Westinghouse

Westinghouse Electric Company
Nuclear Fuel
Columbia Fuel Site
P.O. Drawer R
Columbia, South Carolina 29250
USA

U. S. Nuclear Regulatory Commission
Ms. Mary T. Adams
Fuel Cycle Facilities Branch
Division of Fuel Cycle Safety and Safeguards
Office of Nuclear Material Safety and Safeguards
Mail Stop T-8-F-42
Washington, DC 20555

Direct tel: 803-647-3173
Direct fax: 803-695-4146
e-mail: winiarrj@westinghouse.com

Your ref:
Our ref: LTR-RAC-07-02

Subject: Response to Questions on NCS Validation Documented in ADAMS (Accession number is ML063520590)

January 24, 2007

The following responses (contained in Attachment 1) have been prepared in response to your Request for Additional Information concerning criticality safety, specifically in regards to continuing discussions being held to support continued use of the 0.02 Margin of Subcriticality (MoS), as committed to in our Special Nuclear Material license SNM-1107. The questions being answered are docketed in ADAMS under the accession number ML063520590. If there are any questions please contact me at (803) 647 – 3173.

Sincerely,

Ralph Winiarski
Nuclear Criticality Safety Engineering Manager

A. *Provide a summary of the most important factors providing conservatism for the abnormal condition calculations of k-effective for each major process area. Both controlled and uncontrolled parameters should be considered in determining which parameters provide the greatest conservatism. For each of the most significant (in terms of the potential impact on the calculated k-effective) parameters, describe the nominal value of the parameter, the value assumed in facility calculations, and a minimum difference in k-effective resulting from the difference between nominal and as-modeled conditions. It is not necessary to quantify the conservatism in each parameter for every criticality calculation at the facility, but only those providing the largest amounts of conservatism over broad portions of the process.*

The NRC staff has requested that Westinghouse (WEC) provide the following data for each major process area and for each controlled or uncontrolled parameter providing the largest amount of conservatism: 1) the nominal value of the parameter, 2) the value of the parameter assumed in the NCS calculations, 3) the k_{EFF} corresponding to the nominal value of the parameter, and 4) the k_{EFF} corresponding to the value of the parameter assumed in the NCS analyses. Currently, most of these data are not readily available at the CFFF, since quantifying these parameter values and k_{EFF} margins is not required.

Instead, per SNM-1107, calculations are performed for each process area to demonstrate that the calculated k_{EFF} for normal and anticipated upsets is less than 0.95, and that the calculated k_{EFF} for credible abnormal events is less than 0.98. A graded approach is used to meet these criteria, which did not result in calculations of nominal NCS parameters and associated k_{EFF}'s.

Quantification of the conservative margin in k_{EFF} was not deemed of interest for several reasons:

- No benefit was seen in the quantification of k_{EFF} margins between nominal and upset conditions, since the magnitude of a change in k_{EFF} is not indicative of system safety.

- The nominal conditions in most CFFF processes would involve systems that lie outside of the validated area of applicability of the criticality safety codes (e.g., very dry systems, low fissile densities, etc.).

- Calculated k_{EFF}'s for nominal conditions would be much less than 1.0, and current criticality safety codes are not designed to calculate eigenvalues that are significantly different from unity. In other words, the accuracy of calculating k_{EFF}'s much less than 1.0 has not been quantified.

- Identification and quantification of nominal values for all process parameters would require significant effort, since measurement techniques are not currently in place at the CFFF to assess all of these parameters. For most process variables, bounding credible values are assumed in the NCS analyses instead.

Based on the points above, WEC does not believe that the quantification of conservative margin in k_{EFF} would provide any benefit to the plant safety basis, nor provide any meaningful insight into actual safety margins at the Columbia Fuel Fabrication Facility (CFFF). Finally, WEC estimates that the quantification of these data would require significant effort, and would delay other safety initiatives at the CFFF.

