June 30, 2000

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

SUBJECT: ACCEPTANCE FOR REFERENCING OF CENPD-392-P, "10X10 SVEA FUEL CRITICAL POWER EXPERIMENTS AND CPR CORRELATIONS: SVEA-96" (TAC NO. MA5999)

Dear Mr. Rickard:

We have concluded our review of the subject topical report submitted by Combustion Engineering Nuclear Power, Inc (ABB-CE) by letter dated May 28, 1999. The report is acceptable for referencing in licensing applications 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.

This report describes the analyses conducted by ABB-CE pertaining to the application of the critical power correlation to the SVEA-96 fuel design. The critical power ratio (CPR) correlation for the ABB SVEA-96 fuel is referred to as ABBD1.0. The ABBD1.0 correlation was developed by ABB-CE for application to design and licensing calculations for the SVEA-96 water cross fuel assemblies over the range of steady state, and operational transient conditions for boiling water reactor (BWR) plants.

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

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.

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, Combustion Engineering Nuclear Power 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

original report pages that were replaced. The accepted versions shall include an "-A" (designating accepted) following the report identification symbol.

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SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

RELATING TO TOPICAL REPORT CENPD-392-P,

"10x10 SVEA FUEL CRITICAL POWER EXPERIMENTS AND

CPR CORRELATIONS: SVEA-96"

ABB COMBUSTION ENGINEERING, INC.

1.0 INTRODUCTION AND BACKGROUND

CENPD-392-P describes the analyses conducted by (ABB-CE) pertaining to the application of the critical power correlation to the SVEA-96 fuel design (Reference 1). The critical power ratio (CPR) correlation for the ABB SVEA-96 fuel is referred to as ABBD1.0. The SVEA-96 fuel assembly design is very similar to the NRC approved SVEA-96+ fuel assembly design, and each consist of four sub-bundles in a 5x5 lattice configuration with one fuel rod missing. The only difference between the SVEA-96 and the SVEA-96+ assemblies is in the design, number, and location of the spacers (Reference 2).

The ABBD1.0 correlation was developed by ABB-CE for application to design and licensing calculations for the SVEA-96 water cross fuel assemblies over the range of steady state and operational transient conditions for boiling water reactor (BWR) plants. The ABBD1.0 correlation for the SVEA-96 fuel is very similar to the NRC-approved ABBD2.0 correlation for the SVEA-96+ fuel, and is intended to replace the existing the XL-S96 correlation (Reference 3) currently in use with the SVEA-96 fuel. The XL-S96 correlation was developed with cosine axial power shape, while the ABBD1.0 correlation was developed with substantial additional data, including top-peaked and bottom-peaked axial power shape data that was not available at the time of the development of the XL-S96 correlation. As expected, the additional data resulted in a much enhanced correlation now referred to as the ABBD1.0 correlation.

CENPD-392-P provides a description of the methodology behind the application of the ABBD1.0 correlation to the ABB-CE SVEA-96 fuel design. CENPD-392-P also contains test data taken specifically at the FRIGG loop test facility at Vasteras, Sweden, in support of the application of the ABBD1.0 correlation to the SVEA-96 fuel design, and to the determination of the associated correlation "Additive Constants."

The additive constants are determined in accordance with the NRC-approved procedure described in reference 3. The uncertainties associated with these additive constants are then used in the approved ABB-CE safety limit methodology for BWR fuel designs. The approved methodology is used to ensure that less than 0.1 percent of the fuel rods are in boiling transition during steady-state operation and during anticipated operational occurrences.

The ABBD1.0 correlation is similar to the XL-S96 correlation described in reference 3. However, the definitions of the associated parameters (dependent and independent) as described in Reference 1, are specific to the application of the ABBD1.0 correlation to the SVEA-96 fuel design. The technical analysis of the ABBD1.0 correlation and its exclusive application to the SVEA-96 fuel type is presented below.

2.0 EVALUATION

2.1 The ABBD1.0 Correlation

The ABBD1.0 correlation is a new correlation designed and developed to address the critical power behavior of the ABB-CE SVEA-96 fuel design. The ABBD1.0 correlation is an empirically derived correlation from the SVEA-96 fuel test data using the critical quality-boiling length form directly derived from the base GEXL correlation developed by General Electric (Reference 4). The critical quality-boiling length correlation represents a proven form capable of adequately predicting the onset of dryout during a transient.

The ABBD1.0 correlation is an empirically derived expression that is a complex function of the input parameters: boiling-length, mass flow, and system pressure. These input parameters cover the ranges of pressure, mass velocity, and inlet cooling, consistent with expected operating and accident conditions. The correlation is based on local coolant conditions predicted from uniform and non-uniform axial power distribution test data. The correlation includes correction factors to account for geometry and non-uniform axial power distributions that deviate from the test data conditions.

