March 16, 2000

Mr. Ian C. Rickard, Director
Nuclear Licensing
ABB Combustion Engineering
2000 Day Hill Road
P.O. Box 500
Windsor, Connecticut 06095-0500

SUBJECT: ACCEPTANCE FOR REFERENCING OF CENPD-387-P, REVISION-00-P, "ABB CRITICAL HEAT FLUX CORRELATIONS FOR PWR FUEL" (TAC NO. MA6109)

Dear Mr. Rickard:

We have concluded our review of the subject topical report submitted by the ABB Combustion Engineering Nuclear Power, Inc (ABB-CE) by letter of June 30, 1999. The report is acceptable for referencing in licensing applications for ABB-CE plants subject to the limitations specified in the report and in the associated NRC safety evaluation (SE), which is enclosed. The SE defines the basis of acceptance of the report.

The review of this report was greatly enhanced by the meeting prior to the submittal. As a result of those discussions, the report, as submitted, was nearly complete. Very little clarifying and additional information was needed. This working arrangement facilitated a very timely review by the staff and led to a much more effective use of time and resources. We would like to encourage this working arrangement in the future.

Pursuant to 10 CFR 2.790, we have determined that the enclosed safety evaluation does not contain proprietary information. However, we will delay placing the safety evaluation in the public document room for a period of ten (10) working days from the date of this letter to provide you with the opportunity to comment on the proprietary aspects only. If you believe that any information in the enclosure is proprietary, please identify such information line by line and define the basis pursuant to the criteria of 10 CFR 2.790.

We do not intend to repeat our review of the matters described in the report, and found acceptable, when the report appears as a reference in license applications, except to assure that the material presented is applicable to the specific plant involved. Our acceptance applies only to matters described in the report. Our SE does not include any new staff positions.

In accordance with procedures established in NUREG-0390, "Topical Report Review Status," we request that ABB Combustion Engineering publish accepted versions of this topical report, proprietary and non-proprietary, within 3 months of receipt of this letter. The accepted versions shall incorporate this letter and the enclosed SE between the title page and the abstract. It must be well indexed such that information is readily located. Also, it must contain in appendices historical review information, such as questions and accepted responses, and original report pages that were replaced. The accepted versions shall include an "A" (designating accepted) following the report identification symbol.

Should our criteria or regulations change so that our conclusions as to the acceptability of the report are invalidated, ABB-CE and/or the applicants referencing the topical report will be expected to revise and resubmit their respective documentation, or submit justification for the continued applicability of the topical report without revision of their respective documentation.

Sincerely,

/RA/

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

Project No. 692

Enclosure: Safety Evaluation

cc w/encl: See next page

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SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

RELATING TO ABB COMBUSTION ENGINEERING TOPICAL REPORT

CENPD-387-P, REVISION 00-P

“ABB CRITICAL HEAT FLUX CORRELATIONS FOR PWR FUEL”

1.0 INTRODUCTION

By letter dated June 30, 1999, ABB Combustion Engineering (ABB-CE) requested NRC review of ABB-CE Topical Report CENPD-387-P, Revision 00-P, "ABB Critical Heat Flux Correlations for PWR Fuel," (Reference 1). This report provides a description of the PWR critical heat flux (CHF) correlations for ABB 14 X 14 and 16 X 16 non-mixing vane fuel and for ABB 14 X 14 Turbo mixing vane fuel. The ABB-NV correlation is for non-mixing vane fuel and ABB-TV is for Turbo mixing vane fuel. Both correlations utilize the same form but use different constants for portions of the correlation. These correlations were developed using ABB CHF test data obtained at the Heat Transfer Research Facility at Columbia University. The tests simulated uniform and non-uniform axial power shapes, uniform and non-uniform radial power distributions, with and without guide tubes, with heated lengths of 48 to 150 inches and grid spacings from 8 to 18.25 inches. The CHF correlation is empirical and includes the following variables: pressure, local mass velocity, local quality, distance from grid to CHF location, heated length and heated hydraulic diameter of the CHF subchannel. The 95/95 departure from nucleate boiling ratio (DNBR) limit for both ABB-NV and ABB-TV correlations is 1.13. The NRC staff sent ABB-CE a request for additional information (RAI) by letter dated December 8, 1999 (Reference 2), and ABB-CE responded with additional information in letters dated December 10, 1999 (Reference 3), December 21, 1999 (Reference 4), and February 23, 2000 (Reference 5) .

