Enclosure 3

Responses to Requests for Additional Information on Westinghouse Topical Report WCAP-18869-P/NP, "High Performance Cladding for Use in Boiling Water Reactor Fuel."

(Non-Proprietary)

April 2025

Westinghouse Electric Company
1000 Westinghouse Drive
Cranberry Township, PA 16066

Request for Additional Information (RAI) 1

Please provide any additional data that was collected since publication of the submitted TR for all lead test rod (LTR)/post irradiation examination programs for **HiFi™** cladding.

Response to RAI 1

Table 1 shows a compilation of the fuel assemblies/fuel rods that have continued their irradiation since the publication of the submitted Topical Report. **[**

]a,c

Table 1 Summary of the **[**

]a,c

a,c

[ ]a,c

[

]a,c

[ ]a,c

Figure 1 **[**

]a,c

a,c

Figure 2 **[**

][a,c]

Figure 3 illustrates **[**

][a,c]

a,c

Figure 3 **[**

]a,c

Figure 4 illustrates **[**

]a,c

Figure 5 illustrates **[**

]a,c

a,c

Figure 4 **[**

][a,c]

a,c

Figure 5 **[**

][a,c]

In summary, **[**

]a,c

RAI 2

For the BWR reactor coolant chemistry control programs in the U.S. that are not a part of the Westinghouse LTR program, or not specifically tested for this study, please justify why those chemistry control programs are not expected to have a negative effect on the performance of **HiFi** cladding (cladding corrosion, hydrogen pickup, etc.). If possible, please provide response in a format which lists the program vs. the effect on **HiFi** cladding.

Response to RAI 2

[**]a,c**
Forsmark 2, a known plant for high hydrogen uptake, and Kernkraftwerk Leibstadt. Forsmark 2 operates with ultra-low feedwater iron, as well as very low levels of other corrosion products, which many of the BWRs operating in the US are transitioning towards. Leibstadt is a GE BWR-6 and has many cycles with experience of local fuel rod burnups above 70 MWd/kgU and/or more than 6 years of operation. Leibstadt has transitioned to HWC and OLNC water chemistry which is the typical operation for the US BWRs.

[

]a,c

RAI 3

What is the models' uncertainty of **HiFi** cladding predicted oxide thickness that justifies using **[** **]**^{a,c}

Conversely, if this data and discussion are to be included in the specific fuel bundle design reports, please clarify this method of inclusion.

Response to RAI 3

The currently NRC approved corrosion model for the BWR fuel performance code STAV7.2 is found in WCAP-15836-P-A. Validation was done with the Zircaloy-2 alloys **[** **]**^{a,c} in WCAP-15836-P-A with the aim to have a bounding model **[** **]**^{a,c}

a,c

Figure 6 Corrosion model for **[** **]**^{a,c} *alloys in STAV7.2, from WCAP-15836-P-A*

An additional validation of the STAV7.2 model with **[** **]**^{a,c} The used validation database is seen in Figure 7.

The validation of the best estimate model shows that it bounds more than **[** **]**^{a,c} see Figure 9.

a,c

Figure 7 **[** **]**^{a,c} *validation of the oxide model in STAV7.2*

a,c

Figure 8 *Results from the validation of the STAV7.2* **[** **]**^{a,c} *oxide model*

a,c

Figure 9 Results from the validation of the STAV7.2 **[ ]**^{a,c}

The data (and spread) for **HiFi** cladding **[ ]**^{a,c}, see answer to comment 1.

The model in STAV7.2 is conservative and **[ ]**^{a,c} bounds **HiFi** cladding corrosion.

Any new model approved by the NRC that **[ ]**^{a,c} be applicable for **HiFi** cladding.

The cladding corrosion criterion will be verified in the fuel bundle design reports based both on the actual corrosion database which includes **[ ]**^{a,c} and **HiFi** cladding and based on calculations with an NRC-approved **[ ]**^{a,c} or **HiFi** cladding.

