U. S. NUCLEAR REGULATORY COMMISSION

REQUEST FOR ADDITIONAL INFORMATION (RAI) QUESTIONS FOR

REVIEW OF WESTINGHOUSE ELECTRIC COMPANY (WESTINGHOUSE)

TOPICAL REPORT (TR) WCAP-17642-P, REVISION 0, AND WCAP-17642-NP, REVISION 0,

"WESTINGHOUSE PERFORMANCE ANALYSIS AND DESIGN MODEL (PAD5)" – SET 2

(TAC NO. MF3096)

General Comment: Section 7 of the Westinghouse TR WCAP-17642-P, Revision 0, and WCAP-17642-NP, Revision 0, "Westinghouse Performance Analysis and Design Model (PAD5)," provides an overview of the fuel design bases and fuel performance analysis methodologies used by Westinghouse to provide assurance that the fuel design and expected operational demands meet the regulatory requirements. While the overview provides an informative introduction to the approach Westinghouse anticipates using, the description is inadequate to review and provide acceptance of PAD5 for use in fuel design and safety analyses. The indeterminate language used in describing 1) the preparation of code input data, 2) the treatment of uncertainties, and 3) the methods used to demonstrate compliance to the fuel rod design criteria does not provide the reviewers sufficient information to assess the margin of safety in the use of PAD5 by Westinghouse. Extensive use of the words “may be used” or similar language can be found in the following:

- How the input information is defined for PAD5 (7.2.1).
- How the PAD5 output information is used in the safety analysis (7.2.2).
- How uncertainties in input data, models, and methods are incorporated into the design and safety analysis methodology (7.3.1.2).
- How the limiting fuel rod power histories are generated (7.3.2).
- How the design and safety analysis will be used to demonstrate compliance to the fuel rod design criteria (7.4).

The use of “may be used” language should be avoided in TR or a Licensing Amendment Report. The U. S. Nuclear Regulatory Commission (NRC) approval in the Safety Evaluation (SE) will include the words “shall be used” rather than “may be used.” The text in other sections of the TR are also not always clear on how the code will applied. It is suggested that Section 7 be rewritten to expand on the details describing the PAD5 application methodologies for each specified acceptable fuel design limits (SAFDL) and event in Tables 7.1-2, 7.1-3, 7.1-4, and 7.1-5. This will provide a road map of the methodology for fuel design and safety analysis. In lieu of a more complete description of the fuel design and safety analysis methodology, a set of RAIs have been prepared based on the current Section 7 material. The RAIs 20-22 and 32 below are intended to provide clarity on how PAD5 will be used for the different SAFDLs. It is possible that due to the brevity of Section 7, the responses to RAI questions below will be incomplete.

General Comment on PAD5 uncertainty calculations: The statistical bounds applied to most of the best estimate models presented in the submittal are only at a 95 percent probability level. Previous approvals for other vendors with best estimate fuel performance models and codes have required a 95 percent probability with a 95 percent confidence (95/95) that is more limiting than a 95 percent probability. Previously versions of PAD that were approved with only a 95 percent probability rather than a 95/95 were approved because these previous versions were found to have some level of conservatism in its comparisons to the data available (relatively low burnup temperature data) at the time of approval. Therefore, the NRC staff at the time concluded that due to the inherent conservatism in the earlier PAD versions with a 95 bounding analysis was more conservative than a best estimate prediction with a 95/95 bound and was adequately conservative. This issue of applying a 95/95 bounding analysis is discussed further in several of the RAI questions below.

RAI-21 requests information on the estimation of PAD5 uncertainties and how they are applied in the statistical evaluation of fuel performance parameters such as, rod internal pressure, fuel average temperature, cladding corrosion, fatigue, cladding strain, initial stored energy and any other parameters that are used in the loss of coolant accident (LOCA) analysis initialization. The agency has approved fuel performance models of other fuel vendors with a minimum of 95% probability with a 95% confidence (95/95) level. In the absence of a 95/95 uncertainty analysis, the agency will require the applicant to propose a suitable penalty for all appropriate fuel performance parameters that are analyzed in PAD5 TR, to compensate for the lack of 95/95 uncertainty analysis.

1) The following are related to determining the operational (power and burnup) range the code has been calibrated and validated against. The requested plots will provide clarity on the operational range of data the code has been verified/calibrated against.

RAI-1a – Please provide rod average linear heat generation rate (LHGR) versus burnup for the thermal data used to calibrate and validate the code. Provide separate plots for UO_2 and gadolinia rods.

RAI-1b – Please provide rod average LHGR versus burnup for the fission gas release data used to calibrate and validate the code. Provide separate plots for UO_2 and gadolinia rods.

RAI-1c – Please provide terminal peak and rod average LHGR versus burnup for the transient fission gas release data from power ramp tests used to calibrate and validate the code. Provide separate plots for UO_2 and gadolinia rods.

RAI-1d – Please provide terminal local (at location of measurement) LHGR versus burnup for the cladding diameter change data from power ramp tests used to calibrate and validate the code. Provide separate plots for UO_2 and gadolinia rods.

RAI-1e – Please provide rod average LHGR versus burnup for cladding corrosion and hydriding data used for calibration and validation for each cladding type.

2) The following are in reference to the limits of applicability of the code (Section 2.3 of WCAP-17642-P, Revision 0, and WCAP-17642-NP, Revision 0)).

