March 7, 2001

Mr. Glen A. Watford, Manager
Nuclear Fuel Engineering
Global Nuclear Fuel
P.O. Box 780
Wilmington, NC 28402

SUBJECT: REQUEST FOR ADDITIONAL INFORMATION FOR TOPICAL REPORT NEDC-32981-P, "GEXL96 CORRELATION FOR ATRIUM-9B FUEL" (TAC NO. MB0183)

Dear Mr. Watford:

The NRC staff has reviewed Topical Report NEDC-32981P, "GEXL96 Correlation for ATRIUM-9B Fuel," submitted on September 26, 2000, by Global Nuclear Fuel-Americas and concluded that additional information is needed to complete the review. Enclosure 1 contains a request for additional information (RAI) related to the staff's review of NEDC-32981P.

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

If you have any questions, please call me at (301) 415-3016.

Sincerely,

/RA/

Robert Pulsifer, Project Manager, Section 1
Project Directorate I
Division of Licensing Project Management
Office of Nuclear Reactor Regulation

Project No. 710

Enclosure: Request for Additional Information

cc: See next page

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REQUEST FOR ADDITIONAL INFORMATION

TOPICAL REPORT NEDC-32981-P, "GEXL96 CORRELATION

FOR ATRIUM-9B FUEL"

GLOBAL NUCLEAR FUEL-AMERICAS

PROJECT NO. 710

In order to complete the review of GNF-A Report NEDC-32981-P, "GEXL96 Correlation for ATRIUM-9B Fuel," additional information is needed to clarify certain points in the report. In addition, further clarification is also needed in the approach used to determine the overall uncertainty of the GEXL96 correlation for application to ATRIUM-9B fuel.

Questions asking for more information on the ANFB correlation:

1. The overall uncertainty in the critical power predictions of the ANFB correlation for ATRIUM-9B fuel given in Section 5 (p. 5-2) is not the same as the value given for this parameter in the referenced document, ANFB-1125, Appendix E. How was the value that is used in the current submittal determined?

2. How is the additive constant uncertainty (which is part of the overall uncertainty of the ANFB correlation for ATRIUM-9B fuel) included in the overall ECPR uncertainty of the GEXL96 correlation?

3. What is the 'bounding uncertainty' on the ANFB correlation for ATRIUM-9B fuel, as supplied by Comm Ed (referred to in the report Abstract and on p. 5-2)? How was this 'bounding uncertainty' determined? Please describe in detail the process used to determine this bounding uncertainty, including the range of data used, the mean value of the ECPR, and any statistical tests used to define the boundary.

Questions asking for more information on the GEXL96 correlation:

4. In Section 3.2 (page 3-1), the final step in developing the ATRIUM-9B GEXL96 correlation states that the final additive constants "were determined by adjusting the preliminary additive constants such that the difference between the assembly R-factor and the apparent R-factor was minimized." How was this minimization carried out? What was the effect on the mean ECPR for a given assembly (which in the previous step had been fit to a mean ECPR of 1.0 to determine a set of additive constants to define the apparent R-factor for that assembly)?

5. The information presented in Table 3-1 and Figures 3-2, 3-3, and 3-4 is incomplete, in that it does not show the number of data points included in the various groupings and subgroupings of the matrix. For example, for the first assembly listed in Table 3-1 (to collect "Standard Critical Power and Reproducibility Databases"), the number of peaking patterns is listed as "sufficient to develop additive constants for all 12 unique lattice positions." It does not say exactly how many different peaking patterns are considered sufficient for this task. Nor is there information on how many data points were actually

calculated for each peaking pattern, axial heat flux profile, or the various subdivisions in the ranges of pressure, mass flux, and inlet subcooling.

Please supply information on the number of data points for each assembly and their distribution among the various subdivisions of the parameters, using the tabular format shown in Attachment (1).

Also, describe the number of points and the range of parameters considered in calculations for each radial peaking pattern for each 'Collection Type' defined in Table 3-1.

Describe the data sets used to obtain each of the mean ECPR and standard deviation values plotted in Figures 3-2, 3-3, and 3-4. This information should include the number of data points, the collection type(s), axial heat flux shape(s), and peaking pattern(s) represented by each point in these plots.