RAI 4

Please provide detailed model and data analysis to justify the use of **[ ]**^{a,c} including the data discussed during the NRC regulatory audit of TR WCAP-18869-P/NP, "High Performance Cladding for Use in Boiling Water Reactor Fuel," conducted by the NRC staff on December 12-13, 2024.

Response to RAI 4

Creep measurements are presented in WCAP-18869-P, Revision 0. Thermal creep measurements on unirradiated material are found in Section 3.2.3.1 and Table 3-6 and the measurements demonstrate that **[**
][a,c]

Irradiation creep is found in Section 3.4.2.3 where **[**

][a,c] regarding in-reactor creep.

Since the measurements demonstrate that the creep behavior of **HiFi** cladding **[**
][a,c]

The currently NRC-approved cladding creep model **[**

][a,c]

When a new cladding creep model is approved by the NRC **[**
][a,c] based on the measurement results presented in WCAP-18869-P, Revision 0.

Since **[**
][a,c] A calculation of the irradiation cladding creep is done for a **TRITON11** fuel rod with the fuel performance code STAV7.2 and presented in Figure 10. The irradiation creep is a function of fluence and no pellet cladding mechanical interaction (PCMI) or differential pressure effects are considered.

a,c

*Figure 10 Cladding irradiation creep for a **TRITON11** fuel rod with* **[**

]a,c

Calculations of lift-off pressure for **TRITON11** fuel with the BWR fuel performance code described in WCAP-15836-P-A (STAV7.2) are found in Figure 11. Since **[**

]a,c

Note that the lift-off pressure depends on the fuel, fuel performance code, and connected methodology/model used. As discussed above, **[**

]a,c applicable for **HiFi** cladding.

a,c

*Figure 11 Lift-off pressure for **TRITON11** fuel calculated with STAV7.2. The results are* **[**

]^{a,c}

RAI 5

The following are related to the impact of high-performance cladding response to LOCA and associated analyses:

a) Please provide the detailed data and analysis of the impact of iron on the $\alpha \rightarrow \alpha + \beta$ transformation temperature that justifies **[** **]^{a,c}** including the data discussed during the NRC regulatory audit.

b) Please provide a **[**

]^{a,c} Also, please describe how flow blockage is determined from predicted burst strains for **HiFi** cladding. Conversely, if this data and discussion are to be outside this TR, then please clarify how this information will be addressed.

Response to RAI 5a

Dilatometry was performed **[** **]**^{a,c}; see *Figure 12* and *Figure 13*.

- Thermal expansion measurements (by dilatometry) show **[** **]**^{a,c}; see *Figure 13*.
- The temperature for the initial reaction is **[** **]**^{a,c}

a,c

Figure 12 **[** **]**^{a,c}

a,c

Figure 13 **[**

][a,c]

Response to RAI 5b

Burst testing has been performed **[**

][a,c]

a,c

Figure 14 [
][a,c]

In addition, Westinghouse has performed [
][a,c]

[

][a,c]

Regarding flow blockage determined from predicted burst strains, the burst **[**

][a,c]

RAI 6

What are the textures and second phase particle (SPP) size distributions for the different lead use assembly's (LUA's) cladding with **HiFi**?

Response to RAI 6

The leading **HiFi** rods in the LUAs **[**

][a,c]

Table 2 **[** **]**[a,c]

a,c

Pole figures for **[** **]**[a,c]

SPP data for **[** **]**[a,c] is found in the TR in Table A-1. The specific section is copied below (see highlight):

[ ] a,c

With more detail found in Table 3-3 of the TR copied below (see highlighted cells):

Table 3-3. Results of SPP measurements of HiFi and Zircaloy-2

[ ] a,b,c

RAI 7

What fabrication specifications will be applied to texture and SPPs for **HiFi** cladding in production and how do these compare to current generation Zr-2 specifications for the fuel rods?