RAI-2a – The code is stated to be applicable to fuel pellets coated with ZrB_2 however no limits are provided on the ZrB_2 coating specifications (e.g., ^{10}B enrichment, coating thickness, etc.) that can be modeled by PAD5. Please define the range of applicability

of the ZrB_2 coating performance models used in PAD5. Please indicate if the ranges are based on in-reactor experience, separate effects testing, or analysis assumptions.
RAI-2b – An applicable range of fuel pellet grain sizes are defined for use with PAD5. Please provide a plot of predicted-minus-measured fission gas release versus fuel grain size for measured FGR values > 5%; state whether grain size is 3D or mean linear intercept (MLI), including the data comparisons requested in RAI-8a. Identify the UO_2 and gadolinia rod data in these plots. Please provide a similar plot of predicted-minus-measured cladding hoop strain versus fuel pellet grain size from power ramping (transient) tests.
RAI-2c – The code is said to be applicable to initial fuel densities of **[ ]** theoretical density (TD). Please identify those data used for calibration and validation at an initial fuel pellet density of **[ ]** TD. Are there currently fuel being fabricated with **[ ]** TD for reloads, if so please provide a description of their application, density variation within a pellet, and microstructure. If not, please provide the data to substantiate that fuel with these fuel densities have been fabricated on a large scale without issues related to pellet cracking and radial/axial density variations as a result of fabrication.
RAI-2d – A limit of **[ ]** gadolinia has been requested, however, it appears that the code has not been verified **[ ]** gadolinia. Please provide justification for this **[ ]** limit of gadolinia including past experience.
RAI-2e – The applicability of PAD5 to ^{235}U enrichments up to **[ ]** is indicated in Section 2.3. It is understood that the calibration and validation database includes test reactor rods with enrichment levels at these levels or higher, this is acceptable. However, there is limited experience with commercial fuel operating with ^{235}U enrichments greater than 5 percent. Please provide the justification for the use of PAD5 for commercial fuel performance analysis at enrichment levels of ^{235}U greater than 5 percent.

3) WCAP-12610-P-A and CENDPD-404-P-A, Addendum 2-A, "Westinghouse Clad Corrosion Model for Zirlo and *Optimized* Zirlo," provides a description of the ZIRLO and *Optimized* ZIRLO cladding corrosion models and the corrosion layer thickness and hydrogen content limits for these materials. Furthermore, the NRC issued SE on the TR following a review process that spanned 5 years. The SE approved the use of the ZIRLO and *Optimized* ZIRLO corrosion model based on a correlation between the thermal reaction accumulated duty (TRD) parameter and the measured corrosion layer thickness. The TRD is calculated by **[**

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The SE also approved the use of a best-estimate limit on the maximum cladding corrosion layer thickness (100 microns) and the hydrogen content **[ ]**. While the documentation in WCAP-12610-P-A and CENDPD-404-P-A, Addendum 2-A, addresses the use of the model and limits **[ ]** the details regarding how the model will be used in the core design and fuel design process to demonstrate that the SAFDLs for normal operation, anticipated operational occurrences,

and postulated accidents is not adequately described to understand the impact of uncertainties arising from design methodology, operational variations, fabrication tolerances, and material behavior. In addition, the approval of WCAP-12610-P-A and CENDPD-404-P-A, Addendum 2-A, was based on Westinghouse commitment "to continue to gather surveillance data for cladding corrosion at elevated values of TRD." The NRC SE specifically concentrated on the need for additional surveillance data from *Optimized* ZIRLO at high TRD and high lithium or zinc in high subcooled boiling conditions. The following will address the additional corrosion data collected since the data provided as part of the WCAP-12610-P-A and CENDPD-404-P-A, Addendum 2-A, approval and whether this additional data continues to validate (confirm) the approved models.

The following questions are needed for clarification to understand the application of the model and limits as specified in WCAP-12610-P-A and CENDPD-404-P-A, Addendum 2-A.

RAI-3a – Recent *Optimized* ZIRLO data obtained from three or more reactors with extended TRD values are provided in LTR-NRC-12-40 P-Attachment (See Figures 2-1, and 2.3-13). Please tabulate the TRD values, measured corrosion layer thickness, measured hydrogen content (if available), and the calculated corrosion layer thickness and hydrogen content for each measurement/sample. Please include any mechanical property data (yield stress, uniform elongation, and total elongation) that is available for these samples. Please describe the approach used to obtain the TRD, the calculated corrosion layer thickness and hydrogen content (e.g., how the power histories were generated, what codes were used to develop the coolant channel conditions, etc.). Lastly, please include any additional corrosion and hydrogen content data from *Optimized* ZIRLO cladding obtained since the preparation of LTR-NRC-12-40 along with model predictions.

RAI-3b – Section 2.4 of Addendum 2-A provides oxide thickness data and calculated results for ZIRLO irradiated under 'High' Lithium and Zinc Addition conditions (M vs P in Figure 2.4-1 and M-P vs P in Figure 2.4-2). Please add any available data from *Optimized* ZIRLO from High Lithium operation conditions (using a different color or symbol to identify the points). Please provide a similar table as that shown Table 2.4-1 for *Optimized* ZIRLO data.

RAI-3c – Figure 2.3-10 in WCAP-12610-P-A, Addendum 2-A, M-P corrosion layer thickness vs TRD for *Optimized* ZIRLO. The data **[**

] particularly compared with the data for ZIRLO in Figure 2.2-10. Please add the additional data for *Optimized* ZIRLO listed in LTR-NRC-12-40 and any new corrosion data for *Optimized* ZIRLO that has been obtained since the issuance of LTR-NRC-12-40.

