

Enclosure 3

**Set 2 of Responses to Requests for Additional Information on Westinghouse
Topical Report WCAP 18446-P/NP, “Incremental Extension of Burnup Limit
for Westinghouse and Combustion Engineering Fuel Designs.”**

(Non-Proprietary)

(38 pages including this cover page)

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Request for Additional Information (RAI) 1:

WCAP-18446-P/WCAP-18446-NP, Revision 0, "Incremental Extension of Burnup limit for Westinghouse and combustion engineering Fuel Designs," proposes a revised fuel rod average burnup limit of []^{a,c}.

- a. Please clarify the expected maximum local pellet burnups associated with the proposed rod-averaged burnup limit.
- b. Please identify the specific models relied upon to support WCAP-18446-P/WCAP-18446-NP, Revision 0, that are associated with phenomena sensitive to local fuel burnup.
- c. Please justify that an explicit local pellet burnup limit is not necessary to ensure continued applicability of models sensitive to local burnup conditions.

Response to RAI 1a:

The maximum pellet average burnup can be determined conservatively based on current designs by looking at the peak nodal burnup to the rod average burnup. By determining a conservative value for this ratio, the pellet burnup associated with a rod burnup of []^{a,c} can be calculated. Figures showing the peak-to-average burnup ratio for representative plants with and without axial blankets are shown in Figures 1-1 through 1-3, which depict the decreasing ratio of peak-to-average ratio as assembly burnup increases. With further increased pin burnup, the ratio will continue to decrease. Based on these results and use of a conservative peak-to-average ratio the maximum pellet average burnup associated with a rod average burnup of []^{a,c} is []^{a,c}.

[

[

]

]

a,c

a,c

a,c

Response to RAI 1b and 1c:

The models utilized for licensing basis calculations within mechanical design, fuel rod performance, nuclear design, safety analysis, and thermal-hydraulic design (including rod ejection) were reviewed for dependence on local fuel rod burnup. Fuel rod performance and loss-of-coolant accident (LOCA) analyses use models that are associated with phenomena sensitive to local burnup and must account for limitations in test data, while mechanical design, nuclear design, non-LOCA safety, thermal hydraulic design, containment integrity and radiological dose consequences analyses do not.

For fuel rod performance (Section 3.1 of WCAP-18446-P [1-1]) and LOCA (Section 4 of WCAP-18446-P) analyses, most models are not based directly on local fuel burnup and are instead based on parameters that are related to burnup. For instance, increasing power and/or time will increase burnup. The models for phenomena that are sensitive to local burnup are presented in Table 1-1. The description of how each model/phenomenon is sensitive to local burnup is also included in the table. If not explicitly stated in the table, the model/phenomenon is related to fuel rod performance. The corrosion and hydrogen pickup models are not directly dependent on burnup and are instead based on time and local temperature. Fuel thermal conductivity and decay heat used in LOCA analyses are []^{a,c} Fission gas release, helium solubility and helium release models are based on rod average data. The gas bubble swelling, fuel relocation, and irradiation hardening models exhibit asymptotic behavior with increased burnup and include data to burnup levels which bound the behavior, and they therefore do not require local

burnup limitations. The other models in Table 1-1 are supported by data to local burnups that would exceed local burnup values in rods reaching the rod average burnup limit of []^{a,c}. Therefore, the rod average burnup limit is sufficient to bound any local burnup limitations in existing databases.

For mechanical design, nuclear design, non-LOCA safety, thermal hydraulic, containment integrity and radiological dose consequences analyses, models do not require local burnup limits. Models used for licensing basis mechanical design analyses (Sections 2.3 and 2.4 of WCAP-18446-P) are based on assembly average or rod average effects, so no local burnup limit is required. Nuclear design analyses (Section 3.2 of WCAP-18446-P) account for changes in burnup based on isotopic calculations in lattice physics codes. The latest lattice physics code, PARAGON2, has been approved for use up to local burnups of 100 GWd/MTU (Section 3.2 of WCAP-18443-P-A [1-2]) and the response to RAI 10 addresses the additional validation to extend PHOENIX-P and PARAGON to rod average burnups of []^{a,c}. Non-LOCA safety analysis (Section 5.1 of WCAP-18446-P) and thermal-hydraulic (Section 3.3 of WCAP-18446-P) models are initialized using results obtained by the fuel performance models in Table 1-1. The validity of the models is the same as described in the tables. The containment integrity analyses (Section 5.2 of WCAP-18446-P) are based on core average effects. The radiological dose consequence analyses (Section 6 of WCAP-18446-P) are based on core average or fuel rod average effects, with bounding gap release fractions generated for the entire fuel rod.

