AREVA

ANP-10269NP
Revision 0
Supplement

The ACH-2 CHF Correlation for the U.S. EPR
Topical Report Supplement

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The CHF Testing and Analysis of a U.S. EPR 14 Foot Non-Uniform Axial Power Shape

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ABSTRACT

The fuel assembly for the AREVA NP's U.S. Evolutionary Pressurized Water Reactor (EPR) will utilize High Thermal Performance (HTP) spacer grids. These grids provide lateral fuel rod support via a flow channel in the rod-to-rod gap. At the outlet (downstream edge) of the grid, the flow through these channels is diverted from the vertical to promote increased thermal mixing.

AREVA NP has developed a Critical Heat Flux (CHF) correlation specifically for the fuel geometry of the EPR fuel design. This correlation, known as ACH-2, is based solely on an EPR CHF database developed from CHF testing performed at AREVA's Karlstein Thermal Hydraulic Facility in Germany. The correlation was developed for the EPR fuel design's specific important variables of grid spacing, pin pitch, rod and guide tube diameter and heated length.

The development of the ACH-2 CHF correlation included several conservative provisions, one of which was a 0.05 increase in the application Design Limit. This supplement provides additional CHF test data to confirm the applicability of the ACH-2 CHF correlation for the U.S. EPR fuel and to justify the removal of the 0.05 increase in the application Design Limit.

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Nomenclature

Acronym	Definition
95/95	95% probability / 95% confidence
AFS	Axial Flux Shape
CHF	Critical Heat Flux
DNBRL	Departure from Nucleate Boiling Ratio Design Limit
G	Mass Velocity
HTP	High Thermal Performance
KATHY	KArlstein Thermal Hydraulic FacilitY
M/P	Measured to Predicted

S.1.0 INTRODUCTION

The development of the ACH-2 CHF correlation in ANP-10269P (Reference 1) included several conservative provisions, one of which was a 0.05 increase in the application Design Limit. This supplement provides additional CHF test data to confirm the applicability of the ACH-2 CHF correlation for the U.S. EPR fuel and to justify the removal of the 0.05 increase in the application Design Limit.

Reference 1 addresses the development and basis for the ACH-2 CHF correlation as a conservative predictor of the CHF performance of the EPR High Thermal Performance (HTP) spacer grid. ACH-2 was developed from test data using eight distinct test geometries as seen in Table 2.1 of Reference 1. This data base includes data for [ ], unit cell and guide tube geometry and both cosine and uniform axial flux shapes. The local conditions ranges and fuel design limitations of the ACH-2 CHF correlation are as follows:

Local Conditions Ranges:

- Pressure: 284 to 2565 psia
- Mass Velocity: 0.945 to 3.164 $Mlb/hr\text{-}ft^2$
- Thermodynamic Quality at CHF: less than 37%

Fuel Design Limitations:

- Spacer Grid Type: AREVA NP EPR HTP
- Grid Spacing: 18.5 to 20.0 inches
- Fuel Rod OD: 0.374 inches
- Guide Tube OD: 0.490 inches
- Fuel Rod Pitch: 0.496 inches

The non-uniform axial heat flux shape (AFS) data was [ ] The Standard BWU (Tong) F Factor, defined in Section 5.1 of Reference 1, adjusts the ACH-2 CHF correlation for non-uniform axial heat addition. It was adapted directly from Reference 2 and is based on [ ] distinct flux shapes shown in Figure 4.1 of Reference 1. Subsequent to the submittal of Reference 1, AREVA NP performed additional CHF testing of a [ ] for the length of the U.S. EPR design (14 ft) for the purpose of confirming the adequacy of the ACH-2 CHF correlation and its CHF design limit.

The 14 foot heater rods for [ ].

The results of these additional tests were evaluated with the ACH-2 correlation. These results and their implications for the ACH-2 CHF correlation and departure from nucleate boiling ratio design limit (DNBRL) applicability are addressed in this supplement.

