Enclosure 3

Responses to Requests for Additional Information on Westinghouse Topical Report WCAP 18546-P/NP, "Westinghouse AXIOM® Cladding for Use in Pressurized Water Reactor Fuel."

(Non-Proprietary)

(22 pages including this cover page)

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Request for Additional Information (RAI) 1:

In Section 7.3 of the audited document **[** **]**a,c Axial rod growth **[** **]**a,c it shows that **[** **]**a,c Also, Figure 5.4-2 of the TR shows **[** **]**a,c Please explain **[** **]**a,c

Response to RAI 1:

It is not uncommon for **[** **]**a,c

In this case, a possible cause could be **[** **]**a,c

RAI 2:

(a) Please provide a discussion on the overall impact on **AXIOM®** cladding behavior due to the presence of Vanadium and Cu in **AXIOM** cladding material during the steady-state (Section 6.1 of the TR) and accident conditions in Section 6.2, "Safety Analysis," of the TR.

(b) Please explain what is the impact of Vanadium and Cu in **AXIOM** on burst temperature and time different from **ZIRLO®/Optimized ZIRLO™**.

Response to RAI 2a:

AXIOM® cladding performance parameters and materials properties that are different from **Optimized ZIRLO** and **ZIRLO** cladding are the following:

- Normal Operation
  - Reduced waterside corrosion at high levels of accumulated thermal reactive duty (TRD)
  - Reduced hydrogen pickup
  - Reduced axial growth
  - Reduced diametrical creep strain
  - **[** **]**a,c
  - **[** **]**a,c

- Accident Conditions
    - **[**

      ][a,c]
    - **[**

      ][a,c]
    - **[**

      ][a,c]

The performance differences are due to the combined effects of differences in chemical composition and microstructure as shown in Table 1.2-1 of WCAP-18546. Along with the Vanadium (V) and Copper (Cu) additions, there is also a reduction in Niobium (Nb) and Tin (Sn) content in **AXIOM** cladding compared to **Optimized ZIRLO** and **ZIRLO** cladding, as well as a higher degree of recrystallization. The impact of V and Cu additions are not separated from other differences and are not quantified. V and Cu additions were expected to improve the corrosion and hydrogen pickup (HPU) performance based on empirical experience of the original developers and may play a role in all the performance differences for **AXIOM** cladding, but the amount of the impact due to each element is not separately quantifiable.

AXIOM cladding development started over 20 years ago by melting and testing more than 40 alloy compositions with varying levels and combinations of elements for autoclave corrosion testing. Compositions included Zr-Nb-Sn alloys with Cu only, V only, combinations of Cu and V as well as with other alloying elements. The selection of alloying elements was based on literature searches and years of zirconium alloy development experience and Westinghouse materials expertise. There were no published references with both V and Cu addition to Zr-Nb-Sn alloys. A series of iterative experiments identified composition combinations that yielded promising corrosion performance. Alloy compositions were further refined, ultimately leading to 5 compositions being identified for in-reactor testing. The final selection of the **AXIOM** cladding chemical composition considered in-reactor performance and accident performance via testing. Thus, the alloying element combination and levels for **AXIOM** cladding were empirically determined.

WCAP-18546 addresses the overall performance of this novel cladding which incorporates the unique combination of alloy composition and microstructure. As stated in Chapter 7 of WCAP-18546, “The topical report describes in detail how the properties and performance of

AXIOM cladding are incorporated into existing NRC-approved analytical methods for use in plant-specific safety analyses. Where differences compared to existing claddings have been identified, new models and methods have been developed so that the new cladding alloy can be appropriately analyzed to show compliance with all pertinent regulations and requirements."