Other than the material composition, **[** **]**[a,c] If yes, what are they and what **[** **]**[a,c]

Response to RAI 7

With the exception of **[** **]**[a,c]

As stated in Section 3-1 of the TR:

“This section has demonstrated that the manufacturing processes used for **HiFi** cladding presented in this document show only minimal differences, driven mainly by the capabilities of different manufacturers.

These small differences do not result in significant differences in the resulting annealing parameters and associated microstructures, which demonstrate the equivalence of the manufacturing processes for the new alloy, as well as the closeness to the extensive experience of Zircaloy-2 cladding.”

[

][a,c]

- [

]a,c

Any changes to products and processes will be managed through Westinghouse's 10CFR50 Appendix B program.

RAI 8

Please provide detailed data for the fuel rod design (FRD) criteria along with the evaluations of the use of **HiFi** cladding on the specific criteria (Section 4.2 of TR WCAP-18869-P/NP, Revision 0). This should also include all discussions of Westinghouse acceptance criteria for FRD.

Response to RAI 8

Evaluation of how the use of **HiFi** cladding impacts the analysis, results, and margin is found in WCAP-18869-P, Section 4.2. An example of an analysis is the sample calculations for the **TRITON11** fuel in WCAP-18951-P/NP, "TRITON11® Reference Fuel Design" in Section 4.3.

Section 4.2 of WCAP-18869-P can be clarified as follows (clarification in **bold**):

> 4.2 FUEL ROD DESIGN
>
> Westinghouse BWR fuel designs are analyzed employing the following fuel rod design criteria by using NRC-approved BWR methods and methodologies for **[**
> **]a,c** Each criterion is specified along with the evaluation of the use of **HiFi** cladding on the specific criterion.
>
> 4.2.1 Rod Internal Pressure
>
> Criterion: The design criterion for rod internal pressure states that the internal pressure of the fuel rod shall not exceed a value which would cause the outward cladding creep to

increase the diametrical fuel pellet-cladding gap. This value of fuel rod internal pressure is defined to be that internal pressure which causes the outward cladding creep rate to exceed the fuel effective swelling rate. This requirement is referred to as “the lift-off criterion”.

Evaluation: **The rod internal pressure and the lift-lift off pressure are calculated with an NRC-approved BWR fuel performance code. The pressure depends on the cladding creep, which is [**

][a,c] (see Section 3.2.4.1 and Table 3-4). There is no adverse effect of **HiFi** cladding on the rod internal pressure, irradiation growth, creep or corrosion, compared to Zircaloy-2 cladding. Therefore, there will be no effect on evaluating the lift-off criterion.

4.2.2 Cladding Stresses

Criterion: Fuel rod stresses must be maintained within acceptable limits. This criterion is implemented by establishing design limits for stresses to assure that failure does not occur and that stresses of the fuel rod remain within acceptable limits.

Evaluation: **Cladding stress is evaluated [**

][a,c] is calculated with an NRC-approved fuel performance code and is dependent on [
][a,c] (see Section 3.2.4.1 and Table 3-4). There is no **[ ][a,c]** adverse effect of **HiFi** material on unirradiated or irradiated mechanical properties, irradiation growth, creep or corrosion, compared to Zircaloy-2 cladding. Therefore, there will be no effect on evaluating the cladding stresses.

4.2.3 Cladding Strain

Criterion: The total transient induced elastic and plastic cladding circumferential strain should not exceed 1%. In this context, total transient induced strain is the elastic and plastic strain which can occur during normal operation and anticipated operational occurrences (AOOs) excluding the effects of steady-state creep down and irradiation growth.

Evaluation: **The criterion is evaluated by calculating the transient induced strain with an NRC-approved BWR fuel performance code. The transient strain depends on [ ][a,c] (see Section 3.2.4.1 and Table 3-4) and on the**

strain, which is discussed in Section 3.2.4.2. There is no adverse effect of **HiFi** cladding on the rod internal pressure, unirradiated or irradiated mechanical properties, compared to Zircaloy-2 cladding. Therefore, there will be no effect on the mechanical response for evaluation of the cladding strain.

