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

Request for Additional Information to the Topical Report EMF-2209(P) Revision 0, "SPCB Critical Power Correlation"

Ref.: 1. Letter, N. Kalyanam (NRC) to James F. Mallay (SPC), "Request for Additional Information – Siemens Topical Report, EMF-2209(P) Revision 0, *SPCB Critical Power Correlation (TAC No. MA6639)*," February 22, 2000.

Ref.: 2. Letter, James F. Mallay (SPC) to Document Control Desk (NRC), "Request for Review of EMF-2209(P) Revision 0, *SPCB Critical Power Correlation*," NRC:99:042, September 24, 1999.

In Reference 1, the NRC requested additional information to facilitate the completion of its review of the Siemens Power Corporation topical report on the SPCB correlation (see Reference 2). Responses to this request are provided in two attachments: one proprietary and one nonproprietary.

These responses, along with several editorial corrections, have made it necessary to change numerous pages in the topical report. These changes have been incorporated in Revision 1 to the topical report and are described on page i, "Nature of Changes," in the report.

In addition to the attached responses, four copies of the proprietary version and two copies of the nonproprietary version of Revision 1 of the topical report are enclosed with this letter. When the revised report is found acceptable for referencing in license applications, SPC will publish the accepted versions of the report in accordance with the procedures established in NUREG-0390.

Siemens Power Corporation considers some of the information contained in the attachments and enclosures 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
Regulatory Affairs

cc: N. Kalyanam (3(P) and 1(NP); w/attachment)
Project No. 702 (1(P) and 1(NP); w/attachment)

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Responses to RAI Questions to EMF-2209

Q.	SPCB-Correlation Development RAIs.
1	*On page 1-2, second paragraph, it is stated that an additional [ ] validation data points were included to the [ ] validation data base for the purpose of validating the SPCB correlation. Were the [ ] data points obtained for a different fuel assembly? Please Clarify.* Response: As shown on page 4-6 and 4-7 SPCB was validated with an alternate (different) fuel design comprised of 12 part-length rods and 79 full-length rods. This alternate fuel design is an ATRIUM-10 design with a spacer that is similar in design to the spacer used in the data base. The distinction of the alternate design is essentially the use of 12 rather than 8 part-length rods.
2	*On page 1-2, third paragraph, please explain the need for additional uncertainty required for peaking factors greater than 1.5.* Response: During the dryout testing some tests were performed where the high peaked rods were as high as about 1.45. Because of the trend of the data, one may safely extrapolate to a local peaking of 1.50 for design cases. However, during the safety limit analysis the local peaking may be perturbed so that a design local peaking may increase over the 1.50 limit. If that happens, the safety limit analysis will use the incremental uncertainties for the ATRIUM-9B and ATRIUM-10 designs provided in Table 3.15.
3	*On page 2-4, first paragraph, it is stated that two coefficients are used, one for the mass velocity less than or equal to 0.37 and one for mass velocities greater than or equal to 0.42.* *a. What is the basis for these lower and upper limits?* *b. Provide technical justification for the interpolation between these bounds.* Response: The behavior of critical power is observed to be strongly influenced by flow rate. The rod indicating boiling transition or dryout may change from a high powered rod to a lower powered rod as the flow rate changes. The intention of the correlation is to provide relationships that help describe the phenomena that are observed while maintaining acceptable uncertainty, no singularity, and well behaved transition between regions. The lower limit is based on providing a good fit of what is occurring at the low flows while the upper limit is based on providing a good fit of what is occurring at the higher flows. The fitting of the coefficients for the A and B functions was performed in the following manner: All of the correlation data for the ATRIUM-10 (774 data points) were evaluated to determine coefficients for A and B simultaneously. The result, when applied, provided good estimates for CPR especially for the low flow region. In order to provide improved estimates of CPR for higher flow regions, the data for high flow was correlated (696 data points) and an alternate set of coefficients was determined. In order to provide a smooth transition between the use of the two

