November 24, 2003

Mr. John Galembush, Acting Manager
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Westinghouse Electric Company
P.O. Box 355
Pittsburgh, PA 15230-0355

SUBJECT: DRAFT SAFETY EVALUATION FOR WESTINGHOUSE TOPICAL REPORT WCAP-16047-P, "IMPROVED APPLICATION OF WESTINGHOUSE BOILING-LENGTH CPR CORRELATIONS FOR BWR SVEA FUEL" (TAC NO. MB8042)

Dear Mr. Galembush:

Enclosed for Westinghouse's review and comment is a copy of the staff's draft safety evaluation (SE) for Topical Report (TR) WCAP-16047-P, "Improved Application of Westinghouse Boiling-length CPR Correlations for BWR SVEA Fuel."

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 ten 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. Following your agreement that the draft SE is non-proprietary, we will place it in the public document room while you continue your review for factual errors or clarity concerns. Please identify any such errors or concerns within 20 working days of this letter.

In the event of any comments or questions, please contact Brian Benney at (301) 415-1436.

Sincerely,

/RA/

Stephen Dembek, Chief, Section 2
Project Directorate IV
Division of Licensing Project Management
Office of Nuclear Reactor Regulation

Project No. 700

Enclosure: Draft Safety Evaluation

cc w/encl:
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DRAFT SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

WCAP-16047-P, REV. 0, "IMPROVED APPLICATION OF WESTINGHOUSE

BOILING-LENGTH CPR CORRELATIONS FOR BWR SVEA FUEL"

WESTINGHOUSE ELECTRIC COMPANY

PROJECT NO. 700

1.0 INTRODUCTION

By letter dated February 18, 2003 (Reference 1), Westinghouse Electric Company (Westinghouse) submitted Topical Report (TR) WCAP-16047-P, Rev. 0, "Improved Application of Westinghouse Boiling-Length CPR Correlations for BWR SVEA Fuel," to the NRC for review and approval. Westinghouse had previously discussed the improvements to the SVEA boiling-water reactor (BWR) fuel correlations during a teleconference (Reference 2) with the NRC staff.

The objective of WCAP-16047-P, Rev. 0, is to present two improvements in the application of the NRC approved boiling-length critical power correlations to SVEA BWR fuel for licensing approval. The two improvements consist of: (1) applying a correction factor to the critical power ratio (CPR) correlation prediction when the axial power profile is in the shape of a double hump, and (2) an enhancement to the treatment of the CPR predictions for the four sub-bundles in an SVEA fuel assembly. The two Westinghouse BWR SVEA fuel types currently operating in the U.S. are the SVEA-96 and the SVEA-96+ designs (References 3 and 4). The details of these improvements are presented below.

2.0 REGULATORY EVALUATION

Section 50.34, "Contents of Applications; Technical Information," of Title 10 of the Code of Federal Regulations 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 that key inputs to the safety analyses (such as the CPR) are conservative with respect to the current design cycle. If key safety analysis parameters are not bounded, a reanalysis or reevaluation of the affected transients or accidents is performed to ensure that the applicable acceptance criteria are satisfied.

The TR describes the vendor’s methodology for implementing two improvements to the existing SVEA-96 and SVEA-96+ CPR correlations. Because the NRC staff has previously reviewed and approved these correlations, its review of the TR focused on the two improvements to be implemented to the approved correlations. Specifically, the NRC staff review focused on the two improvements in the application of the CPR correlations to the SVEA BWR fuel. There are no specific regulatory requirements or guidance available for the review of TR revisions. As such, the staff review was based on the evaluation of technical merit and compliance of the revisions with any applicable regulations.

3.0 TECHNICAL EVALUATION

3.1 Background Information

The TR documents the improvements to be made in the application of the Westinghouse SVEA CPR correlations in order to address possible non-conservatisms associated with the double hump power profile and to address the CPR treatment of the four sub-bundles in an SVEA assembly. The application of the improvements are only valid for the SVEA-96 and SVEA-96+ correlations. The improvements presented in the TR are independent of each other and can be described in the following ways:

1. An analytical correction to ensure conservative CPR predictions for double-peaked axial power distributions, and

2. An enhancement to improve the treatment of CPR predictions for the four sub-bundles in an SVEA assembly.

Westinghouse discussed these initiatives with the NRC in a teleconference in November 2001 (Reference 2). During that teleconference, the NRC staff requested that Westinghouse provide a written description of the proposed improvements. Accordingly, Westinghouse submitted documentation of the teleconference for information (Reference 5). Based on its review of Reference 5, the NRC staff requested that the information contained in Reference 5 be provided for formal review. The formal submittal of the request is provided in Reference 1.