Response to RAI 2b:

As noted in Section 6.2.1.2.2 of WCAP-18546, generally, the LOCA burst tests for **AXIOM** cladding fall within the uncertainty range of the **ZIRLO** and **Optimized ZIRLO** cladding data. However, **[**

]a,c

Again, this **[** **]a,c** is due to the combined effects of differences in chemical composition and microstructure (as described in RAI 2a). The impact of V and Cu additions are not separated from other differences and are not quantified. In general, the Cu and V are in Second Phase Particles (SPPs) at low temperatures and then in solution at high temperatures in the beta phase. Since they are in minor amounts, their impact is expected to be minimal on the burst temperature.

As described in Section 6.2.1.2.2 of WCAP-18546, to account for the **[**

]a,c the nominal burst temperature is recalculated at each differential pressure. That is, the **AXIOM** cladding burst model in the **FULL SPECTRUM™** LOCA (**FSLOCA™**) evaluation model (EM) accounts for the **[**
]a,c

RAI 3:

Section 7.2 of the audit document **[** **]a,c** is used to develop the hydrogen pickup model. Please explain why this is acceptable.

Response to RAI 3:

Significant plant-to-plant variations in hydrogen pickup were not seen for **ZIRLO** and **Optimized ZIRLO** cladding, therefore significant variation is not expected for **AXIOM** cladding.

RAI 4:

In the document **[**

][a,c]

Also, in Section 6.2.1.2.2 of WCAP-18546-P there is the following statement:

[

][a,c]

Please explain why/how **AXIOM** cladding data includes **[**
][a,c]

Response to RAI 4:

The LOCA burst tests for **AXIOM** cladding (Figure 6.2-4 of WCAP-18546-P Revision 0) **[** **][a,c]** the **ZIRLO** cladding burst tests (Figure 29.4.2-1 of Reference 4.1). The **[**

][a,c]

Reference(s)

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

RAI 5:

Section 4.1 of **[**

][a,c] Please provide a justification for this **[**

][a,c]

Response to RAI 5:

Figure 6.2-4 of WCAP-18546-P Revision 0 displays the data and the **[**

]a,c

Reference(s)

5.1 WCAP-12610-P-A & CENPD-404-P-A, Addendum 1-A, "**Optimized ZIRLO,**" July 2006.

5.2 PNNL-19400, Volume 1, Revision 2, "FRAPTRAN-2.0: A Computer Code for the Transient Analysis of Oxide Fuel Rods," May 2016.

[ ]a,c

Figure 5-1: Comparison of [ ]a,c

RAI 6:

In Figure 10 of **[ ]a,c** (Figure 6.2-6 of TR) that plots Circumferential Burst Strain against Burst Temperature, there is a **[ ]a,c** Please justify the extension.

Response to RAI 6:

Figure 6.2-6 of WCAP-18546-P Revision 0 displays the data and the proposed **AXIOM** cladding nominal burst strain model. A constant **[**]a,c

[

][a,c]

Reference(s):

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

RAI 7:

[ ][a,c] and Figure 6.2-20 of the TR proposes limits for loss-of-coolant accident (LOCA) PQD (i.e., ECR vs. H content) up to [ ][a,c] H. Please explain how rods with pre-transient H concentrations above [ ][a,c] will be treated.

Response to RAI 7:

Westinghouse does not anticipate cladding hydrogen contents above [ ][a,c]. If future post-irradiation exam (PIE) results at high duty show higher hydrogen content, the ECR limit is expected to follow the slope developed between 100 and [ ][a,c] to higher hydrogen levels.

RAI 8:

Please explain why the normal operation hydrogen content limit of [ ][a,c] is acceptable, given that the proposed LOCA PQD limit curve (i.e., ECR vs. H content) (Figure 3.11-2 of the TR) only extends to [ ][a,c] H.

Response to RAI 8:

The normal operation limit is separate from the LOCA limit. Testing of various zirconium cladding alloys shows ductility up to [ ][a,c] for normal operating conditions as shown in WCAP-12610-P-A & CENPD-404-P-A, Addendum 2-A (Reference 8.1). This includes ductility data from fully recrystallized anneal (RXA) BWR cladding in Figure 3.3-14 of that WCAP demonstrating similar applicability to the partial recrystallized anneal (pRXA) **AXIOM** cladding.