Further, it is not expected that there are any specific conservatisms that are broadly applicable over large areas of the plant, in terms of specific parameter or magnitude of k_{EFF} margin. For example, many systems assume optimal moderation, which is generally a very conservative assumption. However, the nominal moderation ratio for these systems varies widely, and thus the margin in k_{EFF} varies. And, in some cases, optimal moderation is the expected condition, which means that assuming it adds no extra conservatism.

B. *Provide a description of all areas in your facility which have a calculated abnormal condition k-effective value (including uncertainties) exceeding 0.96. Provide sufficient information for the staff to understand the physical configuration of these systems.*

Currently, the calculated 95/95 k_{EFF}'s for all modeled configurations in the plant (as well as detailed descriptions of the configurations modeled) are not maintained in a single list. Rather, these configurations are described in detail in ~150 individual calculation notes. It would take several weeks, at least, to go through each of these documents, extract the bounding k_{EFF}'s, and write up a detailed description of each configuration exceeding 0.96.

Further, many of the favorable geometry vessels in the plant were designed to a criterion of 0.98, and most single parameter limits in use at the site are based on a criterion of 0.98. Given that it is estimated that many, if not most, of the abnormal scenarios modeled in these calculation notes document 95/95 k_{EFF}'s in excess of 0.96, WEC does not believe that this effort would provide any significant benefit.

Instead, WEC believes that a site visit to Columbia and discussion with on-site nuclear criticality safety specialists would be an alternate approach for satisfying this request.

C. *With regard to report LTR-ESH-05-440, submitted September 8, 2006, explain why Rev. 1 to this document changed the calculated variable from the fission fraction (as requested in our August 10, 2006, RAI) to the weighted incident neutron energy causing fission (WINECF). Provide results in terms of the thermal, intermediate, and fast fission fraction. In addition, calculate trends in the bias as a function of the thermal, intermediate, and fast fission fractions, and display the results in graphical form. Justify whether the existing Upper Subcritical Limit is still valid (as also requested in our RAI).*

The calculated variable was changed from fission fraction to the weighted incident neutron energy causing fission because there is no dependence between fission fraction and k_{EFF} that would enable trends in the bias to be calculated as a function of thermal, intermediate, and fast fission fractions.

The only edit available in SCALE 4.4a (the code version currently benchmarked for use at the Westinghouse Columbia Fuel Fabrication Facility (CFFF)) that would allow one to investigate the fission fraction for a given calculation is fission fraction as a function of energy group. Since the 238-Group ENDF library is used for calculations at the Westinghouse CFFF, each critical experiment calculation results in 238 fission fraction data points. The 238 fission fraction data points are all relative to a single k_{EFF}. Fission fraction, alone, relative to k_{EFF} is meaningless. For instance, in one calculation, over 90% of the fissions occur from incident neutrons in the thermal energy range. This result gives one the information necessary to conclude the system under review is thermal, but it doesn't provide a dependent relationship to k_{EFF} that would allow analysis for a trend in the calculation bias to be performed.

The fission fraction as a function of energy group data may be used to determine the most probable energy group causing fission. The most probable energy group causing fission is a single data point for each broad energy range (thermal, intermediate, and fast) that may be linked to the k_{EFF} for the system under review. However, because the 238-group energy fine structure is relatively large and the critical experiments under consideration are neutronically very similar, little useful information may be collected using the most probable energy group causing fission. For the experiments considered in LTR-ESH-05-440, the most probable energy group causing fission for each broad energy range investigated was identical. The only conclusion that one could draw from the most probable energy group causing fission is that the experiments have similar neutronics which one would expect from the H/X ratio for each.

