

## **Enclosure 3**

# **Responses to Requests for Additional Information on Topical Report WCAP-18483-P, “EnCore® Chromium Coated Cladding for Use in Pressurized Water Reactors.”**

**(Non-Proprietary)**

**April 2026**

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**Request for Additional Information #1**

Section 5.3.1.5.2 of the topical report (TR)WCAP-18483-P/NP, Revision 0, “EnCore® Chromium Coated Cladding for Use in Pressurized Water Reactors,” discusses [

] <sup>a,c</sup>. However, Section 5.3.1.6.2 of the TR discusses retention of the 17 percent Baker-Just (BJ) effective cladding reacted (ECR) integral time-at-temperature limit (or the equivalent 13 percent ECR calculated using the Cathcart-Pawel correlation). Please discuss how [

] <sup>a,c</sup> are used when determining the peak cladding temperature and maximum local oxidation.

**Response**

[

] <sup>a,c</sup>

Limitation and Condition #14 in the Safety Evaluation Report for the FSLOCA EM [1-1] states that “the oxidation result using Baker-Just to convert the LOCA transient time-at-temperature to an equivalent cladding reacted shall be compared against the 17 percent limit. If Cathcart-Pawel is used to convert the LOCA transient time-a-temperature to an equivalent cladding reacted, the oxidation result shall be compared to a 13 percent limit with the pre-transient oxide layer thickness being included in the prediction results.”

[

] <sup>a,c</sup>

**Reference(s)**

1-1: WCAP-16996-P-A, Revision 1, “Realistic LOCA Evaluation Methodology Applied to the Full Spectrum of Break Sizes (FULL SPECTRUM LOCA Methodology),” November 2016.

**Request for Additional Information #2**

Section 5.3.2 of the TR states [

] <sup>a,c</sup> Please justify how the LOCA peak cladding temperature and maximum local oxidation calculations remain conservative if [

] <sup>a,c</sup>

**Response**

The **FULL SPECTRUM™** LOCA (**FSLOCA™**) Evaluation Model (EM) considers several different rod types, each with modeling approaches designed to produce limiting results. [

] <sup>a,c</sup>**Reference(s)**

2-1: WCAP-16996-P-A, Revision 1, “Realistic LOCA Evaluation Methodology Applied to the Full Spectrum of Break Sizes (FULL SPECTRUM LOCA Methodology),” November 2016.

**Request for Additional Information #3**

Section 5.1.7 of the TR states that [

]<sup>a,c</sup> and “... the EnCore fuel specific FEA models should be used in stress analyses.” Please explain (a) the differences in the seismic-LOCA and the stress analyses discussed in Section 5.1.7; and (b) why the stress analysis [

]<sup>a,c</sup>.**Response #3**

The fuel assembly seismic-LOCA model is a simplified representation of the fuel assembly used in the dynamic grid impact analysis simulation. Properties such as mass, natural frequency, and mode shapes are captured. The stress analysis model of a fuel assembly is a more detailed FEA model representing many features of a fuel assembly. The same dynamic properties as the seismic-LOCA model are inherently captured in the stress analysis model. Additionally, the stress analysis model includes component features and interactions between components, with the ability to analyze component stresses due to external loads. While both the seismic-LOCA model and the stress analysis model represent fuel assembly behavior, the analysis steps in which they are used are different. The seismic-LOCA model is used to predict fuel assembly

motion and grid impacts, whereas the stress analysis model is used to determine stresses on relevant components using loads input from the previous step.

Comparing the **EnCore** fuel assembly models to the standard fuel assembly models, [

] <sup>a,c</sup>

#### **Request for Additional Information 4**

Section 5.1.7 of the TR states that “Validation of the EnCore fuel assembly FEA [finite element analysis] models by comparison to the mechanical test data should be considered before using the FEA models or results for any plant/utility licensing documentation.” Please provide more information about the validation plan for the FEA models.

#### **Response #4**

**EnCore** fuel assembly analysis models will be validated following typical Westinghouse methodology, as approved in WCAP-9401-P-A. **EnCore** fuel assemblies [

] <sup>a,c</sup>

#### **Reference(s)**

4-1: WCAP-9401-P-A, “Verification Testing and Analyses of the 17 X 17 Optimized Fuel Assembly,” August 1981.

#### **Request for Additional Information #5**

Section 5.2.1.2 of the TR (topical report) states that the cladding hydrogen content will be calculated as [

] <sup>a,c</sup> No basis was provided for the hydrogen pickup model. Please provide justification for this hydrogen pickup model.

#### **Response**

The hydrogen pickup (HPU) proposed in WCAP-18483-P was designed to [

] <sup>a,c</sup>

[ ]<sup>a,c</sup> This can be observed in Figure 5-1 along with the original proposed model in WCAP-18483-P. In addition, [

] <sup>a,c</sup> This can be observed in Figure 5-2.



