FLN-2004-031

GEXL80 CORRELATION FOR SVEA96+ FUEL

NON-PROPRIETARY

Global Nuclear Fuel

A Joint Venture of GE, Toshiba, & Hitachi

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GEXL80 Correlation for SVEA96+ Fuel

UNITED STATES
NUCLEAR REGULATORY COMMISSION
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SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

LICENSING TOPICAL REPORT NEDC-33107P, "GEXL80 CORRELATION FOR SVEA96+ FUEL"

GLOBAL NUCLEAR FUEL

PROJECT NO. 712

1.0 INTRODUCTION

By letters dated September 8, 2003 (Reference 1), and September 17, 2003 (Reference 2), Global Nuclear Fuel (GNF) submitted proprietary and non-proprietary Licensing Topical Reports (LTR) NEDC-33107P and NEDO-33107, "GEXL80 Correlation for SVEA96+ Fuel," for NRC review and approval. The LTR contained the proposed methodology, the correlation development, and a determination of the associated uncertainties derived for modeling the critical power performance of the Westinghouse Electric Company LLC (Westinghouse) SVEA96+ fuel design. This critical power correlation will be applied to the legacy (at least once-burned) SVEA96+ fuel that will co-reside in the Hope Creek Generating Station (Hope Creek) boiling water reactor (BWR), beginning with operating Cycle 13, when GNF first provides a fresh batch reload of the GNF GE-14 fuel design in November 2004.

The GNF submittal was supplemented by two supporting documents submitted by PSEG Nuclear LLC (PSEG) on September 8, 2003, one providing the Westinghouse proprietary Table 2-3, "SVEA96+ Modeling Dimensions," to be used in the NEDC-33107P LTR (Reference 3) and the second providing the PSEG document, "GE14 and SVEA96+ Thermal Hydraulic Compatibility Report," (Reference 4), containing both Westinghouse and GNF proprietary information.

The methodology utilized to develop the GEXL80 critical power correlation is consistent with that used for developing the General Electric critical quality (X_C), boiling length (L_B) correlation (GEXL) form of the critical power correlations for new GNF fuel designs, as defined in the approved General Electric BWR Thermal Analysis Basis (GETAB) LTR (Reference 5). The GEXL critical power form is required in the GNF standard reload design process, as outlined in the approved General Electric Standard Application for Reactor Fuel (GESTAR II) document (Reference 6).

The GNF submittal summarizes the development of the SVEA96+ GEXL80 critical power correlation. As stated, the SVEA96+ GEXL80 correlation will be used to determine the critical power performance of the Westinghouse SVEA96+ fuel design. The legacy Westinghouse SVEA96+ fuel, which is co-resident in a mixed core with fresh GNF GE-14 fuel, will be in at least its second cycle of irradiation. As such, the SVEA96+ GEXL80 correlation would not be

applied to reload quantities of first cycle SVEA96+ fuel. The GNF submittal describes the process used in the development of the GEXL80 correlation for prediction of critical power for SVEA96+ fuel and presents the determination of the ECPR (ratio of the GEXL80 calculated critical power to the PSEG ABBD2.0 calculated critical power) mean value and the uncertainty of that correlation in the prediction of the SVEA96+ critical power performance. The final GEXL80 predicted to SVEA96+ measured critical power mean and uncertainty is presented, as determined by PSEG from comparison to the actual measured experimental critical power data.

2.0 REGULATORY EVALUATION

Title 10 of the Code of Federal Regulations (CFR), Section 50.34, "Contents of Applications; Technical Information," requires that safety analysis reports be submitted that analyze the design and performance of structures, systems, and components provided for the prevention of accidents and the mitigation of the consequences of accidents. As part of the core reload design process, licensees (or vendors) perform reload safety evaluations to ensure that their safety analyses remain bounding for the design cycle. To confirm that the analyses remain bounding, licensees confirm that key inputs to the safety analyses (such as the critical power ratio) are conservative with respect to the current design cycle. If key safety analysis parameters are not bounded, a re-analysis or reevaluation of the affected transients or accidents is performed to ensure that the applicable acceptance criteria are satisfied.

There are no specific regulatory requirements for the review of topical reports. NRC staff guidance for preparing the safety evaluation (SE) input is provided in NRR Office Instruction LIC-500, Revision 2, "Processing Requests for Reviews of Topical Reports." Following such guidance, the NRC staff review was based on the evaluation of the technical merit of the submittal and compliance with any applicable regulations.

3.0 TECHNICAL EVALUATION

The hypothetical critical power database to be used for the development of the GEXL80 correlation was obtained from PSEG. This database consisted of SVEA96+ sub-bundle and full bundle critical power data points generated by the NRC-approved Westinghouse BWR subchannel code "CONDOR" (Reference 7), incorporating the NRC-approved Westinghouse ABBD2.0 critical power correlation (Reference 8) for SVEA96+ fuel. The objective of this data generation and collection was to obtain SVEA96+ critical quality data appropriate for generating the NRC-approved GETAB GEXL PLUS form (Reference 5A) critical power ratio (CPR) values for use in the GNF standard reload safety analysis process (GESTAR II) from Reference 6.

The span of the hypothetical data generation and collection encompasses cosine, top peaked, bottom peaked, and double humped axial power shapes in order to cover the complete range of expected operation of the SVEA96+ fuel in the Hope Creek BWR core. The data was used to develop a new GEXL correlation for the SVEA96+ design. This new GEXL correlation for SVEA96+ fuel was designated as GEXL80. The GEXL80 correlation uses the same functional form as previous GEXL correlations with different values of the constants derived for the GEXL correlation coefficient parameters.

The GEXL form for the critical power correlation has been used in the safety analysis process for GE fueled BWRs since 1974, and is described in the GETAB LTR NEDO-10958-A. The GEXL correlation was developed to provide a best estimate prediction of the onset of boiling transition in BWR fuel assemblies. The GEXL correlation is based on the relationship of critical quality with boiling length. It expresses the bundle average critical quality as a function of boiling length, bundle thermal diameter, system pressure, lattice geometry, local intra-bundle power peaking patterns (R-factor), mass flux and annular flow length.

GEXL was developed to accurately predict the onset of boiling transition in BWR fuel assemblies during both steady-state and reactor transient conditions. The GEXL correlation is necessary for GNF to determine the minimum critical power ratio (MCPR) operating limits resulting from transient analysis, the MCPR safety limit analysis, and the core operating performance and design. The GEXL correlation is an integral part of the transient analysis methodology. It is used to confirm the adequacy of the MCPR operating limit, and it can be used to determine the time of onset of boiling transition in the analysis of other events.

The NRC staff's review considered the following: (1) the adequacy of the hypothetical database generated with the Westinghouse sub-channel code CONDOR, (2) the proper determination of the uncertainty in the GEXL80 correlation predictions for the SVEA96+ fuel design, (3) the applicability of the proposed operating application range of GEXL80 correlation for the SVEA96+ fuel, and (4) the comparison of the GEXL80 correlation critical power predictions to the raw critical power experimental data for the SVEA96+ fuel.

3.1 Validity of the Hypothetical Database and Associated Uncertainties

PSEG used the approved Westinghouse ABBD2.0 critical power correlation for the SVEA96+ fuel (as encoded in the Westinghouse sub-channel code CONDOR) to generate a hypothetical database of predicted critical power values for a range of operating conditions corresponding to the range of the SVEA96+ correlation. This hypothetical database was then treated by GNF in the same way as an experimental database, using the approved methodology for GEXL correlation development. Utilizing this approach, GNF produced a new form of the GEXL correlation, namely GEXL80, intended for plant-specific application (Hope Creek) to the legacy SVEA96+ fuel design with at least one cycle of irradiation.

The data for the GEXL80 development specific to SVEA96+ fuel was generated using the NRC-approved Westinghouse ABBD2.0 correlation encoded in the above stated sub-channel code. GNF specified the values of rod-to-rod power peaking, axial power shapes, pressure, mass flux and sub-cooling that were used with the Westinghouse ABBD2.0 correlation to determine the predicted critical power at dryout.

The SVEA96+ fuel design is a 10x10 fuel lattice array consisting of four mini-bundles, which reside in a channel box. The channel structure has a central water cross that displaces four fuel rod positions, one from each mini-bundle, and four water wing structures that extend from the central water cross to the channel wall. The channel structure is attached to the lower tie plate. The composition of each of the mini-bundles includes upper and lower tie plates, spacer grids, and 24 full-length fuel rods. A handle attaches to the top of the channel box for lifting and transporting the fuel assembly.

As part of the previous Hope Creek fuel vendor transition, Westinghouse (formerly ABB-CE) supplied SVEA96+ thermal hydraulic performance data, as well as local loss coefficients [PSEG File HCA.5-0020], at several power and flow conditions for the current licensed reactor power of 3339 mega-watts thermal (MWt), using the proprietary computer code CONDOR. The FIBWR2 model of Reference 9 was benchmarked against this data. Table 3.1 of Reference 3 displays the pressure loss coefficients that were provided for the upper and lower tie plate and the spacers. The inlet loss coefficients are the values traditionally used at Hope Creek to model the central and peripheral bundle orifices, relative to the reference flow area.

3.2 Determination of Correlation Uncertainties

The hypothetical database used in the development of the GEXL80 correlation for SVEA96+ fuel was summarized in Table 2-1 of Reference 1. This table shows the number of calculated critical power data points obtained using the Westinghouse critical power correlation for cosine, inlet, outlet, and double humped axial power distributions. It also shows the fuel pin dryout location that formed the basis for the 26 different sets of Westinghouse calculated critical power data. Table 2-2 of Reference 1 provides additional information by further dividing the calculated data points collected into subgroups by pressure, mass flux, and inlet sub-cooling.

Although the GEXL80 hypothetical database generated in this manner is artificial in construct, i.e., created with a computer code which has encoded in it the ABBD2.0 correlation, and which at best can only approximate the actual critical power raw data behavior of the SVEA96+ fuel, it can be expected with reasonable engineering practices, and proper statistical accountability, to predict critical power behavior with acceptable uncertainties. Testing the hypothetical database values as if it were real data in the regression analysis, however, introduces unavoidable error into the correlation being derived from it. As described in Section 3.4, it was determined that the error introduced resulted in biases and uncertainties that resulted in acceptable critical power predictions.

The local critical power values predicted with the approved ABBD2.0 correlation can be predicted to vary over the range of the hypothetical database. Since the GEXL80 correlation is fitted to this hypothetical database, the error in the critical power prediction of the GEXL80 correlation for a given set of conditions will have some additional error relative to the real critical power value for those conditions, over and above the uncertainty of the correlation's fit to the hypothetical database. Therefore, the approach of the correlation procedure can be valid only if the overall uncertainty in the new GEXL80 correlation is appropriately characterized in terms of both the uncertainty in its fit to the hypothetical database and the uncertainty of the critical power values in the hypothetical database itself.

The treatment of the overall uncertainty of the GEXL80 correlation for SVEA96+ fuel, as presented in the GNF submittal, is complete in that GNF used standard statistical combination of uncertainty techniques to appropriately combine the uncertainty of the fit of GEXL80 correlation to the hypothetical database and the uncertainty of the database itself, which is a function of the uncertainty of ABBD2.0 correlation.

3.3 Generation of the GEXL80 Correlation and the Range of Applicability

In developing the GEXL80 correlation, GNF took steps to optimize the GEXL80 critical power predictions for the SVEA96+ fuel design, and to minimize the prediction uncertainty. This process is identical to that used by GNF when developing GEXL correlation coefficients for GNF/GE fuel designs using raw test data, and has been used in past development of GEXL correlations applicable to other legacy fuel.

The procedure used for the development of the GEXL80 correlation is summarized below:

- First, a range of generated data covering all parameter(s) variations was selected to form a correlation development database. This database consists of the majority of the generated data. A separate data-set was set aside to form a correlation verification database.
- The GEXL80 correlation coefficients are then chosen (optimized) to minimize the bias and standard deviation in correlating the development database, and to minimize any trend errors in reference to flow, pressure, sub-cooling, and R-factor.
- Once the optimum coefficients were determined, the apparent R-factors are calculated for each assembly. The apparent R-factor is defined as that R-factor which yields an overall ECPR of 1.0 for a given assembly. ECPR is defined as the ratio of the GEXL80 calculated critical power to the PSEG ABBD2.0 calculated critical power.
- A final set of additive constants are determined by adjusting the preliminary additive constants, subject to minimizing the difference between the R-factors.

The range of application for the GEXL80 correlation as stated in the submittal is the same as the range of the hypothetical database over which the correlation is derived and is determined by PSEG to be within the Westinghouse SVEA 96+ experimental development database.

The stated application range covers the complete range of expected operation of the SVEA96+ fuel during normal steady-state and transient conditions in the Hope Creek BWR core, and the limitations on the approved range will be confirmed by GNF and a monitoring capability will be provided for use by PSEG during plant operation.

