# U. S. NUCLEAR REGULATORY COMMISSION

# FINAL SAFETY EVALUATION

# BY THE OFFICE OF NUCLEAR REACTOR REGULATION

# FOR WESTINGHOUSE ELECTRIC COMPANY

# TOPICAL REPORT WCAP-18446-P/WCAP-18446-NP, REVISION 0,

# “INCREMENTAL EXTENSION OF BURNUP LIMIT FOR WESTINGHOUSE AND COMBUSTION ENGINEERING FUEL DESIGNS”

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## 1.0 INTRODUCTION

By letter dated December 14, 2020, Westinghouse Electric Company (Westinghouse) submitted to the U.S. Nuclear Regulatory Commission (NRC) topical report (TR) WCAP-18446-P/ WCAP-18446-NP, Revision 0, “Incremental Extension of Burnup Limit for Westinghouse and Combustion Engineering Fuel Designs” (Reference 1). WCAP-18446-P/WCAP-18446-NP, Revision 0, proposes allowing the maximum fuel rod-average burnup for applicable Westinghouse fuel designs for Westinghouse and Combustion Engineering (CE) pressurized-water reactors (PWRs) to be increased from the currently approved value of 62 GWd/MTU to the proposed value of **[ ]**

As outlined in WCAP-18446-P/WCAP-18446-NP, Revision 0, the proposed extension of the licensed burnup limit to **[ ]** would affect analyses and evaluations that support the demonstration of reactor safety in several areas, including the following:

- fuel assembly mechanical design
- core and fuel rod performance
- loss-of-coolant-accident analysis methods
- non-loss-of-coolant-accident analysis methods
- radiological consequence analyses

WCAP-18446-P/WCAP-18446-NP, Revision 0, describes a methodology to demonstrate that a loss of **[ ]** for fuel in the extended burnup region, even under postulated accident conditions for which limited **[ ]**

Enclosure 1

would be permitted. Ensuring, even under accident conditions, that **[ ]** for fuel in the extended burnup range is intended to **[ ]** for the fragmentation of high-burnup fuel and its subsequent dispersal into the reactor vessel and potentially beyond. Consideration of the possibility that fuel fragmentation and dispersal could affect fuel rods with a rod-average burnup less than the currently approved burnup limit of 62 GWd/MTU is beyond the scope of WCAP-18446-P/WCAP-18446-NP, Revision 0.

While addressing requests for additional information (RAIs) from the NRC staff, Westinghouse proposed an important modification to the original WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology to restrict the placement of assemblies expected to exceed a burnup threshold of 62 GWd/MTU to peripheral core positions. Placing extended burnup assemblies only on the core periphery limits their maximum power level and facilitates the demonstration of **[ ]** under postulated transient and accident conditions.

The technical evaluation section of this safety evaluation (SE) addresses Westinghouse's assessment of the impact of the proposed burnup limit extension in each of these areas, including any modifications or additions to existing analytical methods and practices. The NRC staff's technical evaluation will further review Westinghouse's assessment of the impact of the proposed extended burnup limit on fuel designs incorporating features including the Advanced Doped Pellet Technology (ADOPT™) and AXIOM® cladding, as well as Westinghouse's plan for implementing the proposed burnup extension.

While the NRC staff's initial acceptance review found sufficient information present in the submittal to begin the detailed technical review (Reference 2), the acceptance review identified a set of topics where supplementary information would be necessary to support a timely regulatory review. This set of topics was discussed with Westinghouse in a closed meeting on February 11, 2021 (Reference 3).

As documented in Appendix A to this SE, the NRC staff held an audit with Westinghouse on April 8 and 9, 2021, to further discuss the content of the supplementary information necessary to support the NRC staff's regulatory review. Westinghouse provided a voluntary supplement dated May 13, 2021 (Reference 4), containing further information in the areas identified by the NRC staff during the acceptance review and subsequent audit.

After reviewing WCAP-18446-P/WCAP-18446-NP, Revision 0, and Westinghouse's voluntary supplement, on December 15, 2021, the NRC staff issued a RAI to solicit information necessary to complete its technical review (Reference 5). Westinghouse responded to the NRC staff's RAIs on February 4, 2022 (Reference 6), April 1, 2002 (Reference 7), and June 10, 2022 (Reference 8).

Because Westinghouse's initial responses did not fully resolve all underlying issues associated with the NRC staff's RAIs, the NRC staff issued a second round of RAIs to Westinghouse on September 21, 2022 (Reference 9), to follow up on a subset of the initial RAI questions. Westinghouse replied to these second-round RAIs in submittals dated December 2, 2022 (Reference 10), and February 2, 2023 (Reference 11).

By letter dated May 4, 2023 (Reference 12), Westinghouse further submitted a supplement to the TR to extend the applicability of the incremental burnup extension to include AXIOM cladding.

The NRC staff's SE assesses the information contained in WCAP-18446-P/WCAP-18446-NP, Revision 0, as well as the supplementary submittals discussed above.

## 2.0 REGULATORY EVALUATION

Section 1.3 of WCAP-18446-P/WCAP-18446-NP, Revision 0, identifies significant regulatory guidance that Westinghouse deemed pertinent to its methodology for the analysis of fuel in the extended burnup region from **[ ]** Key applicable regulatory requirements are also noted in this and other sections of WCAP-18446-P/WCAP-18446-NP, Revision 0.

Applicable regulatory requirements and guidance identified by the NRC staff are listed in the following subsections of this SE, organized by topical area.

### 2.1 Fuel Design

Regulatory requirements and guidance for the design of nuclear fuel are intended to ensure acceptable behavior under normal operation, anticipated transients, and postulated accidents:

- General Design Criterion (GDC) 10, in Appendix A to Title 10 of the *Code of Federal Regulations* (10 CFR) Part 50, requires that the reactor core and associated coolant, control, and protection systems shall be designed with appropriate margin to assure that specified acceptable fuel design limits are not exceeded during any condition of normal operation, including the effects of anticipated operational occurrences.

- NUREG-0800, “Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition,” (SRP) SRP Section 4.2, “Fuel System Design” (Reference 13), provides review guidance to the NRC staff concerning the establishment of specified acceptable fuel design limits to assure:

    - the fuel system is not damaged as a result of normal operation and anticipated operational occurrences

    - fuel system damage is never so severe as to prevent control rod insertion when it is required

    - the number of fuel rod failures is not underestimated for postulated accidents

    - core coolability is maintained

### 2.2 Loss-of-Coolant Accident

Regulatory requirements and guidance addressing the loss-of-coolant accident (LOCA) are relevant to the present review because the methodology discussed in Section 4 of WCAP-18446-P/WCAP-18446-NP, Revision 0, and Westinghouse’s RAI responses (e.g., RAI 19) describes an evaluation model for demonstrating satisfactory emergency core cooling system performance with respect to fuel in the extended burnup range from **[ ]** The associated acceptance criteria proposed in WCAP-18446-P/WCAP-18446-NP, Revision 0, for such fuel must be consistent with the regulatory acceptance criteria specified for emergency core cooling system performance during a LOCA.

Significant regulatory requirements pertinent to this review for the LOCA include the following:

- 10 CFR 50.46 specifies requirements pertaining to the performance of emergency core cooling systems during a postulated LOCA. While some operating reactors now use fuel designs that do not conform to the specific features listed in the applicability requirements for 10 CFR 50.46 (e.g., use of zircaloy or ZIRLO® cladding), regulatory requirements in 10 CFR 50.46 currently remain in effect for all domestic operating power reactors, in some cases through exemptions. Requirements of 10 CFR 50.46 particularly relevant to the current review include the following:

    - as described in paragraph (a), analytic evaluation models for calculating emergency core cooling system performance must use realistic models with an estimate of the uncertainty in the calculated results or conform to the required and acceptable features described in Appendix K to 10 CFR Part 50.

    - analytic evaluation models must demonstrate conformance to the acceptance criteria described in paragraph (b) for demonstrating adequate emergency core cooling system performance. Among these acceptance criteria, paragraph (b)(4) requires that calculated changes in core geometry shall be such that the core remains amenable to cooling.

- GDC 35 establishes minimum requirements for water-cooled nuclear power plants with respect to emergency core cooling. In particular, GDC 35 requires abundant core cooling capable of transferring heat from the reactor core following any loss of reactor coolant, such that fuel and cladding damage that could interfere with continued effective core cooling is prevented and cladding metal-water reaction is limited to negligible amounts. GDC 35 further incorporates design requirements for emergency core cooling systems, addressing redundancy, leak detection and isolation, and functionality both with and without offsite power.

