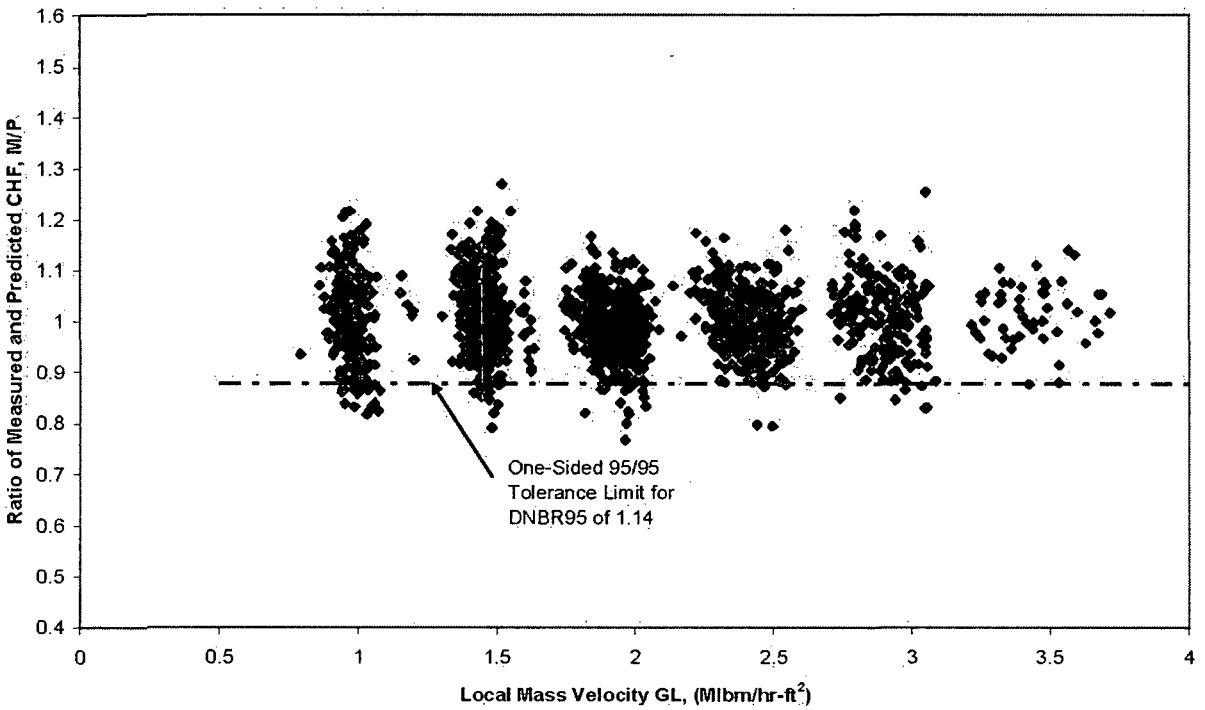

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Figure 4.2-4
Plot of M/P CHF Ratio vs. Local Quality
WNG-1 Correlation

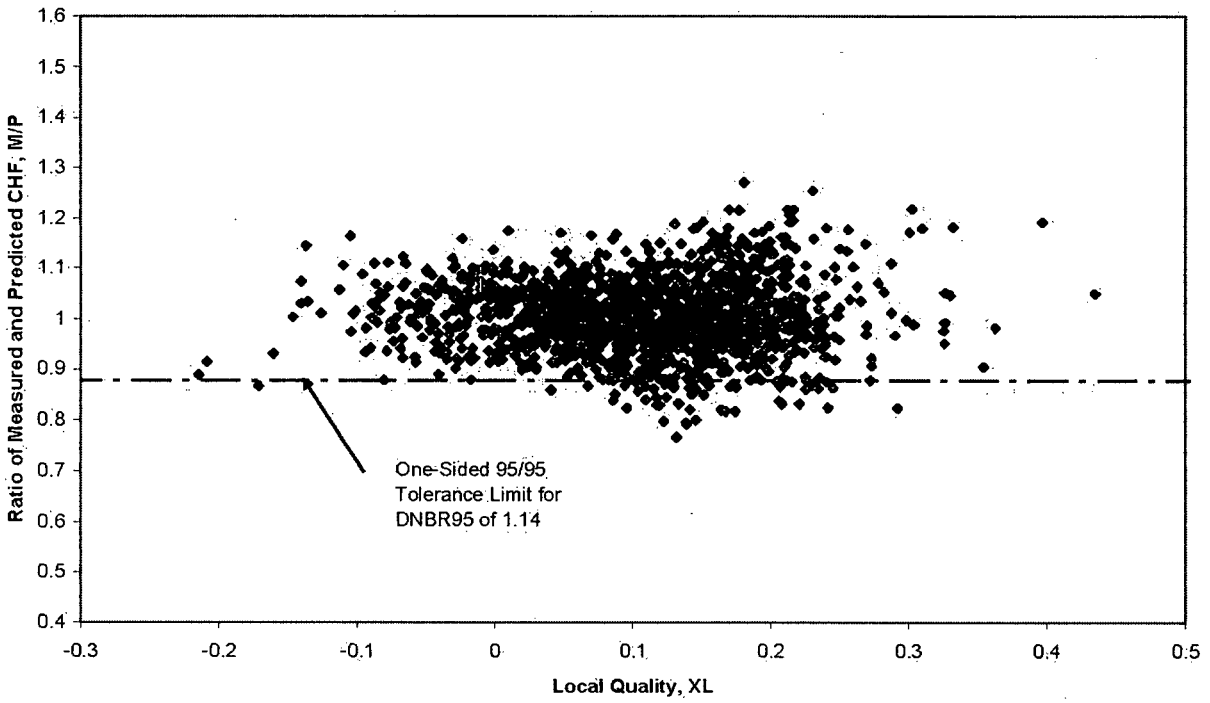

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Figure 4.2-5
Plot of M/P CHF Ratio vs. Matrix Heated Diameter, Dhm
WNG-1 Correlation

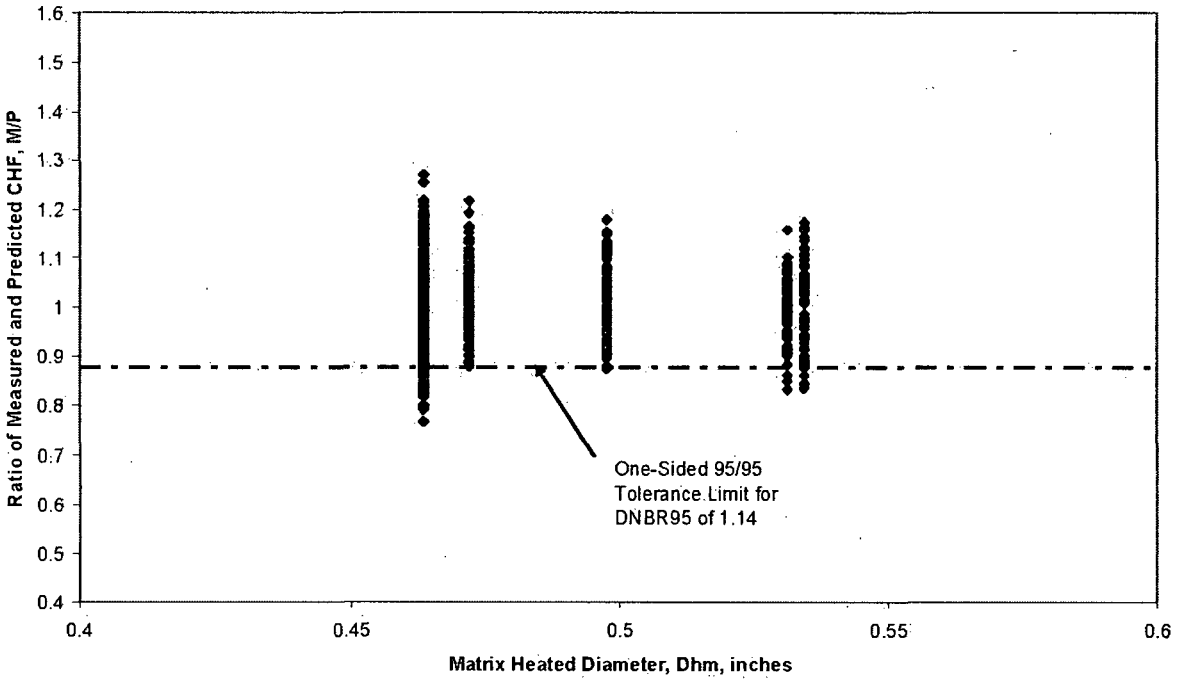

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Figure 4.2-6
Plot of M/P CHF Ratio vs. Heated Hydraulic Diameter, Dh
WNG-1 Correlation

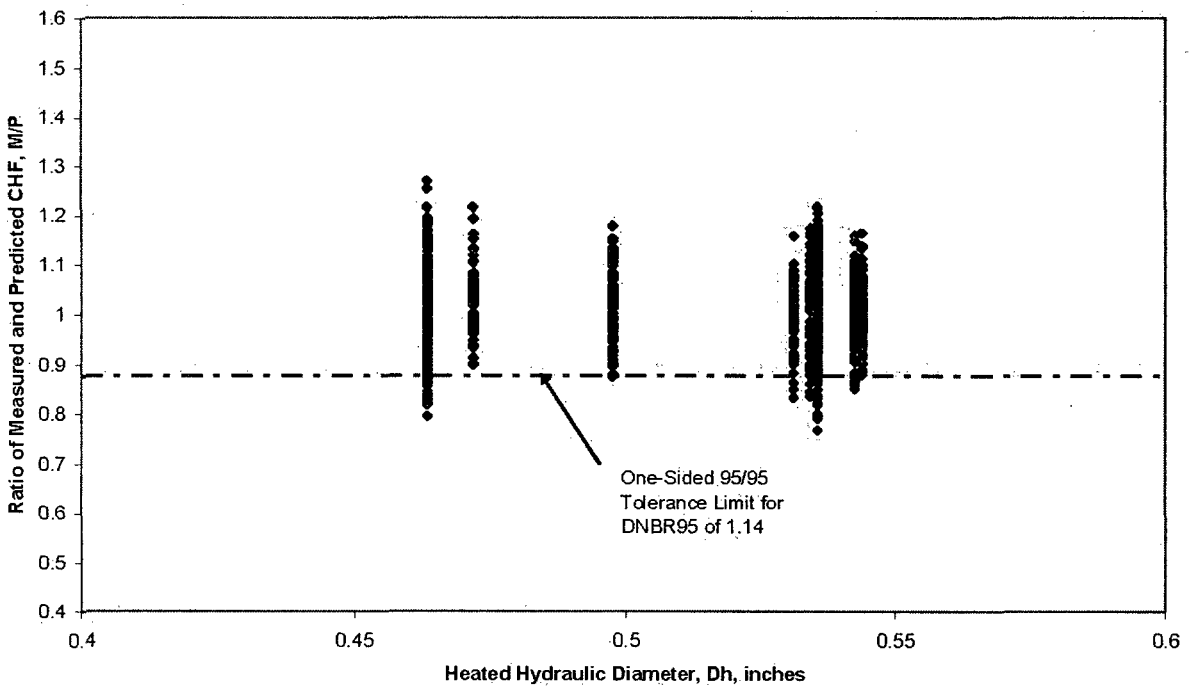

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Figure 4.2-7
Plot of M/P CHF Ratio vs. Grid Spacing Term, GST
WNG-1 Correlation

