Responses to the Requests for Additional Information Received on WCAP-16500-P Supplement 2/WCAP-16500-NP Supplement 2 "Evolutionary Design Changes to CE 16x16 Next Generation Fuel and Method for Addressing the Effects of End-of-Life Properties on Seismic and Loss of Coolant Accident Analyses" (Non-Proprietary)

November 2015

Westinghouse Electric Company
1000 Westinghouse Drive
Cranberry Township, PA 16066

RAI 1. VIPER Loop Testing

Provide justification that the VIPER loop test conditions (e.g. temperature, flow rate, water density, test duration) are representative of those that an assembly would experience in a typical reactor. Also, provide support for the conclusion that double dimple cells do not decrease the Grid to Rod Fretting (GTRF) margin in the outermost inner grid strap locations.

Response:

The VIPER loop test temperature is [ ]^{a,c}, so the temperature effect on the material fretting wear is [ ]^{a,c} of that an assembly would experience in a typical reactor. As stated in Section 2.5.5 of WCAP-16500-P-A and the response to RAI 4b on WCAP-16500-P-A, fretting wear evaluations for the CE 16x16 NGF are performed using [ ]^{a,c}. To date, the relative performance in reactor has been consistent with the relative wear from the VIPER tests for designs with field experience.

As stated in the response to RAI 4b for WCAP-16500-P-A, the wear depth for a given grid design is dependent on the contact surface geometry. Double dimple cells have the same support features and contact surface geometry as the other cells – six point supports, two dimples on two sides and two springs on the other two sides. Since the support features are the same, it was expected that wear from the dimples with smaller spacing would be similar to the typical CE 16x16 NGF dimple pair. This was confirmed in the VIPER test with two CE 16x16 NGF assemblies.

RAI 2. Combined Effects on Grid to Rod Fretting Margin

WCAP-16500-P, Supplement 2, states that the decrease in GTRF margin from [ ]^{a,c} is "mitigated" by the increase in GTRF margin from the Modified Outer Strap (MOS).

a. *What is the net effect of both changes on the GTRF margin?*
b. *If a net decrease in GTRF margin is present, how will this decrease affect safety analyses and compliance with design criteria?*

Response:

a. For the rod support features that are unchanged from the current 16x16 NGF design, the net effect of both changes on GTRF margin is a slight decrease. However, the feature with the limiting GTRF margin for the current 16x16 NGF design,

[ ]^{a,c} has been eliminated so the overall GTRF margin for the fuel assembly has increased.

b. The minor changes in GTRF margin have no impact on safety analysis and the design still meets Westinghouse design criteria.

RAI 3. IFM Grid Fabrication

WCAP16500-P-A, Supplement 2, TR states that [ ]^{a,c} will only be used with concurrent use of the MOS. The lack of springs in the design of IFM spacer grids implies that the MOS will not be applicable to IFM grids.

a. *Will the IFM grids therefore continue to be [ ]^{a,c}?*

b. *If [ ]^{a,c} is to be used for IFM grids, how will [ ]^{a,c} affect safety analyses and compliance with design criteria?*

Response:

a. [ ]^{a,c} will also be used for IFM grids. Since the IFM grids are currently built with a gap, the net effect of both changes is the GTRF margin for the IFM grid will slightly decrease.

b. Since the GTRF wear on the IFM grid is not limiting, this slight decrease will not affect safety analyses and the design will still meet Westinghouse design criteria.

RAI 4. Radial Growth Effects on Gap Size Determination

Will the determination of gap size for simulated end-of-life (EOL) grids account for [ ]^{a,c}? If not, describe the method for EOL gap size determination and why that method is bounding.

Response:

Yes, the determination of gap size for simulated end-of-life (EOL) grids does account for [ ]^{a,c}.

RAI 5. Grid Strength and Stiffness Ratios

Justify the use of EOL/beginning-of-life grid strength and stiffness ratios to predict EOL strength and stiffness of similar grids. Establish and justify a range of applicability for the relationship.