6. The justification offered in Section 4.2 (page 4-3) for expanding the range of application of GEXL96 beyond the range of its data base (obtained using MICROBURN) is insufficient. The range of the 'data' base is given as 0.2 to 1.5 Mlbm/hr-ft^2, but Section 4.2 (page 4-3) claims an application range of 0.1 to 1.8 Mlbm/hr-ft^2 for GEXL96. The range of R-factors in the data base is given as 0.98 to 1.20, but the range claimed for application of GEXL96 is 0.95 to 1.23. Since these extended ranges also exceed the approved ranges of the ANFB correlation for ATRIUM-9B fuel for these parameters, it is obviously not possible to run the calculations with MICROBURN out over the full range of application for GEXL96. However, extrapolation of a correlation beyond its database is generally an ill-advised procedure, and cannot be permitted without some reasonable approach to quantifying the uncertainty of the correlation's predictions in the extrapolated region(s).

The fit of the GEXL96 correlation to its data base is not uniform, and is biased toward larger uncertainty at the extreme edges of its range. This is because of the design of the data base, which has a large number of points concentrated in the 'normal' operating range--1000 psia, 0.5 to 1.5 Mlbm/hr-ft^2, R-factor from 0.98 to 1.12--and relatively few points at the extremes of the ranges on all parameters. This is typical of databases for critical power correlations, but it guarantees a non-uniform fit of the correlation over the data space, with the largest errors tending to be found at the extremes of the range. The plot of mean ECPR and standard deviation as a function of mass flux, shown in Figure 3-2 (page 3-4) illustrates this problem clearly in the trend of increasing standard deviation with increasing mass flux above 1.0 Mlbm/hr-ft^2. Extrapolating the trend in the standard deviation as well as that of the mean ECPR to a mass flux value of 1.8 suggests that the uncertainty in the GEXL96 correlation in this region could be significantly larger than the overall uncertainty claimed for the correlation in this submittal. The trends are different for the low mass flux data, but the problem of appropriately characterizing the uncertainty for conditions outside the correlation's database exists in this region, as well, and also for the very low (<0.98) and very high (>1.20) R-factor regions.

Please provide a reasonable estimate of the uncertainty of the GEXL96 correlation for ranges of parameters outside its data base, and explain how it will be applied to ensure conservative estimates of critical power in these regions for applications of the GEXL96 correlation to ATRIUM-9B fuel.

Questions on the approach used to determine the appropriate overall uncertainty for predications of the GEXL96 correlation for ATRIUM-9B fuel:

7. In Section 5.0 (page 5-1), the critical quality predictions of the GEXL96 correlation are connected to the critical power performance of ATRIUM-9B fuel by means of the following relationship,

$$ECPR = \frac{Q_{GEXL\,96}}{Q_{ANFB-9B}} = \frac{Q_{GEXL\,96}}{ECPR_{ANFB-9B} Q_{ATRIUM-9B\,data}} \quad (1)$$

In this relationship,

Q_{GEXL96} = critical power predicted by the GEXL96 correlation, as optimized over the 'data' base generated using MICROBURN

$Q_{ANFB\text{-}9B}$ = critical power predicted by the ANFB correlation for ATRIUM-9B fuel, used in MICROBURN to generate the data base for GEXL96

$ECPR_{ANFB\text{-}9B}$ = hypothetical critical power ratio that would be obtained with the ANFB correlation for ATRIUM-9B fuel for an experimental data point at the postulated operating conditions (P, G, ΔH_{sub}, R-factor) for the calculation of a data point with MICROBURN

$Q_{ATRIUM\text{-}9B\ data}$ = hypothetical experimental critical power that would be obtained in an ATRIUM-9B test bundle for an experimental data point at the postulated operating conditions (P, G, ΔH_{sub}, R-factor) for a data point obtained with MICROBURN

By assuming $ECPR_{ANFB\text{-}9B}$ = 1.0 for all conditions considered in the MICROBURN calculations, the above relationship is simplified to

$$ECPR = \frac{Q_{GEXL\,96}}{Q_{ANFB-9B}} = \frac{Q_{GEXL\,96}}{ECPR_{ANFB-9B} Q_{ATRIUM-9B\,data}} = \frac{Q_{GEXL\,96}}{Q_{ATRIUM-9B\,data}} \quad (2)$$

It is asserted that this combined ECPR definition results in a GEXL96 correlation that gives a conservative approximation of the critical power behavior of the ATRIUM-9B fuel, relative to the predictions obtained with the ANFB correlation, "since the ANFB correlation is a conservative fit to the data."