The weighted incident neutron energy causing fission is an attempt to calculate a rough average neutron energy causing fission, from the fission fraction as a function of energy group, for each broad energy range investigated (thermal, intermediate, and fast). To obtain the fission fraction weighted energy causing fission for the thermal, intermediate, and fast energy groups, 238 discrete energy values are first selected. The midpoint energy for each energy group is chosen to represent the neutron energy causing fission within that energy range. For example, the energy range for energy group 225 is 1.0x10-2 eV to 2.53x10-2 eV, and the midpoint for the range is 1.77x10-2 eV. The energy range midpoint is then weighted using the normalized fission fraction for that energy range. The weighted energy range midpoints are summed within each broad group (thermal, intermediate, and fast) to give the fission fraction weighted energy causing fission for the thermal, intermediate, and fast energy groups. Three data points are created for each critical experiment investigated: one for the thermal, one for the intermediate, and one for the fast energy groups. For each broad energy data point, an ordered pair is formed with the k_{EFF} for the experiment under investigation. The ordered pairs for all experiments are collected according to broad energy range and three separate graphs are generated. The graphs represent the rough average neutron energy causing fission for the thermal, intermediate, and fast energy groups. Since a relationship has been established between the rough neutron energy causing fission within each broad energy group and k_{EFF}, trends in the bias can be investigated.

D. *With regard to report LTR-ESH-05-440, submitted September 8, 2006, explain how some solid benchmark experiments, and all solution benchmark experiments, can have a calculated value of the WINECF for the fast range below 105 eV. This is the lower limit of the fast energy range, so it does not appear mathematically possible to calculate fast energy values below this threshold.*

A mistake was made in calculating the weighted neutron energy causing fission. Instead of weighting the energy range midpoints with the normalized fission fraction for each broad energy range and summing, the raw fission fraction data was used. This resulted in lower results for rough average neutron energy causing fission. Because the raw fission fraction data in the high energy range is so small, the results were actually less than the cutoff boundary for the fast energy range. Using the normalized fission fraction data corrects this problem.

E. *With regard to report LTR-ESH-05-440, submitted September 8, 2006, explain how the conclusions regarding the lack of trends in the bias as a function of WINECF are consistent with the results in Figures 3 and 6 of the validation report. Figure 3 of the validation report concludes that there is a slight trend in k-effective as a function of the energy of average lethargy causing fission (EALF) for solid benchmark experiments. Because all of the EALF values for these benchmark experiments lie within the thermal range, this graph should be very similar to the thermal WINECF graph in LTR-ESH-05-440. However, Figure 3 of the validation report showed a slight trend, whereas the licensee concluded in LTR-ESH-05-440 that there is no trend in the thermal WINECF.*

Similarly, Figure 6 of the validation report showed a strong trend in the bias as a function of EALF for solution benchmark experiments. Because all of the EALF values for these benchmark experiments lie within the thermal range, this graph should be very similar to the thermal WINECF graph in LTR-ESH-05-440. However, Figure 6 of the validation report showed a strong trend, whereas the licensee concluded in LTR-ESH-05-440 that there is no trend in the thermal WINECF.

Trend lines are drawn on the various figures to illustrate the potential trends examined. None of the displayed trend lines have acceptable goodness-of-fit parameters (R^2). Additionally, the trends from one potential data correlation clearly conflict with the trends in other correlation attempts. Therefore, the displayed trends lines are judged to be meaningless, and the conclusion is that the data are not correlated.

For Figure 3 of the validation report, it appears that the reviewer is looking at a graph, seeing a best fit curve, and concluding there is a slight trend without considering the coefficient of determination (R^2) or the summary text written in support of Figure 3. The R^2 value for Figure 3 is 0.0115. As stated in the validation report, an R^2 value less than 0.3 is considered to indicate no data correlation, while an R^2 value of 0.8 or greater is indicative of data correlation. The R^2 value for Figure 6 in the validation report is 0.5698. For R^2 values between 0.3 and 0.8, an engineering judgment must be made as to data correlation. As stated in the validation report text supporting Figure 6, examining the data reveals a smooth function does not exist for Figure 6. In fact, points with identical abscissa values are found with k_{EFF} values differing by as much as 1% Δk. Therefore, data correlation for Figure 6 is not established.

Since it was concluded that data correlation was lacking for both Figures 3 and 6 in the validation report, it is consistent with the conclusions drawn from graphs derived using the WINECF information in LTR-ESH-05-440.