- Appendix K to 10 CFR Part 50 consists of two parts, the first of which specifies required and acceptable features of LOCA evaluation models, and the second of which specifies documentation required for LOCA evaluation models. Appendix K incorporates requirements for modeling significant physical phenomena throughout all phases of the LOCA event, including relevant heat sources, fuel rod performance, and thermal-hydraulic behavior.

In addition to these regulatory requirements, the NRC staff’s review further considered significant regulatory guidance for the LOCA including the following:

- SRP Section 15.6.5, “Loss-of-Coolant Accidents Resulting from Spectrum of Postulated Piping Breaks within the Reactor Coolant Pressure Boundary” (Reference 14), provides guidance to support the NRC staff's review of LOCA analyses.

- Regulatory Guide (RG) 1.157, “Best-Estimate Calculations of Emergency Core Cooling System Performance” (Reference 15), provides guidance concerning realistic modeling of the LOCA with explicit accounting for relevant uncertainties.

- SRP Section 15.0.2, “Review of Transient and Accident Analysis Methods” (Reference 16), provides guidance to support the NRC staff's review of analytical evaluation models used to perform safety analyses for nuclear reactors.

- RG 1.203, “Transient and Accident Analysis Methods” (Reference 17), provides regulatory guidance to licensees and applicants concerning the development and assessment of evaluation models used to perform safety analyses for nuclear reactors.

## 2.3 Anticipated Operational Occurrences

Section 5.1.1 of WCAP-18446-P/WCAP-18446-NP, Revision 0, describes the treatment of fuel in the extended burnup region with respect to anticipated operational occurrences or transients. Significant regulatory requirements pertinent to this review for the anticipated operational occurrences include the following:

- As discussed above, GDC 10 requires that the reactor core and associated coolant, control, and protection systems shall be designed with appropriate margin to assure that specified acceptable fuel design limits are not exceeded during any condition of normal operation, including the effects of anticipated operational occurrences.

Significant regulatory guidance pertinent to this review for anticipated operational occurrences includes the following:

- SRP Chapter 15, “Transient and Accident Analyses,” which provides guidance to support the NRC staff's review of analytical evaluation models used to perform safety analyses for nuclear reactors, as well as specific guidance for evaluating different types of anticipated operational occurrences, as categorized by their impact on the reactor response.

## 2.4 Reactivity Control Systems

Section 5.1.2 of WCAP-18446-P/WCAP-18446-NP, Revision 0, describes the treatment of fuel in the extended burnup region with respect to reactivity-initiated accidents. Significant regulatory requirements pertinent to this review for reactivity-initiated accidents include the following:

- GDC 27 - Combined reactivity control systems capability.
  The reactivity control systems shall be designed to have a combined capability, in conjunction with poison addition by the emergency core cooling system, of reliably controlling reactivity changes to assure that under postulated accident conditions and with appropriate margin for stuck rods the capability to cool the core is maintained.

- GDC 28 - Reactivity limits.
  The reactivity control systems shall be designed with appropriate limits on the potential amount and rate of reactivity increase to assure that the effects of postulated reactivity accidents can neither:

  (1) result in damage to the reactor coolant pressure boundary greater than limited local yielding nor

(2) sufficiently disturb the core, its support structures or other reactor pressure vessel internals to impair significantly the capability to cool the core. These postulated reactivity accidents shall include consideration of rod ejection (unless prevented by positive means), rod dropout, steam line rupture, changes in reactor coolant temperature and pressure, and cold water addition.

Significant regulatory guidance pertinent to this review for reactivity-initiated accidents includes the following:

- RG 1.236, "Pressurized-Water Reactor Control Rod Ejection and Boiling-Water Reactor Control Rod Drop Accidents" (Reference 18), which provides guidance for analysis of the control rod ejection accidents for PWRs and control rod drop accidents for boiling-water reactors. RG 1.236 describes acceptable methods and procedures for analyzing these accidents, analytical limits for demonstrating compliance with GDC 28, and defines fuel cladding failure thresholds.

## 2.5 Technical Specifications

As discussed in the NRC staff's RAI 17, considerations associated with the specification of burnup-dependent local power density limits in technical specifications (TS) invokes 10 CFR 50.36.

- 10 CFR 50.36, "Technical specifications," provides regulatory requirements related to the content of TSs. Section 50.36(b) of 10 CFR requires that each license authorizing the operation of a facility will include TSs and that the TSs will be derived from the safety analysis. Section 50.36(c) of 10 CFR specifies the categories that are to be included in the TSs including (1) safety limits, limiting safety system settings, and limiting control settings; (2) limiting conditions for operation; (3) surveillance requirements; (4) design features; and (5) administrative controls.

## 2.6 Containment Performance

Section 5.2 of WCAP-18446-P/WCAP-18446-NP, Revision 0, describes how the presence of fuel in the extended burnup region would affect the mass and energy release associated with the containment performance analysis. Significant regulatory requirements pertinent to this review for containment performance include the following:

- GDC 50 - Containment design basis.
  The reactor containment structure, including access openings, penetrations, and the containment heat removal system shall be designed so that the containment structure and its internal compartments can accommodate, without exceeding the design leakage rate and with sufficient margin, the calculated pressure and temperature conditions resulting from any loss-of-coolant accident. This margin shall reflect consideration of:

  (1) the effects of potential energy sources which have not been included in the determination of the peak conditions, such as energy in steam generators and as required by § 50.44 energy from metal-water and other chemical reactions that may result from degradation but not total failure of emergency core cooling functioning,

(2) the limited experience and experimental data available for defining accident phenomena and containment responses, and

(3) the conservatism of the calculational model and input parameters.

### 2.7 Radiological Dose

Section 6 of WCAP-18446-P/WCAP-18446-NP, Revision 0, describes how the presence of fuel in the extended burnup region would affect the radiological consequence analyses for certain postulated accidents, including the LOCA, steam generator tube rupture, main steam line break, locked reactor coolant pump rotor, control rod ejection, and fuel handling accident. Radiological dose limits established for postulated accidents ultimately establish a limit on the number of fuel rods that may fail during a postulated accident.

Significant regulatory requirements pertinent to this review for radiological dose include the following:

- Radiological dose requirements in 10 CFR Part 100 or 10 CFR 50.67
  While the calculation of radiological dose is beyond the scope of WCAP-18446-P/WCAP-18446-NP, Revision 0, the number of failed fuel rods predicted in the safety analysis serves as an input to downstream methods used for radiological dose assessment. Particularly relevant to the proposed burnup extension, the fragmentation of fuel pellets and subsequent dispersal of fragmented fuel could result in increased radionuclide release fractions relative to conditions under which a fuel pellet remains intact. Therefore, **[ ]** in the extended burnup regime would support a determination that applicable radiological dose requirements remain satisfied.

Significant regulatory guidance pertinent to this review for containment performance includes the following:

- RG 1.25, “Assumptions Used for Evaluating the Potential Radiological Consequences of a Fuel Handling Accident in the Fuel Handling and Storage Facility for Boiling and Pressurized Water Reactors” (Reference 19).

- RG 1.183, “Alternative Radiological Source Terms for Evaluating Design Basis Accidents at Nuclear Power Reactors” (Reference 20,21)

- RG 1.195, “Methods and Assumptions for Evaluating Radiological Consequences of Design Basis Accidents at Light-Water Nuclear Power Reactors” (Reference 22).

## 3.0 TECHNICAL EVALUATION

### 3.1 Fuel Assembly Mechanical Design

Section 2.0, “Fuel Assembly Mechanical Design,” of WCAP-18446-P/WCAP-18446-NP, Revision 0, proposes a methodology for assessing the design bases of a fuel assembly to determine if those bases remain applicable at higher burnups. As clarified in response to RAI 4, this section provides a set of criteria, a method of evaluation against those criteria, and the results of that evaluation for a specific design. Included in WCAP-18446-P/WCAP-18446-NP, Revision 0, are the evaluation results for the 17x17 Optimized Fuel Assembly (OFA) design.

