Enclosure 3

Set 1 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)

(35 pages including this cover page)

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Request for Additional Information (RAI) 2:

Section 2.1 of WCAP-18446-P/WCAP-18446-NP, Revision 0, states that Table 1-2 of NUREG-0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants," (SRP) 4.2 provides an overview of the parameters that need to be addressed for an increase in fuel assembly burnup. No such Table 1-2 exists in SRP 4.2. Please clarify which design criteria Westinghouse reviewed to demonstrate that the fuel assembly will be able to perform adequately at an increased burnup.

Response to RAI 2:

Westinghouse reviewed the criteria in Standard Review Plan (SRP) 4.2 Section II.1 [2-1], which was the intended reference. Section 2.1 of WCAP-18446-P [2-2] will be updated as follows.

The Standard Review Plan (SRP), specifically section SRP 4.2 (US NRC, March 2007), provides the guidance for demonstrating the acceptability of a fuel design for use in-reactor. Section II.1 ~~Table 1-2~~ of SRP 4.2 provides an overview of those parameters that need to be addressed with a new fuel design or for an increase in fuel assembly (FA) burnup limits. This section provides the criteria and justification needed to demonstrate that the fuel assembly will meet all criteria up to **[ ]**^{a,c} rod average burnup under the provisions of the incremental burnup extension. This section also provides a list of designs capable for an extension in burnup up to **[ ]**^{a,c} lead fuel rod average and a discussion of all relevant parameters listed in SRP 4.2. Some of the parameters are discussed in the other analysis sections included in this topical report. Not every criterion applies to each component; however, where applicable, the SRP section will be called out and the appropriate criteria will be shown to be met.

Reference(s)

2-1) NUREG-0800, Section 4.2 Revision 3, "Fuel System Design," March 2007.

2-2) WCAP-18446-P Revision 0, "Incremental Extension of Burnup Limit for Westinghouse and Combustion Engineering Fuel Designs," December 2020.

RAI 3:

Section 7.1.1 of WCAP-18446-P/WCAP-18446-NP, Revision 0, provides a complete list of applicable fuel designs. Table 2.2-1 through 2.2-7 of WCAP-18446-P/ WCAP-18446-NP, Revision 0, do not appear to account for all applicable fuel designs, specifically 17-

V5/Vantage 5/ Vantage+, 16x16 HID1, and 16x16 System 80. Please provide tables, similar to Tables 2.2-1 through 2.2-7, for each of the missing fuel designs mentioned above.

Response to RAI 3:

Westinghouse used inconsistent nomenclature between Tables 2.2-1 through 2.2-7 and Section 7.1.1 of WCAP-18446-P [3-1]. The following discussion is provided to clarify the difference in nomenclature, and several updates to the topical report will be made to rectify the inconsistency.

Some fuel designs have evolved with time either via submittal of explicit topical reports, or via the Westinghouse Fuel Criteria Evaluation Process (FCEP) (WCAP-12488-A and WCAP-12488-A, Addendum 1-A, Revision 1) [3-2]. Many times the changes are relatively limited, impacting only a specific feature or features of the fuel assembly. However, the fuel assembly skeletons can be referred to using different names when implementing these changes.

Relative to the Westinghouse 17x17 fuel assembly designs: The 17x17 OFA entry in Table 2.2-1 of WCAP-18446-P covers the OFA design, including V5, Vantage+ and Performance+ features. The 17x17 RFA entry in Table 2.2-1 of WCAP-18446-P covers the RFA / RFA-2 / MRFA-2 designs, including Vantage+ and Performance+ features.

Relative to the Combustion Engineering 16x16 fuel assembly designs: The various STD and NGF designs are provided in Tables 2.2-5 through 2.2-7 of WCAP-18446-P. In Section 7.1.1 of WCAP-18446-P, the NGF designs were cited as "All 16x16 CENGF designs," but different nomenclature was used for the 16x16 CE STD designs.

In order to utilize consistent nomenclature, the following changes will be made to Section 7.1.1 of WCAP-18446-P. These updates result in consistency between the designs cited in Tables 2.2-1 through 2.2-7 and Section 7.1.1 of WCAP-18446-P.

Westinghouse NSSS

17-OFA (including V5, Vantage+, and Performance+ features)

~~17-V5 / Vantage 5 / Vantage+~~

17-RFA~~ / RFA-2 / MRFA-2~~ (including RFA-2 and MRFA-2 grids with Vantage+ and Performance+ features)

17-**AP1000** plant

17-XL

17-NGF

16-NGF

15-Upgrade

14-OFA

14-422V+

Combustion Engineering NSSS

~~16x16 HID1~~

~~16x16 System 80~~

16x16 CE STD designs

PV 16CE STD (for System 80 plant)

WTFD 16CE STD

16x16 CE NGF designs

PV 16CE NGF (for System 80 plant)

WTFD 16CE NGF

ANO2 16CE NGF

Reference(s)

3-1) WCAP-18446-P Revision 0, "Incremental Extension of Burnup Limit for Westinghouse and Combustion Engineering Fuel Designs," December 2020.

3-2) WCAP-12488-A and WCAP-12488-A, Addendum 1-A, Revision 1, "Westinghouse Fuel Criteria Evaluation Process," and "Addendum 1 to WCAP-12488-A Revision to Design Criteria," October 1994 and January 2002.

RAI 4:

Chapter 2 of WCAP-18446-P/WCAP-18446-NP, Revision 0, provides a demonstration that the 17x17 OFA fuel assembly design will satisfy its respective design criteria at an increased burnup. While the 17x17 OFA fuel design may be most limiting, compared to the fuel designs described in Section 7.1.1, it is not sufficient to consider the 17x17 OFA fuel designs as being representative of all fuel designs described in Section 7.1.1. Please clarify if WCAP-18446-P/ WCAP-18446-NP, Revision 0, is seeking approval of an incremental burnup extension for all fuel designs described in Section 7.1.1 or if the analysis in Chapter 2 is simply a demonstration of the analysis that would be included in a design-specific/ plant-specific application as described in Sections 1.2 and 7.2. If WCAP-18446-P/ WCAP-18446-NP, Revision 0, is intending to seek approval for an incremental burnup extension for the aforementioned fuel designs, please provide a demonstration that each

fuel design satisfies all criteria described in Chapter 2 and any additional design-specific criteria that may be applicable for an incremental burnup extension.