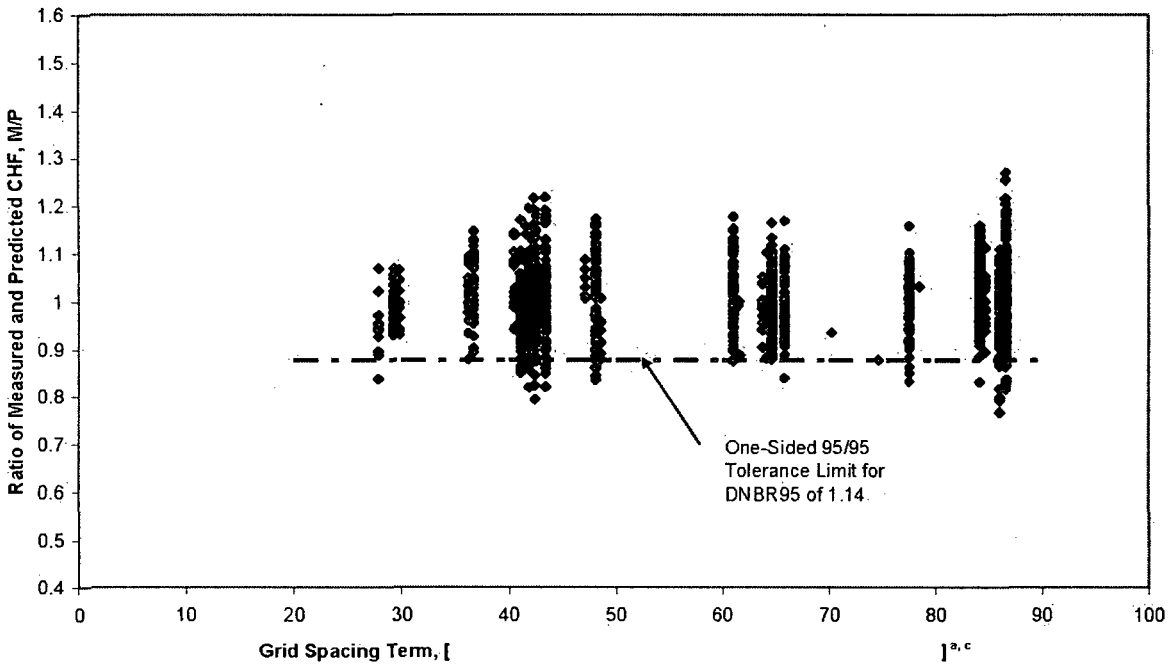

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Figure 4.2-8
Plot of M/P CHF Ratio vs. Heated Length, HL
WNG-1 Correlation

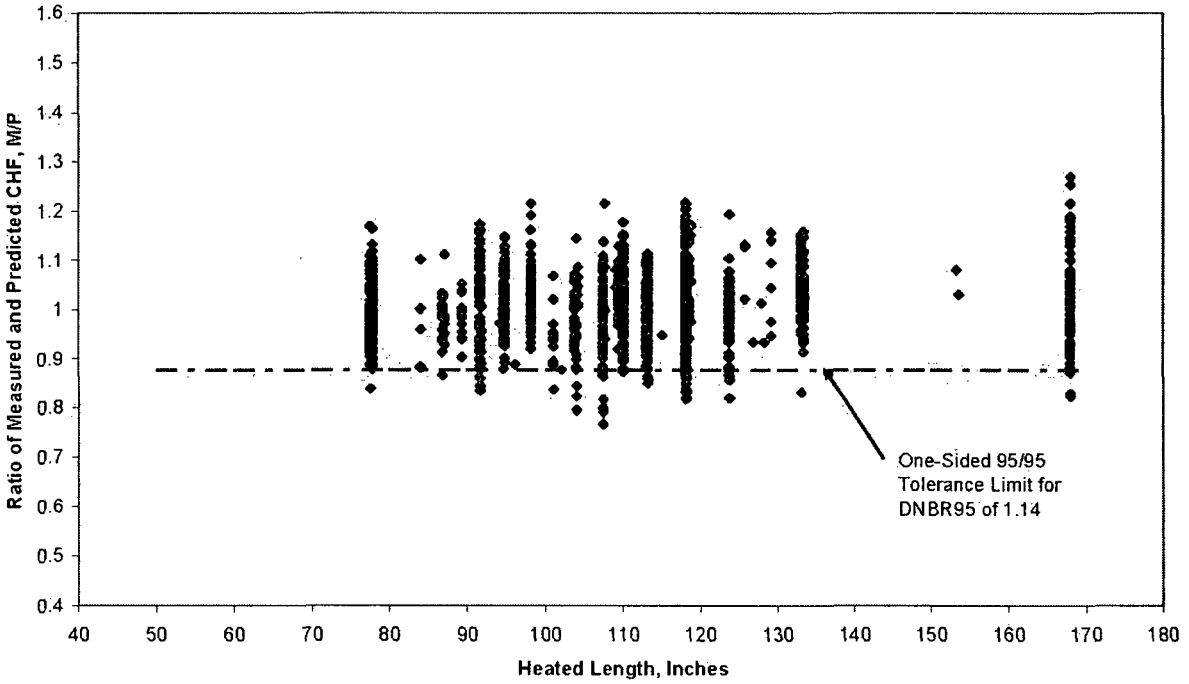

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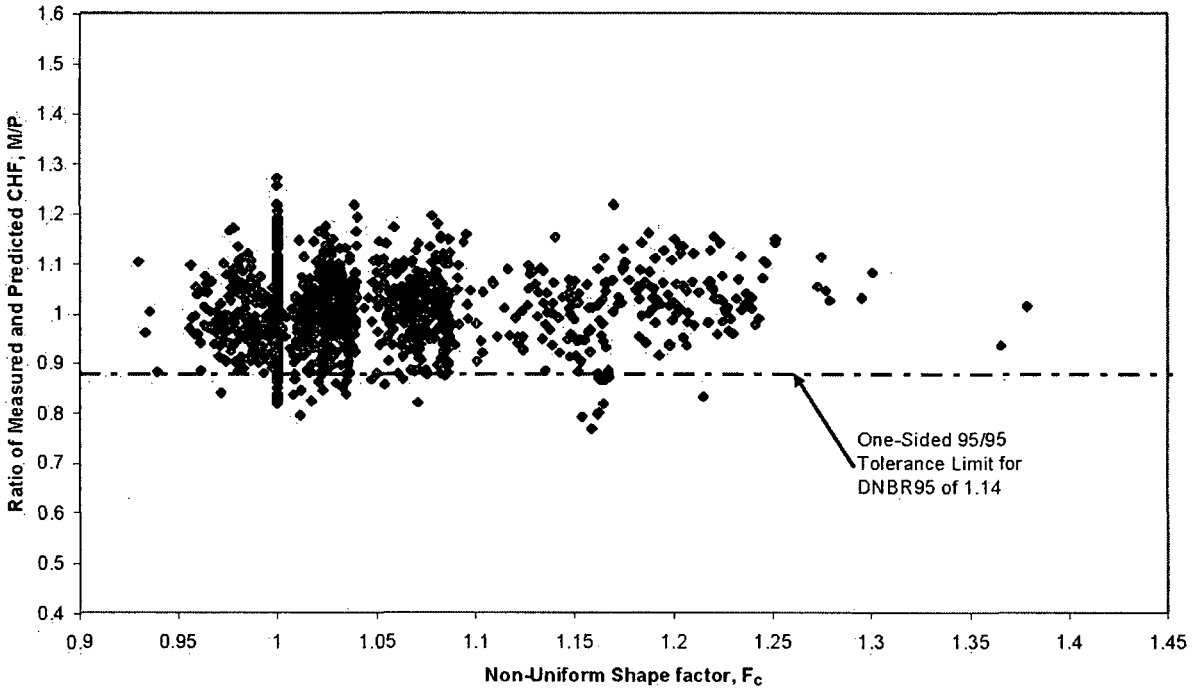
Figure 4.2-9
Plot of M/P CHF Ratio vs. Optimized Non-Uniform Shape Factor, F_C
WNG-1 Correlation



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5.0 Correlation Applications

Westinghouse intends to use the WNG-1 DNB correlation for evaluating DNB margin of the applicable Westinghouse fuel designs in plant licensing applications, in accordance with the CHF or DNB acceptance criterion defined in the Standard Review Plan (SRP), Reference 19. SRP Sections 4.2 and 4.4 state 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 DNB during normal operation or anticipated operational occurrence. 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 WNG-1 95/95 DNBR limit was presented in the previous section. The correlation will be used only with a subchannel code that has been either used for the correlation development or qualified with its 95/95 DNBR limit in compliance with the USNRC requirements, Reference 2. Technology transfer of the WNG-1 correlation will follow through a process that meets the requirements specified in Generic Letter (GL) 83.11 Supplement 1, "Qualification for Performing Safety Analyses."

The ***proposed*** 95/95 DNBR limit of the WNG-1 correlation with Westinghouse version of the VIPRE-01 (VIPRE) code is 1.14. ***The final NRC-approved 95/95 DNBR limit is 1.15.*** The range of applicability for the WNG-1 correlation, based on its database, is summarized in Table 5-1. The WNG-1 correlation is applicable to fuel designs which are within the geometry ranges included in the correlation database. The correlation database includes the following Westinghouse fuel designs: Refer to final SE]

- 16x16 NGF design with 0.360 inch diameter fuel rods
- 17x17 NGF design with 0.374 inch diameter fuel rods
- 17x17 RFA/RFA-2 designs with 0.374 inch diameter fuel rods
- 15x15 Upgrade fuel design with 0.422 inch diameter fuel rods

The correlation application with VIPRE will be in full compliance with the conditions of the Safety Evaluation Report (SER) on the VIPRE code and modeling, Reference 2. A [

] [a, c]. Additional qualification and code modification will be needed if the WNG-1 correlation is used with a subchannel code other than VIPRE.

