First Set of Responses to the 210 Day RAIs from RAI Set 2 for WCAP-17642, "Westinghouse Performance Analysis and Design Model (PAD5)" (Non-Proprietary)

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RAI-6 (part a)

A statistical probability for underprediction can be determined for the upper bound release model utilizing the number of prototypical LTA data [

]^{a,c}. 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.

Response to RAI-6a

PAD5 Upper Bound (UB) model conservatively [

]^{a,c}. The new data requested in RAI-6c (Reference 6-1) [

]^{a,c} as shown in Figure 6-1.

[

]^{a,c}

It should be noted that a significant part of [

]^{a,c}

Accounting for the added data and consistent with the statistical analysis performed at the 95/95 level [

]^{a,c} The updated bounding models and the saturated release data are shown in Figure 6-2. The updated bounding model are expected (with 95% confidence) to cover the saturated helium release for 95% of the total population of ZrB_2 rods.

References

6-1. LTR-NRC-15-87, "Response to the 60 day RAIs from RAI Set 2 for WCAP-17642, "Westinghouse Performance Analysis and Design Model (PAD5)" (Proprietary/Non-Proprietary)" October 30, 2015.

6-2. George, F. and Ramachandran, K. M., "Estimation of Parameters of Johnson's System of Distributions," Journal of Modern Applied Statistical Methods, November 2011, Vol. 10, No. 2, 494-504.

Table 6-1: Data Used to Develop Statistical Uncertainties for Saturated Release

Plant	Thickness (mil)	B^{10} Enrichment (%)	Percent B (%)	Helium Release (Fraction)	Burnup (GWd/MTU)	Time (days)

a,b,c

a,b,c

Figure 6-1: PAD5 Topical Report Helium Release Models (BE, UB, and LB) and Saturated Release Data

a,b,c

Figure 6-2: Updated PAD5 Helium Release Models (BE, UB, and LB) and Saturated Release Data

RAI-7 (parts d-f)

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

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 [

]a, c

Response to RAI-7d

The PAD5 thermal database comprises a large number data points. [

]a, c

Table 7-1 contains the thermal calibration statistics for the PAD5 thermal database including all new and original (calibration and validation) data. [

]a,c

Table 7-1 Statistics for the Predicted Minus Measured (P-M) Residuals in the PAD5 Thermal Calibration and Validation

Role	All Fuel			UO_2			Gadolinia		
	Data Points	P-M Average (K)	P-M Standard Dev. (K)	Data Points	P-M Average (K)	P-M Standard Dev. (K)	Data Points	P-M Average (K)	P-M Standard Dev. (K)

a,b,c

With the newly added data in the responses to RAIs 7a through 7-c (Reference 7-3), it is observed that [ ]a,c Westinghouse has recalculated the thermal model uncertainties to account for the additional data included [

]a,c

Rather than develop [

]a,c

The updated upper-bound model is: a,c

[ ] (7-1)

and the updated lower-bound model is: a,c

[ ] (7-2)

where:

T_{UB} is the upper-bound fuel centerline temperature in kelvins,

T_{LB} is the lower-bound fuel centerline temperature in kelvins,

T_{BE} is the best estimate fuel centerline temperature predicted with PAD5, in kelvins, and

[ ]a,c

The calculation of the bounding lines considered all the additional and original (calibration and validation) data [

]a,c The final bounding models are shown in Eqs. (7-1) and (7-2). A graph of the calibration errors [ ]a,c together with these bounding models is presented in Figure 7-1. Graphs similar to those in Figures A.2.1-20 to A.2.1-23 in Reference 7-1 are presented in the responses to RAI's 7e and 7f.

a,b,c

Figure 7-1: Thermal Calibration Errors and Bounding Models Obtained in this Analysis [
]a,c

[

]a,b,c

Table 7-2: Number of Data Points and Percent of Data [
]a,c Listed by Test [ ]a,b,c

a, b, c

It should be noted that the developed thermal uncertainties [

]a,b,c

[

]a,c

Response to RAI-7e

Figures 7-2 and 7-3 display graphs of the upper-bound biased relative errors versus LHGR and versus burnup, respectively. The graphs include all new and original (calibration and validation) fuel centerline data as provided in the responses to RAI-7a through 7c in Reference 7-3. In the graphs the data are segregated into open- and closed-gap data.

