Responses to Supplemental Requests for Additional Information As Discussed During the NRC Audit of Westinghouse Topical Report WCAP-17794-P/ WCAP-17794-NP, Revision 0, "10x10 SVEA Fuel Critical Power Experiments and New CPR Correlation: D5 for SVEA-96 Optima3" (Non-Proprietary)

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Responses to Supplemental Requests for Additional Information As Discussed During the NRC Audit of Westinghouse Topical Report WCAP-17794-P/ WCAP-17794-NP, Revision 0, "10x10 SVEA Fuel Critical Power Experiments and New CPR Correlation: D5 for SVEA-96 Optima3"

Responses to Requests for Additional Information (RAI) for WCAP-17794-P/ WCAP-17794-NP, Revision 0, were provided by Westinghouse in LTR-NRC-16-53 (Reference 1). After review, the NRC determined that several of the RAI responses remained unresolved. Supplemental RAIs were provided in Appendix A of the NRC Audit Plan (Reference 2), and by NRC letters (References 3 and 4).

The following RAIs were either indicated in Appendix A of the Audit Plan to be resolved, or were resolved through discussion during the audit (held March 21-23, 2017), with no further information to be submitted:

RAI-SNPB-01	RAI-SNPB-12	RAI-SNPB-21	RAI-SNPB-27
RAI-SNPB-02	RAI-SNPB-13	RAI-SNPB-22	RAI-SNPB-30
RAI-SNPB-05	RAI-SNPB-14	RAI-SNPB-23	RAI-SNPB-31
RAI-SNPB-08	RAI-SNPB-15	RAI-SNPB-24	RAI-SNPB-32
RAI-SNPB-10	RAI-SNPB-16	RAI-SNPB-26	RAI-SNPB-35
RAI-SNPB-11	RAI-SNPB-19		

For the unresolved RAIs, additional information is provided in this submittal, as agreed at the NRC audit, with the exception of RAI-SNPB-36 for which a response will be provided at a later date.

References:

1. Westinghouse Letter to U.S. NRC, LTR-NRC-16-53, "Responses to NRC Request for Additional Information for Westinghouse Electric Company Topical Report WCAP-17794-P/WCAP-17794-NP, Revision 0, '10x10 SVEA Fuel Critical Power Experiments and New CPR Correlation: D5 for SVEA-96 Optima3' " (Proprietary/Non-Proprietary), dated August 8, 2016.

2. U.S. NRC Audit Plan, "U. S. Nuclear Regulatory Commission Audit For Westinghouse Electric Company Topical Report WCAP-17794-P, Revision 0, and WCAP-17794-NP, Revision 0, '10x10 SVEA Fuel Critical Power Experiments and New CPR Correlations: D5 For SVEA-96 Optima3' (TAC NO. MF3368)."

3. U.S. NRC Letter, Ekaterina Lenning to James A. Gresham, "Request for Additional Information Re: Westinghouse Electric Company Topical Report WCAP-17794-P, Revision 0, and WCAP-17794-NP, Revision 0, '10x10 SVEA Fuel Critical Power Experiments and New CPR Correlation: D5 For SVEA-96 Optima3' (TAC No. MF3368)," November 21, 2016.

4. U.S. NRC Letter, Ekaterina Lenning to James A. Gresham, "Request for Additional Information Re: Westinghouse Electric Company Topical Report WCAP-17794-P, Revision 0, and WCAP-17794-NP, Revision 0, '10x10 SVEA Fuel Critical Power Experiments and New CPR Correlation: D5 For SVEA-96 Optima3' (TAC No. MF3368)," May 15, 2017.

[ ]^{a,b,c}

In general, the preferred way to handle non-conservative sub-regions of a CPR correlation is to apply a special treatment of those sub-regions in the evaluation of the SLMCPR, i.e. by imposing a non-zero bias and possibly a higher standard deviation error on the CPR of the affected rods. This has the advantage that it preserves important mathematical properties of the correlation function itself, i.e. that it is continuous and differentiable.

