March 27, 2002

Mr. James F. Mallay
Director, Regulatory Affairs
Framatome ANP, Richland, INC
2101 Horn Rapids Road
Richland, WA 99352

SUBJECT: ACCEPTANCE FOR REFERENCING OF LICENSING TOPICAL REPORT BAW-10199P, ADDENDUM 2 , "APPLICATION OF BWU-Z CHF CORRELATION TO THE MARK-BW17 FUEL DESIGN WITH MID-SPAN MIXING GRIDS"

Dear Mr. Mallay:

By letter dated November 22, 2000, Framatome Cogema Fuels (FCF) submitted Topical Report (TR) BAW-10199P, Addendum 2, "Application of the BWU-Z CHF [Critical Heat Flux] Correlation to the Mark-BW17 Design with Mid-Span Mixing [MSM] Grids," for NRC staff review and approval. A reorganization resulted in FCF now being referred to as Framatome ANP. By letter dated October 11, 2001 the staff submitted a request for additional information (RAI). Framatome ANP responsded to that RAI by letter dated November 2, 2001.

The staff has completed its review of the subject TR and the response to the RAI, and has concluded that the proposed application of the BWU-Z correlation to the Mark-BW17 fuel design with MSM grids is acceptable with some limitations on the range of mass, velocity, pressure and quality.

The report is acceptable for referencing in licensing applications to the extent specified and under the limitations delineated in the report and in the associated staff safety evaluation (SE). The enclosed SE defines the basis for acceptance of the TR. Attached to the safety evaluation is a Technical Evaluation Report (TER) from our consultant, Pacific Northwest National Laboratory.

Pursuant to 10 CFR 2.790, we have determined that the enclosed SE does not contain proprietary information. However, we will delay placing the SE in the public document room for a period of ten working days from the date of this letter to provide you with the opportunity to comment on the proprietary aspects only. If you believe that any information in the enclosure is proprietary, please identify such information line by line and define the basis pursuant to the criteria of 10 CFR 2.790.

We do not intend to repeat our review of the matters described in the subject report, and found acceptable, when the report appears as a reference in license applications, except to ensure that the material presented applies to the specific plant involved. Our acceptance applies only to matters approved in the report.

In accordance with procedures established in NUREG-0390, the NRC requests that Framatome ANP publish an accepted version within 3 months of receipt of this letter. The accepted version shall incorporate (1) this letter and the enclosed safety evaluation (SE) between the title page and the abstract, (2) all requests for additional information (RAIs) from the staff and all associated responses, and (3) a "-A" (designating "accepted") following the report identification symbol.

Should our criteria or regulations change so that our conclusions as to the acceptability of the report are invalidated, Framatome ANP and/or the applicants referencing the SE will be expected to revise and resubmit their respective documentation, or submit justification for the continued applicability of the SE without revision of their respective documentation.

Sincerely,

/RA/
Stuart A. Richards, Director
Project Directorate IV
Division of Licensing Project Management
Office of Nuclear Reactor Regulation

Project No. 693

Enclosure: Safety Evaluation

In accordance with procedures established in NUREG-0390, the NRC requests that Framatome ANP publish an accepted version within 3 months of receipt of this letter. The accepted version shall incorporate (1) this letter and the enclosed safety evaluation (SE) between the title page and the abstract, (2) all requests for additional information (RAIs) from the staff and all associated responses, and (3) a "-A" (designating "accepted") following the report identification symbol.

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Sincerely,

/RA/

Stuart A. Richards, Director
Project Directorate IV
Division of Licensing Project Management
Office of Nuclear Reactor Regulation

Project No. 693

Enclosure: Safety Evaluation

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SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

BAW-10199P, ADDENDUM 2 , "APPLICATION OF THE BWU-Z CHF CORRELATION

TO MARK- BW17 FUEL DESIGN WITH MID-SPAN MIXING GRIDS"

FRAMTOME ANP

PROJECT NO. 693

1.0 INTRODUCTION

By letter dated November 22, 2000 (Reference 1), Framatome Cogema Fuels (FCF) submitted licensing topical report (TR) BAW-10199P, Addendum 2, "Application of the BWU-Z CHF [Critical Heat Flux] Correlation to the Mark-BW17 Fuel Design with Mid-Span Mixing (MSM) Grids." A reorganization resulted in FCF now being referred to as Framatome ANP. The purpose of the submittal was to provide additional information to support continuation of the staff review on the applicability of the BWU-Z CHF correlation to Mark-BW fuel with MSM grids.