**Figure 5-1, EnCore Chromium Coated Cladding Hydrogen Level vs In-core Time and Original Proposed HPU Model**



Figure 5-2, EnCore Cladding Hydrogen Level vs In-core Time

[

]a,c

[

]a,c

**Request for Additional Information #6**

The Cr-coated Interim Staff Guidance, ATF-ISG-2020-01, “Supplemental Guidance Regarding the Chromium-Coated Zirconium Alloy Fuel Cladding Accident Tolerant Fuel Concept” (ML19343A121), states that “If it can be shown that the Cr coating has a beneficial or negligible impact on the uniform elongation relative to the reference Zr alloy cladding, then it could be reasonably argued that the current RIA (reactivity insertion accident) failure limits are applicable to Cr-coated Zr cladding.” Therefore, in order to justify the use of [

]a,c

**Response**

A total uniform elongation ( $UE_{total}$ ) comprising both elastic and plastic components is a more accurate representation of the strain failure threshold for fuel cladding. However, it is not available from all laboratories for comparison as there are differences in the mechanical testing data analysis techniques among them. Instead, the plastic uniform elongation ( $UE_{plastic}$ ) is used for comparison. Figure 6-1 is a plot of  $UE_{plastic}$  for [

]a,c

[

] <sup>a,c</sup>



**Figure 6-1, Plastic Uniform Elongation (UE<sub>plastic</sub>) vs Temperature**

**Request for Additional Information #7**

Section 5.3.3 of the TR states that the non-LOCA [

] <sup>a,c</sup>

**Response**

Load vs deflection curves are shown for ring compression tests (RCTs) conducted at the following peak cladding temperatures (PCTs) under steam exposure and times:

[

] <sup>a,c</sup>

The results are shown in Figures 7-1 to 7-3 and correspond to samples metallographically shown in Figure 3.11-22 of WCAP-18483-P. For the first two sets of RCTs the Cr Coated [

] <sup>a,c</sup>

This change in performance with increasing time and temperature can be explained by the microstructural evolution that occurs for Cr coated cladding including diffusion of Cr, formation of oxygen-stabilized alpha-Zr ( $\alpha_{Zr}(O)$ ), and eventual formation of  $ZrO_2$ . As the time/temperature increases, the Cr coating begins to diffuse into the base cladding alloy along grain boundaries (lightly seen below the  $ZrCr_2$  layer in Figure 7-4b and the inset of 4c), a thin intermetallic layer ( $ZrCr_2$ ) begins to form at the coating interface (as described in Section 3.11.2.3 of WCAP-18483-P), and the coating oxidizes, all resulting in consumption of the protective coating layer. Eventually, there is a shift as the coating begins to transition between protective and non-protective stages where the oxygen reacting with the Cr also diffuses into the cladding to form  $\alpha_{Zr}(O)$ . At longer oxidation times and higher temperatures above 1300°C, the coating can transition such that the residual Cr is non-protective and the underlying Zr can oxidize to form  $ZrO_2$  and a eutectic microstructure of diffused Cr and Zr can form (Figures 7-4a and 7-4c). The microstructural evolution is described well in (Reference 7-2) and schematically shown in Figure 7-5.

From an operational modeling perspective, as stated in the request for additional information (RAI), Westinghouse intends to apply the [ ] <sup>a,c</sup> to the **EnCore** chromium coated cladding. While the limit is approximately [ ] <sup>a,c</sup> below the eutectic temperature, the PCTs calculated in the Locked Rotor event are expected to remain significantly below the allowed limit of [ ] <sup>a,c</sup>, even with very conservative assumptions made in the analysis. These conservatisms and the typical results seen are discussed below.

As part of the analysis of the Locked Rotor event, the key parameters for the calculation are conservatively selected. For the PCT and Zr-H<sub>2</sub>O reaction calculations the fuel-clad gap collapses (i.e., fuel-gap heat transfer coefficient is assumed to increase from a steady-state value consistent with the initial fuel temperature to [ ] <sup>a,c</sup>), releasing the large amount of energy stored in the fuel to the clad, and [ ]

] <sup>a,c</sup>.