3.4 Comparison of GEXL80 Critical Power Results to SVEA96+ Raw Data

As part of the Cycle 13 reload design, PSEG had an agreement with GNF to compare the GEXL80 correlation critical power predictions with the SVEA96+ raw critical power data (Reference 10). This comparison was documented in Reference 11, in which PSEG communicated to GNF the final values of the bias and uncertainty to be used in the application of the GEXL80 correlation. On February 17, 2004, members of the NRC staff visited the Hope Creek site in Salem, New Jersey for an on-site review of the results of the above stated comparison and the participation of PSEG in the analyses. Both sub-bundle and full bundle comparisons were conducted by PSEG personnel. The NRC staff reviewed the comparisons for biases and uncertainties that may have been added to or subtracted from the GEXL80

pseudo database, and which might result in non-conservative predictions of critical power, resulting in delayed prediction of fuel going into boiling transition.

The thermal-hydraulic operational ranges of the GEXL80 correlation and the fundamental statistical basis were reviewed, in addition to the comparison to the raw data. The results of the comparisons showed excellent agreement of the GEXL80 correlation critical power predictions to the SVEA96+ critical power database. The NRC staff concurs with the results and conclusions of the comparisons conducted by PSEG, and concludes that the use of the GEXL80 correlation with the stated bias and uncertainty conservatively predicts critical power values for the legacy fuel SVEA96+.

3.5 *Sub-Bundle Mis-Match Factor*

The SVEA96+ bundle is divided into four mini-bundles by the water cross as shown in Figure 2-1 of Reference 1. The four mini-bundles comprised four parallel flow channels that are all subject to the same overall lower template to upper template pressure drop. If the SVEA96+ bundle has a quadrant symmetric pin power distribution, the four mini-bundles have the same power and they will also have the same mass flux and critical power performance. If, on the other hand, the pin power distribution is not symmetric, the four mini-bundles will have different powers. The mini-bundle with the highest power will have the highest steam vapor generation and, therefore, its two-phase pressure drop will increase relative to the other three mini-bundles. Since the four mini-bundles all have the same overall pressure drop, the impact of the higher two-phase pressure drops in the hottest bundle must be offset by a reduced inlet flow and a corresponding lower single phase pressure drop. Similarly, the mini-bundle with the lowest power will have less vapor generation, less two-phase pressure drop and correspondingly must have a higher inlet flow and higher single phase pressure drop. Therefore, the impact of a power mis-match between the four mini-bundles in the SVEA96+ fuel bundle is that the mini-bundle with the highest power has a mass flux that is less than the average for the full bundle, and the mini-bundle with the lowest power has a mass flux that is higher than the average. For a mini-bundle, a reduction in the mass flux will produce a corresponding reduction in the mini-bundle critical power (critical power is a monotonically increasing function with mass flux).

The GEXL methodology calculates the critical power based on the bundle R-factor and the bundle average mass flux. Using this average mass flux, however, does not account for the lower mass flux in the hottest mini-bundle and the corresponding lower critical power. Therefore, an adjustment to the critical power must be developed to account for the impact of any power mis-match between the mini-bundles. The thermal/hydraulic model for the SVEA96+ bundle characterizes the pressure drop as a function of power and mass flux. A relationship between power and flow for a constant pressure drop can be derived from this thermal-hydraulic model. Therefore, the mismatch in mini-bundle mass flux can be determined for a given mini-bundle power mis-match and the average bundle thermal/hydraulic conditions. Since critical power is a monotonically increasing function with mass flux, the mini-bundle mass flux mis-match can be equated to a corresponding reduction in mini-bundle critical power. This reduction in the mini-bundle critical power is then incorporated as a penalty on the R-factor for the mini-bundle.

3.6 Thermal-Hydraulic Compatibility of the GE14 Fuel with the SVEA96+ Fuel

The September 8, 2003, submittal by PSEG (Reference 4), provided independent verification of the conclusion made by GNF that the GE14 and SVEA96+ fuels are thermal-hydraulically compatible.

Westinghouse provided the thermal-hydraulic modeling data for the legacy SVEA96+ fuel [PSEG File HCA.5-0020] and GNF for the GE14 fuel [PSEG File HCG.5-0004]. As part of the new fuel introduction (NFI) work scope, GNF provided PSEG a report containing several mixed core evaluations to support the conclusion that the two distinct fuel designs are thermal-hydraulically compatible [PSEG File NFVD-GE-2003-002-00]. PSEG has taken the data from each fuel vendor and modeled each fuel type using the industry computer code FIBWR2 (Reference 9) as an independent means of verifying the conclusions arrived at by GNF.

The September 8, 2003, PSEG submittal first summarized the FIBWR2 benchmark results of modeling the full cores of each fuel type at various power and flow conditions. The FIBWR2 model for each fuel type was benchmarked with the thermal-hydraulic analysis results provided by the respective fuel vendors. Included also in the September 8 submittal, is a summary of the core performance for a number of projected transition or mixed cores at the same power and flow conditions to verify the fuel vendor's conclusions regarding the thermal hydraulic compatibility of the SVEA96+ and GE14 fuel designs.

The GE14 fuel design consists of 92 fuel rods arranged in a 10x10 lattice array, with two water tubes displacing eight fuel rod positions. Fourteen of the 92 fuel rods are part-length. Additional components in a GE14 assembly include: upper and lower tie plates, spacer grids, a handle that attaches to the upper tie plate for lifting, and a channel box that slides over the fuel rods and has a spring loaded fit against the lower tie plate. As part of the current fuel vendor transition, GNF supplied GE14 thermal hydraulic performance data [PSEG File HCG.5-0004] at several power and flow conditions for a rated power of 3952 MWt, the future extended power uprate (EPU) power level, using the proprietary GNF computer code ISCOR (GESTAR II). The PSEG Hope Creek FIBWR2 model [PSEG File HCT.6-0042] was benchmarked against this data. Table 3.3 of Reference 3 displays the pressure loss coefficients that were provided for the upper and lower tie plate and the spacers. The inlet loss coefficients are the values traditionally used at Hope Creek to model the central and peripheral bundle orifices, relative to the reference flow area. Table 3.4 of the Reference 3 displays a sample comparison of the GE14 information and the FIBWR2 results using a 1.4 peak to average chopped cosine axial power shape.

With respect to the ranges of operability, GNF provided the results of analysis of the reference loading pattern for the Hope Creek Cycle 13 that has core characteristics that are representative of the mixed cores that will be encountered during the transition cycles. The CPR was extracted for all the SVEA96+ fuel throughout the entire cycle.

3.7 Mixed Core Evaluations

The next three cycles at Hope Creek will be designated as mixed cores, with core loadings comprised of SVEA96+ fuel and GE14 fuel. The first transition mixed core, Cycle 13 was modeled with approximately two-thirds SVEA96+ fuel and one-third GE14 fuel. Cycle 14 was modeled with approximately one-half SVEA96+ fuel and one-half GE14 fuel; and Cycle 15 was modeled with approximately one-third SVEA96+ fuel and two-thirds GE14 fuel. Subsequently, PSEG performed independent calculations to verify the mixed core calculation results as obtained by GNF, regarding the similarity in thermal-hydraulic performance of the GE14 and SVEA96+ fuel designs. Proprietary data provided by Westinghouse and GNF was used by PSEG to develop FIBWR2 computer code models to perform the various evaluations.

Specifically, PSEG investigated the compatibility between GE14 and SVEA96+ through a series of mixed cores, progressing from the current full core of SVEA96+ fuel to a projected full core of GE14 fuel. Tables 4.2 through 4.7 of Reference 4 display the FIBWR2 simulation results for each of the core loadings in Table 4.1 of Reference 4 at each of the reactor conditions. The mixed core simulation analyses projected the performance of both fuel types during transition cores, going from a full core of SVEA96+ fuel to a full core of GE14 fuel. During the mixed core transition cycles, only SVEA96+ assemblies are placed at the core periphery. Each of the mixed core loadings will have 92 SVEA96+ bundles placed at the periphery of the core. In the model, one of the SVEA96+ bundles is designated a "hot" SVEA96+ bundle with a 1.56 radial power peaking factor, and one "hot" GE14 bundle with a 1.56 radial power peaking factor, with the remainder of each fuel type allocated (loaded) to reach the respective bundle quantities listed in Table 4.1. The following trends were observed to occur in the mixed core evaluations:

- As discussed in Section 3.4 of Reference 4, the core pressure drop for a full core of GE14 fuel is higher than the core pressure drop for a full core of SVEA96+ fuel at all reactor conditions. As was demonstrated by GNF, the mixed core results showed that as the fraction of GE14 assemblies increases, the core pressure drop also increased to approach the GE14 full core value. The linearity of the core pressure drop increase as a function of GE14 assembly fraction, indicated that the introduction of GE14 fuel assemblies into the SVEA96+ fuel core does not significantly affect the original SVEA96+ performance, while the GE14 fuels maintain their own performance as if they are in the full GE14 cores. This result was expected since the thermal-hydraulic performance of these two fuel types is similar.

- The core active flow (water through the active fuel zone) for the mixed core was found to be essentially the same for all reactor conditions.

- As discussed in Section 3.4 of Reference 4, the core bypass flow (excluding intra-bundle water tube flow) for a full core of GE14 fuel is higher than the core bypass flow for a full core of SVEA96+ fuel. The mixed core evaluations demonstrate a clear progression towards the full core GE14 values observed in Tables 3.7 through 3.12. This is due to differences in the construction of each fuel type as described in Section 3.4 of Reference 4. As the fraction of GE14 fuel increases, more flow paths are available from the fuel channel to the bypass region. Figure 4.3 displays the bypass flow as a function of core loading for each of the reactor conditions evaluated.

The differences in fuel design, though, do not adversely affect the performance of a neighboring fuel assembly.

- Due to the differences in the pressure drop of the two fuel designs, the hot bundle active flows in the mixed core evaluations are affected in the following ways: the GE14 hot bundle active flow in the 573 SVEA96+ and 191 GE14 core is less than the full core GE14 evaluations. As the number of GE14 assemblies increases, the GE14 hot bundle flow increases towards the full core value. Since the GE14 fuel design has a slightly higher pressure drop, the SVEA96+ hot bundle active flow is more than the full core SVEA96+, in the 573 SVEA96+, 191 GE14 core loading.

  As the number of GE14 bundles increases, the SVEA96+ hot bundle active flow increases to become higher than the full core SVEA96+ results.

3.8 GNF Response to NRC Staff's Request for Additional Information (RAI)

During the course of the NRC staff's review of LTR NEDC-33107P, a number of requests for additional information were communicated to both the licensee and GNF. The licensee's questions were resolved by the February 17, 2004 on-site review at Hope Creek, as discussed in Section 3.4 of this SE. GNF submitted a formal response to the remaining questions by a letter dated March 17, 2004 (Reference 12).

The responses provided clarification of data collection and treatment and conclusions stated in the LTR. Included were:

- Additions to the statistical summary Tables 3-2 and 3-3, providing the 95/95 upper tolerance limits for the GEXL80 correlation,
- An explanation of the treatment of the "mini-bundle variation term" in the R-factor calculation,
- Clarification of justification of the GEXL80 correlation "range of applicability" based on the number and span of the points in the hypothetical database and the actual experimental data range, and
- Clarification of the PSEG role and responsibility in comparing the GEXL80 correlation to the actual experimental test database.

Based on these responses, the staff concluded that all outstanding issues had been satisfactorily addressed.

4.0 <u>CONCLUSION</u>

The NRC staff reviewed the analyses and results presented in LTR NEDC-33107P, "GEXL80 Correlation for SVEA96+ Fuel," and the GE14 and SVEA96+ Thermal-Hydraulic Compatibility Report, and has determined that the analyses and results are in accordance with 10 CFR 50.34. In addition, the staff concludes that the analyses presented in the two reports, are acceptable because: (1) the total uncertainty in the correlation's critical power predictions

appropriately takes into account the fact that the uncertainty in the new correlation's fit to the hypothetical database and the uncertainty in the hypothetical database with respect to the underlying experimental data are appropriately treated; (2) generating the hypothetical databases using the ABBD2.0 correlation encoded in the subchannel code CONDOR is a reasonable engineering approach to dealing with mixed core fuel, where the experimental database and critical power correlation for the previous vendor's fuel are not available to the new vendor; (3) GNF intends to utilize the new GEXL80 correlation within the limits of the hypothetical database, further bounded by the experimental limits of the SVEA96+ database; and (4) GNF confirmed that the CPR analyses remain bounding, and that key inputs to the safety analyses (such as the CPR) are conservative with respect to the current design cycle.

In addition, the staff also finds acceptable the full core and mixed core evaluations and the results of analysis performed by PSEG to independently verify the conclusions reached by GNF that the introduction of the GE14 fuel will not adversely impact the performance of the SVEA96+ fuel, and that the two distinct fuel designs are thermal-hydraulically compatible.

As stated above, the GNF GEXL80 correlation is limited to application to the legacy (at least once-burned) Westinghouse SVEA96+ fuel, that will co-reside with GNF-A GE14 fuel in the Hope Creek BWR during the mixed vendor transition cores, beginning with the reload scheduled for operating Cycle 13 in November 2004. The use of the GEXL80 correlation has not been justified for application to fresh (unburned) SVEA96+ fuel or for other than Hope Creek reload cores.