ANFB-1125, Appendix E shows that the fit of the ANFB-9B correlation to its data base has a mean $ECPR_{ANFB\text{-}9B}$ very close to unity, with an essentially normal distribution about the mean. As a result, nearly half the data points have $ECPR_{ANFB\text{-}9B} > 1.0$, while most of the other half have $ECPR_{ANFB\text{-}9B} < 1.0$. The assumption of $ECPR_{ANFB\text{-}9B} = 1.0$ everywhere in the correlation's range of application means that for some conditions the combined ECPR in Eq. (1) will be slightly greater than the corresponding value in Eq. (2), and for other conditions it will be slightly less. This behavior merely reflects the fact that the GEXL96 correlation is a fit to the predictions of the ANFB correlation for ATRIUM-9B fuel, rather than an independent fit to the ATRIUM-9B data. How does the assumption of $ECPR_{ANFB\text{-}9B} = 1$ over the full range of the GEXL96 correlation provide a "conservative" definition of the combined ECPR, since its effect on the combined ECPR may be conservative or non-conservative, depending on the selected conditions in the range of application?

8. In Section 5 (p. 5-1, 5-2), the uncertainty in the combined ECPR is determined from the relationship for the variance of a general function $y = f(x_1,x_2)$,

$$\sigma_y^2 = \left(\frac{\partial f}{\partial x_1}\right)^2 \sigma_{x_1}^2 + \left(\frac{\partial f}{\partial x_2}\right)^2 \sigma_{x_2}^2 + 2\left(\frac{\partial f}{\partial x_1}\right)\left(\frac{\partial f}{\partial x_2}\right)\rho\sigma_{x_1}\sigma_{x_2} \tag{3}$$

It is assumed that the two terms x_1 and x_2 are independent, so that the above relationship simplifies to

$$\sigma_y^2 = \sigma_{x_1}^2 + \sigma_{x_2}^2 \tag{4}$$

However, if the function y is the combined ECPR, the terms x_1 and x_2 are the critical power predictions of the two correlations, denoted Q_{GEXL96} and $Q_{ANFB\text{-}9B}$ respectively. That is,

$$y = f(x_1, x_2) = ECPR = \frac{Q_{GEXL96}}{Q_{ANFB-9B}} = \frac{x_1(A(I), L_B, D_Q, G, P, R(\mathrm{l}_{GEXL96}), L_A, \Delta H_{sub})}{x_2(a_i, L_B, D_e, G, P, R(\mathrm{l}_{ATRIUM-9B}), \Delta H_{sub})} \tag{5}$$

In this relationship, the two functions x_1 and x_2 are not independent, since x_1 is generated by a regression analysis to a data base generated using x_2 The partial derivative of $f(x_1,x_2)$ with respect to x_1 is

$$\frac{\partial f(x_1, x_2)}{\partial x_1} = \frac{\partial ECPR}{\partial x_1} = \frac{\partial (x_1 / x_2)}{\partial x_1} = \frac{1}{x_2}\frac{\partial x_1}{\partial x_1} = \frac{1}{x_2}$$

The partial derivative of $f(x_1,x_2)$ with respect to x_2 is

$$\frac{\partial f(x_1, x_2)}{\partial x_2} = \frac{\partial ECPR}{\partial x_2} = \frac{\partial (x_1 / x_2)}{\partial x_2} = x_1\frac{\partial (1/x_2)}{\partial x_2} = x_1\left(\frac{-1}{x_2^2}\right) = -\frac{x_1}{x_2^2}$$

The variance of the combined ECPR, therefore, is expressed as

$$\sigma_y^2 = \left(\frac{1}{x_2}\right)^2 \sigma_{x_1}^2 + \left(-\frac{x_1}{x_2^2}\right)^2 \sigma_{x_2}^2 + 2\left(\frac{1}{x_2}\right)\left(-\frac{x_1}{x_2^2}\right)\rho\sigma_{x_1}\sigma_{x_2} \tag{6}$$

Even if the covariance term (ρ) is assumed to be zero, the derivatives in the variance equation do not reduce to unity. This shows that the variance equation (Eq. (3)) is inappropriate as a means of defining the overall uncertainty of the combined ECPR.

A rigorous approach to evaluating the uncertainty of a function composed of two related functions would be to use error propagation analysis. This would allow an objective determination of the effect of the ANFB correlation's uncertainty on the uncertainty of the predictions of the GEXL96 correlation. However, the overall uncertainty of each correlation taken separately can be used to determine an estimate of the upper and lower bounds on the combined uncertainty. The fit of the GEXL96 correlation to its data base has some standard deviation, s_{GEXL96} , such that for a given set of conditions, the uncertainty in the predicted critical power can be estimated as

$$Q_{GEXL\,96} = (\overline{ECPR}_{GEXL\,96} \pm s_{GEXL\,96})Q_{ANFB-9B}$$

where $\overline{ECPR}_{GEXL\,96}$ = mean ECPR of the GEXL96 correlation's fit to the data base created using MICROBURN