### 3.1.1 17x17 OFA Design

Westinghouse uses the 17x17 OFA design to demonstrate the evaluation of fuel assembly design bases for an incremental burnup extension. The 17x17 OFA design was **[** **]** described in Section 7.1.1, "Applicable Fuel Designs," of WCAP-18446-P/ WCAP-18446-NP, Revision 0. The NRC staff has determined this approach to be acceptable only for the generic approval of the 17x17 OFA design for an incremental burnup extension through this TR. Other fuel designs, while they **[** **]** cannot necessarily be wholly represented by a single fuel design. The language used in the TR suggests that there may be specific cases in which the other fuel designs may **[** **]** As discussed in Limitation and Condition 1 of this SE, an incremental burnup extension for other fuel designs must be approved in plant-specific applications or future TRs using the design bases and methods of evaluation described in Section 2.0 of this TR as well as any other design bases and evaluations that may be applicable to non-17x17 OFA designs.

### 3.1.2 Fuel Assembly Design Bases and Evaluations

This section assesses the impact of the incremental burnup extension on phenomena relevant to fuel assemblies during normal operation and design-basis events. Westinghouse applies acceptance criteria described in WCAP-18446-P/WCAP-18446-NP, Revision 0, TR to demonstrate that the 17x17 OFA design continues to perform adequately at incremental burnup extension conditions. These criteria are applicable to the other fuel assembly designs described in Section 7.1.1 of the TR, but the evaluation of these criteria for non-17x17 OFA designs must be reviewed on a plant-specific application basis or in other TRs.

#### 3.1.2.1 Fuel Assembly Growth

Fuel assembly growth is a function of burnup. As the burnup of a fuel assembly increases, the axial length of the fuel assembly increases slightly. Excess assembly growth after the assembly makes hard contact with the upper core plate results in compressive forces on the fuel assembly and fuel rods. This compressive force results in bowing and distortion. Hard contact between the core plate and nozzle end plates is precluded by designing the assembly to maintain sufficient axial clearances through assembly life.

Section 2.5.9 and Figure 2.5-9 of WCAP-18446-P/WCAP-18446-NP, Revision 0, TR describe the high-burnup empirical database used to assess the applicability of the existing ZIRLO fuel assembly growth model. In particular, Figure 2.5-9 appears to demonstrate the ability of Westinghouse methods to reasonably predict fuel assembly growth for ZIRLO assemblies (e.g., Low Tin ZIRLO™ thimbles with optimized cladding, ZIRLO thimbles with mixed cladding, etc.) within the upper and lower 95/95 uncertainty bounds of the model. However, the NRC staff found additional justification was required to conclude that the range of applicability for all pertinent existing fuel assembly growth models (i.e., all the growth models that encompass the fuel assembly designs listed in Section 7.1.1 of WCAP-18446-P/WCAP-18446-NP, Revision 0) can be appropriately expanded to include up to **[** **]** rod-average burnup.

Westinghouse’s response to RAI-5 indicates that a wide variety of phenomena influence fuel assembly growth (e.g., hydrogen pickup, thermal and irradiation induced creep, spacer grid force relaxation, fuel rod growth, etc.), and the effects of these phenomena are implicitly included in the growth curve model that was created based on a large database of fuel assembly growth measurements. Figure 5-1 of the response to RAI-5 also demonstrates how this curve is applicable to the 17x17 OFA design, producing reasonable predictions of 17x17 OFA assembly growth within the upper and lower 95/95 uncertainty bounds for up to approximately **[ ]** fuel assembly burnup (**[ ]** rod-average). Beyond this burnup, the data, while reasonably predicted, is sparse. Because the fuel assembly growth versus burnup data presented in Figure 5-1 of the response to RAI-5 are inclusive of the requested rod-average burnup extension limit and within the upper and lower 95/95 uncertainty bounds, the NRC staff finds there is reasonable assurance that any uncertainty in fuel assembly growth associated with burnup will not result in unacceptable assembly bowing or distortion due to end plate contact for the incremental burnup range requested in WCAP-18446-P/WCAP-18446-NP, Revision 0.

Westinghouse states in the response to RAI-5 that a similar conclusion is expected for other Westinghouse fuels designed for use in Westinghouse PWRs. The NRC staff finds the assembly growth curve comparison presented in the response to RAI-5 to be reasonable, but without additional data, the NRC staff cannot approve the model’s extended burnup applicability to other fuel assembly designs listed in Section 7.1.1 of WCAP-18446-P/ WCAP-18446-NP, Revision 0. Per Limitation and Condition 1, additional fuel assembly designs may be justified on a plant-specific basis, a supplement to WCAP-18446-P/WCAP-18446-NP, Revision 0, or a separate TR.

For CE fuel assembly growth evaluations, the response to RAI-5 indicates Westinghouse intends to use the previously approved SIGREEP computer code to assess fuel assembly growth, and states the primary parameters related to fuel assembly growth phenomena are explicitly included in the code. Westinghouse did not specifically request the staff’s review and approval of the SIGREEP code for increased burnup applications as part of the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology. The NRC staff finds Westinghouse’s approach to be reasonable in concept, but the staff did not specifically review and approve the code’s extended burnup applicability for CE fuel assembly designs listed in Section 7.1.1 of WCAP-18446-P/WCAP-18446-NP, Revision 0. Demonstrating applicability of the SIGREEP code to increased burnups could necessitate additional experimental data and associated code validation, consistent with Limitation and Condition 4 from the NRC staff’s SE on WCAP-16500-P-A (Reference 23). Such considerations may also be relevant to Limitation and Condition 1 of this SE, which requires additional fuel assembly designs may be justified on a plant-specific basis, a supplement to WCAP-18446-P/WCAP-18446-NP, Revision 0, or a separate TR.

The NRC staff has concluded that this design-basis criterion and subsequent evaluation of the criterion for the 17x17 OFA design is acceptable because adequate margin exists between the requested burnup limit and the design limit.

#### 3.1.2.2 Fuel Assembly Hydraulic Stability

Fuel assemblies are subject to mechanical degradation during operating conditions, which must be limited to assure acceptable performance. When in contact with other mechanical components, such as mid-grids and intermediate flow mixers (IFM), the fuel cladding can experience wear and fretting. Fretting can reduce the cladding thickness, creating potential for an increased risk of a loss of a fission product barrier. An increase in burnup corresponds to an increase in fuel assembly lifetime, increasing the magnitude of fretting and wear. The magnitude of this degradation is limited, by Westinghouse methodologies, to **[** **]** Westinghouse is not proposing to change this limit under extended burnup conditions. Westinghouse has performed multiple tests that can cause wear and fretting to confirm that the 17x17 OFA design does not exceed this limit.

The NRC staff has concluded that this design-basis criterion and subsequent evaluation of the criterion for the 17x17 OFA design is acceptable because no changes are being proposed to the fretting and wear limit. Additionally, an increase in the burnup limit does not challenge the adequacy of the design criteria for fretting and wear.

### 3.1.2.3 Fuel Assembly Structural Integrity

Fuel assemblies must maintain their structural integrity during seismic and LOCA conditions, including the combination of these loads. Fuel assemblies can be subject to extreme stresses during seismic and LOCA conditions. 10 CFR 50.46(b)(4) requires that any changes in core geometry during LOCA conditions be amenable to cooling. The acceptance criteria for fuel assembly structure integrity are generic enough that the criteria will remain applicable at higher burnups.

Westinghouse verified that the 17x17 OFA design maintains structural integrity at both beginning of life (BOL) and end of life (EOL) under extended burnup conditions. Westinghouse performed BOL dynamic crush testing of the mid-grid and IFM-grids to verify that the assembly maintained structural integrity. NRC Information Notice (IN) 2012-09 (Reference 24) notes that BOL spacer grid strength may not be limiting, as previously thought. Operating conditions have shown that spacer grid strength may be reduced over time due to several phenomena. Westinghouse uses guidelines described in the PWROG-16043-P-A, “PWROG Program to Address NRC Information Notice 2012-09: ‘Irradiation Effects on Fuel Assembly Spacer Grid Crush Strength for Westinghouse and Combustion Engineering (CE) PWR Fuel Designs,’” (Reference 25) to determine EOL assembly structural integrity. This analysis has determined that the **[** **]** Therefore, Westinghouse concluded that the 17x17 OFA design reasonably maintains structural integrity under LOCA and seismic conditions at both BOL and EOL with an incremental burnup extension.