Q.	SPCB-Correlation Development RAIs.
	sets of coefficients, a region was established for which a linear interpolation process would be used. For example a value for the function of A would be determined at the mass velocity corresponding to the usage limit of 0.37 Mlb/hr-ft^2 using the low flow set of coefficients and A would be determined at the high mass velocity lower bound of 0.42 Mlb/hr-ft^2 using the high flow set of coefficients. Then a linear interpolation of A would be performed based on the two flows. Technically the issue is one of avoiding step changes in behavior. Note: Equation 2.7 on page 2.4 shows a double asterisk with the A3 coefficient. This is a typographical error and will be corrected to show a single asterisk in the final approved version of the document.
4	*Tables 2.1 through Table 2.7 provide values for various coefficients, subject to lower and upper bounds. Is one to assume that different values for these coefficients are obtained by interpolation as in the case of Table 2.1?* Response: Yes, for the case of flows falling between the various regions of the various tables, a linear interpolation is used to obtain a value of the overall coefficient for use in the correlation.
5	*Chapter 2, in particular Sections 2.0 to 2.3, contains the mathematical development of the SPCB Correlation. As such it is imperative that one obtains a clear understanding of the various components (variables, parameters, etc.) and their respective use in the formulation of the correlation for the two different fuels. In reviewing Sections 2.0 to 2.3 it quickly became apparent that there are a number of junctions in the road, depending on whether one is addressing the ATRIUM-9B fuel or the ATRIUM-10 fuel. In order to expedite the review of this Topical Report, please provide a road map (Flow Chart/Event Tree) showing the clear and separate routes taken in developing the two forms of the SPCB correlation for each of the fuels in question.* Response: A flow chart is shown in the attachment that depicts the separate routes taken in developing the two forms of the SPCB correlation for each of the fuel types in question. The notation G in the flow chart is interchangeable with $\bar{G}$.
6	*On page 2-23 (Item 2, middle of page), please provide the reasoning for switching from a simple mean to a weighted mean. (Item 2 middle of the page.)* Response: The use of a simple mean from a power weighted mean was introduced with the ANFB-10 correlation (Reference 2.1) and is retained for the SPCB critical power correlation. The Reference indicated on page 2.23 should be to Reference 2.2, the ANFB correlation.
7	*Please provide additional information for Figure 2.3.* Response: Figure 2.3 with a legend is provided in Revision 1 to EMF-2209(P).
8	*On page 2-34, paragraph 2, reference is made to the "ANFB" limits. Should that be the "SPCB" limits?*

Q.	SPCB-Correlation Development RAIs.
	Response: Yes, the letters ANFB have been replaced with the letters SPCB in Revision 1 to EMF-2209(P).
9	*On page 2-35, Section 2.6.2.1, the high and low enthalpy limits addressed. What are the values of these limits?* Response: The values of the limits are depicted in Table 1.2 on page 1-3.
10	*On page 2-36, second paragraph, it is stated that "corresponding quality distributions are artificially increased." What are "quality distributions?"* Response: For each nodal enthalpy, a thermodynamic quality can be determined. As quality is a parameter in the Hench-Levy correlation, then when incrementing the enthalpy, the quality is also incremented. As each node would have a different enthalpy, then within the assembly there would be a distribution of quality.
11	*Is "inlet mass velocity" inter-changeable with "inlet mass flow rate?"* Response: The correlation calculation relates only to inlet mass velocity (a mass flow rate per unit area). The correlation or physical behavior can be visually examined using either mass velocity or mass flow rate.
12	*Figure 3.8 on page 3-15, the x-axis is labeled "Active flow." What is "Active Flow?"* Response: The test assembly uses an electrically heated model of a fuel assembly. One of the differences between a test assembly and an assembly produced for in-reactor use is the test assembly does not typically allow flow through the water channel while an in-reactor fuel assembly would allow flow through the water channel. Thus the flow rate that is measured and delivered to the inlet of a test assembly is the flow rate that is present in the electrically heated region. Within an in-reactor fuel assembly, the flow that passes through the orifice is progressively decreased due to the need for flow in the bypass and the planned flow within the water rod or water channel structure. The flow adjacent to nuclear fuel rods is referred to as active flow to distinguish it from the total flow that might be delivered at the inlet of the assembly. This terminology was borrowed for use in the test assembly to aid the in-house engineer that is reading the document in understanding that the flow that was delivered in test is in-fact the flow that is in the region where the powered rods are located.
13	*Does Figure 3.39 on page 3-41 include all the data for the ATRIUM-9B and that for the ATRIUM-10?* Response: Yes, ATRIUM-9B and ATRIUM-10 validation and verification data are included. Figure 3.39 is an overlay of Figure 1.2 on Figure 1.1.
14	*Page 4-9, Figure 4.7, please provide justification for the difference in magnitude at high inlet flow.* Response: The principle reason for differences in magnitude of power at high inlet flow is due to the influence of axial power shape. Axial power shape (as might be visualized by the gradient of heat flux) has a strong influence at the high mass velocities. The fact that data is observed to behave in this manner results in the use