2.0 EVALUATION

2.1 ABB-CE CHF Correlations

ABB-CE currently uses the CE-1 correlation for 14 X 14 and 16 X 16 non-mixing vane fuel. The 95/95 DNBR limits for CE-1, as approved by NRC, are 1.15 for the 14 X 14 geometry and 1.19 for the 16 X 16 geometry. The form of the CE-1 correlation for uniformly heated tubes is based on the assumption that CHF depends on local coolant conditions and is linearly dependent on quality and inlet subcooling. The CE-1 correlation was approved for use in ABB-CE’s TORC and CETOP thermal hydraulic codes.

A new correlation was needed for ABB-CE non-mixing and mixing vane grid fuel for the following reasons:

1. To incorporate the following improvements in the correlation for non-mixing vane fuel:

   a. Special geometry effects for the grid, heated length, and guide tube to improve the fit and probability of the CHF data,

   b. Optimization of the constants of the Tong F_c shape factor to the ABB-CE non-uniform CHF data, and

   c. Use of primary CHF indication.

2. To incorporate the details of the 14 X 14 Turbo spacer grid for the Turbo fuel

The new ABB-NV correlation will not supersede the CE-1 correlation. The CE-1 correlation will still be valid and available to clients who choose not to use the new ABB-NV correlation.

The form of the new correlation is similar to the ABB-X2 correlation developed for ABB 17 X 17 and 16 X 16 split-vane mixing grid fuel. The form is empirical and based solely on experimental observations of the relationship between the measured CHF and the correlation variables. The form assumes that there is a linear relationship between CHF and local quality. This relationship has been observed in many rod bundle CHF tests and applies well to the ABB-CE CHF tests. The correlation includes the following variables: pressure, local mass velocity, local quality, distance from grid to CHF location, heated length from inlet to CHF location, and heated hydraulic diameter of the CHF channel. Geometry terms are applied to the correlation to correct CHF for grid, heated length, cold wall, and guide tube effects. The F_c shape factor was optimized and applied to the correlation to account for the effects of non-uniform axial power shapes.

2.2 Data Acquisition and Tests

The CHF tests were conducted at Columbia University's Heat Transfer Research Facility. CHF test data from 1971 to 1977 were reevaluated for the ABB-NV correlation. The test data for the ABB-TV correlation were taken from 1993 to 1997. The general test procedures for both sets of tests were the same. It is acceptable to use the test data from the earlier tests for the non-mixing vane correlation, because the mechanical characteristics of the fuel have not been changed. For the ABB-TV tests, a 6 X 6 test array was selected in order to reduce the number of primary peripheral rod CHF indications so that the test would better simulate in-core performance. Also, by using a 6 X 6 array, the geometry around the simulated guide tube is a better representation of the reactor geometry.

The correlation coefficients were based upon a subset of the test data, which was 80 percent of the CHF test points. The remaining 20 percent of the test data was 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 fuel and sub-channel dimensions. The axial geometries were reviewed for discrepancies and nonconformities.

2.3 Development of the ABB-NV Correlation for Non-Mixing Grids

The form of the ABB-NV correlation was initially developed with the primary variables: pressure, local mass velocity, and local quality. The correlation form was then multiplied by additional terms to account for geometry effects among tests for the ABB 14 X 14 and 16 X 16 non-mixing grid fuel assembly designs. The geometric parameters include the heated dynamic diameters of the CHF subchannel, the distance from grid to CHF location (DG), the heated length for beginning of heated length (BOHL) to CHF location, and the proximity of matrix subchannels to large guide tubes in the ABB-CE fuel designs.

An independent validation database was generated using tests excluded from the correlation database to verify performance of the ABB-NV correlation. In addition, data from two special tests were reduced to demonstrate conservative performance in peripheral cells and acceptable performance with a 23 percent power spike. The TORC code was used to predict the CHF for each test in the validation database. The predicted and measured CHFs were compared. The means and standard deviations for the M/P CHF ratio for the validation database and individual test sections were presented in the report. For a total of 187 tests, the mean was 1.004 and the standard deviation was 0.057. The results from the two special tests showed that the M/P CHF ratio was greater than 1 in all cases, indicating that the predictions are conservative. The staff reviewed this section for mathematical correctness of the development of the correlation and applicability of appropriate statistical methods in evaluating the accumulated data.

