framatome

SRP Chapter 15 Non-LOCA Methodology for Pressurized Water Reactors

EMF-2310, Revision 1
Supplement 2NP, Revision 0

Topical Report

February 2022

Nature of Changes

Item	Section(s) or Page(s)	Description and Justification
1	All	Initial Issue

Contents

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Nomenclature

Acronym	Definition
CAC	Correlation Acceptance Criteria
CEA	French Atomic Energy Commission
CHF	Critical Heat Flux
DNB	Departure from Nucleate Boiling
GDC	General Design Criteria
GT	Guide Tube
HMP	Framatome grid type – High Mechanical Performance
HTP	Framatome grid type – High Thermal Performance
HTRF	Columbia University's Heat Transfer Research Facility
IFM	Intermediate Flow Mixing
KATHY	Karlstein Thermal Hydraulic Test Facility
MDNBR	Minimum Departure from Nucleate Boiling Ratio
MSLB	Main Steam Line Break
NRC	Nuclear Regulatory Commission

1.0 INTRODUCTION

This report provides a design limit for the Biasi Critical Heat Flux (CHF) correlation suitable for application to High Thermal Performance (HTP) and High Mechanical Performance (HMP) grids. The Biasi correlation is approved for use in Post-Scram Main Steam Line Break (MSLB) analysis as part of the methodology described in Reference 1. This report describes the validation of a conservative design limit using design-specific CHF data. The modified Barnett correlation is no longer used for analyses covered by this supplement.

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2.0 SUMMARY AND RANGE OF APPLICABILITY

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Application of the design limit requires **ALL** of the below conditions be met:

- The thermal hydraulics conditions are within the bounds listed in Table 2-1.
- [ ]
- The assembly geometry is within the requirements listed in Table 2-2.
- The specific plant application is listed in Table 2-3.
- [ ]
- The code modeling options defined in Table 5-1 are used.

The design limit was [ ] applicable to the HTP spacer grid design. [

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Table 2-1: Range of Application of Thermal Hydraulic Conditions

[ ]

Table 2-2: Range of Application of Fuel Assembly Geometry

[ ]

Table 2-3: Range of Application of Supported Plants

Plant
Calvert Cliffs Unit 1 (CE 14 x 14)
Calvert Cliffs Unit 2 (CE 14 x 14)
Millstone Unit 2 (CE 14 x 14)
St. Lucie Unit 1 (CE 14 x 14)
St. Lucie Unit 2 (CE 16 x 16)

Figure 2-1: Design Limit Application Range and Associated Penalties

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3.0 REGULATORY REQUIREMENTS

Steady state and transient codes and methods used for licensing basis analyses are subject to regulatory requirements and guidance specified in the Standard Review Plan (SRP) (NUREG-0800, Reference 2). SRP Section 4.4, "Thermal and Hydraulic Design" provides criteria acceptable to meet the relevant requirements of General Design Criterion (GDC) 10 of 10 CFR Part 50, Appendix A. GDC 10 requires that: "the reactor core and associated coolant, control, and protection systems shall be designed with appropriate margin to assure that specified acceptable fuel design limits are not exceeded during any condition of normal operation, including the effects of anticipated operational occurrences." Acceptance Criterion 1.A. of SRP Section 4.4 states that for correlations used to predict CHF, there should be a 95% probability at the 95% confidence level that the hot rod in the core does not experience a Departure from Nucleate Boiling (DNB) or boiling transition condition during normal operation or Anticipated Operational Occurrences (AOOs). The design limit in this report passes this criterion when used within the specified ranges of applicability and when applied to the Biasi correlation.

4.0 CHF TESTING AND EXPERIMENTAL DATA

A summary of the experimental tests used to validate the design limit is provided in Table 4-2, Table 4-3, and Table 4-4.

4.1 *Test Facilities*

The test facilities used to obtain data for this report are summarized in Table 4-1.

- All facilities have been used in topical reports previously approved by the Nuclear Regulatory Commission (NRC), which provide descriptions of the facilities and associated quality and test procedures.
- Based on this the treatment of statistical design of the experiments; instrumentation and associated uncertainty and calibration; use of repeat test points; and treatment of test section heat losses are acceptable and consistent with previously approved correlations.