Therefore, on the basis of the above review and justification, the NRC staff concludes that the proposed GEXL80 correlation methodology and results are acceptable.

5.0 <u>REFERENCES</u>

1. Letter, M. E. Harding (GNF) to A. Wang (NRC), Transmittal of GNF Proprietary Report, NEDC-33107P, "GEXL80 Correlation for SVEA96+ Fuel," FLN-2003-010, September 8, 2003.

2. Letter, M. E. Harding (GNF) to A. Wang (NRC), Transmittal of GNF Non-proprietary Report, NEDO-33107, "GEXL80 Correlation for SVEA96+ Fuel," FLN-2003-011,. September 17, 2003.

3. Letter, G. Salamon (PSEG) to NRC, transmitting "SVEA96+ Modeling Dimensions," LR-N03-0386, September 8, 2003.

4. Letter, G. Salamon (PSEG) to NRC, transmitting "GE14 and SVEA96+ Thermal-Hydraulic Compatibility Report," LR-N03-0388, September 8, 2003.

5. NEDE-10958-P-A and NEDO-10958-A, "General Electric BWR Thermal Analysis Basis (GETAB): Data, Correlation and Design Basis," January 1977.

5A. Letter, A, C. Thadani (NRC) to J.S. Charnley (GE), Acceptance for Referencing of Application of Amendment 15 to GE LTR NEDE-24011-P-A, "GE Standard Application for Reactor Fuel," MFN-47-87, March 14, 1988.

6. NEDE-24011-P-A, Revision 14, "General Electric Standard Application for Reactor Fuel (GESTAR II)," June 2000.

7. "CONDOR: A Thermal-Hydraulic Performance Code for Boiling Water Reactors," ABB Report BR 91-255-P-A, Rev. 1, (Proprietary), BR 91-262-NP-A (Non-proprietary), May 1991.

8. CENPD-389-(P)(A), "ABBD2.0 Critical Power Correlation," Rev. 1, July 2000.

9. "FIBWR2 Version 1.08c (with GEXL and ABBD2.0)," PSEG Nuclear Fuel Section Software Configuration Management File SCM-0114, April 2002 [based on FIBWR2 Owners Group version, Scientech, Inc., 1992].

10. Topical Report CENPD-389-P-A, "10x10 SVEA Fuel Critical Power Experiments and CPR Correlations: SVEA96+," September 1999.

11. Letter NFS 03-202, PSG-03-032 from D. V. Notigan (PSEG) to R. E. Kingston (GNF), "Transmittal of PSEG Nuclear LLC GEXL80 Comparison Results," September 2, 2003.

12. Letter, M. E. Harding (GNF) to A. Wang (NRC), Transmittal of GNF Response to NRC RAIs Regarding the GEXL80 Correlation, (proprietary and non-proprietary versions), FLN-2004-001, March 17, 2004.

Attachment: Resolution of Comments

Principal Contributors: A. Attard
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Date: July 19, 2004

RESOLUTION OF COMMENTS

ON DRAFT SAFETY EVALUATION FOR LICENSING TOPICAL REPORT NEDC-33107P,

"GEXL80 CORRELATION FOR SVEA96+ FUEL"

By letter dated June 1, 2004, Global Nuclear Fuel (GNF) provided comments on the draft safety evaluation (SE) for NEDC-33107P, "GEXL80 Correlation for SVEA98+ Fuel." The following is the staff's resolution of those comments.

1. GNF Comment: Line 69, page 2, Section 3, "Technical Evaulation," first paragraph, last sentence – "GETAB GEXL form ..."

   GNF Proposed Resolution: "NRC-approved GETAB GEXL PLUS form (Reference 5A) ..."

   NRC Action: The comment was fully adopted into the final SE.

2. GNF Comment: Line 113, page 3, Section 3.1, "Validity of Hypothetical Database and Associated Uncertainties," first paragraph, last sentence – "SVEA96+ fuel design, located in non-limiting locations with at least one cycle of irradiation."

   GNF Proposed Resolution: "... SVEA96+ fuel design with at least one cycle of irradiation."

   NRC Action: The comment was fully adopted into the final SE.

3. GNF Comment: Lines 204-206, page 5, Section 3.3, "Generation of the GEXL80 Correlation and the Range of Applicability," last paragraph, last sentence – "... this will be confirmed by GNF and monitored by PSEG during plant operation."

   GNF Proposed Resolution: "... the limitations on the approved range will be confirmed by GNF and a monitoring capability will be provided for use by PSEG during plant operation."

   NRC Action: The comment was fully adopted into the final SE.

4. GNF Comment: Lines 425, page 10, Section 4, "Conclusions," "... Westinghouse SVEA96+ fuel, loaded in non-limiting locations, that will co-reside in the Hope Creek BWR..."

   GBF Proposed Resolution: "...Westinghouse SVEA96+ fuel, that will co-reside with GNF-A GE14 fuel in the Hope Creek BWR..."

   NRC Action: The comment was fully adopted into the final SE.

5. GNF Comment: Section 5, "References," add reference 5A.

GNF Proposed Resolution: Add reference 5A – "Letter, A. C. Thadani (NRC) to J. S. Charnley (GE), Acceptance for Referencing of Application of Amendment 15 to GE LTR NEDE-24011-P-A, "GE Standard Application for Reactor Fuel," MFN-47-87, March 14, 1988."

NRC Action: The comment was fully adopted into the final SE.

6. GNF Comment: Section 5, "References," correct reference 8, EMF-2209(P)(A), "ABBD2.0 Critical Power Correlation," Rev. 1, July 2000. .

GNF Proposed Resolution: Correct reference 8, Section 5, "References," – "CENPD-389-(P)(A), "ABBD2.0 Critical Power Correlation," Rev. 1, July 2000."

NRC Action: The comment was fully adopted into the final SE.

Document Title: GEXL80 Correlation for Westinghouse SVEA96+ Fuel October 2004

ABSTRACT

The GEXL80 correlation for determining the minimum critical power ratio (MCPR) during normal and transient operation for the boiling water reactor (BWR) and its development is presented for application to the Westinghouse SVEA96+ fuel design. This fuel design will be co-resident with GE14 fuel in future Hope Creek cycles, and the application of the GEXL80 correlation to the SVEA96+ design will be for SVEA96+ fuel that is in at least its second cycle of irradiation. The basic GEXL correlation is a critical quality and boiling length correlation used to predict the occurrence of boiling transition in BWR fuel designs. The database used to support the development of the GEXL80 correlation was acquired from PSEG Nuclear LLC (PSEG). This matrix of data consisted of calculated critical power data as determined by PSEG using the Westinghouse NRC approved ABBD2.0 critical power correlation. The specific SVEA96+ GEXL80 correlation developed for use in the core design and safety analysis process is intended to adequately predict the expected critical power performance of the fuel assembly design. In the core design process the GEXL80 correlation is used to determine the expected thermal margin for the SVEA96+ fuel in the operating cycle. Thermal margins for the Global Nuclear Fuel (GNF) bundles in the operating cycle will be determined based on the appropriate GEXL correlation for those fuel designs. In the Safety Analysis process the GEXL80 correlation is to be applied to the Westinghouse SVEA96+ fuel in the mixed core while the appropriate GNF GEXL correlation will be applied to the GNF fuel (including the determination of an acceptable MCPR safety limit for the mixed core). Based on the supporting NRC approved Westinghouse ABBD2.0 correlation generated matrix of data, it is concluded that the safety related conditions have been satisfied with respect to the development of an acceptable critical power correlation.

The GEXL80 correlation will be applied for the prediction of critical power with a [[{3}]] ECPR mean and a [[{3}]] uncertainty. This ECPR mean and uncertainty have been conservatively developed such that the GEXL80 correlation adequately bounds the matrix of data developed by PSEG using the NRC approved ABBD2.0 correlation. Furthermore, the ECPR mean and uncertainty conservatively bound the Westinghouse SVEA96+ dryout test data as determined by PSEG in Reference 4.

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Disclaimer of Responsibility

This document was prepared by or for Global Nuclear Fuel. Services rendered in this regard by Global Nuclear Fuel shall be warranted in accordance with Paragraph 8.7 entitled "Services Warranty" of the Contract for Nuclear Fuel Fabrication and Related Services for Hope Creek Generating Station between PSEG Nuclear LLC and Global Nuclear Fuel - Americas LLC effective February 7, 2003.

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Changes From Proprietary Version

This document is the GNF non-proprietary version of the proprietary report NEDC-33107P-A, Revision 1. From the GNF proprietary version, the information denoted as GNF proprietary (enclosed in double brackets) was deleted to generate this version.

Revision Status

Revision Number	Section	Description of Change	Signature
1	4.2	Update upper end of pressure application range such that it does not extend beyond the upper end of the experimental database.	R. Harrington
1	4.2	Update lower end of mass flux application range such that it does not extend beyond the lower end of the experimental database.	
1	4.2	Update both ends of inlet sub-cooling application range such that it does not extend beyond the ranges of the experimental database.	
1	4.2	Update the lower end of the R-factor application range such that it does not extend beyond the ranges of the collected database.	
1	3, 5	Correct typo in correlation database mean ECPR (noted in Appendix B, Response 1)	
1	B	New Appendices to include GNF Response to NRC RAIs regarding Revision 0.	

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1. INTRODUCTION AND SUMMARY

This report summarizes the development of the SVEA96+ GEXL80 correlation. The SVEA96+ GEXL80 correlation will be used to determine the critical power performance of the Westinghouse SVEA96+ fuel. The SVEA96+ fuel in a mixed core will be in at least its second cycle of irradiation. As such, the SVEA96+ GEXL80 correlation would not be applied to reload quantities of first cycle SVEA96+ fuel. This document describes the process used in the development of the GEXL80 correlation for prediction of critical power for SVEA96+ fuel and the determination of the overall ECPR mean and uncertainty of that correlation in prediction of the SVEA96+ critical power performance (see Section 5).

SVEA96+ calculated bundle critical power data was obtained from PSEG Nuclear LLC (PSEG) based on the NRC approved Westinghouse ABBD2.0 correlation (Reference 2). The objective of this data collection was to obtain quality data appropriate for GEXL analysis. The span of the data collection encompasses cosine, top peaked, bottom peaked, and double humped axial power shapes in order to cover the complete range of expected operation of the SVEA96+ fuel in the Hope Creek BWR core. The data was used to develop a new GEXL correlation for the SVEA96+ design. This new GEXL correlation for SVEA96+ fuel is designated as GEXL80. The new GEXL80 correlation uses the same functional form as previous GEXL correlations with different constants for the GEXL correlation coefficient parameters. This report provides the results of the GEXL80 correlation development, including the overall ECPR mean and uncertainty relative to measurement results.

The GE critical quality - boiling length correlation (GEXL) was developed to accurately predict the onset of boiling transition in BWR fuel assemblies during both steady-state and reactor transient conditions. The GEXL correlation is necessary for determining the MCPR operating limits resulting from transient analysis, the MCPR safety limit analysis, and the core operating performance and design. The GEXL correlation is an integral part of the transient analysis methodology. It is used to confirm the adequacy of the MCPR operating limit, and it can be used to determine the time of onset of boiling transition in the analysis of other events.

The GEXL correlation has been used in the safety analysis process for GE fueled BWRs since 1974. The GEXL correlation was developed to provide a best estimate prediction of the onset of boiling transition in BWR fuel assemblies. The GEXL correlation is based on the relationships of critical quality with boiling length. It expresses bundle average critical quality as a function of boiling length, thermal diameter, system pressure, lattice geometry, local peaking pattern (R-factor), mass flux and annular flow length.

The GEXL correlation was originally developed based on test data typical of 7x7 and 8x8 fuel assemblies. Over 14,000 data points having various numbers of rods, heated lengths, axial heat flux profiles, and rod to rod power distributions were used in the development of the original GEXL (GEXL01) correlation. The boiling transition test data available at the time of the development of the GEXL01 correlation are provided in the original licensing topical report (Reference 1). Further background on the development of the GEXL80 correlation is provided in Section 2.

The GEXL correlation requires the development of coefficients for the specific mechanical geometry of the fuel assembly design. The database supporting the development of the GEXL80 correlation is described in Sections 2 and 3.

As described above, the GEXL correlation is a critical quality-boiling length correlation. In the GEXL correlation critical quality is expressed as a function of boiling length, thermal diameter, mass flux, pressure, R-factor, and annular flow length. The axial power profile is not explicitly included in the GEXL correlation, however, the axial power shape is used to calculate boiling length, annular flow length, and axial variation of quality, and thus is inherently included in the critical power correlation. The exact form of the GEXL correlation and the coefficients for SVEA96+ fuel are provided in Section 4.

The measure of the capability of a boiling transition prediction correlation is its ability to predict the collected data. The GEXL80 correlation has been demonstrated to be an adequate predictor of the data generated from the NRC approved Westinghouse ABBD2.0 SVEA96+ critical power correlation. Its capability for predicting SVEA96+ fuel is provided in Sections 3 and 5. The nomenclature and references used in this report are demonstrated in Sections 6 and 7, respectively.