The NRC staff was assisted in its review by its consultant, Pacific Northwest National Laboratory (PNNL). The NRC staff evaluated the subject TR and the Framatome ANP response to the staff's request for additional information (RAI) dated October 11, 2001 (Reference 2). The staff adopted the findings recommended in PNNL's Technical Evaluation Report (TER) (attached).

2.0 EVALUATION

The BWU-Z correlation was developed for thermal margin analysis of fuel with the Mark-BW17 grid design, which is a zircaloy grid with mixing vanes for 17x17 fuel. The BWU-Z correlation has been approved for licensing analysis for this fuel design over the parameter ranges as follows: pressure range from 400 to 2465 psia, mass velocity between 0.36 and 3.55 Mlb/hr-ft^2, equilibrium quality at CHF up to 0.74, subchannel geometry including both unit cell and guide tube, design limit minimum departure from nucleate boiling ratio (MDNBR) of 1.19 for pressure greater than 1000 psia, 1.20 for pressure between 700 psia and 1000 psia, and 1.59 for pressure between 400 and 700 psia.

The BWU-Z correlation was extended to the Mark B11 spacer grid design, a version of BW17 grid design scaled for use with 15x15 fuel, which was approved in BAW-10199P-A, Addendum 1. A multiplicative correction factor, F_{B11} = 0.98, applied to the BWU-Z correlation was developed for this design. The form of the BWU-Z correlation was approved for the range of application with the exception that the design limit MDNBR is 1.183 in the pressure range greater than 1000 psia.

The current submittal, BAW-10199P, Addendum 2, presents an expanded database for the BWU-Z correlation with the multiplicative correction factor, F_{MSM}, for Mark-BW17 fuel design with MSM grids and proposes to extend the range. This review will verify that the proposed application of the BWU-Z CHF correlation for the Mark-BW17 fuel with MSM grids as documented in the new Appendix F in BAW-10199P, Addendum 2, is still within the applicable valid range of the approved BWU-Z CHF correlation. The evaluation was performed in the same manner as the one done for the original submittal in Addendum 1. The only difference between the two submittals is that the data set has been expanded to include another test section with MSM grids, FCF43, which adds 72 additional data points to the original 76 data points obtained in test set BW18. The FCF43 data set consists of one test section with guide tube geometry, and the two test sections of the BW18 data set consist of unit cell (all rods heated) geometry.

Information provided in Appendix F of the submittal (Reference 1) and in response to the staff's RAIs (Reference 2) shows that the BWU-Z CHF correlation with the multiplicative factor F_{MSM} = value fits the data set for MSM grid design quite well. There is no significant bias with the main independent variables of system pressure, mass velocity, or local equilibrium quality at CHF. There is no significant difference in the fit of the correlation for data with CHF occurring in unit cell subchannels, in comparison to data points with CHF occurring in guide tube cell subchannels.

The data set does not quite span the full range of intended application for the correlation as given in the approved TR, BAW-10199P-A. It does not include any data at pressures below 594 psia, the higher equilibrium quality at CHF of only 0.68 rather than 0.74, and the range of mass velocity only down to 0.47 Mlbm/hr-ft^2.

3.0 CONCLUSION

Based on the staff's review of the submittal and the response to the staff's RAIs in relation to the approved basis for BWU-Z CHF correlation, the staff has found that the BWU-Z CHF correlation with multiplicative factor F_{MSM} = value is acceptable to Mark-BW17 fuel with MSM grids over the range of parameters as follows: pressure between 400 and 2465 psia, mass velocity between 0.47 and 3.55 Mlbm/hr-ft^2, equilibrium quality at CHF up to 0.68, and subchannel geometry including unit cell and guide tube cell with a design limit MDNBR of 1.19 for pressure above 594 psia, and 1.59 for pressure between 400 and 594 psia.

4.0 REFERENCES

1. Letter from T. A. Coleman to USNRC transmitting Topical Report BAW-10199P, Addendum 2, "Application of the BWU-Z CHF Correlation to the Mark-BW17 Fuel Design with Mid-Span Mixing Grids," November 22, 2000.

2. Letter from James F. Mallay to USNRC transmitting "Responses to USNRC Request for Additional Information on BAW-10199P, Addendum 2, 'Application of BWU-Z CHF Correlation to the Mark-BW17 Fuel Design with Mid-Span Mixing Grids'," November 2, 2001.