In the present case the non-conservative effect is relatively small **[ ]^{a,c}** and affects non-limiting fuel bundles that are not contributing with any significance to the SLMCPR. Hence, the added administrative work would complicate the SLMCPR evaluation process with limited safety value added. Rather than complicating the SLMCPR process in this case, Westinghouse would **[**

]^{a,c}

RAI-SNPB-04 Supplement

Westinghouse discussed the differences in flow areas between the test channel and the fuel bundle. The flow area of the test channel is slightly smaller than that of the fuel bundle [ ]^{a,c} This mostly due in the corners where the water cross walls are welded to the outer channel section. They confirmed that the inner dimensions of the channel and the rod pitch are not impacted. However, why the total impact on the entire bundle flow area was only [ ]^{a,c} It seems that this localized chance would have a dramatic impact on the local flow area near the water cross corners where the weld exists. This was not addressed in the RAI response. Please address this issue.

Response

The flow area of the FRIGG channel is approximately [ ]^{a,c} smaller than the nominal flow area of a production channel. This difference results from roughly equal contributions of the following three aspects:

- Slightly smaller dimension of the FRIGG channel (but within tolerances of the production channel). This difference is at the limit of what can be measured.
- Slightly larger cladding OD of the FRIGG heater rods (but within cladding tolerances of production rods).
- The SVEA channel has dimples at regular intervals where the outer channel is welded to the cross. The areas between the dimples form openings for flow communication (pressure equalization) between the sub-channels. See the figure below. On the other hand, the FRIGG channel has the same cross section geometry along the entire length of the channel, corresponding to the elevations of the dimples.

[ ]^{a,c}

The [ ]^{a,c} reduction in flow area of the FRIGG channel versus nominal dimensions leads to a reduction in critical power of [ ]^{a,c} on average, when considering the entire FRIGG Optima3 database. The bias is accounted for in the fitting of the D5 CPR correlation through its dependence on mass flux as input variable. The variations in manufacturing outcome for the production channel are accounted for [ ]^{a,c} in the SLMCPR evaluation. Including dimples along the entire length of the FRIGG channel is the conservative choice since it reduces performance locally (of Rods 5 and 21, see figure above).

RAI-SNPB-06 Supplement

After testing, Westinghouse identified an axial shift in a number of grid spacers. Westinghouse provided some analysis of this spacer shift, but did not fully address the issue; therefore additional information was requested in RAI-SNPB-06. In their response, Westinghouse provided a more detailed description of the spacer shift. [

]^{a,c} Westinghouse used a separate subchannel code to calculate the impact of the spacer shift and determined it was on the order of [ ]^{a,c} in CPR. They further stated that the dryout would occur at multiple elevations at the same time, thus demonstrating that the decreased grid span had minimal impact on the CPR.

However, Westinghouse did not provide evidence which demonstrated how often the TC in this grid span did register dryout coincident with other gird spans. Nor did Westinghouse demonstrate test repeatability during the test program which focused specifically at this elevation, which would also show that the experimental error did not increase due to the grid span shift. Please provide the evidence and demonstrate test repeatability.

Response

The question of spacer shifts concerns the cosine test campaign only.

The frequency of thermocouples registering dryout at Spacer 2, coincident with thermocouples at other elevations, is [ ]^{a,c} during the cosine test.

Repeated data points at nominal pressure and subcooling, and with uniform radial power distribution, are shown in the following figure with labels indicating dryout elevation. These are the same data points that were presented in the initial RAI response. No bias or trend is observed in the CPR error for dryout registered by thermocouples at Spacer Level 2 (Sp2). This shows that no significant change in dryout performance occurred in the span between Spacers 2 and 3 during the cosine test.

Furthermore, if there were a systematic increase in the measured critical power performance at Spacer 2 caused by spacer movement either before or during the test, this would appear as a more negative CPR error for this data subset. The CPR error for the entire cosine database is [ ]^{a,c} i.e. the calculated critical power is [ ]^{a,c} than the measured critical power. When considering only the data points with dryout registered at Spacer 2, the CPR error is [ ]^{a,c} Hence, the measured performance at Spacer 2 is actually slightly worse than expected from dryout registered at other elevations.