4.2.4 Hydriding

Criterion: Cladding hydriding from waterside and internal sources shall be maintained sufficiently low that premature cladding failure shall not occur due to hydrogen embrittlement.

Evaluation: There is evidence of the lower hydrogen pickup fraction in **HiFi** cladding with respect to Zircaloy-2 cladding. For the purpose of this Topical Report **[**

]^{a,c}

4.2.5 Cladding Corrosion

Criterion: Cladding corrosion must be limited to assure that excessive cladding corrosion does not lead to premature fuel rod failures due to excessive metal thinning or excessive cladding temperatures. The effect of cladding corrosion shall be included in the thermal-mechanical evaluation of the cladding.

Evaluation: **The criterion is evaluated by calculating the oxide thickness with an NRC-approved BWR fuel performance code.** There is no adverse effect of **HiFi** material on corrosion, as corrosion of **HiFi** cladding has been demonstrated to be **[ ]^{a,c} (see Figure 3-38)**. Therefore, there will be no impact on evaluating the cladding corrosion criterion.

4.2.6 Cladding Collapse

Criterion: Cladding collapse shall not occur during the design life of the fuel rod. Cladding collapse or "elastic and plastic instability" refers to the pressure across the tubing walls at which the cladding will buckle in the elastic and plastic ranges.

Evaluation**: The cladding creep collapse is evaluated with an NRC-approved method. The creep collapse depends on the cladding creep, [ ]^{a,c} (see Section 3.4.2.3).** There is no adverse effect of **HiFi** material on unirradiated or irradiated mechanical properties, irradiation growth, creep or corrosion, compared to Zircaloy-2 cladding. Therefore, there will be no effect on evaluation of cladding collapse. This includes instantaneous collapse at the beginning of life and creep collapse later during operation.

4.2.7 Cladding Fatigue

Criterion: Cladding fatigue shall not cause fatigue damage during normal operation and AOOs. The fatigue evaluation shall account for the effects of cladding corrosion.

Evaluation: **The fatigue limits derived by O'Donnell Langer are used for evaluation of cladding fatigue. In Figure 3-17, it is shown that [ ]^{a,c} The evaluation of fatigue is done with an NRC-approved BWR fuel performance code and relies on the mechanical behavior of the cladding (see Section 3.2.4.2). [ ]^{a,c}** Therefore, there will be no effect of **HiFi** material on the cladding fatigue evaluation.

4.2.8 Cladding Temperature

Criterion: Cladding overheating during normal operation and AOOs shall not cause fuel rod failure.

Evaluation: **[ ]^{a,c}**, and there is no adverse effect of **HiFi** material on the thermal properties of the cladding. Therefore, there will be no effect on evaluation of cladding temperature.

4.2.9 Fuel Temperature

Criterion: The maximum centerline pellet temperature shall remain below the melting temperature of the fuel during normal operation and AOOs.

Evaluation: **The evaluation of fuel temperature is done with an NRC-approved BWR fuel performance code. [ ]^{a,c}** Therefore, there will be no effect of **HiFi** material on the fuel temperature criterion evaluation.

4.2.10 Fuel Rod Bow

Criterion: Excessive fuel rod bowing shall be precluded for the design life of the fuel assembly. Fuel rod bowing shall be evaluated, and any significant impact shall be accounted for in the thermal and mechanical evaluation of the fuel rods and the assembly.

Evaluation: **[**

][a,c]

Therefore, there will be no effect on evaluation of fuel rod bow.

RAI 9

Please confirm that all the performance acceptance criteria and material limits **[**

][a,c] and identify where they are addressed.

Response to RAI 9

The fuel rod design acceptance criteria are **[**

][a,c] are found in WCAP-17769-P-A “Reference Fuel Design SVEA-96 Optima3” in Section 3.3 and 4.3. The fuel rod design acceptance criteria applied for **HiFi** cladding are the ones applicable for the **TRITON11** fuel described in WCAP-18951-P, “TRITON11® Reference Fuel Design” in Section 3.3 and 4.3.