FRAMATOME ANP

BAW-10241(NP)(A)
Revision 1

BHTP DNB Correlation Applied with LYNXT

July 2005

Framatome ANP, Inc.

Non-Proprietary

U.S. Nuclear Regulatory Commission
Report Disclaimer

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

July 25, 2005

Mr. Ronnie L. Gardner, Manager
Site Operations and Regulatory Affairs
Framatome ANP
3315 Old Forest Road
Lynchburg, VA 24501

SUBJECT: FINAL SAFETY EVALUATION FOR FRAMATOME ANP (FANP), APPENDIX A TO TOPICAL REPORT (TR) BAW-10241(P), REVISION 1, "EXTENSION OF THE BHTP CHF [CRITICAL HEAT FLUX] CORRELATION RANGES" (TAC NO. MC6374)

Dear Mr. Gardner:

On March 11, 2005, FANP submitted Appendix A to TR BAW-10241(P), Revision 1, "Extension of the BHTP CHF Correlation Ranges," to the Nuclear Regulatory Commission (NRC) staff. On June 2, 2005, an NRC draft safety evaluation (SE) regarding our approval of BAW-10241(P), Revision 1, was provided for your review and comments. By letter dated June 27, 2005, FANP commented on the draft SE. The NRC staff's disposition of FANP's comments on the draft SE is discussed in the attachment to the final SE enclosed with this letter.

The NRC staff has found that BAW-10241(P), Revision 1, is acceptable for referencing in licensing applications for all pressurized-water reactors to the extent specified and under the limitations delineated in the TR and in the enclosed final SE. The final SE defines the basis for acceptance of the TR.

Our acceptance applies only to 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 FANP publish accepted proprietary and non-proprietary versions of this TR within three months of receipt of this letter. The accepted versions shall incorporate this letter and the enclosed final SE after the title page. Also, they must contain historical review information, including NRC requests for additional information and your responses. The accepted versions shall include a "-A" (designating accepted) following the TR identification symbol.

If future changes to the NRC's regulatory requirements affect the acceptability of this TR, FANP and/or licensees referencing it will be expected to revise the TR appropriately, or justify its continued applicability for subsequent referencing.

Sincerely,

Herbert N. Berkow

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

Project No. 728

Enclosure: Final SE

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

SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

APPENDIX A TO TOPICAL REPORT BAW-10241(P), REVISION 1,

"EXTENSION OF THE BHTP CHF CORRELATION RANGES"

FRAMATOME ANP

PROJECT NO. 728

1.0 INTRODUCTION

By letter dated March 11, 2005 (Reference 1), Framatome ANP (FANP) submitted Appendix A to Topical Report (TR) BAW-10241(P), Revision 1 (Reference 2), "Extension of the BHTP CHF [critical heat flux] Correlation Ranges." This submittal proposes the extension of the range of applicability of the independent variables in the BHTP CHF correlation. The extended range of applicability of the correlation is required because the currently approved ranges will be exceeded in future plant-specific analyses.

2.0 REGULATORY EVALUATION

The primary purpose of the nuclear fuel in operating nuclear reactors is to generate heat. This heat, generated from nuclear fission, must be transferred from the fuel pellet to the surrounding cladding and coolant. In order to maintain safe operation of pressurized light water reactors, the subcooled flow boiling that occurs must be maintained in the nucleate boiling regime. The point at which the boiling regime changes from nucleate boiling to film boiling is defined as the departure from nucleate boiling (DNB). The heat flux at this point is called the CHF. In the film boiling regime, the rate of heat transfer from the fuel cladding is dramatically reduced, resulting in a rapid increase in cladding temperature that can compromise cladding integrity.

In a reactor core, many parameters have an effect on the actual point at which DNB or CHF occurs. Core flow rate, coolant pressure, and thermodynamic quality can all cause changes in the CHF value. Because of this complexity, no mechanistic model presently exists that fully describes the physical phenomena, making it impossible to predict the CHF with 100 percent accuracy. To obtain a reasonable prediction, the relationships between the relevant independent variables and actual experimental CHF observations have been correlated. The range of applicability of the independent variables in these correlations is based solely on the range over which the actual experimental CHF observations were recorded.

General Design Criterion (GDC) 10 of Appendix A to Part 50 of Title 10 of the *Code of Federal Regulations* states that "the reactor core ... 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 [AOO]."

NUREG-0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants," (SRP) Section 4.2, "Fuel System Design," and Section 4.4, "Thermal and Hydraulic Design," give the criteria and practices found acceptable by the Nuclear Regulatory Commission (NRC) staff for meeting GDC 10.

In terms of the specific evaluation of Reference 2, as stated in SRP Sections 4.2 and 4.4, the NRC staff finds that the CHF correlations should be developed such that there is a 95 percent probability at the 95 percent confidence level that the hot rod in the core does not experience DNB during normal operation or AOOs.

3.0 TECHNICAL EVALUATION

The BHTP CHF correlation is based on a set of data points from multiple CHF tests conducted at the Columbia Heat Transfer Facility. In addition to these data, additional data points were also obtained in some of the tests, but were not utilized in establishing the correlation. These "new" data were filtered to ensure that they adequately represented the full range of fuel design parameters. What resulted was a new data base consisting of data points indicating measured CHF values for local conditions of 1400 psia and ranging over the proposed upper quality and lower mass velocity regions.

In this TR, FANP desires extensions of the lower limit of pressure, the upper and lower limits of thermodynamic quality, and the lower limit for mass velocity. The vendor used three approaches to justify extending the range of applicability of these independent variables in the BHTP CHF correlation. First, the existing correlation is applied only to an expanded data set and shown to be conservative over the expanded range of data. Second, the conservatism of extrapolating beyond the data base is shown. This second approach is applied to extrapolations to low quality values. Third, a technique to calculate conservative CHF values when outside the range of data is described. This third approach is used when pressure higher than the upper pressure limit is encountered.

The BHTP CHF correlation is applied using the LYNXT code in BAW-10156-A, Revision 1 (Reference 3). The original CHF data of BAW-10241(P)(A) (Reference 4) and the new data are plotted against thermodynamic quality by FANP to justify extending the limits of upper quality, lower pressure, and lower mass velocity. The new data are shown to be generally conservative with respect to the original data. The predicted CHF to measured CHF (P/M) ratios were plotted over the respective ranges of each of the independent variables. These plots showed no biasing trends and an average P/M ratio less than 1.0, implying predictive conservatism in the extended regions. The NRC staff used the tables and graphs provided by FANP in Reference 2 to independently confirm these results and found that they were acceptable. Therefore, the NRC staff concludes that the new data at 1400 psia provide sufficient verification that the BHTP CHF correlation can adequately predict CHF in the proposed extended regions of upper quality, lower pressure, and lower mass velocity.

FANP examined the extension of the BHTP CHF correlation to verify that it is conservative for each approved assembly geometry. The examination was performed for each test section, since each test section represents a single geometry. The comparison indicates that in no case does the differing geometry produce a non-conservative trend when the BHTP correlation is applied to the extended data. Therefore, FANP concluded that the entire set of extended data can be used to conservatively extend the range of independent variables of the BHTP CHF correlation. The NRC staff reviewed data provided by FANP in Reference 2 to independently confirm this conclusion and has found that it is acceptable.

4.0 LIMITATIONS AND CONDITIONS

The NRC staff has reviewed Reference 2 and assessed the acceptability of the justifications therein for extending the range of applicability of the BHTP CHF Correlation Ranges. The NRC staff concludes as follows:

(1) Based on the comparisons with the additional data, the quantitative statistical assurances continue to be met by the correlation in the regions of lower pressure, higher quality, and lower mass velocity. Therefore, the independent variables of the BHTP CHF correlation can be extended as depicted in Table 1.

Table 1

Range of Independent Variables for the BHTP CHF Correlation with the Extension of the Upper Quality, Lower Mass Velocity, and Lower Pressure Limits

Independent Variable	As Approved		Extended	
	Minimum Value	Maximum Value	Minimum Value	Maximum Value
System Pressure, psia	1775	2425	***1385***	2425
Mass Velocity, Mlb/hr-ft^2	0.897	3.549	***0.492***	3.549
Thermodynamic Quality	-0.130	0.344	-	***0.512***

(2) Actions for analyzing the operating conditions outside of the approved ranges of the maximum pressure (2425 psia) but less than 2600 psia are stated below.

- When pressures greater than the pressure limit of 2425 psia but less than 2600 psia are encountered, all of the local coolant conditions are calculated at the upper pressure limit of 2425 psia using the NRC-approved LYNXT thermal-hydraulic code and then used in the calculation of the BHTP CHF.

- Extrapolations below the minimum quality range are performed with no lower limit, consistent with EMF-92-153(P)(A) Revision 1, "HTP: Departure from Nucleate Boiling Correlation for High Thermal Performance Fuel" (Reference 5).

These methods were put forth in Reference 5. Any other extrapolation requires a plant-specific review.

5.0 CONCLUSION

In References 1 and 2, FANP requested to extend the range of applicability of the independent variables of the BHTP CHF correlation (i.e., the lower limit of pressure, the upper and lower limits of thermodynamic quality, and the lower limit of mass velocity). The NRC staff has reviewed and confirmed the data provided in Reference 2 by FANP. Based on the NRC staff's independent analysis detailed in Section 3.0 of this safety evaluation (SE), the NRC staff finds FANP's extensions of the range of applicability of the independent variables acceptable for use within the limits and conditions provided in Section 4.0 of this SE.

6.0 REFERENCES

1. Letter from J. S. Holm, FANP, to NRC, "Request for Approval of Appendix A to BAW-10241(P), Revision 1, 'Extension of the BHTP CHF Correlation Ranges'," March 11, 2005 (Agencywide Documents Access Management System (ADAMS) Accession No. ML050750124).

2. Appendix A to TR BAW-10241(P), Revision 1, "Extension of the BHTP CHF Correlation Ranges," FANP, March 2005 (ADAMS Accession No. ML050750129 - Non-Pubicly Available).

3. BAW-10156-A, Revision 1, "LYNXT Core Transient Thermal Hydraulic Program," FANP, August 1993.

4. BAW-10241(P)(A), Revision 0, "BHTP DNB Correlation Applied with LYNXT," September 2004 (ADAMS Package Accession No. ML043650303).

5. EMF-92-153(P)(A), Revision 1, "HTP: Departure from Nucleate Boiling Correlation for High Thermal Performance Fuel," FANP, January 2005 (ADAMS Package Accession No. ML051020015).

Attachment: Resolution of Comments

Principal Contributors: A. Attard
D. Johnson

Date: July 25, 2005

RESOLUTION OF COMMENTS

ON DRAFT SAFETY EVALUATION FOR APPENDIX A TO TOPICAL REPORT

BAW-10241(P), REVISION 1, "EXTENSION OF THE BHTP CHF CORRELATION RANGES"

By letter dated June 27, 2005, Framatome ANP (FANP) provided comments on the draft safety evaluation (SE) for Appendix A to topical report BAW-10241(P), Revision 1, "Extension of the BHTP CHF (critical heat flux) Correlation Ranges." The following is the NRC staff's resolution of those comments. Additionally, the NRC staff made minor editorial changes to the Final SE.

1. FANP Comment: Omit first two sentences of third paragraph in Section 3.0 and replace with alternate text in order to properly link the original CHF data to BAW-10241(P)(A), Revision 0, September 2004 (Reference 4) and the correlation application code to BAW-10156-A, Revision 1, August 1993 (Reference 3). The CHF data are provided in Reference 4, with the thermodynamic quality computed using the LYNXT code for the BHTP correlation. The original HTP CHF bundle data initially appeared in Reference 4.

   NRC Action: NRC staff incorporated FANP's comment with minor editorial changes to the proposed alternate text.

2. FANP Comment: Change "5.0" to "6.0" in the Reference Section.

   NRC Action: Comment incorporated.

3. FANP Comment: Add new reference (BAW-10241(P)(A), Revision 0, September 2004) in Reference Section. BAW-10241(P)(A), Revision 0, is referenced in the alternate text (see comment #1).

   NRC Action: Comment incorporated.

NRC Correspondence

FRAMATOME ANP, INC.

AREVA

March 11, 2005
NRC:05:016

Document Control Desk
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555-0001

Request for Approval of Appendix A to BAW-10241(P), Revision 1, "Extension of the BHTP CHF Correlation Ranges"

Ref. 1: Letter, Herbert N. Berkow (NRC) to Jerald S. Holm (Framatome ANP), "Final Safety Evaluation for Framatome ANP Appendix A to Topical Report EMF-92-153(P)(A), 'HTP: Departure from Nucleate Boiling Correlation for High Thermal Performance Fuel,' (TAC No. MC3223)," January 6, 2005.

Framatome ANP requests the NRC's review and approval for referencing in licensing actions a revision to topical report BAW-10241(P)(A), "BHTP DNB Correlation Applied with LYNXT." The revision consists of an appendix to the NRC-approved topical report in order to extend the range of applicability of the independent variables in the correlation. The extended range of applicability of the correlation is required because the currently approved ranges will be exceeded in future plant specific analyses, specifically Entergy's Arkansas Unit 1.