The various criteria are established based on independent phenomenon. The cladding best estimate (BE) oxide limit is based on oxide layer stability, the BE cladding hydrogen limit is based on cladding strain capability. These criteria were justified in section 3 of

WCAP-12610-P-A & CENPD-404-P-A, Addendum 2-A (Reference 8.1), for modern Zirconium based cladding independent of specific alloy. These criteria can be applied to **AXIOM** cladding based on the similarity behavior at operating temperature conditions. The PQD based ECR limit is based on the expected range of LOCA transient ECR and pre-transient cladding hydrogen. If future PIE results at high duty show higher hydrogen content, the ECR limit is expected to follow the slope developed between 100 and **[ ]**[a,c] to higher hydrogen levels and the oxide layer thickness would still be in a stable range.

Reference(s):

8.1 WCAP-12610-P-A & CENPD-404-P-A, Addendum 2-A, "Westinghouse Clad Corrosion Model for **ZIRLO** and **Optimized ZIRLO**," October 2013.

RAI 9:

(a) Document **[ ]**[a,c] provides the details on the uncertainty calculations. Section 5.1.3.5 of TR briefly describes corrosion model uncertainties calculation (eq. 5.1-3). Please provide details of how the uncertainty in corrosion model is determined.

(b) Are AXIOM models for corrosion and hydrogen pick up similar to the PAD5 (Ref. 1) *[Reference 9b.1 in response]* models for **ZIRLO**/**Optimized ZIRLO**? If not, what are the modifications to PAD5 models.

Response to RAI 9a:

The base BE oxide model is listed in WCAP-18546, section 5.1.3.4 on page 5-3 and the oxide model UB uncertainty is provided in section 5.1.3.5 on page 5-3. Uncertainties were determined using the MiniTab statistical program. The relationship between the best estimate and upper bound oxide vs Accumulated TRD is provide in WCAP-18546, Figures 5.1-4 to 5.1-8 on pages 5-7 to 5-9.

Use of the uncertainties to determine an upper bound hydrogen for LOCA are provided in WCAP-18546-P, section 5-3 starting on page 5-16. These are shown in Figures 5.3-1 on page 5-17 and Figure 5.3-3 on page 5-18. For the REA, Figure 5.3-2 and Figure 5.3-4 show the uncertainty. For the specific steps in determining the oxide model uncertainty the following is performed using the chosen BE corrosion model.

1. **[**

][a,c]

2. **[**

3.

4.

5. **]**[a,c]

Response to RAI 9b:

The **AXIOM** models for corrosion and HPU are mostly the same models used for **Optimized ZIRLO** cladding in PAD5 (Reference 9b.1).

For corrosion the determination of Accumulated TRD is the same for both **AXIOM** and **Optimized ZIRLO** cladding. The only difference is the equation for oxide thickness as a function of TRD (Equation 5.1-1 and 5.1-2 in WCAP-18546).

For HPU the determination of hydrogen is the same for both **AXIOM** and **Optimized ZIRLO** cladding. The only difference is the **[**
][a,c]

Reference(s):

9b.1 WCAP-17642-P-A, Revision 1, "Westinghouse Performance Analysis and Design Model (PAD5)," November 2017.

RAI 10:

(a) U.S. Westinghouse plants continue to meet the **AXIOM** fuel cladding allowable limits for Condition III and IV, but not Condition II Operation Basis Earthquake (OBE) load. Please explain this process for complying with Condition IV.

(b) Please explain when the beginning of life (BOL) seismic and LOCA stress analysis are applicable and when the end-of-life seismic stress analysis is applicable.

(c) Please explain the stress criterion used for BOL Condition II (OBE) seismic events.