Low-flow and high-flow behavior of the correlation are captured by refining the parameters in the correlation equations. These parameters address the impact of the variations in the local enthalpy from the planar average enthalpy. One of these parameters is the R-effective, which characterizes the fuel rod local behavior, such as enthalpy rise, and which also factors in additive constants into the calculations. The additive constants are a measure of the dryout sensitivity of each rod in the sub-bundle.

Although the ABBD1.0 correlation is derived from sub-bundle data, ABBD1.0 is applied to full bundles. Overprediction of the critical power is prevented by assuring that the R-factor is modified to accommodate the sub-bundle mismatch among the four sub-bundles comprising the SVEA-96 fuel assemble.

2.2 SVEA-96 Data Base and Test Strategy

The ABBD1.0 correlation data base consisted of 1612 steady-state 24-rod sub-bundle data points. Eighty percent of this data was used to develop the ABBD1.0 correlation and 20 percent of this data set was used to validate the ABBD1.0 correlation. All data was taken at the FRIGG loop at the ABB-Atom laboratories at Vasteras, Sweden. The test setup consists of electrically heated rods that are physically the same as the SVEA 96 fuel assembly. The tests are designed to reproduce the local conditions typically present in a BWR fuel assembly and support the full range of applicability of the ABBD1.0 correlation.

The sub-bundle assemblies were tested subject to the intended full range applicability of the SVEA-96 fuel. The test programs were developed to accumulate a data base representative of the appropriate statistical requirements for the SVEA-96 fuel design. This approach ensures that an adequate number of tests are performed and that sufficient data are gathered to perform appropriate simulation of the behavior of the SVEA-96 fuel design.

Both steady-state and transient tests were performed as part of the validation of the ABBD1.0 correlation. In each case, the tests were designed to include test runs with peaked rods at selected locations. The data base consists of more than 1600 data points taken in a large number of tests performed at the FRIGG test facility. The data base consists of top peaked, bottom peaked, and cosine axial power shapes accounting for adjacent rod positions, rods on the interior of an assembly, and rods adjacent to the water cross, a feature unique to the SVEA-96 fuel design.

The local power peaking patterns were selected to determine the effects of the top peaked axial power profiles as compared to the cosine power profiles in several regions of the test bundle. Local power peaking data were also collected at the corners, and peripheral rows, as well as around the internal water cross to ensure complete understanding of the fuel bundle power performance in these regions.

The range of local power distributions were selected to cover local power distributions expected during reactor operations and to allow an accurate determination of the dryout sensitivity of each fuel rod in the sub-bundle. A broad range of sub-bundle power mismatch factors are also obtained to account for sub-bundle power differences among the four sub-bundles (References 1 and 2). In addition, the full range of R-factors anticipated during normal BWR operations, as well as anticipated operational occurrences (AOOs) and accidents, were covered by the large number of local power distributions performed in the sub-bundle and full bundle tests.

All the data collected was validated by performing periodic instrumentation reliability checks, as well as conducting periodic calibration checks to ensure the accuracy of the data. Instrumentation were checked before and after each test period. Heat balances were performed to ensure that power, flow, and temperature measurements were correct. Pressure drop across the bundle and at different flow rates were measured. Power generated by the heater rods were compared to that of the power supply output for all test points subject to the criteria that the two bundle powers had to agree within +/-1 percent.

2.3 Description of the ABBD1.0 Additive Constants

Correlation parameters such as R-factors account for the local peaking factor effect on the bundle critical power. One part of the R-factor accounts for the local power distribution of the rod of interest and its immediate neighbors, the other part accounts for other local effects, such as bundle cross section geometry and spacer grid designs. These spacer and bundle geometry effects influence the critical power behavior of the bundle. Therefore, an offset term is applied to each rod in the bundle, subject to the rod’s position in the bundle. This offset term is called the "additive constant." The additive constant can be considered as a flow/enthalpy redistribution characteristic of a particular lattice/spacer design, so the additive constants are unique to a particular fuel design.

ABB-CE’s testing program consisted of a number of tests conducted at different local rod power distributions, selected in a systematic way, to ensure that each unique rod location has a sufficient database to determine an associated unique additive constant. The additive constants are explicitly determined for each lattice/spacer design configuration and are utilized in design calculations for the corresponding fuel bundle.

To assert the ability of the correlation to predict steady-state as well as transient upskew and downskew axial power shape, only the cosine test data were used in the determination of the additive constants, thus validating the use of the additive constants in steady-state and transient calculations. The additive constants are experimentally determined from a large data bank representative of the power profile expected during the operational range of the SVEA-96 fuel design.