Response to RAI 4:

The objective of WCAP-18446-P is to provide a set of criteria, a method of evaluation against that criteria and the results of the evaluation of a specific design. That design is the 17OFA fuel assembly. The anticipated result is with the approval of the topical report the 17OFA design will be approved for extended burnup. In addition, the criteria and evaluation method will be approved and can then be used to evaluate further designs.

RAI 5:

Section 2.5.9 and Figure 2.5-9 of WCAP-18446-P/WCAP-18446-NP, Revision 0, describes the high burnup empirical database used to assess the applicability of the existing **ZIRLO®** cladding fuel assembly growth model. Burnup-dependent fuel assembly (i.e., guide tube, thimble) growth characteristics may be sensitive to several parameters including guide tube dimensions, guide tube material, assembly hold-down spring force, fuel assembly and grid cage design (e.g., hydraulic drag), fuel pellet irradiation swelling behavior, etc. Further evidence is required for the staff to approve the expanded applicability of all existing fuel assembly growth models (encompassing all fuel assembly designs listed in Section 7.1.1). Please provide further justification for applicable fuel assembly growth models.

Response to RAI 5:

The information presented in Section 2.5.9 and Figure 2.5-9 of WCAP-18446-P [5-1] includes a sub-set of the available fuel assembly growth measurements at a burnup around the fuel assembly burnup corresponding to the current peak fuel rod average burnup limit of **[ ]**^{a,c}.

There are no changes for the previously reviewed methods to determine Westinghouse NSSS and Combustion Engineering NSSS fuel design growth used to demonstrate that the growth related criteria are met.

For Westinghouse NSSS fuel, the fuel assembly growth as a function of burnup is based on extensive fuel assembly irradiated growth experience for assemblies with Zircaloy-4 grids and guide thimbles and data from assemblies with **ZIRLO** grids and **ZIRLO** guide thimbles. The fuel assembly growth is determined based on Post Irradiation Examination (PIE) inspections in which measurements are made at various locations about each fuel assembly to determine a bounding growth value. Using this plant data, a fuel assembly growth curve was established and reviewed by the NRC as part of the **ZIRLO /Optimized ZIRLO™** topical reports.

It is recognized that the fuel assembly growth is sensitive to fuel assembly design, loading & boundary conditions corresponding to specific fuel management and operational conditions. The guide thimble growth due to hydrogen pickup & irradiation damage and thermal & irradiation induced creep, spacer grid force relaxation, fuel rod growth together with gravity, hydraulic lift & buoyancy and top nozzle holddown forces as well as non-uniform neutronic and temperature fields affect fuel assembly growth. However, these effects are implicitly included in the growth curve created based on the available fuel assembly growth measurements.

The previously established Westinghouse NSSS fuel design growth curve is used to support fuel assembly growth evaluations for the specific fuel design as demonstrated below for 17OFA.

A significant number of inspections to measure assembly growth have been performed over the years on the 17OFA product. Fuel assembly growth measurements have been performed on the 17OFA fuel with assembly-average burnup up to **[ ]**^{a,c}.

17OFA growth results for fuel assemblies with **ZIRLO** guide thimbles are presented in Figure 5-1 below. This plot shows that the majority of the 17OFA growth results fall within the upper bound and lower bounds of the empirical growth model up to a fuel assembly average burnup corresponding to the peak fuel rod average burnup limit of **[ ]**^{a,c}. A few results lie above the upper bound: one point at about **[ ]**^{a,c} and two points at about **[ ]**^{a,c}. However, in any event, none of the results violates the fuel assembly design growth allowance which was used to set fuel assembly skeleton dimensions at a burnup up to the fuel assembly burnup corresponding to the peak fuel rod average burnup limit of **[ ]**^{a,c}. In general, 17OFA growth with **ZIRLO** guide tubes follows expectations and is similar to the growth exhibited by other fuel designs with ZIRLO guide tubes.

a,c

Figure 5-1

Figure 5-1 demonstrates that the fuel growth curve (lower bound) and the fuel assembly design growth allowance cover the 17OFA fuel assembly growths at a burnup up to the fuel assembly burnup corresponding to the peak fuel rod average burnup limit of **[ ]**^{a,c}.

A similar conclusion is expected for other Westinghouse NSSS fuel designs subjected to the Incremental Extension of Burnup Limit fuel management.

<u>For Combustion Engineering NSSS fuel</u>, the fuel assembly growth evaluations employ the previously approved SIGREEP computer code.

Originally, this code was approved for the growth evaluation of Zircaloy-4 guide tubes. As a part of CE 16x16 Next Generation Fuel Core Reference Report [5-2], the SIGREEP code application was extended to the fuel assembly design with **ZIRLO** guide thimble.

The primary parameters related to a fuel assembly growth phenomena are explicitly included in SIGREEP code.

This code is going to be used to assess fuel assembly growth during the Incremental Extension of Burnup Limit fuel management for the Combustion Engineering NSSS together with the available PIE inspection data to confirm prediction accuracy.

Finally, there are no changes for design basis and evaluation methods related to fuel assembly growth for the Incremental Extension of Burnup Limit fuel management.

Note that the fuel growth allowances should be sufficient to accommodate a **[ ]**^{a,c} in the average fuel assembly burnup associated with the Incremental Extension of Burnup Limit fuel management for all currently manufactured Westinghouse and Combustion engineering fuel designs.

In particular, the provided data demonstrates that the 17OFA fuel assembly growth at a burnup up to the fuel assembly burnup corresponding to the peak fuel rod average burnup limit of **[ ]**^{a,c} is acceptable.

Prior to implementing a burnup limit increase to **[ ]**^{a,c} on any other fuel design, the assembly growth assessment for that specific fuel design will be completed.

No updates to WCAP-18446-P are required relative to this response.

Reference(s)

5-1) WCAP-18446-P Revision 0, "Incremental Extension of Burnup Limit for Westinghouse and Combustion Engineering Fuel Designs," December 2020.

5-2) WCAP-16500-P-A, "CE 16x16 Next Generation Fuel Core Reference Report".

