December 9, 2004

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

SUBJECT: FINAL SAFETY EVALUATION FOR TOPICAL REPORT (TR) WCAP-16081-P, "10X10 SVEA FUEL CRITICAL POWER EXPERIMENTS AND CPR CORRELATION: SVEA-96 OPTIMA2" (TAC NO. MB9011)

Dear Mr. Gresham:

On May 12, 2003, Westinghouse Electric Company (Westinghouse) submitted WCAP-16081-P, "10x10 SVEA Fuel Critical Power Experiments and CPR Correlation: SVEA-96 Optima2," to the staff for review. On October 5, 2004, an NRC draft safety evaluation (SE) regarding our approval of WCAP-16081-P was provided for your review and comments. By e-mail dated November 29, 2004, Mr. Rob Sisk of Westinghouse commented on the draft SE. The 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 staff has found that WCAP-16081-P is acceptable for referencing in licensing applications for Westinghouse- and Combustion Engineering-designed pressurized water reactors to the extent specified and under the limitations delineated in the TR and in the enclosed SE. The SE defines the basis for 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 SE between the title page and the abstract. They must be well indexed such that information is readily located. Also, they must contain historical review information, such as questions and accepted responses, draft SE comments, and original TR pages that were replaced. The accepted versions shall include a "-A" (designating accepted) following the TR identification symbol.

Enclosure 1 transmitted herewith contains sensitive unclassified information. When separated from Enclosure 1, this document is decontrolled.

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

Sincerely,

/RA/
Herbert N. Berkow, Director
Project Directorate IV
Division of Licensing Project Management
Office of Nuclear Reactor Regulation

Project No. 700

Enclosures: 1. Proprietary Safety Evaluation
2. Non-proprietary Safety Evaluation

cc w/encl 2:
Mr. Gordon Bischoff, Manager
Owners Group Program Management Office
Westinghouse Electric Company
P.O. Box 355
Pittsburgh, PA 15230-0355

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SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

TOPICAL REPORT WCAP-16081-P, "10X10 SVEA FUEL CRITICAL POWER

EXPERIMENTS AND CPR CORRELATION: SVEA-96 OPTIMA2"

WESTINGHOUSE ELECTRIC COMPANY

PROJECT NO. 700

1.0 INTRODUCTION

By letter dated May 12, 2003 (Reference 1), Westinghouse Electric Company (Westinghouse) submitted Topical Report (TR) WCAP-16081-P, "10x10 SVEA Fuel Critical Power Experiments and CPR Correlation: SVEA-96 Optima2," to the staff for review. By letters dated April 2 (Reference 2) and October 6, 2004 (Reference 3), Westinghouse responded to the staff's requests for additional information (RAIs). This TR documents the experimental data and critical power ratio (CPR) correlation development and validation for the 10x10 SVEA-96 Optima2 fuel assembly design, and describes the test facility and test programs used to obtain a database characterizing the critical power behavior of SVEA-96 Optima2 fuel sub-bundles.

The Optima2 fuel design and its associated CPR correlation, designated D4.1.1, are similar in form to those previously approved for the SVEA-96 and SVEA-96+ fuel designs and their associated CPR correlations, designated ABBD1.0 and ABBD2.0, respectively. All three of these fuel assemblies have similar geometry, consisting of 96 fuel rods arranged in four sub-bundles in a 5x5-1 lattice. The SVEA-96 and SVEA-96+ assemblies are composed of 96 full-length rods while the SVEA-96 Optima2 assembly contains both full-length and part-length rods. The three fuel designs also differ in the geometry and arrangement of the spacer grids.

The TR also describes the derivation of the D4.1.1 CPR correlation for SVEA-96 Optima2 along with its validation for transient conditions as well as typical steady-state operation. It also describes the application methodology for thermal margin analysis with the correlation, including alternative approaches to account for the sub-bundle mismatch factor within the full assembly. In addition, a correction factor is proposed for application to fuel assemblies with a double-peaked axial power profile. This double-peak correction factor is proposed as a multiplier on the CPR predicted with the correlation, and has been derived without reference to experimental data specific to the SVEA-96 Optima2 fuel design.