The contents of this report are consistent with the appendix to topical report EMF-92-153, "HTP Departure from Nucleate Boiling Correlation for High Thermal Performance Fuel," which was approved for referencing in licensing actions on January 6, 2005 (Reference 1). Framatome ANP requests that the safety evaluation report for Appendix A to topical report BAW-10241, Revision 1, be issued by August 1, 2005 in order to support Entergy's ANO-1 next reload. Because of the review schedule and for efficiency purposes, Framatome ANP requests that the NRC consider assigning the same NRC reviewer to Appendix A of BAW-10241, Revision 1 as was assigned to the review of the appendix to EMF-92-153.

The proprietary version of Appendix A to BAW-10241, Revision 1, is provided in the attachment to this letter. Attachment B is the non-proprietary version.

Framatome ANP considers some of the information contained in the enclosed report to be proprietary. As required by 10CFR2.390(b), an affidavit is enclosed to support the withholding of this information from public disclosure.

Sincerely,

Jerald S Holm/Sn

Jerald S. Holm, Director
Regulatory Affairs

3315 Old Forest Road, P.O. Box 10935 Lynchburg, VA 24506-0935
Tel. : (434) 832-3000 - Fax : (434) 832-0622

AFFIDAVIT

COMMONWEALTH OF VIRGINIA)
) ss.
CITY OF LYNCHBURG)

1. My name is Gayle F. Elliott. I am Manager, Product Licensing in Regulatory Affairs, for Framatome ANP ("FANP"), and as such I am authorized to execute this Affidavit.

2. I am familiar with the criteria applied by FANP to determine whether certain FANP information is proprietary. I am familiar with the policies established by FANP to ensure the proper application of these criteria.

3. I am familiar with Appendix A to topical report BAW-10241, Revision 1, "Extension of the BHTP CHF Correlation Ranges," dated March of 2005, and referred to herein as "Document." Information contained in this Document has been classified by FANP as proprietary in accordance with the policies established by FANP for the control and protection of proprietary and confidential information.

4. This Document contains information of a proprietary and confidential nature and is of the type customarily held in confidence by FANP and not made available to the public. Based on my experience, I am aware that other companies regard information of the kind contained in this Document as proprietary and confidential.

5. This Document has been made available to the U.S. Nuclear Regulatory Commission in confidence with the request that the information contained in this Document be withheld from public disclosure.

6. The following criteria are customarily applied by FANP to determine whether information should be classified as proprietary:

(a) The information reveals details of FANP's research and development plans and programs or their results.

(b) Use of the information by a competitor would permit the competitor to significantly reduce its expenditures, in time or resources, to design, produce, or market a similar product or service.

(c) The information includes test data or analytical techniques concerning a process, methodology, or component, the application of which results in a competitive advantage for FANP.

(d) The information reveals certain distinguishing aspects of a process, methodology, or component, the exclusive use of which provides a competitive advantage for FANP in product optimization or marketability.

(e) The information is vital to a competitive advantage held by FANP, would be helpful to competitors to FANP, and would likely cause substantial harm to the competitive position of FANP.

7. In accordance with FANP's policies governing the protection and control of information, proprietary information contained in this Document have been made available, on a limited basis, to others outside FANP only as required and under suitable agreement providing for nondisclosure and limited use of the information.

8. FANP policy requires that proprietary information be kept in a secured file or area and distributed on a need-to-know basis.

9. The foregoing statements are true and correct to the best of my knowledge, information, and belief.

SUBSCRIBED before me this 11 day of March, 2005.

Danita R. Kidd
NOTARY PUBLIC, COMMONWEALTH OF VIRGINIA
MY COMMISSION EXPIRES: 12/31/08

Danita R. Kidd
NOTARY PUBLIC
Commonwealth of VA
Comm. Expires: 12-31-08

Note: The non-proprietary attachment to this letter (Attachment B) has been attached at the end of the Topical Report as Appendix A.

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

September 29, 2004

Mr. James F. Mallay
Director, Regulatory Affairs
Framatome ANP
3315 Old Forest Road
P.O. Box 10935
Lynchburg, Virginia 24506-0935

SUBJECT: FINAL SAFETY EVALUATION FOR TOPICAL REPORT BAW-10241P, REVISION 0, "BHTP CORRELATION APPLIED IN LYNXT" (TAC NO. MB7033)

Dear Mr. Mallay:

On December 19, 2002, Framatome ANP (FANP) submitted Topical Report (TR) BAW-10241P, Revision 0, "BHTP Correlation Applied in LYNXT" to the staff. On August 30, 2004, an NRC draft safety evaluation (SE) regarding our approval of BAW-10241P was provided for your review and comments. By letter dated September 10, 2004, FANP commented on the draft SE. The proposed comments included deletion of proprietary information and three editorial changes. The staff incorporated all of FANP's comments on the draft SE.

The staff has found that BAW-10241P is acceptable for referencing in licensing applications for all pressurized water reactor designs to the extent specified and under the limitations delineated in the TR and in the enclosed SE. The SE defines the basis for acceptance of the TR.

Our acceptance applies only to 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 FANP publish accepted proprietary and non-proprietary versions of this TR within three months of receipt of this letter. The accepted versions 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 historical review information, such as questions and accepted responses, draft SE comments, and original TR pages that were replaced. The accepted version shall include a "-A" (designating accepted) following the TR identification symbol.

If future changes to the NRC's regulatory requirements affect the acceptability of this TR, FANP and/or licensees referencing it will be expected to revise the TR appropriately, or justify its continued applicability for subsequent referencing.

Sincerely,

Robert A. Gramm for/

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

Project No. 728

Enclosure: Safety Evaluation

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

SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

BAW-10241P, REVISION 0, "BHTP DNB CORRELATION APPLIED WITH LYNXT"

FRAMTOME ANP

PROJECT NO. 728

1.0 INTRODUCTION

By letter dated December 19, 2002 (Reference 1), Framatome ANP (FANP) requested NRC review of topical report (TR) BAW-10241P, "BHTP DNB Correlation Applied with LYNXT." This TR describes a departure from nucleate boiling (DNB) correlation that has been developed using the LYNXT thermal-hydraulic code (Reference 2) for fuel designs equipped with high thermal performance (HTP) spacer grids. The BHTP DNB correlation is based on the approved HTP DNB correlation (Reference 3). Adjustments have been made in some of the coefficients (A, B, and HTERM) used to describe the performance of this spacer grid design when the LYNXT (Reference 4) code is used. The HTP DNB correlation was developed using the XCOBRA-IIIC thermal-hydraulic code (Reference 5).

The review includes the subject TR and supplemental information provided by FANP in letters dated June 6 and September 3, 2003, and February 11, June 17, and August 9, 2004 (References 6 through 10).

2.0 REGULATORY EVALUATION

The requirement for analyses of this type originates in Title 10 of the *Code of Federal Regulations* Part 50, Appendix A, "General Design Criteria for Nuclear Power Plants." Specifically, Criterion 10, "Reactor Design" applies. Criterion 10 states:

> 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.

NUREG-0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants," Sections 4.2, "Fuel System Design" and 4.4, "Thermal and Hydraulic Design," provide detailed guidance that is acceptable to the staff in meeting the regulatory requirements given above. FANP has applied this guidance in BAW-10241P, Revision 0.

3.0 SUMMARY OF TOPICAL REPORT

BAW-10241P documents development of the FANP BHTP DNB correlation applied with LYNXT for use in DNB analysis of the HTP fuel design. BHTP represents an extension of the previously approved HTP correlation. The primary difference between the two codes (LYNXT versus XCOBRA-IIIC) associated with critical heat flux (CHF) data reduction is the water properties (Reference 5, ASME property functions versus ASME saturated steam table).

The data from a high pressure test loop at Columbia University's Heat Transfer Research Facility (Reference 3) were used as a data base for the BHTP correlation development. The BHTP data base (Reference 7) consists of data from test sections: representing the typical Westinghouse HTP designs used for FANP development and other vendors' HTP designs in heated lengths, power shapes, presence of spacers and, in some cases, containing intermediate flow mixers (IFMs).

A complete summary of the measured data and the predicted values of relevant variables to the development of the correlation is provided in Reference 7. Dependence of the BHTP correlation on fuel design parameters is also described in the TR. Comparison of correlation predictions to experimental measurements are provided as qualification of its adequacy. The determination of the 95/95 safety limit for BHTP is discussed in the subject submittal (Reference 2).

4.0 TECHNICAL EVALUATION

4.1 BHTP Test Data Base Description

The BHTP correlation data base consists of data points from tests performed in a high pressure test loop at the Columbia University Heat Transfer Research Facility.

These test section characteristics were varied to represent fuel array design for 14x14 through 17x17 rod arrays using both uniform and non-uniform axial power shape. The radial power distribution was non-uniform for all test assemblies. Rod positions were maintained by HTP spacers. The tests were conducted with assemblies with and without IFMs. Fuel design parameters of the test assemblies varied: from 0.36 to 0.44 inch for the fuel rod diameter; from 0.496 to 0.580 inch for the rod pitch; from 8 to 26.4 inches for the axial spacer span; from 0.457 to 0.533 inch for the lattice subchannel hydraulic diameter; and from 7.9 to 14 feet for heated length. Established coolant conditions (Reference 7) of the tests varied: from 1775 to 2425 psia for pressure; from 0.897 to 3.549 Mlb/h/ft^2 for local mass flux; from 383.9 to 644.3 Btu/lb for inlet enthalpy; and from -0.130 to 0.344 for local quality.

Thermocouples are employed to detect the occurrence of DNB in the tests. They are located at the axial position listed in Table 3.5 of Reference 3. For each set of BHTP spacer grid bundle test data, the LYNXT code was used to predict the local thermal-hydraulic conditions (mass velocity, thermodynamic quality, heat flux, and pressure) axially along the test section heated length. The predicted local conditions at the point of detected burnout are provided in the summary of results for the BHTP data base (Reference 7).

4.2 BHTP DNB Correlation Development

The correlation is an empirically derived function of the local coolant thermodynamic state and mass flux at which DNB is observed to occur in the experiment. The base correlation is developed based on local coolant conditions at the point of DNB predicted from test data for the uniform axial power distribution. The local coolant conditions are calculated with the approved LYNXT computer code (Reference 4). The predicted DNB heat flux is modified by factors which account for the effect of non-uniform axial power distribution and fuel assembly design parameters. This aspect is the same as the formulation used in the approved HTP DNB correlation (Reference 3).

The local conditions data from each CHF test statepoint form the data base for the BHTP CHF correlation. These data (mass velocity, thermal dynamic quality, heat flux, pressure, local thermodynamic quality and axial location) were used to determine the coefficients of the BHTP CHF correlation. The method used for coefficient determination is a least squares fit that minimizes the deviation of predicted CHF to the measured CHF ratio of predicted over measured (P/M) around a mean of 1.0. All the BHTP coefficients were re-optimized with the exception of those in the fuel design factor (FDF) term that includes coefficients b7 through b14. The BHTP correlation optimization is documented in the FANP calculational file supporting TR BAW-10241P.

The BHTP DNB correlation is used in the following steps: (1) local coolant conditions are calculated as a function of radial and axial position within the assembly with a LYNXT subchannel model; (2) the DNB heat flux is calculated at each position within the assembly using the local coolant conditions determined in step 1; and (3) the DNB ratio is calculated as the ratio of predicted DNB heat flux to operating heat flux at each position within the assembly. Minimum DNB ratio (MDNBR) is selected as the least value of the DNB ratio to occur in the assembly. The MDNBR is then used as a measure of the margin to DNB for the operating assembly.

4.3 Qualification of BHTP DNB Correlation

The approved LYNXT computer code was used to predict DNB heat fluxes to be compared against the measured heat fluxes. The key variables measured at the point of DNB, such as inlet temperature, inlet mass flux, exit pressure and bundle power, were used as boundary conditions in the LYNXT calculations.

Comparison between the predicted location of DNB and the heated rod and thermocouple number at which the primary DNB indication was recorded, indicated the adequacy of the model. The P/M heat fluxes were plotted for all tests to indicate the degree of agreement between the prediction using the BHTP correlation and the measured data. The plots showed good agreement in most tests and for the other cases nearly all the data fell within the 95/95 tolerance limit lines.

The frequency distribution of P/M ratios for the entire data base was used to determine the 95/95 safety limit for the HTP correlation using a distribution free method, the same method which had been used to determine the HTP DNB correlation limit (Reference 2).

4.4 Applicability of BHTP Correlation

The DNB-based safety limit for the first plant to use the Mark-BHTP fuel design will conservatively represent the allowable pressure-temperature conditions for transition core situations (Mark-B10 fuel with Mark-BHTP fuel), as well as the full core situation (all Mark-BHTP fuel) (Reference 6). Operational and safety limits are being set for core power level, axial power imbalance, control rod insertion, and maximum rod relative power to preserve acceptable DNB performance based on the BHTP correlation predictions. In addition, a variable low pressure trip function provides protection to assure the plant does not reach or exceed the DNB-based safety limit of the technical specifications. The DNB-based operational and safety limits established for the plant provide hot pin/hot subchannel protection for acceptable plant operation, based on the local coolant conditions satisfying the correlation range of applicability defined in Table 1.1 of BAW-10241P. In response to the staff concern on the actions to be taken when local conditions fall outside the application ranges for limiting hot rod/hot subchannel, a treatment for qualities below the low quality limit and for pressures above the upper pressure limit was addressed in Reference 9. The staff has reviewed the justification for the approach to treat the out-of-approved range local conditions and has found them acceptable in principle, because the approach will result in a conservative CHF value. However, the staff will impose an allowable extension beyond the approved range for maximum pressure, but not exceeding 2600 psia and there will be no limit below the approved range for minimum quality. It will be subject to plant-specific review if the condition cannot be met. This conclusion is only applied to this review based on the data bases available to support the subject TR.