RAI 6

Section 3.1 of WCAP-18446-P/WCAP-18446-NP, Revision 0, indicates the corrosion database for **ZIRLO** and **Optimized ZIRLO** contains data for the rod average burnups in the range from 62GWd/MTU to approximately **[ ]**^{a,c}, and these data are plotted in Figure 2.5-3. However, it is not clear whether these data are part of the database that was used to perform the fitting of the **ZIRLO** and **Optimized ZIRLO** corrosion models and develop the uncertainties and the 95 percent upper bounds, as presented within WCAP-12610-P-A & CENPD-404-P-A, Addendum 2-A, "Westinghouse Clad Corrosion Model for **ZIRLO** and **Optimized ZIRLO**." Please confirm that the data presented in Figure 2.5-3 of WCAP-18446-P are included in the database presented in WCAP-12610-P-A & CENPD-404-P-A, Addendum 2-A for the fitting of the corrosion models and the determination of the associated uncertainties. If these data are not part of the WCAP-12610-P-A & CENPD-404-P-A, Addendum 2-A database, please provide updated corrosion model fittings, uncertainties, and 95 percent upper bounds. Conversely, provide justification the existing corrosion models and uncertainties remain applicable.

Response to RAI 6

There is data presented for corrosion performance that was obtained after the formation of the corrosion model in WCAP-12610-P-A & CENPD-404-P-A, Addendum 2-A [6-1]. The upper bound of the corrosion model was demonstrated as applicable to the enhanced data base in the PAD5 topical, WCAP-17642-P-A [6-2]. The following was presented in the response to RAI-3c, in WCAP-17642-P-A, Section D, Submittals of Responses to Requests for Additional Information, Subsection LTR-NRC-15-101 [6-3], page 9:

> "Figure 3c-1 displays the **Optimized ZIRLO** measured minus predicted oxide thickness residuals as a function of Thermal Reaction Accumulated Duty (TRD). The data plotted includes the measurements presented in the submittal of WCAP-12610-P-A & CENPD-404-P-A Addendum 2, measurements presented in LTR-NRC-12-40, and **Optimized ZIRLO** data collected since the issuance of the aforementioned letter. The "Topical" dataset label in Figure 3c-1 represents the data included in the submittal of WCAP-12610-P-A & CENPD-404-P-A Addendum 2. The "New" dataset label represents the **Optimized ZIRLO** data collected since the submittal of WCAP-12610-P-A & CENPD-404-P-A Addendum 2, including data provided in LTR-NRC-12-40. The **Optimized ZIRLO** data presented in Supporting Information for Issue #5 of LTR-NRC-12-40 has been updated to reflect oxide predictions made with plant follow inputs instead of design inputs.
>
> The new **Optimized ZIRLO** data confirms the predictive capability of the **Optimized ZIRLO** corrosion model approved in WCAP-12610-P-A & CENPD-404-P-A Addendum 2-A."

Based on this, the cladding corrosion model and its uncertainty was confirmed to remain applicable as part of the PAD5 topical report review and approval.

Reference(s)

6-1) WCAP-12610-P-A & CENPD-404-P-A, Addendum 2-A, "Westinghouse Clad Corrosion Model for **ZIRLO** and **Optimized ZIRLO**," October 2013.

6-2) WCAP-17642-P-A, "Westinghouse Performance Analysis and Design Model (PAD5)," November 2017.

6-3) LTR-NRC-15-101, "Response to the 90 day RAIs from RAI Set 2 for WCAP-17642, 'Westinghouse Performance Analysis and Design Model (PAD5)' (Proprietary/Non-Proprietary)," January 2016.

RAI 8

Section 3.1.5 of WCAP-18446-P/WCAP-18446-NP, Revision 0, indicates that, for fuel clad oxidation and hydriding the clad corrosion model for **ZIRLO** and **Optimized ZIRLO** from WCAP-12610-P-A & CENPD-404-P-A, Addendum 2-A, will be used, and the clad corrosion and hydriding databases contain high-burnup data. However, it is not clear whether the hydriding data presented in WCAP-18446-P/WCAP-18446-NP, Revision 0, (Figures 2.5-5a and 2.5-5b) are part of the database that was used to develop the best fit for hydrogen absorption in the oxide layer of the **ZIRLO** and **Optimized ZIRLO** corrosion models and develop the uncertainties and the 95 percent upper bounds, the hydrogen absorption fraction, and the upper and lower 95 bounds as presented within WCAP-12610-P-A & CENPD-404-P-A, Addendum 2-A. Please confirm that these data presented in Figures 2.5-5a and 2.5-5b of WCAP-18446-P are included in the database presented in WCAP-12610-P-A & CENPD-404-P-A, Addendum 2-A for the fitting of the hydrogen absorption, the hydrogen absorption fraction, and the upper and lower 95 bounds. If these data are not part of the WCAP-12610-P-A & CENPD-404-P-A, Addendum 2-A database, please provide an updated fit, hydrogen fraction, and 95 bounds. Conversely, provide justification the existing models and bounds remain applicable for burnup to **[   ]**[a,c]

Response to RAI 8

There is data presented for hydrogen pickup (HPU) behavior that was obtained after the formation of the HPU model in WCAP-12610-P-A & CENPD-404-P-A, Addendum 2-A [8-1]. The upper bound of the HPU model was demonstrated as applicable to the enhanced data base in the PAD5 topical, WCAP-17642-P-A [8-2] in the response to RAI-3d in Section D, Submittals of Responses to Requests for Additional Information, Subsection LTR-NRC-15-101 [8-3], page 11:

> "Table 3d-1 lists cladding samples from Figure 2-1 with the following data supplied, material type, Nodal TRD, predicted oxide thickness and measured oxide thickness, predicted hydrogen and measured hydrogen in the metal. New **Optimized ZIRLO** cladding data has been added to Table 3d-1 and is indicated. The new data falls within the ranges observed in the database."

Based on this, the HPU model was confirmed to remain applicable as part of the PAD5 topical report review and approval.

Reference(s)

8-1) WCAP-12610-P-A & CENPD-404-P-A, Addendum 2-A, "Westinghouse Clad Corrosion Model for **ZIRLO** and **Optimized ZIRLO**," October 2013.

