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

Westinghouse

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WCAP–16047-NP, Revision 0

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Windsor Fuel Engineering

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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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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. [ ]

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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.

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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. [

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2. [

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3. [

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4. [

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5. [

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[

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6. [

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7. [

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8. [

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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.

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WESTINGHOUSE ELECTRIC COMPANY LLC

PROPRIETARY AFFIDAVIT

FOR

WCAP-16047-P, REV. 0

IMPROVED APPLICATION OF WESTINGHOUSE BOILING-LENGTH CPR CORRELATIONS FOR BWR SVEA FUEL

Proprietary Affidavit

I, Ian. C. Rickard, depose and say that I am the Licensing Project Manager, Windsor Nuclear Licensing, of Westinghouse Electric Company LLC (WEC), duly authorized to make this affidavit, and have reviewed or caused to have reviewed the information which is identified as proprietary and described below.

I am submitting this affidavit in conformance with the provisions of 10 CFR 2.790 of the Commission's regulations for withholding this information. I have personal knowledge of the criteria and procedures utilized by WEC in designating information as a trade secret, privileged, or as confidential commercial or financial information.

The information for which proprietary treatment is sought, and which documents have been appropriately designated as proprietary, is contained in the following:

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

Pursuant to the provisions of Section 2.790(b)(4) of the Commission's regulations, the following is furnished for consideration by the Commission in determining whether the information included in the documents listed above should be withheld from public disclosure.

i. The information sought to be withheld from public disclosure is owned and has been held in confidence by WEC. It consists of information concerning improved methods for applying boiling-length Critical Power Ratio correlations for the design and evaluation of BWR fuel.

ii. The information consists of test data or other similar data for the design, development and implementation of improved methods for applying boiling-length Critical Power Ratio correlations for the design and evaluation of BWR fuel, the application of which results in substantial competitive advantage to WEC.

iii. The information is of a type customarily held in confidence by WEC and not customarily disclosed to the public.

iv. The information is being transmitted to the Commission in confidence under the provisions of 10 CFR 2.790 with the understanding that it is to be received in confidence by the Commission.

v. The information, to the best of my knowledge and belief, is not available in public sources, and any disclosure to third parties has been made pursuant to regulatory provisions or proprietary agreements that provide for maintenance of the information in confidence.

vi. Public disclosure of the information is likely to cause substantial harm to the competitive position of WEC because:

a. A similar product is manufactured and sold by major competitors of WEC.

b. WEC invested substantial funds and engineering resources in the development of this information. A competitor would have to undergo similar expense in generating equivalent information.

c. The information consists of improved methods for applying boiling-length Critical Power Ratio correlations for the design and evaluation of BWR fuel, the application of which provides a competitive economic advantage. The availability of such information to competitors would enable them to design their product to better compete with WEC, take marketing or other actions to improve their product's position or impair the position of WEC's product, and/or avoid developing similar technical analysis in support of their processes, methods or apparatus.

d. In pricing WEC's products and services, significant research, development, engineering, analytical, manufacturing, licensing, quality assurance and other costs and expenses must be included. The ability of WEC's competitors to utilize such information without similar expenditure of resources may enable them to sell at prices reflecting significantly lower costs.

e. Use of the information by competitors in the international marketplace would increase their ability to market a competing product, reducing the costs associated with their technology development.

I C Rickard

Ian. C. Rickard
Licensing Project Manager
Westinghouse Electric Company LLC

Sworn to before me this **14th** day of **February, 2003**

Linda A. Saata

Notary Public
My commission expires: May 31, 2003