The WNG-1 correlation implementation into reactor design applications is similar to previous implementations of other DNB correlations such as WRB-2M and ABB-NV. WNG-1 has been installed into the VIPRE code in accordance with the procedures delineated from the Westinghouse Quality Management System (QMS) (Reference 26). The WNG-1 correlation does not supersede any existing correlations, Reference 3, 6 or 7, applied for the current fuel designs.

The WNG-1 correlation will be used in DNBR calculations for core thermal limits and reactor trip setpoints and non-LOCA accident analyses. Implementation of the WNG-1 correlation will not result in any adverse impact on Westinghouse USNRC-approved methodology or licensing bases associated with the NGF or other fuel designs. The USNRC-approved methodology includes the Revised Thermal Design Procedure (RTDP) (Reference 20), the transition core evaluation method (Reference 21), the

reload evaluation method (Reference 22), the fuel reconstitution evaluation method (Reference 23), three-dimensional (3D) rod ejection analysis (Reference 24) and RAVE (Reference 25). 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 correlation.

Table 5-1
Applicable Range of WNG-1 CHF Correlation

Parameter	Applicable Range	
Pressure (psia)	**1405 to 2495**	
Local Coolant Quality	**≤ 0.43**	
Local Mass velocity (Mlbm/hr-ft^2)	**0.79 to 3.72**	
Matrix Heated Hydraulic Diameter, Dhm (inches)	**0.46 to *0.50***	Refer to final SER
Heated Hydraulic Diameter Ratio, [ ][a, c]	**0.85 to 1.00**	
Heated Length, HL (inches)	**48* to 168**	
Grid spacing (inches)	**6.4 to 26.0**	
Grid Spacing Term, GST [ ][a.c]	**≥ 26.5****	

*** Set as minimum HL value, applied at all elevations below 48 inches**
**** If Grid is in next node and GST < 26.5, set GST to 26.5**

6.0 Conclusions

The following conclusions and restrictions apply for the WNG-1 CHF correlation ***consistent with the conditions in the final SER***: Refer to final SEI

1. Analysis of the WNG-1 correlation and the source and validation data indicates the correlations accurately reflect the test results of the NGF designs (17x17 NGF, 16x16 NGF) as well as Westinghouse current designs in its database, including 17x17 RFA/RFA-2 ***but excluding*** 15x15 Upgrade. Refer to final SEI

2. Analysis of the WNG-1 correlation and validation data indicates that a minimum DNBR limit of 1.14 for the WNG-1 correlation will provide a 95% probability with 95% confidence of not experiencing CHF on a rod showing the limiting value. ***The final NRC-approved 95/95 DNBR limit for the WNG-1 correlation is 1.15.*** Refer to final SEI

3. Statistical tests support the evaluation of the 95/95 DNBR limit of the WNG-1 correlation.

4. The WNG-1 correlation must be used in conjunction with Westinghouse version of the VIPRE-01 code (VIPRE) since the correlation was developed based on VIPRE calculated local fluid conditions.

5. The WNG-1 correlation must also be used with the Westinghouse optimized F_C shape factor for split vane designs to correct for non-uniform axial power shapes.

The range of applicability for the WNG-1 correlations is provided in Table 5-1.

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7.0 References

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

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20. WCAP-11397-P-A, "Revised Thermal Design Procedure," April 1989.

21. WCAP-11837-P-A, "Extension of Methodology for Calculating Transition Core DNBR Penalties," January 1990.

22. WCAP-9272-P-A, "Westinghouse Reload Safety Evaluation Methodology," July 1985.

23. WCAP-13060-P-A, "Westinghouse Fuel Reconstitution Evaluation Methodology," January 1993.

24. WCAP-15806-P-A, "Westinghouse Control Rod Ejection Accident Analysis Methodology Using Multi-Dimensional Kinetics," October 2003.

25. WCAP-16259-P-A, "Westinghouse Methodology for Application of 3-D Transient Neutronics to Non-LOCA Accident Analysis," August 2006.

26. "Westinghouse Electric Company Quality Management System (QMS)," Revision 5, 2002.

Appendix A
WNG-1 VIPRE Database

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Appendix A: WNG-1 VIPRE Database

A detailed summary of the WNG-1 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. Repeat runs in the correlation database and runs with only cold rods indicating DNB, identified in bold italics, were eliminated in the final correlation database along with points outside the correlation parameter limits. Nomenclature for heading abbreviations in Appendix A 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, NM is Non-Uniform Shape without Guide Thimble , and 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 (fraction)
CHFm = Measured CHF (MBtu/hr-ft^2)
F_C = Non-uniform Shape Factor = 1.00 for Uniform Axial Power Shape
Based on Optimized F_C 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
WNG-1 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)
WNG-1 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)
WNG-1 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)
WNG-1 Correlation Database

a, b, c

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

Refer to LTR-NRC-08-48

Table A-1 (Continued)
WNG-1 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)
WNG-1 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)
WNG-1 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)
WNG-1 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)
WNG-1 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)
WNG-1 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)
WNG-1 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)
WNG-1 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)
WNG-1 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)
WNG-1 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)
WNG-1 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)
WNG-1 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)
WNG-1 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)
WNG-1 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)
WNG-1 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)
WNG-1 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)
WNG-1 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)
WNG-1 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)
WNG-1 Correlation Database

a, b, c

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

Refer to LTR-NRC-08-48

Table A-1 (Continued)
WNG-1 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)
WNG-1 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)
WNG-1 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)
WNG-1 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)
WNG-1 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)
WNG-1 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)
WNG-1 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)
WNG-1 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)
WNG-1 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)
WNG-1 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)
WNG-1 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)
WNG-1 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)
WNG-1 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)
WNG-1 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)
WNG-1 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)
WNG-1 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)
WNG-1 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)
WNG-1 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
WNG-1 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)
WNG-1 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)
WNG-1 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)
WNG-1 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)
WNG-1 Validation Database

a, b, c

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

Refer to LTR-NRC-08-48

Table A-2 (Continued)
WNG-1 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)
WNG-1 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)
WNG-1 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)
WNG-1 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)
WNG-1 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)
WNG-1 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)
WNG-1 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)
WNG-1 Validation Database

a, b, c

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

Appendix B
WNG-1 VIPRE Statistical Output

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Appendix B: WNG-1 VIPRE Statistical Output

A detailed summary of the statistical output of the WNG-1 correlation database is given in Table B-1. A detailed summary of the statistical output of the WNG-1 validation database is given in Table B-2. For each test run in Tables B-1 and B-2, the values for the correlation variables, the measured CHF and WNG-1 predicted CHF 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 Tables B-1 and B-2. The individual test section and overall database statistics are given at the end of the output in Tables B-1 and B-2. The individual test and final combined database statistics are given in Table B-3 for the database used to determine the 95/95 DNBR limit. The database consisted of the correlation database and validation tests for current grids that increased the correlation parameter range. The statistics for the subsets based on test, rod and strap geometries are also given in Table B-3. Nomenclature for heading abbreviations in Appendix B is defined below:

TS = Test Section Number
TD = Test Section Type (UM is Uniform Shape without Guide Thimble, UT is Uniform Shape with Guide Thimble, NM IS Non-Uniform Shape without 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 (fraction)
F_C = Non-uniform Shape Factor = 1.00 for Uniform Axial Power Shape Based on optimized F_C for Non-uniform Axial Power Shape
GS = Upstream Nominal Grid Spacing, [ ] [a, c]
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 = WNG-1 Predicted CHF divided by F_C (MBtu/hr-ft^2)

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Table B-1
Statistical Output of WNG-1 Correlation 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 WNG-1 Correlation Database

a, b, c

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

Refer to LTR-NRC-08-48

Table B-1 (Continued)
Statistical Output of WNG-1 Correlation 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 WNG-1 Correlation 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 WNG-1 Correlation 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 WNG-1 Correlation 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 WNG-1 Correlation 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 WNG-1 Correlation 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 WNG-1 Correlation 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 WNG-1 Correlation 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 WNG-1 Correlation 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 WNG-1 Correlation 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 WNG-1 Correlation Database

a, b, c

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

Refer to LTR-NRC-08-48

Table B-1 (Continued)
Statistical Output of WNG-1 Correlation 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 WNG-1 Correlation Database

a, b, c

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

Refer to LTR-NRC-08-48

Table B-1 (Continued)
Statistical Output of WNG-1 Correlation Database

a, b, c

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

Refer to LTR-NRC-08-48

Table B-1 (Continued)
Statistical Output of WNG-1 Correlation 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 WNG-1 Correlation 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 WNG-1 Correlation 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 WNG-1 Correlation 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 WNG-1 Correlation 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 WNG-1 Correlation 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 WNG-1 Correlation 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 WNG-1 Correlation 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 WNG-1 Correlation 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 WNG-1 Correlation 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 WNG-1 Correlation 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 WNG-1 Correlation 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 WNG-1 Correlation 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 WNG-1 Correlation 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 WNG-1 Correlation 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 WNG-1 Correlation Database

Correlation Data

a, b, c

Table B-2
Statistical Output of WNG-1 Validation 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-2 (Continued)
Statistical Output of WNG-1 Validation 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-2 (Continued)
Statistical Output of WNG-1 Validation 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-2 (Continued)
Statistical Output of WNG-1 Validation 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-2 (Continued)
Statistical Output of WNG-1 Validation 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-2 (Continued)
Statistical Output of WNG-1 Validation Database

a, b, c

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

Refer to LTR-NRC-08-48

Table B-2 (Continued)
Statistical Output of WNG-1 Validation 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-2 (Continued)
Statistical Output of WNG-1 Validation 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-2 Continued
Statistical Output of WNG-1 Validation Database

a, b, c

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

Refer to LTR-NRC-08-48

Table B-2 (Continued)
Statistical Output of WNG-1 Validation Database

Validataion Data

[ ] a, b, c

Table B-3
Statistical Output of WNG-1 Combined Database for DNBR95 Limit

Combined Data

a, b, c

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Appendix C
WNG-1 CHF Test Geometries

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Appendix C: WNG-1 CHF Test Geometries

The test section radial and axial geometries for the tests used in the development and validation of the WNG-1 correlation are shown in Figures C-1 through C-37. The axial relative power input into the VIPRE code for the non-uniform tests in the correlation database is shown in Table C-1. The axial relative power input into the VIPRE code for the non-uniform tests in the validation database is shown in Table C-2.

