FRAMATOME ANP

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FRAMATOME ANP, Inc.

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

Response to Request for Additional Information with Respect to a Revision to EMF-2209(P)(A) Revision 1

Ref.: 1. Letter, J. F. Mallay (Framatome ANP) to Document Control Desk (NRC), "Request for Review of a Revision to EMF-2209(P)(A) Revision 1," NRC:03:039, June 20, 2003.

The NRC requested by fax additional information to facilitate the completion of its review of a revision to EMF-2209(P)(A) Revision 1 submitted in Reference 1. The response to this request is contained in the attachments to this letter. Proprietary and non-proprietary attachments are provided.

Framatome ANP, Inc. considers some of the information contained in Attachment 1 to this letter to be proprietary. This information has been noted by enclosing it within brackets. The affidavit provided with the original submittal of the reference topical report 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
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Enclosures

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Request for Additional Information on SPCB-Mod (MB9719)

Question 1

The request to modify the approved SPCB correlation specified in the June 20 submittal is a significant one. In order to expedite the review process, and to obtain a clear understanding of this request, please provide a detailed response to the following:

(a) Provide a step by step development of the current SPCB correlation alongside a step by step development of the modified SPCB correlation.

(b) Indicated in each step of the development of the modified SPCB correlation, the significance of the modification and its impact on the overall correlation, particularly in the six inch reflector region.

Response 1

The basis of the SPCB CHF correlation has been presented, discussed, and documented in EMF-2209(P)(A) Revision 1, and in a presentation to the NRC staff on July 22, 2003.

The revision to the SPCB Tong factor allowed range was deduced by investigation into the observed behavior of the critical power calculation when a natural uranium node was present. This investigation examined the various terms in the SPCB correlation. The investigation identified equations 2.14 and 2.15 on page 2-8 of the SPCB critical power correlation (EMF-2209(P)(A) Revision 1) as the cause of the observed behavior.

Specifically, the Tong factor was observed to take on values [ ] greater than the values observed in the SPCB database for the exit plane. This examination showed that the maximum value of Tong factor observed in the SPCB database occurred at the exit plane of the test assemblies. [ ]

These observations were used to select a maximum value for the Tong factor that would remove the exit plane from being a contributor to the calculation, when natural uranium is present in the exit plane, and provide assurance that no other plane would be influenced by this choice.

The impact on the overall correlation is that a [ ] could be selected and no change would occur for the statistical information that is reported in EMF-2209(P)(A) Revision 1. Calculated values of Tong Factor for assemblies with natural uranium present in the last six inches result in calculated values of Tong factor that are [ ]. Limiting this value to [ ] removes the exit plane from being the portion of the fuel assembly that is setting the limit.

As discussed in the response to Question 6, the minimum value for the upper portion of the assembly should be selected as a function of mass velocity rather than a constant bounding value. Observations of the behavior of Ω for the SPCB database provide support.

Question 2

For SPCB Critical Power Correlation, Revision 0, page 2-8, equation 2.14, Ω should increase because the critical length will increase and this will increase the Tong Factor which will decrease critical power. Clarify if this is why critical power is reduced when including the additional six inches.

Response 2

The increase in the Tong Factor occurs for the natural uranium region because the local heat flux decreases. Coupled with the decrease in local heat flux, the axial peaking factor for the location also decreases. The decrease in the axial peaking factor results in Ω decreasing. As Ω decreases, the factor (1- exp(-Ω ℓ_c)) decreases. The decrease in the denominator of F-Base is the reason that Tong factor increases for the natural uranium region.

$$F_{Base} = \frac{\Omega}{q''_{\ell_c}\left(1-e^{-\Omega \ell_c}\right)} \int_0^{\ell_c} \left[e^{-\Omega\left(\ell_c - Z\right)} \right] q''(Z)dZ$$

Question 3

For SPCB Critical Power Correlation, Revision 0, page 2-12, Clarify Ω is dependent on FEFF, and Tong Factor is dependent on Ω, and Tong Factor is inversely proportional to the critical heat flux, i.e., critical power is inversely proportional to FEFF.

Response 3

Ω is defined by equation 2.15 on page 2-8 of EMF-2209 (P)(A) Revision 1 and shows a dependency on [

]

[

]

Question 4

In reference to page A-2, first paragraph, second sentence indicates that the plane indicating boiling transition shifts from 8 to 12 feet to the end of the heated length. Please provide a detailed physical description of the "heated length".

Response 4

The axial extent of interest in the analysis occurs for the length of the fuel rods that transmit energy to the fluid by either direct deposition or conduction heat transfer. This length is the fueled length, including natural blankets, and is referred to as the heated length.

<u>Question 5</u>

In reference to page A-2, third paragraph it is stated that the value of omega has an inverse relation to memory length. Please provide a definition to the term "memory length".

<u>Response 5</u>

Lahey and Moody provide a discussion on the memory effect (page 135, *Thermal-Hydraulics of Boiling Water Reactors, Second Edition*) describing how the exponential term dies out strongly for large values of omega – hence, providing more importance to the local heat flux than the upstream memory effect. Furthermore, as quality increases, the values of omega become smaller and the importance of upstream memory becomes more important.

The term "memory length" is employed as a pneumonic device to indicate that the inverse of the omega parameter (which would have length associated with it) represents the relative importance of the upstream fluid conditions effect. A larger value of memory length implies more importance of upstream fluid conditions.

<u>Question 6</u>

It is not clear to the staff what the 3rd paragraph on page A-2 of the June 20 submittal is trying to communicate, and there are too many concerns to list in one question. Please be prepared to provide a much needed clearer depiction of what it is being conveyed by this paragraph.

