Enclosure 13

AREVA Report ANP-3138(NP)

Monticello Improved K-factor Model for ACE/ATRIUM 10XM Critical Power Correlation

Revision 0

36 pages follow

ANP-3138(NP)
Revision 0

Monticello Improved K-factor Model for ACE/ATRIUM 10XM Critical Power Correlation

August 2012

AREVA NP Inc.

AREVA

Controlled Document

AREVA NP Inc.

ANP-3138(NP)
Revision 0

Monticello Improved K-factor Model for ACE/ATRIUM 10XM Critical Power Correlation

Controlled Document

AREVA NP Inc.

ANP-3138(NP)
Revision 0

Monticello Improved K-factor Model for ACE/ATRIUM 10XM Critical Power Correlation

Nature of Changes

Item	Page	Description and Justification
1.	All	This is the initial release.

Controlled Document

Contents

Tables

Figures

Nomenclature

Acronym	Definition
ACE	AREVA Critical power Evaluator
AOO	Anticipated Operational Occurrence
BT	Boiling Transition
BWR	Boiling Water Reactor
CPR	Critical Power Ratio
ECPR	Experimental Critical Power Ratio; the ratio of calculated to the measured critical power
LOCA	Loss Of Coolant Accident
MCPR	Minimum Critical Power Ratio
PLR	Part Length Rod

1.0 Introduction and Summary

Reference 1 presents the approved ACE/ATRIUM 10XM critical power correlation for ATRIUM™* 10XM fuel. A concern with the calculation of the K-factor within the approved ACE correlation was identified. Since K-factor was integrated over the entire heated length of the assembly, it was possible for the local peaking factors in the upper lattices to contribute significantly to the K-factor used, even when dryout occurs much lower in the bundle.

Reference 2 presents a revision to the ACE critical power correlation for ATRIUM 10XM fuel. The Reference 2 correlation is very similar to the Reference 1 critical power correlation with a couple of exceptions. The K-factor methodology was modified in response to deficiencies found in the axial averaging process. In addition, the additive constants were revised as a result of the change to the K-factor model. Evaluations confirmed that the Reference 1 critical power correlation coefficients do not require revision as a result of these changes.

The purpose of this document is to present the ACE/ATRIUM 10XM critical power correlation that will be used in licensing analyses for Monticello until Reference 2 is generically approved and included in the Monticello Plant Technical Specifications. The correlation presented in this document is exactly the same as that presented in Reference 2.

Reference 3 provides a description of the rod local peaking function (called K-factor). The improved K-factor method used in the Monticello ACE/ATRIUM 10XM critical power correlation is described in this document. This modified method supersedes the one described in Reference 3 and used in Reference 1. This document also describes the minor changes in the method for determining additive constants that became necessary due to the changes in the K-factor methodology.

The comparison between measured and predicted critical power data is shown in Figure 1-1. The correlation experimental critical power ratio (ECPR) mean with the improved K-factor methodology and updated additive constants is [ ] and the ECPR standard deviation is [ ]. The ECPR mean and standard deviation from Reference 1 were [ ] and [ ] respectively.

---

* ATRIUM is a trademark of AREVA NP Inc.

The range of applicability of the critical power correlation is unchanged from Reference 1. The modified correlation is applicable to Monticello steady-state design and analysis, core monitoring, MCPR safety limit, anticipated operational occurrences (AOO's), accidents, LOCA, and instability analysis for the ATRIUM 10XM fuel design.

Figure 1-1: Comparison of Calculated to Measured Critical Power

2.0 Standard Review Plan Requirements

There are no critical power correlation specific requirements in the standard review plan.

3.0 Revised Correlation

All modern critical power correlations contain a function that accounts for rod peaking. This function is called K-factor in the ACE formulation of the correlation. The model equation for the ACE correlation is given in Equation 3.1 of Reference 1 (including symbol definitions). The revision is in the [ ] term:

[ ] (3.1)

The K-factor, [ ]

This assumption was found to be inappropriate because (1) it allows downstream conditions above the location of dryout to non-physically influence the critical power, and (2) it provides equal weighting to all axial locations (low power regions as well as regions far from the location of dryout). Both of these problems were found to be capable of influencing the predicted results in a non-conservative manner.