Q.	SPCB-Correlation Development RAIs.
	of an upstream memory effect such as the Tong-Factor or the non-uniform axial correction factor of SPCB. At the lower mass velocities, the importance of heat flux increases and the axial shape is not as dominant.
15	*Page 4-9, the last sentence in the second paragraph states that Test 48.1 consists of transient data only. Does that mean that Test 29.5 consist of data other than transient data?* Response: Yes, as shown on page 3-32 Test assembly 29.5 was used for steady state critical power data and then was used for transient data. Test 48.1 was only used for transient data.
16	*In Section 5.3, the third paragraph brings up the subject of peaked rods going into dryout. For both fuel types, what procedure is used in determining which rods are peaked and which rods go into dryout.* Response: The first thing to consider when developing the planned peaking pattern for dryout testing is that the peaking pattern does not necessarily mimic a neutronic design. Instead, by peaking certain rods one may take advantage of the bundle symmetry and minimize the number of tests required. Rods are peaked in groups in an attempt to drive certain locations into dryout. Because of the methodology for determining additive constants, if a group of rods are peaked and only one rod goes into dryout, it is conservatively assumed that the other two rods went into dryout at the same power. If a rod location is not peaked at all during the dryout testing, then that position has its additive constant determined by assuming that it went into dryout during the test that had the highest peaking in this location.
17	*Page 5-11, last paragraph. Please provide additional discussion regarding as to why only two tests were needed to be performed on the ATRIUM-9B to demonstrate that the ATRIUM-10 additive constant methodology is applicable to the ATRIUM-9B fuel.* Response: The methodology for determining the effect of local peaking on additive constants was developed in ANF-1125, Supplement 1(P)(A). That methodology has remained the same for both ANFB-10 and SPCB. During the testing of the ATRIUM-10 bundle several tests were run to drive rods into dryout at different local peakings. The positions of these tests were in positions that represented each different bundle location; i.e., 3x3 corner, edge rods, interior, etc. The ATRIUM-9B bundle geometry is therefore represented in the ATRIUM-10 testing. Bear in mind also, that the additive constant methodology considers the effect of the rods surrounding the peaked rod of interest. Therefore, the methodology doesn't know whether the bundle is a 4x4, 5x5, 9x9, or 10x10 assembly.
18	*Page 5-12, in the last paragraph refers to "individual case." Is this same as "individual test?"* Response: The word "individual" is used three times in the document. One time it modifies "tests," a second time it modifies "rod," and the third time it modifies "case." The context for which it is used as a modifier to case would be this: each line in Table 5.5 would represent a different individual case.

Q.	SPCB-Correlation Development RAIs.
	Note: The reference to Table 5.9 on page 5-14 has been corrected to Table 5.5 in Revision 1 of EMF-2209(P).

Q	SPCB Statistical RAIs
1	*A general statement: Whenever presenting mean and standard deviation (such as in the bottom sentence of page 1-1) include the sample size and the associated tolerance limit.* Response: See Tables 3.1, 4.1, 4.2, and 4.3 in Revision 1 of EMF-2209(P).

2 *Page 1-2, Section 1.1. Provide statistical tests that compare the behavior (mean, variance) of the 1,876 correlation points to the [ ] validation points. Also, did the [ ] additional validation points differ in behavior from the [ ] validation points?*

Response: Statistical tests can be performed to compare the means and/or the variances between or among these data groups. Due to the large number of data, the statistical tests would be expected to show statistical difference. However, the nature of the difference would be of no practical significance. As can be observed, the standard deviation of the three groups are similar in magnitude and the mean values of the two groups of importance are less than unity.

Group	Number	Mean ECPR	Standard Deviation
Verification	1876	0.992	0.0204
Validation	781	0.983	0.0241
Validation2	316	1.002	0.0233

Comparison of means:

$0.0204/\sqrt{(1876)} = 0.0005$

$0.0241/\sqrt{(781)} = 0.0009$

$0.0233/\sqrt{(316)} = 0.0013$

Group	
Verification	0.992 ± 0.0005
Validation	0.983 ± 0.0009
Validation2	1.002 ± 0.0013

This implies a slight statistical difference in the means of the groups, i.e., 0.01 difference between the Verification and the Validation group. However, there is not a practical difference.