The BHTP correlation range of applicability, stated in Table 1.1 of BAW-10241P for local coolant conditions, is used in establishing the DNB-based limits associated with the above described operational and safety limits. The BHTP correlation range of applicability, stated in Table 1.2 of BAW-10241P, for fuel design parameters must be verified by the licensee prior to performing any DNB analyses using the BHTP correlation. The staff has reviewed acceptable ranges for both local coolant conditions and fuel design parameters against the BHTP data base in BAW-10241P and the data base in Reference 3. The acceptable ranges are provided in Table 1 and Table 2 attached to this safety evaluation.

5.0 CONCLUSION

The staff has reviewed BAW-10241P and the supplemental information (References 6 through 10) to determine acceptability of the BHTP correlation for use in DNB analysis of the HTP fuels and has concluded as follows:

(1) Based on the data in Reference 3, the BHTP DNB correlation is applicable to fuels whose design characteristics fall within the correlation data base in Table 2 below.

(2) Based on the data in Reference 7, the application of the BHTP correlation for DNB analysis is restricted to the operating conditions given in Table 1, except as noted in Condition 5 below.

(3) The BHTP correlation limit is determined to be as stated in the subject TR (Reference 2).

(4) DNB penalty relative to DNB prediction for a full core of Mark-BHTP fuel during transition core application shall be addressed in the plant-specific application.

(5) Actions for analyzing the operating conditions outside of the approved ranges of the maximum pressure, but less than 2600 psia are acceptable in principle for this application (Reference 9). Extrapolations below the minimum quality range using the process described in the TR are permitted with no lower limit. Any other extrapolation requires a plant-specific review.

6.0 REFERENCES

1. Letter from James F. Mallay, Framatome ANP to USNRC, Issuance of BAW-10241P, "BHTP DNB Correlation Applied with LYNXT," for Review and Acceptance, dated December 19, 2002. (ADAMS Accession No. ML023600367)

2. Topical Report BAW-10241P, Revision 0, "BHTP DNB Correlation Applied with LYNXT," December 2002. (ADAMS Accession Nos. ML023600394; non-proprietary version ML023600376)

3. EMF-92-153(P)(A), Supplement 1, "HTP: Departure from Nuclear Boiling Correlation for High Thermal Performance Fuel," March 1994. (ADAMS Accession Nos. 9403240220 for letter; 943240226 for proprietary version of TR; 9403240222 for non-proprietary version of TR)

4. BAW-10156-A, Revision 1, "LYNXT Core Transient Thermal-Hydraulic Program," August 1993. (ADAMS Accession Nos. 9309130167 for letter; 09130194 for TR)

5. XN-NF-75-21(P)(A), Revision 2, "XCOBRA-IIIC: A Computer Code to Determine the Distribution of Coolant during Steady State and Transient Operation," January 1986. (ADAMS Accession No. 8605140222)

6. Letter from James F. Mallay, Framatome ANP to USNRC, "Response to RAI [Request for Additional Information] Regarding BAW-10241(P), Revision 0, 'BHTP DNB Correlation Applied with LYNXT'," dated June 6, 2003. (ADAMS Accession No. ML031710023)

7. Letter from James F. Mallay, Framatome ANP to USNRC, "Response to RAI Regarding BAW-10241(P), Revision 0, 'BHTP DNB Correlation Applied with LYNXT'," dated September 3, 2003. (ADAMS Accession Nos. ML032480676 for letter and non-proprietary version of attachment; ML032480690 for proprietary version of attachment)

8. Letter from James F. Mallay, Framatome ANP to USNRC, "Response to RAI Regarding BAW-10241(P), Revision 0, 'BHTP DNB Correlation Applied with LYNXT'," dated February 11, 2004. (ADAMS Accession Nos. ML040440489 for letter and non-proprietary version of attachment; ML040440491 for proprietary version of attachment)

9. Letter from James F. Mallay, Framatome ANP to USNRC, "Response to RAI Regarding BAW-10241(P), Revision 0, 'BHTP DNB Correlation Applied with LYNXT'," dated June 17, 2004. (ADAMS Accession No. ML041750287)

10. Letter from James F. Mallay, Framatome ANP to USNRC, Additional Information Related to the Review of BAW-10241(P), dated August 9, 2004. (ADAMS Accession No. ML04229252)

Attachment: Table 1: Range of Coolant Conditions for BHTP Correlation
Table 2: Range of Fuel Design Parameters for BHTP Correlation

Principal Contributor: T. Huang

Date: September 29, 2004

Table 1: Range of Coolant Conditions for BHTP Correlation

Pressure (psia)	1775 to 2425
Local Mass Flux (Mlb/hr/ft^2)	0.897 to 3.549
Inlet Enthalpy (Btu/lb)	383.9 to 644.3
Local Quality	-0.130 to 0.344

Table 2: Range of Fuel Design Parameters for BHTP Correlation

Fuel Rod Diameter (in)	0.360 to 0.440
Fuel Rod Pitch (in)	0.496 to 0.580
Axial Spacer Span (in)	10.5 to 26.2
Hydraulic Diameter (in)	0.4571 to 0.5334
Heated Length (ft)	9.8 to 14.0

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August 9, 2004
NRC:04:040

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U.S. Nuclear Regulatory Commission
Washington, D.C. 20555-0001

Additional Information Related to the Review of BAW-10241(P)

Ref.: 1. Letter, James F. Mallay (Framatome ANP) to Document Control Desk (NRC), "Issuance of BAW-10241P, 'BHTP DNB Correlation Applied with LYNXT'," NRC:02:065, December 19, 2002.

Ref.: 2. Letter, James F. Mallay (Framatome ANP) to Document Control Desk (NRC), "Response to a Request for Additional Information Regarding BAW-10241(P), 'BHTP DNB Correlation Applied with LYNXT'," NRC:04:033, June 17, 2004.

Framatome ANP requested the NRC's review and approval of the topical report BAW-10241(P) in Reference 1. In response to a verbal request from the NRC on August 6, 2004 additional information to support the review is being provided.

Attachment A to this letter is a plot of CHF versus system pressure from 2200 to 2600 psia. In Reference 2, a similar plot was submitted to the NRC of CHF versus system pressure from 2200 to 2500 psia. In Figure 2 of this reference, two numbers were transposed and one number was incorrectly labeled. This has been corrected on the attached plot. Since the key component of the labeling is the "Hi/Lo" designation, we view the CHF data point designation as insignificant for interpreting and applying the figures.

Very truly yours,

James F. Mallay, Director
Regulatory Affairs

Attachment

cc: M. C. Honcharik (w/attachment)
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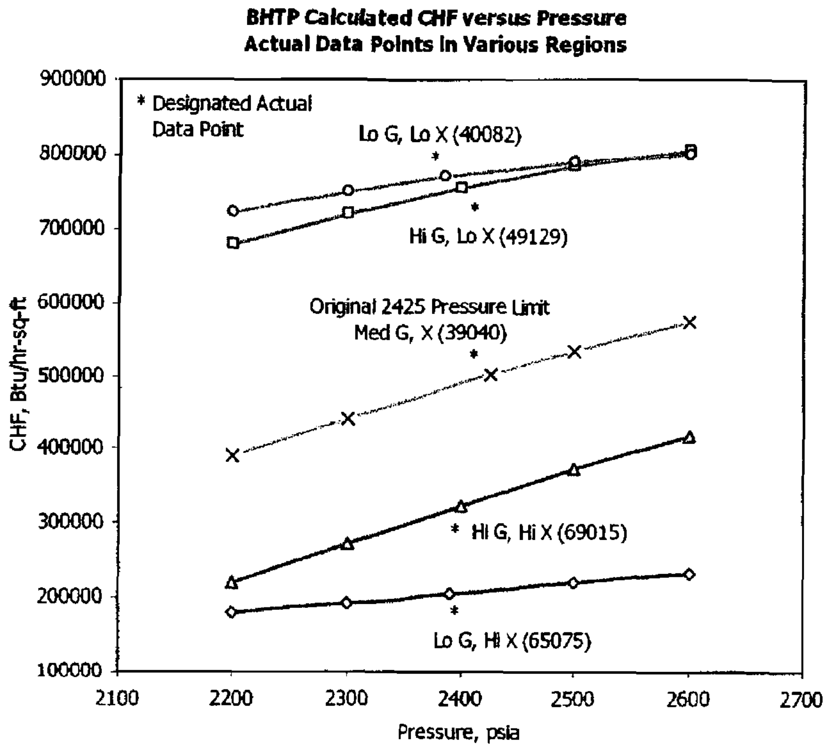
Attachment A



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June 17, 2004
NRC:04:033

Document Control Desk
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555-0001

Response to a Request for Additional Information regarding BAW-10241(P), "BHTP DNB Correlation Applied with LYNXT"

Ref.: 1. Letter, James F. Mallay (Framatome ANP) to Document Control Desk (NRC), "Issuance of BAW-10241P, 'BHTP DNB Correlation Applied with LYNXT,' for Review and Acceptance," NRC:02:065, December 19, 2002.

Ref.: 2. Letter, James F. Mallay (Framatome ANP) to Document Control Desk (NRC), "Request for Additional Information – BAW-10241P Revision 0, 'BHTP DNB Correlation Applied with LYNXT'," NRC:03:035, June 6, 2003.

Ref.: 3. Letter, James F. Mallay (Framatome ANP) to Document Control Desk (NRC), "Request for Additional Information – BAW-10241P Revision 0, 'BHTP DNB Correlation Applied with LYNXT'," NRC:03:054, September 3, 2003.

Ref.: 4. Letter, James F. Mallay (Framatome ANP) to Document Control Desk (NRC), "Topical Report BAW-10241(P), 'BHTP DNB Correlation Applied with LYNXT'," NRC:04:005, February 11, 2004.

Framatome ANP requested NRC review and approval of the topical report BAW-10241(P), "BHTP DNB Correlation Applied with LYNXT" in Reference 1. Responses to requests for additional information were provided in References 2, 3, and 4. A supplemental request for additional information was discussed in a telephone call on April 13, 2004. A statement of the question and a response are provided in Attachment A to this letter. The question was provided by the NRC in an e-mail.

Very truly yours,

James F. Mallay, Director
Regulatory Affairs

Attachments

cc: F. Akstulewicz
M. C. Honcharik
T. Huang
Project 728

Attachment A

Response to a Request for Additional Information (RAI) on BAW-10241

Subject: Extension of the BHTP CHF Correlation Ranges

Question: *This is relating the review of BAW-10241(P) BHTP DNB Correlation Applied with LYNXT (TAC No. MB7033). Framatome requests to extend the applicable ranges beyond the approved ranges for local quality lower than -0.125 and pressure higher than 2425 psia.*

A CHF correlation is an empirical function relating a set of independent parameters (such as pressure, mass flux, thermodynamic quality, and fuel geometry) to a set of experimentally measured critical heat flux values by means of a statistical regression analysis. The purpose of the statistical fit is to capture significant trends in the relationship between CHF and the various independent variables. In general, correlations derived in this manner do a very good job of predicting CHF as a function of the independent parameters within the range of the database. However, experience has shown that such correlations do not generally do a very good job when extended to conditions outside their database. There are several reasons for this behavior: 1) the correlation is a statistical fit to data, not a mathematical expression of the physical behavior of the system; 2) the functional form of the correlation is generally some type of polynomial, the coefficients of which are iterated on to produce a curve that most closely matches the measured data over the full range of the database; and 3) polynomial functions are extremely flexible, and can be made to fit almost any reasonable distribution of data, but they have a disconcerting tendency to sometimes go off in odd directions when applied outside their range of derivation.

The staff has reviewed available information provided by Framatome dated February 11, 2004 and has found further information needed to support the staff review is given as follows:

1. *In order to justify even a relative minor extrapolation of a correlation beyond its database, it is necessary to examine the correlation's behavior very carefully in the extrapolated region, to be certain it maintains the expected trends. The plot in Figures 1 and 2 shows that the BHTP does exhibit the expected behavior, but the examples shown are for only two data points, both of which is at mass flux values near middle of the range of normal operation. Would the correlation show the same trends at very low mass flux? At very high mass flux? At low pressure and low mass flux? At high pressure and low mass flux?*

2. *Because the correlation is non-linear in the independent parameters, the example of one or two data points in the middle of the range, as presented in Figures 1 and 2, is not sufficient to demonstrate the general applicability of the correlation to this extended range. In order to show that the BHTP correlation appropriately captures the trend of thermodynamic quality versus critical heat flux, and that of the pressure versus critical heat flux, over the full operating range of mass flux and pressure, please provides a family of curves like those in Figures 1 and 2. These curves need to encompass the full range of mass flux and pressure starting at the lowest thermodynamic qualities tested. If the correlation is able to hold up through this extrapolation, then the additional curves should all look very much like the examples in Figures 1 and 2, and it will have successfully demonstrated the applicability of the correlation when extended beyond its database over the relatively small range of extrapolation considered.*

Response:

Treatment of Qualities Below the Low Quality Limit

The lower quality limit for the BHTP CHF Correlation is –0.1301. If, during calculation of CHF at any axial location of CHF, a quality below this limit is encountered, the quality used in the calculation of the BHTP CHF is raised to this limit (-0.1301). Figure 1 and its accompanying table show that this technique is conservative in all of the PG (pressure, P, versus mass velocity, G) regions.