The []^{a,c} rod average burnup limit is acceptable for limiting models that are sensitive to local burnup. The models sensitive to local burnup are either developed using data that is not directly defined by local burnup or have been developed using data with local burnups that would exceed the maximum local burnup associated with a rod average burnup of []^{a,c}.

Reference(s)

- 1-1) WCAP-18446-P, Revision 0, "Incremental Extension of Burnup Limit for Westinghouse and Combustion Engineering Fuel Designs," December 2020.
- 1-2) WCAP-18443-P-A, "Qualification of the Two-Dimensional Transport Code PARAGON2," July 2021.
- 1-3) WCAP-17642-P-A, Revision 1, "Westinghouse Performance Analysis and Design Model (PAD5)," November 2017.
- 1-4) J.J. Carbajo, G.L. Yoder, S.G. Popov, V.K. Ivanov, "A Review of the Thermalphysical Properties of MOX and UO₂ Fuels," Journal of Nuclear Materials, 299, 181, (2001).

Table 1-1: Models Sensitive to Local Burnup

Model	Description of Model Sensitivity to Burnup
Fuel Thermal Conductivity	The model includes a local burnup term used directly in calculations. The data in the database is split between expansion thermometer, which is a rod average measurement, and thermocouple data, which is a local measurement. As can be seen in the response to RAI 1 of RAI set 1, Tables RAI 1-1 and RAI 1-2 of WCAP-17642-P-A, Revision 1 (LTR-NRC-15-10 P) [1-3], fuel temperature data above rod average burnups of [] ^{a,c} were used in the thermal model calibration.
Fuel Melting Point	The model includes a local burnup term used directly in calculations. As described in Section 6.1.5 of WCAP-17642-P-A, Revision 1, the model described in Carbajo [1-4] is used for fuel melt. As seen in Figure 3 of Carbajo, local burnups greater than 90 GWd/MTU are used to develop the decrease in fuel melt temperature as a function of burnup.
Fuel Radial Relocation	[] ^{a,c} Figure 5.6-1 of WCAP-17642-P-A, Revision 1, shows the behavior of this model.
Solid Swelling Densification	Fuel pellet ring burnup is used in this model to determine overall volume change. The rate of swelling is constant as a function of fuel ring burnup. The response to RAI 15a in WCAP-17642-P-A, Revision 1 (LTR-NRC-15-87-P) evaluates the model to a variety of test data up to [] ^{a,c}
Gas Bubble Swelling	[] ^{a,c} Increased local burnup does not impact model predictions. Local burnups greater than [] ^{a,c} were used to develop the model, which is well beyond the thresholds used to determine when gaseous swelling begins in the model. The response to RAI 1 of RAI set 2, Figure 1-11 of WCAP-17642-P-A, Revision 1 (LTR-NRC-15-69-P) shows the data used to develop models contributing to rod diameter changes during transient power increases.
Fission Gas Release	The model is dependent on fuel ring burnup; however, models are calibrated to the fission gas release of the entire rod. Therefore, the applicability range of the model is defined based on rod average burnup.
Helium Solubility and Release	The model is dependent on local fuel burnup but is calibrated to rod average gas measurements. This model only has an impact when a large majority of the gas contained in the rod is helium (i.e., beginning of life). It has negligible impact on results at high burnups due to the release of fission gas.
Cladding Steady-State Oxidation	The model is dependent on time and local temperature, which is dependent on local power. [] ^{a,c}

Model	Description of Model Sensitivity to Burnup
	[] ^{a,c}
Cladding Steady-State Hydrogen Concentration	The model is dependent on cladding oxidation.
Cladding Diametral Growth and Steady-State Creep	The model is dependent on local cladding fluence. Unfueled samples from Plant R with fluences equivalent to local burnups greater than [] ^{a,c} were used to validate the PAD5 creep model. The response to RAI 9, Figure 9-7 of WCAP-17642-P-A, Revision 1 (LTR-NRC-16-5 P) shows the available data.
Cladding Yield Strength and Ultimate Tensile Strength	The model is dependent on local fluence. The effect of irradiation hardening [] ^{a,c} (Figure 6.3-1 of WCAP-17642-P-A, Revision 1)
Fuel Thermal Conductivity (LOCA Analysis)	The model is implemented [] ^{a,c}
Decay Heat (LOCA Analysis)	The decay heat is a function of the local powers achieved within a fuel pellet throughout operation. However, for the LOCA calculations, [] ^{a,c}