2.0 REGULATORY EVALUATION

The regulations of Title 10 of the *Code of Federal Regulations,* Part 50 (10 CFR Part 50), Appendix A, General Design Criterion (GDC) 10, "Reactor design," require that the reactor core and associated coolant, control, and protection systems shall be designed with appropriate margin to assure that specified acceptable fuel design limits are not exceeded during any condition of normal operation, including the effects of anticipated operational occurrences (AOOs).

To assure compliance with GDC 10, the staff confirms that the thermal and hydraulic design of the core and the reactor coolant system (RCS) has been accomplished using acceptable analytical methods; is equivalent to or is a justified extrapolation from proven designs; provides acceptable margins of safety from conditions which would lead to fuel damage during normal reactor operation and AOOs; and is not susceptible to thermal-hydraulic instability. NUREG-0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants" (SRP), Section 4.4, "Thermal and Hydraulic Design," describes the normal review of thermal and hydraulic design and requires that additional independent audit analyses be performed for new CPR correlations.

Specific acceptance criteria in SRP Section 4.4 for evaluation of fuel design limits necessary to meet the requirements of GDC 10 include the following:

> Uncertainties in the values of process parameters, core design parameters, and calculational methods used in the assessment of thermal margin should be treated with at least a 95% probability at a 95% confidence level.
>
> For CPR correlations, the limiting (minimum) value of CPR is to be established such that at least 99.9% of the fuel rods in the core would not be expected to experience departure from nucleate boiling or boiling transition during normal operation or anticipated operational occurrences.

3.0 TECHNICAL EVALUATION

The technical review of WCAP-16081-P included the following areas: (1) assessment of the suitability of the D4.1.1 CPR correlation for licensing analyses in operating reactors with SVEA-96 Optima2 fuel; and (2) evaluation of the test facility and test program as described in the TR, the derivation and validation of the correlation, the correlation uncertainty, and the application methodology.

The D4.1.1 CPR correlation is fit to the SVEA-96 Optima2 test data using a critical quality-boiling length formation that is similar in form to the correlation for SVEA-96 and SVEA-96+ fuel (ABBD1.0 and ABBD2.0, respectively.) The dryout behavior of the SVEA-96 Optima2 design, which differs qualitatively from that observed in the SVEA-96 and SVEA-96+ fuel designs, is captured with a new set of empirical coefficients and additive constants derived by fitting the correlation form to the SVEA-96 Optima2 database. The fit of the correlation to the database was assessed using statistical analysis, and a specific mean and standard deviation of the prediction error was obtained and will be used in conjunction with the other uncertainties associated with establishing a CPR to derive the safety limit minimum CPR (SLMCPR) in accordance with the SRP for defining the 95/95 tolerance limit for thermal margin protection.

3.1 Test Facility and Test Program

The FRIGG loop in the Westinghouse laboratories in Sweden was used to obtain the experimental critical power data for the SVEA-96 Optima2 fuel design. This is a well-documented test facility with a long history of producing high-quality two-phase flow data for reactor thermal-hydraulic research and development. The review was limited to evaluation of the TR on the instrumentation and experimental uncertainty, the geometric exactness of the test sections compared to the SVEA-96 Optima2 fuel assembly, and the range of parameters tested.

The measurement uncertainties in the FRIGG loop instrumentation, as described in the TR, are quite small and well within the range expected with careful adherence to the sound experimental design principles. The actual uncertainties in the measurements from the various types of instrumentation are given in terms of a range of uncertainty in appropriate measurement units; **[ ]**. This means that the percent uncertainty in the measurement varies with the magnitude of the measured value and, in general, the lower the measured value the greater the uncertainty in the measurement.

The test sections used to obtain the database for the D4.1.1 CPR correlations are close copies of the SVEA-96 Optima2 fuel assembly sub-bundle, but they are not exactly prototypic in a number of potentially important respects. The cross-sectional area for flow is approximately **[ ]** in the test section sub-bundles, compared to the flow area of a sub-bundle in a fuel assembly. The total heated area of the rods is **[ ]** in the test sections, compared to the fuel assembly sub-bundle. Distances between the spacer grids (which are uniformly spaced in the fuel assembly sub-bundles) vary by **[ ]** in the test sections. The locations of the spacers, relative to the beginning of the heated length, are offset by **[ ]** in the top-peaked and bottom-peaked test sections, compared to the cosine test section.