Representative data for each region was chosen as follows. The high pressure region was defined as data in the 2400 psia subset of the data base. The highest and lowest measured mass velocity groups were identified and the points with the lowest quality in these subsets were chosen. An analogous procedure was followed in the low pressure (1800 psia) subset. The data chosen are shown in the following table. The Data ID is XXYYY where XX is the test number and YYY is the run number.

Data ID	Description	Pressure (psia)	Mass Velocity (Mlb/hr-ft^2)	Quality at CHF
40107	Hi P, Hi G	2420	2.896	-0.1301 *
51133	Lo P, Lo G	1800	1.011	0.098
40102	Lo P, Hi G	1805	3.393	-0.062
68088	Hi P, Lo G	2405	0.984	0.056
68052	Med P, Med G	2005	2.008	0.004

* Limiting Low Quality Point

To illustrate the conservatism of this technique, examine point 40107 with the actual quality limit of -0.1301. The BHTP calculated CHF for these conditions is 1,221,918 Btu/hr-ft^2. If the quality upstream of this data point was, for example, -0.190 then (as shown on Figure 1) the BHTP calculated CHF would be 1,353,881 Btu/hr-ft^2. Thus the technique of increasing the quality from -0.190 to -0.1301 is (in this case) conservative by 131,963 Btu/hr-ft^2 (the difference between 1,221,918 at a quality of -0.1301 and 1,353,881 at a quality of -0.190). Figure 1 shows that there would be varying degrees of conservatism in different PG regions. However, the technique is seen to be conservative in all regions since a negative slope is always observed with increasing quality.

Treatment of Pressures Above the Upper Pressure Limit

The upper pressure limit for the BHTP CHF correlation is 2425 psia. If, during calculation of CHF for any given core condition, the system pressure is above this limit, the Framatome ANP procedure is to rerun the LYNXT case at 2425 psia. This action is consistent with the procedure for the treatment of the upper limit for the HTP correlation as described in Reference 1, EMF-92-153(P) Addendum 1, which was provided in response to Question 1 in Reference 2, letter NRC:03:035, dated June 6, 2003.

The procedure in this case differs from the quality case. In raising the quality to the lower limit, no recalculation of the local conditions was performed. Only the calculation of CHF was affected. In lowering the pressure to the upper limit and rerunning the LYNXT case, the local conditions are all recalculated and then used in the calculation of CHF. The reduction of pressure causes a corresponding increase in the calculated quality because the enthalpy at any point is the same (reflecting the same heat input) and the saturated liquid enthalpy is reduced. Figure 2 shows that this technique is conservative in all of the GX (mass velocity, G, versus quality, X) regions.

The procedure for treating the situation where the high pressure limit is exceeded is different from that for the case when the low quality limit is exceeded because in some of the GX regions a decrease of pressure with no other change (of G or X) results in an increase of the calculated CHF. (Note that this is not physically possible. As explained above, the quality, X, increases with a decrease in system pressure.) Thus, a reduction of pressure requires a recalculation of all the local conditions. The Framatome ANP process for using the BHTP CHF correlation in the LYNXT computer code insures that this approach is followed. Note that the response provided in the Reference 3, letter NRC:04:005, dated February 11, 2004, was incorrect in that it stated that quality and pressure were treated in a similar manner and did not address the difference in EMF-92-153(P) Addendum 1 between the treatment of quality and pressure. Further, at no time has the upper pressure limit of 2425 psia been exceeded for reload analyses utilizing the BHTP CHF correlation. Thus the additional upper pressure limit procedure is anticipatory (not corrective) in nature.

Representative data for each region were selected as follows. The highest and lowest mass velocity groups with corresponding low (negative) qualities were identified. The data points with the actual lowest quality were selected from this subset. For the high and low high mass velocity at the high quality region, analogous points were chosen. The midpoint region is represented by the data point at the high pressure limit. The data chosen is shown in the following table.

Data ID	Description	Pressure (psia)	Mass Velocity (Mlb/hr-ft^2)	Quality at CHF
49129	Hi G, Lo X	2400	3.017	-0.014
40082	Lo G, Lo X	2385	1.492	-0.019
69015	Hi G, Hi X	2400	2.049	0.264
65075	Lo G, Hi X	2390	0.957	0.275
39040	Med G, Med X	2425 *	2.451	0.155

* Designates Limiting High Pressure Point

In this example, case ID point 39040 (at the actual pressure limit of 2425 psia) is used to demonstrate the conservatism of this technique. The BHTP calculated CHF for these conditions is 500,850 Btu/hr-ft^2. If the actual pressure of this data point was, for instance, 2500 psia then (as shown on Figure 2) the BHTP calculated CHF would be 533,488 Btu/hr-ft^2. Thus the technique of decreasing the pressure from 2500 psia to 2425 psia is (in this case) conservative by 32,638 Btu/hr-ft^2 (the difference between 500,850 at a pressure of 2425 and 533,488 at 2500). Figure 2 shows that varying degrees of conservatism in different GX regions. However, the technique is seen to be conservative in all regions since a positive slope is always observed with increasing pressure.

Clarification

As noted above in the response, Framatome ANP discovered that its previous response provided in Reference 3, letter NRC:04:005, dated February 11, 2004, was erroneous in two areas. First, the treatment of qualities below the low quality limit is different (not similar as stated in Reference 3) than the treatment of pressures above the high pressure limit. The difference in treatment is discussed in EMF-92-153(P) Addendum 1, provided in the letter NRC:03:035, dated June 6, 2003, but was overlooked while preparing the Reference 3 RAI response. Second, Framatome ANP believed that the pressure versus CHF behavior shown in Figure 2 of the letter NRC:04:005, dated February 11, 2004, was representative of the correlation behavior across the entire correlation space. Framatome ANP has since concluded the pressure versus CHF behavior is not consistent across the correlation space. This difference in behavior of the correlation across its independent space is the reason for the difference in treatment of quality and pressure as described in EMF-92-153(P) Addendum 1.

Summary

Figures 1 and 2 show the behavior of the BHTP CHF correlation for various combinations of pressure, mass velocity, and quality. The trends observed for these combinations consistently demonstrate the conservative nature of imposing the lower quality limit and/or upper pressure limit when quality and/or pressure conditions fall outside the BHTP applicability ranges when applied with the implementation requirements below.

Implementation Requirements

a) When local coolant qualities less than the lower quality limit are encountered, the calculation of the BHTP critical heat flux is made using the quality at the BHTP lower quality limit. This action results in a conservative quality value substitution in the BHTP critical heat flux calculation prior to the determination of the DNB ratio.

b) When pressures greater than the upper pressure limit are encountered, all the local coolant conditions are calculated at the upper pressure limit using LYNXT and then used in the calculation of the BHTP critical heat flux. This action results not only in a pressure condition equal to the upper pressure limit, but also in a set of corresponding coolant conditions (including quality and mass velocity) that yield a conservative BHTP critical heat flux calculation prior to the determination of the DNB ratio.

The above implementation requirements result in a BHTP correlation application that is conservative.

References

1. EMF-92-153(P), Addendum 1, *HTP: Departure From Nucleate Boiling Correlation For High Thermal Performance Fuel*, May 2003.

2. Letter, James F. Mallay (Framatome ANP) to Document Control Desk (NRC), "Request for Additional Information – BAW-10241(P) Revision 0, 'BHTP DNB Correlation Applied with LYNXT'," NRC:03:035, June 6, 2003.

3. Letter, James F. Mallay (Framatome ANP) to Document Control Desk (NRC), "Topical Report BAW-10241(P), 'BHTP DNB Correlation Applied with LYNXT'," NRC:04:005, February 11, 2004.

Figure 1
BHTP Calculated CHF versus Quality at CHF
Actual Data Points in Various Regions

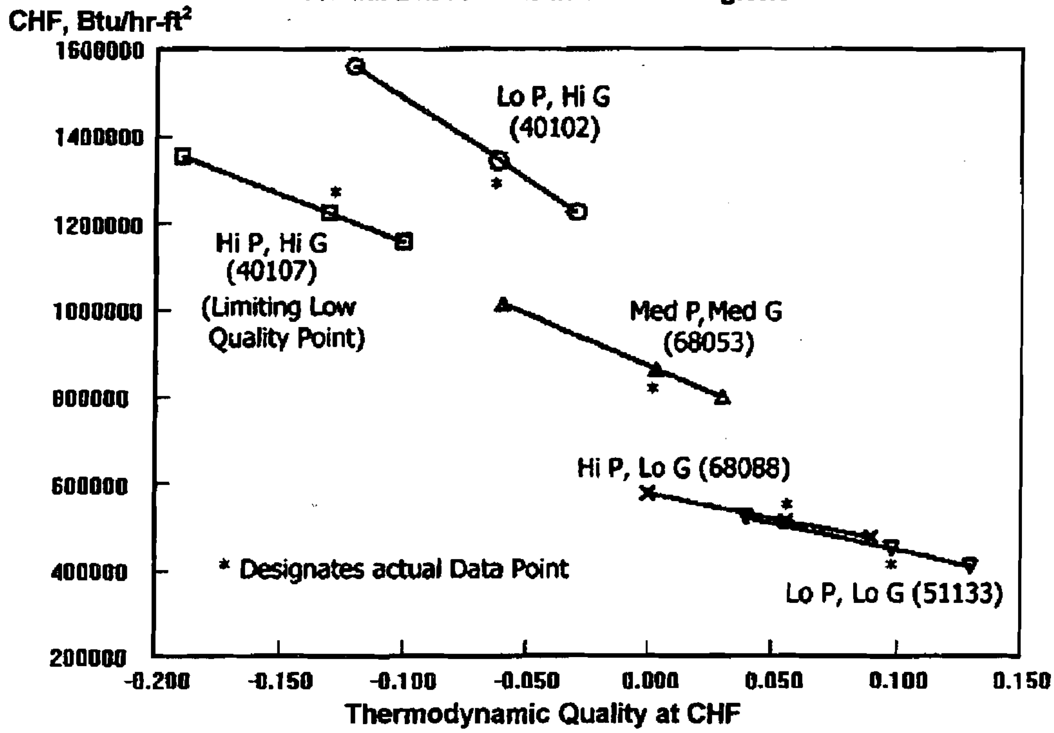
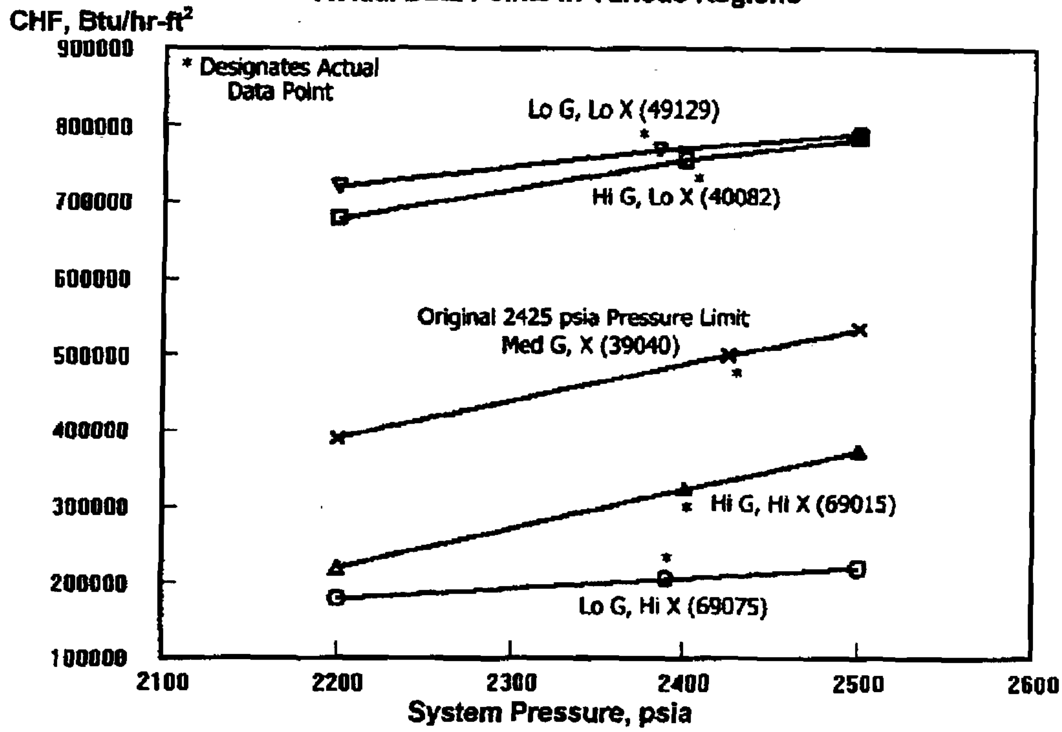


Figure 2
BHTP Calculated CHF versus Pressure
Actual Data Points in Various Regions



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February 11, 2004
NRC:04:005

Document Control Desk
ATTN: Chief, Planning, Program and Management Support Branch
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555-0001

Topical Report BAW-10241(P), "BHTP DNB Correlation Applied with LYNXT"

Ref.: 1. Letter, James F. Mallay (Framatome ANP) to Document Control Desk (NRC), "Issuance of BAW-10241P, 'BHTP DNB Correlation Applied with LYNXT,' for Review and Acceptance," NRC:02:065, December 19, 2002.

