FRAMATOME ANP

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FRAMATOME ANP, Inc.

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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
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Attachments

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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

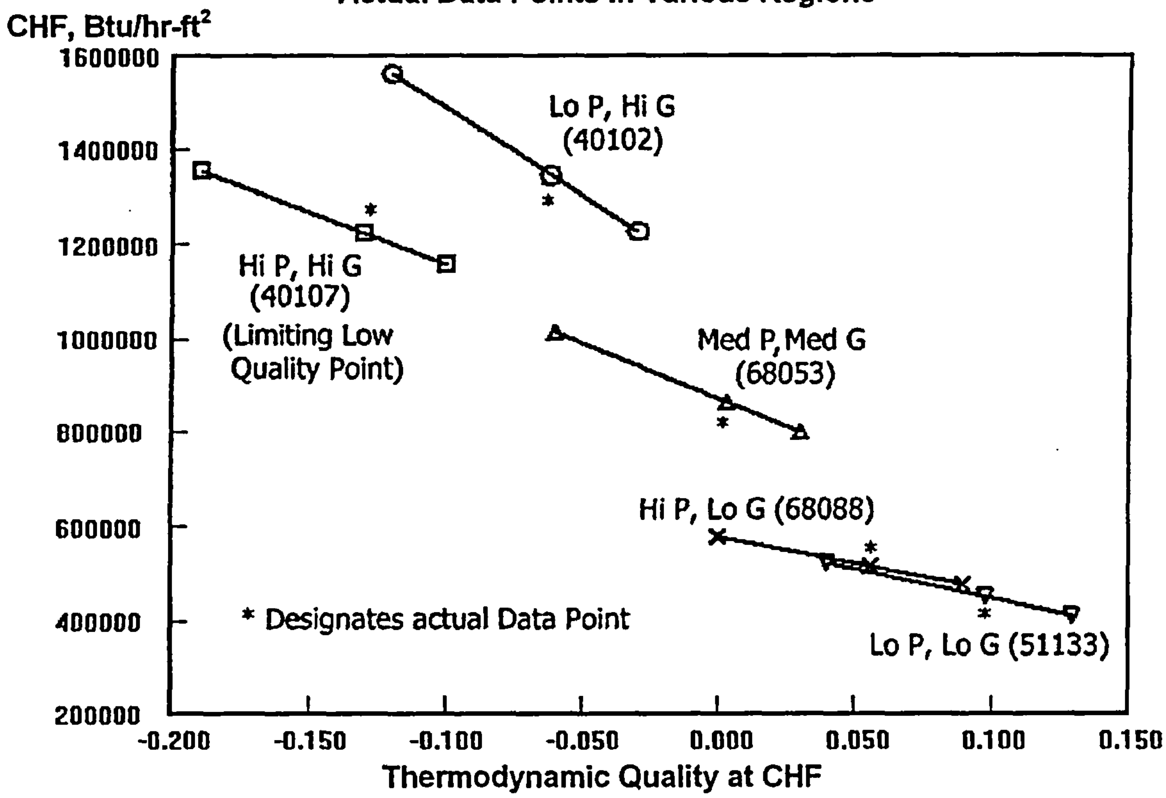

Figure 2
BHTP Calculated CHF versus Pressure
Actual Data Points in Various Regions