Response to RAI 10a:

There are many conservative factors in the stress analysis results of Condition II OBE load AOR cases. A compressive strength criterion is used for BOL Condition II (OBE) seismic events. Previously, compressive and tensile stresses were analyzed using the same criteria. The tensile strength criterion is more limiting than the compressive criteria. The

compressive criterion used in evaluation is the same as used in the PAD5 Topical WCAP-17642-P-A (Reference 10a.1). There is no criteria difference for Condition III and IV load limits for compressive and tensile loading.

Reference(s):

10a.1 WCAP-17642-P-A, Revision 1, "Westinghouse Performance Analysis and Design Model (PAD5)," November 2017.

Response to RAI 10b:

The BOL analysis is for as-built, unirradiated fuel assemblies at operating temperature. When the gap between the fuel rod and the grid opens and stabilizes, the EOL analysis is applicable. WEC conducted an analysis to calculate the fuel rod-to-grid gap conditions, which factors in swelling of the fuel rod and growth of the grid.

Response to RAI 10c:

A compressive strength criterion is used for BOL Condition II (OBE) seismic events. Previously, compressive and tensile stresses were analyzed using the same criteria. The tensile strength criterion is more limiting than the compressive criteria. The compressive criterion used in evaluation is the same as used in the PAD5 Topical WCAP-17642-P-A (Reference 10c.1).

Reference(s):

10c.1 WCAP-17642-P-A, Revision 1, "Westinghouse Performance Analysis and Design Model (PAD5)," November 2017.

RAI 11:

[ ]^{a,c} says that the finite element models (FEA) are used at BOL in mechanical analyses instead of PAD5 because **AXIOM** has **[ ]**^{a,c} compared to **ZIRLO** and **Optimized ZIRLO**. Please provide additional details on why the FEA models are used for calculations instead of PAD5 for **AXIOM** at BOL.

Response to RAI 11:

Fuel Rod Design (FRD) group has concluded that "It is expected that the **[ ]**^{a,c} will not meet the licensed limits detailed in the PAD5 topical for BOL conditions." Therefore, for **AXIOM** cladding, the clad stress will require consideration of alternate simulation for addressing the **[ ]**^{a,c} of **AXIOM** cladding material compared to **ZIRLO** and **Optimized ZIRLO** cladding material. This alternate simulation requires additional testing and development of

an alternate method of the PAD5 clad stress criterion to mitigate the **[** **]**^{a,c} of **AXIOM** cladding material.

WEC implemented the use of strain acceptance criteria in the rod cladding stress analysis. WEC used FEA models to calculate BOL strain, which were benchmarked to the autoclave test. The FEA models can provide a more detailed stress distribution than the PAD5. The BOL FEA analyses loads and the stress definition are consistent with the PAD5 analysis loads and clad stress defined methodology.

Due to the **[** **]**^{a,c} to maintaining the PAD5 clad stress acceptance criteria at BOL. As such, WEC implemented the use of FEA models which were benchmarked by autoclave tests to calculate BOL strain. The FEA calculation can calculate a more detailed local strain and stress distribution than the previously licensed PAD5 methodology. The FEA calculation provides assurance that the cladding integrity is maintained.

RAI 12:

(a) Please provide plots of yield strength and ultimate tensile strength UTS as a function of burnup for both **AXIOM** and **Optimized ZIRLO**.

(b) Please provide any rod bow data collected for **AXIOM** cladding and documentation on the **AXIOM** rod bow models.

(c) For the plots in Section 5.4.1, "Fuel Rod Axial Growth Model," of the TR where fluence is the independent variable, please provide plots that show peak rod average as an independent variable or identify on the plots the 62 and 68 GWd/MTU peak rod average equivalent.

Response to RAI 12a:

The data are plotted as a function of rod average burnup in Figure 12(a)-1 for yield strength (YS) and in Figure 12(a)-2 for ultimate tensile strength (UTS) for both **AXIOM** and **Optimized ZIRLO** claddings. Note that there is **[** **]**^{a,c} The basis for stating that **[**

]^{a,c}

In response to the **Optimized ZIRLO** cladding topical report RAI #25 (Reference 12a.1, page 329, response 25), yield strength of unirradiated and irradiated RXA **ZIRLO**, RXA Zircaloy-4 as well as stress relief annealed (SRA) Zircaloy-4 were compared. The results

show that "even with different alloys and different heat treatments that the irradiation hardening has an overriding equalizing effect on the mechanical strength of zirconium-based material which have minor differences in alloy content."