Response:

Spacer grids in fuel assemblies for plants designed by Combustion Engineering have either a 16x16 array of fuel rods with five large guide thimbles or a 14x14 array of fuel rods with five large guide thimbles. The discussion that follows pertains specifically to spacer grids fabricated by Westinghouse for plants designed by Combustion Engineering.

Spacer grids fail during impact loading by column buckling of the grid straps in the rows between guide thimbles or in rows between the outer guide thimbles and the impact face of the grid. Buckling is not initiated in the rows with guide thimbles because the guide thimbles reinforce those rows.

The decrease in grid strength and stiffness at EOL is due to the presence of gaps between fuel rods and spacer grid rod support features. Having rods in contact with the rod support features increases the lateral stability of the grid straps and thereby increases the buckling strength and the grid stiffness.

The degree to which the reduction in lateral stability due to the presence of small gaps affects grid strength and stiffness depends on several factors:

- Type of grid (i.e., wavy inner straps vs. straight inner straps) - The stabilizing effect of the rods may be greater for grids with straight inner straps than for grids with wavy inner straps that are, in a sense, pre-buckled. Therefore, a greater percentage reduction in strength and stiffness is expected for gapped grids with straight inner straps than for gapped grids with wavy inner straps, and the EOL/BOL ratio determined from testing a straight strap grid should not be applied to a wavy strap grid, and vice versa.
- Guide thimble/fuel rod pattern – As noted above, buckling is initiated in rows that are not reinforced by guide thimbles. The lengths of the columns where buckling can occur, and therefore, their susceptibility to buckling in the absence of rod support (longer columns are more susceptible to buckling) are established by the guide thimble and fuel rod pattern. The effectiveness of the lateral support provided by the fuel rods is also affected by the guide thimble and rod pattern (a larger number of more closely spaced rods is more effective in reducing susceptibility to buckling and in increasing stiffness than a smaller number of more widely spaced rods). Therefore, the percentage reduction in grid strength and stiffness for gapped grids that have, for example, a 16x16 array of rods is not necessarily expected to be the same as for gapped grids that have a 14x14 array of rods, and the EOL/BOL ratio determined for one configuration should not be applied to the other.

- BOL grid strength/stiffness – Within a family of grids of a particular type (e.g., wavy strap vs. straight strap) and a particular guide thimble/fuel rod pattern (i.e., 16x16 array vs. 14x14 array), some designs may be inherently stronger and stiffer than others due to differences in strap thickness, strap height, cutout geometry, strap material, etc. On a percentage basis, the stabilizing effect of rods without gaps will be greater for a grid that is inherently weaker and softer than for a grid that is inherently stronger and stiffer. Therefore, the EOL/BOL ratios determined from testing of a grid design that is significantly stronger or stiffer should not be applied to a grid design that is significantly weaker or softer, and vice versa. Considering the scatter in grid strength and stiffness test data, it is judged to be reasonable to apply the same EOL/BOL ratios determined for one grid design to another grid design provided that the average[1] strengths and stiffnesses of the two designs are within **[ ]**^{a,c} of each other. If this condition is met, the ratios may be applied to grids that have different strap heights, different strap thicknesses, different strap materials, etc., because even with these types of differences, if the buckling loads are similar to the buckling loads for the base design, the effectiveness of the rod support, on a percentage basis, is expected to be the same.

Based on these considerations, Westinghouse intends to apply the EOL/BOL strength and stiffness ratios determined from one grid design to another design provided that the following conditions are satisfied:

- Both designs must have the same type of inner straps (straight or wavy).
- Both designs must have the same pattern of guide thimbles and fuel rods.
- Average[1] strengths and stiffnesses for the two design must be within **[ ]**^{a,c} of each other.

[1] Average of the test grids used to establish the grid strengths or stiffnesses.

RAI 6. Flowing Water Damping Testing of CE 16x16 NGF

Explain the differences, if any, in procedure, analysis, range of testing, or number of tests that exist between the flowing water tests to be performed on the CE 16x16 NGF design and those presented in Reference 6 of WCAP-16500-P, Supplement 2.