RAI-3d – Section 3.0 of Addendum 2-A, "Clad Corrosion Model Criterion and Design Methodology," addresses Strength and Ductility of the cladding material, however, only hydrogen content and mechanical property data for Zircaloy-4 (79 data points) and ZIRLO (40 data points) are provided (Ref: Table 3.3-1 and Figures 3.3-1 through 3.3-7). Subsequently, LTR-NRC-12-40 provides limited data on hydrogen content (M vs P in Figure 2-1) for 11 data points (4 Low-Tin ZIRLO and 7 *Optimized* ZIRLO) from three reactors and oxide thickness (M vs P for 14 *Optimized* ZIRLO fuel rods in Figure 2.3-13)

from one “high burnup LTA.” Please indicate the material type for the hydrogen content data shown in Figure 2-1 of LTR-NRC-12-40. Please include any new hydrogen content data for *Optimized* ZIRLO. Please describe the calculation used to obtain the predicted hydrogen content values in Figure 2-1 in LTR-NRC-12-40 and any additional data. Please include the TRD values for these samples and compare the measured oxide thickness with the calculated oxide thickness.

RAI-3e – Please indicate if the *Optimized* ZIRLO corrosion layer thickness data shown in Figure 2.3-13 (LTR-NRC-12-40) is related to the hydrogen content data shown in Figure 2-1 (LTR-NRC-12-40) and the *Optimized* ZIRLO corrosion layer thickness data above 65 GWd/tU in Figure 6.5-1 from WCAP-17642-P, Revision 0, and WCAP-17642-NP, Revision 0. Please tabulate the calculated TRD values for the corrosion layer thickness and hydrogen content samples along with the time-average Li content, maximum Li content, T_{out}, T_{in}, and core average power. Please add the corrosion layer thickness data shown in Figure 2.3-13 and the data above 65 GWd/tU in Figure 6.5-1 from WCAP-17642-P, Revision 0, and WCAP-17642-NP, Revision 0, to Figure 3.3-2 in WCAP-17642-P, Revision 0, and WCAP-17642-NP, Revision 0.

RAI-3f – Please provide the plant parameters (T_{out}, T_{in}, pH, Li content, cycle length, and core average LHGR) for all rods shown in Figure 3.3-1 and 3.3-2 in WCAP-17642-P, Revision 0, and WCAP-17642-NP, Revision 0, with TRD values **[**

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RAI-3g – Please provide maximum TRD values representative of the peak burnup fuel rods in a high duty 17x17 4-loop plant, e.g., Braidwood/Bryon, which achieve peak burnup in two 18-month cycles and in three 18-month cycles.

RAI-3h – Please provide an explanation for the **[** **]** oxide values shown in Figures 3.3-1 and 3.3-2 of the TR, as well as the significance of the **[**negative**]** values on the oxide model uncertainty assessment.

RAI-3i – For a plant core design analysis that reaches a predicted best estimate oxide thickness of 100 microns for ZIRLO and *Optimized* ZIRLO cladding, please provide a census of the rods that exceed a TRD level of **[** **]** Please bin the census into **[** **]** TRD intervals (e.g., number of rods between **[** **]** etc.). This analysis should be performed for both ZIRLO and *Optimized* ZIRLO. Using the standard deviation and statistical distribution used to establish the upper 95 percent bounding corrosion model, please calculate the distribution of ZIRLO and *Optimized* ZIRLO oxide thickness for each TRD bin.

RAI-3j – For the oxide distributions determined in RAI-3i, please calculate the distribution of hydrogen content using the best-estimate **[** **]** for each TRD bin.

4) The following are related to the code's gap conductance model and verifying the model.

RAI-4a – How is the value of K_{eff} from Equation 3-32 applied to Equations 3-25 and 3-26?

RAI-4b – Table 2.2-1, Item 3.5, under comments states **[** **]** but no discussion is provided in the TR. What was the purpose of the **[** **]**

RAI-4c – No value is provided for the effective surface roughness in the gap conductance model. How is the effective surface roughness, δr, in Equation 3-25 calculated from the cladding and fuel roughnesses?

RAI-4d - Please provide an example calculation of gap conductance with two gas fractions of 100 percent helium and then with 50 percent helium and 50 percent xenon at 1 atmosphere of gas pressure. For these two gas compositions provide gap conductance results for a diametral gap of 10, 20, and 30 microns for a total of six calculations. Also perform a similar calculation assuming contact pressures of 1000, 2000, and 3000 psi at 100 percent helium and 50 percent helium and 50 percent xenon.

RAI-4e – Please compare the PAD5 gap conductance model to ex-reactor measured gap conductance versus gas pressure for 100 percent helium and a mixture of helium and xenon for radial open gaps less than 20 microns in NUREG/CR-0330, Volume 2, (*Ex-Reactor Determination of Thermal Gap Conductance Between Uranium Dioxide and Zircaloy-4 – Stage II: High Gas Pressure* by J Garnier and S Begej). Also compare to the gap contact conductance as a function of contact interfacial pressure for both helium and helium/xenon mixtures in NUREG/CR-0330 (*Ex-Reactor Determination of Thermal Gap Conductance Between Uranium Dioxide: Zircaloy-4 Interfaces – Stage I: Low Gas Pressure* by J Garnier and S Begej).

5) The helium solubility model **[** **]**

RAI-5a – **[** **]** How was the absorption data taken, rod puncture or melting of pellet and measuring total helium offgas? Also provide an estimate of the uncertainty in this data.

RAI-5b – Have rod pressures been measured on the low burnup data from puncture? If so, please provide these values that demonstrate lower pressures than initially introduced during fabrication and compare to those predicted due to helium solubility.

RAI-5c - Equation 4-1 gives the helium solubility in UO_2. Solubility **[** **]** What is the temperature range that this model is valid over? Provide the data that illustrates the range of validity.

6) The helium release data for ZrB_2 has **[**

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RAI-6a – A statistical probability for underprediction can be determined for the upper bound release model utilizing the number of prototypical LTA data **[** **]**

Based on this probability provide an estimate of how many fuel rods in a core (4 loop plant) with ZrB_2 operating for both 18 and 24 month cycles will be underpredicted using the upper bound helium release model. Please justify the underprediction of helium release for these rods with ZrB_2. Please describe how the statistical analysis of probability was performed along with a tabulation of the predicted values identifying the data from Table 4.2-1.