Figure 12(a)-3 is a plot which shows that the yield strength for **[**

]^{a,c} Studies also show that **[**

]^{a,c}

In response to NRC Condition 8.a in Section 5.0 of the Safety Evaluation Report (SER) to the topical report prepared for **Optimized ZIRLO** cladding WCAP-12610-P-A & CENPD-404-P-A Addendum 1-A (Reference 12a.1), low fast fluence irradiated data for **Optimized ZIRLO** cladding and **ZIRLO** cladding have been obtained. The data demonstrate that the irradiated yield stress and ultimate stress for **Optimized ZIRLO** cladding exceed the irradiated yield and ultimate stress values for **ZIRLO** cladding used in Westinghouse fuel design analysis at very low fluence levels by **[**

]^{a,c} (Reference 12a.2) due to irradiation hardening effects. Figure 12(a)-4 shows the low fast fluence irradiated data for **Optimized ZIRLO** and **ZIRLO** claddings materials.

Based on these studies, zirconium alloys SRA Zircaloy-4, RXA Zircaloy-2, **ZIRLO** cladding and **Optimized ZIRLO** cladding all demonstrate irradiation hardening and reach similar strength by **[** **]**^{a,c} **AXIOM** cladding with minor difference in alloy composition is expected to have the same irradiation hardening behavior as **ZIRLO** and **Optimized ZIRLO** cladding.

a,c

Figure 12(a)-1, Cladding Yield Strength vs Rod Average Burnup

a,c

Figure 12(a)-2, Cladding Ultimate Tensile Strength vs Rod Average Burnup

a,c

Figure 12(a)-3 Yield Strength for Various Zirconium Claddings

[ ]a,c

Figure 12(a)-4 Optimized ZIRLO (OZ) Cladding Yield Stress and ZIRLO (Z) Cladding Yield Stress versus Fast Fluence (RTT at 385ºC), Compared to the Optimized ZIRLO Cladding Yield Stress by SER Condition 8.a and the Irradiated ZIRLO Cladding Yield Stress Used in Westinghouse Design Analysis (Figure 4 in LTR-NRC-15-84, Reference 12a.2)

Reference(s):

12a.1 WCAP-12610-P-A & CENPD-404-P-A, Addendum 1-A, "**Optimized ZIRLO**," July 2006.

12a.2 LTR-NRC-15-84, "Submittal of Response to Condition 8.a of the Safety Evaluation Report (SER) on WCAP-12610-P-A & CENPD-404-P-A Addendum 1-A, "**Optimized ZIRLO**," (Proprietary/Non-Proprietary)," September 2015.

Response to RAI 12b:

There have been a number of irradiation programs in commercial reactors with fuel assemblies (FA) using **AXIOM** lead test rods (LTRs) as described in Chapter 4 of WCAP-18546. For all these comprehensive irradiation programs, standard visual inspections were conducted on all **AXIOM** clad fuel assemblies after each cycle of irradiation. In addition, some detailed visual inspections using high magnification camera have been conducted on selected assemblies with a focus on examining rod bows. No rod bow (reduced rod to rod spacing, or non-straight extracted rods) was observed in **AXIOM** clad fuel rods. **[**

]a,c

[

]a,c The **AXIOM** rod bow behavior was comparable to other Westinghouse cladding material such as **ZIRLO** or **Optimized ZIRLO** cladding. Based on these observations, [

]a,c on the **AXIOM** cladding, as described in Reference 12b.1.