The NRC staff has concluded that this design-basis criterion and subsequent evaluation of the criterion for the 17x17 OFA design is acceptable because the analyses will ensure that fuel assemblies maintain structural integrity under seismic and LOCA conditions.

### 3.1.2.4 Fuel Assembly Bow and Control Rod Insertion

Fuel assembly guide thimbles must maintain their structural integrity such that there is full and timely insertion of control rods (referred to in WCAP-18446-P/WCAP-18446-NP, Revision 0, as rod control assemblies (RCA) or rod cluster control assemblies (RCCA)). Assembly bowing, which tends to increase with fuel burnup, could theoretically result in sufficient distortion of the guide thimbles such that control rods are not able to be fully inserted or the drop time is unacceptably increased during a SCRAM. This criterion assures that fuel assemblies are designed such that this distortion does not occur, even at the maximum licensed fuel burnup. Westinghouse has not proposed any changes to limits associated with the timely and complete insertion of an RCCA or RCA. The NRC staff has not identified any phenomena associated with an increase in the burnup limit that would necessitate more restrictive limits associated with RCCA or RCA insertion.

The primary contributor to insertion time from burnup is in the form of a mechanical resistance force resulting from guide thimble distortion. The timely and complete insertion of an RCCA or RCA is characterized by the drag work limit. Westinghouse stated that it has performed assessments of the drag force variation for high-burnup fuel management. Westinghouse has concluded that the RCCA drag work limit will not be exceeded at a burnup of **[ ]** for the 17x17 OFA design.

The NRC staff has concluded that this design-basis criterion and subsequent evaluation of the criterion for the 17x17 OFA design is acceptable because RCCA or RCA insertion will be evaluated against the same limits as they would under current burnup limits and the NRC staff has not identified any need for more restrictive limits associated with RCCA or RCA insertion.

### 3.1.2.5 Fuel Rod Bow

Fuel rod bowing is a phenomenon that results from radiation-induced stresses in the fuel rod, causing the rod to bow. Fuel rod bowing can reduce the gap size between fuel rods, which can compromise the coolability of the fuel rods. Excessive fuel rod bowing is typically precluded by limiting burnup such that the radiation-induced stress is limited and by using spacer grids to maintain the geometry of the assembly and fuel rods.

This design-basis limit is intended to maintain the bowing between spacer grids, whether they are intermediate flow mixing grids or protective grids, to previously established allowable limits. The primary concern associated with rod bowing is the increased likelihood of departure from nucleate boiling (DNB) due to channel closure and reduced cooling. The 17x17 OFA design incorporates ZIRLO grids and cladding that reduce rod bowing such that the current DNB penalty associated with a fuel assembly burnup below 33 GWD/MTU is bounding compared to a DNB penalty established at a burnup of **[ ]** This is due to higher burnup assemblies typically being at lower power, and, therefore, no longer being limiting with respect to DNB.

The NRC staff has concluded that this design-basis criterion is acceptable because it would effectively protect against degradation of DNB margin due to rod bow. The NRC staff further concluded that Westinghouse's subsequent evaluation of the criterion for the 17x17 OFA design is acceptable because lower burnup fuel assemblies tend to be more limiting with respect to DNB penalties caused by fuel rod bow than higher burnup assemblies. Westinghouse stated that licensees credit a reduction in power with burnup, such that assemblies with elevated burnups tend not to be limiting with respect to DNB. In this regard, any credit taken for power burndown to compensate for assembly bow, whether implicit or explicit, should be within the proposed burndown associated with the core operating limits report item discussed below in Section 3.3.5.6 that is associated with preventing cladding rupture in a LOCA for fuel rods in the incremental burnup range (accounting for any difference in rod versus assembly burnup, uncertainty application, etc.).

### 3.1.2.6 Fuel Assembly Design Bases and Evaluations Conclusion

The NRC staff has reviewed the criteria that Westinghouse has proposed for evaluating acceptability of a fuel assembly design up to a rod-average burnup of **[ ]** and has determined the evaluation criteria to be acceptable. The evaluation criteria will provide a generic set of criteria for assessing the impact of the proposed incremental burnup extension on fuel assembly mechanical design for Westinghouse fuel assemblies. The criteria described above are generic in nature but may not be comprehensive for all assembly designs. Assembly designs that feature novel technologies or characteristics may have assembly-specific parameters that should be evaluated in addition to the above parameters.

Additionally, the NRC staff has reviewed the evaluations of the 17x17 OFA design against these criteria and determined that the evaluations are acceptable because the 17x17 OFA design meets the above evaluation criteria, which were found to be acceptable. The 17x17 OFA design is acceptable for use at a rod-average burnup of **[ ]**

### 3.1.3 Structural Components Design Bases and Evaluations

#### 3.1.3.1 Top and Bottom Nozzles

Fuel assembly components are designed such that they do not experience structural deformation caused by shipping and handling loads. The top and bottom nozzles are designed such that they can transmit shipping and handling loads associated with accelerations of up to 4g (i.e., four times the acceleration of gravity) without permanent deformation. Westinghouse confirmed that this criterion is adequate through confirmatory and functional testing for the 17x17 OFA design. An incremental increase in burnup is not expected to challenge the adequacy of this criteria. Therefore, the NRC staff concluded that this design-basis criterion and subsequent evaluation of the criterion for the 17x17 OFA design is acceptable because the design-basis criteria will continue prevent fuel assembly component structural deformation.

#### 3.1.3.2 Fuel Assembly Holddown Springs

Fuel assembly holddown springs are mounted on the top nozzle and are used to prevent fuel assembly liftoff from the lower core plate for Condition I and II events (with the exception of the turbine overspeed transient associated with a loss of external load). The 17x17 OFA holddown springs are designed and tested to tolerate deflection from fuel assembly liftoff. This is confirmed via hydraulic testing. Section 2.4.3 of the WCAP-18446-P/WCAP-18446-NP, Revision 0, TR states, “A final verification analysis using standard Westinghouse methodology will be performed for plant-specific requirements to verify that holddown requirements are met.” An increase in burnup is not expected to substantially challenge the adequacy of the design bases for fuel assembly holddown springs. Any changes that could occur due to plant-specific parameters should be captured in the final verification. Therefore, the NRC staff has concluded that this design-basis criterion and subsequent evaluation of the criterion for the 17x17 OFA design is acceptable because an incremental burnup is not expected to have a significant effect on fuel assembly liftoff and any reduction in the holddown spring characteristics will be captured in a plant-specific analysis.

#### 3.1.3.3 Guide Thimbles and Instrumentation Tube

The guide thimbles and instrumentation tubes support positioning of mobile core components and structural continuity. The guide thimbles must maintain their structural integrity and functionality. The guide tubes must maintain adequate clearance for control rod insertion such that the ability to scram the reactor is not impeded. Westinghouse has identified that the most limiting loads on the fuel assembly structure will occur during a fuel handling accident. The 17x17 OFA is designed to sustain shipping and handling accelerations of up to 6g.

Westinghouse has performed stress analyses for the guide thimbles demonstrating adequate margin on shipping and handling limits. An increase in burnup is not expected to substantially challenge the adequacy of the design bases for the guide thimbles and instrumentation tubes. Therefore, the NRC staff has concluded that this design-basis criterion and subsequent evaluation of the criterion for the 17x17 OFA design is acceptable.

### 3.1.3.4 Joints and Connections

During normal operation and postulated design-basis events, deformation of the joints and connections shall not inhibit the performance of critical safety functions. The mechanical design basis for assemblies does not permit permanent deformation during Condition I and II events (i.e., normal operation and incidents of moderate frequency). Furthermore, the loads experienced during these conditions shall not prevent continued use of the fuel assembly following those events for the design life of the assembly. Additionally, the criteria states that there shall be no deformation resulting from loads during Condition III and IV events (i.e., infrequent events and postulated accidents) such that emergency core cooling or safe shutdown is prevented.[1] Lastly, any loads during shipping and handling shall not prevent the fuel assembly from meeting all the operating requirements for its design life. These criteria are independent of burnup and will maintain the same level of safety following an incremental burnup extension. Therefore, the proposed generic criteria remain applicable following an incremental burnup extension.

Westinghouse performed confirmatory testing demonstrating structural integrity of joints and connections under the aforementioned loads for the 17x17 OFA design. An increase in the burnup limit is not expected to significantly reduce the structural integrity of the joints and connections in the 17x17 OFA design such that they would not be able to meet the above acceptance criteria. Therefore, the NRC staff has concluded that this evaluation for the 17x17 OFA design for the above criteria is acceptable.