Comparison of variances:

For example consider an F test between Verification and Validation
Then

$$F = (0.0241/0.0204)^2 = 1.396$$

Comparing this with an estimate from a table would suggest a slight statistical difference. However there is not a practical difference in as much as the overall statistics that are used in the analysis process specifically includes the effect of the differences within test and between tests.

Q.	SPCB-Correlation Development RAIs.
3	*Page 1-2, Second paragraph. Text states that transient tests are performed on ATRIUM 10 (not mentioning ATRIUM 9-B). Page 3-36, second paragraph says that dryout tests were performed on the ATRIUM-9B and ATRIUM-10.* Response: Distinction is made between transient test and quasi-steady state dryout tests. Quasi-steady state dryout tests maintain parameters such as flow, inlet subcooling, and pressure constant while slowly increasing power to attain a dryout condition. Transient tests are purposely varying power and flow in accord with a desired plan and detecting dryout. The ATRIUM-10 was selected for performing transient tests while both ATRIUM-9B and ATRIUM-10 assemblies are tested for steady state dryout.
4	*Pages 2-4 thru 2-10 (Tables 2.1 thru 2.7). Is "G" in these tables the same as G bar ($\bar{G}$) given in, say, equation (2.7)?* Response: Yes. Revision 1 to EMF-2209(P) has ($\bar{G}$) in these tables.
5	*Page 2-6, Equation 2.12. The coefficient "f1" in equation 2.12 is not defined.* Response: The definition of f1 shown on page 2-6 in the first line following Equation 2-11 is intended to be the same f1 as used in Equation 2-12. An explanatory note could be added to the text to indicate this common usage for the approved version.
6	*Page 2-13, Equation 2.23. Identify/explain how the coefficients 0.624 and 0.314 were obtained.* Response: Equation 2.23 remains identical to the formulation for FEFF presented in EMF-1997, "ANFB-10 Critical Power Correlation" and ANF-1125, Supplement 1, "ANFB Critical Power Correlation." The empirical formulation developed for the 1990 critical power correlation is used so as to minimize the review of some different or new formulation.
7	*Page 2-26, Figure 2.3. Symbols (like X, square, and diamond) need a legend.* Response: See response to question 7 of SPCB-Correlation Development RAIs.
8	*Page 3-1, Table 3.1. Show how Sigma (given as 0.021) for ATRIUM-9B was derived.* Response: The value of 0.021 for the ATRIUM-9B is obtained by applying the standard relationship for standard deviation such as found as equation 1.7 on page 9 or equation 1.9 on page 10 of NUREG/CR-4604 for the 1629 data of ATRIUM-9B tabulated in Section 5 of the topical report.

Q.	SPCB-Correlation Development RAIs.
9	*Page 3-1, Table 3.1:* • *Expand the table to include for each test the 95/95 upper tolerance limit for ECPR,* • *maximum value obtained for the test,* • *number of data points in the test that exceed the tolerance limit, and* • *the percent number of points below the tolerance limit.* *Provide similar entries, separately for each fuel, and for all tests of the same profile.* Suggestion: Follow the style of Table 4.1 for ANFB 10 that you provided in your May 26, 1998 communication to E.Y. Wang. Response: Tables 3.1, 4.1, 4.2, and 4.3 have been revised in Revision 1 of EMF-2209(P).
10	*Page 3-2, Table 3.2. Show a complete table of the analysis of variance (ANOVA). Please provide separate analysis for each fuel type. Did any analysis detect significant test differences? Was the data tested for homogeneity of variances prior to constructing the ANOVA?* Response: From a practical viewpoint, data from one test to another are expected to behave statistically differently. Thus, it is appropriate to combine those differences. The actual way these differences are combined for Safety Analysis is through uncertainty in Additive Constants. This Analysis of Variance is provided as supplementary information. The Analysis of Variance process used by SPC produces the information shown below. The input is the Table 3.1 entries by test section for the number of data points, the mean ECPR, and the standard deviation. The output is the information shown in Table 3.2. This table shows the result of the Analysis of Variance. This approach is used to separate the components of variance in order to estimate the population variance and the degrees of freedom. The variance model is: $\sigma^2_{TRUE} = \sigma^2_{Between} - \frac{\sigma^2_{WithinTest}}{ESS}$ where σ^2_{TRUE} = True between mean variance $\sigma^2_{BETWEEN}$ = Total between test variance $\sigma^2_{WithinTest}$ = Within test variance ESS = Effective sample size The degrees of freedom are computed using Satterthwaite's formula.