RAI 7:

Section 3.1.1 of WCAP-18446-P/WCAP-18446-NP, Revision 0, indicates the PAD5 code (Reference 3) conservatively accounts for all high burnup phenomena that contribute to rod internal pressure and identifies rod internal pressure is strongly dependent on cladding creep and fuel densification and swelling. Table 7.3.2-1 in Section 7.3.2 of the PAD5 topical report (TR) lists the values and upper and lower bounds for these parameters.

- a. Regarding the fuel densification and swelling, the PAD5 TR references WCAP-10851-P-A, "Improved Performance for Models for Westinghouse Fuel Rod Design and Safety Evaluations." However, the fuel densification and swelling model presented in WCAP-10851-P-A does not appear to be validated beyond [redacted]^{a,c} Additionally, Figure 2-16 of WCAP-10851-P-A shows a cluster of datapoints at [redacted]^{a,c} the vast majority of which the fuel densification and swelling model appears to [redacted]^{a,c} which contrasts with the model performance for the rest of the data. This could be indicative of a growing disparity between prediction and measurements as a function of burnup. Please provide justification demonstrating that the swelling and densification model in PAD5 (documented in WCAP-10851-P-A) and the uncertainties identified in Table 7.3.2-1 of the PAD5 TR are applicable for burnup to [redacted]^{a,c}
- b. Regarding cladding creep, there does not appear to be data presented for this model in the PAD5 TR beyond approximately [redacted]^{a,c} This can be seen in Figures A.2.3-3, A.2.3-6, and A.2.3-8. Please provide justification that the cladding creep model adequately predicts creep beyond 62GWd/MTU and is applicable for burnup to [redacted]^{a,c}

Response to RAI 7a:

The data plotted in Figure 2-16 of WCAP-10851-P-A [7-1] comes from the Zion rods in Table 2.3 of the same reference. These data were obtained from [redacted] measurements using a mercury pycnometer technique. The initial as-fabricated densities were also individually measured, except for rods A8, A9, and G15, for which the region [redacted]^{a,c} See WCAP-10473 [7-2] (Table 6-12), WCAP-10543 [7-3] (Table 6-7), and WCAP-10544 [7-4] (Table 6.7.1).

The value of initial fuel density used to produce the model line in Figure 2-16 of [7-1] [redacted]

The average true as-fabricated density for those pellets [redacted]^{a,c} Figure 7-1 presents a [redacted]

and lower densification model lines are also included in the plot.

The pellets with burnups [redacted]

[redacted]^{a,c}

Figure 7-2 presents [

]a,c The upper and lower densification model lines are also included in the plot.

An examination of Figures 7-1 and 7-2 confirms that, [

]a,c the experimental variability is well covered by the model uncertainty lines.

[

]a,c the plots shown in Figure 7-3 are obtained. The plots show that the Westinghouse design methodology covers the combined effects of manufacturing variability and variation in swelling and densification behavior.

Figures 5.7-1 through 5.7-4 of the PAD5 topical report [7-5] show a more detailed assessment of the performance of the PAD5 fuel densification and swelling model against available data, including the Zion data presented here. An evaluation of the PAD5 swelling and densification model []a,c was performed as part of RAI-15a to the PAD5 Topical Report, [7-5], and documented in LTR-NRC-15-87 [7-6] (which is also attachment LTR-NRC-15-87-P to [7-5]). The evaluation included data with [

]a,c

The conclusion of that evaluation is that the PAD5 predictions [

]a,c

The effects of incremental burnup to rod average burnups of [

]a,c

[

] a,c



[a,c

Response to RAI 7b:

Irradiation effects on cladding creep saturates at lower fluence. [

]a,c

Reference(s)

- 7-1) WCAP-10851-P-A, "Improved Fuel Performance Models for Westinghouse Fuel Rod Design and Safety Evaluations," August 1998.
- 7-2) WCAP-10473, "Final Report EP80-16, Hot Cell Examination of Zion Fuel Cycles 1 through 4," April 1985.
- 7-3) WCAP-10543, "Final Report EP80-16, Hot Cell Examination of Zion Fuel Cycle 5," June 1985.
- 7-4) WCAP-10544, "Zion High Burnup and Contacting Rod Hot Cell Program," August 1984.
- 7-5) WCAP-17642-P-A, Revision 1, "Westinghouse Performance Analysis and Design Model (PAD5)," November 2017.
- 7-6) 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.