The GEXL80 correlation will be applied for the prediction of critical power with a [[{3}]] ECPR mean and a [[{3}]] uncertainty. This ECPR mean and uncertainty have been conservatively developed such that the GEXL80 correlation adequately bounds the matrix of data developed by PSEG using the NRC approved ABBD2.0 correlation. Furthermore, the ECPR mean and uncertainty conservatively bound the Westinghouse SVEA96+ dryout test data as determined by PSEG in Reference 4.

2. CRITICAL POWER DATABASE FOR GEXL80

The current form of the GE critical quality-boiling length correlation (GEXL) was developed to provide an accurate means of predicting the occurrence of boiling transition in BWR fuel. The primary source of boiling transition data used in the development and verification of the GEXL correlation are dryout tests at the GE ATLAS facility in San Jose, California. The ATLAS test loop generates pressure, flow and temperature conditions that accurately simulate the actual operating reactor environment.

The data for the GEXL80 development specific to SVEA96+ fuel was generated using the NRC approved Westinghouse ABBD2.0 correlation. Specified rod-to-rod peakings, axial power shapes, pressure, mass flux and sub-cooling were used with the Westinghouse ABBD2.0 correlation to determine critical power at dryout.

SVEA96+ fuel is a 10x10 fuel bundle with a central water cross design (consisting of a central channel and four water wings) whose central channel displaces 4 fuel rod positions. It contains a total of 96 full-length fuel rods and no part length rods. It has 14 unique fuel rod locations (Figure 2-1) within the 10x10 lattice for which dryout data was collected. In Section 4, the final GEXL80 correlation for SVEA96+ fuel is given, including additive constants. The database used in the development of the GEXL80 correlation for SVEA96+ fuel is summarized in Table 2-1. This table shows the number of calculated critical power data points obtained using the Westinghouse critical power correlation for cosine, inlet, outlet, and double humped axial power distributions. It also shows the fuel pin dryout location that formed the basis of the 26 different sets of Westinghouse calculated critical power data. Table 2-2 shows the same information but further divides the data collected into subgroups of pressure, mass flux, and inlet sub-cooling.

The SVEA96+ modeling dimensions used in the Westinghouse generation of the ABBD2.0 dryout data as well as in the development of the GEXL80 correlation are provided in Table 2-3. The generated data was based on chopped cosine, top and bottom, and a double humped peaked axial power profiles. The axial power profiles are shown in Figure 2-2.

Table 2-1. GEXL80 Database for SVEA96+ Fuel

[[

Data Set	Number of Critical Power Data Points				Fuel Pin Dryout Position
	Cosine Power Shape	Inlet Power Shape	Double Hump Power Shape	Outlet Power Shape	
Total Data Points					

{3}]]

Table 2-2. GEXL80 Database Details

[[

{3}]]

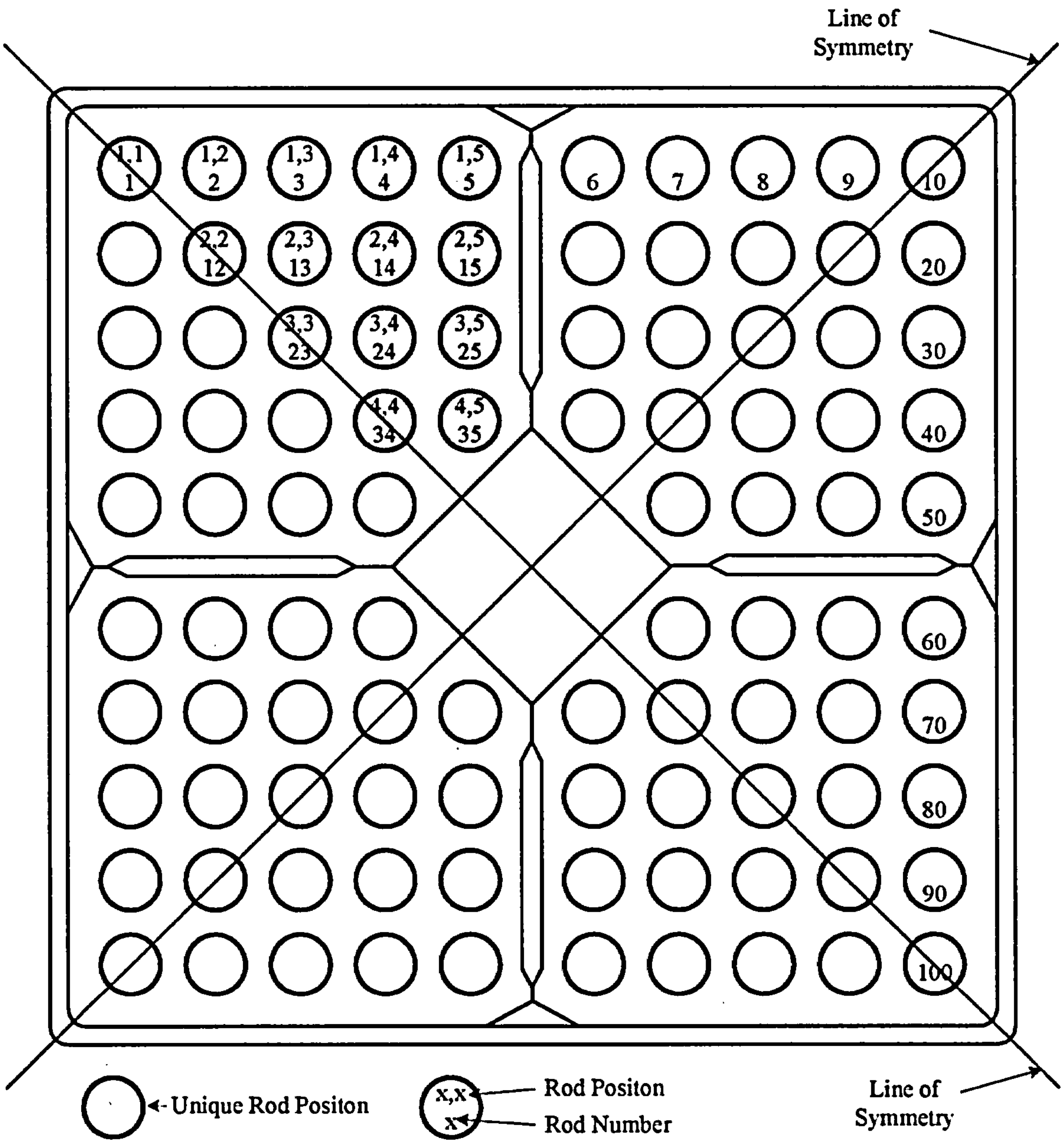

Figure 2-1. SVEA96+ Assembly Rod Numbering System

Table 2-3. SVEA96+ Modeling Dimensions

Characteristic	Assembly
Data sets	1 through 19
Lattice	10 x 10
Nominal Inside Width of Channel	[[ ]]**
Inside Corner Radius of Channel	[[ ]]**
Rod Pitch	[[ ]]**
Diameter of Heated Rods	[[ ]]**
Axial Heat Flux Profiles of Full Length Rods	1.4 Peak-to-Average Cosine 1.6 Peak-to-Average Bottom and Top Peaked, 1.2 Peaked Double Humped Shape
Number of Full Length Heated Rods	96
Heated Length of Full Length Rods	150 in. (381 cm)
Number of Spacers	7
Central Water Cross	Represented in GEXL80 design as a Central Channel (Displacing 4 Fuel Rod Positions) and Four Water Wings
Hydraulic Parameters Used in GEXL80 Active Channel Flow Area True Hydraulic Diameter True Thermal Diameter GEXL80 Hydraulic Diameter GEXL80 Thermal Diameter*	 [[{3}]] [[{3}]] [[{3}]] [[{3}]] [[{3}]]

[[* {3}]]

** This information is Westinghouse proprietary information and is contained in: Letter LR-N03-0386, G. Salamon to NRC Document Control Desk, "SVEA-96+ MODELING DIMENSIONS, HOPE CREEK GENERATING STATION, FACILITY OPERATING LICENSE NPF-57, DOCKET NO. 50-354, dated [September 8, 2003].

[[

{3}]]

Figure 2-2. Bundle Axial Power Shapes - PSEG Critical Power Data Collection

3. DATA COLLECTION MATRIX AND CORRELATION PROCEDURES

3.1. THE SVEA96+ DATA COLLECTION MATRIX

The SVEA96+ data collection matrix is outlined in detail in Table 3-1. This matrix shows the minimum range of data required for the GEXL80 correlation development. The data was generated by PSEG using the NRC approved Westinghouse ABBD2.0 critical power correlation (Reference 2). [[

{3}]]

[[

{3}]]

3.2. CORRELATION PROCEDURE FOR GEXL80

The procedure used for development of the SVEA96+ GEXL80 correlation can be summarized as follows:

- A range of generated data covering all parameter variations was selected to form a development database. This is the majority of the data. A separate set of data was used as the verification database.
- The correlation coefficients were chosen to minimize the bias and standard deviation in correlating the data and to minimize any trend errors in reference to flow, pressure, sub-cooling, and R-factor.
- Once the optimum coefficients were determined, the apparent R-factors were calculated for each assembly. The apparent R-factor is defined as that R-factor which yields an overall ECPR of 1.0 for a given assembly. In this document, ECPR is defined as the ratio of the GEXL80 calculated critical power to the PSEG calculated critical power.
- [[

  {3}]]

These steps were taken to optimize GEXL80 for the SVEA96+ fuel design and to minimize the prediction uncertainty. This identical process is used when developing GEXL correlation coefficients for GNF/GE fuel designs using test data, and was used in the past development of GEXL correlations applicable to other legacy fuel.

Table 3-1. SVEA96+ Critical Power Data Minimum Collection Matrix (Steady-state)

[[

{3}]]

3.3. GEXL80 CORRELATION

Figure 3-1 shows the SVEA96+ ABBD2.0 calculated critical power data versus the calculated critical power for SVEA96+ fuel using the GEXL80 correlation developed herein. The final SVEA96+ GEXL80 correlation coefficients and additive constants are shown in Section 4. The GEXL80 correlation is developed from the majority of the data that consists of [[{3}]] points for 19 different local peaking patterns and 4 axial power shapes with R-factors ranging up to [[{3}]]. The overall statistics for the GEXL80 correlation are shown in Table 3-2 and Table 3-3. The statistics show that the correlation was tuned to give a mean ECPR less than 1.0 such that the correlation on average is slightly conservative. Figures 3-2 through 3-4 show the ECPR mean and standard deviation for mass flux, pressure, and inlet sub-cooling for the correlation database which included all collection types except high R-factor (discussed below), all axial heat flux shapes, and pin peaking patterns which were used explicitly in the GEXL80 ECPR mean and uncertainty calculation ([[{3}]] data points). Figure 3-2 includes data for mass fluxes in the range of [[{3}]] Mlb/hr-ft^2, Figure 3-3 includes data for pressures in the range of [[{3}]] psia, and Figure 3-4 includes data for inlet sub-cooling in the range of [[{3}]] Btu/lbm. These figures demonstrate that there are no substantial trend errors in the GEXL80 correlation and that the GEXL80 correlation closely replicates the Westinghouse correlation over the given ranges.

The GEXL80 correlation was separately assessed against high R-factor data with R-factor values up to [[{3}]], and a mean ECPR of [[{3}]] and a standard deviation of [[{3}]] were obtained. [[{3}]] The higher uncertainty is due to the tuning of the correlation to the very low R-factor data where the SVEA96+ bundles are expected to operate in the next cycle. High R-factors in the range mentioned are generally obtained for controlled bundles, which are non-limiting bundles, and therefore these data are not included in the correlation statistics.

Table 3-2. Statistical Summary for SVEA96+ GEXL80

[[

	Total Correlation Database	Development Database	Verification Database
Number of data points			
Mean ECPR			
Standard deviation, σ (%)			

{3}]]

Table 3-3. Statistical Summary for Each Axial Power Shape for SVEA96+ GEXL80

[[

	Axial Power Shape			
	Cosine	Inlet	Outlet	Double Hump
Number of data points				
Mean ECPR				
Standard deviation, σ (%)				

{3}]]

[[

{3}]]

Figure 3-1. ABBD2.0 Calculated vs. GEXL80 Calculated Critical Power

[[

{3}]]

Figure 3-2. GEXL80 Mass Flux Trends

[[

{3}]]

Figure 3-3. GEXL80 Pressure Trends

[[

{3}]]

Figure 3-4. GEXL80 Inlet Sub-cooling Trends

4. CRITICAL POWER CORRELATION

4.1. FORM OF THE GEXL CORRELATION

As discussed in Section 2, the critical quality versus boiling length plane was chosen by GE as the coordinate system for correlating the boiling transition data described in Section 3. This approach was chosen because (1) it yields good precision, (2) is conceptually simple to apply, and (3) will account for variations in the axial heat flux profile. The critical quality - boiling length correlation developed to predict the critical power in BWR fuel assemblies is called GEXL.

The GEXL correlation, expressed in the most general terms, is:

$$X_C = f(L_B, D_Q, G, P, R, L_A) \qquad (4\text{-}1)$$

where:

- X_C = Critical quality (dimensionless)
- L_B = Boiling length (in.)
- D_Q = Thermal diameter (in.)
- G = Mass flux (10^6 lb/hr-ft^2)
- P = Pressure (psia)
- R = Bundle R-factor (dimensionless)
- L_A = Annular flow length (in.)