Table 4-1: Test Facility Summary

Test Campaign Prefix	Test Facility	Previous Applications
"K" "SI700/1"	KATHY - Framatome's test facility (Karlstein, Germany)	References 4, 3
"SP010"	OMEGA - French Alternative Energies and Atomic Energy Commission (CEA) test facility (Grenoble, France)	Reference 3
"SP" (except SP010)	HTRF - Columbia University's Heat Transfer Research Facility (New York, New York)	References 5, 3

4.2 *Test Data*

The Biasi correlation was originally compared to academic experimental burnout data, as described in Section 3 of Reference 6. This data was not considered during the design limit development as discussed in this report.

[ ]

[ ] have not been specifically used in correlations previous approved by the NRC. However, these tests were performed consistent with the quality programs of their respective test facilities and are considered appropriate for inclusion in this design limit assessment. Considering the large amount of data [ ] employed to develop the design limit, these tests do not impact the final conclusion supporting the appropriateness of the design limit.

Test definitions for these new tests are provided in Figure 4-4 through Figure 4-11 and Table 4-5.

Figure 4-1 through Figure 4-3 display the distribution of the test data across the pressure, mass flux, and quality design space as well as the expected domain. In most cases the expected domain is explicitly populated with test data. [ ]

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Table 4-2: CHF Test Summary – Part 1: 17x17 HTP Lattice Design

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Table 4-3: CHF Test Summary – Part 2: Non-17x17 HTP Lattice Design

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Table 4-4: CHF Test Summary – Part 3: 17x17 HMP Lattice Design

[ ]

Figure 4-1: Test Data Domain – Pressure vs. Mass Flux

Figure 4-2: Test Data Domain – Pressure vs. Quality

[ ]

Figure 4-3: Test Data Domain – Mass Flux vs. Quality

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Table 4-5: Radial Power Distributions of CHF Tests

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Figure 4-4: Radial Geometry of Test SP660

Figure 4-5: Axial geometry of CHF test SP660

Figure 4-6: Radial Geometry for Test SP010

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Figure 4-7: Axial Geometry of CHF Test SP010

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Figure 4-8: Radial Geometry of Test SI700/1

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Figure 4-9: Axial Geometry of CHF Test SI700/1

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Figure 4-10: Radial Geometry of Test K8800

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Figure 4-11: Axial Geometry of CHF Test K8800

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4.3 *Experimental Considerations*

This section provides justifications for common assumptions made during the evaluation of CHF data.

Test Facility Comparison

As previously demonstrated in the response to RAI-SNPB-02 to Reference 3, data obtained from [

] Therefore, combining data from these facilities is not a concern. This conclusion remains true for the current application.

Test Section Heat Loss

As previously demonstrated in the response to RAI-SNPB-05 to Reference 3, test section heat losses [

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Transient Behavior

Consistent with prior applications (Reference 3), it is common practice to assume the CHF during a transient situation will be exceeded when the local instantaneous conditions are equivalent to those causing its occurrence under steady state conditions. Therefore, transient CHF is not considered as it is bounded by the steady state testing.

Training and Validation Data

As discussed in Section 6.0 the Biasi correlation was developed externally using academic experimental burnout data.

The validation of the Biasi correlation and design limit development was performed using [.]

The statistical analysis provided in Section 7.0, further demonstrating the acceptability of the design limit, [ ]

Simple Support Grids

As previously demonstrated in the response to RAI-SNPB-08 to Reference 3, the use of simple support grids [ ] This conclusion remains true for the current application.

5.0 SUBCHANNEL CODE

The design limit was developed and verified using the subchannel code COBRA-FLX, which has been reviewed and approved by the U.S. NRC for application to nuclear core thermal-hydraulic analysis for steady-state and transient conditions in Reference 7.

MSLB analyses performed in accordance with Reference 1 use the XCOBRA-IIIC subchannel solver. While the COBRA family of sub-channel codes predict local conditions similarly, small code-to-code differences are expected. Therefore, the design limit defined in Section 2.0, [ ]

Previous code comparisons when applying a correlation design limit developed with COBRA-FLX to XCOBRA-IIIC have demonstrated [ ]

The parameters in Table 5-1 are to be used when applying the Biasi correlation for safety analysis in XCOBRA-IIIC.

Table 5-1: XCOBRA-IIIC Modeling Options

[ ]

6.0 CORRELATION DEFINITION

The Biasi correlation was developed in Reference 6 and is part of the method approved in Reference 1. The correlation was not modified for this application.

The design limit was developed using the methods described in [

]

The conservatism of this design limit is demonstrated in Section 7.0.

7.0 CORRELATION ASSESSMENT AND STATISTICAL ANALYSIS

This section provides a summary of the comparison of the data predicted by the correlation to the CHF test data.