Ref.: 2. Letter, James F. Mallay (Framatome ANP) to Document Control Desk (NRC), "Request for Additional Information - BAW-10241P Revision 0, 'BHTP DNB Correlation Applied with LYNXT'," NRC:03:035, June 6,2003.

Ref.: 3. Letter, James F. Mallay (Framatome ANP) to Document Control Desk (NRC), "Request for Additional Information - BAW-10241P Revision 0, 'BHTP DNB Correlation Applied with LYNXT'," NRC:03:054, September 3,2003.

Framatome ANP (FANP) requested NRC review and approval of the topical report BAW-10241(P), "BHTP DNB Correlation Applied with LYNXT" in Reference 1. Responses to Requests for Additional Information were provided in References 2 and 3. A supplemental request for additional information was discussed in a telephone call on January 29, 2004. A statement of the question and a response are provided in Attachment 1 to this letter.

Framatome ANP considers some of the information contained in the attachment to this letter to be proprietary. The affidavit provided with the original submittal of the reference report (Reference 1) satisfies the requirements of 10 CFR 2.790(b) to support the withholding of this information from public disclosure.

Very truly yours,

James F. Mallay, Director
Regulatory Affairs

Enclosures

cc: F. Akstulewicz
D. G. Holland
T. Huang
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The proprietary version of Attachment 1 has been omitted from BAW-10241(NP)(A)

Attachment 1

Response to a Request for Additional Information on BAW-10241P

Question 1: *In Section 1.1 of BAW-10241P it is stated the "low qualities and high pressures outside of the limits of Table 1.1 will be treated as described in Reference 4." Please describe and justify the treatment of low qualities and high pressures outside of the limits in Table 1.1*

Response 1: There are two conditions that can occur in the application of the BHTP correlation where local coolant conditions for DNB predictions can fall outside the limits defined in Table 1.1 of BAW-10241P:

1) local coolant qualities below the lower quality limit and
2) coolant pressures greater than the upper pressure limit.

Examples for each condition are 1) local coolant qualities in the lower region of the core could be below the BHTP lower quality limit and 2) the system pressure for an operating statepoint could be above the upper pressure limit. Local coolant qualities below the BHTP quality lower limit are encountered in all steady state and transient analyses because the CHF calculations are initiated at the entrance to the assembly (where the coolant is highly subcooled). The system pressure may, in limited cases, be above the upper pressure limit for transients that challenge the system pressure limit. Framatome ANP has adopted a conservative technique for applying the BHTP correlation for such conditions.

If a local coolant condition is calculated that requires evaluation with the BHTP correlation where the quality is below the correlation lower quality limit then the value of the quality will be increased to the lower limit for the determination of the critical heat flux. If a local coolant condition is calculated that requires evaluation with the BHTP correlation where the pressure is above the correlation pressure upper limit then the value of the pressure will be reduced to the upper limit for the determination of the critical heat flux. These specific adjustments to the values of quality and pressure in the critical heat flux determination are conservative. These adjustments result in a reduction in the calculated CHF relative to the expected or true value. The purpose of these adjustments is to assure that the correlation is only used within its range of acceptance.

The conservatism in the pressure adjustment is supported by the Framatome ANP experience in CHF testing at the Columbia University test facility. During CHF testing it is observed that an increase in pressure when CHF is imminent suppresses the onset of CHF and in turn requires an increase in the heat flux to reach CHF.

These adjustments are consistent with the observed behavior of critical heat flux measurements for changes in local quality and pressure. The use of a higher than calculated local coolant quality will yield a lower CHF prediction. Similarly, the use of a lower pressure than calculated will yield a lower CHF prediction. These facts are illustrated in the attached two figures. The plots in the figures were generated using equation 2.1 in the BHTP topical by fixing the values of the variables in the correlation except the variable being plotted. The CHF sensitivity to thermodynamic quality is demonstrated in the first figure and the sensitivity to pressure is demonstrated in the second figure.

Figure 1

[ ]

Figure 2

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September 3, 2003
NRC:03:054

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Washington, D.C. 20555-0001

Request for Additional Information - BAW-10241(P) Revision 0, "BHTP DNB Correlation Applied with LYNXT"

Ref.: 1. Letter, James F. Mallay (Framatome ANP) to Document Control Desk (NRC), "Issuance of BAW-10241P, 'BHTP DNB Correlation Applied with LYNXT,' for Review and Acceptance," NRC:02:065, December 19, 2002.

Ref.: 2. Letter, James F. Mallay (Framatome ANP) to Document Control Desk (NRC), "Request for Additional Information - BAW-10241(P) Revision 0, 'BHTP DNB Correlation Applied with LYNXT'," NRC:03:035, June 6, 2003.

In Reference 1, Framatome ANP submitted the report BAW-10241(P) for review and approval. In Reference 2, Framatome ANP provided responses to an initial set of questions. Additional questions were discussed in a telephone call with the NRC on August 27, 2003. A set of responses to these questions is provided in Attachment A to this letter. Proprietary and non-proprietary versions of the attachment are provided.

Framatome ANP considers some of the information contained in the attachments to this letter to be proprietary. The affidavit provided with the original submittal of the reference report (Reference 2) satisfies the requirements of 10 CFR 2.790(b) to support the withholding of this information from public disclosure.

Very truly yours,

Gerald J Holm for

James F. Mallay, Director
Regulatory Affairs

Enclosures

cc: D. G. Holland
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The proprietary version of Attachment A has been omitted from BAW-10241(NP)(A)

Response to RAI on BAW-10241(P) "BHTP DNB Correlation Applied with LYNXT"

Question 1: *Please provide the following information:*

1) *the LYNXT-predicted local conditions for the 1481 CHF test statepoints,*
2) *a short description of the BHTP correlation optimization process,*
3) *the reference for the correlation coefficient optimization process, and*
4) *a statement that the process and results are documented in an auditable calculational analysis.*

Response 1: For each set of Mark-B-HTP spacer grid bundle test data, the LYNXT code was used to predict the local thermal-hydraulic conditions (mass velocity, thermodynamic quality, heat flux, and pressure) axially along the test section heated length. The predicted local conditions at the point of detected burnout are provided in Table 1. Note that these predicted local conditions using the LYNXT code differ only slightly from the predicted local conditions contained in Table 3.8 of Reference 1 for the development of the HTP CHF correlation using the XCOBRA-IIIC code. The maximum and minimum values from Table 1 were used to establish the BHTP correlation range of applicability shown in Table 1.1 of Reference 2.

The local conditions data from each CHF test statepoint form the data base for the BHTP CHF correlation. These data (mass velocity, thermodynamic quality, heat flux, pressure, local thermodynamic quality and axial location) were used to determine the coefficients of the BHTP CHF correlation. The method used for coefficient determination is a least squares fit that minimizes the deviation of the predicted CHF to the measured CHF ratio (P/M) around a mean of 1.0.

If the correlation (equation) is linear, any fitting technique is suitable. If it is multi-part or highly non-linear, more sophisticated techniques must be used. The Linearization and Sequential Optimization technique (Reference 3) was specifically developed for use with the optimization of multi-part non-linear correlations such as the BWCMV (Reference 4), the BWU (Reference 5), and BHTP (Reference 2) CHF correlations. In Reference 3, the example of the BWCMV correlation optimization is shown, however, the technique was subsequently adapted to the BWU and BHTP correlation forms.

All of the BHTP coefficients were re-optimized with the exception of those in the FDF (Fuel Design Factor) term that includes coefficients b_7 through b_{14}. The BHTP correlation optimization is documented in a Framatome ANP calculational file and is available for NRC review.

Question 2: *Please provide the basis of the 405 statepoints acknowledged in the Response to Question 3 in the previous RAI for BAW-10241.*

Response 2: To compare the thermal-hydraulic performance for the Mark-B-HTP spacer grid relative to the Mark-B spacer grid (in the response to question 3 of the RAI for BAW-10241P, Reference 6), Framatome ANP provided a DNBR comparison of a core using the BHTP CHF correlation (for a Mark-B-HTP spacer grid) to the BWC CHF correlation (for a Mark-B grid). Since a thorough comparison of the performance of the two spacer grid designs would involve DNBR predictions extending from approximately the correlation design limits to much higher DNBR predictions, Framatome ANP selected a broad set of operating statepoint conditions.

Framatome ANP had developed a set of 405 such statepoints that were used in establishing a statistical design limit (SDL) using statistical core design (SCD) methodology. Each statepoint was defined by the core power (Q), the core flow (W), the core inlet temperature (T), the core outlet pressure (P), and the radial (R) and axial heat (A, Z) output distribution of each of the fuel assemblies in the core. The ranges of these independent variables are shown below for a 177 fuel assembly core. These values are not CHF test data, but are potential conditions that an operating core could encounter during operation.

Variable	Minimum Value	Nominal Value	Maximum Value
Q – Power	50	95	140
W – Flow	65	95	125
P – Pressure	1800	2200	2600
T - Temperature	40	75	110
R – Radial Peak	1.1	1.5	1.9
A – Axial Peak	1.1	1.5	1.9
Z – Axial Location	0.2	0.5	0.8

Q = Percent of Nominal Core Power
W = Percent of Nominal RCS Flow
P = Core Exit Pressure, psia
T = Inlet Temperature Subcooling, F
R = Normalized Maximum Radial Pin Peaking Factor
A = Normalized Maximum Axial Pin Peaking Factor
Z = Normalized Location of A

The fact that the figure in the response to question 3 in Reference 6 shows that they are strongly correlated (that is when the BWC MDNBR for that statepoint increases the BHTP MDNBR for that statepoint increases and vice versa) indicates that each correlation is performing without bias with respect to the absolute MDNBR level. The 405 statepoints are documented in a calculational file available for NRC review.

References

1. EMF-92-153(P)(A), *HTP: Departure From Nucleate Boiling Correlation For High Thermal Performance Fuel*, March 1994.

2. BAW-10241P, *BHTP DNB Correlation Applied With LYNXT*, December 2002.

3. D. A. Farnsworth, "Linearization and Sequential Optimization of Nonlinear Empirical Correlations," *Advances in Mathematics, Computations, and Reactor Physics*, Vol. 2, International Topical Meeting, 1991.

4. BAW-10159P-A, *BWCMV, Correlation of Critical Heat Flux in Mixing Vane Grid Fuel Assemblies*, July 1990.

5. BAW-10199P-A, *The BWU Critical Heat Flux Correlations*, August 1996.

6. Letter, James F. Mallay (Framatome ANP) to Document Control Desk (NRC), "Request for Additional Information - BAW-10241(P) Revision 0, 'BHTP DNB Correlation Applied with LYNXT'," NRC:03:035, June 6, 2003.

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FRAMATOME ANP

An AREVA and Siemens company

FRAMATOME ANP, Inc.

June 6, 2003
NRC:03:035

Document Control Desk
ATTN: Chief, Planning, Program and Management Support Branch
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555-0001

Request for Additional Information - BAW-10241(P) Revision 0, "BHTP DNB Correlation Applied with LYNXT"

Ref.: 1. Fax, Brian Benney for Drew Holland (NRC) to Jerry Holm (Framatome ANP), "Request for Additional Information Relating to Review of Framatome ANP Licensing Topical Report BAW-10241P, 'BHTP DNB Correlation Applied with LYNXT,' " April 25, 2003.

Ref.: 2. Letter, James F. Mallay (Framatome ANP) to Document Control Desk (NRC), "Issuance of BAW-10241P, 'BHTP DNB Correlation Applied with LYNXT,' for Review and Acceptance," NRC:02:065, December 19, 2002.

In Reference 1, The NRC requested additional information to facilitate the completion of its review of the Framatome ANP topical report BAW-10241(P). Responses to this request are provided in two attachments--one proprietary and one non-proprietary.

Framatome ANP considers some of the information contained in the attachments to this letter to be proprietary. The affidavit provided with the original submittal of the reference report (Reference 2) satisfies the requirements of 10 CFR 2.790(b) to support the withholding of this information from public disclosure.

Very truly yours,

Gerald S Holm for

James F. Mallay, Director
Regulatory Affairs

Enclosures

cc: D. G. Holland
Project 728

FRAMATOME ANP, Inc.
2101 Horn Rapids Road - Richland, WA 99352
Tel.: 509-375-8100 Fax: 509-375-8402 www.us.framatome-anp.com

Attachment A (proprietary) has been omitted from BAW-10241(NP)(A)

Attachment B Non-Proprietary
Response to RAI on BAW-10241(P)
"BHTP DNB Correlation Applied with LYNXT"

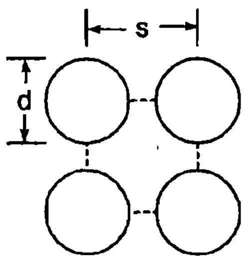
Question 1: *Provide a detailed sketch to show the definition of DHYD, FDF, FPBZ, LEN, SP, and WPR. Also, provide a CD to cover all approved methodologies used to support this licensing topical report including EMF-92-153(P), HTP, Addendum 1 and pp. 599-601 of Annals of Mathematical Statistics, Vol. 29, No. 2, June 1958.*

Response 1: The definitions of these parameters are provided in Section 2 of the topical report. [

]

A CD containing the references in BAW-10241P is enclosed.