### 3.1.3.5 Grid Assemblies

Spacer grids on fuel assemblies perform a variety of functions related to assembly performance and lateral support. The grid assemblies must continue to perform their intended function adequately at increased burnup. Higher burnup conditions can potentially challenge the design criteria of the grid assemblies. The grid assemblies, in part, are responsible for reducing fuel assembly bowing, but are also capable of inducing clad wear, or fretting. Therefore, the grid assemblies must be capable of simultaneously mitigating rod bowing while also limiting fretting to within allowable limits.

Analyses were performed for the 17x17 OFA design to evaluate the adequacy of grid assembly performance at an incremental burnup extension. Westinghouse's evaluations were based on multiple factors that contribute to grid-to-rod fretting. The results of that analysis demonstrate that an incremental burnup extension will not challenge the current design basis of limiting clad wear to less than **[ ]**

---

[1] Note that the event categorization scheme applied by Westinghouse derives from American Nuclear Society Standard 51.1. However, as defined in Section 15.0.2 of the Standard Review Plan, Condition II and III events are both categorized as anticipated operational occurrences, as defined in 10 CFR Part 50, Appendix A.

The NRC staff has concluded that this design-basis criterion and the subsequent evaluation of the criterion for the 17x17 OFA design are acceptable because there are no proposed changes to the design criteria. Furthermore, Westinghouse's analyses have demonstrated acceptable performance in limiting clad wear.

### 3.1.3.6 Structural Components Design Bases and Evaluations Conclusion

The NRC staff has reviewed Westinghouse's design bases and corresponding evaluations for the 17x17 OFA design related to structural components. Westinghouse has not proposed to revise any design bases or introduce any new design bases to compensate for phenomena that may occur as a result of an incremental burnup extension. The NRC staff has determined this approach to be acceptable, as the current design bases remain applicable for the proposed incremental burnup extension, and there is no significant reduction in margin that would call into question the adequacy of the design bases. Furthermore, the NRC staff determined that Westinghouse has demonstrated that the 17x17 OFA design meets the above design criteria.

## 3.1.4 Materials

### 3.1.4.1 Fuel Rod Materials

Westinghouse does not propose to use any new fuel rod materials to compensate for phenomena that may occur due to higher burnup conditions. Westinghouse asserts that the behavior of these materials and their properties are understood at higher burnups and remain acceptable under those conditions. The fuel road materials that were considered in Westinghouse's evaluation and which have been reviewed by the NRC include ZIRLO and Optimized ZIRLO™ cladding, zirconium diboride ($ZrB_2$) fuel pellet coating, and gadolinia. Westinghouse already has **[**

**]** Section 3.2 of this SE contains additional information related to material performance under extended burnup conditions. The NRC staff has determined that Westinghouse's evaluation of fuel rod materials is acceptable, as all materials properties have been verified by various means, and there is significant PIE data to support the evaluation of material properties for the extended burnup range.

### 3.1.4.2 Vogtle Creep and Growth

Westinghouse performed an analysis of cladding creep and growth data to improve their models. The results are being used to justify the continued applicability of Westinghouse codes and methods for cladding creep and growth at higher burnups. The data was taken from **[** **]** fabricated from ZIRLO and Optimized ZIRLO that were irradiated in an operating PWR.

Figure 2.5-1 of WCAP-18446-P/WCAP-18446-NP, Revision 0, shows that **[**

**]**

This supports the conclusion that current methods continue to remain applicable due to their good agreement in comparisons between calculated and measured values. A similar relationship is observed in Figure 2.5-2 of WCAP-18446-P/WCAP-18446-NP, Revision 0, for data within the range of the incremental burnup extension. The NRC staff notes that **[**

**]**

**[**

**]**

The NRC staff determined that Westinghouse methods for evaluating cladding creep and growth of ZIRLO and Optimized ZIRLO maintain adequate predictive capability up to **[ ]**

### 3.1.4.3 Rod Oxide Thickness

Figure 2.5-3 of WCAP-18446-P/WCAP-18446-NP, Revision 0, plots the fuel rod oxide thickness against the fuel rod-average burnup for burnups between 62 GWd/MTU and **[ ]** The design limit for cladding corrosion is a best-estimate, circumferentially averaged rod oxide thickness of 100 microns. The use of a best-estimate value for a design limit implies that a fraction of fuel rods may have the potential to exceed the best-estimate value due to uncertainties in fuel design or operating conditions. In actuality, Figure 2.5-3 shows **[**

**]**

The data provides a high degree of confidence that ZIRLO and Optimized ZIRLO rods will perform adequately with respect to rod oxide thickness limits under incremental burnup extension conditions. The NRC staff determined that this data demonstrates that the Westinghouse cladding materials, ZIRLO and Optimized ZIRLO, can perform adequately under higher burnup conditions because the rod oxide thickness largely remains below the 100-micron threshold up to **[ ]**

### 3.1.4.4 Rod Growth

Rod growth occurs as a result of radiation, and the extent of that growth is affected by many parameters, including burnup. Westinghouse does not propose any changes to the design bases and evaluation methods related to rod growth (See Section 3.2.1.10 of this SE). Additionally, Westinghouse has stated in Section 3.1.10 of the TR that excessive axial growth will be shown to be prevented in plant-specific applications. A review of Figures 2.5-4a and 2.5-4b in WCAP-18446-P/WCAP-18446-NP, Revision 0, shows that rod growth for ZIRLO and Optimized ZIRLO remains within tolerable levels at higher burnups, and Westinghouse Performance Analysis and Design Model (PAD5) predictions remain within the upper 95/95 uncertainty bounds. Further discussion of the growth characteristics of these alloys in the extended burnup region is provided below in Section 3.2.1.10 of this SE. Therefore, the NRC staff determined that the rod growth models for ZIRLO and Optimized ZIRLO demonstrate adequate predictive capability for the incremental burnup range and finds it acceptable that Westinghouse will assure on a reload basis that rod growth remains within acceptable levels and will not exceed associated design criteria at higher burnups.

### 3.1.4.5 Hydrogen

The cladding hydrogen pickup design limit is **[ ]** Figures 2.5-5a and 2.5-5b demonstrate that Optimized ZIRLO cladding remains within this limit over the proposed range of extended burnup. The design limits for hydrogen pickup remain applicable at higher burnups. The 17x17 OFA design **[** **]** will not exceed this limit. According to Figure 2.5-5b, a significant amount of **[**

**]** Additional information related to the NRC safety determination related to hydriding is contained in Section 3.2.1.5 of this SE.

3.1.4.6 Mechanical Properties

As seen in Figure 2.5-6, the yield stress and ultimate stress **[**

**]** The NRC staff has determined that the data presented in Figure 2.5-6 demonstrates adequate performance with respect to yield stress and ultimate stress for both ZIRLO and Optimized ZIRLO because **[**

**]** Furthermore, a number of conservatisms have been incorporated into the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology, such as with respect to the prediction of cladding rupture under LOCA conditions, as discussed below in Section 3.3 of this SE. **[**

**]**

Figure 2.5-7 shows **[** **]** for uniform plastic strain and total plastic strain. Westinghouse identifies a **[**

**]** Therefore, there is sufficient justification that ZIRLO and Optimized ZIRLO will perform acceptably up to a rod-average burnup of **[** **]** in conjunction with the constraints proposed in WCAP-18446-P/ WCAP-18446-NP, Revision 0, and this SE.

3.1.4.7 Grids

Westinghouse stated in WCAP-18446-P/WCAP-18446-NP, Revision 0, that the grid metal waste design limit is 18 percent. Figures 2.5-8 shows oxide thickness versus burnup for Low Tin ZIRLO and ZIRLO grids for burnups up to the requested incremental burnup extension. Westinghouse stated that the oxide thicknesses in the figure correspond to grid metal wastages below the 18 percent design limit. Therefore, the NRC staff determined that the ZIRLO and Low Tin ZIRLO grids have acceptable grid metal wastage at burnups up to **[** **]**

#### 3.1.4.8 Assembly Growth

Figure 2.5-9 shows that the assembly growth PIE data is reasonably represented by the ZIRLO cladding model up to **[ ]** The NRC staff finds it reasonable to expect that assembly growth up to **[ ]** will continue to be adequately addressed by existing models.