RAI 10:

Both PARAGON and PHOENIX-P are validated, in part, by using Saxton and Rowe measured actinide isotopic data to assess the codes' accuracy in predicting buildup and depletion of higher-order isotopes as a function of burnup. The NRC staff noted these data range from a burnup of []^{a,c} and that at the higher end of the burnup range, there appears to be []^{a,c} for several of the isotopes, specifically []^{a,c}. In both codes, the data is too limited to determine whether this is a consistent outlier or the beginning of a trend. Because these codes provide nuclear data to downstream codes and methods, it is important to accurately track the production and removal of major fission-related isotopes. Please provide justification that PARAGON and PHOENIX-P can acceptably predict nuclear data for burnup to []^{a,c} which exceeds the current validation range of data. Additionally, please provide justification that the apparent []^{a,c} for the aforementioned isotopes is not indicative of a trend.

Response to RAI 10:

Calculations were performed to provide additional validation data supporting justification for higher burnup. These calculations were performed to compare with three different post irradiation examination (PIE) measurements of small rod samples of increasing burnup. Details are as follows:

- []^{a,c}
- []^{a,c}
- []^{a,c}

Additional details regarding these PIE examinations can be found in Michel-Sendis, 2017 [10-1]. Modeling conditions were obtained from Michel-Sendis, 2017 [10-1] for core operation which resulted in the samples below. Acceptable assumptions were made to model local conditions available, with final pin burnup similar to the burnup listed (Michel-Sendis, 2017 [10-1]). C/E-1 (%) results are given in Table 10-1 for []^{a,c} for both PARAGON and PHOENIX-P.

Table 10-1: Final Results for Selected Isotopes for Grams of Isotope per Gram of Initial Uranium

Reactor	Sample Burnup GWd/MTU	C/E-1 (%)			
		[] ^{a,c} PARAGON	[] ^{a,c} PHOENIX-P	[] ^{a,c} PARAGON	[] ^{a,c} PHOENIX-P
[]					

Measurement uncertainty from Michel-Sendis, 2017 [10-1] is included in Table 10-2 to provide additional results interpretation.

Table 10-2: 2σ Measurement Uncertainty for the Chosen Benchmarks

Reactor	Sample Burnup GWd/MTU	Measurement Uncertainty, 2σ (%)			
		[] ^{a,c}	[] ^{a,c}	[] ^{a,c}	[] ^{a,c}
[]					

Results indicate that both PARAGON and PHOENIX-P predict well the final isotopics for []^{a,c}, and in many cases are in line with the measurement uncertainty given. Additionally, inspection of the data indicates there is no significant evidence of a trend with burnup.

Reference(s)

- 10-1) "SFCOMPO-2.0: An OECD NEA Database of Spent Nuclear Fuel Isotopic Assays, Reactor Design Specifications and Operating Data", F. Michel-Sendis et al., Annals of Nuclear Energy, Vol. 110, 2017.

RAI 17:

10 CFR 50.36(c)(2)(ii) requires establishment of a technical specification limiting condition for operation of a nuclear reactor for:

- Each process variable, design feature, or operating restriction that is an initial condition of a design basis accident or transient analysis that either assumes the failure of or presents a challenge to the integrity of a fission product barrier.
- Each structure, system, or component that is part of the primary success path and which functions or actuates to mitigate a design basis accident that either assumes the failure of or presents a challenge to the integrity of a fission product barrier.