RAI-6b – Please justify the assumption that helium release **[** **]**

RAI-6c – Fission gas release data are provided for **[** **]** rods from Plant Y in Table A.2.2-3. Are helium release data from these rods provided in the submittal? If so, please indicate where that data is identified. If not, please provide the measured helium release fraction data for these rods.

RAI-6d – In Table A.2.5-2, please confirm that rods from Plant Y are IFBA (ZrB_2) fuel type.

RAI-6e – Also, discuss why the helium release **[** **]**

RAI-6f – Please confirm that the x-axis of Figure 4.2-2 is **[** **]** Similarly, confirm that **[** **]** in Table 4.2-1 should be **[** **]**

RAI-6g – Please provide the relationship between the equation for ^{10}B depletion (Equation 4-5) and the helium release model shown in Figure 4.2-2. Describe how the rod burnup defined in Equation 4-5 **[** **]** for use in the release model summarized on page 4-10. Please provide an example set of curves showing the helium generation in the ZrB_2 coating, the instantaneous helium released, and the cumulative helium release as function of burnup.

7) The following are related to the calibration and validation of the code to measured fuel centerline temperatures.

RAI-7a – Please identify the SAFDLs for any Westinghouse fuel designs that are limiting at beginning-of-life (BOL) or fuel burnup less than 0.5 GWd/MTU. **[** **]** If some are limiting at BOL and/or low burnup, **[** **]** Please provide code comparisons to the following additional data that **[** **]** Identify the data from each of these rods in the plots provided. The IFA-513 rods have achieved the highest fuel temperatures of the Halden tests such that they are of interest for fuel melt, fuel stored energy, and cladding strain (temperature impacts thermal expansion) verification. Provide the assumed power histories and axial shapes used for input.

RAI-7b – The PAD5 thermal database versus burnup **[** **]** Provide, additional comparisons to the following **[** **] [** **]** is in the PAD5 database provide these individual comparisons in the response. Provide individual code data comparisons both predictions and data (plots) versus burnup for each of these tests identifying the rods in the plots. Also include these additional data comparisons predicted-minus-measured/measured versus burnup, predicted versus measured, and predicted-minus-measured/measured versus LHGR) along with the original PAD5 database (calibration and validation) that allows the additional test data to be identified by test. Have separate plots for closed and open gap data comparisons.

RAI-7c - Please provide additional comparisons **[** **]** using similar plots to those requested in RAI-7b for open and closed gap data comparisons. Additional data from this rod may also be in other Halden reports than the one identified. Provide predicted-minus-measured/measured versus gadolinia level for the new rod data as well as the calibration and validation rod data.

RAI-7d – Please recalculate uncertainty (and 95/95 bounding relationships) using the additional and original (calibration and validation) data comparisons in terms of relative error (predicted-minus-measured/measured). All predicted-minus-measured temperature data comparisons should be provided as relative error (predicted-minus-measured/measured).

RAI-7e – Please provide plots similar to those in Figures A.2.1-20 to A.2.1-23 in terms of relative error on Y-axis that illustrates the upper bound 95/95 tolerance that includes all new and original (calibration and validation) fuel centerline data for open and closed gaps. Provide explicitly how the 95/95 tolerance values are determined.

RAI-7f – Are there any applications where the lower bound temperatures are applied? If so, provide similar plots for lower bound predictions at a 95/95 tolerance level (similar to RAI-7g). It is noted that the lower bound temperature curve **[**

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8) The following are related to the modeling, calibration, and validation of the code to measured fission gas release.

Comment - The thermal fission gas release model **[**

] It may be appropriate to check code calculations to make sure they are not applied outside of the range of the data.

RAI-8a - There are additional fission gas release data from the Halden Project that includes measurements of both fuel centerline temperatures and fission gas release that will confirm that the PAD5 fission gas release model adequately captures the strong relationship between fuel temperatures and fission gas release for both UO_2 and gadolinia fuel. Please provide PAD5 predictions of fuel temperatures versus burnup and end-of-life fission gas release for **[**

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RAI-8b – Figure A.2.2-7 of Appendix A (PAD5 Calibration/Validation/Uncertainty Results) appears to suggest that the **[** **]** Please discuss why this is acceptable, particularly when this is the **[** **]** Please add the data comparisons requested in RAI-8a to the Figure A.2.2-7.

RAI-8c – The standard approach used by the NRC for fuel performance is to bound the data with a 95/95 tolerance level, **[** **]** Past uncertainty calculations for codes reviewed by NRC have been based on release **[** **]** because this is the release range in which the peak rod pressures are calculated to demonstrate that the rod pressure limit is met. Utilizing values **[** **]** reduces the standard error for release values **[** **]** this reduced error including the **[** **]** are not applicable to **[** **]** release. The gadolinia release model **[** **]** The upper and lower bound gadolinia release models should significantly bound all **[** **]** Please provide justification why the UO_2 and gadolinia fission gas release models **[** **]**

RAI-8d – Examination of Figures A.2.2-4 and A.2.2-5 **[**

] Please discuss the reason **[**

] Also, discuss whether **[**

]

9) The following are related to the modeling and calibration/verification of the code to cladding creep data for normal operation.

RAI-9a – Please provide details on how the effective stress mentioned on page 5-9 is calculated.

RAI-9b – What are the units on $\dot{\varepsilon}_{irr}$ in Equation 5-26? Page 5-8 implies %/hr, but a more reasonable rate is obtained assuming in/in/hr. Please confirm the correct units.

RAI-9c – For each data set specified in Table A.2.3-1 provide the range of temperature (mean wall), stress, and fast flux.