These two improvements in the application of the boiling-length CPR correlations to SVEA fuel are not directly related to each other and can be implemented separately. The double-peaked correction factor improvement is a result of recent critical power measurements for a single heated rod in a heated annulus conducted at the Royal Institute of Technology (KTH) in Stockholm, Sweden. The ABBD1.0 and ABBD2.0 CPR correlations (References 3 and 4), are used in the U.S. for SVEA-96 and SVEA-96+ fuel CPR determinations for core supervision calculations and licensing analyses. These critical-quality/boiling-length CPR correlations are based on top-peaked, bottom-peaked, and cosine-shaped axial power distributions. The KTH measurements indicated that the Westinghouse boiling-length CPR correlations may overpredict the assembly CPR for certain types of axial power distributions generally characterized as double-peaked shapes. Westinghouse has reviewed this KTH data and developed a method of conservatively correcting the predictions of boiling-length CPR correlation predictions for this type of axial power distribution for SVEA fuel in general, and for the ABBD1.0 and ABBD2.0 correlations in particular. CPR is calculated as described in References 3 and 4, then corrected as required to ensure conservatism in the CPR prediction for each assembly. The enhancement to improve the treatment of CPR predictions for the four sub-bundles in an SVEA assembly is related to the establishment of the CPR correlations primarily based on 24-rod sub-bundle measurements. Traditionally, the method for applying these CPR correlations to a full assembly has utilized the mismatch factor method described in References 3 and 4. However, recent experience with high energy cycles with relatively large feed fuel batches has demonstrated that the mismatch factor method described in Reference 3 can lead to the incorrect prediction that highly controlled assemblies become limiting.

Accordingly, Westinghouse has developed an improved method of applying the CPR values calculated as described in References 3 and 4 for SVEA assemblies including the SVEA-96 and SVEA-96+ assemblies.

3.2 Licensing Application

Westinghouse will continue using the ABBD1.0 and ABBD2.0 CPR correlations as described in References 3 and 4. Although the annular tube configuration upon which the KTH test information is based does not represent the configuration of SVEA-type Westinghouse BWR fuel assemblies, Westinghouse has found that the CPR calculated by ABBD1.0 and ABBD2.0 and corrected for double-peaked axial power distributions using the process described in Section 4 of Reference 1, conservatively encompasses both the recent FRIGG loop and KTH data. Therefore, Westinghouse will implement the double-peaked correction factor in licensing analysis applications of the ABBD1.0 and ABBD2.0 CPR correlations.

The ABBD1.0 and ABBD2.0 CPR correlations are intended to provide best-estimate CPR predictions. Uncertainties which assure conservative CPR limits are treated by the safety limit maximum critical power ratio (MCPR) and are incorporated in operating limit MCPR analyses discussed in Reference 6. The sub-bundle model described in Reference 1 is designed to augment the currently NRC accepted mismatch factor method described in References 3 and 4 in a manner which assures that the ABBD1.0 and ABBD2.0 CPR correlations do not overpredict margins to dryout. For some applications and fuel types, the mismatch factor method has been demonstrated to be adequate for steady-state applications. Therefore, Westinghouse intends to continue using the mismatch factor method for these fuel types and applications, for which it has been demonstrated.

3.3 Axial Power Shape Correction Factor

The ABBD1.0 and ABBD2.0 CPR correlations documented in References 3 and 4 are based on top-peaked, bottom-peaked, and cosine-shaped axial power distributions. These correlations are based upon and exhibit a very good fit to the extensive FRIGG loop database. Experience to date has confirmed that these correlations accurately capture the databases from which they were derived. Current BWR industry practice is to base critical power tests on these three axial power shapes. However, the recent KTH test data indicates that boiling length CPR correlations, including the ABBD1.0 and ABBD2.0 correlations, may overpredict CPR for double-peaked axial power shapes. The possibility that the Westinghouse boiling length CPR correlations may overpredict the assembly CPR for double-peaked axial power shapes is based on critical power measurements for a single heated rod in a heated annulus conducted recently at the Royal Institute of Technology (KTH) in Stockholm, Sweden. A description of some of these KTH measurements is provided in Reference 7. The tests described in Reference 7 involved an annular geometry consisting of one heated central test rod within a concentric heated outer tube. The benefit of this relatively simple KTH geometry is that it facilitates testing of a relatively broad spectrum of axial power shapes. This tube data may not be fully representative of the CPR performance of the current SVEA-type Westinghouse BWR fuel assemblies since the annular test configuration is believed to be more conducive to dryout than are the actual fuel rods in the SVEA-96 and SVEA-96+ assembly geometric configuration, which have fuel rods adjacent to cold unheated surfaces as well as to other fuel rods.