### 3.1.5 Fuel Assembly Mechanical Design Conclusion

Section 2.0 of WCAP-18446-P/WCAP-18446-NP, Revision 0, provides a set of criteria, a method for evaluating against those criteria, and the results of that evaluation specific to the 17x17 OFA design.

First, Westinghouse has requested generic approval of the aforementioned set of criteria and evaluation methods for all fuel assembly designs described in Section 7.1.1 of TR WCAP-18446-P/WCAP-18446-NP, Revision 0, such that this evaluation could be applied to those fuel designs at a later time. The NRC staff has determined that the criteria and evaluation methods described in Section 2.0 of TR WCAP-18446-P/WCAP-18446-NP, Revision 0, are applicable for all assembly designs described in Section 7.1.1 of the TR. Future fuel assembly designs, which may incorporate novel features, would require evaluation to determine whether additional design criteria and evaluations not described in this SE may be necessary. Such additional design criteria or evaluations may be addressed in future regulatory reviews.

Additionally, Westinghouse requested generic approval of a burnup increase for the 17x17 OFA design given that it was used as an example in the Section 2.0 evaluations. Each of the evaluations was reviewed on a generic basis and a specific basis with respect to the 17x17 OFA design. The NRC staff has concluded that the Section 2.0 criteria and evaluations are applicable to the 17x17 OFA design and that the 17x17 OFA design meets those criteria. Therefore, the 17x17 OFA design is acceptable for use at rod-average burnups up to **[ ]** when operated in a manner consistent with the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology, including applicable limitations and conditions described in this SE.

## 3.2 Core and Fuel Rod Performance

In Section 3.0 of TR WCAP-18446-P/WCAP-18446-NP, Revision 0, Westinghouse provides discussions across three separate phenomenological areas of its codes and methods to justify an extension of the rod-average burnup limit: fuel thermal-mechanical, neutronics, and core thermal-hydraulics. The NRC staff assessment of each of these areas is provided below.

### 3.2.1 Fuel Rod Performance

Section 3.1, “Fuel Rod Performance,” of WCAP-18446-P/WCAP-18446-NP, Revision 0, identifies that fuel performance analyses will be performed using the NRC-approved PAD5 code, Westinghouse’s most recent fuel performance and design model. Because WCAP-18446-P/WCAP-18446-NP, Revision 0, seeks to extend burnup beyond the currently approved rod-average burnup limit of 62 GWD/MTU for Westinghouse and CE fuel designs, Section 3.1 of the TR provides a series of justifications to extend the approved range of applicability of the PAD5 code. Of specific note, while WCAP-18446-P/WCAP-18446-NP, Revision 0, seeks to extend the approved rod-average burnup limit to **[ ]** Westinghouse states that the calibration and validation of PAD5 models considers fuel performance data for rod-average burnups beyond **[ ]** Although the PAD5 fuel performance data may encompass rod-average burnups beyond **[ ]** the NRC staff assessed the justifications presented for applicability only up to the requested burnup extension of **[ ]**

The justifications presented by Westinghouse in Section 3.1 of the TR are broken into two parts, (1) various fuel and cladding material phenomena pertinent to the requested burnup extension have already been considered in PAD5, and (2) the existing evaluation procedure in PAD5 for meeting the acceptance criteria of the fuel rod design bases remains applicable to rod-average burnups of **[ ]** The individual discussions for each of the fuel rod design bases frequently reference phenomenological models contained within PAD5 but not directly presented in Section 3.1. Therefore, the NRC staff's assessment of the applicability of PAD5 to the requested burnup extension considers each of the pertinent phenomenological models and is presented within the framework of each fuel rod design basis. Each fuel rod design basis is presented in turn below.

The fuel and cladding material phenomena pertinent to the requested burnup extension that Westinghouse indicates have already been considered in PAD5 (along with the corresponding location of the NRC staff's assessment within this SE) are as follows:

- Rim structure and its impact on fission gas release (FGR) (Section 3.2.1.1)
- Continuing degradation of fuel thermal conductivity (Section 3.2.1.6)
- Potentially enhanced rod growth (Section 3.2.1.10)
- Potentially enhanced clad corrosion (Section 3.2.1.5)
- Enhanced fission gas swelling (Section 3.2.1.1)
- Continuing degradation of mechanical strength due to higher hydrogen pickup (Section 3.2.1.5)

While fuel rod burnup limits are specified in Westinghouse methods on a rod-average basis, burnup itself is a process that occurs locally, at the level of the fuel pellet. Some models and methods consider burnup at the fuel pellet level and then use the results to determine rod-average effects. In such instances, limitations in the available local fuel pellet burnup data may limit applicability of these models. As such, the NRC staff inquired in RAI-1 what the expected maximum local fuel pellet burnups are for the requested rod-average burnup limit extension, what specific models pertinent to WCAP-18446-P/WCAP-18446-NP, Revision 0, are dependent upon phenomena sensitive to local pellet burnups, and what justification exists that a local pellet burnup limit is not necessary to ensure continued applicability of these models. Westinghouse's response identified a list of models dependent upon phenomena sensitive to local pellet burnups. The NRC staff's assessment of these models is also presented within the framework of each fuel rod design basis. These models and the location of the NRC staff's assessment within this SE are as follows:

- Fuel thermal conductivity (Section 3.2.1.6)
- Fuel melting point (Section 3.2.1.6)
- Fuel radial relocation (Section 3.2.1.4)
- Solid swelling densification (Section 3.2.1.1)
- Gas bubble swelling (Section 3.2.1.1)
- Fission gas release (Section 3.2.1.1)
- Helium solubility and release (Section 3.2.1.1)
- Cladding steady-state oxidation (Section 3.2.1.5)
- Cladding steady-state hydrogen concentration (Section 3.2.1.5)
- Cladding diametral growth and steady-state creep (Section 3.2.1.1)

- Cladding yield strength and ultimate tensile strength (Section 3.2.1.2)
- Fuel thermal conductivity for LOCA (Section 3.3.4.4)
- Decay heat for LOCA (Section 3.3.4.5)

Westinghouse's response to RAI-1 clarified that a conservative maximum pellet-average burnup corresponding to a rod-average burnup of **[ ]** can be determined analytically from calculations of the peak nodal burnup and rod-average burnup from representative core designs by establishing a conservative value for the ratio of these two parameters. Based on this approach and comparisons of the ratioed parameters supplied in the response, Westinghouse indicated a conservative maximum pellet-average burnup associated with the requested rod-average burnup extension is **[ ]** The NRC staff finds this approach reasonable because the conservative ratio that is established bounds the EOL results supplied for the representative plants. The NRC staff considered this conservatively determined maximum pellet-average burnup value in its assessment of the models listed above that are dependent upon phenomena sensitive to local pellet burnups.

Westinghouse's response to RAI-1 also provided justification that a local burnup limit was not needed for the models employed in PAD5. Succinctly, while the models listed above rely on phenomena sensitive to local pellet burnups, they are either (1) not directly dependent on local pellet burnups, (2) **[ ]** (3) supported by local pellet burnup data that exceeds the local pellet burnup associated with the requested rod-average burnup extension, or (4) exhibit asymptotic behavior with burnup that is well bounded by available data. The NRC staff's assessment of each of the models Westinghouse considered to be sensitive to local pellet burnup, as discussed below within the framework of each fuel rod design basis, considered these justifications and found them reasonable. Therefore, the NRC staff finds it acceptable that a local fuel pellet burnup limit is not specified for the Westinghouse fuel performance models in PAD5.

#### 3.2.1.1 Fuel Rod Internal Pressure

The design basis for fuel rod internal pressure is to ensure the fuel system will not be damaged due to excessive fuel rod internal pressure. Specifically, the internal pressure of the limiting rod in the reactor should be limited such that (1) the diametral gap does not increase due to outward cladding creep during steady-state operation, (2) cladding hydride reorientation in the radial direction does not occur, and (3) DNB propagation does not occur.

Fuel rod internal pressure is dependent on several phenomena that are discussed below, including **[**

**]**

*Fission Gas Release and the Impact of Rim Structure on Fission Gas Release*

The PAD5 FGR model is divided into three parts: a low-burnup athermal FGR model, a high-burnup athermal FGR model, and a thermal FGR model. The athermal models are intended to capture the effects of FGR from low-temperature and relatively low-power rods. The low-burnup athermal model is based on FGR due to recoil and knockout. The high-burnup athermal model is based on accounting for the increased FGR observed at higher burnups. The thermal model is intended to capture the effects of FGR due to temperature effects and fuel temperature transients and is based on concepts drawn from mechanistic models of high-temperature gas release through interlinking of grain-edge fission gas bubbles.