Example: 4 Heated Rods



Heated Rod Diameter: d

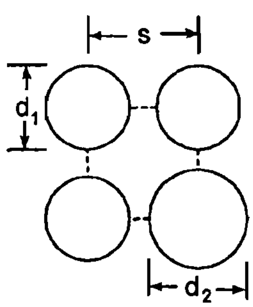
Lattice Pitch: s

Flow Area: $A = s^2 - \frac{\pi}{4} d^2$

Wetted Perimeter: $P_w = \pi d$

Heated Perimeter: $P_h = \pi d$

Example: 3 Heated Rods and 1 Guide Tube



Heated rod diameter: d_1

Guide tube diameter: d_2

Flow Area: $A = s^2 - \frac{\pi}{16}\left(3d_1^2 + d_2^2\right)$

Wetted Perimeter: $P_w = \frac{\pi}{4}\left(3d_1 + d_2\right)$

Heated Perimeter: $P_h = \frac{3\pi}{4} d_1$

Figure 1 Examples Showing Definition for DHYD and WPR

Figure 2 Illustration of Definitions for LEN and SP

Figure 3 Definition of FPBZ

Question 2: *Provide rational for submitting this topical report, which is similar to EMF-92-153(P)(A) Supplement 1, HTP: Departure from Nucleate Boiling Correlation for High Thermal Performance Fuel and identify the difference between these two topical reports.*

Response 2: The topical report BAW-10241P was submitted to obtain NRC approval for the BHTP correlation as implemented in the LYNXT code. The topical report EMF-92-153(P)(A) and Supplement 1 was submitted and received NRC approval for the use of the HTP correlation in the XCOBRA-IIIC code. [

]

Question 3: *Describe the difference between the HTP grid for Mark-B/HTP fuel design and the Mark-B grid on Mark-B10 fuel design and provide the testing data to show any improvement of the thermal-hydraulic performance for the HTP grid relative to the Mark-B grid.*

Response 3: The primary difference between the mechanical designs for the earlier Mark-B grid design and the HTP grid on the Mark-B/HTP fuel design is the fuel rod mechanical contact region. The Mark-B grid, typically identified as a Mark-B10 grid to acknowledge the use of Zircaloy-4 strip material, utilizes a combination of hard stops and spring stops to hold the fuel rod within the grid as seen in Figure 4. The Mark-B10 grid design is a standard non-mixing vaned spacer.

Figure 4 Top View of Section of Mark-B10 Spacer Grid

The HTP grid used on the Mark-B/HTP fuel assembly design utilizes flow channels to retain the fuel rod within the grid as seen in Figure 5.

Figure 5 Top View of Section of HTP Spacer Grid

The thermal-hydraulic performance of the Mark-B10 spacer grid is given by the BWC CHF correlation. The BWC correlation is documented in BAW-10143P-A[1] and is based on seven separate CHF tests (601 data).

[

]

1 BAW-10143P-A, "BWC Correlation of Critical Heat Flux," Babcock & Wilcox, Lynchburg, Virginia, April 1985.

Figure 6 Comparison between BHTP and BWC DNB Performance

Question 4: *Describe schematically the fuel rod failures that occurred in the core baffle of B&W 177-FA plants and physically identify the cause and the corrective action based on any plant data relative to the proposed methodology.*

Response 4: The fuel rod failures have occurred in assemblies on the periphery of the core next to the core baffle at baffle penetrations (LOCA holes and baffle slots). The LOCA holes are present to enhance flow to the core during a LOCA. The baffle slots provide a mechanical benefit during the LOCA event. These baffle penetrations allow cross flow between the region behind the core baffle and the core which can cause vibration in the fuel rod. The vibration of the fuel rods has led to a small number of fuel failures, no more than 0 to 2 rods per cycle (a total of 12 spacer grid fretting failures have occurred in B&W 177 plants for fuel utilizing zircaloy spacer grids which were introduced in 1984). The location of the assemblies which typically may have fuel failures is shown in Figure 7. The fuel rod failures occur on the periphery of the assembly adjacent to the baffle penetrations.

Figure 7 Fuel Assembly Locations Where Fuel Rods Have Failed Due to Flow-Induced Vibration

The fuel rod failures provide the motivation for using the Mark-B/HTP fuel design in a B&W plant. No fuel rod failures due to fretting have ever occurred at an HTP spacer location since the introduction of the HTP fuel assembly design.

Question 5: *Justify the need to use LYNXT code for the proposed licensing topical report relative to XCOBRA-IIIC code. Please identify the differences in relation to the data bases to support the code development and verification, assumptions, ranges of the application, and expected results of the analysis under same conditions between the proposed licensing topical reports using LYNXT code and the HTP DNB correlation using XCOBRA-IIIC and describe in details the reason causing the differences, if any.*

Response 5: The LYNXT code is part of the approved BAW-10179P-A methodology. Two basic approaches exist to use the HTP DNB correlation for analyses in conjunction with BAW-10179P-A. The first is to incorporate the XCOBRA-IIIC code and HTP DNB correlation into the BAW-10179P-A methodology. This approach requires changes to XCOBRA-IIIC to interface with the remainder of the methods in BAW-10179P-A. The second approach is to implement the BHTP DNB correlation into the LYNXT code. Framatome ANP chose to pursue the second approach in order to maintain consistency with the methods in BAW-10179P-A.

The XCOBRA-IIIC code is described in XN-NF-75-21(P)(A) and the LYNXT code is described in BAW-10156-A Rev. 1. The codes are similar since they were both derived from the COBRA series of codes.

The database used to verify that the codes can predict the critical heat flux of the HTP fuel assembly design is the same. To provide an indication of the performance difference between the BHTP correlation/LYNXT code package and the HTP correlation/XCOBRA-IIIC code package, the four lowest MDNBR points from the statistical core design analysis shown in Figure 6 are chosen for comparison. The MDNBR, pressure, mass flux, and quality for these four points are shown under "Statistical Core Design" in Table 1. The closest match to the geometry used for the statistical core design is HTP Test 49. The key geometrical differences are shown in Table 2. The four closest statepoints from Test 49, by pressure, mass flux, and quality, are provided in Table 1 to compare the relative performance of the codes. [

]

Table 1 Comparison of Critical Heat Flux between BHTP/LYNXT and HTP/XCOBRA-IIIC

Table 2 Comparison of Geometry between First Application of Mark-B/HTP and HTP Test 49

Question 6: *It appears that the entire data bases used for EMF-92-153(P)(A) are the same one obtained from* **[ ]** *experimental test programs performed at the Columbia University, which are also used for the proposed BHTP topical report. Please demonstrate the applicability of these data bases to BHTP with respect to any or no minor fuel design changes. Also, describe the axial power shapes used in the tests if available and their direct impact on the development of the BHTP DNB correlation relative to the correction factor used for non-uniform power shape conditions, and any plan for the future testing to verify the accuracy and conservatism of the BHTP DNB correlation with respect to with and without any fuel design changes.*

Response 6: The HTP spacer design has not been changed in a functional sense since the original database was developed. Thus, no new DNB tests have been performed. The range of design characteristic to which the HTP DNB correlation is applicable was defined in the SER for EMF-92-153(P)(A) and Supplement 1 (Table 2 in the SER) and is repeated in BAW-10241P.

The motivation for submitting the topical report BAW-10241P at this time is to support an initial plant specific application at a B&W plant. The values of the fuel design parameters for the first expected use of the topical report BAW-10241P are: fuel rod diameter =.430 inches, fuel rod pitch = .568 inches, axial spacer span = 19.34 inches, hydraulic diameter = .525 inches, heated length = 143 inches. These parameter values are within the range specified in Table 2 of the SER for EMF-92-153(P)(A) and Supplement 1 and in Table 1.2 of BAW-10241P. It is anticipated that the BHTP correlation will be applied to any fuel assembly design using the HTP spacer grid with fuel design parameters that falls within the specifications shown on page 1-3 of BAW-10241P.

The axial power shapes used in the test are described in EMF-92-153(P)(A) and Supplement 1 (Table 3.4 on page 34). The axial correction factor is the same for the correlation as implemented in LYNXT and XCOBRA-IIIC. The statistical evaluation of the correlation presented in BAW-10241P includes the effect of the axial shapes as represented in the DNB tests.

There are no current plans for further testing of the HTP spacer as currently configured.

Question 7: *It appears that the 13% band does not bound data shown in Figures 3.10 (Test 52), 3.12 (Test 56), 3.19 (Test 68) and 3.20 (Test 69). Please provide the bases: (1) to conclude that the ideal versus fitted lines is within a 13% band including the origin of the 13% limit lines; and (2) to justify the conservative nature of the fit and its significant impact on the correlation safety limit.*

Response 7: [

]

Question 8: *Provide: (1) plant specific application of the proposed BHTP submittal with respect to the safe reactor operation; (2) the interrelation of the final 95/95 safety limit for the BHTP correlation with the other reactor operating parameters as far as an input to the core monitoring system or equivalent monitoring system in the control room for operator actions; and (3) description of the actions to be taken if the plant operating outside the approved ranges stated in Tables 1.1 and 1.2.*

Response 8: The BHTP correlation, as defined in BAW-10241P, will be used in conjunction with the methodology and safety criteria described in BAW-10179P-A, "Safety Criteria and Methodology for Acceptable Cycle Reload Analyses" to support plant Technical Specification limits which are based on DNBR analyses. A separate submittal has been made to incorporate BAW-10241P into BAW-10179P once BAW-10241P has been approved.

The steady-state and transient DNB analyses are still in progress for the first batch implementation of the Mark-B/HTP fuel design at a B&W plant. However, the process used to demonstrate safe reactor operation is consistent with BAW-10179P-A and discussed below.

[

]

The DNB analyses are being performed in accordance with the statistical core design methodology defined in BAW-10187P-A. A Thermal Design Limit (TDL) has been set well above the Statistical Design Limit (SDL) to provide DNB margin to offset the DNB transition core penalty for the Mark-B/HTP fuel design with adequate remaining DNB margin to offset other cycle-specific needs. The flexibility to accommodate cycle-specific needs using the margin afforded with the TDL is discussed in Section 5 of BAW-10187P-A.

The DNB-based safety limit for the first plant to use the Mark-B/HTP fuel design will conservatively represent the allowable pressure-temperature conditions for the transition core situations (Mark-B10 fuel with Mark-B/HTP fuel), as well as the full core situation (all Mark-B/HTP fuel). The limiting DNB transients for Condition I/II events will be shown to have acceptable DNB performance or DNB predictions greater than the TDL. The DNB performance of the limiting DNB Condition III event will be used to demonstrate acceptable radiological consequences for the small permissible fraction of fuel failure.

Operational and safety limits are being set for core power level, axial power imbalance, control rod insertion, and maximum rod relative power ($F_{\Delta H}$) to preserve acceptable DNB performance based on the BHTP correlation predictions. In addition, a variable low pressure trip function provides protection to assure the plant does not reach or exceed the DNB-based safety limit of the Technical Specifications. The above operational and safety limits govern the core operational flexibility available to the plant operators.

The DNB-based operational and safety limits established for the plant provide hot pin/hot subchannel protection for acceptable plant operation based on the local coolant conditions satisfying the correlation range of applicability defined in Table 1.1 of BAW-10241P. In establishing these limits, conservative actions have been used for the treatment of low quality and high pressure when local coolant conditions fall outside of the application ranges for the limiting hot rod/hot subchannel. These actions are consistent with those defined for the HTP correlation in EMF-92-153(P), Addendum 1. However, there are less limiting situations when plant operation can occur outside the correlation range of applicability (Table 1.1) at conditions that are substantially less severe than the conditions used in establishing the safety and operational limits. For example, the lower limit of the local coolant quality for BHTP, -0.130, can be exceeded when fuel rods are operating at reduced power levels and/or lower coolant temperatures are encountered. These situations cannot be limiting with respect to the DNBR criterion and thus the issue of the correlation range of applicability is not pertinent (and thus does not need to be addressed).

The BHTP correlation range of applicability, stated in Table 1.1 of BAW-10241P, for local coolant conditions, is used in establishing the DNB-based limits associated with the above described operational and safety limits. For example, the plant will trip before reaching the minimum or maximum local coolant pressure values in Table 1.1. The DNB-based safety limit and the allowable maximum rod relative power (FΔH) limits (commonly referred to as Maximum Allowable Peaking limits) used to set the axial power imbalance and control rod insertion limits are all based on the BHTP correlation performance predictions for the limiting hot rod/hot subchannel within the application ranges defined in Table 1.1 using the conservative actions from EMF-92-153(P) Addendum 1 where appropriate.

The BHTP correlation range of applicability, stated in Table 1.2 of BAW-10241P, for fuel design parameters is verified prior to performing any DNB analyses using the BHTP correlation. It is a fundamental requirement that the fuel design parameter ranges for the CHF correlation database must be representative of the fuel design for which the correlation is applied. Once it is concluded the BHTP correlation is applicable to the fuel design relative to the fuel design parameters in Table 1.2, no further verification is necessary.