The graphs show that the updated PAD5 upper-bound thermal model uncertainties [

]a,c

[ ]a,c
conservatively accounts for the behavior of the predictions.

a, b, c

Figure 7-2: Upper-Bound Fuel Centerline Temperatures (Predicted Minus Measured)/Measured vs. LHGR.

a,b,c

Figure 7-3: Upper-Bound Fuel Centerline Temperatures (Predicted Minus Measured)/Measured vs. Burnup.

Response to RAI-7f

The lower-bound thermal uncertainties are used to provide input to non-LOCA safety analyses. Figures 7-4 and 7-5 display graphs of the lower-bound biased relative errors versus LHGR and versus burnup, respectively. The graphs include all new and original (calibration and validation) fuel centerline data as provided in the responses to RAI-7a through 7c in Reference 7-3. In the graphs the data are segregated into open- and closed-gap data.

The graphs show that the updated PAD5 lower-bound thermal model uncertainties [

]a,c

a,b,c

Figure 7-4: Lower-Bound Fuel Centerline Temperatures (Predicted Minus Measured)/Measured vs. LHGR.

a, b,c

Figure 7-5: Lower-Bound Fuel Centerline Temperatures (Predicted Minus Measured)/Measured vs. Burnup.

References

7-1. WCAP-17642, "Westinghouse Performance Analysis and Design Model (PAD5), October 2013.

7-2. ISO 16269-6, "Statistical interpretation of data – Part 6: Determination of statistical tolerance intervals," January 2014.

7-3. LTR-NRC-16-5, Response to the120 day RAIs from RAI Set 2 for WCAP-17642, "Westinghouse Performance Analysis and Design Model (PAD5)" (Proprietary/Non-Proprietary), February 2016.

7-4. LTR-NRC-15-87, "Response to the 60 day RAIs from RAI Set 2 for WCAP-17642, "Westinghouse Performance Analysis and Design Model (PAD5)" (Proprietary/Non-Proprietary)," October 2015.

7-5. HWR-1038, "The Gadolinia fuel test IFA-681: Overview of in-pile measurements from beginning of irradiation to unloading," March 2013.

7-6. HWR-1080, "Data uncertainties in experiments and modelling – workshop minutes," November, 2013.

7-7. HWR-1141, "Monte Carlo uncertainty and sensitivity analysis of the power determination in a Halden test rig containing multiple rods," December 2014.

RAI-8 (part c)

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

RAI-8c – The standard approach used by the NRC for fuel performance is to bound the data with a 95/95 tolerance level, [ ][a,c]. Past uncertainty calculations for codes reviewed by NRC have been based on release [ ][a,c] 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 [ ][a,c] reduces the standard error for release values [ ][a,c], this reduced error including the [ ][a,c] are not applicable to [ ][a,c] release. The gadolinia release model [ ][a,c]. The upper and lower bound gadolinia release models should significantly bound all [

][a,c]. Please provide justification why the UO_2 and gadolinia fission gas release models [ ][a,c].

Response to RAI-8c

PAD5 thermal FGR uncertainty model is based on [

][a,c] Including these data is appropriate for PAD5 [ ][a,c] uncertainty model. However, it is recognized that these data will decrease the standard deviation of [ ][a,c] and should not be used when 95/95 statistical analysis on [ ][a,c] is performed.

In the PAD5 thermal FGR database [

][a,b,c]

Table 8-1 summarizes [

][a,b,c]

It should be noted that [

][a,b,c]

Additionally, the PAD5 FGR model uncertainty included [

]a,c

The gadolinia thermal FGR model uncertainties (including steady-state and transient FGR) are based on [

]a,b,c

In summary, the PAD5 thermal FGR model uncertainties are conservative for application because

1) [

]a,c

2) [

]a,c

Updates to Section A.2.2 of PAD5 Topical Report:

[

]a,b,c

References

8-1. ISO 16269-6, "Statistical Interpretation of Data – Part 6: Determination of Statistical Tolerance Intervals," January 2014.
8-2. NUREG-1475, Revision 1, "Applying Statistics," U.S. NRC, March 2011.
8-3. DOE/NE/34032-1, "Final Report of the Super-Ramp Project," June 1985.