8-2) WCAP-17642-P-A, “Westinghouse Performance Analysis and Design Model (PAD5),” November 2017.
8-3) LTR-NRC-15-101, “Response to the 90 day RAIs from RAI Set 2 for WCAP-17642, ‘Westinghouse Performance Analysis and Design Model (PAD5)’ (Proprietary/Non-Proprietary),” January 2016.

RAI 9:

It is expected that, in developing a core design capable of achieving individual rod average burnups of **[ ]**^{a,c} the core-average enrichment will increase slightly. This increase in reactivity can be accounted for through several possible ways, among which are the use of additional burnable absorbers or an increase in critical boron concentration. Anticipating a possible increase in critical boron concentration, it is noted that both PARAGON (WCAP-11596-P-A and PHOENIX-P (WCAP-16045-P-A)) are validated, in part, through core follow comparisons of critical boron concentration. If new core designs are expected to utilize higher critical boron concentrations in comparison to existing core designs, what is the magnitude of the change in critical boron concentration in ppm? If the change in critical boron concentration is outside the validation range for PARAGON and PHOENIX-P, please provide justification the codes can acceptably predict critical boron concentrations beyond the present validation range.

Response to RAI 9:

The critical boron concentration for each cycle varies slightly based on the reactivity of fuel carried over from the previous cycle, enrichment of feed fuel and the number of burnable absorbers present in the fuel. In developing core designs capable of achieving rod burnups of **[ ]**^{a,c} any boron changes due to the slight enrichment increase will be within the current cycle by cycle variation. The maximum critical boron concentration of any core design is limited by chemistry considerations, minimum required boron concentrations in safety systems, and the technical specification moderator temperature coefficient. Without changes to technical specifications for moderator temperature coefficient and minimum boron concentrations in safety systems such as the refueling water storage tank, the boron concentrations will remain largely unchanged. Since the boron concentrations do not change, the PARAGON and PHOENIX-P validation ranges remain appropriate.

RAI 12:

10 Code of Federal Regulations (CFR) 50.46(a)(1) permits evaluation models used to demonstrate compliance with the criteria in 10 CFR 50.46(b) to have two forms: (1) realistic with accounting for uncertainty, or (2) conforming to Appendix K to 10 CFR 50. Considering that the deterministic option proposed in WCAP-18446-P/ WCAP-18446-NP, Revision 0, for assuring that fuel rods in the extended burnup region will not rupture during a loss-of-coolant

accident would support a demonstration of compliance with the requirement in 10 CFR 50.46(b)(4) for maintaining a coolable core geometry, WCAP-18446-P/WCAP-18446-NP, Revision 0, does not adequately justify that the proposed deterministic approach complies with either allowable approach for evaluation model development. Based upon the initial review, the deterministic approach does not appear to follow all required modeling practices in Appendix K to 10 CFR 50, nor does it appear explicitly to address the uncertainties of all significant physical parameters associated with cladding rupture for high burnup fuel. Please justify that the proposed deterministic approach in WCAP-18446-P/WCAP-18446-NP, Revision 0, complies with the evaluation model requirements prescribed in 10 CFR 50.46(a)(1), propose changes to the approach to ensure compliance therewith, or clarify whether Westinghouse envisions that licensee implementation of the proposed approach would require an exemption to these requirements.

Response to RAI 12:

The deterministic approach for the cladding rupture calculations developed by Westinghouse was viewed as a supplement to existing analyses which demonstrate compliance with 10 CFR 50.46, as opposed to directly pertaining to 10 CFR 50.46(b)(4). As Appendix K to 10 CFR Part 50 does not address phenomena important to the analysis of high burnup fuel, Westinghouse does not envision a method could be developed wholly within that framework that would be acceptable for performing the cladding rupture calculations.

Therefore, Westinghouse elects to **[**

]^{a,c} the topical report to reflect this RAI response. Since the number of updates is substantial, the specific changes are not provided as part of this RAI response.

Reference(s)

12-1) WCAP-18446-P, Revision 0, “Incremental Extension of Burnup Limit for Westinghouse and Combustion Engineering Fuel Designs,” December 2020.

12-2) WCAP-16996-P-A, Revision 1, "Realistic LOCA Evaluation Methodology Applied to the Full Spectrum of Break Sizes (**FULL SPECTRUM** LOCA Methodology)," November 2016.

RAI 13:

General Design Criterion 35 requires assurance of accomplishing the safety function of the emergency core cooling system for both (1) scenarios relying on onsite electrical power and (2) scenarios relying on offsite electrical power. Accordingly, in its review of the loss-of-coolant accident evaluation model described in WCAP-16996, the staff found it necessary for Westinghouse to perform separate sets of calculations for these two distinct scenarios. Section 4.7.3.2.2 of WCAP-18446-P/WCAP-18446-NP, Revision 0, **[**

][a,c] While the general insights offered in Section 4.7.3.2.2 appear reasonable, the loss-of-coolant accident is a complex event with the capacity to confound simplified reasoning. Absent substantial additional evidence to support revisiting the conclusion reached in the regulatory review of the base WCAP-16996-P-A/WCAP-16696-NP-A, Revision 1, methodology, it is not clear that the specific framework of sensitivity cases considered in Table 4.7-2 is adequate to bound the range of variation expected from a full set of statistical analyses of both electrical power availability scenarios. Please provide additional justification that the approach proposed in Section 4.7.3.2.2 is sufficient to bound the results of both scenarios specified in General Design Criterion 35 for all pressurized-water reactor designs within the scope of the methodology or modify the approach to provide explicit treatment of each electrical-power-availability scenario.

Response to RAI 13:

The treatment of the offsite power availability for the large-break LOCA cladding rupture calculations as discussed in Section 4.7.3.2.2 of WCAP-18446-P [13-1] is modified in response to this RAI. The cladding rupture calculations will be conducted twice: once assuming a loss-of-offsite power (LOOP) and once assuming offsite power available (OPA). An acceptable result requires that cladding rupture is not predicted to occur for either configuration. Section 4.7.3.2.2 of WCAP-18446-P will be updated as follows.

Offsite Power Availability

[

]a,c

[

]a,c

[

]a,c

Reference(s)

13-1) WCAP-18446-P Revision 0, "Incremental Extension of Burnup Limit for Westinghouse and Combustion Engineering Fuel Designs," December 2020.