Attachment: Technical Evaluation Report

Principle Contributor: A. Attard

Date: March 27, 2002

TECHNICAL EVALUATION REPORT for

BAW-10199P-A, **The BWU Critical Heat Flux Equations**, Addendum 2:
Appendix F -- Application of the BWU-Z CHF Correlation to the Mark BW17 Fuel Design with Mid-Span-Mixing Grids

Judith M. Cuta

December 2001

Prepared for
Office of Nuclear Reactor Regulation
U.S. Nuclear Regulatory Commission
Washington, D.C.   20555
under Contract DE-ACO6-76RLO 1830
NRC J2435

Pacific Northwest National Laboratory
Richland, WA   99352

SUMMARY

Addendum 2 to BAW10199-P seeks to extend the BWU-Z critical heat flux [CHF] correlation to fuel with the Mark BW17 and MSM [mid-span mixer] grid designs. After careful review of Appendix F of BAW10199-P (which comprises Addendum 2) and consideration of the responses to the Request for Additional Information (RAIs), it is recommended that the BWU-Z critical heat flux correlation should be approved for application to Mark BW17 fuel with MSM [mid-span mixing] grids over pressures in the range 400 to 2465 psia, mass velocities in the range 0.47 to 3.55 Mlbm/hr-ft^2, and qualities up to 68 percent at the location of MDNBR [minimum departure from nucleate boiling ratio]. The correlation has been shown to be applicable to both unit cell and guide tube cell subchannel geometry.

BACKGROUND

The BWU-Z CHF correlation was developed for thermal margin analysis of fuel with the BW17 grid design, which is a zircaloy grid with mixing vanes for 17x17 assemblies. The correlation has been approved (see Ref. 1 and 2) for licensing analysis of this fuel over the range shown in Table 1.

Table 1. Approved Range of Application for BWU-Z CHF Correlation with BW17 Grids

pressure:	400 to 2465 psia
mass velocity:	0.36 to 3.55 Mlbm/hr-ft^2
equilibrium quality at CHF:	up to 0.74
subchannel geometry:	unit cell and guide tube cell
design limit MDNBR:	1.19 for P > 1000 psia 1.20 for pressure range 700 < P < 1000 psia 1.59 for pressure range 400 < P < 700 psia

Subsequently, the BWU-Z correlation was extended to the Mark B11 spacer grid design, a version of the BW17 grid design scaled for use with 15x15 fuel. (See Ref. 3.) A multiplicative correction factor, FB11 = 0.98, applied to the BWU-Z correlation was developed for this design. This form of the BWU-Z correlation was approved for the range of application described in Table 1 above, with the exception that the design limit MDNBR is 1.183 in the pressure range P > 1000 psia.

A multiplicative factor, F_{MSM} , for the BWU-Z correlation was also developed for the BW17 fuel design with mid-span mixing vane grids. Using the FCF18 data set, a design limit MDNBR of 1.184 was developed for this form of the BWU-Z correlation (with F_{MSM} = 1.15). The application range of this form of the correlation was originally limited to the range of the FCF18 data set used to derive the F_{MSM} factor.

The current submittal, BAW-10199P, Addendum 2, presents an expanded database for the BWU-Z correlation with the multiplicative MSM correction factor (redefining the factor as F_{MSM} = value, and proposes to extend the range of applicability to that shown in Table 1. Based on the fit of the correlation to the FCF18 and FCF43 data sets, the design limit MDNBR is specified as 1.19 for fuel with BW17 grids and mid-span mixing vanes.

EVALUATIONS

The proposed application of the BWU-Z correlation as documented in the new Appendix F in BAW-10199P, Addendum 2, can be evaluated in the same manner as the original submittal in Addendum 1. The only difference between the two submittals is that the data set has been expanded to include another test section with MSM grids, FCF43. This test section also includes the guide tube cross-sectional geometry, and so provides a means of evaluating the fit of the correlation to guide tube cell as well as unit cell subchannels.

Information presented in the new Appendix F and in response to the Request for Additional Information (RAI) shows that the BWU-Z correlation with the multiplicative factor F_{MSM} = value fits the data set for the MSM grid design quite well. There is no significant bias with the main independent variables of system pressure, mass velocity, or local equilibrium quality at CHF. There is no significant difference in the fit of the correlation for data with CHF occuring in unit cell subchannels, in comparison to data points with CHF occuring in guide tube cell subchannels.

The database for the MSM grid design is still rather small, however, even with the FCF43 data set added. It consists of only 148 data points, 76 of which were obtained in the two test sections of data set FCF18. The additional 72 data points are from a single test section of the FCF43 data set. The two test sections of the FCF18 data set consist of unit cell (all rods heated) geometry, and the FCF43 data set consists of one test section with guide tube geometry. Separately, these two data sets do not span the full range of application proposed for the correlation, but their combined coverage almost extends to the limits defined in Table 1 above. The total range of conditions covered by the database is shown in Table 2.