<u>Response 6</u>

This paragraph provides the information to support the request for changing the minimum value for omega from a constant value to a function of mass flow. This change does not affect the comparison of the SPCB correlation to the measured CHF database as reported in EMF-2209(P)(A) Revision 1. Figure 2.0 shows the set of values of omega as calculated for the SPCB database at the predicted location of dryout and superimposes the proposed minimum value function.

An examination of calculated values of the omega function might help to clarify the third paragraph. This parameter attempts to capture the influence of a memory effect – how the behavior upstream influences the local behavior. The evaluation process typically performs evaluations on a six inch increment. If the memory effect is characterized by some length at one location, then the memory effect at the next location should not be characterized by a memory length that is more than six inches longer.

The SPCB correlation originally accounted only for the observation that the omega function should be no less than [ ] on an absolute basis for the entire database. The insertion of natural uranium in the last 6 to 12 inches of the assembly leads to step changes in the omega function that mathematically suggest an increasingly longer memory effect for the natural uranium nodes – well beyond the added six inches per node when compared to the upstream values.

Question 7

In reference to page A-2, fourth paragraph where the proposed modifications to eliminate excessive conservatism are noted, please provide background theory leading to choices a and b as proposed modifications.

Response 7

J.G. Collier, *Convective Boiling and Condensation*, provides some guidance pertaining to cold patch tests. Cold patches near the inlet of a tube resulted in power for the critical condition being close to that obtained for the same heated length with uniform heating. A cold patch toward the exit of the tube showed a sharp increase in power that could be greater than that obtained for the same total length with uniform heating. Collier also reports that the range of the Tong factor is typically between 1 and 3.

This guidance suggests that the observed behavior of SPCB, as heat flux decreases significantly at the top end of the heated length (due to presence of natural uranium), is overly conservative as it allows the limiting value to occur at the end of the heated length, a behavior that is counter to observation.

The cause within context of the SPCB correlation has been traced to the Tong Factor. This led to the evaluation that was performed and the proposed limitation of the value of the Tong Factor as a mechanism to reduce the overly conservative result.

Lahey and Moody, *The Thermal Hydraulics of a Boiling Water Reactor, Second Edition*, provides guidance pertaining to omega – specifically that omega decreases in value as quality increases.

For the application of SPCB, the relation shown for omega versus flow is representative of the trend with quality suggested by Lahey.

The investigation of the Tong Factor showed the overly conservative behavior of the omega function and led to the suggestion that the minimum value of omega be modified.

Question 8

In reference to page A-2 where the modification for Ω is shown at the bottom of the page, please provide further qualitative and quantitative background for the new equation for Ω_{min}. That is, show how the equation was developed. Also provide quantitative data showing why the maximum value of F_{base} should be 100.

Response 8

The equation was developed by placing a bounding line below the family of omega values that were observed to occur for the SPCB database. Figure 2 shows the family of omega values at the SPCB prediction of dryout for the database as a function of mass velocity.

The limiting value of F_{base} was chosen to be [ ]. An evaluation of actual power distributions observed in reactor designs indicated that as the power decreased in the top 6-inch segment of the fuel, the critical heat flux decreased significantly. The limitation of [ ] provided a conservative value for the critical heat flux without producing unreasonably low values. Over the 6-inch segment, the F_{base} value was changing from numbers of approximately [ ]

Question 9

In reference to Page A-3, Figure 2, please provide a detailed explanation as to what exactly this plot represents.

Response 9

The values of omega are the [ ] values of omega for the SPCB database at the predicted locations of dryout as a function of mass velocity. The bounding line is shown as a function of mass velocity.

Question 10

How will this modification to the SPCB correlation impact the power production in the rod(s) and the safety margin.

Response 10

The use of depleted uranium has been implemented for some designs as a means to counteract the conservatism of the SPCB correlation. The changes proposed to the SPCB correlation ranges will allow fuel designs to be constructed using natural uranium. There will be no significant change in safety margin or power production in the rods between these two designs.

A comparison between the use of SPCB with and without the proposed changes shows a difference of about [ ].

Question 11

On the neutron front, one would expect that accounting for power production in the reflector would impact neutron leakage in the region. One would also expect an increase plutonium production in the same region. Please provide a detailed technical description on a neutronic base, of the impact of operating the fuel in the reflector region.

Response 11

Natural UO_2 blankets are added to BWR fuel to improve fuel cycle economics. Indeed, for the same energy output, the replacement of the top and bottom 6-inch segments of the active fuel with natural uranium reduces the overall enrichment of the bundle by about 0.07 w/o U-235 enrichment. The trade-off is a reduction in LHGR margin of the bundle and reduced bundle cold shutdown capability. In theory, moving more U-235 toward the center of the core improves U-235 utilization by reducing neutron leakage out of both the top and bottom of the high enriched fuel. The top blanket is worth more than the bottom blanket in enrichment savings. However, relatively little power is produced in the natural UO_2 blankets themselves.

Natural blankets have always been a part of Framatome ANP BWR designs. However, the details of the blanket power distributions were not fully considered in developing SPCB CHF correlation. Unlike enriched sections of the fuel assembly, where the radial enrichment distribution is tailored to minimize radial peaking factors, the natural blankets utilize a uniform radial enrichment (0.711). The result is that the local peaking depends primarily on the moderator distribution.

For a D-lattice plant with asymmetric water gaps between assemblies, the relative local peaking and consequently the maximum lattice F-effective can be quite high despite the low planar powers. The high F-effectives for the D-lattice natural blanket, coupled with the unbounded Tong Factor result in the assembly being limited by the natural blanket region.

For C-lattice plants the results show similar trends but are not as exaggerated. C-lattice plants exhibit the same unbounded Tong behavior. The local pin-peaking of the C-lattice for the natural lattice is not as great as that of the D-lattice, therefore the F-effective is not as limiting for the C-lattice as for the D-lattice.