RAI 14:

Individual calculations produced by the complex thermal-hydraulic evaluation models used in modern reactor safety analyses can exhibit substantial variation that is not proportionate to a prior expectation (e.g., apparently random, non-linear variation in response to slight input changes). Based upon the initial review, it is not clear whether such random variations may impact the accuracy of conclusions drawn from the deterministic approach proposed by Westinghouse Electric Company (Westinghouse). For instance, as noted in Section 4.8.3 of WCAP-18446-P/ WCAP-18446-NP, Revision 0, Figure 4.8-4 illustrates a **[**

]a,c is inherently deterministic and repeatable, or whether it represents a statistical behavior that is difficult to characterize in a single simulation. If the observed behavior is statistical and significant to the outcome the simulations (or if other analogous statistical behaviors may impart a significant, random influence on the outcomes of individual simulations), it would call into question the efficacy of a deterministic approach such as proposed in WCAP-18446-P/WCAP-18446-NP, Revision 0:

a. Please estimate the random variation inherent in the results of the deterministic approach and justify that, when decoupled from statistically based calculation procedures that tend to smooth out variations in individual simulations, the modeling approaches supporting the deterministic approach proposed in WCAP-18446-P/ WCAP-18446-NP, Revision 0, are capable of providing well-behaved deterministic

results that are not unduly influenced by random variation with non-linear physical phenomena associated with the loss-of-coolant accident.

b. Please identify the **[**

]^{a,c} described in Section 4.8.3 were drawn.

Response to RAI 14

There are three different sub-phases which can occur during the blowdown phase of a large-break LOCA, which are evident in the flow patterns and cladding heatup during blowdown. First is the blowdown heat-up, characterized by a rapid heatup of the cladding. Second is the upflow cooling phase, which can occur if the reactor coolant pumps (RCPs) are not sufficiently degraded, such that they are capable of continuing to push fluid up through the core. Finally, the downflow cooling phase occurs when the break dominates the flow pattern and pulls fluid down through the core, as the RCPs degrade due to voiding and no longer have sufficient capability to maintain upward flow through the core. The timing and degree to which these flow patterns persist at various elevations within the core is dependent on parameters such as (but not limited to) the break type, break size, relative loop resistances, and RCP characteristics.

The global model run matrix developed as part of the deterministic approach **[**

]^{a,c}

RAI 15

At present, the base loss-of-coolant accident evaluation model described in WCAP-16996-P-A/WCAP-16696-NP-A, Revision 1, is not approved for Westinghouse 2-loop and Combustion Engineering pressurized-water reactors. These plant designs, while fundamentally similar to the Westinghouse 3- and 4-loop reactors for which WCAP-16996-P-A /WCAP-16696-NP-A, Revision 1, has been approved, incorporate design differences relevant to modeling a loss-of-coolant accident (e.g., different emergency core cooling system injection points, significant variations in accumulator pressure). In principle, any future version of the base methodology eventually applied to these plants, from the phenomenon identification and ranking process, to the code models, to the calculational procedures (e.g., selection of limiting breaks, uncertainty methodology), may ultimately turn out differently than currently envisioned. While Westinghouse's proposed Limitation #6 addresses the need for approval of the base methodology prior to application of WCAP-18446-P/WCAP-18446-NP, Revision 0, to Westinghouse 2-loop or Combustion Engineering pressurized-water reactors, the proposed limitation does not address the potential for changes implemented during the regulatory review of the base evaluation model to impact the methodology described in WCAP-18446-P/WCAP-18446-NP, Revision 0. Please clarify how WCAP-18446-P/WCAP-18446-NP, Revision 0, could be accepted unconditionally for plants beyond the current scope of the WCAP-16996-P-A/ WCAP-16696-NP-A, Revision 1, base methodology, or propose an alternative limitation or regulatory pathway to facilitate an effective and efficient review process for such plants.

Response to RAI 15

Westinghouse has previously licensed the extension of best-estimate LOCA evaluation models (EMs) to Westinghouse-designed 2-Loop PWRs equipped with upper plenum injection (UPI) and Combustion Engineering-designed PWRs. The Code Qualification Document (CQD) EM (WCAP-12945-P-A, Volume I, Revision 2, and Volumes II through V, Revision 1 [15-1]) was originally licensed for Westinghouse-designed 3-Loop and 4-Loop pressurized water reactors (PWRs). It was later extended to Westinghouse-design 2-Loop PWRs equipped with UPI in WCAP-14449-P-A, Revision 1 [15-2]. When the uncertainty analysis method was revised within the Automated Statistical Treatment of Uncertainty Method (ASTRUM), the EM was further extended to Combustion Engineering-designed PWRs per WCAP-16009-P-A [15-3]. Considering the ASTRUM EM (which was the predecessor to the **FULL SPECTRUM** LOCA (**FSLOCA**) methodology for Region II), there were **[**

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[

]a,c

Westinghouse has [

]a,c An update is proposed to Limitation #6 as shown below to clarify the requirement, with removed text shown in red font with strikethrough and added text shown in blue font. In concert with the updated Limitation #6 from WCAP-18446-P, this approach supports acceptance of WCAP-18446-P for Westinghouse-designed 2-loop PWRs and Combustion Engineering-designed PWRs.

Note that the last sentence in Limitation #6 is also removed as the relationship between the cladding rupture calculations and existing licensing basis LOCA analyses has been clarified via the response to RAI #12 and Part B to RAI #28.

Limitation #6: This topical report is applicable to Westinghouse-designed 2-loop, 3-loop, and 4-loop pressurized water reactors (PWRs) and Combustion Engineering (CE)-designed PWRs. The methodology for the LOCA rupture calculations can only be applied to the Westinghouse 2-loop PWR and CE PWR designs ~~if~~after the **FSLOCA** EM is approved for these designs. The cladding rupture calculations for these designs [

]a,c for 3-loop and 4-loop PWRs. ~~No change to the licensing basis LOCA analyses is necessary for Westinghouse-designed 3-loop and 4-loop PWRs.~~

Reference(s)

15-1) WCAP-12945-P-A, Volume I, Revision 2, and Volumes II through V, Revision 1, "Code Qualification Document for Best Estimate LOCA Analysis," March 1998.
15-2) WCAP-14449-P-A, Revision 1, "Application of Best Estimate Large Break LOCA Methodology to Westinghouse PWRs With Upper Plenum Injection," October 1999.
15-3) WCAP-16009-P-A, Revision 0, "Realistic Large-Break LOCA Evaluation Methodology Using the Automated Statistical Treatment Of Uncertainty Method (ASTRUM)," January 2005.
15-4) WCAP-16996-P-A, Revision 1, "Realistic LOCA Evaluation Methodology Applied to the Full Spectrum of Break Sizes (**FULL SPECTRUM** LOCA Methodology)," November 2016.
15-5) WCAP-18446-P, Revision 0, "Incremental Extension of Burnup Limit for Westinghouse and Combustion Engineering Fuel Designs," December 2020.