Question 9: *Compare the performance of the BHTP correlation against that of the ANFP correlation and demonstrate that the predictions by the use of the BHTP correlation are as or more conservative than those obtained with the ANFP correlation over the range of applicability of ANFP.*

Response 9: The ANFP correlation is no longer used in the United States. The HTP correlation in EMF-92-153(P)(A) and Supplement 1 is the base for the BHTP DNB correlation as implemented in BAW-10241P. A comparison of the results from the HTP correlation as implemented in XCOBRA-IIIC (EMF-92-153(P)(A) and Supplement 1) and the BHTP correlation as implemented in LYNXT (BAW-10241P) is provided in the response to Question 5.

FRAMATOME ANP

An AREVA and Siemens company

FRAMATOME ANP, Inc.

December 19, 2002
NRC:02:065

Document Control Desk
ATTN: Chief, Planning, Program and Management Support Branch
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555-0001

Issuance of BAW-10241P, *BHTP DNB Correlation Applied with LYNXT*, for Review and Acceptance

Ref.: 1. BAW-10156P-A, Revision 1, *LYNXT Core Transient Thermal-Hydraulic Program*, August 1993.

Ref.: 2. EMF-92-153(P)(A) Supplement 1, *HTP: Departure from Nucleate Boiling Correlation for High Thermal Performance Fuel*, March 1994.

Ref.: 3. XN-NF-75-21(P)(A), Revision 2, *XCOBRA-IIIC: A Computer Code to Determine the Distribution of Coolant during Steady State and Transient Operation*, January 1986.

Framatome ANP requests the NRC's review and acceptance of topical report BAW-10241P, *BHTP DNB Correlation Applied with LYNXT.* This report describes a DNB correlation that has been developed using the LYNXT thermal-hydraulic code (Reference 1) for fuel designs equipped with HTP spacer grids. Enclosed are two CDs, one containing the proprietary version of the topical report and one for the non-proprietary version.

The BHTP DNB correlation is of the same form and uses the same CHF database as the HTP DNB correlation (Reference 2). Adjustments have been made in some of the coefficients used to describe the performance of this spacer grid design when the LYNXT code is used. The HTP DNB correlation was developed using the XCOBRA-IIIC thermal-hydraulic code (Reference 3).

Framatome ANP believes that the approval of this correlation should be based on the previous approval of Reference 2. The only new aspect to be accepted is the use of the DNB correlation using a different thermal-hydraulic computer code. The uncertainties, confidence level, and ranges of application are the same or similar to the approved HTP correlation. The first planned application of the BHTP correlation is for the Mark-B/HTP fuel design, which uses HTP spacer grids and is scheduled for installation in Crystal River Unit 3 Cycle 14 in the Fall of 2003.

FRAMATOME ANP, Inc.
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In view of the limited review being requested, Framatome ANP requests that an acceptable SER be issued by June 30, 2003. Framatome ANP would be pleased to meet with appropriate members of the NRC staff in January to describe the contents of the report and the specific areas requiring NRC review.

Framatome ANP considers some of the material contained in the enclosed documents to be proprietary. As required by 10 CFR 2.790(b), an affidavit is enclosed to support the withholding of the information from public disclosure.

Very truly yours,

Gerald S Holm

James F. Mallay, Director
Regulatory Affairs

Enclosures

cc: D. G. Holland
Project 728

AFFIDAVIT

COMMONWEALTH OF VIRGINIA)
) ss.
CITY OF LYNCHBURG)

1. My name is James F. Mallay. I am Director, Regulatory Affairs, for Framatome ANP ("FANP"), and as such I am authorized to execute this Affidavit.

2. I am familiar with the criteria applied by FANP to determine whether certain FANP information is proprietary. I am familiar with the policies established by FANP to ensure the proper application of these criteria.

3. I am familiar with the information contained in BAW-10241P, "BHTP DNB Correlation Applied with LYNXT," and referred to herein as "Document." Information contained in this Document has been classified by FANP as proprietary in accordance with the policies established by FANP for the control and protection of proprietary and confidential information.

4. This Document contains information of a proprietary and confidential nature and is of the type customarily held in confidence by FANP and not made available to the public. Based on my experience, I am aware that other companies regard information of the kind contained in this Document as proprietary and confidential.

5. This Document has been made available to the U.S. Nuclear Regulatory Commission in confidence with the request that the information contained in the Document be withheld from public disclosure.

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(c) The information includes test data or analytical techniques concerning a process, methodology, or component, the application of which results in a competitive advantage for FANP.

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(e) The information is vital to a competitive advantage held by FANP, would be helpful to competitors to FANP, and would likely cause substantial harm to the competitive position of FANP.

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8. FANP policy requires that proprietary information be kept in a secured file or area and distributed on a need-to-know basis.

9. The foregoing statements are true and correct to the best of my knowledge, information, and belief.

SUBSCRIBED before me this 17th

day of December, 2002.

Ella F. Carr-Payne

Ella F. Carr-Payne
NOTARY PUBLIC, STATE OF VIRGINIA
MY COMMISSION EXPIRES: 8/31/05

ELLA F. CARR-PAYNE
Notary Public
Commonwealth of Virginia
My Commission Exps. Aug. 31, 2005

BAW-10241
Revision 0

BHTP DNB Correlation Applied with LYNXT

December 2002

Framatome ANP, Inc.

ISSUED IN FRA-ANP ON-LINE
DOCUMENT SYSTEM
DATE: 12-19-02

BAW-10241
Revision 0

BHTP DNB Correlation
Applied With LYNXT

Contributing Analysts: D. Farnsworth and K. R. Greene

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Approved:	See attached page D. M. Brown, Manager PWR Engineering	Date
Approved:	J. Holm for J. Mallay, Director Regulatory Affairs	12/18/02 Date

kah

Framatome ANP, Inc.

BAW-10241
Revision 0

BHTP DNB Correlation
Applied With LYNXT

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Approved:	J. Mallay, Director Regulatory Affairs	Date

kah

Nature of Changes

Item	Page	Description and Justification
1.	All	This is a new document.

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Appendix A Extension of the BHTP CHF Correlation Ranges

Tables

1.1 BHTP Correlation Range of Applicability: Coolant Conditions 1-3

1.2 BHTP Correlation Range of Applicability: Fuel Design Parameters 1-3

[ ]

Figures

[ ]

Nomenclature

Acronym	Definition
AOO	Anticipated Operational Occurrence
BHTP	Designation for the principal correlation described in this report
DHYD	[ ] equivalent diameter
DNB	Departure from Nucleate Boiling
[	]
[	]
[	]
HTP	The Framatome ANP pressurized water reactor fuel assembly design for which the BHTP DNB correlation is developed.
IFM	Intermediate Flow Mixer
[	]
[	]
LYNXT	Computer code for performing core DNBR analysis
[	]
PWR	Pressurized Water Reactor
[	]
[	]
XCOBRA-IIIC	Computer code for performing core DNBR analysis
[	]

1.0 Introduction and Summary

This document describes the Framatome ANP, Inc., Departure from Nucleate Boiling (DNB) correlation, HTP (Reference 1), and its proposed use with the LYNXT computer code (Reference 2). The HTP correlation has been used for the HTP fuel designs since 1994. The HTP correlation was reviewed and approved by the Nuclear Regulatory Commission (Reference 1). The HTP correlation is presently used with the XCOBRA-IIIC computer code (Reference 3).

The database for the HTP correlation was obtained in a high pressure test loop at Columbia University's Heat Transfer Research Facility. [

] The HTP DNB data base is fully described in Reference 1.

The HTP correlation is an empirically derived function of the local coolant thermodynamic state and mass flux at which DNB is observed to occur in experiment. The heat flux at which DNB occurs is predicted using local coolant quality, local mass flux, and [ ] pressure. A minor [ ] dependence is also present. The HTP correlation contains factors to account for the effects of [

]

DNB correlations are applied with a specified computer code in order to obtain local conditions. [

]

The correlation predictions of the measured data are summarized in the following sub-sections. The BHTP correlation is described in detail in Section 2.0 of this document. The qualification of the correlation against the experimental database is discussed in Section 3.0. The statistical characterization of the correlation is presented in Section 4.0.

1.1 *Range of Applicability*

The BHTP correlation application range of coolant conditions are provided in Table 1.1. The coolant conditions commonly encountered during steady-state operation and Anticipated Operational Occurrences (AOO) in PWRs are also within this range. The range of fuel design parameters are provided in Table 1.2. These are unchanged from Reference 1. [ ]

1.2 *Comparison of BHTP Correlation Predictions to Experimental Measurements*

The BHTP correlation is used to predict the DNB heat flux for each test point in the database. The distribution is characterized [ ] A statistical summary of the P/M ratios for the individual test sections is provided in .

A comparison of predicted DNB heat flux to measured DNB heat flux for the entire database is given in Figure 1.1. Upper and lower dashed lines on this plot enclose a band [ ] about the measured value.

The frequency distribution of the P/M ratios for the entire database is depicted in Figure 1.2. The 95/95 safety limit for the BHTP correlation is 1.132, derived using a [ ] as discussed in Section 4.0.

Table 1.1 BHTP Correlation Range of Applicability: Coolant Conditions

Variable	Minimum Value	Maximum Value
Pressure (psia)	1775	2425
Local Mass Flux (Mlb/h/ft^2)	0.897	3.549
Inlet Enthalpy (Btu/lb)	383.9	644.3
Local Quality	-0.130	0.344

Table 1.2 BHTP Correlation Range of Applicability: Fuel Design Parameters

Parameter	Value
Fuel Rod Diameter, in	0.360 – 0.440
Fuel Rod Pitch, in	0.496 – 0.580
Axial Spacer Span, in	10.5 – 26.2
Hydraulic Diameter, in	0.4571 – 0.5334
Heated Length, ft.	9.8 – 14.0

2.0 The BHTP DNB Correlation

The BHTP correlation is based on the HTP correlation that was approved in Reference 1. [

]

2.1 *Base Correlation*

The BHTP correlation is a [ ] function of [

]

Q_{base} is the predicted DNB heat flux (MBtu/h/ft^2) prior to application of the [ ] factors and the [ ] factor.

[

]

[

]

2.2 *Fuel Design Factor*

The predicted DNB heat flux obtained from Equation (2.1) is modified by terms which account for the effects of the [ ]

[

]

The DNB heat flux including [ ] effects, Q_{pred}, is obtained from Equation (2.1) and the factor FDF defined above: [

]

2.3 *Non-Uniform Axial Power Distribution Correction Factor*

The predicted DNB heat flux obtained from the base correlation is modified as follows for [

]

3.0 Qualification of the BHTP DNB Correlation

The [ ] data points supporting the BHTP DNB correlation are obtained from [ ] programs performed at the Columbia University Heat Transfer Research Facility. The test data and test sections are fully described in Reference 1. The correlation comparison to data and the thermal hydraulic models employed in the LYNXT (Reference 2) simulations of the tests are presented in this section.

3.1 *Thermal Hydraulic Models of Test Assemblies*

The local coolant conditions for each statepoint in the DNB data base are computed with the approved LYNXT computer code (Reference 2). The LYNXT simulation includes a specification of the test assembly geometry and power peaking, single phase friction and component loss coefficient correlations, two-phase flow correlations, a turbulent mixing correlation, and appropriate calculation control parameters. The standard LYNXT models (Reference 2, Appendix B) are used with the BHTP correlation.

3.2 *Calculation Results and Analysis of Residuals*

[

]

4.0 Statistical Characterization of the BHTP DNB Correlation

The BHTP DNB correlation safety limit is derived using the ratio of the [ ] DNB heat flux to the [ ] DNB heat flux [ ]. The correlation safety limit is the value of the [ ] ratio [ ] which, with 95% confidence, 95% of the population of P/M values fall. The correlation safety limit is derived using a [ ]

To evaluate the safety limit, the data sample is sorted in descending order of [ ] ratio. There are [ ] data points in the sample. [ ] defines the degree of confidence, g, associated with the fractional probability, P, that [ ] values chosen [ ] This degree of confidence, g, is defined in terms of [

] 1.132. Hence, the value of the correlation safety limit is 1.132. With 95% confidence, at least 95% of the population of [ ] ratios will be [ ] than this value.

5.0 References

1. EMF-92-153(P)(A) and EMF-92-153(P)(A) Supplement 1, *HTP: Departure From Nucleate Boiling Correlation for High Thermal Performance Fuel*, Siemens Power Corporation, March 1994.

2. BAW-10156-A Revision 1, *LYNXT – Core Transient Thermal-Hydraulic Program*, B&W Fuel Company, August 1993.

3. XN-NF-75-21(P) (A) Revision 2, *XCOBRA-IIIC: A Computer Code to Determine the Distribution of Coolant During Steady State and Transient Operation*, Exxon Nuclear Company, January 1986.

4. [

]

5. [

]

Appendix A

Extension of the BHTP CHF Correlation Ranges

D. A. Farnsworth

R. L. Harne

March 2005

A.1 Introduction and Summary

This Appendix represents Revision 1 to the original version of the topical report BAW-10241(P)(A) (Reference 1) which forms the main body of the report. The purpose of this revision is to extend the range of applicability of the correlation in terms of its independent variables. The need to extend the range of applicability of the independent variables exists because conditions are generated in plant specific analyses which are outside of the original range. The extensions discussed in this appendix are consistent with the extensions granted in Reference 3 for the HTP correlation.