Table 8-1: Thermal FGR Data Excluding Plants AA and Z Fuel

a,b,c

Rod Name	Time	Burnup	Measured	Predicted	P - M
	h	MWd/MTU	%	%	%

a,b,c

Figure 8-1: Predicated vs. Measured FGR for Plant AA and Z Data and More Recent Data

a,b,c

Figure 8-2: Comparison of PAD5 UB Thermal FGR Results to 95/95 UB Results versus BE Predicted FGR

a,b,c

Figure 8-3: Comparison of PAD5 UB Thermal FGR Results to 95/95 UB Results versus Measured FGR

a,b,c

Figure 8-4: Comparison of PAD5 LB Thermal FGR Results to 95/95 LB Results versus BE Predicted FGR

a,b,c

Figure 8-5: Comparison of PAD5 LB Thermal FGR Results to 95/95 LB Results versus Measured FGR

a,b,c

[ ]

Figure 8-6: Comparison of PAD5 Transient FGR Results between UO_2 and Gadolinia Fuel

RAI-9 (part i)

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

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.

Response to RAI-9i

The requested plots are shown in Figures 9-1 and 9-2 for ZIRLO® and **Optimized ZIRLO**™ and Figures 9-3 and 9-4 for Zircaloy-4, identifying data by plants. The number of rods, data points, and data points not bounded are listed in Table 9-1 for ZIRLO and **Optimized ZIRLO** rods, and Table 9-2 for Zircaloy-4 rods.

PAD5 cladding creep model uncertainties use **[**

]^{a,c}

For ZIRLO and **Optimized ZIRLO** cladding, some of the data not bounded are **[**

]^{a,c}

The results are shown in Table 9-3. PAD5 UB and LB ACREEP values are more conservative than the 95/95 tolerance intervals based on **[** **]**^{a,c}

For Zircaloy-4 rods, the uncertainties are impacted by **[**

]^{a,c}

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[

]^{a,c}

The results are shown in Table 9-4. PAD5 UB and LB ACREEP values are more conservative than the 95/95 tolerance intervals based on [ ]^{a,c}

In summary, some of the data used in creep model uncertainty development are [

]^{a,c}

Additionally, real uncertainties in creep model should be significantly smaller as shown by [

]^{a,c}

References

9-1. ISO 16269-6, “Statistical Interpretation of Data – Part 6: Determination of Statistical Tolerance Intervals,” January 2014.

9-2. George, F. and Ramachandran, K. M., “Estimation of Parameters of Johnson’s System of Distributions,” Journal of Modern Applied Statistical Methods, November 2011, Vol. 10, No. 2, 494-504.

Table 9-1: ZIRLO/**Optimized ZIRLO** Creep Data by Plants

	Rods	Data Points	UB - Not Bounded	LB - Not Bounded

a,b,c

Table 9-2: Zircaloy-4 Creep Data by Plants

	Rods	Data	UB - Not Bounded	LB – Not Bounded

a,b,c

Table 9-3: ZIRLO/**Optimized ZIRLO** Creep Statistical Results

	LB ACREEP	UB ACREEP

a,b,c

Table 9-4: Zircaloy-4 Creep Statistical Results

	LB ACREEP	UB ACREEP

a,b,c

a,b,c

Figure 9-1: ZIRLO and **Optimized ZIRLO** Cladding Creep Upper Bound Predictions

a,b,c

[ ]

Figure 9-2: ZIRLO and **Optimized ZIRLO** Cladding Creep Lower Bound Predictions

a,b,c

[ ]

Figure 9-3: Zircaloy-4 Cladding Creep Upper Bound Predictions

a,b,c

Figure 9-4: Zircaloy-4 Cladding Creep Lower Bound Predictions

RAI-10 (part f)

Provide a plot of upper bound uncertainty for ramped rods with [ ]^{a,c} that are bounded at a 95/95 tolerance level.

Response to RAI-10f

[ ]^{a,c} As shown in Section A.2.4.3 of the PAD5 topical report (Reference 10-1), [ ]^{a,c}

Additionally, the PAD5 ramp diameter change model uncertainty included [ ]^{a,b,c}

As explained above, the upper bound uncertainty of [ ]^{a,c} a plot is provided as requested for the UB uncertainty in Figure 10-1.

References

10-1. WCAP-17642-P, "Westinghouse Performance Analysis and Design Model (PAD5)," October 2013.

10-2. STIR-53 "Final Report of the Inter-Ramp Project," August 1979.

10-3. RISO-FGP3-FINAL, Pt. 2, "The Third Riso Fission Gas Project, Final Report: The Methods," March 1991.

10-4. STUDSVIK/N-05/154, STUDSVIK-SCIP-42, "SCIP, Task 0; Ramp Test Results," Final Report, December 2005.

a,b,c

Figure 10-1: UB Predicted Diameter Change vs Measured Diameter Change