December 26, 2006

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

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

Dear Mr. Gresham:

By letter dated March 17, 2006, Westinghouse Electric Company (Westinghouse) submitted TR WCAP-16523, "Westinghouse Correlations WSSV and WSSV-T for Predicting Critical Heat Flux in Rod Bundles with Side-Supported Mixing Vanes," to the U.S. Nuclear Regulatory Commission (NRC) staff for review. Enclosed for Westinghouse review and comment is a copy of the NRC staff's draft safety evaluation (SE) for the TR.

Pursuant to Section 2.390 of Title 10 of the *Code of Federal Regulations* (10 CFR), we have determined that the enclosed draft SE does not contain proprietary information. However, we will delay placing the draft SE in the public document room for a period of 10 working days from the date of this letter to provide you with the opportunity to comment on the proprietary aspects. If you believe that any information in the enclosure is proprietary, please identify such information line-by-line and define the basis pursuant to the criteria of 10 CFR 2.390. After 10 working days, the draft SE will be made publicly available and an additional 10 working days are provided to you to comment on any factual errors or clarity concerns contained in the draft SE. The final SE will be issued after making any necessary changes and will be made publicly available. The NRC staff's disposition of your comments on the draft SE will be discussed in the final SE.

To facilitate the NRC staff's review of your comments, please provide a marked-up copy of the draft SE showing proposed changes and provide a summary table of the proposed changes.

If you have any questions, please contact Jon Thompson at 301-415-1119.

Sincerely,

/RA/

Stacey L. Rosenberg, Chief
Special Projects Branch
Division of Policy and Rulemaking
Office of Nuclear Reactor Regulation

Project No. 700

Enclosure: Draft SE

cc w/encl:
Mr. Gordon Bischoff, Manager
Owners Group Program Management Office
Westinghouse Electric Company
P.O. Box 355
Pittsburgh, PA 15230-0355

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OFFICE	PSPB/PM	PSPB/LA	SNPB/BC*	PSPB/BC
NAME	JThompson	DBaxley	RLandry	SRosenberg
DATE	12/22/06	12/21/06	11/29/06	12/26/06

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DRAFT SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

TOPICAL REPORT WCAP-16523-P

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

WESTINGHOUSE

PROJECT NO. 700

1.0 INTRODUCTION AND BACKGROUND

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

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

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

2.0 REGULATORY EVALUATION

Title 10 of the *Code of Federal Regulations* (10 CFR) Part 50, Section 34, “Contents of applications; technical information,” requires that Safety Analysis Reports be submitted that analyze the design and performance of structures, systems, and components provided for the prevention of accidents and the mitigation of the consequences of accidents. As part of the core reload design process, licensees (or vendors) perform reload safety evaluations to ensure that their safety analyses remain bounding for the design cycle. To confirm that the analyses remain bounding, licensees confirm those key inputs to the safety analyses (such as the CHF) are conservative with respect to the current design cycle. If key safety analysis parameters are not bounded, a re-analysis or a reevaluation of the affected transients or accidents is performed to ensure that the applicable acceptance criteria are satisfied.

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

3.0 TECHNICAL EVALUATION

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

Revised CHF correlations were developed for the following reasons:

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

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

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

3.1 Database

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

The test data used in the correlation development and validation were from 5x5 and 6x6 rod bundles simulating the PWR fuel designs. Tests were performed with uniform and non-uniform axial power shapes for test arrays with, and without, guide thimbles. The supplemental data with mixing vane grids for the grid spacing term in the correlation form were obtained for test section heated lengths ranging from 96 to 168 inches, for grid spacing from 9.3 to 26 inches, for a rod diameter ranging from 0.374 to 0.423 inches and for a guide thimble diameter ranging from 0.474 to 0.482 inches. For the development of the WSSV and WSSV-T correlations and validation database, additional data were obtained for test section heated lengths ranging from

118.1 to 150 inches, for grid spacing from 10.28 to 18.86 inches, for a rod diameter ranging from 0.374 to 0.440 inches, and for a guide thimble diameter ranging from 0.98 to 1.115 inches.

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

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

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

3.2 Correlation Form

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

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

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

The non-uniform Tong shape factor, F_c, described in CENPD-387-P-A was optimized by using the correlation form and coefficients from the uniform axial power data to evaluate the available non-uniform data. The non-uniform tests used to evaluate the empirical term "C" in CENPD-387-P-A had quality ranges covering the proposed range for the WSSV and WSSV-T correlations, from the beginning of subcooled boiling to the end of the heated assembly length. Therefore, in the region where the minimum DNBR could have occurred, the quality range in the non-uniform data was larger than the quality range for the final ABB-TV and ABB-NV correlations. Data from the supplemental non-uniform test were used to validate the use of the F_c coefficients determined in CENPD-387-P-A for the development of the WSSV and WSSV-T correlations over the proposed local quality range. Scatter plots provided in Section 5 of WCAP-16523-P also showed no trend with quality or the value of F_c.

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

As stated in CENPD-387-NP-A (Reference 9), the original correlation form assumed that there was a linear relationship between the CHF and the local quality, up to the previously accepted local quality value of about 0.22. Based on visual observations made by Westinghouse, when considering the data at the high quality conditions, the heat flux did not continue to behave similarly with quality and an adjustment term was added to the correlation to account for the change in flow regimes observed with the mixing grids. The NRC staff requested that Westinghouse provide clarification on the selection of the local quality value above which the adjustment term would be applied to the CHF calculation.

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

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

3.3 Statistical Evaluation

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

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

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

3.4 One-Sided 95/95 DNBR Limit

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

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

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

4.0 <u>CONCLUSIONS</u>

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

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

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

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

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

Parameter	Units	Range
Pressure	psia	1,495 to 2,450
Local coolant quality	--	$\leq$ 0.34
Local mass velocity	10^6 lbm/hr-ft^2	0.90 to 3.46
Matrix heated hydraulic diameter, Dhm	inches	0.4635 to 0.5334
Heated hydraulic diameter, Dh	inches	0.679 to 1.00
Heated length, HL	inches	48* to 150
Grid spacing	inches	10.28 to 18.86

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

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

5.0 REFERENCES

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

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

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

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

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

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

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

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

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

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

Principle Contributor: E. Throm

Date: December 26, 2006