Because GEXL is a dimensional correlation, the above units must be used in specific analyses.

The explicit form of the GEXL correlation is:

[[{3}]] (4-2)

where the correlation parameters, V(I), and the coefficients, A(I), are shown in Table 4-1. The additive constants are shown in Table 4-2.

Table 4-1. GEXL80 Correlation Coefficients

[[

[3]]]

4.2. GEXL80 APPLICATION RANGE

The GEXL80 correlation for SVEA96+ fuel is valid over the range stated below:
[[

{3}]]

The database spanned all application ranges. The data was generated only to [[{3}]] psia due to an application range limit for the Westinghouse ABBD2.0 correlation. Analysis of the GEXL80 trends show that the correlation is [[{3}]] with high pressure and its behavior is consistent with what we have seen in other GEXL correlations (i.e. GEXL14) where we have data to [[{3}]] psia.

The application range covers the complete range of expected operation of the SVEA96+ fuel during normal steady state and transient conditions in the Hope Creek BWR core.

4.3. CALCULATION OF CRITICAL POWER BY GEXL

For steady-state conditions, critical power is predicted by an iterative procedure. Given the pressure, flow rate, inlet sub-cooling, axial power shape and fuel lattice design, a value for the critical power is assumed and the local quality and boiling length are computed for each axial node (24 nodes are assumed) using energy and mass balance relationships. The critical quality is also computed for each node using Equation 4-2. If, at any of the nodes, the local quality is greater than the critical quality, a smaller value for the critical power is assumed. If the local quality is less than the critical quality at all of the nodes, a greater value for the critical power is assumed. The iteration continues until the local quality is just equal to the critical quality at one of the nodes and is less at all other nodes. The power for this last iteration is the predicted critical power.

This process is illustrated in Figure 4-1 where the dashed/solid lines show the critical and equilibrium quality profiles for the first and last iterations. The equilibrium quality X is a function of bundle elevation z and is calculated from:

$$X(z) = \left[Q(z)/W - (h_f - h_{in})\right] / (h_g - h_f) \quad (4\text{-}3)$$

In Equation 4-3, X is the local quality; z is the axial coordinate for elevation in the bundle; Q is the integrated power input to the coolant up to location z; W is the bundle coolant flow rate; h_f is the saturated liquid enthalpy; h_{in} is the inlet liquid coolant enthalpy; and h_g is the saturated vapor enthalpy.

For design application the correlation is intended to iteratively determine the bundle power which satisfies the requirement that for some z, $X = X_C$ and $X < X_C$ for all other z. It also should be noted that the values of X_C, X and z at which $(X_C - X)$ is a minimum, change with each iteration on bundle power.

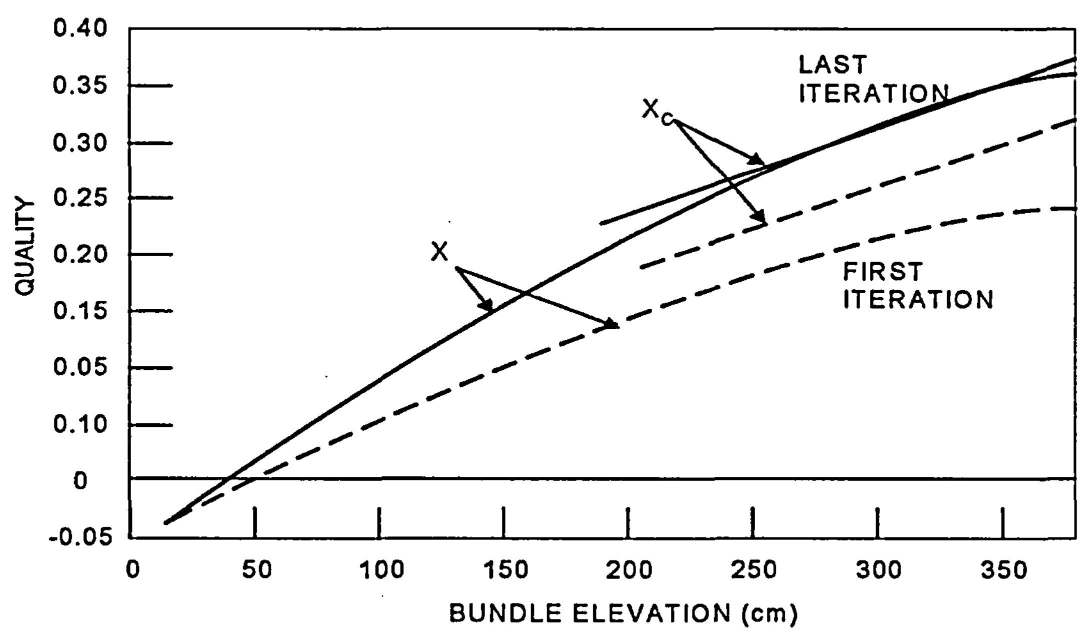

Figure 4-1. Critical Power Iteration Scheme

The critical power ratio (CPR) is the ratio of the predicted critical power to the actual power of the particular fuel assembly, both evaluated at the same pressure, mass flux and inlet sub-cooling. The minimum critical power ratio (MCPR) is defined as the minimum CPR for any fuel assembly within a core and is the figure of merit to represent the reactor thermal performance or margin.

4.4. GEXL INPUT PARAMETERS

This section describes the necessary inputs to the GEXL correlation for the bundle critical power calculation. Based on Equation 4-1, there are six input parameters required for the calculation of critical power. These parameters are: (1) boiling length, L_B; (2) thermal diameter, D_Q; (3) mass flux, G; (4) pressure, P; (5) bundle R-factor, R; and (6) annular flow length, L_A. These parameters are discussed in more detail below.

4.4.1. Boiling Length

Boiling length, L_B, is the distance from the onset of thermodynamic average bulk boiling to the point of boiling transition. Boiling length is not a direct input to GEXL, but it is calculated through the energy balance during the calculation of critical power described in Section 4.3. The boiling length is dependent on the core pressure, enthalpy at the fuel assembly inlet, normalized axial power shape, mass flux and bundle power level.

4.4.2. Thermal Diameter

The thermal diameter, D_Q, is a characteristic diameter defined in the heated length region as four times the bundle active coolant flow area divided by the total rodded perimeter, i.e. the perimeter of the fuel rods and the water cross (consisting of a central channel and four water wings). The rodded perimeter does not include the channel. The thermal diameter used in the GEXL80 correlation for SVEA96+ fuel is [[{3}]], and the active flow area is [[{3}]]. Both parameters are assumed constant over the length of the fuel assembly. The thermal diameter is a normalization parameter in the boiling length and annular length terms of the GEXL correlation. The value calculated for SVEA96+ fuel is specific to the GEXL80 correlation and is calculated to be consistent with GNF-A engineering computer program (ECP) calculations. [[

{3}]]

4.4.3. Mass Flux

The mass flux, G, is defined as the [[{3}]] coolant flow per unit flow area in the heated region.

4.4.4. Pressure

The pressure, P, is defined as the system pressure, taken as the core pressure [[
{3}]]

4.4.5. R-Factor

The R-factor is a parameter that accounts for the effects of the fuel rod power distributions and the fuel assembly local spacer and lattice critical power characteristics. Its formulation for a given fuel rod location depends on [[{3}]] In addition, there is an additive constant applied to each fuel rod location [[{3}]], and a "mini-bundle variation term" that accounts for the flow distribution sensitivity that may occur among the four mini-bundles within the SVEA96+ fuel bundle configuration created by the central water cross design. A detailed description of the R-factor calculation method is provided in Appendix A. For SVEA96+ the additive constants used in the design process are provided in Table 4-2. The bolded positions represent unique rod locations for which data were generated in order to cover all symmetric locations.

Table 4-2. GEXL80 Additive Constants for SVEA96+ Fuel

[[

{3}]]

[[

[3]]]

See Appendix A for a more detailed explanation on the mini-bundle variation term.

4.4.6. Annular Flow Length

[[

[3]]]

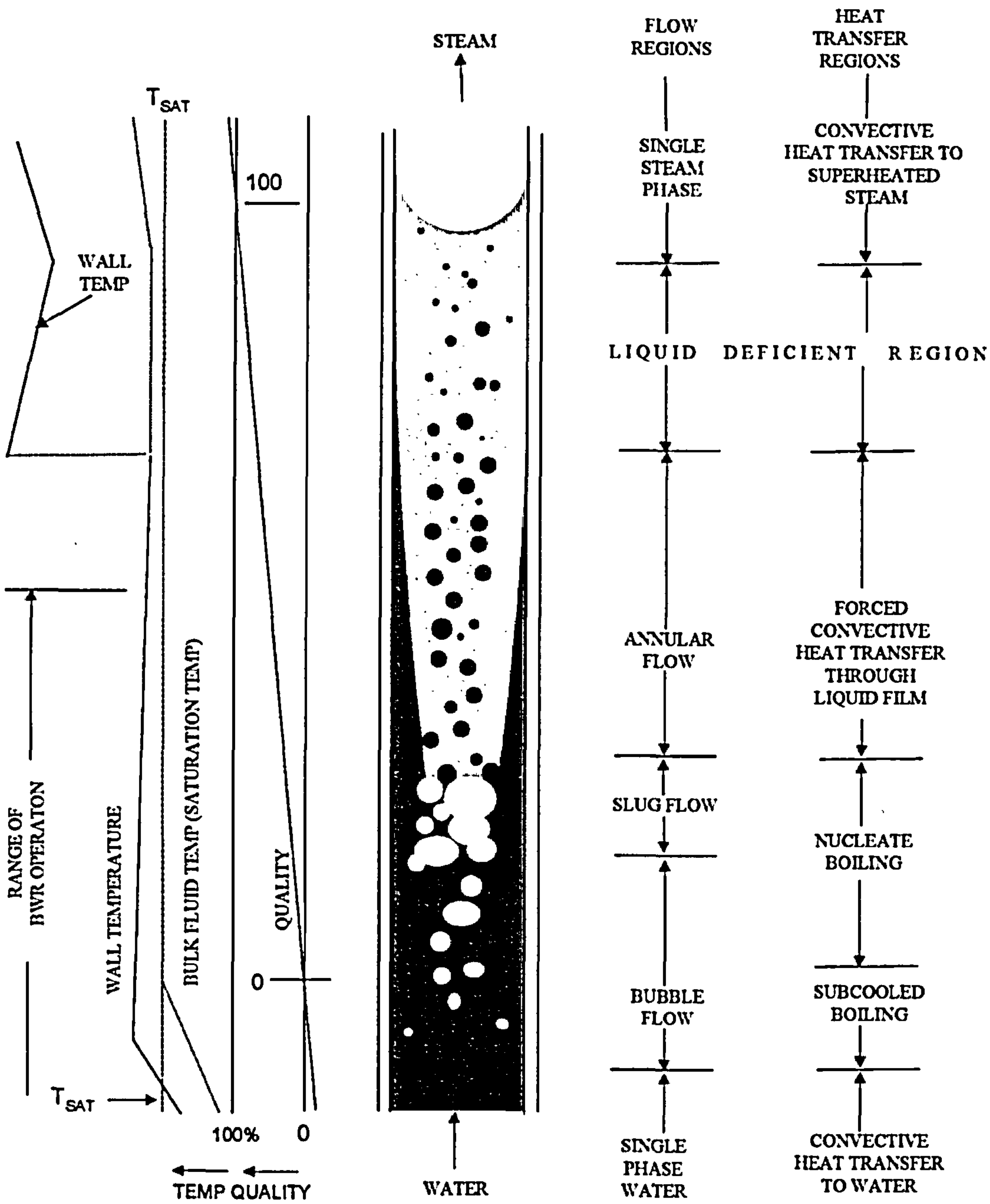

Figure 4-2. Regimes of Two-Phase Flow

5. SVEA96+ GEXL80 CRITICAL POWER EVALUATION

The GE critical quality-boiling length correlation (GEXL) was developed to be an accurate, best estimate predictor of boiling transition in BWR fuel. A large critical power test database was obtained as part of the development of the form of the GEXL correlation. The data covered the full range of BWR steady-state operating conditions for which an accurate prediction of critical power is an important element of the safety analysis process.

The GEXL80 correlation was developed from data generated using the NRC approved Westinghouse ABBD2.0 critical power correlation. This section provides the results of statistical analyses performed to demonstrate the application of the final GEXL80 correlation to predict the SVEA96+ simulated critical power data.

A statistical analysis was performed for the SVEA96+ correlation database consisting of [[{3}]] data points for [[{3}]]. The data and analyses cover the range for which the SVEA96+ GEXL80 correlation is considered valid, as identified in Section 4. To facilitate the statistical evaluation of the predictive capability of the SVEA96+ GEXL80 correlation, the concept of an experimental critical power ratio (ECPR) is used. The ECPR is determined from the following relationship:

$$ECPR = \frac{\text{GEXL80 Calculated Critical Power}}{\text{ABBD2.0 Calculated Critical Power}} \qquad (5\text{-}1)$$

In this equation, "GEXL80 Calculated Critical Power" refers to critical power values calculated using the GEXL80 correlation, and "ABBD2.0 Calculated Critical Power" refers to the data generated by PSEG using the Westinghouse ABBD2.0 critical power correlation for SVEA96+.