3.0 STATISTICAL ASPECTS OF THE SVEA-96 CORRELATION

The ABBD1.0 correlation is designed to predict heat flux from several physical input parameters, including mass flux, outlet pressure, subcooling temperature, and power shape ("profile"). The data base used in the evaluation ("correlation development") stage consists of 1289 steady-state critical power points. These points reflect 234 sub-bundle local power distributions, randomly selected to represent the complete applicable range of the input parameters. The selection of the associated points was made by using well established Monte Carlo procedures.

Perhaps the most telling performance index derived in this study, regarding the correlation ability to "predict" is the CPR. A good correlation would predict a CPR value near 1.00 (unity), with a very small associated uncertainty. ABB-CE’s calculation fluctuates near 1.00 for all subsets of the data (different pressure, mass flux, and subcooling range). The calculation of the CPR also involves the calculation of an individual additive constant that accounts for the geometric position of a rod within a bundle. A detailed description of the process used in identifying and generating those constants is given in Chapter 4 of the topical report; since the calculated additive constant are estimates, there is a measure of variability associated with their calculation. Both additive constants and their variability are considered in the total variability of the correlation development. No attempt is made (nor is one needed) to isolate or calculate the contribution of individual components from the total variability of the correlation.

To ensure that the overall uncertainty of the correlation is within the accepted limit, ABB-CE performed a 95/95 upper tolerance limits for the CPR calculations (Reference 1, Tables D 5.3 and D 5.5). The staff confirmed ABB-CE’s limits by running parallel calculations using parametric (less conservative, assuming a normal distribution) statistics. Both ABB-CE’s and the NRC staff’s calculation of the 95/95 upper tolerance limit were found to be well within reasonable and acceptable statistical bounds.

The applicability and behavior of the correlation over a wide range of parameters was demonstrated and documented by charting (plotting) the correlation against a full range of each parameter of interest. The charts demonstrate convincingly that the correlation is more than adequate in its ability to predict the CPR. Furthermore, the quality (error) associated with the

CPR calculation does not deteriorate as one moves from one range of the parameter to another.

The validation of the correlation is achieved by applying the prediction method to assemblies that are not part of the evaluation (correlation construction) data. To that end ABB-CE uses 323 sub-bundle critical power points. The mean error of the sub-bundle validation data is smaller, in both magnitude of error and in the associated standard deviation, than the statistics obtained for the evaluation data, thus validating the appropriateness of the correlation for sub-bundle operations.

4.0 SVEA-96 CORRELATION BEHAVIOR

The SVEA-96 correlation (ABBD1.0) was tested to ensure smooth functions and that no significant discontinuities exist in its behavior over the entire range of operability of the fuel. ABBD1.0 is a critical boiling-length plane correlation. Its main objective is to correlate the SVEA-96 critical power test data. The boiling-length correlation has proven in the past (GE has used it and continues to use this type of correlation), to be a very good correlation for representing the onset of dryout during steady-state and transient conditions. The credibility of ABBD1.0 (which was formulated under steady-state conditions), is established by adequately predicting the change in critical power during a transient condition.

A number of tests were conducted to determine the sensitivity of the major functions within the ABBD1.0 to flow, inlet -subcooling, pressure variation, R-factors, and axial power shape. The R-factors account for the local power distributions, cross section geometry, and the spacer grid configuration. Review of the data, figures, and tables, indicate that the SVEA-96 correlation behaves well over the applicable range of the fuel.

5.0 SVEA-96 CORRELATION VALIDATION

ABB-CE performed several tests to validate the behavior of the SVEA-96 correlation in steady-state and transient events. The validation data base consisted of steady-state data points that were not included in the correlation data base. The data were collected from tests conducted on 24-rod sub-bundles. The validation data set (20 percent of the total data set) was used to: (1) validate the analytical method of the ABBD1.0 critical power ratio (CPR) correlation, and (2) to further validate the overall predictive capability of the ABBD1.0 CPR correlation. The predicted results of the ABBD1.0 correlation critical power versus the measured critical power for these tests showed very good agreement and that no biases exist as a function of critical power, mass flux, inlet subcooling or outlet pressure. In addition, no bias was detected with respect to the ABBD1.0 correlation as a function of the R-factor and as a function of boiling length. After reviewing submitted figures and tables indicative of the ABBD1.0 correlation behavior, the staff agrees with the conclusion that the ABBD1.0 correlation provides a good fit to the test data, and that no apparent systematic biases exist that would limit the validation of the correlation to predict the bundle critical power performance in design and licensing applications.

6.0 ABBD1.0 TRANSIENT APPLICATION

Transient CPR predictions involve evaluation of the flow, enthalpy, and pressure in the fuel assembly at each axial node as a function of time during the transient. ABB-CE uses the BISON-SLAVE channel code to conduct the transient system analysis. ABB-CE's objective of this analysis is to confirm the proper implementation of the steady-state CPR correlation in the transient code and also to confirm the capability of the steady-state CPR correlation to calculate dryout during transients with adequate accuracy to provide conservative predictions.