RAI 16

Sections 4.7.1 and 4.7.2 of WCAP-18446-P/WCAP-18446-NP, Revision 0, present an **[**

][a,c] While this position may be representative of many pressurized-water reactors, it is not clear that a robust conclusion can be made with reasonable assurance for all plants when considering (1) existing plant design differences, including low-pressure accumulators, and (2) the potential for future changes (e.g., fuel design, plant design, regulatory requirements). Therefore, please demonstrate that the proposed approach is applicable for all pressurized-water reactors, or propose an alternative, such as **[**

][a,c]

Response to RAI 16

The rationale for the **[**

][a,c]

[

]a,c The following updates are made to the topical report to reflect this change.

The following text is added at the end of Section 4.7.1:

Based on this discussion, if the [

]a,c

RAI 18:

An adequate degree of inherent conservatism in the deterministic approach proposed in WCAP-18446-P/WCAP-18446-NP, Revision 0, has not been demonstrated. For instance:

- While a limited number of key parameters would be treated conservatively, many other uncertain parameters from the WCAP-16996 evaluation model of high significance to the prediction of cladding temperature and rupture behavior are treated in a purely nominal fashion.
- For some of the [
-

]a,c discussed in Section 4.7.3.2 of WCAP-18446-P/WCAP-18446-NP, Revision 0, is capable of encompassing the full range of applicable uncertainties associated with the loss-of-coolant accident, which affect numerous additional parameters associated with the fuel rod initial conditions, plant initial conditions, thermal-hydraulic modeling, etc. Please demonstrate that the [
]a,c described in Section 4.7.3.2 of WCAP-18446-P/WCAP-18446-NP, Revision 0, is sufficient to ensure the conservatism of the proposed deterministic approach for verifying no rupture of fuel rods in the extended burnup region. Alternatively, if credit must

be taken for **[** **]^{a,c}** please propose modifications to WCAP-18446-P/WCAP-18446-NP, Revision 0, to clarify the required modeling practices.

Response to RAI 18:

Westinghouse has elected to **[**

]^{a,c} as discussed in response to RAI #12.

RAI 20:

Please provide evidence to support the following statement made in Section 4.4.1 of WCAP-18446-P/WCAP-18446-NP, Revision 0:

> A comparison of the gap conductance predicted by WCOBRA/TRAC-TF2 versus PAD5 for high burnup fuel indicates reasonable agreement between the two codes, with WCOBRA/TRAC-TF2 tending to under-predict the gap conductance relative to PAD5.

Response to RAI 20:

The steady-state and transient fuel rod conditions were considered in order to assess the reasonableness of the WCOBRA/TRAC-TF2 (WCT-TF2) predicted gap conductance. Comparisons of PAD5 data and the WCT-TF2 predicted gap conductance were made. In addition, the changing fuel rod conditions following the initiation of the LOCA transient were considered.

In order to achieve an acceptable steady-state, calibration of the fuel stored energy in WCT-TF2 to values determined from PAD5 is necessary because accurate prediction along the length of the rod requires more complicated models than are present in WCT-TF2. **[**

]^{a,c}

The reactor coolant system (RCS) and fuel rod conditions experience significant changes upon the LOCA transient initiation. The RCS depressurizes and approaches the containment pressure toward the end of the blowdown phase of a large-break LOCA. Within the fuel rod, the cladding temperatures tend to increase as the heat transfer to the coolant

reduces, the fuel temperatures decrease as the core becomes subcritical and stored energy is transferred from the fuel, and the rod internal pressure decreases given the changes in pressure and temperature (and the potential associated fuel rod deformation). Under these conditions, the cladding expands, the fuel pellet shrinks, and the gap conductance will change correspondingly. For the high burnup peripheral rods of interest for the incremental burnup extension, **[**

][a,c] However, the gap conductance following a LOCA is expected to decrease due to the fuel pellet temperature drop and the associated thermal contraction as well as the cladding thermal expansion, which in turn can reduce the contact pressure or re-open the gap. The associated change in gap conductance can be represented by the difference in the **[**

][a,c]

WCT-TF2 simulates the noted important phenomena following the initiation of the LOCA transient. Figure 20-2 shows WCT-TF2 predicted the gap conductance and gap width for a high burnup low power peripheral rod for the example PWR plant. **[**

][a,c]

A reasonable approximation of the gap conductance in WCT-TF2 is necessary given the fuel rod surface conditions in the low power periphery. Initially, **[**

][a,c]

Based on the provided discussion, **[**

][a,c]

Reference(s)

20-1) WCAP-16996-P-A, Revision 1, "Realistic LOCA Evaluation Methodology Applied to the Full Spectrum of Break Sizes (**FULL SPECTRUM** LOCA Methodology)," November 2016.

[ ]a,c

a,c

RAI 21:

Section 4.7.3.2.1 of WCAP-18446-P/WCAP-18446-NP, Revision 0, states that, for cladding rupture calculations:

> The **[**
>
> **]**^{a,c}

Please clarify the following: (1) the distinction between the terms **[**

]^{a,c}

Response to RAI 21:

Within the fuel performance calculations, there are some parameters which are **[**

]^{a,c}

As discussed in the response to RAI #12, Westinghouse has elected to **[**

]^{a,c}

RAI 22:

Section 4.4.3.3 of WCAP-18446-P/WCAP-18446-NP, Revision 0, discusses cladding deformation due to rupture. The relevance of this section to the extended burnup regime is not clear, since Westinghouse has stated that rupture of fuel rods in this regime will be avoided. Please clarify the intent of including Section 4.4.3.3 in WCAP-18446-P/WCAP-18446-NP, Revision 0, and explain any information therein that is relied upon to support the proposed methodology.

