Westinghouse Non-Proprietary Class 3

WCAP-16047-NP-A
Revision 0

March 2004

Improved Application of Westinghouse Boiling-Length CPR Correlations For BWR SVEA Fuel

Westinghouse

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WCAP–16047-NP-A, Revision 0

Improved Application of Westinghouse Boiling-Length CPR Correlations For BWR SVEA Fuel

March 2004

Windsor Fuel Engineering

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UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

December 15, 2003

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

SUBJECT: FINAL SAFETY EVALUATION FOR TOPICAL REPORT WCAP-16047-P, REV. 0, "IMPROVED APPLICATION OF WESTINGHOUSE BOILING-LENGTH CPR CORRELATIONS FOR BWR SVEA FUEL" (TAC NO. MB8042)

Dear Mr. Galembush:

By letters dated February 18, 2003, and September 3, 2003, 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 staff. On November 24, 2003, an NRC draft safety evaluation (SE) regarding our approval of WCAP-16047-P was provided for your review and comments. By e-mail dated December 4, 2003 (ADAMS Accession No. ML033430277), Westinghouse commented on the draft SE. The staff agreed with Westinghouse's comments on the draft SE and made the appropriate changes.

The staff has found that WCAP-16047-P, Rev. 0 is acceptable for referencing as an approved methodology in plant licensing applications. The enclosed safety evaluation documents the staff's evaluation of Westinghouse's justification for the improved methodology.

Our acceptance applies only to the 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 an accepted version within three months of receipt of this letter. The accepted version 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, draft SE comments, and original report pages that were replaced. The accepted version shall include a "-A" (designating "accepted") following the report identification symbol.

If the NRC's criteria or regulations change so that its conclusions in this letter, that the topical report is acceptable, is invalidated, Westinghouse and/or the licensees referencing the TR will be expected to revise and resubmit its respective documentation, or submit justification for the continued applicability of the TR without revision of the respective documentation.

Sincerely,

Robert A Gramm for /

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

Project No. 700

Enclosure: Safety Evaluation

cc w/encl:
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UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

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 minimum 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 test data conducted at the Royal Institute of Technology (KTH) in Stockholm, Sweden, 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. 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: December 15, 2003

EXECUTIVE SUMMARY

Westinghouse intends to introduce two improvements in the application of its boiling-length Critical Power Ratio (CPR) correlations to SVEA (i.e. water cross) BWR fuel. The purpose of this report is to describe these improvements and request NRC acceptance of their application to Westinghouse SVEA fuel currently operating in the U.S. Application of these improvements to advanced Westinghouse BWR fuel designs not currently operating in the U.S will be addressed in the licensing topical reports (LTRs) requesting acceptance of the CPR correlations for those fuel types. The two Westinghouse BWR SVEA fuel types currently operating in the U.S are the SVEA-96 and SVEA-96+ designs. References 1 and 2 describe the ABBD1.0 and ABBD2.0 Critical Power Ratio (CPR) correlations used to predict dryout in the Westinghouse SVEA-96 and SVEA-96+ fuel, respectively.

The two improvements in the application of these correlations which are addressed in this document are independent of each other and can be summarized as follows:

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 a SVEA assembly.

Westinghouse will implement the double-peaked correction factor in licensing analysis applications of the ABBD1.0 and ABBD2.0 CPR correlations. The Sub-bundle Model described in this document will augment the currently accepted Mismatch Factor Method described in References 1 and 2 in a manner which assures that the margins to dryout are not over-predicted by the ABBD1.0 and ABBD2.0 CPR correlations. Implementing these improvements does not involve any change to the approved ABBD1.0 and ABBD2.0 CPR correlations described in References 1 and 2.

Formal staff review and approval of these enhancements is requested.

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APPENDIX 1 RESPONSE TO NRC REQUESTS FOR ADDITIONAL INFORMATION

1 INTRODUCTION AND SUMMARY

Westinghouse intends to introduce two improvements in the application of its boiling-length Critical Power Ratio (CPR) correlations to SVEA (i.e. water cross) BWR fuel. The purpose of this report is to describe these improvements and request NRC acceptance of their application to Westinghouse SVEA fuel currently operating in the U.S. Application of these improvements to advanced Westinghouse BWR fuel designs not currently operating in the U.S will be addressed in the licensing topical reports (LTRs) requesting acceptance of the CPR correlations for those advanced fuel types. The two Westinghouse BWR SVEA fuel types currently operating in the U.S are the SVEA-96 and SVEA-96+ designs. References 1 and 2 describe the ABBD1.0 and ABBD2.0 Critical Power Ratio (CPR) correlations used for Westinghouse SVEA-96 and SVEA-96+ BWR fuel.