Figure 5-1 shows the frequency distribution of the calculated ECPR results for SVEA96+ and is a graphical representation of the ECPR results that were used to calculate the statistics shown in Tables 3-2 and 3-3. The high R-factor statistics are not included in this histogram but are included in Figure 5-2.

[[

{3}]]

Figure 5-1. Frequency versus ECPR Histogram for GEXL80 Correlation Database

[[

{3}]]. The mean and standard deviation of the GEXL correlation impacts the safety limit calculated by the Engineering Computer Program GESAM. For each trial, GESAM determines a CPR distribution for all the rods and calculates the likelihood that the rod is in boiling transition, assuming a normal ECPR distribution for the GEXL correlation, where $\text{ECPR}=\frac{Q_{\text{C-GEXL}}}{Q_C}$. If the critical power ratio is $\text{CPR}=\frac{Q_{\text{C-GEXL}}}{Q}$, the rod is in boiling transition if $Q>Q_C$ or $\text{ECPR}>\text{CPR}$. Consequently the likelihood that the rod is in boiling transition is given by:

$$P_{\text{GEXL80}}(\text{CPR})=\int_{\text{CPR}}^{\infty}\frac{1}{\sigma\sqrt{2\pi}}e^{-0.5(\frac{x-\mu}{\sigma})^2}dx \tag{5-2}$$

The number of rods in boiling transition is then given by:

$$\text{NRSBT}=\sum_{\text{All Rods}}P_{\text{GEXL80}}(\text{CPR}) \tag{5-3}$$

The actual uncertainty in the GEXL80 correlation is determined from the comparison to the data (ECPR distribution) shown in the histogram in Figure 5-2.

[[

{3}]]

Figure 5-2. Frequency versus ECPR Histogram for GEXL80 Collection Matrix of Data

The ECPR distribution shown in Figure 5-2 has a mean of [[{3}]] and a standard deviation of [[{3}]]. This histogram includes all data in the GEXL80 collection database, including the high R-factor data. If the critical power ratio of the rod is CPR, the actual probability that the rod is in boiling transition is given by the probability that the ECPR value is greater than CPR. The integrated probability that the ECPR value is greater than CPR is shown by the curve labeled "P_{Data}(CPR)" in Figure 5-3. This is the probability of the rod being in boiling transition determined from the ECPR distribution. The other curves in Figure 5-3 are the integrated probability of being in boiling transition for a normal distribution (Equation 5-2) with [[{3}]] and standard deviation equal to [[{3}]].

[[

{3}]]

Figure 5-3. Integrated Probability

The requirement that the GEXL80 correlation conservatively bounds the ECPR distribution is given by:

$P_{GEXL80}(CPR) > P_{Data}(CPR)$ for all values of CPR

It is seen that the data is bounded very well with a mean of [[{3}]] and standard deviation of [[{3}]] . The very slight under prediction for [[{3}]] is insignificant. A slightly larger mean may be chosen to cover any error in the Westinghouse ABBD2.0 correlation used to generate the collection matrix of data. A higher uncertainty and biased ECPR mean provide a correlation that will conservatively estimate the likelihood that a rod is in boiling transition and, therefore, the safety limit will be conservatively estimated. It will also provide an adequate bound for the ECPR distribution from the comparison of GEXL80 to the SVEA96+ critical power test database (Reference 4).

Based on the collection matrix of data generated by PSEG, a correlation uncertainty of [[{3}]] and a biased ECPR mean of [[{3}]] are recommended for the GEXL80 correlation. In order to conservatively bound the comparison to SVEA96+ dryout test data as determined by PSEG (Reference 4), GEXL80 will use a biased ECPR mean of [[{3}]] with the [[{3}]] uncertainty.

6. NOMENCLATURE

The nomenclature and acronyms used in this report are provided below. The units shown here are general dimensions of the variables. Actual units required for dimensional calculations V (I) terms in Equation 4-2 are described in Section 4.

Table 6-1. Nomenclature

Symbol	Definition	Units
A	Bundle flow area	in^2 (m^2)
A (I)	Fuel type specific GEXL coefficients	Values in Section 4 consistent with specific English units
D_H	Hydraulic diameter	in (m)
D_Q	Thermal diameter	in (m)
F	Number of active fuel rods	dimensionless
G	Mass flux	lb/ft^2-sec (kg/m^2-sec)
G_f	Mass flux of the liquid phase alone	lb/ft^2-sec (kg/m^2-sec)
G_g	Mass flux of the gaseous phase alone	lb/ft^2-sec (kg/m^2-sec)
g	Gravitational constant	ft/sec^2 (m/sec^2)
h_f	Saturated liquid enthalpy	Btu/lb (kJ/kg)
h_g	Saturated vapor enthalpy	Btu/lb (kJ/kg)
h_{in}	Inlet liquid enthalpy	Btu/lb (kJ/kg)
j_f	Average liquid velocity = $W_f/\rho_f A = G_f/\rho_f$	ft/sec (m/sec)
j_g	Average vapor velocity = $W_g/\rho_g A = G_g/\rho_g$	ft/sec (m/sec)
j_f^*	Dimensionless liquid velocity	dimensionless
j_g^*	Dimensionless vapor velocity	dimensionless
L_A	Annular flow length	in (m)
L_B	Boiling length	in (m)
l_i	Additive constant	dimensionless
n_j	Number of rods in position j	dimensionless
n_k	Number of rods in position k	dimensionless
P	Pressure	psia (Pa)

Symbol	Definition	Units
q	Correction for adjacent low power rods	dimensionless
$Q(z)$	Integrated power input to the coolant up to location (z)	BTU/sec (Watts)
R	Bundle R-factor	dimensionless
R_i	R-factor for an individual rod	dimensionless
R_{FC}	R-factor at fully controlled	dimensionless
r_i	Local peaking factor for rod i	dimensionless
r_j	Local peaking factor for rod j	dimensionless
r_k	Local peaking factor for rod k	dimensionless
T	Total number of lattice positions	dimensionless
$V(I)$	GEXL correlation parameters	Values in Section 4 consistent with specific English units.
W	Bundle coolant flow rate	lb/hr (kg/sec)
W_f	Liquid mass flow	lb/hr (kg/sec)
W_g	Vapor mass flow	lb/hr (kg/sec)
W_i	Weighting factor for rods in position i	dimensionless
W_j	Weighting factor for rods in position j	dimensionless
W_k	Weighting factor for rods in position k	dimensionless
X	Local quality	dimensionless
X_C	Critical quality	dimensionless
X_{TR}	Annular flow transition quality	dimensionless
Z_C	Axial coordinate for the point of critical quality	ft (m)
Z_{TR}	Axial coordinate for the point of transition to annular flow	ft (m)
z	Axial coordinate for elevation in bundle	ft (m)
ρ_f	Liquid density	lb/ft^3 (kg/m^3)
ρ_g	Vapor density	lb/ft^3 (kg/m^3)

Table 6-2. Acronyms

ABBD2.0	The NRC approved Westinghouse ABB critical power correlation encoded in the ABBD2.0 thermal hydraulic model.
BWR	Boiling Water Reactor
CPR	Critical Power Ratio defined as the predicted critical power to the actual power of the particular fuel assembly, both evaluated at the same pressure, mass flux and inlet sub-cooling
ECPR	Experimental Critical Power Ratio defined as the GEXL80 calculated critical power divided by the NRC approved ABBD2.0 correlation calculated critical power
ECP	Engineering Computer Program
GESAM	General Electric Statistical Analysis Method ECP
GETAB	General Electric BWR Thermal Analysis Basis
GEXL	GE critical quality-boiling length correlation
GNF	Global Nuclear Fuels
GNF-A	Global Nuclear Fuels - Americas
MCPR	Minimum Critical Power Ratio defined as the minimum CPR for any fuel assembly within a core and is the figure of merit to represent the reactor thermal performance or margin
NRC	Nuclear Regulatory Commission

7. REFERENCES

1. NEDE-10958P-A, General Electric BWR Thermal Analysis Basis (GETAB): Data, Correlation and Design Basis, GE Proprietary Report, January 1977.
2. EMF-2209(P)(A), "ABBD2.0 Critical Power Correlation", Rev. 1, July 2000.
3. NEDC-32505P-A, R-Factor Calculation Method for GE11, GE12, and GE13 Fuel, Revision 1, GE Proprietary Report, July 1999.
4. NFS 03-202, PSG-03-032, Letter from PSEG Nuclear LLC (D. V. Notigan) to GNF (R. E. Kingston), "Transmittal of PSEG Nuclear LLC GEXL80 Comparison Results", dated September 2, 2003.

APPENDIX A. R-Factor Calculation Method

A.1 Introduction

The R-factor is an input to the GEXL correlation that accounts for the effects of the fuel rod power distributions and the fuel assembly and channel geometry on the fuel assembly critical power. Its formulation for a given fuel rod location depends on the power of that fuel rod, as well as the power of the surrounding fuel rods. In addition, there is an additive constant applied to each fuel rod location that is dependent on the fuel assembly and channel geometry. The complete R-factor methodology is documented in Reference 3.

A.2 R-factor Calculation Process

Local two-dimensional fuel rod power distributions vary axially in BWR fuel assemblies due to axial variations in nuclear design, exposure, void fraction and control state. These factors are considered when calculating the axially integrated powers for individual rods. The two-dimensional distribution of integrated rod powers for a bundle is then used to calculate individual rod R-factors. The bundle R-factor for a particular bundle average exposure and control fraction is the maximum of all of the individual fuel rod R-factors. The steps used in the R-factor calculation process are as follows:

1. Obtain relative 2D rod-by-rod power distributions from TGBLA, which are a function of lattice nuclear design, average exposure, void fraction, and control state.
2. [[

   {3}]]
3. Calculate an R-factor for each individual fuel rod. [[{3}]]
4. The bundle R-factor is the maximum value of all individual rod R-factors.
5. Repeat these calculations for each desired bundle average exposure, control fraction and channel bow.

A.3 Bundle Average Axial Distributions

A 25-node axial shape is used to define a bundle axial relative power shape for the purposes of calculating R-factors. This shape is a function of control fraction. Bundle axial void fraction and bundle axial relative exposure shapes are used to determine two-dimensional radial distributions as a function of axial height.

- [[

  {3}]]
- [[

  {3}]]

- The **bundle axial relative exposure shape** is defined as that shape which is consistent with the uncontrolled axial relative power shape assuming uniform fuel density; and
- The **bundle axial void fraction shape** is defined as a shape that is consistent with the uncontrolled axial relative power shape and gives a prototypical bundle average void fraction.

Figure A-1 provides a summary of these normalized axial shapes for SVEA96+ fuel. The corresponding numbers are listed in Table A-2.

[[

{3}]]

Figure A-1. SVEA96+ Axial Shapes for Rod Power Integration (Normalized)

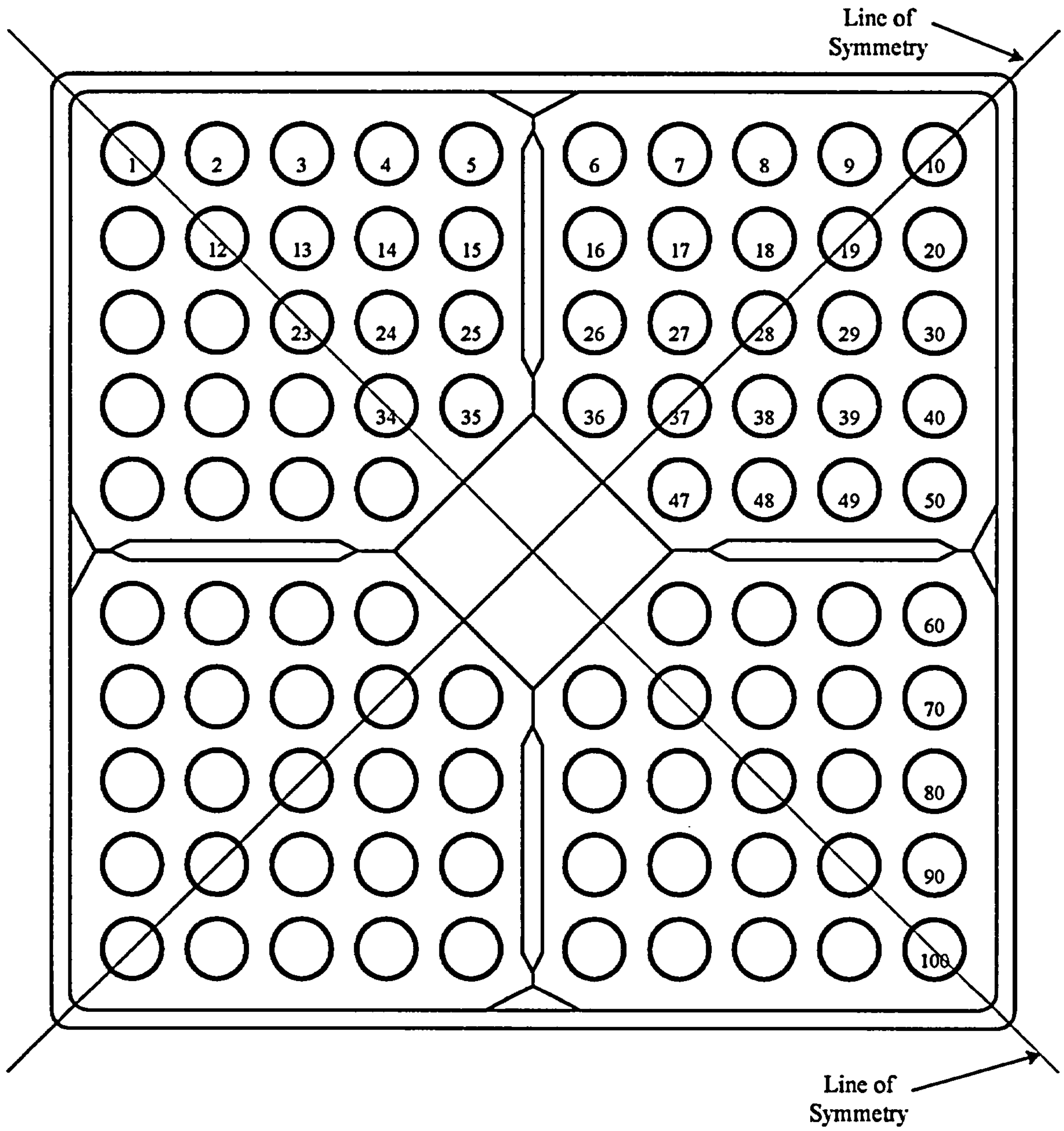

Figure A-2. SVEA96+ Lattice

Table A-1. SVEA96+ Axial Shapes for Rod Power Integration

[[

{3}]]