3.1 *Rod Peaking Function*

The K-factor characterizes the rod peaking effect on the bundle critical power. The critical power varies inversely with K-factor. That is, as K-factor increases in value, the critical power decreases in value. [ ]

[ ]

This description of the local rod peaking function is unchanged from the description in References 1 and 3.

3.2 *Applying Rod Peaking Function in the Critical Power Correlation*

[

] The maximum of the averaged K-factors over all the rods was then chosen for use in the critical power correlation according to Equation 3.46 in Reference 3. This averaging of the axial K-factor distribution for each rod was found to be inappropriate for the reasons discussed in Section 3.0 and is therefore excluded in the improved K-factor method.

[

] Thus this solution explicitly addresses both problems noted in Section 3.0.

In the improved method, [

]

3.3 *Method for Calculation Additive Constants*

The spacers and bundle geometry characteristics influence the critical power behavior of the individual rods within the fuel bundle. Therefore, a factor is needed to distinguish the critical power performance of each rod. These position dependent factors are termed additive constants. Additive constants can be considered as a flow/enthalpy redistribution characteristic for a given bundle and spacer design.

In critical power testing, [

]

[ ]

In accordance with the [ ] the CHF database was randomly divided into a defining data set and a validating data set. Approximately [ ] was set aside as the validating set of data. The remaining [ ] form the defining data set and were used to develop the critical power correlation. The additive constants for all the rod positions were determined from the defining data set. The calculation of additive constants uses the same partition of data as was used during the critical power correlation development. [ ]

The defining and validating data sets used for correlation development in Reference 1 are unchanged. The additive constants are determined [ ]

[ ]

[ ]

3.3.4 Additive Constants for ACE/ATRIUM 10XM Correlation

The revised ATRIUM 10XM additive constants are shown in Figure 3-4. For comparison purposes, both the revised ATRIUM 10XM additive constants and the ACE/ATRIUM 10XM additive constants from Reference 1 are presented in Figure 3-5. The observed changes in additive constant are generally small and [

]

Figure 3-1: Adjacent Rod Identification for K-factor Calculation

Figure 3-2: Rods Observed to Dryout in Testing

Figure 3-3: Peaked Symmetric Rods Not Observed to Dryout in Testing

Figure 3-4: ACE/ATRIUM 10XM Additive Constants

Figure 3-5: Additive Constant Comparison

3.4 *Additive Constant Uncertainty*

The overall uncertainty in additive constants is determined [ ]. The following steps are applied:

[ ]

[ ]

The resulting overall additive constant uncertainty for the Monticello ACE/ATRIUM 10XM correlation is [ ]. The additive constant uncertainty from Reference 1 is [ ].

An additional high peaking uncertainty is imposed in the MCPR safety limit methodology for those rods whose local peaking exceeds [ ] Table 3-1 shows the results of these calculations.

Table 3-1: Additive Constant Uncertainty for High Local Peaking

[ ]

3.5 *Critical Power Correlation Conservatisms*

With the improved K-factor model, the Monticello ACE/ATRIUM 10XM correlation has an average ECPR of [ ] with a standard deviation of [ ]. For the Reference 1 correlation, the average ECPR was [ ] with a standard deviation of [ ]. The correlation was used to assess each rod in each of the tests. The associated critical powers of each rod were then compared to the measured critical power and a count made of the number of rods which were predicted to be in boiling transition (BT) and this was compared to the number of rods actually observed to be in boiling transition in the experimental data. With the improved K-factor methodology and additive constants, this ratio of predicted to measured rods in boiling transition is [ ]. This compares with a value of [ ] in Reference 1.

4.0 Transient Benchmarking

An industry accepted standard in BWR transient methodology is that steady-state dryout correlations are conservative for use in transient methodology. Transient dryout tests [ ] were performed to reconfirm this for the ATRIUM 10XM fuel design when using the ACE/ATRIUM 10XM critical power correlation.