The database for the D4.1.1 CPR correlation for SVEA-96 Optima2 fuel consists of **[ ]** data points obtained in test sections with three different axial power profiles: cosine, bottom-peaked, and top-peaked. The mass flux, system pressure, inlet subcooling, and local pin power distribution were varied over ranges corresponding to the expected range of application of the correlation, which includes normal steady-state conditions and AOOs. The ranges of the testing are given as follows: **[ ]** for mass flux; **[ ]** for system pressure; **[ ]** for inlet subcooling; and the range of radial power factor distributions tested corresponding to R-factors ranging from **[ ]** in the cosine and bottom-peaked test sections, and from **[ ]** in the test section with top-peaked axial power profile.

3.2 Development and Validation of D4.1.1 CPR Correlation

The D4.1.1 CPR correlation was developed and validated using appropriate data fitting procedures and statistical analysis techniques, as documented in the TR. However, the general conclusion that the fit of the correlation over the entire range of application can be characterized by the mean and standard deviation of the prediction error for the entire database is not supported by the analysis presented in Section 6 of the TR. The observed variation in the fit of the correlation over the range of the database is in large part due to the variation in the number of data points between normal and off-normal conditions. Because of the non-uniform distribution of the prediction uncertainty of the correlation, it is not possible to accurately characterize the correlation uncertainty using only the mean and standard deviation of the fit to the entire database. For the D4.1.1 CPR correlation, the fit of the correlation errors for the upper tolerance limit ranges from **[ ]** when the prediction errors for the data are grouped by pressure, mass flux, and inlet subcooling. The worst fit is in the low pressure range at low subcooling, where the 95/95 upper tolerance limit on the mean prediction error is **[ ]**, considering the data at all mass flux values.

3.3 Application Methodology for D4.1.1 CPR Correlation

In general, the D4.1.1 CPR correlation has been derived and applied in essentially the same manner as previously approved correlations for SVEA-96 and SVEA-96+ fuel, ABBD1.0 and ABBD2.0. Application of these correlations with the double-peaked correction factor and the sub-bundle model described above was previously approved for SVEA-96 and SVEA-96+ fuel in WCAP-16047-P-A, "Improved Application of Westinghouse Boiling-Length CPR Correlations for BWR SVEA Fuel," dated March 2004. There are, however, a number of significant changes in the D4.1.1 CPR correlation, compared to the ABBD1.0 and ABBD2.0 correlations.

A power mismatch factor was developed for the D4.1.1 CPR correlation with respect to approved methodology for design and licensing calculations in which the correlation is applied to the full assembly rather than the sub-bundle, and for applications in plant core monitoring systems. The purpose of the power mismatch factor is to capture the effect of flow distribution among the four sub-bundles of an assembly when the sub-bundles are not at the same power. The factor is based on **[**

]. The power mismatch factor has been shown to yield a conservative estimate of the effect of power and flow mismatch within an assembly, and is part of the methodology previously approved for SVEA-96 and SVEA-96+ fuel.

The D4.1.1 CPR correlation can also be applied to the analysis of SVEA-96 Optima2 fuel assemblies using an alternative approach of the sub-bundle model, in which the power mismatch factor is not used, **[**

]. The application of this sub-bundle model to SVEA-96 and SVEA-96+ fuel was addressed in WCAP-16047-P-A.

Based on the experimental FRIGG loop uncertainties, a multiplicative correction factor **[ ]** was developed to account for the increased probability of detecting dryout in an assembly with all four sub-bundles at essentially the same power. The analysis concluded that the effect essentially disappears when the sub-bundle relative power factor **[ ]**, and in general is **[ ]** when all four of the sub-bundles in an assembly are operating at the same thermal-hydraulic conditions. However, the correction factor is generally conservative for non-uniform power distributions, and the effect of the greater uncertainty of the correlation predictions at low flow rates is reflected in other conservatisms imposed on the implementation of the correlation and its application to SVEA-96 Optima2 assemblies. Therefore, it is acceptable for the **[ ]** correction factor to be based on the average uncertainty in dryout power in the normal operating range, which for FRIGG loop test sections is on the order of two percent.