7.1 *Acceptance Criteria*

Traditionally, a ratio of the predicted heat flux to the measured heat flux (P/M) is used to characterize the predictive capability of the correlation, and a design limit is selected to bound at least 95% of the P/M population (assuming poor performing points are randomly distributed). The validation error as given by the CHF measured-to-predicted values are determined at the MDNBR location as predicted by the correlation.

This analysis makes two minor deviations from this standard practice.

[ ]

7.2 *Analysis Overview*

The data analysis was performed as follows:

- Each data point was modeled in COBRA-FLX to calculate the predicted heat flux and develop a P/M ratio. A summary of these results is presented in Table 7-1. The full results are presented in Appendix A.

- The statistics of the resulting population were inspected for concerns, including residual trends and non-conservative subregions.

7.3 *Results*

A summary of the test statistics is shown in Table 7-1. "Failing Points" are those for which the measured heat flux is not predicted conservatively relative to the design limit. Results are provided both with and without the penalties defined in Figure 2-1.

Figure 7-1 through Figure 7-4 present a graphical representation of the data.

Figure 7-1 shows the distribution of data. [

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[

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Table 7-1: Overall Statistics of CHF Test Data Predications

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Figure 7-1: CAC Distribution

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Figure 7-2: Unpenalized CAC vs. Equilibrium Quality

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Figure 7-3: Unpenalized CAC vs. Mass Flux

Figure 7-4: Unpenalized CAC vs. Pressure

7.4 *Subregion Assessment*

An inspection of the data was performed to ensure that the correlation statistics behaved similarly across all subregions of the application range.

Subregion results based on test configurations are presented in Table 7-2 and show no concerning trends.

Subregion results based on operating conditions are presented in Table 7-3. [

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Table 7-2: Test Configuration Subregion Assessment

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Table 7-3: Operating Condition Subregion Assessment (Unpenalized)

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Table 7-4: Operating Condition Subregion Assessment (Penalized)

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7.5 *Intended Application*

The design limit defined herein will be used to support MSLB analysis for the plants identified in Table 2-3 for the HTP 14 and HTP 16 fuel assembly designs.

Assembly Design

All key geometry values of the HTP fuel assembly are within the ranges supported by the design limit as specified in Table 2-2. The HTP assembly has two grid types relevant to DNB analysis in the heated region.

- The bottom most grid is an HMP structural grid. [ ] The HMP data compared favorably against the design limit, as seen in Table 7-2.
- All other grids in the heated region are of the HTP design. HTP data [ ] and is predicted favorably.

Therefore, the Biasi design limit is applicable to DNB calculations spanning the entire HTP assembly.

Methodology

The Biasi correlation is approved for use in MSLB analyses per Reference 1. This method is typically implemented by modeling each assembly in the limiting stuck rod region as a single channel; assemblies outside this region are lumped into two additional channels.

To ensure that the modeling assumptions used in the reload are conservative relative to those used in the development of the design limit, [

]

As described in Section 5.0, the Reference 1 methodology is implemented using XCOBRA-IIIC; therefore, an appropriate correction factor has been applied.

Table 7-5: MDNBR Correction Factor

Plant Type	Correction Factor
CE 14x14	0.880
CE 16x16	0.826

8.0 QUALITY ASSURANCE PROGRAM

The Biasi design limit and supporting analysis was performed under a quality assurance program that meets the regulatory requirements of 10 CFR Part 50 Appendix B.

9.0 REFERENCES

1. EMF-2310(P)(A) Revision 1, "SRP Chapter 15 Non-LOCA Methodology for Pressurized Water Reactors."

2. NUREG-0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Plants: LWR Edition," March 2007.

3. ANP-10341P-A Revision 0, "The ORFEO-GAIA and ORFEO-NMGRID Critical Heat Flux Correlations."

4. ANP-10269P-A Revision 0, "The ACH-2 CHF Correlation for the U.S. EPR."

5. EMF-92-153(P)(A) Revision 1, "HTP: Departure from Nucleate Boiling Correlation for High Thermal Performance Fuel."

6. "Studies on Burnout, Part 3 - A New Correlation for Round Ducts and Uniform Heating and its Comparison with World Data," L. Biasi et al., *energia nucleare*, vol. 14, n. 9, September 1967.

7. ANP-10311P-A Revision 1, "COBRA-FLX: A Core Thermal-Hydraulic Analysis Code."

8. [

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APPENDIX A

Appendix A is proprietary in its entirety.