The ANFB correlation for ATRIUM-9B fuel also has a standard deviation, $s_{ANFB-9B}$, relative to the fit to its data base, such that for a given set of conditions, the uncertainty in the predicted critical power can be estimated as

$$Q_{ANFB-9B} = (\overline{ECPR}_{ANFB-9B} \pm s_{ANFB-9B})Q_{ATRIUM-9B\,data}$$

where $\overline{ECPR}_{GEXL\,96}$ = mean ECPR of the fit of the ANFB correlation for ATRIUM-9B fuel to the ATRIUM-9B database

Substituting the relation for $Q_{ANFB-9B}$ into the relation for Q_{GEXL96} yields a relationship for the bounding uncertainty on the GEXL96 correlation in terms of the uncertainty of its fit to its data base and the uncertainty of the ANFB-9B correlation's fit to its experimental data base. That is,

$$Q_{GEXL\,96} = (\overline{ECPR}_{GEXL\,96} \pm s_{GEXL\,96})(\overline{ECPR}_{ANFB-9B} \pm s_{ANFB-9B})Q_{ATRIUM-9B\,data} \tag{7}$$

Because the two correlations are not independent, their uncertainties multiply rather than combine additively. An estimate of the upper bound on the uncertainty of the GEXL96 predictions of critical power can be obtained by considering the upper limit on the uncertainty of each component, such that

$$Q_{GEXL\ 96|(upper\ bound)} = (\overline{ECPR}_{GEXL96} + s_{GEXL\ 96})(\overline{ECPR}_{ANFB-9B} + s_{ANFB-9B})Q_{ATRIUM\ -9B\ data} \quad (8)$$

The lower bound on the uncertainty for a given set of conditions can be similarly estimated as

$$Q_{GEXL\ 96|(lower\ bound)} = (\overline{ECPR}_{GEXL96} - s_{GEXL\ 96})(\overline{ECPR}_{ANFB-9B} - s_{ANFB-9B})Q_{ATRIUM-9B\ data} \quad (9)$$

Since both correlations have mean ECPR values very near unity, with essentially normal distributions about the mean over their respective data bases, a non-conservative error is as likely as a conservative one. The largest non-conservative error occurs when both correlations are simultaneously at the upper limit of their respective standard deviations. For the mean and standard deviation values reported in the submittal, Eq. (8) yields the following estimate of the upper bound on a GEXL96 critical power prediction;

$$Q_{GEXL96} = 1.060\, Q_{'real'}$$

where $Q_{'real'}$ = the actual critical power in ATRIUM-9B fuel for a given set of conditions

This suggests that the upper bound on the uncertainty of the GEXL96 critical power predictions for ATRIUM-9B fuel could be as high as 6%, or possibly higher, when other sources of uncertainty (such as the additive constant uncertainty) are taken into account. That is, the GEXL96 correlation could overpredict the critical power by 6% or more in ATRIUM-9B bundles for some conditions. This estimate is somewhat higher than the overall uncertainty reported in the submittal for the GEXL96 correlation.

Please provide an estimate of the variance of the combined ECPR that appropriately takes into account the interdependence of the GEXL96 correlation and the ANFB correlation for ATRIUM-9B fuel. The estimate should also take into account the effects of the additive constant uncertainty for both correlations. The approach should provide a conservative estimate of the uncertainty over the entire range of application of the GEXL96 correlation for ATRIUM-9B fuel.

Attachment: Table

Attachment 1:

Format for Table showing number of calculated 'data' points at each Pressure, Mass Flux and Inlet Subcooling, for each axial power shape of each Collection Type (to supply information omitted from Table 3-1 of NEDC-32981P, Rev. 0):

Collection Type	**axial shape**	**Pressure (psia)**					**Mass Flux (Mlbm/hr-ft2)**						inlet subcooling (Btu/lbm)						
		800	**900**	**1000**	**1200**	**1300**	**0.2**	**0.3**	**0.5**	**0.8**	**1.2**	**1.5**	**10**	**20**	**30**	**40**	**60**	80	100
Standard Critical Power and Reproducibility Databases	cosine																		
	bot.pk																		
	top pk																		
Off-Rated Pressure Critical Power	cosine																		
	bot.pk																		
	top pk																		
Low Mass Flux Critical Power	cosine																		
	bot.pk																		
	top pk																		
High R-factor Critical Power	cosine																		
High sub-cooling Critical Power	cosine																		
	bot.pk																		