In general, the top-peaked profile is the most limiting axial power distribution for dryout, the cosine profile is considered the most typical profile for normal operating conditions, and the bottom-peaked distribution yields the most generous margin to critical power. Based on the test data obtained in earlier fuel designs, it has been observed that the dryout behavior with a double-peak profile usually falls between the two extremes of the top-peaked and bottom-peaked profiles. However, recent work at Sweden's Royal Institute of Technology (KTH) indicates that the validity of the assumption that the top-peaked profile bounds the dryout behavior relative to axial power distribution for fuel designs has been called into question. An experimental investigation by Blomstrand et al. (Reference 4) of the effect of axial power distribution and space grid placement has shown that there may be circumstances at low pressures and high subcooling where the double-peak power profile is more limiting than a top-peaked profile. These conditions are outside of the range typically requiring thermal monitoring in U.S. boiling water reactors.

Based on the observed behavior in the KTH annular channel tests, a double-peak correlation factor was developed for application as a multiplier on the predicted CPR obtained with the D4.1.1 CPR correlation. Experimental results showing the effect of axial power distribution on dryout behavior have been conducted almost entirely in annular test sections. Based on the KTH data and an assessment of the capability of a boiling-length correlation to adequately treat double-peaked correction factors, Westinghouse has developed a correction factor to account for the reduction in dryout power expected with a double-peak axial power distribution. Westinghouse's verification of the conservatism of the double-peaked correction factor is based on the predictions of dryout behavior in rod arrays obtained using the MONA-3 subchannel code with their film flow dryout analytical model, since there is no double-peaked test data for the 10x10 SVEA fuel design.

To address staff concerns regarding lack of SVEA data to support the MONA-3 code validation and extrapolations of the dryout model for this application, Westinghouse provided (in Reference 3) MONA-3 predictions of critical power for **[ ]** data points selected from the D4.1.1 CPR correlation database to assure the required accuracy of the dryout predictions for double-peaked fuel assemblies. However, the range of conditions encompassed by the supplemental data set only spanned about half of the mass flow rate range of the D4.1.1 CPR correlation, specifically **[ ]** on flow rate (equivalent to **[ ]**). Westinghouse has acknowledged that the film flow model encounters difficulties at low mass flux values, but maintains the expectation that the MONA-3 subchannel code with the film flow model adequately captures trends in critical power for various axial power distributions in the 10x10 SVEA fuel design.

Because Westinghouse could not provide sufficient validation data for extrapolating the double-peak axial power profile correction factor to low flow rates, it is necessary to place a conservative restriction on the application of the double-peaked axial power profile correction factor at sub-bundle flow rates below **[ ]** (equivalent to **[ ]**). Therefore, the low flow-rate dependent **[ ]** term in Equation 5.3-2 of the TR must be limited to a value of **[ ]** at a flow rate below **[ ]** at all pressures and inlet subcooling values because of insufficient validation of the basis for extrapolating the double-peaked axial power profile correction factor to low flow rates.

3.4 Validation for Transient Applications

It has generally been assumed that CPR correlations derived with data obtained under steady-state or quasi-steady conditions will yield conservative predictions of critical power when applied to fast transients. This was verified for the D4.1.1 CPR correlation by comparison to a series of transient dryout tests carried out in the test sections used for steady-state dryout testing. The transient tests in this series simulate conditions sufficiently representative of conditions that would be observed in the reactor during AOOs, to validate the reliability and conservatism of the CPR prediction under such conditions. The D4.1.1 CPR correlation is in reasonable agreement with the transient tests, and in general conservatively predicts the time to boiling transition. The comparisons between the calculational results and the transient data show that the performance of the D4.1.1 CPR correlation in transient applications is essentially the same as in steady-state for normal operating conditions.

4.0 <u>CONDITIONS AND LIMITATIONS</u>

The staff reviewed WCAP-16081-P and the RAI responses by Westinghouse. The NRC staff was assisted in this review by its consultant, the Pacific Northwest National Laboratory (PNNL). The staff adopted the findings recommended in a PNNL Technical Evaluation Report (Reference 5), which provided independent audit analyses and a detailed evaluation. The staff has concluded that the subject TR is acceptable with the conditions and limitations described as follows:

(1) The range of application claimed for the D4.1.1 CPR correlation is acceptable insofar as it corresponds to the range of parameters in the database for the correlation. The correlation will be applied to the SVEA-96 Optima2 fuel assembly over the applicable range for mass flux, system pressure, sub-bundle R-factor, boiling length, and **[ ]** as specified in Section 8 of the subject TR.