2.4 Development of the ABB-TV Correlation for 14 X 14 Turbo Mixing Grids

The functional form of the ABB-TV correlation is the same as the ABB-NV correlation with different coefficients. The correlation was optimized with data from the non-uniform Turbo mixing grid test combined with the Tong F_c shape factor for non-uniform axial power distributions. All available data points were used to optimize the coefficients. The coefficients were optimized using the actual test section geometry for the heated hydraulic diameter in the matrix and guide tube channels. The initial correlation was then used to evaluate the non-uniform axial power shape data and the constants for the coefficient C in the Tong expression for the axial shape factor $F_{c.}$ As with the NV correlation, the TORC code was used to predict the CHF for each test in the validation database. The predicted and measured CHFs were compared. The means and standard deviations for the M/P CHF ratio for the validation database and individual test sections were presented in the report. For a total of 62 tests, the mean was 0.9974 and the standard deviation was 0.0477. This section was reviewed for mathematical correctness of the development of the correlation and applicability of appropriate statistical methods in evaluating the accumulated data.

2.5 Tong F_c Shape Factor for Non-Uniform Axial Power Distributions

The Tong F_c shape factor is used to account for non-uniform axial power distributions. The process used was a typical straightforward mathematical procedure similar to that used for any correlation, whether it is a PWR or BWR correlation. The combined ABB-CE non-uniform test data from the ABB-NV correlation database and the ABB-TV correlation database were used for the optimization of the Tong F_c shape factor for non-uniform axial power distributions. The non-uniform test data for the correlation and validation databases were then evaluated to ensure the ABB-NV and ABB-TV correlations, combined with the modified values of F_c, conservatively covered all regions of the correlation parameter range. The non-uniform tests were performed with five axial power distributions. The staff's review consisted of examining the mathematical development of the Tong factor to ensure no anomalies were introduced either intentionally or unintentionally. The supplied data was reviewed for engineering soundness and the provided figures were scrutinized for their statistical correctness and the presence of any anomalies.

2.6 Statistical Evaluation

This section consisted of the evaluation of all the statistical data that went into the development of the two correlations. The following topics were considered: outliers, normality distribution, comparison of the various data groups, the homogeneity of variance, and the 95/95 DNBR limit. As previously mentioned, the means and standard deviation for the ratio of measured to ABB-NV predicted CHF were given for the correlation database and the individual test sections and for the validation database and the individual test sections. Similar means and standard deviations were presented for the ABB-TV correlation. A statistical evaluation was performed with the ABB-NV and ABB-TV correlations for each test section, 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.

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 to examine the correlation for trends or regions of nonconservatism. The measured to correlation predicted CHF ratio was plotted as a function of pressure, local mass velocity, local quality, heated hydraulic diameter, distance from bottom to adjacent upstream grid, and heated length from BOHL to location of CHF. The staff examined these plots and determined that no trends or regions of nonconservatism were evident. The 95/95 DNBR limit was also shown on these plots to show the number of points that fall below the limit and the location of those points. The staff examined all the plots and determined that the results were typical.

Each database was examined for outliers. Suspect points were eliminated after being tested by the procedure described in Experimental Statistics, National Bureau of Standards Handbook 91. The staff reviewed the elimination of the outliers and agreed that it was appropriate.

2.7 Application of the Correlations in Reloads

The impact of using either the ABB-NV or ABB-TV correlation instead of the CE-1 CHF correlation in reload analysis and the approach for using ABB-NV along with ABB-TV in transition cores were described in great detail in the report. Items covered under the impact of ABB-NV and ABB-TV on existing topical reports are application of the new CHF correlations with TORC and CETOP-D codes, the setpoint report, Extended Statistical Combination of Uncertainties and Modified Statistical Combination of Uncertainties reports, Rod Bow Reports, the Inert Replacement Rod Report, the Loss of Flow Report, and the HID-1 Grid Spacing Departure From Nucleate Boiling Penalty. The staff has reviewed the detailed application of the ABB-NV and ABB-TV correlations on existing topical reports and concluded that the methods described are acceptable, as long as they are followed explicitly. Any change from what is described in Section 7.1 of CENPD-387-P, Revison 00-P must have staff approval.

As Turbo fuel is introduced to a reactor, transition cores will exist in which ABB Turbo mixing vane grid fuel assemblies are co-resident with ABB non-mixing vane grid fuel assemblies. As was previously reviewed and approved by the staff, the 14 X 14 dual bundle test results demonstrate the accurate prediction of axial flow redistribution by the TORC code. For transition cores with Turbo fuel, a margin neutral approach in which a TORC analysis would be performed to show that improvements in CHF due to the mixing vane grids more than compensate for any decrease in predicted DNBR due to flow diversion for Turbo to adjacent non-mixing vane grid fuel assemblies or a detailed TORC analysis will be performed each cycle to credit the full benefit of the Turbo grids minus the transition core penalty due to flow diversion. For a full core of Turbo fuel assemblies, the entire DNBR margin benefit would be credited in the reload analysis.