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Table C-1
VIPRE Axial Power Distribution Input for Correlation Tests

a, b, c

[ ]

Table C-2
VIPRE Axial Power Distribution Inputs for Correlation Tests

a, b, c

[ ]

Figure C-1
RADIAL GEOMETRY – CHF TEST SECTION 82

a, b, c

[ ]

Figure C-2
AXIAL GEOMETRY – CHF TEST SECTIONS 82 , 83 and 94

a, b, c

[ ]

Figure C-3
RADIAL GEOMETRY – CHF TEST SECTION 94

a, b, c

[ ]

Figure C-4
RADIAL GEOMETRY – CHF TEST SECTION 85-1
First 82 CHF Points

a, b, c

[ ]

Figure C-5
RADIAL GEOMETRY – CHF TEST SECTION 85-2
Last 24 CHF Points

a, b, c

[ ]

Figure C-6
AXIAL GEOMETRY – CHF TEST SECTION 85

a, b, c

[ ]

Figure C-7
RADIAL GEOMETRY – CHF TEST SECTION 87

a, b, c

[ ]

Figure C-8
AXIAL GEOMETRY – CHF TEST SECTION 87

a, b, c

[ ]

Figure C-9
RADIAL GEOMETRY – CHF TEST SECTION 89

a, b, c

[ ]

Figure C-10
AXIAL GEOMETRY – CHF TEST SECTION 89

a, b, c

[ ]

Figure C-11
RADIAL GEOMETRY – CHF TEST SECTION 104

a, b, c

[ ]

Figure C-12
AXIAL GEOMETRY – CHF TEST SECTIONS 104 and 105

a, b, c

[ ]

Figure C-13
RADIAL GEOMETRY – CHF TEST SECTION 105

a, b, c

[ ]

Figure C-14
RADIAL GEOMETRY – CHF TEST SECTION 90

a, b, c

[ ]

Figure C-15
AXIAL GEOMETRY – CHF TEST SECTION 90

a, b, c

[ ]

Figure C-16
RADIAL GEOMETRY – CHF TEST SECTION 96

a, b, c

[ ]

Figure C-17
AXIAL GEOMETRY – CHF TEST SECTIONS 96, 97 and 103

a, b, c

[ ]

Figure C-18
RADIAL GEOMETRY – CHF TEST SECTION 97

a, b, c

[ ]

Figure C-19
RADIAL GEOMETRY – CHF TEST SECTION 98

a, b, c

[ ]

Figure C-20
AXIAL GEOMETRY – CHF TEST SECTIONS 98 and 99

a, b, c

[ ]

Figure C-21
RADIAL GEOMETRY – CHF TEST SECTION 99

a, b, c

[ ]

Figure C-22
RADIAL GEOMETRY – CHF TEST SECTION 95

a, b, c

[ ]

Figure C-23
AXIAL GEOMETRY – CHF TEST SECTION 95

a, b, c

[ ]

Figure C-24
RADIAL GEOMETRY – CHF TEST SECTION 107

a, b, c

[ ]

Figure C-25
AXIAL GEOMETRY – CHF TEST SECTION 107

a, b, c

[ ]

Figure C-26
RADIAL GEOMETRY – CHF TEST SECTION 108

a, b, c

[ ]

Figure C-27
AXIAL GEOMETRY – CHF TEST SECTIONS 108 and 109

a, b, c

[ ]

Figure C-28
RADIAL GEOMETRY – CHF TEST SECTION 109

a, b, c

[ ]

Figure C-29
RADIAL GEOMETRY – CHF TEST SECTION 110

a, b, c

[ ]

Figure C-30
AXIAL GEOMETRY – CHF TEST SECTION 110

a, b, c

[ ]

Figure C-31
RADIAL GEOMETRY – CHF TEST SECTION 112

a, b, c

[ ]

Figure C-32
AXIAL GEOMETRY – CHF TEST SECTIONS 112 and 113

a, b, c

[ ]

Figure C-33
RADIAL GEOMETRY – CHF TEST SECTION 113

a, b, c

[ ]

Figure C-34
RADIAL GEOMETRY – CHF TEST SECTION 83

a, b, c

[ ]

Figure C-35
RADIAL GEOMETRY – CHF TEST SECTION 100

a, b, c

[ ]

Figure C-36
AXIAL GEOMETRY – CHF TEST SECTION 100

a, b, c

[ ]

Figure C-37
RADIAL GEOMETRY – CHF TEST SECTION 102

a, b, c

[ ]

Figure C-38
AXIAL GEOMETRY – CHF TEST SECTION 102

a, b, c

[ ]

Figure C-39
RADIAL GEOMETRY – CHF TEST SECTION 103

a, b, c

[ ]

Figure C-40
RADIAL GEOMETRY – CHF TEST SECTION EPRI 132

a, b, c

[ ]

Figure C-41
AXIAL GEOMETRY – CHF TEST SECTION EPRI 132

a, b, c

[ ]

Figure C-42
RADIAL GEOMETRY – CHF TEST SECTION EPRI 158

a, b, c

[ ]

Figure C-43
AXIAL GEOMETRY – CHF TEST SECTIONS EPRI 158

a, b, c

[ ]

Figure C-44
RADIAL GEOMETRY – CHF TEST SECTION EPRI 160

a, b, c

[ ]

Figure C-45
AXIAL GEOMETRY – CHF TEST SECTION EPRI 160

a, b, c

[ ]

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Section C

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Our ref: LTR-NRC-07-66
January 16, 2008

Subject: Response to NRC's Request for an Electronic Copy of Appendix A, "WNG-1 VIPRE Database," and Appendix B, "WNG-1 VIPRE Statistical Output," of Topical Report (TR) WCAP-16766-P, "Westinghouse Next Generation Correlation (WNG-1) for Predicting Critical Heat Flux in Rod Bundles with Split Vane Mixing Grids" (Proprietary)

Enclosed is one compact disk containing the Proprietary response to the NRC's Request for an Electronic Copy of Appendix A, "WNG-1 VIPRE Database," and Appendix B, "WNG-1 VIPRE Statistical Output," of Topical Report (TR) WCAP-16766-P, "Westinghouse Next Generation Correlation (WNG-1) for Predicting Critical Heat Flux in Rod Bundles with Split Vane Mixing Grids."

Also enclosed is:

1. One (1) copy of the Application for Withholding, AW-08-2368 (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.

The compact disk being submitted with this letter is submitted for use by the NRC solely in connection with NRC review of Westinghouse proprietary WCAP-16766-P. The NRC may not use the compact disk for any other purpose, and may not make copies of this disk. The information on the compact disk may not be made available in the Public Document Room ("PDR") or in the Agency Document Access and Management Systems ("ADAMS"), either externally or internally. Upon completion of NRC review of WCAP-16766-P, proprietary information from, or derived from, the compact disk should be irretrievably deleted from any computer outside the control of Westinghouse.

Correspondence with respect to the affidavit or Application for Withholding should reference AW-08-2368 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

Enclosures
cc: J. Thompson, NRR

Westinghouse

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Our ref: AW-08-2368
January 16, 2008

APPLICATION FOR WITHHOLDING PROPRIETARY
INFORMATION FROM PUBLIC DISCLOSURE

Subject: Response to NRC's Request for an Electronic Copy of Appendix A, "WNG-1 VIPRE Database," and Appendix B, "WNG-1 VIPRE Statistical Output," of Topical Report (TR) WCAP-16766-P, "Westinghouse Next Generation Correlation (WNG-1) for Predicting Critical Heat Flux in Rod Bundles with Split Vane Mixing Grids" (Proprietary)

Reference: Letter from J. A. Gresham to Document Control Desk, LTR-NRC-07-66, dated January 16, 2008

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-08-2368 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-08-2368 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

Cc: A. Mendiola, NRR
J. Thompson, NRR

AW-08-2368

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 17th day
of January, 2008.

Sharon L Markle
Notary Public

COMMONWEALTH OF PENNSYLVANIA
Notarial Seal
Sharon L. Markle, Notary Public
Monroeville Boro, Allegheny County
My Commission Expires Jan. 29, 2011
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 Appendix A, "WNG-1 VIPRE Database," and Appendix B, "WNG-1 VIPRE Statistical Output," of Topical Report (TR) WCAP-16766-P, "Westinghouse Next Generation Correlation (WNG-1) for Predicting Critical Heat Flux in Rod Bundles with Split Vane Mixing Grids" (Proprietary), for submittal to the Commission, being transmitted by Westinghouse letter (LTR-NRC-07-66) and Application for Withholding Proprietary Information from Public Disclosure, to the Document Control Desk. The proprietary information as submitted by Westinghouse Electric Company is a response to the NRC's Request for Electronic Copies.

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

(a) Obtain generic NRC licensed approval for the Westinghouse Next Generation Correlation (WNG-1) for Predicting Critical Heat Flux in Rod Bundles with Split Vane Mixing Grids for Westinghouse fuel designs.

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

Further this information has substantial commercial value as follows:

(a) Westinghouse can use this 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 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

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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The reports transmitted herewith each bear a Westinghouse copyright notice. The NRC is permitted to make the number of copies of the information contained in these reports which are necessary for its internal use in connection with generic and plant-specific reviews and approvals as well as the issuance, denial, amendment, transfer, renewal, modification, suspension, revocation, or violation of a license, permit, order, or regulation subject to the requirements of 10 CFR 2.390 regarding restrictions on public disclosure to the extent such information has been identified as proprietary by Westinghouse, copyright protection notwithstanding. With respect to the non-proprietary versions of these reports, the NRC is permitted to make the number of copies beyond those necessary for its internal use which are necessary in order to have one copy available for public viewing in the appropriate docket files in the public document room in Washington, DC and in local public document rooms as may be required by NRC regulations if the number of copies submitted is insufficient for this purpose. Copies made by the NRC must include the copyright notice in all instances and the proprietary notice if the original was identified as proprietary.

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Section D

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Westinghouse

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Our ref: LTR-NRC-08-37
July 25, 2008

Subject: Response to NRC's Request for Additional Information by the Office of Nuclear Reactor Regulation for Topical Report (TR) WCAP-16766-P, "Westinghouse Next Generation Correlation (WNG-1) for Predicting Critical Heat Flux in Rod Bundles with Split Van Mixing Grids" (TAC No. MD7230) (Proprietary/Non-Proprietary)

Enclosed are copies of the Proprietary and Non-Proprietary responses to NRC's Request for Additional Information by the Office of Nuclear Reactor Regulation for Topical Report (TR) WCAP-16766-P, "Westinghouse Next Generation Correlation (WNG-1) for Predicting Critical Heat Flux in Rod Bundles with Split Van Mixing Grids" (TAC No. MD7230) (Proprietary/Non-Proprietary).