S.2.0 TEST SECTION GEOMETRY

In the additional CHF testing, the cross-sectional geometries for the [ ] were identical to the eight baseline tests as described in Section 3.2 of Reference 1. Both the [ ] axial flux shapes have maximum peaks of [ ] as shown in Figure S.2-1. The normalized lengths are shown in Figure S.2-2. The grid spacing is identical in each EPR HTP test section [ ]

Figure S.2-1: EPR [ ] Axial Flux Shapes

[ ]

Figure S.2-2: EPR [ ] Axial Flux Shapes

[

]

S.3.0 ADDITIONAL DATA

The 14 foot non-uniform APS tests were performed at the AREVA Karlstein Thermal Hydraulic Facility (KATHY), as were the other EPR HTP CHF tests described in Reference 1. A standard test matrix was planned and executed for each 14 foot non-uniform APS test. [ ]

The initial phase of the [ ]

The bundle condition data for the 14 foot [ ] tests are provided in Table S.A-1. The results and local conditions for each individual test point are listed in Table S.A-2.

S.4.0 ANALYSIS AND RESULTS

The data from tests [ ] have been examined and compared to the predicted performance using the ACH-2 CHF correlation, defined in Section 5.0 of Reference 1. Table S.4-1 provides the ACH-2 CHF correlation performance for both tests.

Table S.4-1: ACH-2 CHF Correlation Performance for Additional CHF Tests

[ ]

Visual demonstrations of applicability of the 14 foot [ ] data are presented in bias plots (with trend lines included) in Figures S.4-1 through S.4-4 for pressure, mass velocity, thermodynamic quality at CHF, and axial elevation of CHF. Figure S.4-5 is a non-typical bias plot of measured to predicted (M/P) CHF versus the magnitude of the Standard BWU F Factor for each point. The absence of bias (as shown by the flat trend line) in Figure S.4-5 confirms that the originally chosen F Factor coefficients from Reference 2 are valid for the 14 foot [ ]. Finally, Figure S.4-6 shows the measured versus predicted heat flux with [ ] limit lines corresponding to the limit lines shown in Figure 6-6 of Reference 1. The 14 foot [ ] data supports the conclusion that the ACH-2 CHF correlation is conservative.

Figure S.4-1: Measured to Predicted CHF versus Pressure 14 Foot [ ] Data

[

]

Figure S.4-2: Measured to Predicted CHF versus Mass Velocity 14 Foot [ ] Data

[ ]

Figure S.4-3: Measured to Predicted CHF versus Thermodynamic Quality 14 Foot [ ] Data

[

]

Figure S.4-4: Measured to Predicted CHF versus Axial Location of CHF 14 Foot [ ] Data

[

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Figure S.4-5: Measured to Predicted CHF versus AREVA (Tong) F Factor 14 Foot [ ] Data

[

]

Figure S.4-6: Measured CHF to Predicted CHF 14 Foot [ ] Data

[ ]

The data were grouped into several common groups for assessing the group statistics. A DNBRL value for each group is determined using both Owen (Reference 3) and Sommerville (Reference 4) methods in the same manner as used in Reference 1.

Owen DNBRL (assumes normal or near normal distribution)

In Owen theory the standard deviation of the M/P distribution is adjusted upwards to account for the number of degrees of freedom of the optimized correlation.

Where:

S = standard deviation of the M/P distribution

N = number of data in the correlation data base

nc = number of undetermined coefficients in the correlation

Ndf = N – 1 – nc

$$(S_{limit})^2 = (S)^2 * Ndf / (N-1)$$

Then:

$$DNBRL = 1 / (M/P - K_{95/95/N} * S_{limit})$$

Where:

K = the 95/95 one-sided Factor for one-sided Tolerance Limits.

Sommerville DNBRL (any distribution, no normality requirements)

DNBRL = Inverse of the Nth ranked M/P value.

Where N is determined by the table in Reference 4 and is dependent on the number of data in the group and the desired protection and confidence. Again, the 95/95 protection and confidence is used.

Table S.5-2 shows the statistics associated with various groupings of CHF data, including the ACH-2 data base from Reference 1. Note that none of the groupings have a DNBRL larger than the [ ] Sommerville DNBRL from Reference 1 for the ACH-2 data base.