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10	It is apparent from the data in Table 3.1 that the measurement variances are not from the same statistical populations. Most of the differences can be explained by differences in test equipment and particular test. Inclusion of all valid test data provides a more robust and conservative basis for the analysis that establishes the Safety Limit. As the purpose of the Analysis of Variance is to account for the differences of the data, tests for homogeneity of variances was not performed. The summary of information by design and overall is shown below: Parameter / All Data / ATRIUM-10 / ATRIUM-9B Within Test Variance / 0.000349876 / 0.000421355 / 0.000305357 Between Test Variance / 0.000133328 / 0.0000742898 / 0.0001763 Weighted Mean ECPR / 0.99104 / 0.99495 / 0.98315 Standard Deviation / 0.021982 / 0.02226 / 0.021946 Population Variance / 0.0004832 / 0.0004956 / 0.0004817 Equivalent Sample Size / 51 / 44 / 80 Degrees of Freedom (Satterthwaite) / 302 / 439 / 56 The correction to Table 3.2 is provided in Revision 1 of EMF-2209(P).
11	*Pages 3-2 and 3-3, equations for m2, m3, m4, β1, and β2. What is the numeric value of "n" in each of these calculations?* Response: All values of ECPR were used in the analysis. Thus, n=2657 Note: the following corrected values are shown below and will be included in the approved version of the document. $m_2 = 0.000491$ $\sqrt{\beta_1} = 0.004488$ $\beta_2 = 2.83$
12	*Page 3-5, Paragraph 3.2. Justify the use of 1 percent as a level of significance for testing normality. What is the numerical value of Lillifor's statistic?* Response: The numerical value of the Lillifor statistic is 0.0173. This compares with the 0.02 critical value for 1 percent and the 0.017 value for the 5 percent. The requirement for the data going into the Safety Analysis is that it be approximately normally distributed. The 1 percent level of significance assures this. A tighter level of significance such as 5 or 10 percent could be harmful in that valid data could be excluded.
13	Pages 3-4 thru 3-29, Figures 3.1 through 3.36. Indicate the sample size associated with each figure. Response: The figures were modified in Revision 1 of EMF-2209(P) as requested.

Q.	SPCB-Correlation Development RAIs.
14	*Page 3-38, last paragraph. Indicate where the upper 95 percent confidence limits on the additive constants are implemented.* Response: The implementation of the upper 95 percent confidence limit for an incremental additive constant uncertainty is presented in Table 3.15. The values of additive constant uncertainty and the corresponding incremental value for rods peaked more than 1.5 are implemented in the determination of the safety limit MCPR in the methodology contained in ANF-524 (P)(A), Revision 2, "Advanced Nuclear Fuels Corporation Critical Power Methodology for Boiling Water Reactors," November 1990.
15	*Page 4-2, Tables 4.1, 4.2 and 4.3.* Expand the tables as requested for Table 3.1. Response: Tables 3.1, 4.1, 4.2, and 4.3 have been revised in Revision 1 of EMF-2209(P).
16	*Page 4-8, Figure 4-6 (and others): What do the different lines represent? Provide the necessary labels. Similarly, provide the necessary labels for Figures 5.7 thru 5.89.* Response: The lines represent the SPCB correlation prediction of the data as a function of inlet subcooling. The separation among the lines is due to different flow families for the data.
17	*Were there any outliers in the evaluation, and if so, what was their disposition?* Response: In EMF-1997, the comment is made that runs 125.4 and 132.4 for test 29.2 are experimentally determined to be outliers. Several low flow points were excluded in EMF-1997 as being below the flow limit for applicability. Due to the refitting process of the "A" and "B" coefficients in EMF-2209, these points are included in the evaluation process. That is, the low flow points are in the domain of the correlation and retained and the two experimental outliers were retained. The inclusion of the outliers provides conservatively greater value of uncertainty.