RAI-9d – Please provide plots of predicted-minus-measured/measured in-reactor creepdown versus stress, versus fast flux, and versus temperature for each alloy. For these plots identify the creep test distinguishing between actual fuel rods and creep specimens (no fuel present).

RAI-9e – Please provide plots of predicted-minus-measured/measured secondary creep rate versus stress, versus fast flux and versus temperature for each alloy for experiments where times were sufficient to determine secondary creep. If data is not included specify the reason for not including data.

RAI-9f – The calibration data for ZIRLO/*Optimized* ZIRLO **[**

] Is this because the calibration data **[**

] Please justify using **[**

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[

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RAI-9g – The **[** **]** provided in Figure A.2.3-13 **[**

] What benefit does this data have in relation to verifying the Zr-4 creep model for commercial fuel rod application? Please justify the use of this **[** **]** (utilize responses to RAIs 9d and 9e for this response).

RAI-9h – Please provide comparisons to the following **[** **]** If data is not applicable, please provide an explanation of why.
RAI-9i – Please provide plots similar to Figures A.2.3-14 thru A.2.3-17 identifying the number of rods and data points in these plots using data from RAI-9h responses and the calibration/validation data. Also identify those rods and number of data that are not bounded. Please provide an upper and lower bound at a 95/95 tolerance level for each alloy along with a plot demonstrating these bounds similar to Figures A.2.3-14 thru A.2.3-17.
RAI-9j – Please provide PAD5 predictions (P-M vs axial elevation) of cladding diametral creep data from **[** **]** that were compared with the PAD4 code calculations in LTR-NRC-07-58, Revision 1P – Attachment (see Figure 3).
RAI-9k – In Figure A.2.3-3 and A.2.3-4, to which plant(s) in Table A.2.3-2 does the label "INREAC" refer?

10) The following are related to the calibration and validation of the code to cladding diameter change (strain) due to power ramp tests. Please provide the following data comparisons for all the ramped rods from Table A.2.4-1.
RAI-10a – Provide predicted-minus-measured diameter change versus local ramp terminal power (data from 3 highest power nodes if available) for ramped rods with **[** **]** identifying the rods by burnup range, e.g., 5 to 15 GWd/MTU, >15 to <30 GWd/MTU, >30, and > 45. Identify rods with gadolinia fuel.
RAI-10b – Provide predicted-minus-measured diameter change versus local ramp terminal power (data from 3 highest power nodes if available) for ramped rods with **[** **]** identifying the rods by burnup range, e.g., 5 to 15 GWd/MTU, >15 to <30 GWd/MTU, >30, and > 45 GWd/MTU.
RAI-10c - Provide predicted-minus-measured diameter change versus ramp hold time for ramped rods (data from 3 highest power nodes if available) with **[** **]** identifying the rods by burnup range, e.g., 5 to 15 GWd/MTU, >15 to <30 GWd/MTU, >30, and > 45 GWd/MTU.
RAI-10d – Provide predicted-minus-measured diameter change versus local ramp terminal power (data from 3 highest power nodes if available) for ramped rods with **[** **]** identifying the remainder rods individually by rod ID. Also identify ramped rods with gadolinia fuel.
RAI-10e – Provide predicted-minus-measured versus elevation for ramped rods for rods with **[** **]** identifying the rods by burnup range, e.g., 5 to 15 GWd/MTU, >15 to <30 GWd/MTU, >30, and > 45 GWd/MTU. Different length rods can be plotted separately.
RAI-10f – Provide a plot of upper bound uncertainty for ramped rods with **[** **]** that are bounded at a 95/95 tolerance level.

11) The following are related to cladding diameter change versus burnup due to steady-state power operation after the gap is closed to verify the integral behavior of several models.

RAI-11 – **[** **]** (Section 5.6, page 5-16) are modeled correctly as a function of burnup, including the effects of cladding creep and solid swelling. This includes the recovery of fuel relocation strain (also see RAI-14 below). P-M plots versus burnup are provided in Appendix A.2.3 of the LTR that include all the different fuel designs on a single plot. However, no cladding diameter change versus burnup plots are shown. Please provide plots of predicted and measured cladding diameter change (for the three highest power nodes per rod) versus burnup for several **[** **]** single rods for both ZIRLO and *Optimized* ZIRLO, grouping rods with the same initial gap-to-pellet diameter ratio. Please provide additional plots to those shown in Figure A.2.3-6 and A.2.3-8 that separate out the same initial gap-to-pellet diameter ratio.

12) The following are related to the verification of fuel rod void volume data. Figure A.2.5-3 (and Table A.2.5-2, PAD5 Cold Void Volume Database) demonstrates **[** **]** volume range of nearly all commercial rods irradiated today.

RAI-12a – Please identify the lattice designs of these data in Tables A.2.2-3 and A.2.5-2, and on Figure A.2.5-3 identify those rods that are IFBA.

RAI-12b – It is obvious that **[** **]** please discuss the possible **[** **]**

13) The following are related to verification of the cladding diametral irradiation growth model. Virtually no background data are given on the data used to perform the calibration/validation. However, the following observations are made in relation to the diametral growth data in Figures 5.5-1, 5.5-2, and 5.5-3.

In an earlier response to the NRC (LTR-NRC-04-122 (MTLS-04-18, January 27, 2004)), the composition of ZIRLO was expanded to include a broader range of Sn content with the lower limit set at 0.6 percent. There are subsequent documents that mention different Sn contents, e.g., 0.66 percent and 0.77 percent, as well as different heat treatments, e.g., SRA or pRXA, which produce different levels of yield strength, tensile strength, and creep rates.