The maximum allowable hot-spot peaking factor is assumed ( $F_Q$ ). Additionally, maximum fuel pellet average and surface temperatures are assumed including uncertainties. The byproduct of these conservative assumptions is that the PCT and Zr-H<sub>2</sub>O reaction calculated in the analysis are artificially large. However, despite these conservatisms, the PCTs calculated for the Locked Rotor event do not challenge the PCT limit and are typically hundreds of degrees below the acceptance criterion of [ ] <sup>a,c</sup>. Therefore, while the PCT limit and eutectic temperature are only approximately [ ] <sup>a,c</sup> apart, in practice the calculated PCTs for Locked Rotor analyses will remain hundreds of degrees below the eutectic temperature.

a,b,c

**Figure 7-1. Compression Tests for Runs at Nominal [**

**]<sup>a,c</sup>**



a,b,c

**Figure 7-2. Compression Tests for Runs at Nominal [**

**]a,c**

a,b,c

**Figure 7-3. Compression Tests for Runs at Nominal [**

**]<sup>a,c</sup>**

a,b,c

**Figure 7-4. Representative images of (a) Cr penetration zones and specimens that (b) retained and (c) lost the metallic Cr coating. Images pertain to samples subjected to [**

**] <sup>a,c</sup>**

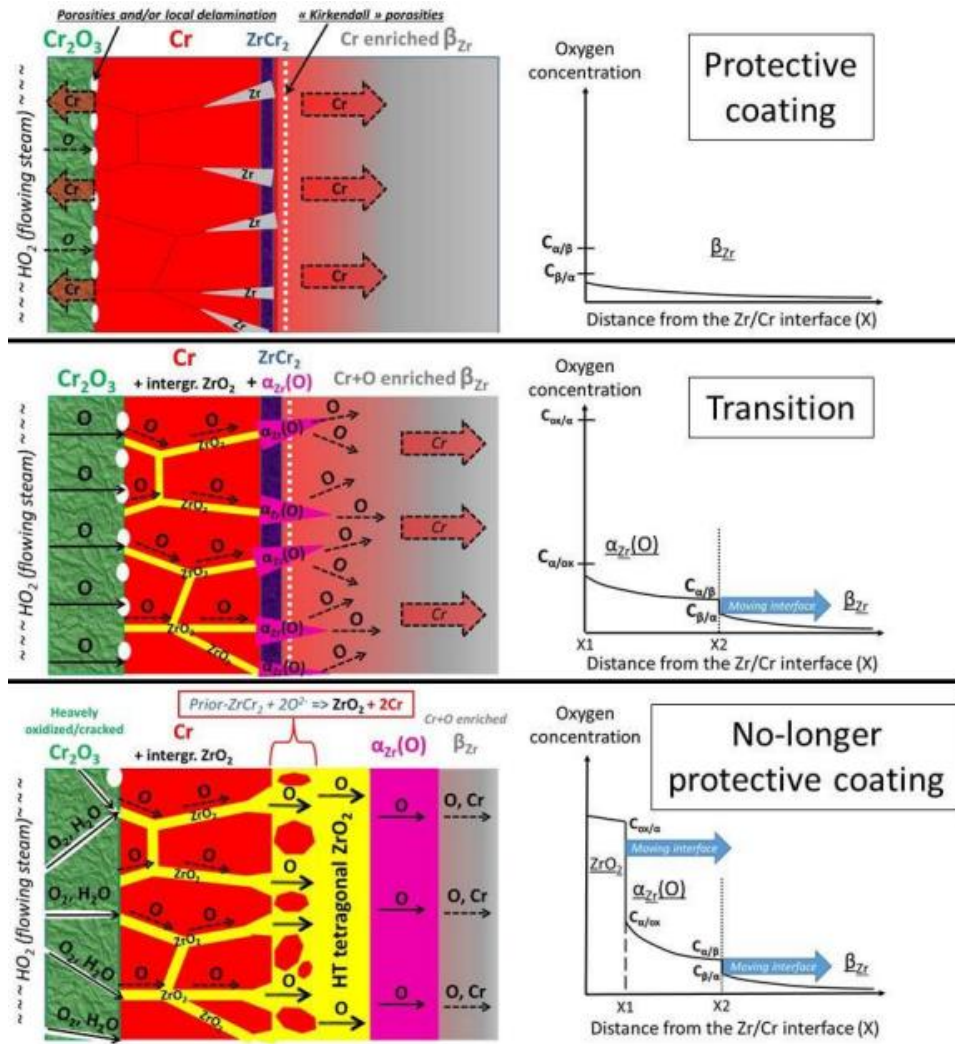


Figure 7-5. Schematic overview of the HT steam oxidation process of Cr-coated zirconium-based (Zircaloy-type) alloys (Reference 7-2)

**Reference(s)**

7-1: [

] <sup>a,c,e</sup>

7-2: Brachet, J-C., Rouesne, E., Ribis, J., Guilbert, T., Urvoy, S., Nony, G., Toffolon-Masclat, C., Le Saux, M., Chaabane, N., Palancher, H., David, A., Bischoff, J., Augereau, J., & Pouillier, E. (2020). High temperature steam oxidation of chromium-coated zirconium-based alloys: Kinetics and process. Corrosion Science, 167, 108537. <https://doi.org/10.1016/j.corsci.2020.108537>

**Request for Additional Information #8**

During the regulatory audit conducted by the NRC staff, Westinghouse stated that there were some errors in the TR. The regulation at 10 CFR 50.9 states that information provided to the Commission by an applicant for a license or by a licensee or information required by statute or by the Commission's regulations, orders, or license conditions to be maintained by the applicant or the licensee shall be complete and accurate in all material respects. As such, please correct any typos/errors in the submittal.