The limiting transient tests of interest are the simulated load rejection without bypass (LRNB) events that consist of power and pressure ramps and flow decay and the simulated loss of flow events that consist of flow decay and power decay. The power, pressure, and flow were all controlled by a function generator. The forcing functions were programmed to produce the transient rod surface heat flux typical of the various events.

A total of [ ] ATRIUM 10XM LRNB and loss of flow transients were run which were either measured or predicted to have dryout. Of these [ ] transient critical power tests, [ ] The initial conditions for these tests are given in Table 7-7 of Reference 1.

Evaluations of the transient critical power tests were repeated using the improved K-factor methodology. [ ] The AREVA NP transient thermal hydraulic code XCOBRA-T (References 5 and 6), was used to predict the transient test results using the ACE/ATRIUM 10XM critical power correlation. The test power forcing function provides the boundary condition of power, which is modeled in XCOBRA-T [ ]

[

]

The results [ ] are summarized in Table 4-1.

[

]

The transient benchmark results with the modified correlation are consistent with those presented in Reference 1.

Table 4-1: XCOBRA-T Transient Dryout Results, [ ]

[ ]

Table 4-1: XCOBRA-T Transient Dryout Results, [ ]
(continued)

[ ]

Table 4-2: XCOBRA-T [ ] Transient Dryout Results
[ ]

[ ]

5.0 [ ] K-factor Method

With the improved K-factor method, the critical power correlation is used to [

]

6.0 Implementation of Improved K-factor Methodology

The improved K-factor methodology has been implemented into MICROBURN-B2 (Reference 8), SAFLIM3D (Reference 7), XCOBRA (Reference 11), XCOBRA-T (References 5 and 6), RELAX (Reference 9), and RAMONA5-FA (Reference 10). It will be used in Monticello core design and analysis, core monitoring, MCPR safety limit methodology, AOO's, LOCA, and other codes and methods that use the critical power correlations.

The MCPR safety limit methodology performs a rod-by-rod evaluation to estimate the number of rods in BT associated with a particular safety limit. [

]

7.0 References

1. ANP-10298PA Revision 0, "ACE/ATRIUM 10XM Critical Power Correlation," AREVA NP Inc., March 2010.

2. ANP-10298PA Revision 0, Supplement 1P Revision 0, "Improved K-Factor Model for ACE/ATRIUM 10XM Critical Power Correlation," AREVA NP, Inc., December 2011.

3. ANP-10249PA Revision 1, "ACE/ATRIUM-10 Critical Power Correlation," AREVA NP Inc., September 2009.

4. C. Bennett and N. L. Franklin. "Statistical Analysis in Chemistry and the Chemical Industry," Marbern House, October 1987.

5. XN-NF-84-105(P)(A) Volume 1 and Volume 1 Supplements 1 and 2, "XCOBRA-T: A Computer Code for BWR Transient Thermal-Hydraulic Analysis," Exxon Nuclear Company, February 1987.

6. XN-NF-84-105(P)(A) Volume 1 Supplement 4, "XCOBRA-T: A Computer Code for BWR Transient Thermal-Hydraulic Core Analysis Void Fraction Model Comparison to Experimental Data," Advanced Nuclear Fuels Corporation, June 1988.

7. ANP-10307PA Revision 0, "AREVA MCPR Safety Limit Methodology for Boiling Water Reactors," AREVA NP Inc., June 2011.

8. EMF-2158(P)(A) Revision 0, "Siemens Power Corporation Methodology for Boiling Water Reactors: Evaluation and Validation of CASMO-4 / MICROBURN-B2," Siemens Power Corporation, October 1999.

9. EMF-2361(P)(A) Revision 0, "EXEM BWR-2000 ECCS Evaluation Model," Framatome ANP Richland, Inc., May 2001.

10. BAW-10255PA Revision 2, "Cycle-Specific DIVOM Methodology Using the RAMONA5-FA Code," AREVA NP Inc., May 2008.

11. XN-NF-80-19(P)(A) Volume 3 Revision 2, "Exxon Nuclear Methodology for Boiling Water Reactors, THERMEX: Thermal Limits Methodology Summary Description," Exxon Nuclear Company, Inc., January 1987.

12. [

]