Table 2. Range of CHF Test Conditions for MSM Grid Design

parameter	**FCF18 data set**	**FCF43 data set**	**MSM database**
pressure (psia)	1005 to 2425	594 to 2425	594 to 2425
mass velocity (Mlbm/hr-ft^2)	0.91 to 3.38	0.47 to 2.35	0.47 to 3.38
equilibrium quality at CHF:	up to 0.49	up to 0.68	up to 0.68
subchannel geometry:	unit cell	guide tube cell	unit cell and guide tube cell
		design limit MDNBR:	1.19

This data set does not quite span the full range of intended application for the correlation as described in Table 1. It does not include any data at pressures below 594 psia, and the highest equilibrium quality at CHF is only 0.68, rather than 0.74. The range of mass velocity extends only down to 0.47 Mlbm/hr-ft^2, which is somewhat short of the lower limit shown in Table 1.

However, the performance of the correlation is quite consistent over the entire database, with no significant biases with mass velocity, pressure or geometry.

From Table 2, it can be seen that the design limit MDNBR of 1.19 is applicable to pressures in the range 594 to 2425 psia. Comparing the design limit MDNBR values given in Table 1, it can be seen that the specified limit of 1.20 for pressures between 700 psia and 1000 psia is slightly conservative for the BWU-Z correlation with the MSM grid factor. The design limit MDNBR of 1.59 for pressures below 600 psia can reasonably be expected to be conservative for this form of the correlation, as well. (Note that the difference in the upper limit of the two ranges – 2425 psia vs. 2465 psia – is small enough to be neglected, and it is acceptable to take the higher of the two as the upper limit on the correlation's range.)

The range of mass velocity for the database is slightly smaller than that desired for the application range proposed for the correlation, as can be seen by comparing Table 1 with Table 2. At the upper end of the range, the extrapolation is relatively small, and is unlikely to result in any significant increase in the correlation's uncertainty. The behavior of CHF at high mass velocities is relatively linear with small increases in this parameter, and in this case, there is only about a 5 percent difference between the two upper limits. It is therefore acceptable to use the value of 3.55 Mlbm/hr-ft^2 as a reasonable estimate of the upper limit of the mass velocity range of the correlation.

Extrapolating at the lower end of the mass velocity range, however, is much more difficult to justify. Experience has shown that in this region, small changes in mass velocity can result in very large changes in the CHF behavior of a test section, due to nonlinear flow and heat transfer regime transitions associated with two-phase flow. In this regime, the difference between the two lower limits, 0.36 and 0.47 Mlbm/hr-ft^2, is on the order of 30 percent. This is not a small difference, and it is therefore inappropriate to assume that the design limit of 1.19 can be extrapolated to the lower of the two values. The limit of the database must in this case be used to define the lower limit of the range of applicability for this important parameter.

Similar reasoning applies to the appropriate limit on the range of quality at CHF. The highest values of local quality at CHF are generally obtained for conditions at the lowest mass velocities. For the FCF43 data set, the test conditions with quality at CHF in the range of 0.67 are those with mass velocities at or near the lower limit of 0.47 Mlbm/hr-ft^2. Since it is not advisable to extend the lower limit on the mass velocity by extrapolation, there is no justification (nor any real need) to extend the limit on local quality at CHF beyond the range of the database.

RECOMMENDATIONS

The BWU-Z correlation with multiplicative factor F_{MSM} = value has been shown to be applicable over nearly the same operating range as that previously approved for the BWU-Z correlation for fuel with BW17 grids. Some minor limitations must be imposed because of the limited range of the database available for validation of this form of the correlation. The recommended ranges of applicability and design limit MDNBR for this correlation are given in Table 3.

Table 3. Approved Range of Application for BWU-Z CHF Correlation with MSM Factor

pressure:	400 to 2465 psia
mass velocity:	0.47 to 3.55 Mlbm/hr-ft^2
equilibrium quality at CHF:	up to 0.68
subchannel geometry:	unit cell and guide tube cell
design limit MDNBR:	1.19 for P > 594 psia 1.59 for pressures in the range 400 < P < 594 psia

REFERENCES

1. BAW-10189P-A, CHF Testing and Analysis of the Mark BW Fuel Assembly Design, D.A. Farnsworth and G.A. Meyer, Babcock and Wilcox, January 1996.

2. BAW-10199P(A), The BWU Critical Heat Flux Correlations, D.A. Farnsworth and G.A. Meyer, Framatome Cogema Fuels, August 1996.

3. BAW-10199P(A), Addendum 1, The BWU Critical Heat Flux Correlations, Appendix E -- Application of the BWU-Z CHF Correlation to the Mark B11 Spacer Grid Design, D.A. Farnsworth and G.A. Meyer, Framatome Cogema Fuels, April 2000.