While the KTH geometry is not entirely representative of the Westinghouse SVEA 10x10 geometric configuration including the SVEA-96 and SVEA-96+ assemblies, the possibility exists that the non-conservative trends implied by the tube data could occur for Westinghouse 10x10 SVEA fuel design critical-quality/boiling-length CPR correlations. Accordingly, detailed comparisons of the Westinghouse 10x10 SVEA fuel design critical-quality/boiling-length CPR predictions, including ABBD1.0 and ABBD2.0, with the trends in the KTH database were performed to establish a means to correct the CPR predictions to accommodate the KTH trends. The result was an assembly flow-dependent correction factor which avoids non-conservative predictions when compared with the KTH data while still predicting the relative CPR performance of the FRIGG loop power distributions.

The derivation of the correction factor preserves the relative CPR performance of the FRIGG loop database for top-peaked, bottom-peaked, and cosine-shaped axial power distributions. The correction factor preserves the fit to the FRIGG Loop databases described in References 3 and 4, while reducing CPRs for double-peaked axial power shapes, thereby avoiding a possible overprediction of CPR implied by the KTH test data.

4.0 SUB-BUNDLE CPR CALCULATIONAL MODEL FOR SVEA FUEL

In calculating the CPR for the SVEA-type assemblies, a special consideration has been given to the fact that the SVEA channel consists of four sub-channels separated by a water cross with flow communication slots between the sub-channels along the channel length. Each sub-channel contains a sub-bundle. Since the CPR correlation is applied to full (e.g., 96-rod) SVEA-type assemblies in design and licensing applications as well as for CPR monitoring in the plant core monitoring system, the impact on critical power caused by a mismatch in the power between the sub-bundles and the flow mismatch caused by this power mismatch must be taken into account. As described in References 3 and 4, this power mismatch is currently accounted for in the critical-quality/boiling-length CPR correlations for SVEA-type fuel by an adjustment built into the correlation referred to as the mismatch factor.

Experience from reload analyses has shown that this mismatch factor approach can lead to very conservative CPR predictions. Since the mismatch factor is unity for the same power in each sub-bundle, the conservatism in the mismatch factor tends to increase as the power mismatch increases. Consequently, the mismatch factor tends to become increasingly conservative for highly skewed radial power distributions, such as those caused by the presence of a control rod adjacent to the assembly for which CPR is being calculated. Historically, a conservative mismatch factor is more acceptable when applied to the relatively small reload fuel batches associated with short cycles since fresh (relatively high power) fuel assemblies adjacent to inserted control blades can generally be avoided.

Recent industry trends toward more efficient operation with higher energy cycles have increased the probability of control rod insertion adjacent to relatively fresh assemblies. Furthermore, an important source of double-peaked axial power distributions is the partial insertion of a control rod. Consequently, the combination of the conservative double-peaked axial power shape correction and the mismatch factor can lead to CPR underprediction and significantly increase the probability that highly controlled assemblies will erroneously be predicted to be limiting.

As a result, Westinghouse has developed an alternative method of accommodating sub-bundle power mismatch in SVEA-type fuel. This improved method is referred to as the "sub-bundle model."

The sub-bundle model calculates the CPR on a sub-bundle basis for consistent relative sub-bundle power, flow, inlet enthalpy, and exit pressure. The sub-bundle model performs a specific parallel channel CPR calculation for each sub-bundle each time the assembly CPR is calculated for the actual conditions for which the CPR is being evaluated. This sub-bundle model represents a substantial improvement for calculating SVEA assembly CPR values.