Also enclosed is:

1. One (1) copy of the Application for Withholding, AW-08-2462 (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 the affidavit or Application for Withholding should reference AW-08-2462 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,

M. J. Brady /FOR

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

Enclosures
cc: A. Mendiola, NRR
G. Bacuta, NRR

Westinghouse

Westinghouse Electric Company
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U.S. Nuclear Regulatory Commission
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Direct tel: 412/374-4643
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e-mail: rodackt@westinghouse.com

Our ref: AW-08-2462
July 25, 2008

APPLICATION FOR WITHHOLDING PROPRIETARY
INFORMATION FROM PUBLIC DISCLOSURE

Subject: LTR-NRC-08-37 P-Enclosure, "Response to NRC's Request for Additional Information by the Office of Nuclear Reactor Regulation for Topical Report (TR) WCAP-16766-P, 'Westinghouse Next Generation Correlation (WNG-1) for Predicting Critical Heat Flux in Rod Bundles with Split Van Mixing Grids'" (TAC No. MD7230) (Proprietary)

Reference: Letter from J. A. Gresham to Document Control Desk, LTR-NRC-08-37, dated July 25, 2008.

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-08-2462 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-08-2462 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,

Thomas Rodack

T. Rodack, Director
Quality and Licensing Programs

Cc: A. Mendiola, NRR
J. Thompson, NRR

AW-08-2462

AFFIDAVIT

COMMONWEALTH OF PENNSYLVANIA:

ss

COUNTY OF ALLEGHENY:

Before me, the undersigned authority, personally appeared T. Rodack, 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:

Thomas Rodack

T. Rodack, Director
Quality and Licensing Programs

Sworn to and subscribed
before me this 25th day
of July, 2008.

Margaret L Gonano

Notary Public

COMMONWEALTH OF PENNSYLVANIA
Notarial Seal
Margaret L. Gonano, Notary Public
Monroeville Boro, Allegheny County
My Commission Expires Jan. 3, 2010
Member, Pennsylvania Association of Notaries

(1) I am Director, Quality and Licensing Programs, in Nuclear Fuel, 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.

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(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.

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

(a) Obtain generic NRC licensed approval for the Westinghouse Next Generation Correlation (WNG-1) for Predicting Critical Heat Flux in Rod Bundles with Split Vane Mixing Grids for Westinghouse fuel designs.
(b) Assist customers in improving their fuel performance (zero defects).

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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.

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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.

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Response to NRC's Request for Additional Information by the Office of Nuclear Reactor Regulation for Topical Report (TR) WCAP-16766-P, "Westinghouse Next Generation Correlation (WNG-1) for Predicting Critical Heat Flux in Rod Bundles with Split Van Mixing Grids" (TAC No. MD7230) (Non-Proprietary)

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

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REQUEST FOR ADDITIONAL INFORMATION
ON WCAP-16766-P

1. *Define Dh, Dhm.*

Response:
Dhm is the heated hydraulic diameter in a matrix channel (i.e., typical cell), a square channel with 4 heated rods in the corners. Dh is the heated hydraulic diameter for the channel of interest. It could be a thimble channel with heated rods in three corners or a matrix channel for the applicable designs. Therefore, for the fuel geometries of interest, the heated hydraulic diameter ratio [ ]^{a,c} ranges from 0.85 to 1.0.

2. *To which specific fuel designs does the WNG-1 correlation apply?*

Response:
As discussed in Section 5.0 of the topical report WCAP-16766-P, the WNG-1 correlation is applicable to Westinghouse NSSS PWR fuel designs which are within the geometry ranges included in the correlation database and have similar grid design features. The correlation database includes test data simulating the following the PWR fuel designs:

- 16x16 NGF design with 0.360 inch diameter fuel rods,
- 17x17 NGF design with 0.374 inch diameter fuel rods,
- 17x17 RFA/RFA-2 designs with 0.374 inch diameter fuel rods,
- 15x15 Upgrade fuel design with 0.422 inch diameter fuel rods.

Therefore, the WNG-1 correlation is applicable to the above fuel designs.

3. *Describe the process for applying the WNG-1 correlation to a new fuel design (i.e., a design which the WNG-1 correlation was not previously applied to).*

Response:
The Fuel Criteria Evaluation Process (FCEP) (Reference 3-1) established criteria and a process for confirming the applicability of CHF correlations to modified fuel designs. FCEP would be applied to evaluate applicability of the WNG-1 correlation to a modified fuel design that is not in the current WNG-1 correlation database. If the correlation were determined to be applicable, an FCEP notification letter would be sent to the NRC. If it were demonstrated that FCEP does not apply, then a topical report on qualification of the existing correlation or development of a new CHF correlation for the fuel design would be submitted to the NRC for review and approval.

Reference:
3-1) Davidson, S.L., et al., "Westinghouse Fuel Criteria Evaluation Process," WCAP-12488-A (Proprietary)/WCAP-14204-A (Non-Proprietary), October 1994.

4. *For each specific fuel design (as identified in RAI question 2), are there any anticipated changes in grid spacer location with reference to the tested assembly for that fuel design? If yes, provide a reasoning why the change in grid spacer location is a minor change and does not constitute a new fuel design.*

Response:
There is no change in grid spacer location anticipated for the fuel designs currently in the WNG-1 database. Minor adjustment to grid elevations may be made to fuel assemblies in mixed cores to ensure grid-to-grid overlap among different fuel designs. However, grid spacing will be maintained to be similar to the test configurations, since CHF is sensitive to grid spacing. The correlation application to each fuel design will be within the range of the grid spacing specified in WCAP-16766-P.

5. *Provide justification for the use of the correlation at qualities [ ].*

Response:
The [ ]^{a,c} at the predicted Minimum DNBR locations in the correlation database cover a wide range of pressure and flow conditions; the M/P value for this range is conservative relative to the remainder of the correlation and shows a slight conservative trend (Figure 1). [ ]^{a,c} are at the measured elevation. Additionally, there are [ ]^{a,c} where the local quality at the measured DNB elevations ranged from [ ]^{a,c} to [ ]^{a,c} and there are over [ ]^{a,c} where the local quality at the thermocouple locations ranged between [ ]^{a,c} to [ ]^{a,c}. All these conditions were included in the VIPRE evaluations with the WNG-1 correlation for these tests. The WNG-1 predictions at the measured elevations show the conservative trend for the data [ ]^{a,c} (Figure 2). It is noted that the highest quality points are from separate tests and cover pressures from 1400 to 2400 psi and flows from 1 to 3 Mlbm/ht-ft^2. There is no abnormality in the M/P value for the measured elevation locations with qualities [ ]^{a,c} in comparison to the entire measured elevation database. The data for the RFA/RFA-2 fuel designs are shown with a different symbol than the NGF fuel design to demonstrate that the performance, trends and quality range are the same for the 0.374 inch diameter rod fuel designs in the WNG-1 database. Since the correlation covers a wide range of flow and pressure conditions with a [ ]^{a,c} and the underlying database includes [ ]^{a,c} quality, the correlation quality range less than 43% defined in WCAP-16766-P is appropriate and justified.

Figure 1
WNG-1 Correlation M/P Ratio vs. Local Quality
At MDNBR Elevations

a,b,c

[ ]

Figure 2
WNG-1 Correlation M/P Ratio vs. Local Quality
At Test Measured Elevations [ ]a,c

a,b,c

[ ]

6. *Provide additional explanation related to the axial location of critical heat flux, namely the uncertainty surrounding the exact location, the effect of this uncertainty on the correlation, and the instrumentation used to capture the location.*

Response:
Adequate instrumentation was installed to detect the first signal of Critical Heat Flux (CHF) or DNB, since all the DNB test bundles in the WNG-1 database contain thermocouples at multiple axial locations as shown in Figures C-1 through C-45 of the topical report WCAP-16766-P. Depending on the axial power profiles, the thermocouples are positioned at the axial elevations of most-likely DNB occurrence, typically 1/2 inch below the leading edges of grid spacers for a non-uniform axial power shape, or at the end of heated length (EOHL) for uniform axial power test. It is noted that [

]^{a,c} the measured elevation was at EOHL for all points for these tests. In addition, as part of the testing procedure, a post-test inspection of the test bundle and test rods was always performed after each test to inspect condition of the rods and any burn marks on any test rod at the elevations without thermocouples installed. The burn marks would potentially be indicative of DNB occurrence. There have been no reports of burned areas or rod damage at any location away from the thermocouples for the tests included in the WNG-1 database.

7. *Reproduce Figures 4.2-2, 4.2-3, and 4.2-4 of WCAP-16766-P for each fuel design (identified in RAI question 2). Also provide a 95/95 for each fuel design.*

Response:
As indicated in the response to question 2, the four Westinghouse NSSS PWR fuel designs considered in the WNG-1 database are the 17x17 RFA/RFA-2 designs with a 0.374 inch diameter rod, the 17x17 NGF fuel design with a 0.374 inch diameter rod, the 16x16 NGF fuel design with a 0.360 inch diameter rod, and the 15x15 Upgrade fuel design with 0.422 inch diameter rod. The majority of the data in the WNG-1 database is for fuel designs with the 0.374 inch rod diameter. The WNG-1 database only includes the test bundles of fuel designs that showed similar CHF performances as indicated in the test results. The database does not include test bundles that simulated the 17x17 Optimized Fuel Assembly (OFA) with 0.360-inch diameter fuel rods (Reference 7-1), the 17x17 VANTAGE5 fuel with 0.360-inch diameter fuel rods (Reference 7-2), and the 17x17 VANTAGE5H fuel with 0.374-inch diameter fuel rods (Reference 7-3), because the CHF results from the simulating test bundles are different from those in the WNG-1 database.

For the fuel designs with the 0.374 inch fuel rod diameter in the WNG-1 database, there are two types of vane designs, shown in Figure 1-1 of WCAP-16766-P, that yielded similar CHF performances. The RFA/RFA-2 fuel designs have mixing vane type 2 and the NGF fuel design has mixing vane type 1. Prior to the correlation process, raw data from Columbia University were plotted for test sections with the two mixing vane types and it was concluded that the CHF data were essentially the same and therefore were combined into a single database. These data are separated for plots of WNG-1 correlation M/P vs. pressure, flow and quality to demonstrate the data are not only poolable, but also have no trends with the various fluid parameters. The data applicable to the RFA/RFA-2 mixing vane designs are taken from [ ]^{a,c}

[ ]a,c. The data applicable to the NGF mixing vane design are taken from [ ]a,c. [ ]a,c were added to the validation database to demonstrate the correlation robustness. Plots of M/P vs. pressure, flow and quality are shown in Figures 3, 4 and 5 for the 17x17 fuel designs, respectively. To best demonstrate that there are no relative trends, the data are provided on the same plot. The data for the 0.374 inch diameter fuel designs are poolable and the [ ]a,c.