The two improvements in the application of these correlations which are addressed in this document are independent of each other and can be summarized as follow:

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 a SVEA assembly.

Westinghouse discussed these initiatives with the NRC in Reference 3. During that telephone conversation, the NRC requested that Westinghouse provide a written description of the proposed improvements. Accordingly, Westinghouse submitted Reference 4 for information. Based on its review of Reference 4, the NRC requested that the information in Reference 4 be provided for formal review in Reference 5. This LTR is submitted in response to the NRC request.

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 Critical Power Ratio (CPR) correlations, References 1 and 2, are used in the U.S. for SVEA-96 and SVEA-96+ fuel CPR determinations for core supervision 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 over-predict the assembly CPR for certain types of axial power distributions generally characterized as double-peaked shapes. Westinghouse has carefully 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 our SVEA fuel in general, and for the ABBD1.0 and ABBD2.0 correlations in particular. CPR is calculated as described in References 1 and 2, then corrected as required to ensure conservatism. [ ]

[

]

The enhancement to improve the treatment of CPR predictions for the four sub-bundles in a 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 1 and 2. [

] For example, recent experience with high energy cycles with relatively large feed fuel batches has demonstrated that the Mismatch Factor Method described in Reference 1 can lead to the prediction that highly controlled assemblies become limiting.

Accordingly, Westinghouse has developed an improved method of applying the CPR values calculated as described in References 1 and 2 for SVEA assemblies including the SVEA-96 and SVEA-96+ assemblies. [

]

2 LICENSING APPLICATION

1. The ABBD1.0 and ABBD2.0 CPR correlations will continue to be evaluated as described in References 1 and 2.

2. 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 CPR calculated by ABBD1.0 and ABBD2.0 and corrected for double-peaked axial power distributions using the process described in Section 4 conservatively encompasses both the 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.

3. 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 MCPR and incorporated in Operating Limit MCPR analyses discussed in Reference 7. The Sub-bundle Model described in this document will augment the currently accepted Mismatch Factor method described in References 1 and 2 in a manner which assures that the ABBD1.0 and ABBD2.0 CPR correlations do not over-predict margins to dryout. [

]

3 AXIAL POWER SHAPE CORRECTION FACTOR

The ABBD1.0 and ABBD2.0 CPR correlations documented in References 1 and 2 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 over-predict CPR for double-peaked axial power shapes.

The possibility that the Westinghouse boiling length CPR correlations may over-predict 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 6. The tests described in Reference 6 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. [

]

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 designs critical quality-boiling length CPR correlations. [

] [ ]

The correction factor is [ ] when applied [ ] to the CPR predicted by the critical quality-boiling length correlation such as ABBD1.0 and ABBD2.0.

The correction factor is established through the following two-step process:

[ ]

[ ]

Specifically the correction factor is given by:

[Equation 3-1

Equation 3-2

Equation 3-3

]

Figure 3-1 illustrates the establishment of the correction factor. Assuming that Node 1 is the bottom of the assembly, [

]

The derivation of the correction factor in this manner [

]

Figure 3-1 – Example of Axial Shapes Defining Correction Factor

4 SUB-BUNDLE CPR CALCULATIONAL MODEL FOR SVEA FUEL

4.1 Background

A special consideration in calculating the R-factor for the SVEA-type assemblies has to do with 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 1 and 2, this power mismatch is currently accounted for in the boiling-length critical-quality CPR correlations for SVEA-type fuel by an adjustment to the [ ] CPR calculation by a factor referred to as the "Mismatch Factor."

Experience 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 under-prediction and significantly increase the probability that highly controlled assemblies will erroneously be predicted to be limiting. Therefore, the incentive to adopt the more accurate sub-bundle model for CPR evaluation of SVEA-type fuel is more important today than in the past.