Analyses performed in accordance with the evaluation model described in WCAP-18446-P/WCAP-18446-NP, Revision 0, would in general appear to satisfy both of these criteria for the design-basis loss-of-coolant accident inasmuch as they would (1) rely upon limiting the local power density (e.g., heat flux hot channel factor or linear heat generation rate) in order to demonstrate the integrity of fuel cladding, and (2) support technical specification limiting conditions for operation intended to assure acceptable performance of the emergency core cooling system. Based upon an initial review of the information in WCAP-18446-P/WCAP-18446-NP, Revision 0, and the voluntarily supplement dated May 13, 2021, the NRC staff understands that the methodology proposed in WCAP-18446-P/WCAP-18446-NP, Revision 0, credits a burnup-dependent reduction to the local power density that typically does not currently exist in pressurized-water reactors' technical specifications or core operating limits reports. Therefore, please provide additional justification that a licensee's implementation of the approach proposed in WCAP-18446-P/WCAP-18446-NP, Revision 0, would comply with 10 CFR 50.36(c)(2)(ii), or confirm that the approach may require a licensee to implement additional restrictions in the technical specifications (e.g., potentially by reference, via the core operating limits report) to ensure compliance with the burnup-dependent local power density necessary to support acceptable emergency core cooling system performance for the loss-of-coolant accident.

Response to RAI 17:

Rod power burndown is not a process variable, design feature, or operating restriction. Unlike peak core rod power, that can be controlled by changes in core power, rod power burndown cannot be controlled during operation. It is primarily influenced by the core design and for this reason is verified during the core reload safety analysis. Likewise, rod burnup is not a process variable, design feature, operating parameter or structure, system, or component that is part of the primary success path which functions or actuates to mitigate a design basis accident. Consequently, there is currently no Limiting Condition for Operation (LCO) or Tech Spec surveillance for peak rod burnup even though it is a licensing restriction on application of the safety analysis methodology (including PAD5 [17-1], the **FULL SPECTRUM™** LOCA (**FSLOCA™**) evaluation model (EM) [17-2], and the Incremental Burnup methodology [17-3]). Instead, the rod burnup restriction has been imposed as a binding licensing restriction by the inclusion of the COLR methodology list in STS 5.6.3.b. The inclusion of the Incremental Burnup Method, described in WCAP-18446-P, into the

Tech Spec COLR reference list will provide the same binding licensing restriction for the rod power burndown analyzed for rods with an average burnup > 62 GWd/MTU.

There are currently [

J^{a,c}

Technical Specification surveillances and plant measurements are used to confirm the continued applicability of the safety analysis uncertainties. Reactivity and power distribution measurements are performed periodically during the cycle as required by a plant's Technical Specifications to verify that core reactivity and peaking factors are within their respective design limits. Measured power distributions and core reactivity are also compared against predicted power distributions and core reactivity. These comparisons, when coupled with startup physics testing results following refueling, are used to verify the core design model and to demonstrate the core is operating as designed. This confirmation provides confidence in the predictive capability of the core design model used to verify safety analysis input assumptions and its ability to predict core performance. If the core is determined to not be operating as designed, an evaluation would be performed to assess analysis margins, understand the reasons for the deviation, and make appropriate adjustments on a case-by-case basis to plant operations or setpoints to ensure operation within safety analysis limits.

Current Westinghouse methodology for confirming the key core parameters input to the LOCA and Fuel Rod Design (PAD5) analyses uses approved design methods and uncertainties that ensure the cycle-specific values are bounded by those used in the safety analysis as previously discussed. This approach was also recently approved in WCAP-16996-P-A, Revision 1 for the Westinghouse **FSLOCA** EM. The intent to confirm the power distribution safety analysis limits on a reload basis was written in the third paragraph of page A-265 of the appendices to WCAP-16996-P-A, Revision 1, and the intent to confirm the burnup limits on a reload basis was written in the fourth paragraph of the response on page A-290 of appendices to WCAP-16996-P-A, Revision 1. These statements are reflected in the second paragraph of Section 4.6.3.3 and the first paragraph of Section 4.6.3.4 of the Safety Evaluation Report (SER) on the **FSLOCA** EM (SER is included with Volume I of WCAP-16996-P-A, Revision 1). The approach of using approved design code predictions with uncertainties to confirm cycle specific compliance with fuel rod design limits and to provide inputs to the safety analysis was also recently approved for the PAD5 code (See SER to WCAP-17642-P-A).