The available data for the two additional rod diameters were added to expand the geometric range, as stated in Section 3.1 of WCAP-16766-P. The data for the NGF 16x16 design with 0.360 inch diameter rod are shown in Figures 6 through 8. There is a [ ]a,c for pressures below 1800 psi and no trend with flow or quality. The data from [ ]a,c for the 16x16 0.360 inch diameter rods are consistent and conservative relative to the data for the 0.374 inch diameter rods. The [ ]a,c. The data for the 0.422 inch diameter data applicable to the 15x15 Upgrade design are shown in Figures 9 through 11. [ ]a,c with 0.422 inch diameter rods was added to the validation database to demonstrate the correlation robustness. From Figures 9 through 11, there is a [ ]a,c and no trend with pressure or flow. The [ ]a,c of the subset.

a,c

Westinghouse NSSS PWR Fuel Designs	
16x16 NGF design with 0.360 inch diameter fuel rods	
17x17 NGF design with 0.374 inch diameter fuel rods	
17x17 RFA/RFA-2 design with 0.374 inch diameter fuel rods	
15x15 Upgrade fuel design with 0.422 inch diameter fuel rods	

All fuel designs listed in the table above have been tested over a large range of flow, pressures and qualities. The same statistical tests for poolability applied in References 7-4 – 7-6 have been applied and all of the data have been found to be poolable with the WNG-1 correlation. Therefore, the WNG-1 95/95 DNBR limit of 1.14 given in WCAP-16766-P is appropriate and valid for the fuel designs covered in the database.

References:

7-1) Davidson, S.L., et al., "Verification Testing and Analysis of the 17x17 Optimized Fuel Assembly," WCAP-9401-P-A (Proprietary)/WCAP-9402-A (Non-Proprietary), August 1981.

7-2) Davidson, S.L., et al., "Westinghouse Reference Core Report VANTAGE 5 Fuel Assembly," WCAP-10444-P-A (Proprietary)/WCAP-10445-NP-A (Non-Proprietary), September 1985.

7-3) Davidson, S.L., et al., "VANTAGE 5H Fuel Assembly," WCAP-10444-P-A Addendum 2-A (Proprietary)/WCAP-10444-A Addendum 2-A (Non-Proprietary), February 1989.

7-4) Joffre, P.F., "ABB Critical Heat Flux Correlations for PWR Fuel," CENPD-387-P-A Rev.00 (Proprietary)/CENPD-387-NP-A Rev.00 (Non-Proprietary), May 2000.

7-5) Joffre, P.F., et al., "Westinghouse Correlations WSSV and WSSV-T for Predicting Critical Heat Flux in Rod Bundles with Side-Supported Mixing Vanes," WCAP-16523-P-A (Proprietary)/WCAP-16523-NP-A (Non-Proprietary), September 2007.

7-6) Sung, Y.X., et al., "Extended Application of ABB-NV Correlation and Modified ABB-NV Correlation WLOP for PWR Low Pressure Applications," WCAP-14565-P-A Addendum 2-P-A (Proprietary)/ WCAP-15306-NP-A Addendum 2-NP-A (Non-Proprietary), April 2008.

Figure 3
WNG-1 M/P Ratio vs. Pressure
0.374 Inch Rod Data

a,b,c

Figure 4
WNG-1 M/P Ratio vs Mass Velocity
0.374 Inch Rod Data

a,b,c

Figure 5
WNG-1 M/P Ratio vs Quality
0.374 Inch Rod Data

a,b,c

Figure 6
WNG-1 M/P Ratio vs Pressure
0.360 Inch Rod Data

a,b,c

Figure 7
WNG-1 M/P Ratio vs Mass Velocity
0.360 Inch Rod Data

a,b,c

Figure 8
WNG-1 M/P Ratio vs Quality
0.360 Inch Rod Data

a,b,c

Figure 9
WNG-1 M/P Ratio vs Pressure
0.422 Inch Rod Data

a,b,c

Figure 10
WNG-1 M/P Ratio vs Mass Velocity
0.422 Inch Rod Data

a,b,c

Figure 11
WNG-1 M/P Ratio vs Quality
0.422 Inch Rod Data

a,b,c

[ ]

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Section E

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Our ref: LTR-NRC-08-48
October 1, 2008

Subject: Response to NRC's Second Request for an Electronic Copy of Appendix A, "WNG-1 VIPRE Database," and Appendix B, WNG-1 VIPRE Statistical Output," of Topical Report (TR) WCAP-16766-P, "Westinghouse Next Generation Correlation (WNG-1) for Predicting Critical Heat Flux in Rod Bundles with Split Vane Mixing Grids," (Proprietary)

The enclosed compact disk was previously transmitted to the NRC under LTR-NRC-07-66 and affidavit AW-08-2368. The previous transmittal letter and affidavit still cover providing the compact disk back to the NRC for a second time with the same limitations: (1.) Used by the NRC solely in connection with NRC review of Westinghouse proprietary WCAP-16766-P; (2.) No copies of the disk may be made; (3.) Information on the compact disk may not be made available in the Public Document Room ("PDR") or in the Agency Document Access and Management Systems ("ADAMS"), either externally or internally; (4.) Upon completion of NRC review of WCAP-16766-P, proprietary information from, or derived from, the compact disk should be irretrievably deleted from any computer outside the control of Westinghouse. As previously noted to the NRC staff when the compact disk was provided the first time, a few lines in the tables in Appendix A and Appendix B were noted to be missing in the hard copy of WCAP-16766-P (table pagination errors). It was agreed that Westinghouse would correct these tables in the final approved version of the topical report. The enclosed compact disk has the corrected data tables.

Correspondence with respect to the affidavit or Application for Withholding should reference AW-08-2368 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,

Thomas Rodack

T. Rodack, Director
Quality and Licensing Programs

Enclosures
cc: A. Mendiola, NRR
G. Bucuta, NRR
A. Attard, NRR
J. Keiser, NRR

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Section F

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Our ref: LTR-NRC-09-11
February 12, 2009

Subject: Further Clarifications on RAIs for Topical Report (TR) WCAP-16766-P, "Westinghouse Next Generation Correlation (WNG-1) for Predicting Critical Heat Flux in Rod Bundles with Split Vane Mixing Grids," (TAC No. MD-7230) (Proprietary/Non-Proprietary)

Enclosed are copies of the Proprietary and Non-Proprietary response to NRC's Request for Additional Information By the Office Of Nuclear Reactor Regulation Topical Report WCAP-16766-P, "Westinghouse Next Generation Correlation (WNG-1) for Predicting Critical Heat Flux in Rod Bundles with Split Vane Mixing Grids".

Also enclosed is:

1. One (1) copy of the Application for Withholding, AW-09-2533 (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 the affidavit or Application for Withholding should reference AW-09-2533 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

Enclosures
cc: A. Mendiola, NRR
G. Bucuta, NRR
H. Cruz, NRR
A. Attard, NRR
J. Keiser, NRR

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Our ref: AW-09-2533
February 12, 2009

APPLICATION FOR WITHHOLDING PROPRIETARY
INFORMATION FROM PUBLIC DISCLOSURE

Subject: Further Clarifications on RAIs for Topical Report (TR) WCAP-16766-P, "Westinghouse Next Generation Correlation (WNG-1) for Predicting Critical Heat Flux in Rod Bundles with Split Vane Mixing Grids," (TAC No. MD-7230)(Proprietary)

Reference: Letter from J. A. Gresham to Document Control Desk, LTR-NRC-09-11, dated February 12, 2009.

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-09-2533 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-09-2533 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

Cc: A. Mendiola, NRR
G. Bucuta, NRR
H. Cruz, NRR
A. Attard, NRR
J. Keiser, NRR

AW-09-2533

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 12th day
of February, 2009.

Sharon L. Markle
Notary Public

COMMONWEALTH OF PENNSYLVANIA
Notarial Seal
Sharon L. Markle, Notary Public
Monroeville Boro, Allegheny County
My Commission Expires Jan. 29, 2011
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 "Further Clarifications on RAIs for Topical Report (TR) WCAP-16766-P, "Westinghouse Next Generation Correlation (WNG-1) for Predicting Critical Heat Flux in Rod Bundles with Split Vane Mixing Grids," (TAC No. MD-7230)(Proprietary), for submittal to the Commission, being transmitted by Westinghouse letter (LTR-NRC-09-11) and Application for Withholding Proprietary Information from Public Disclosure, to the Document Control Desk. The proprietary information as submitted by Westinghouse Electric Company is that associated with response to NRC's Request for Additional Information for WCAP-16766-P.

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

(a) Obtain generic NRC licensed approval for the WNG-1 Correlation.
(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

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).

COPYRIGHT NOTICE

The reports transmitted herewith each bear a Westinghouse copyright notice. The NRC is permitted to make the number of copies of the information contained in these reports which are necessary for its internal use in connection with generic and plant-specific reviews and approvals as well as the issuance, denial, amendment, transfer, renewal, modification, suspension, revocation, or violation of a license, permit, order, or regulation subject to the requirements of 10 CFR 2.390 regarding restrictions on public disclosure to the extent such information has been identified as proprietary by Westinghouse, copyright protection notwithstanding. With respect to the non-proprietary versions of these reports, the NRC is permitted to make the number of copies beyond those necessary for its internal use which are necessary in order to have one copy available for public viewing in the appropriate docket files in the public document room in Washington, DC and in local public document rooms as may be required by NRC regulations if the number of copies submitted is insufficient for this purpose. Copies made by the NRC must include the copyright notice in all instances and the proprietary notice if the original was identified as proprietary.

Further Clarifications on RAIs for Topical Report (TR) WCAP-16766-P, "Westinghouse Next Generation Correlation (WNG-1) for Predicting Critical Heat Flux in Rod Bundles with Split Vane Mixing Grids," (TAC No. MD-7230)(Non-Proprietary)

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Further Clarifications on RAIs for Topical Report (TR) WCAP-16766-P, "Westinghouse Next Generation Correlation (WNG-1) for Predicting Critical Heat Flux in Rod Bundles with Split Vane Mixing Grids," (TAC No. MD-7230)(Non-Proprietary)

On November 18, 2008, the NRC and Westinghouse held a meeting to discuss the supplemental requests for additional information (RAIs) related to statistical poolability and applicability range of the WNG-1 correlation in WCAP-16766-P. The Westinghouse presentation made at the meeting is attached as part of the RAI response. Several of the supplemental responses, provided below, address the applicability range questions raised by the NRC Staff. Additional points made during the November meeting also focused on the applicability range question. The following is a brief summary of those discussion points.