[

]

[ ]

Ideally, the determination of these sub-bundle hydraulic conditions for which to evaluate the correlation would incorporate the following features:

1. [ ]
2. [ ]
3. [ ]

Unfortunately, [ ] our understanding is that most current core simulators supporting on-line Core Monitoring Systems only have the capability to calculate converged power/void distributions on a full assembly basis.

Accordingly, Westinghouse has developed a simplified method of accommodating sub-bundle power mismatch in SVEA-type fuel [ ] This improved method is referred to as the "Sub-bundle Model" and is described in Section 4.2. This Sub-bundle Model approach of calculating the CPR [ ] described in Section 4.2 represents a substantial improvement for establishing SVEA assembly CPR relative to the full assembly calculation and the Mismatch Factor method described in References 1 and 2. The Mismatch Factor approach described above also [ ]

4.2 Sub-bundle Model Description

As noted in Section 4.1, the CPR evaluation of SVEA-type fuel using the Sub-bundle Model is performed in a manner which can be supported by three dimensional core simulators typically used in U.S. plant core supervision systems

[

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1. [

]

2. [

]

3. [

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4. [

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5. [

]

[
]

6. [
]

7. [
]

8. [
]

4.3 Application of Sub-bundle Model

The accuracy of the Mismatch Factor Method can depend on the CPR correlation database. Westinghouse BWR CPR correlations to date [

]

Furthermore, [
]

[

] 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 using the transient analysis methodology described in Reference 7 was provided in References 1 and 2, respectively. [

]

Therefore, the Sub-bundle Model described in this document will augment the currently accepted Mismatch Factor method described in References 1 and 2 in a manner which assures that the ABBD1.0 and ABBD2.0 CPR do not over-predict, or grossly under-predict, margins to dryout. [

]

5 REFERENCES

1. CENPD-392-P-A, 10x10 SVEA Fuel Critical Power Experiments and CPR Correlations: SVEA-96, September 2000.
2. CENPD-389-P-A, 10x10 SVEA Fuel Critical Power Experiments and CPR Correlations: SVEA-96+, September 1999.
3. Telecommunication, J. Cushing (NRC) to W. Harris (WEC), November 7, 2001.
4. LTR-ESI-02-030, improved Application of Westinghouse Boiling Length CPR Correlations (Contains Proprietary Information), February 8, 2002.
5. Telecommunication, Anthony Attard (NRC) to W. Harris (WEC), July 16, 2002.
6. 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, 25-29 September, 2000.
7. CENPD-300-P-A Reference Safety Report for Boiling Water Reactor Reload Fuel, July, 1996.
8. CENPD-390-P-A, Rev. 00, The Advanced PHOENIX and POLCA Codes for Nuclear Design of Boiling Water Reactors, December 2000.

Appendix 1

Response to NRC Requests for Additional Information

Responses to NRC Requests for Additional Information (RAIs) were submitted to the NRC in the Enclosure to Westinghouse letter LTR-NRC-03-52, H. A. Sepp to Document Control Desk, "Response to Request for Additional Information Regarding WCAP-16047-P, 'Improved Application of Westinghouse Boiling-Length CPR Correlations for BWR SVEA Fuel' (Proprietary)," September 3, 2003. The following pages of this appendix are copies of the actual pages from the Enclosure to LTR-NRC-03-52 with proprietary content deleted.

Enclosure

Response to Request for Additional Information (RAI) for WCAP-16047-P

1. Introduction and Background

This Enclosure provides responses to the Nuclear Regulatory Commission (NRC) Request for Additional Information (RAI), Reference 1, supporting review of Westinghouse Electric Company LLC (Westinghouse) topical report WCAP-16047-P, "Improved Application of Westinghouse Boiling-Length CPR Correlations for BWR SVEA Fuel", Reference 2.

The purpose of Reference 2 was to describe improvements in the application of Westinghouse boiling-length Critical Power Ratio (CPR) correlations to Boiling Water Reactor (BWR) SVEA fuel and to request NRC acceptance of their application to Westinghouse SVEA fuel currently operating in the United States. Accordingly, the RAI responses provided herein apply to the SVEA-96 and SVEA-96+ fuel designs for which the ABBD1.0 and ABBD2.0 CPR correlations are documented in References 3 and 4.