Response:

The test procedure, data reduction method, and range of testing for the new test and the previous test (documented in Reference 6 of WCAP-16500-P, Supplement 2) are basically the same. Test data points will be repeated. The test assembly will be a CE 16x16 NGF design. The main difference is the test loop. The test for the CE 16x16 NGF is performed in the Vibration Investigation and Pressure-drop Experimental Research (VIPER) test loop with new flow housing and hardware located at the Westinghouse Product Engineering Test lab in Columbia SC. The previous test was performed at the Fuel Assembly Test System (FATS) loop which Westinghouse no longer has. The VIPER loop can operate at higher temperatures than the old test loop, so the new test covers a larger range of test conditions than the previous test.

RAI 7. Maximum Credible Grid Deformation

Explain how maximum predicted loads are obtained and how the bounding load used to test for the maximum credible grid deformation is determined.

Response:

Maximum predicted loads are obtained using the CESHOCK code as described in CENPD-178-P, Rev. 1-P (Reference 3 of WCAP-16500-P, Supplement 2). CESHOCK models spacer grids with spring rates that do not change even if loads greater than the grid strength are predicted. However, the stiffness of an actual grid decreases when the grid strength is exceeded, resulting in lower loads and more deflection than predicted by CESHOCK. Therefore, to simulate the effect of an impact that exceeds grid strength, it is not appropriate, and in some cases not possible, to apply the load predicted by CESHOCK to a test grid. Instead, the simulation must be based on the energy absorbed by the grid.

During an impact, a grid must absorb essentially the same amount of energy whether the grid strength is exceeded or not. Since CESHOCK models spacer grids as linear springs, the amount of energy absorbed (E_{max}) during the maximum impact may be readily determined knowing the CESHOCK predicted maximum impact force (F_{max}) and the grid spring rate (k_{hot}) modeled in CESHOCK (i.e., $E_{max} = F_{max}^2 / 2k_{hot}$). Similarly, the energy absorbed (E_{linear}) up to the point of grid failure can be determined knowing the grid strength at operating temperature (P_{crit}) and k_{hot} (i.e., $E_{linear} = P_{crit}^2 / 2k_{hot}$). The ratio of these two energies $(F_{max} / P_{crit})^2$ multiplied by the energy required to fail a test grid at room temperature is the minimum amount of energy that is to be applied to a test grid at room temperature to simulate the deformation caused by the maximum impact energy predicted by CESHOCK. The amount of deformation resulting from the application of, at least, that amount of energy can be characterized for use in a coolability determination.

RAI 8. Modified Outer Strap Details

It has been stated in Section 2 of TR WCAP-16500-P-A, Supplement 2, that there are small changes in grid loss coefficients, grid/fuel assembly pressure drop, and flow distribution. Please respond to the following requests:

a. *Provide a quantification summary of the changes in grid loss coefficients, pressure drop, and flow distribution.*
b. *Provide the results of the thermal-hydraulic evaluation performed with the modified CE 16x16 fuel design that led to the conclusion that the thermal hydraulic effects, as listed in Section 2.1.3 of WCAP-16500-P-A, Supplement 2, do not require changes in methodology, but do impact some of the design bases discussed in the TR.*
c. *It is stated in Section 2.1.3 of WCAP-16500-P-A, Supplement 2, that "the effects are explicitly accounted for in the standard analyses." List these "standard analyses."*

Response:

a. Calculations are used to perform a quantitative comparison between the 16x16 standard NGF fuel design and the 16x16 MOS NGF design. Based on those evaluations, the [ ][a,c]. There is no impact on inlet flow distribution since the inlet geometry is the same and Thermal Hydraulic codes are used to assess flow distribution within the core.
b. There is no change to the design bases discussed in WCAP-16500-P-A. Verification was required for some design criteria due to the small changes to the grid specified in response part a. Standard and approved methods were applied and documented for verification of the affected design criteria. Documentation in Section 2.1.3 of the topical report will be modified as follows in the approved version.