F. *Provide a license commitment to evaluate the hydrogen-to-fissile isotope (H/X) ratio and the EALF value in conjunction when determining whether future calculations lie within the validated area of applicability.*

The NRC staff noted that the WEC validation analyses performed for homogeneous, hydrogenous, low-enriched, well-moderated uranium systems for the SCALE criticality computer code yield calculated k_{EFF} data points that all fall on a narrow band of EALF vs. H/X ratio. When NRC staff asked about this phenomena, WEC described that it was expected since EALF and H/X are not independent variables in the type of systems covered by the validation and are thus very well correlated (i.e., as moderators increase in a system, average neutron speed decreases).

The NRC staff questioned if there could be hypothetical scenarios where this relationship between EALF and H/X did not occur. WEC responded that physics would not allow any critical configuration where this relationship did not hold, as long as the parameters of the system fell within the established areas of applicability (AOAs) for H/X and EALF as defined in the validation report.

NRC responded by suggesting several hypothetical configurations that they believed could potentially violate this relationship. WEC performed explicit criticality analyses of these configurations and demonstrated that none of them violated the relationship between EALF and H/X, as long as both parameters were within the established AOA.

Given that WEC has provided a great deal of supporting evidence regarding the relationship between EALF and H/X, and given that WEC is committed to demonstrating that any modeled systems fall within the AOA of an appropriate validation analysis (including EALF and H/X), WEC does not believe that any additional, coincident evaluation of H/X and EALF is warranted.

G. *With regard to report LTR-ESH-06-239, submitted September 8, 2006, explain how the results are consistent with those from the validation report. Figures 5 and 6 of the validation report show that k-effective has a negative slope as a function of H/X and a positive slope as a function of EALF, for solution benchmark experiments. However, the H/X coefficient for these benchmark experiments in Table 1 of LTR-ESH-06-239 is positive, and the EALF coefficient is negative. This appears to be the opposite of the trends shown in the validation report.*

In addition, the relationship between H/X and EALF is:

$$EALF = 18.039\ (H/X)^{-0.8875}$$

The regression fit for solutions is:

$$k_{EFF} = 0.985 + 2.0117E\text{-}5\ (H/X) - 4.0056E\text{-}2\ (EALF)$$

Substituting the first equation into the second gives an expression for how quickly k_{EFF} varies as a function of H/X when constrained to the H/X-EALF curve:

$$k_{EFF} = 0.985 + 2.0117E\text{-}5\ (H/X) - 0.7226\ (H/X)^{-0.8875}$$

This function has a minimum value of ~0.92 at the lower range of H/X, which, if correct, would challenge the validity of the USL in this region of the area of applicability. The analysis does not address this. Explain how this result is consistent with the USL determined in the validation report, or else revise your USL to account for this trend.

First, trend lines are drawn on the various figures to illustrate the potential trends examined. None of the displayed trend lines have acceptable goodness-of-fit parameters (R^2). Additionally, the trends from one potential data correlation clearly conflict with the trends in other correlation attempts. Therefore, the displayed trends lines are judged to be meaningless, and the conclusion is that the data are not correlated. For example, the average sum of the squares of the calculation and experimental k_{EFF} uncertainties of solution data set is 0.0004 (1 sigma). A least squares linear fit through the solution k_{EFF} vs EALF data has a positive slope and a sum of the error squares of 0.0018. The multi-variant fit has a negative EALF coefficient and a sum of the error squares of 0.0013. However, because the two fits differ by the uncertainty in the k_{EFF} values, it is not possible to judge one fit as being more correct than the other.

Additionally, the positive slope of the solution k_{EFF} vs EALF data linear fit is physically incredible because other experimental data (e.g., the solids) with higher EALF values lie nowhere near an extrapolation of this line.

Second, WEC believes an arithmetic error was made in generating this question. When the solution minimum H/X value (450) is substituted into the NRC modified solution equation a value of 0.99 is obtained.

Third, the bias and bias uncertainty for the solution USL is evaluated per NUREG/CR-6698 using the single-sided lower tolerance technique to yield a conservative value for uncorrelated data. This is our justification for the validity of the USL.