The BHTP CHF correlation is based on [ ] data from [ ] separate CHF tests at the Columbia University Heat Transfer Research Facility (HTRF). These tests were conducted in the late 1980s to early 1990s time frame. The HTRF was officially closed by the university on December 31, 2003.

The BHTP CHF correlation is [ ]. This type of correlation is termed a [ ] correlation. Its major independent variables, in addition to quality, are system pressure and local mass velocity. The CHF calculated from these local thermal hydraulic conditions is modified by a [ ]. All of these terms are applied multiplicatively as shown in Section 2 of the main body of this report.

Other examples of [ ] correlations are the Westinghouse W-3 correlation (Reference 5) and the Framatome ANP BWC and BWCMV correlations, References 6 and 7, respectively. This type of correlation is generally limited to relatively low qualities at CHF (well below 40%), mass velocities above 0.8 Mlb/hr-sq ft and pressures above about 1400 psia. The specific ranges of the BHTP correlation, as approved in Reference 1, are shown in Table A.1. These are the ranges over which the BHTP correlation was optimized (correlated).

Table A.1 Approved Range of Independent Variables for the BHTP CHF Correlation

Independent Variable	Minimum Value	Maximum Value
System Pressure, psia	1775	2425
Mass Velocity, Mlbm/hr-ft^2	0.897	3.549
Thermodynamic Quality at CHF	-0.130	0.344

The revised range of applicability of the BHTP correlation justified in this Appendix is shown in Table A.2 below along with the specific requirements defined in the notes. The changes in the range of applicability are:

1. A reduction in the lower pressure limit, lower mass velocity limit, and lower quality limit, and
2. An increase in the upper quality limit and flexibility to apply the correlation up to <2600 psia under specific requirements.

Table A.2 Revised Range of Independent Variables for the BHTP CHF Correlation

	As Approved in Reference 1		Extended (see Notes)	
Independent Variable	Minimum Value	Maximum Value	Minimum Value	Maximum Value
Pressure, psia	1775	2425	1385	2425
Mass Velocity, Mlbm/hr-ft^2	0.897	3.549	0.492	3.549
Thermodynamic Quality at CHF	-0.130	0.344	No Lower Limit*	0.512

* because of the increasingly conservative trend of lower quality extrapolation

Notes: Actions for analyzing the operating conditions outside of the approved ranges of the maximum pressure (2425 psia) but less than 2600 psia are as follows.

When pressures greater than the pressure limit of 2425 psia but less than 2600 psia are encountered, all of the local coolant conditions are calculated at the upper pressure limit of 2425 psia using the NRC-approved LYNXT thermal-hydraulic code and then used in the calculation of the BHTP CHF.

Extrapolations below the minimum quality range are performed with no lower limit consistent with Reference 3.

The previously approved range of inlet enthalpy and the fuel design parameters from Tables 1.1 and 1.2, respectively, of Reference 1 will remain applicable.

A.2 Extension of the Correlation

The independent variable ranges are extended using three approaches. First, the existing correlation is applied to an expanded data set and shown to be conservative over the expanded range of data. Second, the conservatism of extrapolating beyond the data base is shown. This second approach is applied to extrapolations to low quality values. Third, a technique to calculate conservative CHF values when outside the range of the data is described. This third approach is used when pressures higher than the upper pressure limit are encountered. Part 1 below presents the first approach and Part 2 below summarizes the second and third approach which was presented in Reference 3.

A.3 Part 1 – Extension of the Correlation Using Data

A.3.1 *Data Base for Justification*

A significant amount of BHTP CHF data were obtained at the Columbia HTRF beyond the approved applicability ranges defined in Table A.1. These additional CHF data were not utilized in the establishment of the BHTP CHF correlation. The additional data were obtained in [ ] of the [ ] tests and consisted of [ ] data overall. The additional data are in pressure groups of 1400, 1000 and 600 psia, mass velocities down to 0.25 Mlb/hr-ft^2 and thermodynamic qualities at CHF of up to 58 percent.

These [ ] tests covered the range of physical fuel design parameters in the correlation as defined in Table 1.2 of the body of the report (Reference 1). The data at 600 and 1000 psia were obtained in only 5 of the tests and did not cover a sufficiently wide range of fuel design parameters. Thus, only the 1400 psia data will be used to justify the extension to lower pressure, lower mass velocity and higher quality [( )].

In addition, there were only two of the 1400 psia data at low mass velocities (0.25 Mlb/hr-ft^2) and one point at high quality (at 58 percent). These three data were removed from the 1400 psia group of data leaving [ ] data with which to justify the extensions. This [ ] data base will be referred to as the "New" or "Uncorrelated" data while the original [ ] data base will be referred to as the "Original" or "Correlated" data.

The test conditions (experimental) for the New data are contained in Table A.3. Table A.4 contains the resulting local conditions and P/M CHF values resulting from the application of the original BHTP CHF correlation with the LYNXT thermal-hydraulic analysis code (Reference 2).

A.3.2 *Extension of the Upper Quality Limit*

The New data range in thermodynamic quality from –0.026 to 0.512. The Original and New data are plotted against quality (using the original BHTP CHF correlation) in Figures A.1 and A.2, respectively. Both data sets are combined and shown in Figure A.3. The New data is generally conservative with respect to the Original data, P/M values below 1.0 are conservative in that the Measured (M) CHF obtained in the test are greater than the value Predicted (P) by the BHTP correlation. The New data is about 24 percent conservative overall with an average P/M of 0.7413 versus the Original average P/M of 0.994.

The upper limit in thermodynamic quality at CHF can be extended to 0.512 (51.2 percent) based on these data and analysis with the original BHTP correlation,.

A.3.3 *Extension of the Lower Mass Velocity Limit*

The New data range in mass velocity from 0.492 to 3.513 Mlb/hr-ft^2. The Original and New data are plotted against mass velocity (using the original BHTP CHF correlation) in Figures A.4 and A.5. The data sets are combined and shown in Figure A.6. All of the New data is conservative with respect to the Original data as shown in Figures A.5 and A.6.

The data below one million lb/hr-ft^2 is the most important data for the extension of the lower mass velocity limit. In this subgroup of [ ] data the mean P/M is 0.730 (27 percent conservative) with all of the data having a P/M less than 1.0. The combined scatterplot (Figure A.6) shows this conservatism.

The lower limit in mass velocity can be extended to 0.492 Mlb/hr-ft^2 based on these data and analysis with the original BHTP correlation.

A.3.4 *Extension of the Lower Pressure Limit*

The New data is comprised of the 1400 psia data group (1385 to 1430 psia). The 1400 psia data is conservative by about 24 percent overall with all P/M values below a value of 1.0 The conservatism of the data is shown in Figure A.7.

The lower limit in pressure can be extended to 1385 psia based on these data and analysis with the original BHTP correlation,

A.3.5 *Effect of Different Geometries on the Extended Data*

The extension of the BHTP correlation was examined to verify that the extension of the BHTP correlation is conservative for each approved assembly geometry. The examination was performed for each test section since each test section represents a single geometry.

The Average P/M CHF values are shown for each test section in Figure A.8. The test section averages for the original data are represented by the open bars. The shaded bars (which overlay the open bars) represent the average of the extended data only.

Note that there is extended data for [ ] tests: only tests 62, 63 and 66 through 68 lacked extended data. Further note that in each test section that had extended data, the average of the extended data is conservative with respect to the original data (the extended data P/M is lower than the original data P/M in all cases).

This comparison indicates that in no case does the differing geometry produce a non-conservative trend when the BHTP correlation is applied to the extended data. Therefore, it is concluded that the entire set of the [ ] extended data can be used to conservatively extend the range of independent variables of the BHTP correlation.

Figure A.1 P/M CHF versus Thermodynamic Quality at CHF Original BHTP Data Base with BHTP Correlation

**Figure A.2 P/M CHF versus Thermodynamic Quality at CHF
New (Uncorrelated) BHTP Data with BHTP Correlation**

Figure A.3 P/M CHF versus Thermodynamic Quality at CHF
Original and New (Uncorrelated) BHTP Data with BHTP Correlation

Range of Independent Variables for the BHTP CHF Correlation with the Extension of the Upper Quality Limit

	As Approved		Extended	
Independent Variable	Minimum Value	Maximum Value	Minimum Value	Maximum Value
System Pressure, psia	1775	2425	1775	2425
Mass Velocity, Mlbm/hr-ft^2	0.897	3.549	0.897	3.549
Thermodynamic Quality at CHF	-0.130	0.344	-0.130	**0.512**

**Figure A.4 P/M CHF versus Local Mass Velocity
Original BHTP Data Base with BHTP Correlation**

**Figure A.5 P/M CHF versus Local Mass Velocity
New (Uncorrelated) BHTP Data with BHTP Correlation**

**Figure A.6 P/M CHF versus Local Mass Velocity
Original and New (Uncorrelated) BHTP Data with BHTP Correlation**

Range of Independent Variables for the BHTP CHF Correlation with the Extension the Upper Quality and Lower Mass Velocity Limits

	As Approved		Extended	
Independent Variable	Minimum Value	Maximum Value	Minimum Value	Maximum Value
System Pressure, psia	1775	2425	1775	2425
Mass Velocity, Mlbm/hr-ft^2	0.897	3.549	**0.492**	3.549
Thermodynamic Quality at CHF	-0.130	0.344	-0.130	**0.515**

Figure A.7 P/M CHF versus System Pressure
Original and New (Uncorrelated) BHTP Data with BHTP Correlation

Range of Independent Variables for the BHTP CHF Correlation with the Extension of the Upper Quality and Lower Mass Velocity and Pressure Limits

	As Approved		Extended	
Independent Variable	Minimum Value	Maximum Value	Minimum Value	Maximum Value
System Pressure, psia	1775	2425	**1385**	2425
Mass Velocity, Mlbm/hr-ft^2	0.897	3.549	**0.492**	3.549
Thermodynamic Quality at CHF	-0.130	0.344	-0.130	**0.512**

Figure A.8 Histogram of Test Section P/M CHF Averages For the Original BHTP Data Base and for the New Data

A.4 Part 2 – Extension of the Correlation Outside the Data Ranges

Reference 3 dealt with the extension of the thermodynamic quality lower limit and the pressure upper limit in great detail. The extensions for the thermodynamic quality lower limit and the pressure upper limit were modified during the review process for Reference 3. The extensions proposed for the BHTP correlation are identical to those finally approved by the NRC in Reference 3. In addition, it has been shown in Part 1 that the application of the BHTP correlation to the new data is much more conservative than the application of the original HTP correlation to this same new data. (The original HTP application was roughly 10 percent conservative. The present BHTP application is about 24 percent conservative.) Therefore, the analytical conclusions observed in Reference 3 for the HTP correlation are appropriate for the correlation extensions in lower quality and higher pressure for the BHTP correlation.

In the SER of Reference 3, the HTP correlation application for the extensions of the lower quality limit and upper pressure limit were approved with the following stipulations.

> *"Actions for analyzing the operating conditions outside of the approved ranges of the maximum pressure (2425 psia) but less than 2600 psia are stated below. Extrapolations below the minimum quality range using the process described in Reference 1 are permitted with no lower limit. Any other extrapolation requires a plant-specific review.*
>
> *When pressures greater than the upper pressure limit of 2425 psia but less than 2600 psia are encountered, all of the local coolant conditions are calculated at the upper pressure limit of 2425 psia using the NRC-approved thermal-hydraulic code and then used in the calculation of the HTP CHF."*

Table A.3 Additional BHTP Data – Bundle Conditions

Following are the bundle conditions (test conditions) of the [ ] additional data. These data are used for justification of the extension of the independent variables beyond the applicability ranges defined by the original BHTP data base in Reference 1.

Units:

ID : LXXYYY where L designates low pressure, XX is the test section number, and YYY is the run number
P : Pressure, psia
Tin : Inlet Temperature, F
G : Mass Velocity, Mlb/hr-ft^2
Q" : Average Heat Flux, MBtu/hr-ft^2

Table A.4 Additional BHTP Data – Local Conditions and BHTP Results

Following are the results of applying the original BHTP CHF correlation to the [ ] additional data. These data are used for the justification of the extension of the independent variables beyond the applicability ranges defined by the original BHTP data base in Reference 1.

Units:

ID	:	LXXYYY where L designates low pressure, XX is the test section number, and YYY is the run number
P/M CHF	:	Predicted to Measured CHF Ratio
CHF	:	Measured CHF, Btu/hr-ft^2
P	:	Pressure, psia
G	:	Mass Velocity, lb/hr-ft^2
Zchf	:	Location of CHF, inches
F Fact	:	Non-uniform AFS factor
Hin	:	Inlet Enthalpy, Btu/lb

A.6 References

1. BAW-10241(P)(A), "BHTP DNB Correlation Applied with LYNXT," Framatome ANP, September 2004.

2. BAW-10156-A Revision 1, "LYNXT Core Transient Thermal-Hydraulic Program," August 1993.

3. EMF-92-153(P)(A) Revision 1, "Extension of HTP CHF Correlation Ranges," Framatome ANP, January 2005