The sub-bundle model described in Reference 1 provides a more accurate analytical method of treating sub-bundle power mismatch than the mismatch factor method. The mismatch factor method uses a polynomial function correlated from the results of a representative set of calculations which treat the four sub-channels in the SVEA assembly as non-communicating parallel channels. The sub-bundle model performs a specific parallel channel CPR calculation for each of the four sub-channels in an SVEA assembly each time the assembly CPR is evaluated for the actual conditions occurring at that time. For a given SVEA-type assembly, sub-bundle powers and axial power shapes are inferred from the full assembly power and axial power shape calculated in the 3-D core simulator in conjunction with relative sub-bundle powers obtained from lattice calculations. Using these sub-bundle powers and axial power shapes with the full assembly flow rate, inlet enthalpy, and exit pressure, a hydraulic calculation for the assembly is performed to establish the flow rates to the four SVEA sub-channels conservatively assuming no transverse flow between the sub-channels. Using this information, the critical power ratio in each sub-channel is then calculated. The minimum value of the four sub-bundle CPRs is used to represent the entire assembly in the 3-D core simulator.

Although the sub-bundle model was shown to provide a more accurate analytical solution than the mismatch factor method (response to request 3 of the request for additional information [Reference 8]), Westinghouse will utilize the sub-bundle model for steady-state applications to the ABBD1.0 correlation only. The reason for this is that the database for the SVEA 96 fuel consists of only sub-bundle data. That is, no full-bundle data exists to optimize the mismatch factors. Consequently, in this case, Westinghouse will use the sub-bundle model rather than the mismatch factor method since the sub-bundle model provides a more accurate analytical solution. Regarding the ABBD2.0 correlation, the availability of full-bundle data makes it possible to obtain fully optimized mismatch factors. Consequently, Westinghouse will continue to use the mismatch factor method for steady-state applications of the ABB2.0 correlation.

Furthermore, both correlations will continue to use the mismatch factor method when these correlations are applied in transient analyses. Historically, correlations that were developed with steady-state data have been found to be conservative when applied to transient conditions.

For example, confirmation that the ABBD1.0 and ABBD2.0 CPR correlations provide conservative results when used to predict changes in CPR during simulated fast transients is provided in References 3 and 4, respectively.

Qualification of the fast transient methodology discussed in Reference 8 for the sub-bundle model would require substantial effort on behalf of the vendor without any expected improvement in the overall accuracy of the results. Therefore, the sub-bundle model described in this submittal will serve only to augment the currently accepted mismatch factor method (which is already overly conservative when applied to fast transients), described in References 3 and 4, in a manner which assures that the ABBD1.0 and ABBD2.0 CPR do not overpredict, or grossly underpredict, margins to dryout. Since there is no benefit associated with adopting the sub-bundle model for some licensing analyses, such as the fast transient analysis described in Reference 6, and since the mismatch factor method has been demonstrated to be adequate for the SVEA-96 and SVEA-96+ fuel types, the mismatch factor method will continue to be used for applications in which it has been demonstrated to provide margins to dryout which are not overpredicted. The NRC staff agrees with the technical analysis and conclusions provided by the vendor in support of the proposed requests, because they are technically sound and meet the regulatory requirements stipulated in Section 2.0 of this safety evaluation.

5.0 LIMITATIONS

1. Westinghouse will utilize the sub-bundle model for steady-state applications to the ABBD1.0 correlation only.

2. The application of the improvements are only valid for the SVEA-96 and SVEA-96+ correlations.

6.0 CONCLUSION

The NRC staff has reviewed the TR, its supporting documentation, and additional information obtained through discussions with Westinghouse. Based on the considerations and limitations provided above, the NRC staff has concluded that the proposed TR is acceptable for use in licensing applications.

7.0 REFERENCES

1. WCAP-16047-P, Rev. 0, "Improved Application of Westinghouse Boiling-Length CPR Correlations for BWR SVEA Fuel," February 2003.

2. Telecommunication, J. Cushing (NRC) to W. Harris (WEC), November 7, 2001.

3. CENPD-392-P-A, "10x10 SVEA Fuel Critical Power Experiments and CPR Correlations: SVEA-96," September 2000.

4. CENPD-389-P-A, "10x10 SVEA Fuel Critical Power Experiments and CPR Correlations: SVEA-96+," September 1999.

5. LTR-ESI-02-030, "Improved Application of Westinghouse Boiling Length CPR

Correlations" (contains Proprietary Information), February 8, 2002.

6. CENPD-300-P-A, "Reference Safety Report for Boiling Water Reactor Reload Fuel," July 1996.

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

8. LTR-NRC-03-52, "Responses to Request for Additional Information," Westinghouse Electric Company, to the U. S. Nuclear Regulatory Commission, August 28, 2003.

Principle Contributor: A. Attard

Date: