Enclosure 3

Westinghouse Revised Responses to RAIs 7a, 11, and Supplemental Response to RAI 9 for WCAP-18482-P/WCAP-18482-NP

(Non-Proprietary)

(17 pages Including Coversheet)

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SFNB RAI 7a

Chapter 5.2.2 of WCAP-18482-P/WCAP-18482-NP, Revision 0, demonstrates that **ADOPT**™ fuel pellets promote larger fuel rod growth. In Figure 6-3, PWR fuel rod growth measurements are plotted against the PAD5 upper bound fuel rod growth model. As shown in Figure 6-3, the level of confidence in the upper bound growth model has clearly diminished based on the increased **ADOPT** fuel rods growth.

a. Please explain why the existing upper bound model remains valid.

NRC Clarification Request on RAI 7

Section 5.2.2 of WCAP-18482-P describes Westinghouse's fuel rod growth measurements on both BWR and PWR ADOPT™ fuel rods. An important impact of ADOPT fuel reduced in-reactor densification is an earlier closure of the fuel pellet-to-cladding gap. After gap closure, irradiation-induced fuel swelling will strongly influence fuel rod growth. The empirical database clearly shows an increase in fuel rod growth compared to standard UO2 fuel rods. In response to an RAI regarding the continued applicability of the PAD5 upper bound growth model (RAI #7a Reference b), Westinghouse states that the current PAD5 growth model remains applicable for ADOPT fuel and any loss of confidence in the UB growth is either conservative (e.g., for RIP), negligible (e.g., for strain), or can be offset with available design margin (e.g., fatigue and fuel rod growth). Please clarify how credit for available margins relative to design criteria (to offset known non-conservative aspects of an analytical method) is captured and tracked. The staff has concerns with this response in that credit for available margins relative to design criteria, to offset known non-conservative aspects of an analytical method, need to be captured and tracked.

Response to SFNB RAI 7a.

Following clarification discussions with the NRC, the response to RAI #7a has been revised as provided below. The following response supersedes the response provided previously in Reference 7-1.

Figure RAI-7-1 updates Figure 6-3 of Reference 7-2 with **[** **]**^{a,c}. The figure displays rod axial growth data for **ADOPT [** **]**^{a,c} and standard UO_2 pellets **[** **]**^{a,c}. As stated in Reference 2, these data were collected as part of **[** **]**^{a,c}. The data presented in Figure RAI-7-1 suggest that the use of **ADOPT** fuel pellets results in an increase in rod axial growth. Westinghouse has developed an adjustment to the current PAD5 model for rod axial growth that accounts for this increase in axial growth. Westinghouse performed a quantitative evaluation of the impact of this adjustment on the fuel rod design criteria that are sensitive to rod growth.

Figure RAI-7-2 shows the data in Figure RAI-7-1 overlaid on the PAD5 database for the rod growth model for UO_2 fuel. For clarity, **[**]^{a,c}

[ ][a,c]. Figure RAI-7-2 also shows plots of the PAD5 rod growth model for UO_2 fuel.

In Figure RAI-7-2 the PAD5 database is **[** **]**[a,c]. As mentioned in Reference 7-1, there were **[** **]**[a,c]. This provides an extra level of conservatism when considering the entire dataset.

In developing an adjustment for **ADOPT** fuel, Westinghouse **[**

][a,c].

[ ] a,c

*Figure RAI-7-1 Rod axial growth data for **ADOPT** and standard UO_2 pellets. The PAD5 upper-bound model is also shown*

[ ]a,c

Figure RAI-7-2 Comparison of the rod growth data from Figure RAI-7-1 to the PAD5 database and model

[ ]a,c. The resulting adjusted model is plotted in Figure RAI-7-4 along with the data for **ADOPT** fuel. [ ]a,c.

[ ] a,c

Figure RAI-7-3 A model for the effect of ***ADOPT*** *fuel on rod growth*

Westinghouse used this adjusted model to quantitatively evaluate the impact on the fuel rod design criteria more sensitive to rod growth: rod internal pressure, fuel rod growth, cladding fatigue, and cladding transient strain. As expected, the impact on the rod internal pressure criterion was found to be in the direction of increasing the margin. The impact on the fuel rod growth criterion is to reduce margin, as expected. **[** **]**[a,c]. The impact on cladding fatigue **[** **]**[a,c].

Westinghouse **[** **]**[a,c]. As stated in the response to RAI #7b (Reference 7-1) Westinghouse plans to collect more performance data for **ADOPT** fuel. Future rod growth data for **ADOPT** fuel will be incorporated into Westinghouse fuel performance models and methods using Westinghouse processes for model and methods development, as were used to develop the approved PAD5 model and methods. This process will continue to ensure that the models used to evaluate the fuel rod design criteria include adequate level of confidence and conservatism.

a,c

*Figure RAI-7-4 Rod axial growth data for **ADOPT** and adjusted PAD5 model*

References

7-1 LTR-NRC-21-9, "Submittal of "Westinghouse Responses to RAIs 2, 3, 4, 5, 6, 7, 8, 12, 13, and 14 for WCAP-18482-P/WCAP-18482-NP, Revision 0 (Proprietary/Non-Proprietary)"", March 2021.

7-2 WCAP-18482-P, "Westinghouse Advanced Doped Pellet Technology (ADOPT™) Fuel," May 2020.

7-3 WCAP-17642-P-A, "Westinghouse Performance Analysis and Design Model (PAD5)," November 2017.

SFNB RAI 9

Section 5.3 of WCAP-18482-P/WCAP-18482-NP, Revision 0, describes potential impacts of ADOPT fuel pellets on fuel rod performance under reactivity-initiated accident (RIA) conditions. Japan Atomic Energy Agency (JAEA) Top Fuel technical paper (Takeshi Mihara, et. al.) documents an investigation of recent prompt pulse tests conducted on doped UO2 fuel pellets. Test rod OS-1, which contained ADOPT fuel pellets, failed at 38 Δcal/g, which is below all previous test failures for rods close in BU and hydrogen content. The JAEA technical paper concluded the following with respect to the results of the OS-1 test:

The pre- and post-test examinations suggested that one of the reasons of the lower failure limit may be the effect of the hydrides radially oriented and precipitated more densely in the specific angle range in the cladding tube. However, since the possible contribution of ADOPT™–pellets specific effects cannot be ruled out at the present, further investigation *is needed on fuel pellet behavior under both normal-operation and pulse-irradiation conditions.*

a. Please provide evidence (e.g., irradiated ADOPT fuel rod segments used in expansion due to compression testing) that differences between UO2 and ADOPT fuel performance (i.e., steady-state swelling, pellet-clad mechanical interaction) will not introduce differences in cladding properties and microstructure (e.g., hydride morphology) which may influence fuel rod performance under RIA conditions.

b. Hundreds of prompt pulse tests have been conducted in research reactors such as the Nuclear Safety Research Reactor (NSRR) to evaluate the performance of irradiated fuel rods under RIA conditions. In these test programs, comparisons have been made between large grain and standard grain fuel rod performance (e.g., NSRR test OI-10 vs. OI-11). Tests have also been performed on a variety of different fuel compositions and doping agents. Please review the extensive RIA empirical database and compile data to characterize the fuel thermal expansion of ADOPT fuel under RIA conditions and support your finding that ADOPT fuel will behave similarly to standard UO_2 fuel.

Supplemental Response to SFNB RAI 9

The submittal of this supplement follows a clarification discussion with the NRC on August 8th, 2021.

This is a supplement to the previous response to a request for additional information (RAI) 9 [9-1] on ADOPT fuel pellets. This supplement adds the basis for applicability of the current UO_2 pellet cladding mechanical interaction (PCMI) cladding failure criterion under a rod ejection accident (REA) to the **ADOPT** fuel pellets. The PCMI cladding failure enthalpy for **ZIRLO** or **Optimized ZIRLO** cladding with **ADOPT** fuel pellets in an REA is expected to be represented by the failure curves for stress relieved annealed (SRA) cladding at temperatures > 500 °F, as presented in RG 1.236 [9-2]. The main factors impacting the PCMI failure criteria are the expansion of the pellet, the overall cladding hydrogen level in excess of the solubility levels, H_{EX}, and the orientation of hydrides in the cladding, in particular, the fraction of hydrides that are radially oriented.

In the response to RAI 9, **ADOPT** fuel pellets were shown to be equivalent to UO_2 pellets in terms of the resulting pellet expansion from the energy pulse associated with a REA. In addition, the pellet to clad gap at low power levels (< 5% Full Power) at the end of cycle where the REA is more limiting would be similar. Therefore, the cladding strain during an REA would be similar.

Previously, **Optimized ZIRLO** cladding had been justified to have the same PCMI enthalpy rise limits as **ZIRLO** cladding. This position was documented internally at Westinghouse and was demonstrated based on the following evidence:

a. Comparison of ductility as a function of hydrogen for irradiated cladding for **ZIRLO** and **Optimized ZIRLO** cladding.

b. Comparison of hydride orientation and reorientation under tensile stress for un-irradiated **ZIRLO** and **Optimized ZIRLO** cladding.
c. Comparison of hydride orientation of irradiated **ZIRLO** and **Optimized ZIRLO** cladding.

The evaluation of this evidence demonstrated that the trend in cladding ductility as a function of hydrogen, hydride distribution after irradiation, and hydride reorientation behavior under stress are similar for **ZIRLO** and **Optimized ZIRLO** cladding. This position was reviewed and approved following an audit by the NRC [9-3]:

> "The NRC staff agreed with this comment. On February 13, 2020, the staff conducted an audit of the Westinghouse documentation supporting the application of the SRA PCMI cladding failure threshold to Optimized ZIRLO. Based on the results of the audit (ADAMS Accession No. ML20049F944), the staff accepts the use of the SRA PCMI cladding failure thresholds for Optimized ZIRLO cladding."

Based on this, the cladding failure strain should be the same for **ADOPT** and UO_2 fuel under a REA. There is no change in any UO_2 fuel failure threshold and criteria for the fuel rods containing the ADOPT pellets. Therefore, the PCMI limits of RG 1.236 are applicable to **ADOPT** fuel pellets with either **ZIRLO** or **Optimized ZIRLO** cladding.

References:

9-1 LTR-NRC-21-20, Submittal of "Westinghouse Responses to RAIs 1, 9, 10, 11, and Supplemental Information for RAI 6 for WCAP-l 8482-P/WCAP-18482-NP, Revision 0" (Proprietary/Non-Proprietary), June 20, 2021.
9-2 ADAMS Accession No. ML20055F490, REGULATORY GUIDE RG 1.236, Revision 0, PRESSURIZED-WATER REACTOR CONTROL ROD EJECTION AND BOILING-WATER REACTOR CONTROL ROD DROP ACCIDENTS, June 2020.
9-3 ADAMS Accession No. ML20055F489, Response to Second Round of Public Comments, Draft Regulatory Guide (DG)-1327, (NRC Docket-2016-0233; ADAMS Accession No. ML20055F489), June 2020.

SFNB RAI 11

Section 6.1.1 of WCAP-18482-P/WCAP-18482-NP, Revision 0, describes validation of the PAD5 gaseous swelling model against a Studsvik ramp test with ADOPT rods. In this discussion Westinghouse states that the volume change from the Studsvik test show that **[**

] ^{a,c}

Based on past fuel design reviews, the NRC staff is aware of multiple ramp tests on irradiated fuel rod segments containing large grain fuel pellets which exhibited larger incremental cladding strain relative to tests conducted on irradiated fuel rod segments with standard UO_2 pellets. **[**

][a,c]

a. Please provide incremental cladding strain measurements from ramp testing on irradiated fuel rod segments containing ADOPT fuel pellets.

b. Please provide details of the PAD5 fuel thermal expansion and gaseous swelling model validations, including PAD5 predictions of incremental cladding strain versus measurements.

NRC Clarification Request on RAI 11

Section 4.1 of WCAP-18482-P describes a base irradiation and subsequent ramp testing program conducted on two BWR, barrier lined, segmented rods containing standard UO_2 (D0) and two different variants of doped UO_2 fuel (D1 and D3). Ceramography (D0, D1), fission gas release measurements (D0, D1, D3), and fuel volume change (D0, D1), calculated from profilometry and gap measurements, are presented. Based on the predicted volume change (D0 versus D1), Section 6.1.1 of WCAP-18482-P concludes that applying the PAD5 fission gas swelling model for ADOPT fuel will predict slightly larger pellet deformation and therefore is conservative to the calculated cladding diameter change for transient strain analysis.

[

] [a,c]

Revised Response to SFNB RAI 11

Following clarification discussions with the NRC, the response to RAI 11 has been revised as provided below. The following response supersedes the response provided previously.

a. There are two test series: Barseback-Studsvik and O3-SCIP II (Sections 4.1 and 4.3 of Reference 11-2). The test conditions (burnup, Ramp Terminal Level (RTL), and hold time) for doped fuel and reference UO_2 fuel are listed in Table RAI-11-1 and Table RAI-11-2. The measurements for the incremental cladding strain are presented in part b of this response along with the predicted value. Consistent with Section A.2.4 of the PAD5 topical Report (Reference 11-1), the incremental cladding strain are presented as cladding diameter change from ramp tests.

[ ]a,c

[ ]a,c

b. [

]a,c

[

] a,c

References:

11-1 WCAP-17642-P-A, Revision 1, "Westinghouse Performance Analysis and Design Model (PAD5)," November 2017.
11-2 WCAP-18482-P, "Westinghouse Advanced Doped Pellet Technology (ADOPT™) Fuel," May 2020.

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