Proposed Method of Verification of Power Burndown Assumption

The Reload Safety Analysis Checklist (RSAC) currently contains explicit limits on peak rod power, peak pellet power, fuel rod power burndown, as well as many other inputs to the plant safety analysis that must be satisfied for confirmation of the safety analysis for a specific reload cycle. Confirmation is accomplished by calculating a bounding cycle specific value using approved methods, augmenting this value by uncertainties and other operational allowances which are used in determining if the limit is met. This approach has been accepted in many past submittals by the staff for licensing basis LOCA evaluations and analyses which demonstrate compliance with the acceptance criteria for emergency core cooling systems.

For plants implementing the Incremental Burnup extension, [

] ^{a,c} The basis for this approach is as follows:

- a. Bounding values of $F\Delta H$ (peak fuel rod power) as well as a bounding rod power history (rod power versus rod burnup) are used in several of the LOCA and non-LOCA reload safety analysis. Confirmation of these values are done on a cycle specific basis in both the reload analysis (e.g. with ANC) and also during core operation (e.g. with BEACON). The confirmation utilizes uncertainty values on $F\Delta H$ as described in WCAP-7308-P-A [12-4] and WCAP-12472-P-A [12-5]. The uncertainty used on individual rod power history is described in Table 7 of the SER for WCAP-17642-P-A.
- b. The rod power histories used in the PAD5 calculations for confirmation of cycle specific compliance to fuel rod design criteria and for fuel rod inputs to the safety analysis considers the uncertainty on both rod power and rod burnup per Table 7 of the SER for WCAP-17642-P-A. These uncertainties are based on analysis of measured to predicted assembly powers and assembly burnups as described below in Item d.
- c. The 95/95 uncertainty values approved in WCAP-7308-P-A that are applied to both the predicted (ANC) and monitored (BEACON) values of $F\Delta H$ are based on the standard deviation of measured to predicted assembly powers for all instrumented assemblies for a large sample of power distributions covering a wide range of plants and core designs. The uncertainty in fuel rod to assembly power is based on the standard deviation of measured – predicted results of rod powers from the critical experiments. Thus, the uncertainty applied to $F\Delta H$ already account for measured to predicted differences for all rods in the core, not just the peak location.
- d. The approved rod power measurement uncertainties from WCAP-7308-P-A are exactly the same as the approved calculational uncertainties. [

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]a,c

Reference(s)

- 17-1) WCAP-17642-P-A, Revision 1, "Westinghouse Performance Analysis and Design Model (PAD5)," November 2017.
- 17-2) WCAP-16996-P-A, "Realistic LOCA Evaluation Methodology Applied to the Full Spectrum of Break Sizes (FULL SPECTRUM LOCA Methodology)," November 2016.
- 17-3) WCAP-18446-P, Revision 0, "Incremental Extension of Burnup Limit for Westinghouse and Combustion Engineering Fuel Designs," December 2020.
- 17-4) WCAP-7308-P-A, Revision 0, "Evaluation of Nuclear Hot Channel Factor Uncertainties," June 1988
- 17-5) WCAP-12472-P-A, Revision 0, "BEACON – Core Monitoring and Operations Systems," August 1994.

RAI 24:

Section 4.4.5 of WCAP-18446-P/WCAP-18446-NP, Revision 0, concludes that [

]a,c Please address the following questions on this topic:

- a. Across the spectrum of postulated loss-of-coolant accidents, following the initial decrease in core power, fuel pellets would be expected to undergo a significant temperature decrease. This decrease would be followed by a smaller, but potentially substantial temperature increase as the core is uncovered. [

]a,c

- b. For the loss-of-coolant accident analysis cases shown in Figures 4.4-17 and 4.4-18 of WCAP-18446-P/WCAP-18446-NP, Revision 0, please provide a plot displaying the peak cladding temperature transient behavior for the associated fuel rods.
- c. Section 4.4.5 of WCAP-18446-P/WCAP-18446-NP, Revision 0, states that the several analytical cases considered by Westinghouse showed []^{a,c} However, this inductive argument appears to be based on very limited data, and WCAP-18446-P/WCAP-18446-NP, Revision 0, does not provide adequate basis for concluding that fuel rods in the extended burnup range will always []^{a,c} Neither does the rupture-prevention criterion specified in WCAP-18446-P/WCAP-18446-NP, Revision 0, for fuel rods in the extended burnup region appear to provide assurance that []

] ^{a,c}

Response to RAI 24:

The introduction to RAI 24 states that WCAP-18446-P [24-1] []

] ^{a,c} Westinghouse clarifies that the cited position is relative to the extended burnup region under the constraints of the incremental burnup extension methodology described in WCAP-18446-P, including Limitation #8 from LTR-NRC-21-16 [24-2] which []

] ^{a,c} during a postulated LOCA. This is not a generic Westinghouse position relative to high burnup fuel.