The high-burnup athermal FGR model is discussed in Section 4.3.2, “Athermal Fission Gas Release Models,” of the PAD5 TR and is described as an enhanced athermal FGR fraction, the intent of which is to account for the measured significant increase in the FGR of rods that operate at relatively low power at higher burnups. Section 1.2, “Scope and Summary,” of the PAD5 TR and Section 3.1 of WCAP-18446-P/WCAP-18446-NP, Revision 0, indicate the enhanced athermal FGR fraction model simulates the FGR from the rim region of the fuel pellet.

The NRC staff’s previous assessment of the PAD5 FGR model is documented in Section 3.2, “Fission Gas Release and Helium Release Models and Assessment,” of the final SE approving the PAD5 methodology (Reference 26). The NRC staff’s previous assessment for the PAD5 methodology concluded the validation database supports FGR to a rod-average burnup of 62 GWd/MTU, but beyond this burnup, **[ ]** for normal operation and AOOs. The NRC staff’s assessment also noted “there appears to **[ ]** that would be necessary to model the effects of high burnup fuel.” This note was made with consideration of the enhanced athermal FGR fraction.

Westinghouse did not present updated FGR models or additional FGR data within WCAP-18446-P/WCAP-18446-NP, Revision 0. As such, the NRC staff’s assessment of the FGR model remains as documented in the final SE approving the PAD5 TR. However, the NRC staff notes that this assessment was conducted in broad consideration of the generic applicability of the PAD5 methodology, rather than a narrowly defined, specific application. As such, the NRC staff re-examined the FGR model in consideration of the limited scope of the present review: the placement of low-power fuel rods within the proposed incremental burnup range on the core periphery in non-limiting locations.

The low-burnup athermal FGR model accounts for FGR due to recoil and knockout. There is some amount of FGR due to these effects at all fuel burnups, but the contribution to the overall FGR is relatively small. For burnups at the requested rod-average burnup limit extension, other phenomena dominate the FGR response (e.g., pellet rim effects), and the contribution from recoil and knockout is expected to be less than **[ ]** Because this small contribution has a minor impact, the NRC staff finds the low-burnup athermal FGR model is applicable to the fuel rods being considered within the scope of the present review.

Regarding the enhanced athermal FGR fraction, the NRC staff notes that, although Westinghouse describes it as modeling pellet rim effects incurred with burnup, it is not an explicit, mechanistic rim-effects model. The NRC staff’s assessment is the enhanced athermal FGR fraction is an empirical model introduced with the intent of accounting for, per the PAD5 TR, the observed “significant increase in the FGR of rods that operated at relatively low power at high burnups.” The effects of the enhanced athermal FGR fraction are only included beyond **[ ]** but the NRC staff’s position is the impacts of rim structure on FGR could occur before **[ ]** and are primarily dependent upon power history, not just burnup. Nevertheless, because of the empirical nature of the model and its calibration to data gathered from low-power rods with burnups to **[ ]** the effects of the rim structure on FGR as measured in the available data do manifest within PAD5’s FGR results.

Calibration of the model is designed to minimize the error between the prediction and measurement (i.e., a best-estimate fit to the data). About half of the available PAD5 athermal FGR database was used for calibration of the model, with the remaining half being used for validation. Using this approach, the NRC staff observed there are **[** **]** of the model for rod-average burnups greater than 62 GWd/MTU (see Figure A.2.2-5 of the PAD5 TR). The spread in these data is large and indicative of the expected increased difficulty in modeling FGR at higher burnups. The limited number of datapoints also introduces difficulty in assessing whether an uncertainty quantified for the model using the balance of the dataset is representative of the model's predictive capability at higher burnups. Therefore, the NRC staff examined whether the PAD5 upper and lower uncertainty bounds for the model, as respectively presented in Figures A.2.2-14 and A.2.2-16 of the PAD5 TR, fully encapsulate the spread of data within the 62 GWd/MTU to **[** **]** range. (As discussed in the NRC staff's SE approving the PAD5 methodology, these bounds are multipliers applied to the athermal FGR model predictions and are equivalent to or greater than the 95/95 tolerance limits of the data.) The NRC staff observed that, for data within the 62 GWd/MTU to **[** **]** rod-average burnup range, no data exist outside the PAD5 lower bound and only one datum exists outside the upper bound. That is, after application of the upper uncertainty bound multiplier, a single datum remains under-predicted by approximately **[** **]** and by comparing the information in the figures discussed above with additional information in Table A.2.2-4 of the PAD5 TR, the NRC staff observed that this datum represents the requested burnup extension limit.

Generally, a difference of approximately **[** **]** in FGR is considered negligible but given the **[** **]** a PAD5 upper bound that completely bounds the available data with some margin would provide additional assurance the increased FGR expected at higher burnups and the associated uncertainty are acceptably taken in to account. However, within WCAP-18446-P/WCAP-18446-NP, Revision 0, all higher burnup rods will be placed on the core periphery. These locations are generally expected to be non-limiting with respect to normal operation and most postulated design-basis events. Additionally, when consideration is given to the overlapping uncertainties of other phenomena that contribute to rod internal pressure (discussed within this section of the SE), a difference of approximately **[** **]** in FGR is not expected to have a discernable impact. Therefore, the NRC staff finds the enhanced athermal FGR fraction is applicable to fuel rods in the proposed incremental burnup range under the associated core design restrictions being considered in the scope of the present review.

The PAD5 thermal FGR model is a phenomenological model based on the irradiation dependence of the FGR from a series of mechanistic models. The mechanistic models account for the diffusion of the gas generated in fuel grains to the grain boundaries, formation of fission gas bubbles, and release of this gas when grain boundary bubbles interconnect. The thermal FGR model incorporates a time-dependence, for use in determining transient FGR, and a temperature dependence wherein the various FGR burnup thresholds are determined by fitting the model to data. This calibration of the model is performed as discussed above for the athermal FGR model: approximately half of the available dataset is used for calibration, while the remaining portion is used for validation. For the data used in calibration, thermal release is the dominant form of FGR.

The NRC staff assessed the PAD5 thermal FGR results for applicability of the model to the requested rod-average burnup extension limit of **[** **]** Figure A.2.2-7 of the PAD5 TR shows there are very few data available within the extended burnup range, only **[** **]** For the steady-state functionality of the model, the NRC staff considers the available data adequate to demonstrate the continued functionality of the model for the present review in conjunction with additional engineering insights. In particular, higher burnup rods are operated at a relatively low power and temperature, in a range where fission gas production is relatively low, and the release of long-lived fission gases is fairly well-characterized under steady-state conditions. The small changes in steady-state fuel temperature do not result in large changes in FGR. This is especially true of the higher burnup rods for WCAP-18446-P/WCAP-18446-NP, Revision 0, which will be placed on the core periphery and operated at substantially lower powers and temperatures than leading rods on the core interior. It is expected that the thermal FGRs of higher burnup rods within the PAD5 database will be bounded by those of lower burnup rods and exhibit no observable increasing trend in uncertainty with burnup. Although the data available in the PAD5 database for **[ ]** are few, they are consistent with this expectation, and they are also bounded by the PAD5 upper and lower uncertainty bounds.

However, higher burnup fuel rods tend to exhibit large releases of long-lived fission gases stored within the fuel pellet for large increases in fuel temperatures characteristic of thermal transients, and the magnitude of these releases can be difficult to model. Therefore, an increase in predictive uncertainty is expected for FGR from higher burnup fuels under transient conditions. Regarding the transient functionality of the thermal FGR model, the few data available **[ ]** in the PAD5 transient FGR database (listed in Table A.2.2-6 of the PAD5 TR) appear to demonstrate a clear and substantial increase in FGR uncertainty for higher burnup rods relative to lower burnup rods. However, the NRC staff notes the substantial increase in uncertainty is attributable to a tendency to **[ ]** which is conservative.