The application of these correlation transients was addressed via RAIs to the vendor. These correlations, like other DNB correlations for PWR safety analyses, were developed from steady-state test data. These correlations will be used with appropriate codes in calculating DNBRs for PWR power ramp, and flow coastdown transients, such as complete loss of flow, locked rotor, and control rod malfunctions. Studies of transient CHF data have shown that the transient CHF for power ramp and flow coastdown transients is higher than the steady-state CHF, and that the use of DNB correlations developed with steady-state data can correctly (conservatively) predict the transient CHF when the instantaneous local fluid conditions are used.

2.8 Technology Transfer

In response to an RAI, ABB-CE described in their February 23, 2000, letter (Reference 5), the technology transfer program which licensees must successfully complete in order to perform their own thermal hydraulic (TH) calculations using the ABB TORC and /or CETOP-D codes in support of reload analysis. The overall process consists of training, benchmarking and change control. In addition, ABB-CE described the process for a licensee to implement the new correlations (ABB-NV and ABB-TV). This process includes ABB-CE performing an independent bench marking calculation for comparison to the licensee generated results to verify that the new CHF correlations are properly applied. The staff has reviewed the process and finds it acceptable because training bench marking and change control have been adequately addressed.

3.0 CONCLUSION

In summary, the new correlation is based primarily on data taken from 1971 to 1977, supplemented by more recent data. The correlation approach is the same as that used for a previously approved correlation (ABB-X2), and the statistics are performed in an acceptable manner. The staff has performed an extensive review of the analyses in Topical Report CENPD-387-P, Revision 00-P, and concludes that on the basis of its findings presented above, CENPD-387-P, Revision 00-P, is acceptable for licensing applications, subject to the following conclusions and conditions to which ABB-CE has agreed (References 1 and 5):

1. The ABB-NV and ABB-TV correlations indicate a minimum DNBR limit of 1.13 will provide a 95 percent probability with 95 percent confidence of not experiencing CHF on a rod showing the limiting value.

2. The ABB-NV and ABB-TV correlations must be used in conjunction with the TORC code since the correlations were developed on the basis of the TORC and the associated TORC input specifications. The correlations may also be used in the CETOP-D code in support of reload design calculations.

3. The ABB-NV and ABB-TV correlations must also be used with the ABB-CE optimized F_c shape factor to correct for non-uniform axial power shapes.

4. Range of applicability for the ABB-NV and ABB-TV correlations:

Parameter	ABB-NV Range	ABB-TV Range
Pressure (psia)	1750 to 2415	1500 to 2415
Local mass velocity (Mlbm/hr/ft^2)	0.8 to 3.16	0.9 to 3.40
Local quality	-0.14 to 0.22	-0.10 to 0.225
Heated length, inlet to CHF location (in)	48 to 150	48 to 136.7
Grid spacing (in)	8 to 18.86	8 to 18.86
Heated hydraulic diameter ratio, Dhm/Dh	0.679 to 1.08	0.679 to 1.000

5. The ABB-NV and ABB-TV correlation will be implemented in the reload analysis in the exact manner described in Section 7.1 of Topical Report CENPD-387-P, Revision 00-P.

6. Technology transfer will be accomplished only through the process described in Reference 5 which includes ABB-CE performing an independent benchmarking calculation for comparison to the licensee generated results to verify that the new CHF correlations are properly applied for the first application by the licensee.

4.0 REFERENCES

1. Letter from Ivan Rickard, ABB-CE to NRC Document Control Desk, dated June 30, 1999, submitting CENPD-387-P, Revision 00-P, "ABB Critical Heat Flux Correlations for PWR Fuel," June 1999.

2. Letter from J. Cushing, NRC, to I.C. Rickard, ABB-CE, dated December 8, 1999.

3. Letter from Ivan Rickard, ABB-CE, to NRC Document Control Desk, dated December 10, 1999.

4. Letter from Ivan Rickard, ABB-CE, to NRC Document Control Desk, dated December 21, 1999.

5. Letter from Ivan Rickard, ABB-CE, to NRC Document Control Desk, dated February 23, 2000.

Principle Contributor: M. Chatterton

Date: March 16, 2000