1. It was noted and agreed to by the NRC Staff that CHF is primarily a local phenomenon. The local aspects of CHF are not truly empirical but are modeled through a subchannel code and a DNB correlation based on first principle aspects and the relationship between CHF and local fluid parameters. Based on thirty plus years of fuel design experience (i.e., specifically grid design and optimization), Westinghouse has identified [ ]^{a,c} that tend to affect CHF performance. While the SER for WCAP-8762-P (WRB-1) raised questions about the representative [ ]^{a,c} and first principle understanding, over time the NRC SERs on correlations have also reflected increased understanding of the first principle aspects and impacts of [ ]^{a,c} on CHF performance. Later, these parameters formed the basis of Section 6 in the Fuel Criteria Evaluation Process (FCEP) topical report approved by the NRC (WCAP-12488-A, Reference 1). In fact, the Technical Evaluation Report prepared by the Pacific Northwest Laboratory (PNL), concurred with the approach that Westinghouse uses based on first principle aspects. Based on this approach and evaluation of similarity in the [ ]^{a,c}, the fuel designs that comprise the DNB correlation database should yield essentially the same CHF performance relative to the correlation prediction. The statistical poolability evaluations then demonstrate that the designs are poolable and that there are no non-conservative trends in the CHF predictions over the applicable range.

2. Based on the above justification and similarity of fuel design parameters, all the fuel designs in a Westinghouse DNB correlation database yield essentially the same CHF performance relative to the correlation prediction. Thus, if 1) each design has a statistically significant number of data points, 2) the CHF measured-to-predicted ratios (M/P) of each design are demonstrated to be in the same population as the correlation database (i.e., poolable), and 3) correlation predictions show no non-conservative trends over the applicable range, then the need to test every single design over the entire range is unnecessary. This is not extrapolation, it is the use of extensive engineering experience backed by a first principle understanding of the phenomenological aspect of CHF and confirmatory testing results. This experience has been proven repeated times where new designs were developed and CHF tested and compared against existing CHF correlations to substantiate the expected CHF performance. The following summary captures the precedence where the NRC has accepted a CHF correlation and approved it for all the fuel designs specified, based on results of confirmatory tests that did not cover the entire applicable range.

WRB-1, WCAP-8762-P-A

- Test series A-1 through A-19 were "R-grid designs", Test series A-20 through A-24 were "L-grid designs". NRC approved the designs with two separate CHF limits since the grouped "L-grid" data did not pass the F-test: "R-grid" had a 1.17 DNBR and "L-grid" had a 1.37 DNBR. The NRC accepted that both designs were valid over the full range of the correlation even though the "R-grid" designs did not cover all the way down to the lower end of the Pressure and Quality range and the "L-grid" designs did not cover all the way up to the high end of the Pressure and Quality ranges.

- The test series for the 14x14 OFA was approved by the NRC later on as a supplement. Again this was a confirmatory test since the NRC questioned Westinghouse's scaling techniques. The scaling technique was not simply scaling, but was based on the first principle knowledge of which [ ] [a, c] were key to CHF performance. The 14x14 OFA test covered a reduced range relative to that which the correlation covered. The actual CHF testing confirmed that not only was the 1.17 correlation limit acceptable and applicable to the 14x14 OFA, but the actual testing could have supported a 1.122 limit. Since the full range of the correlation was approved for the 14x14 OFA, Westinghouse accepted the 1.17 correlation limit approved by the NRC.

WRB-1, WCAP-9401-P-A

- The test series for the 17x17 OFA was approved by the NRC in WCAP-9401-P-A. Again this was a confirmatory test since the NRC questioned Westinghouse's scaling techniques. The scaling technique was not simply scaling but was based on the first principle knowledge of which [ ] [a, c] were key to CHF performance. The 17x17 OFA test covered a reduced range relative to that which the correlation covered. The actual CHF testing confirmed that not only was the 1.17 correlation limit acceptable and applicable to the 17x17 OFA, but the actual testing could have supported a 1.165 limit. Since the full range of the correlation was approved for the 17x17 OFA, Westinghouse accepted the 1.17 correlation limit approved by the NRC.

Note: All existing Westinghouse split vane designs are representative of the original "R-grid" design. The same [ ] [a, c] are applicable today as they were twenty years ago. All confirmatory testing has substantiated that the specified correlation limit is not only applicable, but a lower limit may actually be justifiable (i.e., 17x17 OFA, 14x14 OFA, 15x15 VANTAGE 5H with IFMs, etc). If no trend is indicated in the data results and one of the designs covers the full range of data, then the other designs in the correlation database should also be covered.

All the fuel designs in the WNG-1 DNB correlation database yield essentially the same CHF performance relative to the correlation prediction. Each design has a statistically significant number of data points. The CHF measured-to-predicted ratios (M/P) of each design are demonstrated to be in the same population as the correlation database (poolable). However, during the Staff's review of the topical report, it was discovered that the WNG-1 predictions for the 15x15 fuel design showed a trend with respect to the local quality. If extended to the higher quality, the WNG-1 predictions may be non-conservative for the 15x15 design. Because of the M/P trend and lack of confirmatory test data at higher quality, Westinghouse would agree that the WNG-1 correlation applicability should not be applied to the 15x15 design until such time as additional data could be obtained to substantiate its acceptability. There

is no non-conservative trend in WNG-1 predictions for the other fuel designs. Therefore, based on similarity of the [ ] [a, c], demonstration of the data poolability and no trend in the correlation predictions, the WNG-1 correlation 95/95 DNBR limit of 1.14 is applicable to the 16x16 NGF, 17x17 RFA, and 17x17 NGF fuel designs within the applicable range as defined by the correlation database.

Further clarifications on RAI #5 (Reference 2):

d. *Provide technical justification for the use of the WNG-1 correlation for the 15x15 fuel for qualities above [ ] [a, b, c]. There is no data above that value and the trend is in the non-conservative direction. If a pool-ability argument is made provide sufficient technical justification why other fuel is similar to 15x15 fuel.*

Response:

Figure 11 of the RAI response in LTR-NRC-08-37 (Reference.2) [

] [a, b, c], Westinghouse would agree that the WNG-1 correlation would not include the 15x15 design until such time as additional data are available to substantiate its acceptability for [ ] [a, c].

e. *Provide technical justification for the use of the WNG-1 correlation for the 16x16 fuel for qualities above [ ] [a, b, c]. There is no data above that value. If a pool-ability argument is made provide sufficient technical justification why other fuel is similar to 16x16 fuel.*

Response:

The WNG-1 M/P predictions for the 16x16 fuel have been verified to be pool-able or to be in the same population as the WNG-1 database. Figure 8 of the RAI response in Reference 2 shows no significant trend in the WNG-1 M/P predictions with respect to local quality. Based on the WNG-1 M/P being in the same population and lack of any non-conservative trend or bias, the WNG-1 applicable range is applicable to the 16x16 fuel, as discussed in the introduction. The grid design of the 16x16 fuel is functionally the same as the 17x17 grid design so that the [

] [a, c] in the WNG-1 correlation database. The fact that the 16x16 data can be pooled with the 17x17 data with no significant trends confirms that the designs are functionally the same. As stated in the introduction, this is the same approach that has been reviewed and approved for the same grid design with different rod diameters for WRB-1 correlation in WCAP-9401-P-A, WCAP-8762-P-A, WRB-2 correlation in WCAP-10444-P-A, WSSV correlation in WCAP-16523-P-A, References 3 - 6. For the 16x16 fuel, it is noted [

] [a, c] fuel so that these data have been grouped in WCAP-9401, WCAP-10444 and Addendum 2 to WCAP-14565-P-A, Reference 7. This is also seen [

] [a, c], Figures 1 and 2. Although local quality at [

] [a, c], as shown in Figure 2. It is noted that [

] [a, c]. These data also support the fact that the grid designs are functionally the same as the 17x17 data. In summary, the similar grid designs and similar CHF performance through the data comparisons conclude that the proposed quality range in Table 5-1 of WCAP-16766-P is applicable to the 16x16 fuel.

Figure 1
WNG-1 Critical Heat Flux versus Mass Velocity for 16x16 and 17x17 Fuel Designs

a, b, c

Figure 2
WNG-1 Critical Heat Flux versus Local Quality for 16x16 and 17x17 Fuel Designs

a, b, c

f. Provide technical justification for the use of the WNG-1 correlation for the 17x17 fuel for qualities above [ ]a, b, c. There is limited data above that value. Provide justification why [ ]a, b, c.

Response:

The WNG-1 M/P predictions show a conservative trend at high quality conditions. As stated in section 6.2.4 of WCAP-16523-P-A, a [ ]a, c. Based upon the [ ]a, c. As noted in the response to question 5 in LTR-NRC-08-37 (Reference 2), there are [ ]a, c where the local quality range at the measured DNB elevation ranged from [ ]a, c and additional test points where the local quality [ ]a, c. The data came from both uniform and non-uniform axial power tests, tests bundles with and without Intermediate Flow Mixers (IFMs), and test bundles with and without guide thimbles. The data covered a range in pressure from 1400 to 2400 psi and a range in flow from 0.9 to 3 Mlbm/hr-ft^2. The data at the [ ]a, c demonstrated the correlation conservatism for three different operating conditions from three separate tests. Additional [ ]a, c, providing further evidence at multiple conditions that the correlation is conservative at qualities from [ ]a, c. The data that demonstrate the conservatism of the correlation over the quality range of [ ]a, b, c include:

[ ] a, b, c

Figure 3
Critical Heat Flux versus Quality
[ ] a, c

[ ] a, b, c

Figure 4
Critical Heat Flux versus Quality
[ ] a, c

[ ] a, b, c

Figure 5
Critical Heat Flux versus Quality

[ ] a, c

[ ] a, b, c

Figure 6
Critical Heat Flux versus Quality

[ ] a, c

[ ] a, b, c

Figure 7
Critical Heat Flux versus Quality
[ ] a, c

[ ] a, b, c

Figure 8
Critical Heat Flux versus Quality
[ ] a, c

[ ] a, b, c

Figure 9
Critical Heat Flux versus Quality

[ ] a, c

[ ] a, b, c

Figure 10
Critical Heat Flux versus Quality

[ ] a, c

[ ] a, b, c

Figure 11
Critical Heat Flux versus Quality

[ ] a, c

[ ] a, b, c

Further clarifications on RAI #7: (Reference 2)

a. Provide technical justification for the statistical pooling of data from the 17x17 tests with emphasis on the following difference:
i. The difference between the mixing vanes of NGF and RFA/RFA-2 type fuel.

Response:

Although there is a [

] a, c, Figures 12 and 13, show that the NGF and RFA/RFA-2 vane designs had the same or similar CHF performance, independent of any correlation predictions. Therefore, both the 17x17 NGF and the RFA fuel designs are included in the WNG-1 database. Since the vane designs are [

] a, c are applied. As described in LTR-NRC-08-37 (Reference 2), there were no trends in the 17x17 data when plotted by design and as shown in Table 1, the [

] a, b, c. Based on the raw data

comparisons, the results of the M/P t-test, the trend plots presented in Reference 2, and the fact that the sample variances are within the typical range for CHF testing of the same design, it is concluded that statistical pooling of the 17x17 test data is justified.