[ ]a,b,c

[

]a,c

RAI-SNPB-07 Supplement

Needs to be discussed.

Response

Supplemental information on the radial power distribution testing procedure followed during each test campaign (i.e. for each axial power shape) at FRIGG is given below.

[

]a,c

RAI-SNPB-09 Supplement

May be resolved, needs explanation and further discussion.

Response

[

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[ ]a,b,c

RAI-SNPB-03 Supplement

[

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Response

This is a combined response to RAI-SNPB-03 and RAI-SNPB-37.

The two RAIs mention in total 8 different sub-regions that are all part of the greater sub-region defined by the condition R > 1.1. Westinghouse agrees with the observations of potential non-conservative CPR biases and standard deviation errors for those sub-regions. The CPR biases range from [ ]^{a,c} The standard deviation errors range from [ ]^{a,c}

In the following, the importance of conditions with R > 1.1 are discussed in terms of their possibility of challenging the core minimum CPR (and thereby the SLMCPR). The bundle design optimization process seeks to minimize the R-factor (i.e. maximize CPR) at the time when Gd has almost entirely depleted and the bundle reaches its peak reactivity (k_{inf}) and lowest CPR margin. This occurs near the end of the first cycle or beginning of the second cycle. An example of a resulting R-factor distribution as a function of burnup is shown in the following figure for the case where the control rod is fully withdrawn. Conditions of R > 1.1 are, by design, avoided for a CPR limiting bundle since it would otherwise degrade CPR margins. The conditions that could yield R > 1.1 are situations with a strong lateral power tilt across the sub-bundle caused by a deeply inserted control rod or a skewed distribution of Gd rods during early depletion. The latter would require a quite extreme Gd design outside normal applications. In both cases the power of the affected sub-bundle (with R > 1.1) is suppressed to an extent that the CPR is normally far from being limiting for the core.

RAI-SNPB-17 Supplement

RAI-SNPB-17 has not been resolved. In their response to RAI-SNPB-17, Westinghouse discussed how the variation in the D5 CPR prediction between similar tests was used to determine the uncertainty of the measured CPR value. However, that variation does not separate out the repeatability (i.e., uncertainty) of the experimental facility. Instead, it convolutes that repeatability with other uncertainties in the D5 model. Therefore, Westinghouse should provide an assessment of the repeatability of the experimental facility (taking into account the inability to obtain exact repeat test points) and demonstrates this test repeatability is small compared to the uncertainty in the D5 model.

Response

Repeat tests were performed at [ ]^{a,c} subcooling, and at specific flow levels. The radial power distribution was as close to [ ]^{a,c} The repeat points were taken at very similar conditions, but to account for any small deviations, a comparison of CPR is more appropriate than comparing the measured critical powers directly.

For each pair of repeated test points, the relative difference in CPR was calculated as $(CPR_1-CPR_2)/((CPR_1+CPR_2)/2)$. The standard deviation of this quantity was estimated from the sample of [ ]^{a,c} Treating CPR_1 and CPR_2 as independent random variables with the same (relative) standard deviation, σ_{CPR}, the latter can be estimated to be [ ]^{a,c} Since nearly identical input conditions were used in the CPR correlation, the derived standard deviation of [ ]^{a,c} is considered representative of (only) the experimental uncertainty.

As an alternative to the above method, the standard deviation of the relative difference, $(Q_1-Q_2)/((Q_1+Q_2)/2)$, in measured critical powers was calculated for the pairs of repeated test points. The result is [ ]^{a,c} Again, treating Q_1 and Q_2 as independent random variables with the same (relative) standard deviation, σ_Q, the latter can be estimated to be [ ]^{a,c}

The fact that σ_{CPR} and σ_Q are nearly equal confirms that the variation in the test conditions between repeated test points is small. Hence, both σ_{CPR} and σ_Q can be taken as representative of the experimental uncertainty on critical power which indeed is [ ]^{a,c} as stated in Section 3.5.

RAI-SNPB-18 Supplement

RAI-SNPB-18 has not been resolved. In response to RAI-SNPB-18, Westinghouse discussed how the heat losses were determined, but did not discuss how the heat losses were accounted for in terms of impacting the measured critical power value. Also, Westinghouse did not discuss how heat losses are impacted by changing powers in the test assembly.