   "These thermal/hydraulic effects do not require changes to methodology discussed in WCAP-16500-P-A, but did require design verification of some design criteria due to the minor changes. The effects of the changes are explicitly accounted for in standard analyses used to demonstrate compliance with the applicable design criteria, which remain unchanged."

c. The list of standard analyses are: DNB analyses by USNRC approved methods, fuel assembly hold down force, effect of rods bowing, LOCA, Non-LOCA, Fuel Performance, Crud analysis, and thermo-hydrodynamic stability.

RAI 9. Clarification of Changes to CENPD-178-P

Section 3.2 of TR WCAP-16500-P-A, Supplement 2, introduces several modifications to CENPD-178-P seismic/loss-of-coolant-accident methodologies. Describe these modifications in more detail and specify the resulting changes to CENPD-178-P.

Response:

Of the modifications outlined in Section 3.2 in WCAP-16500-P, Supplement 2, only two are considered changes to the CENPD-178-P, Rev. 1-P methodology: the use of damping values derived from flowing water testing, and the use of the flow area reduction resulting from maximum credible deformation in lieu of maximum hypothetical deformation in coolability analyses. The responses to RAIs 6 and 7 provide additional details about these changes. The other modifications discussed in WCAP-16500-P, Supplement 2, are considered to be advancements to the test technique that do not constitute a change to the methodology. For instance, the use of gapped cells is not considered a methodology change since the approach for obtaining the required model parameters is not impacted. The discussion of gapped cells was included in WCAP-16500-P, Supplement 2, to inform the NRC of how Westinghouse intends to address Information Notice (IN) 2012-09 and the responses to RAIs 4 and 5 provide additional details about this subject.

When the CENPD-178-P, Rev. 1-P topical report was prepared, the report described the analysis methodology. An integral part of the methodology is how the fuel assembly is modeled (i.e., as a uniform beam with torsional springs at each end, mass nodes at the spacer grid elevations, linear springs representing spacer grid stiffnesses, etc.). Many of the fuel assembly analytical model parameters (e.g., the moment of inertia of the beam, the torsional spring stiffnesses, the spacer grid stiffnesses, etc.) are derived from testing. CENPD-178-P, Rev. 1-P describes the testing that was performed in support of its submittal. The explicit details of the testing (e.g., types of equipment and instrumentation, types of measurements, etc.) described in CENPD-178-P, Rev. 1-P are not considered to be part of the methodology and were not intended to be strictly followed as test practices evolve.

In addition, the specific set of tests that were performed to support the development of CENPD-178-P, Rev. 1-P was not intended to define the set of tests required to comply with the methodology going forward for each new design. It is often appropriate to develop the fuel assembly analytical model parameters for a new design from testing performed on a prior design. In these instances, fuel assembly data from the testing of other fuel assemblies is adjusted to model new or updated fuel designs. For instance, CENPD-178-P, Rev. 1-P describes testing that was performed to determine natural frequencies, damping ratios, and hydrodynamic mass. These parameters can be adjusted for fuel assemblies with different lengths that are otherwise similar to the originally tested design. Making such an adjustment in lieu of repeating the complete set of tests described in CENPD-178-P, Rev. 1-P is an acceptable approach consistent with the overall methodology. The set of tests described in CENPD-178-P, Rev. 1-P and outlined in subsection 3.2.3 of the safety evaluation report

(Reference 1) are intended to be performed for new fuel designs to the extent necessary to determine model parameters that cannot be adjusted from prior testing. For example, it would be inappropriate to adjust model parameters for a design in which the spacer grids are welded to the guide tubes from a design in which the grids are bulged to the guide tubes since the effects of such a change on natural frequencies and damping ratios are difficult to quantify.

Reference:

1. Letter to Mr. A. E. Scherer (C-E Power Systems) from Harold Bernard (U. S. Nuclear Regulatory Commission), "Acceptance for Referencing of Topical Report CENPD-178(P)," August 6, 1982.