Response to RAI 22:

Section 4.4.3.3 of WCAP-18446-P [22-1] was included for completeness so that the impact of burnup on all the various cladding deformation and rupture models was addressed. However, that specific model is not relevant to the LOCA calculations for the incremental

burnup extension since rupture must be precluded within the extended burnup regime as identified by the staff in the request.

A reference to this RAI and response will be added to Section 4.4.3.3 of WCAP-18446-P.

Reference(s)

22-1) WCAP-18446-P Revision 0, "Incremental Extension of Burnup Limit for Westinghouse and Combustion Engineering Fuel Designs," December 2020.

RAI 23:

Please provide the results of the sensitivity analysis showing that the **[**

][a,c] Please summarize any inputs used that differ from those assumed in WCAP-18446-P/WCAP-18446-NP, Revision 0, and discuss any significant results that have not already been covered in WCAP-18446-P/WCAP-18446-NP, Revision 0.

Response to RAI 23:

The calculations are based on a **[**

][a,c] as summarized below:

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

For the limiting case from the demonstration analysis presented in Figure 4.8-2 of WCAP-18446-P, it is observed that the **[**

][a,c]

Tables 3.2.4-1 and 3.2.4-2 of LTR-NRC-21-16 [23-2] indicate that the core average enrichment for the incremental burnup extension will tend to be **[** **]**[a,c]

[

]a,c

Reference(s)

23-1) WCAP-18446-P Revision 0, "Incremental Extension of Burnup Limit for Westinghouse and Combustion Engineering Fuel Designs," December 2020.

23-2) 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.

a,c

a,c

a,c

RAI 27:

Unlike the LOFTRAN and RETRAN methodologies for performing steam line break mass and energy release analyses, Section 5.2.3 of WCAP-18446-P/ WCAP-18446-NP, Revision 0, summarily states that the SGNIII methodology does not require any changes when modeling fuel rods at extended burnup due to “overall conservatism.” However, no basis for concluding that these conservatisms are sufficient to accommodate the potential for increased decay heat and stored energy relative to fuel in the increased burnup regime is provided. Please justify that the overall conservatism of the SGNIII methodology addresses the potential for increased heat inputs associated with the extended burnup regime or clarify how inputs to the analysis will be revised to accommodate the potential for more limiting conditions.

Response to RAI 27:

The SGNIII computer code is described in CESSAR Appendix 6B [27-1]. This is cited in WCAP-18446-P [27-2], Section 5.3 as Reference 3:

> Combustion Engineering, January 1974, “Description of the SGNIII Digital Computer Code Used in Developing Main Steam Line Break Mass/Energy Release Data for Containment Analysis,” CESSAR Appendix 6B.

The following responses to the issues raised in RAI#27 are based on the code description in CESSAR Appendix 6B.

<u>Decay Heat</u>

The SGNIII code uses a one-group point kinetics representation with six delayed neutron groups. Following reactor trip the point kinetics representation is modified to conservatively describe decay heat production using the ANS-5 (1971) curve, for an infinite life core with the heavy element contribution included. The decay heat representation used in SGNIII therefore remains conservative with increased core burnup.

<u>Core Stored Energy</u>

The nodal specific heat, volume, and heat transfer coefficient are defined via input.

The construction of the initial fuel temperatures is based on a specific time in life (burnup) with appropriate gap conductivity and fuel conductivity values. These are the parameters which establish the initial core stored energy and are the way in which fuel conductivity, gap conductance, fuel rod pressurization and fuel densification effects are considered in SGNIII. Analyses at increased burnup conditions would adjust the inputs as required.

<u>Conservatism in SGNIII</u>

The SGNIII topical (CESSAR Appendix 6B) considered the conservatism in the models and concluded (in Section H) that heat effects in the reactor coolant system such as core stored

energy, core to coolant heat transfer and decay heat tend to maintain the temperature in the reactor coolant system following a steam line break. The CESSAR goes on to note that a wide variation in these parameters has little effect on the rate of energy release from the steam generators.

Revised WCAP-18446 text in Section 5.2.3

SGNIII Methodology

The heat effects in the reactor coolant system such as core stored energy, core to coolant heat transfer, and decay heat tend to maintain the temperature in the reactor coolant system following a steamline break. A wide variation in these parameters, however, has little effect on the rate of energy release from the steam generators. ~~Due to the overall conservatism in the SGNIII methodology,~~

The decay heat model is based on an infinite life core, so no changes are necessary to account for increased burnup. Initial core stored energy is determined by code input; analyses at increased burnup would adjust the inputs as required.

In conclusion, no changes to the methodology are needed when modeling an increased core-wide fuel burnup limit.

Reference(s)

27-1) CESSAR Appendix 6B, "Description of the SGNIII Digital Computer Code Used in Developing Main Steam Line Break Mass/Energy Release Data for Containment Analysis," January 1974.

27-2) WCAP-18446-P Revision 0, "Incremental Extension of Burnup Limit for Westinghouse and Combustion Engineering Fuel Designs," December 2020.

RAI 28:

Westinghouse's proposed Limitation #7 for WCAP-18446-P/WCAP-18446-NP, Revision 0, states that PAD5 must be incorporated into the plant licensing basis for licensing-basis fuel and safety analysis, with the exception of LOCA.

a. Please confirm that proposed Limitation #7 applies even in cases where WCAP-18446-P/WCAP-18446-NP, Revision 0, or other approved TRs do not specifically mention PAD5. For instance, the NRC staff observed in Section 5.2.2 of WCAP-18446-P/WCAP-18446-NP, Revision 0, that, while the discussion of the WCAP-17721-P (Reference 5) methodology refers specifically to PAD5, discussion of fuel thermal-mechanical modeling with respect to the WCAP-10325 and

CENPD-132 methodologies refer less restrictively to “approved fuel performance methods” or “approved methodology.”

b. Please justify allowing an exception to the implementation of PAD5 methods for the loss-of-coolant accident, considering that (1) stored energy is of particular importance to the loss-of-coolant accident, and (2) some plants may still be using ad hoc, interim methods for addressing stored energy that vendors developed approximately a decade ago following the emergence of the thermal conductivity degradation issue, which have not been formally approved on a generic basis.