Other documents (patents) have indicated that different fabrication lots of 0.66 percent and 0.77 percent Sn *Optimized* ZIRLO received different final heat treatments, while the same mechanical reduction schedule was employed that would result in different amounts of cold work. *Optimized* ZIRLO is typically pRXA, while ZIRLO (including improved ZIRLO, i.e., with Sn in the range of 0.8-1.2 percent) has been traditionally cold work stress relieved (CWSR). Westinghouse has suggested in other correspondence to the NRC that fabrication lots of *Optimized* ZIRLO with 0.77 percent Sn content were given a variety of final heat treatments, e.g., SRA (CWSR) and possibly partially recrystallized (pRXA) (LTR-NRC-07-58, Rev. 1), but it is not clear the heat treatments of the *Optimized* ZIRLO data in Figures 5.5-2 and 5.5-3.

Figure 5.5-3, *Optimized* ZIRLO Cladding Steady-State Diametral Irradiation Growth Rate, and Figure 5.5-2, *Optimized* ZIRLO Cladding Diameter Irradiation Growth, show that diametral cladding irradiation growth **[** **]** On the other hand, the data in Figure 5.5-1, ZIRLO Cladding Irradiation Growth Diameter Strain, **[** **]** For **[** **]** the diametral growth data **[** **]** If the Westinghouse conclusion **[** **]** effect on growth.

RAI-13a – With respect to the thermo-mechanical processing and composition, please provide the fabrication and composition parameters that define the *Optimized* ZIRLO used in actual fuel reload quantities in contrast to ZIRLO or improved ZIRLO?

RAI-13b – Please provide information on the composition and process for the material used in Figures 5.5-2 and 5.5-3, such as fabrication heat treatment, fast flux, and irradiation temperature, verify that this was irradiated free of stress.

RAI-13c – The **[** **]** growth of the **[** **]** in Figure 5.5-2 is **[** **]** that is known to have some effect on growth, however, the **[** **]** is also known to have a strong impact on growth. It is also known that there is a narrow temperature range for recrystallization annealing of zirconium alloys. How does the variability in thermo-mechanical process, e.g., annealing temperature and time, influence the irradiation growth **[** **]** for these **[** **]** Please address variability in **[** **]** between *Optimized* ZIRLO cladding lots and its effect on the variability (uncertainty) in diametral growth.

RAI-13d – Due to **[** **]** for ZIRLO and *Optimized* ZIRLO there will be **[** **]** Please provide an upper bound and lower bound growth models. What impact do these uncertainties have on SAFDL (including the rod pressure limit) and accident analyses?

RAI-13e – Please provide evidence or data supporting the use of **[** **]**

14) The fuel relocation model (Section 5.6) **[** **]** is experienced, this assumption could **[** **]** within the transition between soft and hard contact for a given fuel design (varies with **[** **]**).

RAI-14a – Please provide further explanation with examples of how the fuel relocation is recovered, particularly for power ramped rods. Also, please provide data to

calibrate/validate this recovery for a given fuel design and cladding type (see RAI-11 above).

RAI-14b - It appears that Q in Equation 5-30 should be input in units of kW/m rather than kW/ft as stated. Please confirm the correct units.

15) The solid swelling model appears to be **[ ]** The use of **[ ]** to determine dimensional changes of the pellet have been shown to overestimate the dimensional change due to solid swelling in the diametral and axial directions based on Halden tests, particularly if the pellet is constrained due to soft or hard contact with the cladding. In addition, it appears that PAD5 **[ ]** however recent evidence from Halden tests suggests that **[ ]** The solid swelling model influences the internal rod pressure limit to prevent cladding liftoff such that this model is important for demonstrating that the rod pressure SAFDL is satisfied. The following are related to the verification of the solid swelling model for UO_2 and gadolinia fuel.

RAI-15a – Please compare the PAD5 solid swelling model to the solid swelling data for UO_2 fuel rods from the following **[ ]**

RAI-15b – Please compare the PAD5 solid swelling model to the solid swelling data for gadolinia rods from the following **[ ]** and any other relevant data for fuel in soft or hard contact with the cladding.

16) The following is related to the modeling and calibration of the gaseous swelling model.

RAI-16a – It appears that T in Equation 5-39 should be input in units of °C rather than °F in order to be used with **[ ]** Please confirm the correct units.

RAI-16b – Are all of the burnup terms in **[ ]** gaseous models using **[ ]** values? If not please define how they are applied.

RAI-16c – Please justify the application of the **[ ]** (Table A.2.4-4).

RAI-16d – Please justify the **[ ]** (Table A.2.4-4).

17) In Figures 5.9-1 and 5.9-3, the fuel rod cladding growth data **[ ]** the irradiation growth behavior. It would appear that **[ ]** the upper bound of the model given.

RAI-17a – What is unique or significant **[ ]** that would cause the **[ ]**

RAI-17b – What modifications to the best estimate irradiation growth model would be developed to account for the **[ ]** fuel rod growth behavior.
RAI-17c – Do the upper and lower bounds of the model specifically include **[ ]** in the respective figures?
RAI-17d – How many ZIRLO data are from plants **[ ]** in Figures 5.9-1 and 5.9-2? How many ZIRLO data lie outside (are overpredicted) by the lower bound growth curve in these two figures?
RAI-17e – How many *Optimized* ZIRLO data are from plants **[ ]** in Figures 5.9-3 and 5.9-4? How many *Optimized* ZIRLO data lie outside (are overpredicted) by the lower bound growth curve in these two figures?

18) The TR has assumed that **[ ]** Past experience has shown (References 18.1 and 18.2) that differences in strength of unirradiated Zircaloy do not disappear by a fast fluence of 3 E21 n/cm^2 (E > 1 MeV). This is further confirmed by the yield and ultimate strength **[ ]** A similar observation is evident in the **[ ]** Therefore, it appears that *Optimized* ZIRLO strength **[ ]** PNNL agrees that **[ ]** The original approval of *Optimized* ZIRLO required a reduction in yield and ultimate strength for irradiated *Optimized* ZIRLO compared to irradiated ZIRLO.