Response

The following heat losses were experimentally determined after the latest upgrade of the FRIGG loop and have since then been applied generically:

[ ]^{a,c}

The heat losses are applied directly to the measured critical power, thus reducing it by [ ]^{a,c}

As part of FRIGG procedures a heat balance test is performed before each test campaign to verify applicability of the above values. The conditions are:

- Inlet temperature: [ ]^{a,c}
- Pressure: [ ]^{a,c}
- Variation of power levels

An example test matrix which was applied at the beginning of the cosine test campaign for SVEA-96 Optima3 is shown below. It covers a variation in outlet temperatures between [ ]^{a,c}

[ ]^{a,c}

RAI-SNPB-20 Supplement

Please explain the answer to the NRC staff.

Response

The global I_2 parameter used for CPR prediction is defined in Equation (5-3.6) in WCAP-17794-P. The local I_2 parameter used for dryout location prediction is defined in Equation (5.4-1). In both cases, Equation (5.3-2) is solved iteratively to determine CPR or axial location, respectively.

RAI-SNPB-25 Supplement

NRC staff would like to discuss it further to understand why [
]^{a,c}

Response

In general, the critical quality (x_{crit}) is a monotonically decreasing function of mass flux. In the limit of zero mass flux, i.e. pool boiling with vertical heated walls, critical quality corresponds to complete boiling of the coolant and hence $x_{crit} = 1$. In the case of high mass flux, high heat flux is required and the CHF mechanism changes from annular film dryout to steam blanketing (DNB-type) which corresponds to a much lower quality.

RAI-SNPB-28 Supplement

Needs further discussion to confirm that this RAI is resolved.

Response

Concerning sparse sub-regions in the mass flux (G) versus R-factor plane (Figure 4-8 in WCAP-17794-P), it is worth noting that empirically it has been shown (not only with the present data, but also in previous tests) that the [

]^{a,c}

RAI-SNPB-29 Supplement

NRC staff would like to review a plot of the distributions. NRC staff would like to hear explanation and see data that explains what is happening at low I2's (staff's concern is that there is something happening vs. power shape).

Response

The distributions (histograms) of CPR error are given separately for each axial power profile in the following figures, along with a plot of CPR error versus I_2. The error distribution for the top-peaked power shape shows no degraded behavior, i.e. it follows a normal distribution with no visible skewness or abnormal behavior in the tails.

a,b,c

[ ]

[ ]a,b,c

RAI-SNPB-33 Supplement

Needs further discussion to confirm that this RAI is resolved.

Response

Westinghouse clarifies that limiting transients have been modeled with the Westinghouse BISON code and forcing functions for the FRIGG tests have been chosen based on those simulated data.

RAI-SNPB-34 Supplement

NRC staff needs more detailed discussion.

Response

In general, the DNB correlations developed for PWR safety analysis are code-dependent. This is because they are developed locally at the sub-channel level where lateral mass, momentum and energy transfer models are needed. These models can be complex and can significantly vary from code to code. Hence, potential variations in DNB correlation performance (and statistics) are expected.

In the case of BWR safety analysis, the critical quality correlations, along with the associated calculations of critical power and CPR, depend only on boundary conditions and primary parameters averaged over the assembly (or sub-assembly) cross-section. The individual rod performances are assessed empirically using the R-factor model. Under steady-state conditions, these primary parameters (in fact, only the axial distribution of quality is needed since the flow is constant) come from the steady-state one-dimensional two-phase mixture energy balance, which does not make use of constitutive models and is hence code-independent. The boundary conditions are input to the correlation.

The power-to-coolant, in steady-state, comes directly from the assembly power, regardless of the rod-to-coolant heat transfer coefficient which affects only the rod temperature at equilibrium.

Only negligible variations between different implementations could occur due to differences in nodalization and water property tables.

(NEW) RAI-SNPB-37

An analysis of the data [

]a,c

Response

The response to RAI-SNPB-37 has been combined with the response to RAI-SNPB-03. See the response to RAI-SNPB-03.