(2) The CPR correlation uncertainty used to determine the thermal margin limit at all mass flux values should be **[ ]** for system pressure below 45 bar, and **[ ]** for system pressure above 45 bar, based on the values given in Tables 6.3 through 6.6 of the subject TR.

(3) It is acceptable either to apply the power mismatch factor in analysis of the full assembly or to evaluate the CPR on a sub-bundle basis, but the sub-bundle approach represents an improvement in the methodology and yields a better characterization of

the local sub-bundle flow, thus making the application of the correlation more consistent with its derivation.

(4) It is acceptable for the multiplicative correction factor, **[ ]** to be based on the average uncertainty in dryout power in the normal operating range to account for the effect of applying the D4.1.1 CPR correlation to a full assembly.

(5) The **[ ]** term in Equation 5.3-2 of the TR is limited to a value of **[ ]** at flow rates below **[ ]** at all pressures and inlet subcooling values because of insufficient validation of the basis for extending the double-peak axial power profile correction factor to low flow rates.

(6) It is acceptable to apply the same uncertainty and limitations to D4.1.1 CPR correlation for both transient calculations and steady-state analysis.

5.0 CONCLUSION

The staff concludes that the D4.1.1 CPR correlation for the SVEA-96 Optima2 fuel assembly described in WCAP-16081-P, subject to the conditions and limitations listed above, meets the requirements of GDC 10 of Appendix A to 10 CFR Part 50 and is acceptable for licensing applications.

6.0 REFERENCES

1. Letter from H.A. Sepp (Westinghouse) to NRC, "Submittal of WCAP-16081-P, Revision 0 and WCAP-16081-NP, Revision 0, '10x10 SVEA Fuel Critical Power Experiments and CPR Correlation: SVEA-96 OPTIMA2' (Proprietary/Non-proprietary)," LTR-NRC-03-18, dated May 12, 2003. (Accession No. ML031400791)

2. Letter from J.A. Gresham (Westinghouse) to NRC, "Response to Request for Additional Information Regarding WCAP-16081-P, '10x10 SVEA Fuel Critical Power Experiments and CPR Correlation: SVEA-96 OPTIMA2' (Proprietary)," LTR-NRC-04-18, dated April 2, 2004. (Accession No. ML040990267)

3. Letter from J.S. Galembush (Westinghouse) to NRC, "Response to the NRC Proposed SER for WCAP-16081-P/WCAP-16081-NP - '10x10 SVEA Fuel Critical Power Experiments and CPR Correlation: SVEA-96 OPTIMA2' (Proprietary/Non-proprietary)," LTR-NRC-04-58, dated October 6, 2004. (Accession No. ML042860070)

4. "Loop Studies Simulating - in Annular Geometry - The Influence of the Axial Power Distribution and the Number of Spacers on Dryout in 8x8 BWR Assemblies," J. Blomstrand, et al., Second Japanese-European Two-Phase Flow Group Meeting, University of Tsukuba, Japan, 25-29 September 2000.

5. "Technical Evaluation Report for WCAP-16081-P, 10x10 SVEA Fuel Critical Power Experiments and CPR Correlation: SVEA-96 Optima2," J. Cuta, PNNL, October 2004.

Attachment: Resolution of Comments

Principal Contributor: T. Huang, NRR

Date: December 9, 2004

RESOLUTION OF COMMENTS

ON DRAFT SAFETY EVALUATION FOR TOPICAL REPORT WCAP-16081-P, "10X10 SVEA FUEL CRITICAL POWER EXPERIMENTS AND CPR CORRELATION: SVEA-96 OPTIMA2"

By e-mail dated November 29, 2004, Westinghouse provided comments on the draft safety evaluation (SE) for WCAP-16081-P, "10x10 SVEA Fuel Critical Power Experiments and CPR Correlation: SVEA-96 Optima2." The following is the staff's resolution of those comments.

1. Westinghouse Comment: Page 3, Section 3.1, line 13. Westinghouse requested that the NRC remove proprietary words from the non-proprietary version of the SE.

   NRC Action: The comment was adopted into the final SE. Proprietary information was appropriately marked.