**Response**

The content of this letter is divided into the sections requiring minor updates to the as-submitted topical report. For the updates, the black text is retained from the as-submitted topical report, the blue text denotes additions to the topical report, and the red (strikethrough) text denotes deletions from the submitted topical report. In addition to the below technical corrections, minor formatting corrections (e.g., errant punctuation or bolded brackets) will be incorporated into the approved topical report for consistency.

**Topical Report Section 3.6.1**

There is no change to the originally submitted text for Section 3.6.1. There is a minor change to originally submitted Figure 3.6-1, now shown in Figure 8-1, [

] <sup>a,c</sup>. The

conclusions are not impacted by this change.

] a,b,c

**Figure 8-1 Figure 3.6-1 Combined average normalized corrosion results for simulated PWR water autoclave tests [ ]<sup>a,c</sup>.**

### **Topical Report Section 3.9.1**

There is no change to the originally submitted text for Section 3.9.1. There is a minor change to the x-axis label on Figure 3.9-1 for clarity. The label text and changes are shown below. No data was changed.

[

] <sup>a,c</sup>

### **Topical Report Section 3.11.1**

Minor corrections to the final paragraph and Figure 3.11-8 caption in Section 3.11.1 are shown below. The correction is made to match information provided in the peer reviewed journal referenced in the WCAP (Reference 3.3). The conclusions are not impacted by this change.

To determine the impact of cracks in a postulated accident condition, pre-strained samples were subjected to ~2200 °F (1200 °C) steam [ ]<sup>a,c</sup> at Westinghouse (similar to the test described in Section 3.9.1). Cold sprayed samples were pre-strained in the hoop direction up to an approximate strain of ~~1.1%~~ 2.4% by expanding plug testing at the University of Virginia. An example cross-sectional SEM of a sample after oxidation testing from (Reference 3.3) is shown in Figure 3.11-8. No oxidation was seen at the crack tip in Figure 3.11-8b while the uncoated inner surface (Figure 3.11-8a) had nearly 100 μm thick oxide.

[ ]<sup>a,c</sup>.

Figure 3.11-8 Cross-sectional SEM images of a ~~1.1%~~ 2.4% hoop strained cold spray coated sample after ~2200°F (1200°C) steam oxidation testing for [ ]<sup>a</sup> (Reference 3.3).

### **Topical Report Section 3.11.2.3**

There is no change to the originally submitted text for Section 3.11.2.3. There is a minor change to the x-axis label on Figure 3.11-12 for clarity. The label text and changes are shown below. No data was changed.

[ ]<sup>a,c</sup>

### **Topical Report Section 3.11.8**

Correction of the erroneous melting point for pure Cr listed in relation to the binary Zr-Cr phase diagram provided in Figure 3.11-21.

As with the introduction of any new material, there is a possibility of material reactions with varying temperatures and concentrations. Sometimes for a given material interaction, a new melting phase, or eutectic phase, can develop at which point a lower material melting point than the pure materials can occur. Such a reaction is possible for the Zr-Cr binary system as shown in the phase diagram in Figure 3.11-21 where the individual melting points of Cr and Zr are ~~3465 °F (1907 °C)~~ 3385 °F (1863 °C) and 3371 °F (1855 °C), respectively, but around 22 atomic percent Cr and 2430 °F (1332 °C) a lower melting point (eutectic) occurs. Consideration for this new lower melting temperature was discussed in the (Reference 3.1).

### **Topical Report Section 4.1.3**

Paragraph corrected to add missing link to Table 4.1-2.

In Spring 2020, a second LTR program containing EnCore Chromium Coated [ ]<sup>a,c</sup> LTRs was initiated in Plant AP Unit 4. Four assemblies each contained eight (8) Cr coated LTRs with UO<sub>2</sub> fuel pellets. Select rods contained a higher manufactured rod internal pressure and UO<sub>2</sub> pellets with [ ]<sup>a,c</sup> as shown in Table 4.1-2. Poolside visual inspections were performed after each irradiation cycle. The assemblies have been discharged after completing three cycles of irradiation [ ]<sup>a,c</sup>.

### **Topical Report Section 4.2.8**

Erroneous temperature units in the first paragraph of Section 4.2.8 are corrected. The irradiated mechanical properties of the EnCore Cr Coated [ ]<sup>a,c</sup> cladding were evaluated using a ring tensile test (RTT). The rings were cut from a defueled cladding irradiated for two-cycles [ ]

[ ]<sup>a,c</sup>