RAI-18a – Please provide yield and ultimate tensile strengths for irradiated *Optimized* ZIRLO over the operating range of fast fluence (>1 MeV) of 1 to 12 E21 n/cm^2 for application to **[ ]**
RAI-18b – Please justify the use of **[ ]**

References

18.1 R. S. Kemper and D. L. Zimmerman, <u>Neutron Irradiation Effects on the Tensile Properties of Zircaloy-2</u>, HW-52323, General Electric Company (1957).

18.2 D. H. Hardy, "The Effect of Neutron Irradiation on the Mechanical Properties of Zirconium Alloy Fuel Cladding in Uniaxial and Biaxial Tests", <u>Irradiation Effects on Structural Alloys for Nuclear Reactor Applications</u>, *ASTM STP 484*, p. 215, American Society for Testing and Materials, Toronto, Canada (1970).

19) Figure 7.2-2 refers to a "coated cladding."

RAI-19 – Is the "coated cladding" a debris-resistant feature? Will this process be modified since *Optimized* ZIRLO is more oxidation resistant? How does this process affect the degree of recrystallization and microstructure of the base metal? What is the impact of the coating on normal operation, transients, and accidents?

20) Sections 7.2.1.4.2 and 7.3.2 provide a description of the method used to create power histories for the various fuel design criteria and input to safety analyses, however, these descriptions are short on details. The following questions are related to understanding how these power histories are determined by providing examples and example applications for each specific design criteria or input to safety analyses.

RAI-20a – There is no mention of application of calculational or measurement uncertainties for the individual power histories generated, these uncertainties are not insignificant, therefore, need to be accounted for in analyses. Please provide an example of how calculational and measurement uncertainties are included in the steady-state power and transient powers histories for each analysis application including uncertainties in axial offset.

RAI-20b – Please provide an example of how a deviation from planned power operation during a cycle is accounted for in cycle specific analyses. Is the reactor required to have a revised analysis before they can deviate from planned operation? If not, please justify.

RAI-20c – Please provide an explicit example of how individual limiting power histories with uncertainties are selected for each analysis application.

RAI-20d - Please provide an explicit example using **[** **]** (Condition I and II events) that are included in these histories for each analysis application. A power uprated plant should be selected for this example providing the core average power. Please provide analysis results using these composite power histories (including power uncertainties), and model and fabrication uncertainties for each analysis application (see RAI-21). Provide a plot of rod power histories (LHGR versus burnup) for the core of a power uprated plant (provide the uprated core average power) with the plants LHGR limit in the same plot.

RAI-20e – Please provide an explicit example of how individual Condition I and II events are evaluated for rod pressure and cladding strain. For cladding strain and fatigue please provide an explicit example of **[** **]**

RAI-20f – Please provide an example of how a **[** **]** Provide an example of how an axial shape is determined for a limiting Condition I and II transient (AOOs).

21) Little information is given on the uncertainties and how they are applied in the statistical evaluation.

RAI-21a – Please provide a table that tabulates the uncertainties (fabrication parameters, models, and operation) and the upper and/or lower bounds applied to each analysis application. Provide a description of how these were determined. Are power

uncertainties included in the **[ ]** analysis? If not describe how they are included.

RAI-21b – Significantly more details will be needed if a Monte Carlo statistical approach is to be approved. For example, a recent code submittal for a Monte Carlo analysis included nearly 80 pages of description of the statistical approach, assumptions, parameters selected, uncertainties, and assumed distributions with extensive justification for each of these. Please provide more details describing how the Monte Carlo analysis will be implemented with PAD5 for each fuel design and reload analysis application.

RAI-21c – Please provide a specific example using **[ ]** with uncertainties (the values in response to RAI-20a) and the use of **[ ]** for the rod pressure, fuel average, cladding corrosion, fatigue, and cladding strain SAFDL analyses at a 95/95 tolerance level (see RAI-21a). Provide the code input for these analyses such that an audit calculation can be made with FRAPCON.

RAI-21d – Provide an example bounding fuel melt calculation at the maximum burnup level at which maximum power can be achieved (burnup just prior to decreasing power with burnup). Provide the code input for this analysis such that an audit calculation can be made with FRAPCON.

RAI-21e – Please provide an example worst-case analyses (upper and lower bound) for rod pressure, initial stored energy (any other parameters passed for loss-of-coolant accident (LOCA) initialization), cladding corrosion, fatigue, and cladding strain SAFDL analyses. Provide the code input for these analyses such that an audit calculation can be made with FRAPCON.

RAI-21f – Please provide an example best estimate calculation of rod pressure, initial stored energy, fuel melting, cladding oxidation and hydriding, cladding fatigue, and cladding strain using example **[ ]** with power uncertainties and limiting power transients for limiting (power uprated in Westinghouse fleet) 15 x15 and 17x17 plant. As per RAI-21a please provide the **[ ]** for each uncertainty parameter associate with each of these analyses.

RAI-21g – Please provide an example calculation of the rod pressure limit based on no cladding liftoff and hydride reorientation for each cladding type.

RAI-21h – The development of model uncertainties are described in Appendix A for the fuel centerline temperature, fission gas release, cladding creep, and deformation calculations using a 95 percent bounding approach. An assessment of the calculated cold internal void volume calculation using predicted minus measured plots is also summarized in Appendix A. PAD5 example fuel rod calculations for several fuel designs are provided in Appendix B. However, the TR does not provide any examples on the method using PAD5 to demonstrate compliance to the fuel rod SAFDLs defined in Section 7.0 for the operational modes outlined in Tables 7.1-1 through 7.1.5. Please provide example calculations for each SAFDL defined in Section 7.0 for the limiting event (Condition I, II, III, or IV) for the SAFDL. Please include the uncertainties using a 95 percent bounding approach as discussed in the TR. For one of these example calculations (e.g., one with the smallest margin to the limit), please repeat the analysis

using a 95/95 treatment of uncertainties or using an appropriate equivalent acceptable statistical method.
RAI-21i – As indicated in the General Comment section, in the absence of a 95/95 uncertainty analysis, the agency requests the applicant to propose a suitable penalty estimated for all appropriate fuel performance parameters that are analyzed in PAD5 TR, to compensate for the lack of 95/95 uncertainty analysis.