The responses to the various parts of the RAI are provided as follows.

Part A

Industry LOCA transient fission gas release testing has generally been performed by heating fuel rods to a relatively low temperature (where the cladding temperature may reflect typical operation but the fuel temperature is lower than in-reactor conditions), maintaining that temperature for a duration of time, and then heating up the sample to characterize any resulting fission gas release. The data are generally interpreted to inform the amount of fission gas which is released, as well as potential cladding strain and temperature thresholds which can lead to release.

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Part B

The peak cladding temperature (PCT) for the transients associated with Figures 4.4-17 and 4.4-18 of WCAP-18446-P is presented in Figures 24-1 and 24-2, respectively.

Part C

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j^{a,c}

Reference(s)

- 24-1) WCAP-18446-P, Revision 0, "Incremental Extension of Burnup Limit for Westinghouse and Combustion Engineering Fuel Designs," December 2020.
- 24-2) LTR-NRC-21-16, "Submittal of Voluntary Supplement to WCAP-18446-P / WCAP-18446-NP, 'Incremental Extension of Burnup Limit for Westinghouse and Combustion Engineering Fuel Designs' (Proprietary/Non-Proprietary)," May 2021.
- 24-3) Une, K., Kashibe, S., and Hayashi, K., "Fission Gas Release Behavior in High Burnup UO₂ Fuels with Developed Rim Structure," *Journal of Nuclear Science and Technology*, Suppl. 3, pp. 668 - 674, November 2002.
- 24-4) Turnbull, J. A., et al., "An Assessment of the Fuel Pulverization Threshold During LOCA-Type Temperature Transients," *Nuclear Science and Engineering*, 179, pp. 477 – 485, 2015.
- 24-5) Yueh, K., et al., "Fuel Fragmentation Data Review and Separate Effects Testing," *Proceedings of WRFPM 2014*, Sendai, Japan, Paper No. 100117, September 2014.
- 24-6) Une, K., Kashibe, S., and Takagi, A., "Fission Gas Release Behavior from High Burnup UO₂ Fuels under Rapid Heating Conditions," *Journal of Nuclear Science and Technology*, Vol. 43, No. 9, pp. 1161 – 1171, 2006.
- 24-7) STUDSVIK/N-19/105 / STUDSVIK-SCIP III-253, "SCIP III – Subtask 1.1: Fuel Fragmentation, Relocation and Dispersal, Final Summary Report," October 2019 (signed March 2020).
- 24-8) RIL 2021-13, "Interpretation of Research on Fuel Fragmentation, Relocation, and Dispersal at High Burnup," December 2021.
- 24-9) Pontillon, Y., et al., "Experimental and Theoretical Investigation of Fission Gas Release from UO₂ up to 70 GWd/t under Simulated LOCA Type Conditions: The GASPARD Program," *Proceedings of the 2004 International Meeting on LWR Fuel Performance*, Orlando, Florida, Paper 1025, September 2004.
- 24-10) Marcet, M., et al., "Contribution of High Burn-Up Structure to Fission Gas Release Under Transient Conditions," *Proceedings of Top Fuel 2009*, Paris, France, Paper 2055, September 2009.
- 24-11) Bianco, A., et al., "Experimental investigation on the causes for pellet fragmentation under LOCA conditions," *Journal of Nuclear Materials*, 465, pp. 260-667, 2015.
- 24-12) HWR-1096, "PIE on the Rod from the LOCA Test IFA-650.14 on High Burn-Up BWR Fuel," August 2014.



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a,c

RAI 25:

NRC-sponsored research findings associated with the proposed 50.46c rulemaking have identified the potential for cladding performance during a loss-of-coolant accident to be degraded by several mechanisms that may not be fully addressed in existing evaluation models, including hydrogen-enhanced beta layer embrittlement, cladding inner diameter oxygen ingress, and breakaway oxidation. Although the 50.46c rulemaking proposal presently remains before the Commission, the associated research findings are equally relevant to satisfaction of the existent acceptance criteria in 50.46(b), including the requirement to maintain a coolable core geometry. The proposal in WCAP-18446-P/WCAP-18446-NP, Revision 0, to extend fuel rod burnup may further exacerbate the potential for these potential degradation mechanisms. Please clarify how Westinghouse will address these research findings concerning cladding performance during a loss-of-coolant accident for fuel rods across the full range of existing and proposed burnups []^{a,c}, either within the framework of WCAP-18446-P/WCAP-18446-NP, Revision 0, or, alternatively, in a planned future regulatory submittal.