The NRC-approved ABBD2.0 correlation (Reference 2) also used the BISON-SLAVE code to demonstrate the ability of the ABBD2.0 correlation to conservatively predict transient behavior . Since the ABBD1.0 correlation is very similar in construction (different coefficients), ABB-CE assumed that the ABBD1.0 correlation, in conjunction with the BISON-SLAVE code, will also predict conservative results. The staff agrees with this conclusion.

The same transient data used to validate the approved XL-S96 correlation (Reference 3) for the same SVEA-96 fuel, was used to validate the transient behavior of the ABBD1.0 correlation.

The BISON-SLAVE channel version of the time domain reactor dynamics code BISON (References 5 and 6) is used in conjunction with the ABBD1.0 CPR correlation to predict transient CPR behavior for reload fuel licensing analysis applications and other operational transient simulations.

BISON is a time domain BWR dynamics code used for analyzing operational and safety related transients. The core simulates the entire primary core coolant loop including the recirculating pumps. A two-group diffusion theory model describes the axial distributions of neutron flux and power generation in the reactor core. Heat conduction in the fuel is solved in the radial direction at each axial segment. The influence from external systems such as the turbine, control systems, scram signals and relief valves can also be simulated in BISON. The ABBD1.0 CPR correlation is incorporated in the BISON-SLAVE code. The various instantaneous fluid properties such as mass flow, pressure, and inlet subcooling, are used in evaluating the CPR correlation under transient condition.

Five transient tests were conducted at the FRIGG loop. All five tests were simulated by the BISON-SLAVE code. The BISON-SLAVE code was used in conjunction with the ABBD1.0 correlation to predict transient critical power ration (CPR) behavior for reload fuel licensing analysis applications and other operational transient simulations. Review of the BISON-SLAVE simulation results indicates that the BISON-SLAVE code predicted dryout to occur in two of the five tests, thus demonstrating that the dryout threshold in the BISON-SLAVE code provides a conservative indication of dryout. Predicted times to dryout were also compared with measured times to dryout, with the BISON-SLAVE code predicting shorter times to dryout than measured times for all five tests. Thus, the predicted BISON-SLAVE times are conservative. The staff agrees with the submitted analysis and results.

7.0 TECHNOLOGY TRANSFER

ABB-CE described the technology transfer program (Reference 7) which the licensees must successfully complete in order to perform their own thermal-hydraulic calculations using any ABB-CE BWR CPR correlation and associated transient code in support of reload analyses, and which has satisfied the appropriate NRC acceptance criteria. The overall process consists of training, benchmarking, and change control. In addition, ABB-CE described the process for a licensee to implement the NRC approved correlation. This process includes performance of an independent benchmarking calculation by ABB-CE for comparison to the licensee-generated results to verify that the new CPR correlation is properly applied. The staff has reviewed the process and finds it acceptable because training benchmarking and change control have been adequately addressed.

8.0 CONCLUSION

The staff has reviewed the analyses in Topical Report CENPD-392-P, "10X10 SVEA Fuel Critical Power Experiments and CPR Correlations: SVEA-96." Topical Report CENPD-392-P is acceptable for licensing applications, subject to the range of parameters which encompass the test data used to develop the ABBD1.0 CPR correlation. If ABB-CE wishes to extend the range of applicability of the ABBD1.0 CPR correlation beyond the data range documented in Table 5.7 in Section 5 of CENPD-392-P, it will either revalidate or develop a new correlation and submit one or the other for NRC staff review and approval. ABB-CE concurs with this conclusion (Reference 7).

9.0 REFERENCES

1. Letter from Ian C. Rickard to the U.S. Nuclear Regulatory Commission, submitting Topical Report CENPD-392-P, May 28, 1999.

2. Letter from Ian C. Rickard to the U.S. Nuclear Regulatory Commission, submitting Topical Report CENPD-389-P, June 9, 1998.

3. "SVEA-96 Critical Power Experiments on Full Scale 24-Rod Sub-Bundle," ABB Report UR-89-210-P-A, October 1993.

4. "General Electric BWR Thermal Analysis Basis (GETAB): Data, Correlation and Design Application," NEDO-10958, November 1973.

5. "BISON - A One Dimensional Dynamic Analysis Code for Boiling Water Reactors," ABB Report RPA 90-90-P-A, December 1991.

6. "BISON - A One Dimensional Dynamic Analysis Code for Boiling Water Reactors: Supplement 1 to Code Description and Qualification," ABB Report CENPD-292-P-A, July 1996.

7. Letter from Ian C. Rickard to the U.S. Nuclear Regulatory Commission, "Methodology Constraint Affirmation and Minimum Criteria for Licensee Performing Licensing Basis Analyses Using the ABB1.0 CPR Correlation," May 8, 2000.

Principal Contributor: A. Attard

Date: June 30, 2000