Figure 12

[ ] a, c

[ ] a, b, c

Figure 13

[ ] a, c

[ ] a, b, c

ii. The difference between the spacer grids and spacer grid arrangement. For example, some tests like 82, 85, 94, and 107 contain only Mixing Vane Grids (MV). Tests 89 and 90 contain one Intermediate Mixing Grid (IFM) between the MVs. Tests 108, 109, and 110 contain two IFMs between the MVs. Provide sufficient technical justification for the use of these 3 different types of mixing vane arrangements to be pooled into one data base.

Response:

The WNG-1 correlation contains a grid spacing term to explicitly account for effect of grid spacing on CHF (DNB) performance, similar to other DNB correlations (WRB-1, WRB-2, WRB-2M, and etc.) that are applicable to fuel designs with or without IFM grids. All the fuel designs with IFM grids are manufactured with different grid spacings: the bottom half of the fuel region without IFM grids, and the top half of the fuel containing IFM grids. As a result, CHF (DNB) tests were performed with and without IFM grids, in order to account for CHF changes with different grid spacings of the actual fuel designs. For WNG-1, the correlation calibration database included tests with the grid spacing term, GST, ranging from [ ] [a, b, c]. The grid spacing [ ] [a, c], the correlation GST limit was specified to be: GST ≥ 26.5. To confirm the correlation accounted for the range of GST properly, [ ] [a, c] in WCAP-16766-P.

The results of the normality test and analysis of variance F-test are given in Table 1. The fact that [ ] [a, c]. Based upon these tests, [ ] [a, c], so the limit of 1.14 remained valid. Scatter plots for the four groups did not show any significant trend. [ ] [a, c]. Therefore, the [ ] [a, c]. Based upon these comparisons, it is concluded that the 17NGF and 17RFA data can be pooled and treated as one design for the WNG-1 correlation.

Figure 14
Grid Spacing Multiplier, F_{GS}, versus Grid Spacing Term

[ ] a, b, c

Table 1
Comparison Tests for WNG-1 Data

[ ] a, c

a, b, c

b. *Provide technical justification for the use of the WNG-1 correlation for the 15x15 fuel for Local Mass Velocity [ ]a, b, c. There is no data beyond that range. If a pool-ability argument is made provide sufficient technical justification why other fuel is similar to 15x15 fuel.*

Response:

As stated in the introductory section and in response to Part b for Further Clarification of RAI #5 (Reference 9), the [ ]a, c. Therefore, the [ ]a, c are applied. The fact that the CHF M/P data pass the pool-ability tests [ ]a, c. As shown in Figures 9 and 10 of LTR-NRC-08-37 (Reference 2), there was no trend in the 15x15 data with mass velocity [ ]a, c. Based on the fact that the [ ]a, c, the CHF M/P data are pool-able and no trends are observed as a function of mass velocity, the WNG-1 flow parameter range in Table 5-1 of WCAP-16766-P is applicable to the 15x15 fuel, as discussed in the introductory section. However, as stated above, due to the [ ]a, c, Westinghouse would agree that the WNG-1 correlation applicability would not include the 15x15 design until such time as additional data are available to substantiate its acceptability for [ ]a, c.

c. *Provide technical justification for the use of the WNG-1 correlation for the 16x16 fuel for Local Mass Velocity [ ]a, b, c. There is no data beyond that range. If a pool-ability argument is made provide sufficient technical justification why other fuel is similar to 16x16 fuel.*

Response:

As stated in the introductory section and in the response to part b for further clarification of RAI #5, the [ ]a, c, similar to the approved topical reports listed in the response. Therefore, the [ ]a, c is applied. The fact that the CHF M/P data pass the pool-ability tests [ ]a, c. As shown in Figures 7 and 8 of LTR-NRC-08-37 (Reference 2), there was no trend in the 16x16 data with mass velocity [ ]a, c. Based on the fact that the [ ]a, c, the CHF M/P data are pool-able and no trends are observed as a function of mass velocity, the WNG-1 parameter range in Table 5-1 of WCAP-16766-P is applicable to the 16x16 fuel, similar to the approved topical reports listed in response to part b for further clarification to RAI #5.

d. Provide technical justification for the use of the 95/95 from the pooled data when the 95/95 from the specific fuel type may be more appropriate due to dissimilarities between the fuel types tested.

Response:

As stated previously, the fuel designs included in the WNG-1 correlation are [

]^{a,c}.

Based upon raw data comparisons for the same test geometries, it was shown that the RFA and NGF 17x17 designs [ ]^{a,c}. As stated in response to RAI #19 for the WRB-2 correlation in WCAP-10444-P-A, the approach to calculate the DNBR 95/95 limit may be justified by either 1) demonstrating there are no test geometry effects on the M/P values or distribution, or 2) demonstrating that explicitly accounting for any test section to test section variation does not affect the DNBR calculation. The fact that the data are pool-able when [

]^{a,c}, demonstrates that geometry effects have been properly accounted for in the WNG-1 correlation, and the WNG-1 database can be treated as samples from the total population of DNB data that could be obtained for the tested designs. To examine item 2, the DNBR limit was [

]^{a,c}. Following the Total Variance approach in WCAP-10444-P-A, [

]^{a,c}. Following the most conservative approach described in NS-NRC-85-3033, attached to WCAP-10444-P-A, the variance within tests, [

]^{a,b,c}. It is noted that the DNBR limit computed with the Total Variance approach remains at 1.140 when the 15x15 data are deleted. As stated in WCAP-16776-P, there are only 3.5% of the points with M/P values below the DNBR limit of 1.14 compared to slightly over 4% using the binomial distribution or the distribution free limit. A third approach examined [

]^{a,c}. This further provides support that there are no test geometry effects on the M/P values for the WNG-1 correlation. The DNBR limit for the limiting test sections is 1.15; however, only 3% of the data have M/P values below the DNBR limit of 1.15, [

]^{a,c}. Therefore, the proposed 95/95 DNBR limit of 1.14 based on the whole WNG-1 data base is appropriate. The 95/95 DNBR limit determination in the future will continue to follow the existing method, which has been NRC-approved, and is based on evaluation of the fuel DNB performance, supplemented with statistical evaluation of data poolability.

e. *Provide reference for statistical methods for pooling data.*

Response:

In addition to the references provided in WCAP-16776-P on statistical methods previously applied for pooling data, described in Section 4.1, the following references describing the statistical methods for pooling data are listed below:

d.) WCAP-12488-A (Reference 1) describes statistical method for pooling data.

e.) WCAP-9401-P-A (Reference 3) describes statistical method for pooling the CHF data of the 17x17 Optimized Fuel Assembly (OFA) having a rod OD of 0.360 inch with the WRB-1 database.

f.) WCAP-8168-P-A (Reference 8) describes repeatability of DNB tests.

Additional References that provide background on statistical tests that have been or could be applied on correlation Measured/Predicted data from DNB tests.

d.) A. Hald, "Statistical Theory with Engineering Applications". J. Wiley, N.Y, N.Y., 1952, describes Bartlett Test, Sec. 11.6, including a method for investigating whether the distribution of individual subgroup variances are distributed in accordance with χ^2. Also, two sample t-test, Sec. 15.4, and F-test for the equality of multiple means, Sec. 16.4.

e.) J. V. Bradley, "Distribution-Free Statistical Tests", Prentice-Hall, Inc. Englewood Cliffs, N.J. 1968, describes Wilcoxon (Mann-Whitney) & Kruskal Wallis tests.

f.) W. J. Conover, "Practical Nonparametric Statistics, 2nd edition", J. Wiley, N.Y., N.Y., 1980, describes Wilcoxon (Mann-Whitney) & Kruskal Wallis tests, a test like Wilcoxon for variances of two populations and a test like Kruskal Wallis for multiple variances.

g.) H. M. Wadsworth, "Handbook of Statistical Methods for Engineers and Scientists", McGraw-Hill, Inc., N.Y., N.Y., 1990 (Chapter 16, "Robust Estimation & Identifying Outliers", P. J. Rousseeuw) describes the "M.A.D." method for detecting outliers (median of all absolute deviations from the sample median)

h.) R. M. Bethea, B. S. Duran, T. L. Boullion, "Statistical Methods for Engineers & Scientists", Marcel Dekker, Inc., N.Y., N.Y., 1975, discusses the "robust" nature of the F-test for multiple means with respect to deviations from normality and variances which fail the Bartlett test (Sec. 8.6).

i.) N. R. Draper and H. Smith, "Applied Regression Analysis", J. Wiley & Sons, N.Y., N.Y., 1966, discusses the fact that regression analyses will have a zero mean error when there is a constant term in the regression or correlation (p.13).

References:

1. WCAP-12488-A, "Westinghouse Fuel Criteria Evaluation Process," April 1994.

2. LTR-NRC-08-37, "Response to NRC's Request for Additional Information by the Office of Nuclear Reactor Regulation for Topical Report (TR) WCAP-16766-P, "Westinghouse Next Generation Correlation (WNG-1) for Predicting Critical Heat Flux in Rod Bundles with Split Van Mixing Grids" (TAC No. MD7230) (Proprietary/Non-Proprietary)," July 29, 2008.

3. WCAP-9401-P-A, "Verification Testing and Analysis of the 17x17 Optimized Fuel Assembly," August 1981.

4. WCAP-8762-P-A, "New Westinghouse Correlation WRB-1 for Predicting Critical Heat Flux in Rod Bundles with Mixing Vane Grids," March 1978.

5. WCAP-10444-P-A, "Reference Core Report – VANTAGE 5 Fuel Assembly," September 1985.

6. WCAP-16523-P-A, "Westinghouse Correlations WSSV and WSSV-T for Predicting Critical Heat Flux in Rod Bundles with Side-Supported Mixing Vanes," August 2007.

7. WCAP-14565-P-A Addendum 2-P-A, "Addendum 2 to WCAP-14565-P-A, Extended Application of ABB-NV Correlation and Modified ABB-NV Correlation WLOP for PWR Low Pressure Applications," April 2008.

8. WCAP-8168-P-A, "Evaluation of DNB Test Repeatability," April 1975.

9. NRC-RCPL-08-083, "Request for Additional Information RE: Westinghouse Electric Company (Westinghouse) Topical Report (TR) WCAP-16766-P, "Westinghouse Next Generation Correlation (WNG-1) for Predicting Critical Heat Flux in Rod Bundles with Split Vane Mixing Grids" (TAC NO. MD7230)," November 25, 2008.