In addition to the visual inspection, rod-to-rod spacings (channel closure) were measured in one assembly with **AXIOM** clad fuel rods from Plant T **AXIOM** lead test assembly (LTA) project. The channel closure measurement values for Plant T are included in the channel closure measurements database from some European plants. The Plant T data are shown in Figure 12(b)-1 as [ ]a,c The FA with **AXIOM** fuel rods is the red filled circle at [ ]a,c in Figure 12(b)-1. It can be observed that the water channel closure for all FAs examined, particularly at higher burnups, is below the tolerance limit of the gap closure correlation (Reference 12b.2) that defined the current rod bow penalty for Westinghouse 17x17 fuel designs.

[ ]a,c

Figure 12(b)-1 Flow Channel Closure Maximum Standard Deviation, %

Reference(s):

12b.1 LTR-NRC-11-40, “Re-send of WCAP-8691-R1, “Fuel Rod Bow Evaluation” and Accompanying SER for Information Only (Proprietary),” August 2011.

12b.2 NS-EPR-2572, “Remaining Response to Request Number 1 for Additional Information on WCAP-8691, Revision 1,” March 1982.

Response to RAI 12c:

Figures 5.4-1, 5.4-2, and 5.4-3 in the Topical Report WCAP-18546 have been reproduced in Figures 12(c)-1, 12(c)-2, and 12(c)-3, respectively, as a function of rod average burnup. It is noted that the rod axial growth model is developed as a function of rod average fast neutron fluence, not of rod average burnup. There are slight variations in the fluence models, as a function of burnup, among the different fuel designs.

a,c

Figure 12(c)-1 Fuel Rod Growth Data for AXIOM, Optimized ZIRLO and Standard ZIRLO Alloys as a Function of Rod Average Burnup

a,c

Figure 12(c)-2 AXIOM Cladding Axial Rod Growth Data and Rod Growth Model Predictions as a Function of Rod Average Burnup

a,c

Figure 12(c)-3 AXIOM Cladding Axial Rod Growth Model Measured Minus Predicted Residual Plot as a Function of Rod Average Burnup

RAI 13:

In **[ ]^{a,c}** it states that the seismic and LOCA analysis is done for RFA-2 and OFA fuel designs (W). Was the analysis done for CE reactor fuel design, 14x14 and/or 16x16 fuel assembly designs?

Response to RAI 13:

The seismic and LOCA analyses performed are just two examples (based on Westinghouse licensed methodology). When the **AXIOM** fuel cladding is implemented, the seismic and LOCA analysis for CE fuels, 14x14 and/or 16x16, will be evaluated using the same process (based on CE licensed methodology) as the two examples.

RAI 14:

[ ]^{a,c} describes 10 CFR 50.46 acceptance criteria (AC) for **AXIOM** cladding. Most of the elements of criteria are based on **[ ]**^{a,c} **AXIOM**. What is (if any) the difference in **AXIOM** behavior with respect to LOCA AC for **Optimized ZIRLO**?

Response to RAI 14:

No changes to the current 10 CFR 50.46 acceptance criteria have been identified for **AXIOM** cladding. However, **[**

]^{a,c}

RAI 15:

[ ]^{a,c} provides details on non-LOCA AC for **AXIOM** cladding. What is the impact of **AXIOM** cladding on control rod drop accidents (RIA) using Regulatory Guide (RG) 1.236, “Pressurized-Water Reactor Control Rod Ejection And Boiling-Water Reactor Control Rod Drop Accidents”?

Response to RAI 15:

For RIA, control rod drop (CRD) accidents only apply to boiling water reactors (BWRs). For pressurized water reactors (PWRs) where **AXIOM** cladding will be used the applicable RIA event is control rod ejection (CRE). The impact on CRE or RIA limits is discussed in Section 3.10.1 of WCAP-18546, which documents the **AXIOM** cladding pellet-clad mechanical interaction (PCMI) failure threshold limits based on an interpolation of SRA and RXA PCMI limits in RG 1.236 (Reference 15.1). As noted in Section 6.2.2.2 of WCAP-18546, the RG 1.236 limits, and the **AXIOM** cladding-specific limits in Section 3.10.1 for CRE core coolability and fuel and cladding failure will be addressed as part of the implementation of the three-dimensional (3-D) rod ejection analysis methodology (WCAP-15806-P-A) (Reference 15.2) for a specific plant.