The RAIs in Reference 1 deal with the application of the Sub-bundle Model and the Mismatch Factor Method currently used in Westinghouse boiling-length critical-quality CPR correlations for 10x10 SVEA fuel. Therefore, it is useful to summarize the difference between these approaches. As discussed in References 2, 3, and 4, Westinghouse BWR CPR correlations [

]^{a,c} As discussed in References 2, 3 and 4, the SVEA-96 designs consist of 96 fuel rods arranged in four (4) sub-bundles. These sub-bundles are contained in four (4) sub-channels formed by a double-walled water cross with a series of flow communication slots located at axial intervals which provide flow communication between the sub-channels. A non-uniform sub-bundle power mismatch leads to a non-uniform sub-channel flow distribution. As described in References 2, 3, and 4, this power mismatch in SVEA-type fuel has been accounted for in the past in Westinghouse boiling-length critical-quality CPR correlations by an adjustment to the [ ]^{a,c} CPR calculation by a factor referred to as the "Mismatch Factor." As discussed in References 2 through 4 for SVEA-96 and SVEA-96+ assemblies, the Mismatch Factor is derived by conservatively treating the four sub-channels in the 96-rod SVEA assembly as four non-communicating parallel channels with hydraulic calculations determining the relative sub-channel flow and quality distributions in each sub-channel for a representative set of conditions. Based on these representative parallel channel hydraulic calculations for a range of conditions, [

]^{a,c}

A more accurate method of treating sub-bundle power mismatch is to perform the same type of parallel channel calculation as those used to establish the Mismatch Factor each time the assembly CPR is evaluated for the actual conditions occurring at that time. This approach is referred to as the Sub-bundle Model in Reference 2. Treatment of the sub-channel power mismatch [

]^{a,c}

Ninety-six fuel rod full assembly CPR data have been obtained for two SVEA-96 type designs. Full assembly data are available for the SVEA-96+ design as discussed in Reference 4 and for the SVEA-96 Optima desion. SVEA-96 Optima is a preliminary part-length rod version of the SVEA-96 design [

]^{a,c} When full assembly data are available, these data can be used to assess the accuracy of the relatively simple Mismatch Factor Method and can be used as required to adjust the Mismatch Factor to provide a best fit to the full-assembly data for non-uniform relative sub-bundle power distributions. In general, the Sub-bundle Model provides the more accurate of the two methods since it involves a specific parallel channel hydraulic calculation each time the assembly CPR is evaluated for the actual conditions for which the CPR is being evaluated.

Unless otherwise noted, references to sections and sub-sections in the text in this Enclosure refer to Reference 2.

2. Response to RAIs in Reference 1

NRC Request 1

In Section 4, sub-Section 4.2, reference is made in the first and second steps, page 4-3, reference is made to "assembly". Should that be sub-assembly?

Westinghouse Response to NRC Request 1

The reference to assembly average quantities in Steps 1 and 2 in Section 4.2 is correct and can be clarified as follows. It is assumed that the core simulator in which the Sub-bundle Model is being applied does not necessarily have the capability to model the four sub-channels in the SVEA design. This assumption recognizes that three dimensional core simulators typically used in United States plant core supervision systems, or those typically in use at utilities for core analyses, may not have the capability to explicitly model and perform power/void calculations for the individual SVEA sub-channels. Therefore, [

]^{a,c}

[

] a,c

NRC Request 2

In Sub-Section 4.3, in the middle of the paragraph, reference is made to "other applications and fuel types". Please clarify (provide examples of other application and fuel types).

Westinghouse Response to NRC Request 2

In Section 4.3, the phrase "other applications" refers to application of a CPR correlation to transient, as opposed to steady state, conditions. The response to NRC Request 4 clarifies the application of the Westinghouse current boiling length correlations to transient applications.

In Section 4.3, the phrase "other...fuel types" reflects the fact that the relative merits of using the Mismatch Factor Method or the Sub-bundle Model for steady-state applications could depend on the CPR data base for that fuel assembly type. The response to NRC Request 5 clarifies the bases for utilizing the Mismatch Factor Method or Sub-bundle Model for steady-state applications.

NRC Request 3

Please provide (demonstrate) the conservatism of the sub-bundle method by comparing the results of the sub-bundle model to those of the mismatch factors.