A.4 R-factor Distribution

[[

[3]]]

A.5 R-factor Calculation Examples

Using the procedures defined in the previous sections, R-factors are calculated for different lattice locations in a bundle as a function of fuel assembly exposure, control state and channel bow using Equation A-1. The following example is for a 10x10 SVEA96+ lattice. The interior positions next to the water cross were treated as being next to the channel (i.e. with a correction factor of 0.0 for adjacent water channel/water wings).

Consider Equation A-1 for the various cases as shown in Figure A-3:

Corner Rod:

Applying Equation A-1 to a corner rod (as in Figure A-3a or A-3g),

---

[1] Subscripts i, j, and k refer to relative rod positions; i-position for which R-factor is calculated; j- position face adjacent to i; and k – position diagonally adjacent to i.

[[{3}]] (A-2)

Side Rod:

Applying Equation A-1 to a side rod (as in Figure A-3b or A-3f),

[[{3}]] (A-3)

Interior Rod:

Applying Equation A-1 to an interior rod (as in Figure A-3c),

[[{3}]] (A-4)

If there is one unheated lattice position (as in Figure A-3d),

[[{3}]] (A-5)

If there are four unheated lattice positions (as in Figure A-3e),

[[{3}]] (A-6)

A summary of the R-factor calculation method for each SVEA96+ lattice position (as identified in Figure A-3) is given in Table A-2.

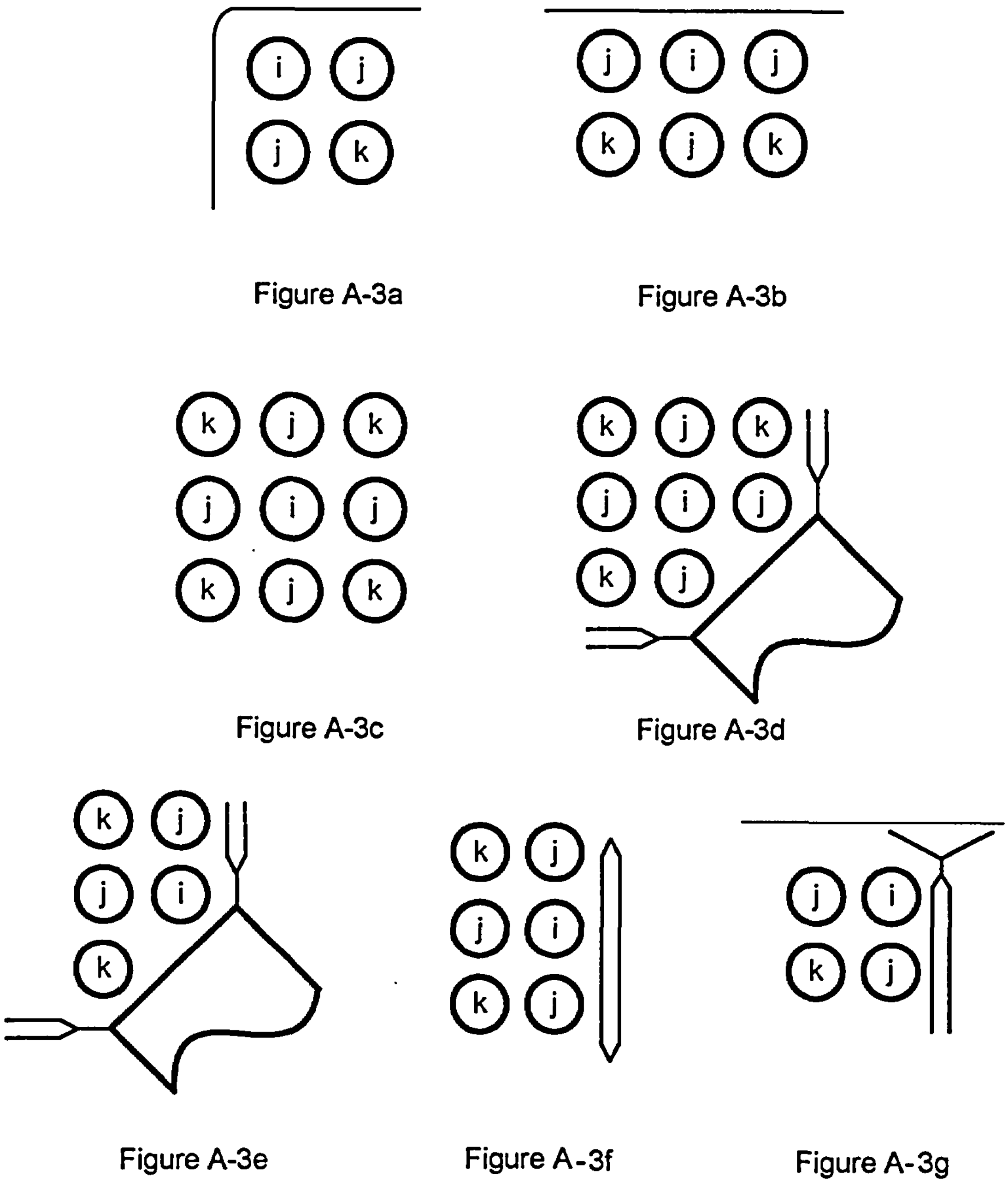

Figure A-3. Identification of Rods in Positions Adjacent to Rod i

Table A-2. R-factor Calculation by Lattice Position

Lattice Position	Apply Figure	Use Equation
(1,1)	A-3a	A-2
(1,2)	A-3b	A-3
(1,3)	A-3b	A-3
(1,4)	A-3b	A-3
(1,5)	A-3g	A-2
(2,2)	A-3c	A-4
(2,3)	A-3c	A-4
(2,4)	A-3c	A-4
(2,5)	A-3f	A-3
(3,3)	A-3c	A-4
(3,4)	A-3c	A-4
(3,5)	A-3f	A-3
(4,4)	A-3d	A-5
(4,5)	A-3e	A-6

A.6 Mini-Bundle Variation Term

[[

{3}]]

[[

{3}]]

Figure A-4. SVEA96+ Flow Versus Power Relationship for Constant Pressure Drop

[[

-

{3}]]

Figure A-5. SVEA96+ Bundle Power to First Order Related to Average R-factor for Rods in Mini-Bundle

[[

-

{3}]]

Figure A-6. SVEA96+ Relative Change in Critical Power vs. Relative Change in Relative Mass Flux

A.7 Fuel Assembly R-factor

The fuel assembly R-factor is determined in accordance with Equation A-8 for any specified fuel assembly exposure, control state and channel bow.

$$R = \overline{\text{Max}}\left[R_i\right] \qquad \text{taken over all } i \qquad \text{(A-8)}$$

APPENDIX B. GNF Response to NRC RAIs Regarding the GEXL80 Correlation

1. **For Tables 3-2 and 3-3, on page 3-3, please provide a 95/95 uncertainty, as well as the upper and lower bounds on these 95/95 values, for each of the power profiles provided in Table 3-3 and for the correlation data bases of Table 3-2.**

Table 3-2. Statistical Summary for SVEA96+ GEXL80

[[

	Total Correlation Database	Development Database	Verificatio Database
Number of data points			
Mean ECPR			
Standard deviation, (%)			
k Value			
95/95 Upper Tolerance Limit ($\mu + k\sigma$)			

{3}]]

Table 3-3. Statistical Summary for Each Axial Power Shape for SVEA96+ GEXL80 Correlation Database

[[

	Axial Power Shape			
	Cosine	Inlet	Outlet	Double Hum
Number of Data Points				
Mean ECPR				
Standard Deviation (%)				
k Value				
95/95 Upper Tolerance Limit (μ kσ)				

{3}]]

Note: The GEXL80 report contained a typo for the Total Correlation Database ([[{3}]]).

2. **On page 4-6, the R-factor is discussed, as accounting for the need to address the "mini-bundle term variation term". The staff does not fully appreciate the methodology developed for calculating the "mini-bundle term", or the so-called "mismatch factor." Please be prepared to derive each of the terms alluded to in the derivation of the final expression for "delta R", provided on page 4-7.**

The SVEA96+ bundle is divided into four mini-bundles by the water cross as shown in Figure 2-1. The four mini-bundles are four parallel flow channels that all are subject to the same pressure drop. If the SVEA96+ bundle has a quadrant symmetric pin power distribution, the four mini-bundles have the same power and they will also have the same mass flux and critical power performance. If, on the other hand, the pin power distribution is not symmetric the four mini-bundles will have different powers. The mini-bundle with the highest power will have the highest vapor generation and, therefore, its two-phase pressure drop will increase relative to the other three mini-bundles. Since the four mini-bundles all have the same pressure drop, the impact of the higher two-phase pressure drop in the hottest bundle must be offset by a reduced inlet flow and a corresponding lower single phase pressure drop. Similarly the mini-bundle with the lowest power will have less vapor generation, less two-phase pressure drop and correspondingly must have a higher inlet flow and higher single phase pressure drop. Therefore the impact of a power mis-match between the four mini-bundles in the SVEA96+ fuel bundle is that the mini-bundle with the highest power has a mass flux that is less than the average for the bundle, and the mini-bundle with the lowest power has a mass flux that is higher than the average. For a mini-bundle a reduction in the mass flux will produce a corresponding reduction in the mini-bundle critical power (critical power is a monotonically increasing function with mass flux).

The GEXL methodology calculates the critical power based on the bundle R-factor and the bundle average mass flux. Using this average mass flux, however, does not account for the lower mass flux in the hottest mini-bundle and the corresponding lower critical power. Therefore an adjustment to the critical power must be developed to account for the impact of any power mis-match between the mini-bundles. The thermal/hydraulic model for the SVEA96+ bundle characterizes the pressure drop as function of power and mass flux. A relationship between power and flow for a constant pressure drop can be derived from this thermal/hydraulic model. Therefore the mismatch in mini-bundle mass flux can be determined for a given mini-bundle power mis-match and average bundle thermal/hydraulic conditions. Since critical power is a monotonically increasing function with mass flux, the mini-bundle mass flux mis-match can be equated to a corresponding reduction in mini-bundle critical power. This reduction in the mini-bundle critical power is then incorporated as a penalty on the R-factor for the mini-bundle.

3. **After reading Section 5.0 of the September 8, 2003, submittal, it is not clear to the staff how the ECPR distribution and the standard mean were obtained. Please provide the technical justification, i.e., the calculations, displaying these results.**

   As stated at the end of Section 5.0, the standard mean was chosen based on the GEXL80 critical power comparison to SVEA96+ dryout test data as determined by PSEG. GNF does not have access to this proprietary study, however, the PSEG recommendation letter (Reference 4 in the GEXL80 document) provides justification for the mean and standard deviation.

4. **On page 5-1, equation 5-1 for the ECPR is provided in the form of a ratio of two correlations, each having unique uncertainty associated with it. As such, these two correlations are not totally independent of each other, since the GEXL80 correlation is derived from a data set generated by a sub-channel code incorporating the ABB2.0 correlation (as alluded to in the 3rd. sentence of the first paragraph on page 5-4). How is the uncertainty of each correlation captured, and the lack off independency between the two correlations accounted for in the overall statistical calculation of uncertainty. Please be specific and detailed in this regard.**

   See response to Question 3 above.