Reference(s):

15.1 U.S. NRC Regulatory Guide 1.236, Revision 0, “Pressurized-Water Reactor Control Rod Ejection and Boiling-Water Reactor Control Rod Drop Accidents,” June 2020 (ADAMS ML20055F490).

15.2 WCAP-15806-P-A, Revision 0, “Westinghouse Control Rod Ejection Accident Analysis Methodology Using Multi-Dimensional Kinetics,” November 2003.

RAI 16:

Tables 3.2-2 and 3.2-3 of the TR lists phase transition temperatures from DSC and thermal expansion, respectively. Please explain what constitutes tube reduced extrusion material. Also explain why there are discrepancies in the corresponding temperatures listed.

Response to RAI 16:

TREX is the acronym for Tube Reduced Extrusion. It is an intermediate size tube produced during the cladding manufacturing process with the approximate dimensions of 2.5-inch outer diameter x 0.43-inch wall thickness. **[**

][a,c] as discussed in WCAP-18546 Section 3.2.

Tables 3.2-2 and 3.2-3 of WCAP-18546 lists the phase transition temperatures determined from differential scanning calorimetry (DSC) specific heat testing and from dilatometer thermal expansion testing, respectively. The testing methods for specific heat and thermal expansion are vastly different. The DSC tests measure thermal energy input using a very small disk sample of approximately 5.2 mm diameter by 1 mm thick (around 135 milligrams) and a heating rate of 20°C/min. The dilatometer measures dimensional changes and is more of a bulk test using 6 mm diameter by 12 mm long rods and a slower heating rate of 3°C/min. Both tests provide a general estimated range of where the transition is located but do not yield identical results due to the differences in the testing techniques. Additionally,

there is some test-to-test variation with each technique from general repeatability and local sample chemistry variations.

Therefore, the differences in temperatures within each technique table represent testing variation. Differences between the techniques is inherent in the different methods and expected. Since an exact phase transformation isn't determined by these complimentary tests, a general range incorporating both sets of results is used for analysis as concluded in Section 3.2.3 of WCAP-18546.

RAI 17:

For several of the mechanical properties of **AXIOM** such as specific heat (Section 3.2.1 of TR Figures 3.2-1 and 3.2-2), thermal expansion in axial direction (Section 3.2.2, Table 3.2-1), phase transition temperatures (Section 3.2.3, Tables 3.2-2 and 3.2-3), thermal diffusivity and thermal conductivity (Section 3.2.4, Figures 3.2-5 and 3.2-6) three to four samples have been represented for each of the properties. Please provide the composition of each of these samples.

Response to RAI 17:

Table 17-1 below shows the average ingot composition for **AXIOM** cladding samples in the thermal analysis section of WCAP-18546. The majority of the samples were obtained from ingot U09089E material. The **AXIOM** Sample 4 in Figures 3.2-1 and 3.2-2 along with the samples listed in the first row of Tables 3.2-2 and 3.2-3 are from ingot U05377E material. The chemical composition ranges for **AXIOM** cladding as shown in Table 1.2-1 of WCAP-18546 are also listed for comparison.

Table 17-1: AXIOM Cladding Sample Composition for Thermal Property Results

a,c

WCAP-18546 Table/Figure #	**Ingot**
Samples 1-3 in Figures 3.2-1, 3.2-2, 3.2-3, 3.2-5 & 3.2-6	U09089E
Rows 3-5 in Table 3.2-1	
Rows 2-4 in Tables 3.2-2 and 3.2-3	
Sample 4 in Figures 3.2-1 and 3.2-2	U05377E
Row 1 in Tables 3.2-2 and 3.2-3	
AXIOM Cladding Range	