Response to RAI 25:

A summary of how Westinghouse addressed the research findings as part of the proposed 10 CFR 50.46c rulemaking was provided in LTR-NRC-21-16 [25-1] as follows:

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] ^{a,c}

As noted above, the basis for the Westinghouse approach is that the [

] ^{a,c}

[

] ^{a,c} in Section 4.2.2 of WCAP-18446-P.

This response clarified how Westinghouse addressed the research findings within the framework of WCAP-18446-P; the request for additional information (RAI) also requested information regarding future regulatory submittals. Westinghouse notes that the

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] ^{a,c}

Reference(s)

- 25-1) LTR-NRC-21-16, Revision 0, "Submittal of Voluntary Supplement to WCAP-18446-P / WCAP-18446-NP, 'Incremental Extension of Burnup Limit for Westinghouse and Combustion Engineering Fuel Designs' (Proprietary/Non-Proprietary)," May 2021.
- 25-2) WCAP-18446-P, Revision 0, "Incremental Extension of Burnup Limit for Westinghouse and Combustion Engineering Fuel Designs," December 2020.
- 25-3) WCAP-16996-P-A, Revision 1, "Realistic LOCA Evaluation Methodology Applied to the Full Spectrum of Break Sizes (**FULL SPECTRUM** LOCA Methodology)," November 2016.
- 25-4) LTR-NRC-21-2, Revision 0, "Transmittal of Topical Report Submittals Forecast for CY2021 (Proprietary)," January 2021.

RAI 26:

Ongoing assessment of recent NRC-sponsored research indicates that fuel fragmentation, relocation, and dispersal phenomena begin to become relevant below existing burnup limits (e.g., 62 GWd/MTU). For example, Section 6 of NUREG-2121, "Fuel Fragmentation, Relocation, and Dispersal During the Loss-of-Coolant Accident," states that "... it could be postulated that, with a large enough rupture opening, fuel loss cannot be excluded below the current licensed burnup limit of 62 GWd/MTU." The proposal in WCAP-18446-P/WCAP-18446-NP, Revision 0, to extend fuel rod burnup may further exacerbate the potential for fuel fragmentation, relocation, and dispersal. Please clarify how Westinghouse will address fragmentation, relocation, and dispersal for fuel rods at exposures below existing burnup limits, either within the framework of WCAP-18446-P/WCAP-18446-NP, Revision 0, or, alternatively, in a planned future regulatory submittal.

Response to RAI 26:

The response to RAI 26 is provided as follows.

Background

Westinghouse agrees that existing test data for high burnup fuel rods indicate the potential for fine fragmentation and dispersal for fuel rods below the current burnup limit. The intent of the incremental burnup extension was to [

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]a,c

a,c

a,c

a,c

a,c

Discussion

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]a,c

Reference(s)

- 26-1) WCAP-18446-P, Revision 0, "Incremental Extension of Burnup Limit for Westinghouse and Combustion Engineering Fuel Designs," December 2020.
- 26-2) LTR-NRC-21-16, Revision 0, "Submittal of Voluntary Supplement to WCAP-18446-P / WCAP-18446-NP, 'Incremental Extension of Burnup Limit for Westinghouse and Combustion Engineering Fuel Designs' (Proprietary/Non-Proprietary)," May 2021.
- 26-3) STUDSVIK/N-19/105 Revision 0, "SCIP III – Subtask 1.1: Fuel fragmentation, relocation and dispersal, Final summary report," October 2019 (report also numbered STUDSVIK-SCIP III-253; approved March 2020).
- 26-4) RIL 2021-13, "Interpretation of Research on Fuel Fragmentation, Relocation, and Dispersal at High Burnup," December 2021.
- 26-5) NUREG-2160, Revision 0, "Post-Test Examination Results from Integral, High-Burnup, Fueled LOCA Tests at Studsvik Nuclear Laboratory," August 2013.