Westinghouse Response to NRC Request 3

Comparison with available full 96-rod SVEA assembly data is the most effective means of demonstrating the level of conservatism associated with the Sub-bundle Model. As shown in this response, [

] a,c

Figure 3-1 is a comparison of the predictions of the ABBD2.0 CPR correlation using the Mismatch Factor Method and the Sub-bundle Model for the SVEA-96+ full assembly data base discussed in Reference 4 and provided in Appendix C of Reference 4. The independent variable, "Relative Sub-bundle Power Mismatch", in Figure 3-1 is the maximum sub-bundle relative power referred to as "Fsub" in Appendix C of Reference 4. The experimental value of CPR for each data point is unity. Therefore, predicted CPR values less than unity imply a critical power less than the measured value and are, therefore, conservative.

As shown in Figure 3-1, the Mismatch Factor Method and Sub-bundle Model [

][a,c]

[ ][a,c]

It should be noted that the availability of the full assembly data [ ][a,c]

NRC Request 4

In the last paragraph on page 4-4, it is stated that, substantial effort would be required to demonstrate that the sub-bundle method is conservative in predicting fast transient CPR behavior. Regardless, the staff still need tangible confirmation that if the sub-bundle model is to be used for predicting transient behavior, it must be demonstrated that it is conservative.

Westinghouse Response to NRC Request 4

Westinghouse agrees with the observation in Request 4 that a tangible confirmation of the capability of the sub-bundle model used in conjunction with a given CPR correlation to conservatively predict CPR for transient conditions would be required. This tangible confirmation would follow the methodology described in Sections 7 and 6 of References 3 and 4, respectively, for the ABBD1.0 and ABBD2.0 CPR correlations using the Sub-bundle Model rather than Mismatch Factor Method. As discussed in Sections 7 and 6 of References 3 and 4, respectively, this methodology involves confirmation that a given steady-state CPR correlation, including the method used to establish full assembly CPR values based on the application of the correlation on a sub-bundle basis, in conjunction with a given transient code, is capable as a package of providing conservative predictions of CPR response to the transient. As noted in Section 4.3, utilization of the Mismatch Factor Method is adequate for this purpose, and there is currently no benefit associated with adopting the Sub-bundle Model for the fast transient analysis application. Therefore, Westinghouse will continue to use the Mismatch Factor Method for any required CPR evaluations of fast transient analyses of SVEA-96 and SVEA-96+ fuel.

NRC Request 5

In the last paragraph, on page 4-5, it is alluded to, that the sub-bundle model and the mismatch factor method will be utilized in a manner dependent on the situation at hand. It is not made clear how this random process will work; that is, who and when makes the decision at the time of need?? How is the staff assured that those that are making the decision(s) are qualified to do so?? etc., etc. This need to be discussed with the staff and documented.

Westinghouse Response to NRC Request 5

Recognizing that the Sub-bundle model is conservative as demonstrated in the Response to Request 3, and recognizing that the Sub-bundle Model is more accurate than the Mismatch Factor Method, Westinghouse will utilize the Sub-bundle Model for steady-state applications in general. Exceptions to this general practice can be made in those cases in which it can be demonstrated for a given application that the Mismatch Factor provides sufficiently accurate results for that application. For example, use of the ABBD2.0 Mismatch Factor for steady-state applications is acceptable since the SVEA-96+ full assembly database allowed the Mismatch Factor to be adjusted to fit the full assembly database and, thereby, adequately capture the effect of sub-bundle power mismatch.

In the U.S. this general approach will be applied to the SVEA-96 and SVEA-96+ applications as follows:

1. Steady-state licensing applications of ABBD1.0 (SVEA-96) will use the four sub-bundle model.
2. Steady-state licensing applications of ABBD2.0 (SVEA-96+) will use the Mismatch Factor Method.

As noted in the Response to Request 4, Westinghouse will continue to use the Mismatch Factor Method for any required CPR evaluations of fast transient analyses of SVEA-96 and SVEA-96+ fuel.

References

1. Email, A. C. Attard (NRC), "Double Hump RAIs", May 09, 2003, 10:27am
2. WCAP-16047-P, "Improved Application of Westinghouse Boiling-Length CPR Correlations for BWR SVEA Fuel", February 2003
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.

a,b,c

Figure 3-1 ABBD2.0 Predictions of Full Assembly Data Base using Mismatch Factor Method and Sub-bundle Model