Table S.5-2: Statistics and Design Limits for Various Groupings

[ ]

S.6.0 DISCUSSION AND CONCLUSION

During the development of the ACH-2 CHF correlation and design limit for Reference 1, two major conservatisms were implemented. First, three CHF tests were conservatively omitted from the correlation optimization. As addressed in Section 4.4 of Reference 1, [

]

Subsequent testing showed that the 14 foot [

]

Although there is a technical basis for the [

], AREVA NP concludes it is acceptable to retain the present conservative ACH-2 CHF correlation coefficients. AREVA also concludes it is justifiable to remove the DNBRL conservative increase, [ ], and to restore the DNBRL to 1.25 as supported by the 14 foot non-uniform data. Additional support for the later conclusion is presented in Table S.5-2, where none of the resulting DNBRL values exceeds [ ], confirming the conclusion that the original 1.25 DNBRL in Reference 1 is valid. The measured CHF versus predicted CHF performance for the original [ ] data, shown in Figure 6-6 of Reference 1, are shown in Figure S.6-1 with the +/-25% limits.

Based on the evidence presented in this supplement, the ranges and limitations of the ACH-2 CHF correlation would be maintained from Reference 1 with the exception of the Design Limit which would be 1.25 as shown in Table S.6-1.

Table S.6-1: Ranges and Limitations of the ACH-2 CHF Correlation

Local Conditions:

- Pressure: 284 to 2565 psia
- Mass Velocity: 0.945 to 3.164 Mlb/hr-ft^2
- Thermodynamic Quality at CHF: less than 37%

Fuel Design:

- Spacer Grid Type: AREVA NP EPR HTP
- Grid Spacing: 18.5 to 20.0 inches
- Fuel Rod OD: 0.374 inches
- Guide Tube OD: 0.490 inches
- Fuel Rod Pitch: 0.496 inches

Application:

- Code: LYNXT
- DNBRL: 1.25

Figure S.6-1: Measured CHF versus Predicted CHF for ACH-2

[ ]

S.7.0 REFERENCES

1. D. A. Farnsworth and R. L. Harne, "The ACH-2 CHF Correlation for the U.S. EPR," ANP10269(P), AREVA NP Inc., December 2006.

2. D. A. Farnsworth and G. A. Meyer, "The BWU Critical Heat Flux Correlations," BAW-10199PA, Rev. 3, Babcock & Wilcox, November 2005.

3. D. B. Owen, "Factors for One-Sided Tolerance Limits and For Variables Sampling Plans," Sandia Corporation Monograph (SRC-607), March 1963.

4. Paul N. Somerville, "Tables for Obtaining Non-Parametric Tolerance Limits," Annals of Mathematical Statistics, Vol. 29, No. 2, pp. 599-601, June 1958.

Appendix S.A

Bundle Conditions Data and Local Conditions Results with ACH-2 for the 14 Foot [ ] Tests

General Notes:

[ ]

Parameter Units

P - psia, G - Mlb/hr sq-ft, T - F, Zchf - inches, q" - Mbtu/hr sq-ft
Pm - Mpa, Gm - t/hr-m^2 , Tm - C, Zm - meters, qm" - Mw/hr-m^2

Table S.A-1: Bundle Conditions Data for the 14 Foot [ ] Tests

[ ]

Table S.A-1: Bundle Conditions Data for the 14 Foot [ ] Tests (cont'd)

[ ]

Table S.A-1: Bundle Conditions Data for the 14 Foot [ ] Tests (cont'd)

[

]

Table S.A-1: Bundle Conditions Data for the 14 Foot [ ] Tests (cont'd)

[ ]

Table S.A-1: Bundle Conditions Data for the 14 Foot [ ] Tests (cont'd)

[

]

Table S.A-2: Local Condition Results with ACH-2 for the 14 Foot [ ] Tests

[ ]

Table S.A-2: Local Condition Results with ACH-2 for the 14 Foot [ ] Tests (cont'd)

[

]

Table S.A-2: Local Condition Results with ACH-2 for the 14 Foot [ ] Tests (cont'd)

[ ]

Table S.A-2: Local Condition Results with ACH-2 for the 14 Foot [ ] Tests (cont'd)

[

]

Table S.A-2: Local Condition Results with ACH-2 for the 14 Foot [ ] Tests (cont'd)

[

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