22) Section 7.4.2 for Cladding Strain *Design Evaluation* states **[**

]

RAI-22 – Please explain what is meant **[** **]** because this appears to suggest that **[** **]** may be used. Please provide an example. Use of **[** **]** would not be a conservative bounding result because **[** **]** in the cladding strain analysis.

23) It is stated that the code uses only 10 equal volume radial rings for fuel temperature, fission gas release, and fuel swelling.

RAI-23 – Please justify that 10 equal volume rings is adequate in terms of accuracy for predicting fuel temperature, fission gas release and fuel swelling.

24) The thermal model in page 3-1 includes **[** **]** which **[**
]

RAI-24 – What value or code is used for analyses and how is it **[**
]

25) The following are related to understanding the application of the cladding corrosion models.

RAI-25a – The cladding corrosion model defined on page 3-4 and following includes **[** **]** How are these values determined?
RAI-25b – **[** **]** as stated on pages 3-3 and 3-4? If so, please provide a description of how this is done for licensing analyses.
RAI-25c – Are the values of A and B in Equation 3-14 and $C_{OPTZIRLO}$ in Equation 3-15 still those given in Equations 2-7, 2-8, and 2-10 of WCAP-12610-P-A and CEND-404-P-A, Addendum 2-A.
RAI-25d – Is the variable, **[** **]** in Equation 3-16, the previous time step **[** **]** If not please define this term.

26) Section 3.6.2 mentions that there is **[**
]

RAI-26 – Is this ever done for licensing analyses? If so, please provide a description of the methodology used to perform these analyses.

27) The following analyses are requested to confirm the predictions of the fission gas release model.

RAI-27 – Please provide fission gas release fraction as a function of burnup from sample calculations for the following cases:

i. PWR 17x17 node with flat axial power profiled and constant power history of 6kW/ft to 70 GWd/MTU.
ii. PWR 17x17 node with flat axial power profiled and constant power history of 8kW/ft to 70 GWd/MTU.
iii. PWR 17x17 node with flat axial power profiled and constant power history of 10kW/ft to 40 GWd/MTU.
iv. PWR 17x17 node with flat axial power profiled and constant power history of 12kW/ft to 30 GWd/MTU.
v. PWR 17x17 node with flat axial power profiled and constant power history of 6kW/ft to 30 GWd/MTU then power ramped to the LHGR limit and held for a limiting Condition I event. Perform same analysis but power ramped to a limiting power for a Condition II event.
vi. PWR 17x17 node with flat axial power profiled and constant power history of 6kW/ft to 50 GWd/MTU then power ramped to the LHGR limit and held for a limiting Condition I event. Perform same analysis but power ramped to a limiting power for a Condition II event.

28) Section 7.2.1.4.4 describes the input of fast neutron flux and fluence data.

RAI-28 – Please describe how fast neutron fluxes are input and how it is ensured that the input flux history is consistent with the input power history.

29) The following addresses the calibration and verification of IFBA rods.

RAI-29 – Please identify the IFBA rods in Table A.2.2-3 PAD5 FGR Model Calibration Results: Thermal FGR Database and the Lattice *G*eometries (e.g., 17x17, or 15x15, etc.).

30) The first section of Appendix A (A.1.1) states: **[**

] Past experience has shown that empirical models, particularly related to material performance, cannot be extrapolated outside of their range of data because at given burnup, temperature or power levels of the mechanism often changes. For example, past extrapolations have resulted in unanticipated fuel performance problems not predicted by the extrapolation.

RAI-30 – Please define explicitly how and when extrapolation will be performed. For example, will it be based on the collection of new data? If so, is there a limit on the number of new data points that need to be collected before extrapolation is permitted? How is it determined that the new data are consistent with the existing model? In future applications, will the model be extrapolated beyond the calibration/validation data and the new data collected?

31) In TR WCAP-12610-P-A and CENDPD-404-P-A, Addendum 2-A (Figure 3.3-13 and LTR-NRC-12-40), Westinghouse provides data concerning plastic strain (ductility) as a function of hydrogen content at **[ ]**

RAI-31 – For AOOs where the 1 percent cladding strain criterion is applicable, what is the limiting cladding temperature? What is the measured cladding plastic strain at this temperature as a function of hydrogen content?

32) RAI-32 - Before PAD5 can be approved for use in demonstrating compliance to SAFDLs for Conditions I and II operation, or as a source of fuel rod parameters for input into Conditions III and IV transients, a detailed methodology approach must be described for using PAD5 for each of the events provided in Tables 7.1-2, 7.1-3, 7.1-4, and 7.1-5. The detailed description should include the decision criteria that will be used to select between a PAD5 analysis or an alternative calculation method when demonstrating compliance to a design limit (for example see 7.4.5 and 7.4.6). If an alternate method/calculation is to be applied, the alternative method needs to be defined and where the alternate method has been previously approved. The PAD5 specific input used for an analysis in Tables 7.1-2, 7.1-3, 7.1-4, and 7.1-5 should be defined (e.g., fuel temperature, rod pressure, gap conductance, etc.) along with how uncertainties are applied (e.g., 95/95 upper bound, 95/95 lower bound, best estimate plus uncertainties, etc.).