5. **On page A-1, the R-factor calculational process is discussed. In this discussion, the subject of "control state" is raised. Please define the control state.**

   Control state refers to the number of nodes controlled and is used to integrate rod power as indicated in Table A-1.

6. **On pages A-9 to A-10, three figures are briefly discussed. Please be prepared to discuss these same figures in detail.**

   These figures address the 'mini-bundle variation term.' See response to Question 2 above.

7. **Table 3-2. The standard deviation for the Total Correlation Database does not appear to be in agreement with the individual standard deviations of the power profiles in Table 3-3. Also, it is surprising that the standard deviation of the Total Correlation Database is smaller than either the Development or the Verification databases. Please provide the NRC a data disk to enable us to verify the calculations.**

   This observation is incorrect. The standard deviation of the Total Correlation Database [[({3}]] is between the values of the Development [[( ) {3}]] and Verification [[( ) {3}]] databases. To address the agreement of the Total Correlation Database with the individual standard deviations of the power profiles in Table 3-3, the following statistical method is provided in the GEXL Development Technical Design Procedure (TDP-0117).

If the data consists of m sets of data, e.g., m different axial power shapes, correlation statistics can be developed for each set using:

$$\overline{\mathrm{ECPR}_j} = \frac{1}{n_j}\sum_{i=1}^{n_j}\mathrm{ECPR}_i \qquad \sigma_j = \sqrt{\frac{1}{n_j-1}\sum_{i=1}^{n_j}(\mathrm{ECPR}_i - \overline{\mathrm{ECPR}_j})^2} \qquad (1)\ (2)$$

where the summation is over the data in set j.

The following relation exists:

$$\overline{\mathrm{ECPR}} = \frac{\sum_{j=1}^{m} n_j\overline{\mathrm{ECPR}_j}}{\sum_{j=1}^{m} n_j} \qquad \sigma^2 = \frac{\sum_{j=1}^{m}(n_j-1)\sigma_j^2}{\left(\sum_{j=1}^{m} n_j\right)-1} + \frac{\sum_{j=1}^{m} n_j(\overline{\mathrm{ECPR}}_j^2 - \overline{\mathrm{ECPR}}^2)}{\left(\sum_{j=1}^{m} n_j\right)-1} \qquad (3)\ (4)$$

The first term in equation (4) is the average of the standard deviation for the data sets. The second term is the variance of the means for the data sets and represents the trend error in predicting the axial power shape effects.

Use of equation (3) for combining individual ECPR Means from Table 3-3 above:

[[

$$\overline{\mathrm{ECPR}} = \frac{\sum_{j=1}^{m} n_j\overline{\mathrm{ECPR}_j}}{\sum_{j=1}^{m} n_j} =$$

$\overline{\mathrm{ECPR}}$= {3}]]

Use of equation (4) for combining individual uncertainties:

$$\sigma^2 = \frac{\sum_{j=1}^{m}(n_j-1)\sigma_j^2}{\sum_{j=1}^{m} n_j - 1} + \frac{\sum_{j=1}^{m} n_j(\overline{\mathrm{ECPR}}_j^2 - \overline{\mathrm{ECPR}}^2)}{\sum_{j=1}^{m} n_j - 1}$$

First term of equation (4):

[[

$$\frac{\sum_{j=1}^{m}(n_j-1)\sigma_j^2}{\sum_{j=1}^{m} n_j - 1} =$$

= {3}]]

Second term of equation (4) (the combined ECPR mean was calculated above using equation (3)):

$$\frac{\sum_{j=1}^{m} n_j(\overline{\mathrm{ECPR}}_j^2 - \overline{\mathrm{ECPR}}^2)}{\sum_{j=1}^{m} n_j - 1} =$$

[[

{3}]] (More significant digits than shown above for mean ECPR were used in this calculation)

Combining the two terms of equation (4):

[[

{3}]]

Taking the square root:[[σ = {3}]], convert to percent by multiplying by 100, and reduce to two significant digits:

[[σ = {3}]]

Note that the ECPR mean and standard deviation calculated above using equations (3) and (4) are equivalent to those values shown for the Total Correlation Database in Table 3-2.

8. **Table 3-2. Please identify all statistical tests that compare the Development database and the Verification database. Specifically, show such tests for each power profile and for all profiles combined. Please report the outcome of such tests and relevant intermediate steps.**

Shown below are the histograms for the development and verification databases.

[[

{3}]]

The mean and standard deviations for the Development and Verification databases are shown in the response to Question 1 ([[{3}]], respectively). A Two-Tailed Two-Sample T test was completed with a 95% confidence interval where the null hypothesis was H0: $\mu 1 = \mu 2$ and the alternate hypotheis was H1: $\mu 1 \neq \mu 2$, where μ is the population mean.

This hypothesis test yielded P=0.047. The 'P' value represents the probability of rejecting the null hypothesis when it is true. The smaller the P-value, the smaller the probability of making a mistake by rejecting the null hypothesis. In this case (P<0.05), typically the null hypothesis would be rejected and the alternative accepted: the means are not equal. However, in this instance the difference between the means is 0.008, which is insignificant compared to the correlation uncertainty. Thus the null hypothesis is accepted and the means are considered equal since they can not be easily differentiated.

9. **Table 3-2 and 3-3. These tables need to be expanded to include a 95/95 tolerance limit for each database (Total Correlation, Development, and Verification) and for each power profile in the Total Correlation Database.**

   See the response to Question 1 above.

10. **Section 4.2. The report claims that the range of application is valid for pressure [[{3}]] psia. Table 2-2, however, shows that the study uses very few points for which pressure is different from [[{3}]] psia and none for pressure above [[{3}]] psia. The range of application for mass flux is claimed to be valid for [[{3}]] Mlbm/hr-ft^2. Table 2-2 shows that the study uses very few points below [[{3}]] Mlbm/hr-ft^2. The range of application for inlet subcooling is claimed to be valid for [[{3}]] Btu/lbm. Table 2-2 shows that the study uses very few points above [[{3}]] and none below [[{3}]] Btu/lbm.**

    The bulk of the data is collected in the expected operating range for the bundle: [[{3}]] psia,[[{3}]] Mlbm/hr-ft^2, [[{3}]] Btu/lbm. Additional data was collected outside these ranges for trend analyses in the development of the GEXL80 correlation. The additional data was collected at pressures of [[{3}]] psia, mass flux of [[{3}]] Mlb/hr-ft^2, and inlet subcoolings of [[{3}]] Btu/lbm. Trends show that the GEXL80 correlation is well behaved within the database ranges and outside these ranges, specifically where the application ranges have been extended slightly outside the database. The application ranges for GEXL80 are:

    [[

    {3}]]

11. **The paucity of data at the low and high value of the claimed range of applicability needs further elaboration. The extrapolation beyond [[[3]]] psia and below [[[3]]] Btu/lbm is worrisome even in light of the explanation offered in Section 4.2. Note that such extrapolations have not been accepted by the staff in the past.**

The use of "Database" and "data" above refers to calculated hypothetical data points generated using the NRC approved Westinghouse ABBD2.0 correlation, which itself has an underlying experimental database that is proprietary to Westinghouse

The licensee, having access to the proprietary data, must also verify that the application ranges of the calculated hypothetical database **must not exceed** *the upper and lower bounds of the actual experimental database.*

The licensee has directly compared the range of applicability of the GEXL80 correlation to the Westinghouse experimental database. The licensee has verified that the experimental database ranges were not exceeded.

FLN-2004-031

GEXL80 CORRELATION FOR SVEA96+ FUEL

PROPRIETARY CD

FLN-2004-031

AFFIDAVIT

Affidavit

I, Margaret E. Harding, state as follows:

(1) I am Manager, Fuel Engineering Services, Global Nuclear Fuel – Americas, L.L.C. ("GNF-A") and have been delegated the function of reviewing the information described in paragraph (2) which is sought to be withheld, and have been authorized to apply for its withholding.

(2) The information sought to be withheld is contained in the attachment, NEDC-33107P-A, "GEXL80 Correlation for SVEA96+ Fuel," Rev. 1, October 2004. GNF proprietary information is indicated by enclosing it in double brackets. In each case, the superscript notation {3} refers to Paragraph (3) of this affidavit, which provides the basis for the proprietary determination.

(3) In making this application for withholding of proprietary information of which it is the owner or licensee, GNF-A relies upon the exemption from disclosure set forth in the Freedom of Information Act ("FOIA"), 5 USC Sec. 552(b)(4), and the Trade Secrets Act, 18 USC Sec. 1905, and NRC regulations 10 CFR 9.17(a)(4) and 2.390(a)(4) for "trade secrets and commercial or financial information obtained from a person and privileged or confidential" (Exemption 4). The material for which exemption from disclosure is here sought is all "confidential commercial information," and some portions also qualify under the narrower definition of "trade secret," within the meanings assigned to those terms for purposes of FOIA Exemption 4 in, respectively, Critical Mass Energy Project v. Nuclear Regulatory Commission, 975F2d871 (DC Cir. 1992), and Public Citizen Health Research Group v. FDA, 704F2d1280 (DC Cir. 1983).

(4) Some examples of categories of information which fit into the definition of proprietary information are:

a. Information that discloses a process, method, or apparatus, including supporting data and analyses, where prevention of its use by GNF-A's competitors without license from GNF-A constitutes a competitive economic advantage over other companies;

b. Information which, if used by a competitor, would reduce his expenditure of resources or improve his competitive position in the design, manufacture, shipment, installation, assurance of quality, or licensing of a similar product;

c. Information which reveals cost or price information, production capacities, budget levels, or commercial strategies of GNF-A, its customers, or its suppliers;

d. Information which reveals aspects of past, present, or future GNF-A customer–funded development plans and programs, of potential commercial value to GNF-A;

e. Information which discloses patentable subject matter for which it may be desirable to obtain patent protection.

The information sought to be withheld is considered to be proprietary for the reasons set forth in paragraphs (4)a. and (4)b., above.

(5) To address the 10 CFR 2.390 (b) (4), the information sought to be withheld is being submitted to NRC in confidence. The information is of a sort customarily held in confidence by GNF-A, and is in fact so held. Its initial designation as proprietary information, and the subsequent steps taken to prevent its unauthorized disclosure, are as set forth in (6) and (7) following. The information sought to be withheld has, to the best of my knowledge and belief, consistently been held in confidence by GNF-A, no public disclosure has been made, and it is not available in public sources. All disclosures to third parties including any required transmittals to NRC, have been made, or must be made, pursuant to regulatory provisions or proprietary agreements which provide for maintenance of the information in confidence.

(6) Initial approval of proprietary treatment of a document is made by the manager of the originating component, the person most likely to be acquainted with the value and sensitivity of the information in relation to industry knowledge, or subject to the terms under which it was licensed to GNF-A. Access to such documents within GNF-A is limited on a "need to know" basis.

(7) The procedure for approval of external release of such a document typically requires review by the staff manager, project manager, principal scientist or other equivalent authority, by the manager of the cognizant marketing function (or his delegate), and by the Legal Operation, for technical content, competitive effect, and determination of the accuracy of the proprietary designation. Disclosures outside GNF-A are limited to regulatory bodies, customers, and potential customers, and their agents, suppliers, and licensees, and others with a legitimate need for the information, and then only in accordance with appropriate regulatory provisions or proprietary agreements.

(8) The information identified in paragraph (2) is classified as proprietary because it contains details of GNF-A's fuel design and licensing methodology.

The development of the methods used in these analyses, along with the testing, development and approval of the supporting methodology was achieved at a significant cost, on the order of several million dollars, to GNF-A or its licensor.

(9) Public disclosure of the information sought to be withheld is likely to cause substantial harm to GNF-A's competitive position and foreclose or reduce the availability of profit–making opportunities. The fuel design and licensing methodology is part of GNF-A's comprehensive BWR safety and technology base, and its commercial value extends beyond the original development cost. The value of the technology base goes beyond the extensive physical database and analytical methodology and includes development of the expertise to determine and apply the appropriate evaluation process. In addition, the technology base includes the value derived from providing analyses done with NRC–approved methods.

The research, development, engineering, analytical, and NRC review costs comprise a substantial investment of time and money by GNF-A or its licensor.

The precise value of the expertise to devise an evaluation process and apply the correct analytical methodology is difficult to quantify, but it clearly is substantial.

GNF-A's competitive advantage will be lost if its competitors are able to use the results of the GNF-A experience to normalize or verify their own process or if they are able to claim an equivalent understanding by demonstrating that they can arrive at the same or similar conclusions.

The value of this information to GNF-A would be lost if the information were disclosed to the public. Making such information available to competitors without their having been required to undertake a similar expenditure of resources would unfairly provide competitors with a windfall, and deprive GNF-A of the opportunity to exercise its competitive advantage to seek an adequate return on its large investment in developing and obtaining these very valuable analytical tools.

I declare under penalty of perjury that the foregoing affidavit and the matters stated therein are true and correct to the best of my knowledge, information, and belief.

Executed at Wilmington, North Carolina, this 22nd day of October, 2004.

Margaret E. Harding

Margaret E. Harding
Global Nuclear Fuel – Americas, LLC