Response to RAI 28a:

All of the LOCA M&E release methodologies (WCAP-10325-P-A [28a-1], WCAP-17721-P-A [28a-2], and CENPD-132 [28a-3]) intend to use fuel performance data as analysis inputs that is provided by the most up-to-date fuel performance code that is available within Westinghouse (currently PAD5).

Revised WCAP-18446 text in Section 5.2.2

WCAP-10325-P-A Methodology

The core is modeled as an average core for the generation of the long term LOCA M&E releases. There is no hot rod or hot assembly modeled when generating long term LOCA M&E. It is conservative for the long term LOCA M&E to maximize the rate of transfer of energy from the core into the coolant and out of the break. Thus, pellet and cladding interaction and rod burst are not modeled because this would retard the release of the energy stored in the fuel to the coolant and then the break flow. The specific fuel product is modeled with respect to rod inside and outside diameter, flow area through the core, proposed peaking factors, rod initial gas fractions, rod initial internal pressure, theoretical density of the pellet, the material properties of the pellet, the material properties of the cladding material, and the burnup where the highest fuel temperature during the proposed cycle would occur. The licensed LOCA mass and energy release methodology in (Westinghouse, May 1983) does not have any limitations defined with respect to individual rod average burnup. The data that comes from the PAD5 fuel performance calculations is used as input for the generation of the LOCA mass and energy releases. It is the fuel performance methodology that has the burnup limitation. Therefore, the use of approved fuel performance methods at higher burnups will result in the generation of conservative long term LOCA M&E releases for use in the containment integrity analyses.

CENPD-132P Methodology

The CE methodology is documented in (CE, August 1974 – March 2001). The CEFLASH-4A computer code is used for the blowdown portion of the transient for both the emergency core cooling system (ECCS) and LOCA M&E calculations. Nominal, cold conditions are the foundation for the fuel dimensions. This approved methodology is based on a hot rod. The fuel temperatures that are used are based on a bounding fuel centerline temperature versus linear heat rate over the entire fuel cycle. No burnup limit is listed for this methodology. The fuel performance data that is used as an input is generated using ~~an approved methodology~~ PAD5. It is the fuel performance methodology that has the burnup limitations.

Reference(s)

28a-1) WCAP-10325-P-A, "Westinghouse LOCA Mass and Energy Release Model for Containment Design March 1979 Version," May 1983.

28a-2) WCAP-17721-P-A, "Westinghouse Containment Analysis Methodology - PWR LOCA Mass and Energy Release Calculation Methodology," September 2015.

28a-3) CENPD-132, "Calculational Methods for the C-E Large Break LOCA Evaluation Model," August 1974 – March 2001.

Response to RAI 28b:

The calculations described in this topical report, specific to prediction of cladding rupture in high burnup fuel rods during a postulated LOCA, will utilize the most recent NRC-approved Westinghouse best-estimate LOCA thermal-hydraulic code (with modifications as described in this topical report). The calibration of the stored energy will rely on the NRC-approved PAD5 code (WCAP-17642-P-A, Revision 1 [28b-1]) to determine initial fuel rod conditions.

The implementation of the method described in this topical report for high burnup cladding rupture is **[**

]^{a,c}

Specific to thermal conductivity degradation (TCD): The initial assessments of TCD for Westinghouse LOCA evaluation models were provided in response to letters issued pursuant to 10 CFR 50.54(f). In those letters, the NRC indicated that action was needed to address the potentially significant error, as defined in 10 CFR 50.46, associated with TCD in

Westinghouse-furnished realistic LOCA evaluation models. Since that time, licensees utilizing Westinghouse LOCA methods have incorporated TCD into their licensing basis analyses as required by 10 CFR 50.46 (a)(3) via various approaches: evaluations reported pursuant to 10 CFR 50.46, application of plant-specific evaluation models explicitly considering TCD which have been reviewed and approved by the NRC, and applications of the **FULL SPECTRUM** LOCA (**FSLOCA**) EM (WCAP-16996-P-A, Revision 1 [28b-2]) which have been reviewed and approved by the NRC.

The latest Westinghouse fuel performance code approved by the NRC is PAD5. **[**

][a,c]

Reference(s)

28b-1) WCAP-17642-P-A, Revision 1, "Westinghouse Performance Analysis and Design Model (PAD5)," November 2017.

28b-2) WCAP-16996-P-A, Revision 1, "Realistic LOCA Evaluation Methodology Applied to the Full Spectrum of Break Sizes (**FULL SPECTRUM** LOCA Methodology)," November 2016.

RAI 29:

Section 7.2 of WCAP-18446-P/WCAP-18446-NP, Revision 0, states that "The incremental burnup extension does not impact any of the containment analyses." This statement does not appear consistent with information provided earlier in Section 5.2, which acknowledges that, while containment analysis methods do not typically include fuel-related models, they accept inputs from fuel performance codes, including decay heat and stored energy values. Based upon the discussion in Section 5.2, a potential appears to exist for changes in input values associated with extended burnup to affect containment analyses for at least some plants. Therefore, please explain how the discussion in these sections of WCAP-18446-P/

WCAP-18446-NP, Revision 0, is self-consistent, or, as necessary, propose a modification to the TR to ensure a clear, consistent position with respect to the potential need for updating containment analyses.

Response to RAI 29:

Section 7.2 of the topical report was written with respect to the acceptability of the existing methodology, not the results from the generation of the long-term LOCA mass and energy releases or the subsequent containment response to new LOCA mass and energy releases. The incremental burnup extension does not impact any of the LOCA mass and energy release methodologies or codes used for the generation of a containment integrity response. The generation of the long-term LOCA mass and energy releases for any analysis that would address the incremental burnup extension would be handled via inputs. The containment analyses would be impacted if the incremental burnup extension would result in an increase in the initial core stored energy or increases in the decay heat curve.

Revised WCAP-18446 text in Section 7.2

Containment Analysis

The incremental burnup extension does not impact any of the containment ~~analyses~~ methodologies or codes. All LOCA M&E release analysis for incremental burnup extension will use fuel performance data as analysis inputs that are provided by the most up-to-date fuel performance code that is available within Westinghouse (currently PAD5).