While the variation associated with these **[ ]** the paucity of data makes it difficult to confirm that the upper uncertainty bound remains representative of the transient FGR model's predictive uncertainty for rod-average burnups greater than 62 GWd/MTU. However, should the tendency of the PAD5 model to **[ ]** as compared to representative test data, the potential to challenge the no-rupture criterion for fuel rods with rod-average burnups greater than 62 GWd/MTU. Additionally, the fuel rods with burnups greater than 62 GWd/MTU within WCAP-18446-P/WCAP-18446-NP, Revision 0, will be placed along the core periphery; the power increase (and temperature change) for these rods during a transient event is not likely to be as severe as it would be for an interior rod and thus not as likely to challenge the thermal FGR model. Therefore, the NRC staff finds the thermal FGR model (steady-state and transient capabilities) to be applicable to the fuel rods being considered in the scope of the present review.

Per Westinghouse's response to RAI-1, the PAD5 FGR model is dependent on local burnup effects. The NRC staff notes that while the model is based on local burnup, the coefficients of the model are tuned to minimize error between predicted and measured FGR on a rod-average basis. The available PAD5 rod-average burnup database exceeds the requested burnup extension limit of **[ ]** rod-average burnup. Therefore, the equivalent local burnup is bounded by the available data and the NRC staff finds there is no need for a local burnup limit due to this model.

*Fission Gas Bubble Swelling (Enhanced Fission Gas Swelling)*

Modeling the swelling caused by gaseous fission products is necessary to properly account for the observed swelling in high-burnup fuel rods. In particular, both pellet thermal expansion and fission gas swelling are necessary to fully account for the cladding permanent hoop strain observed in ramp test data. PAD5 contains different fission gas swelling models for short transients versus long transients and steady-state operation. In the final SE approving the PAD5 methodology, the NRC staff assessed these models and found them acceptable based on the acceptable prediction of cladding permanent hoop strain following a power ramp.

Section A.2.4.2 of the PAD5 TR indicates the coefficients for the fission gas swelling model were calibrated to best predict the cladding diameter change data from various ramp tests. The NRC staff therefore examined the cladding diametral change (i.e., permanent hoop strain) results from the ramp tests in Figure A.2.4-2 and Figure A.2.4-4 of the PAD5 TR to assess applicability of the fission gas bubble swelling model to the requested rod-average burnup extension limit. The NRC staff took note of several observations regarding these figures. First, there are comparatively few data present at burnups beyond the current rod-average burnup limit of 62 GWd/MTU. Second, while there appears to be a multitude of data available at a given burnup, **[** **]** Third, the uniform burnup of the experimental rods/rodlets is such that the local burnup variability of data collected from each test rod is minimal. These observations, taken in aggregate, suggest there are a total of **[** **]** independent ramp test data with only **[** **]** data beyond the current burnup limit. Although the data span the model's proposed burnup range, **[** **]** difficulty in discerning whether the expected differences in the behavior of gaseous swelling between low and high burnups are adequately captured for the full range of possible transient conditions. As a result, the NRC staff finds it difficult to conclude the fission gas swelling model is applicable to the requested rod-average burnup extension limit on a generic basis.

However, **[** **]** Westinghouse's uncertainty bounds are developed in consideration of the spread of these data to provide a tolerance limit with at least 95 percent probability and 95 percent confidence. Additionally, the higher burnup assemblies discussed in the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology will be placed in non-limiting locations on the core periphery. These assemblies are not expected to experience limiting power ramps under transient conditions. The ramp test data presented in Figure A.2.4-2 and Figure A.2.4-4 of the PAD5 TR are either representative of or bounding of these assemblies. Based on this, the NRC staff finds the fission gas bubble swelling model is reasonably applicable to the higher burnup fuel assemblies within the application scope of the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology.

Per Westinghouse's response to RAI-1, the PAD5 enhanced fission gas swelling (fission gas bubble swelling) model is dependent on local burnup effects. Westinghouse indicates local burnups greater than **[** **]** were used to develop the model. The NRC staff notes that the data referenced in Westinghouse's response are for **[** **]** local burnup, which does not bound the equivalent local burnup of **[** **]** for the requested rod-average burnup extension limit. However, while the available data are not bounding, the cladding diametral change (i.e., hoop strain) data are reasonably predicted at this local burnup (as mentioned above, fission gas swelling is necessary to fully account for the cladding permanent hoop strain observed in ramp test data). Additionally, fission gas swelling behavior is not expected to change substantially across the range of **[** **]** local burnup spanning the available data and the requested burnup extension limit. When considering the reasonable prediction of hoop stress and that the extended burnup rods will be placed on the core periphery, the NRC staff finds it is reasonable that a local burnup limit is not necessary for this model for the application scope of the present review.

*Fuel Solid Swelling and Densification*

The fuel swelling and densification models in PAD5 are a function of initial fuel density, burnup, and the pellet sintering temperature. In the final SE approving the PAD5 methodology, the NRC staff assessed the swelling and densification models for $UO_2$ (uranium dioxide) and $UO_2$-$Gd_2O_3$ (uranium dioxide fuel with gadolinia burnable absorber) and found them acceptable based on (1) the upper and lower bounds for the PAD5 uncertainty approach providing at least a 95/95 bound for the expected swelling rate, (2) the reasonable prediction with data from several **[ ]** and (3) the good agreement with FRAPCON predictions.

The maximum burnup considered in the NRC staff's assessment in the SE approving the PAD5 methodology was 62 GWd/MTU, rod-average. The NRC staff, therefore, examined the models, comparisons, and data, consistent with the prior approach, for applicability to the requested rod-average burnup extension up to **[ ]** The PAD5 TR references WCAP-10851-P-A, "Improved Performance for Models for Westinghouse Fuel Rod Design and Safety Evaluations" (Reference 27), for data comparisons of the fuel densification and swelling models. The NRC staff noted the data in Figure 2-16 of WCAP-10851-P-A shows a cluster of data at **[ ]** the vast majority of which the model appears to **[ ]** This contrasts with model performance for the rest of the data and could be indicative of a growing disparity between prediction and measurements as a function of burnup.

The NRC staff requested justification regarding the continued applicability of the PAD5 uncertainties for the model in RAI-7. Westinghouse's response indicated these data are **[ ]** Westinghouse demonstrated that accounting for this difference adjusts the model predictions to better reflect the **[ ]** Westinghouse also indicated that, in addition to the **[ ]** Westinghouse demonstrated that, when the effects of these uncertainties are combined in the PAD5 uncertainty approach, the resulting upper and lower uncertainty bounds encapsulate the available data to at least a 95/95 tolerance limit. The NRC staff finds this reasonable.

Westinghouse's response to RAI-7 provided a brief discussion of the continued applicability of the fuel solid swelling and densification models to higher burnups by referencing data from **[ ]** and the response to RAI-15a for the PAD5 TR. The NRC staff examined the referenced data and observed **[ ]** were in excess of 62 GWd/MTU rod-average burnup. These data were all predicted by the fuel solid swelling and densification models to within **[ ]** Given the upper and lower uncertainty bounds discussed above, the NRC staff assessed that **[ ]** will fall within the uncertainty bounds. When the aggregate database is considered, this remains consistent with the 95/95 bounds. The NRC staff finds this acceptable.

The NRC staff also examined the PAD5 and FRAPCON comparisons presented in the SE approving the PAD5 methodology. These comparisons demonstrate reasonable agreement for both the $UO_2$ and $UO_2$-$Gd_2O_3$ fuel solid swelling and densification models up to the requested extended burnup limit of **[ ]** This provides additional confidence in the ability of the PAD5 models to reasonably predict fuel solid swelling and densification. Therefore, based on the discussions provided in the preceding paragraphs, the NRC staff finds the fuel solid swelling and densification models of PAD5 are applicable up to **[ ]** rod-average burnup under the constraints discussed in WCAP-18446-P/WCAP-18446-NP, Revision 0, and this SE.

Per Westinghouse's response to RAI-1, the PAD5 fuel solid swelling and densification models are dependent on local burnup effects. The NRC staff notes that, while a local fuel pellet surface (i.e., ring) burnup is used in this model to determine the overall volume change, the model is validated via multiple test data with rod-average burnups that exceed the requested burnup extension limit of **[ ]** rod-average burnup. Therefore, the equivalent local burnup is bounded by the available data and the staff finds there is no need for a local burnup limit due to this model.

*Helium Solubility and Release*

Helium solubility in PAD5 is a function of the fuel density initial gas pressure and fuel burnup. The model is developed based on multiple linear regressions on hot cell data over a range of densities, initial fill pressures, and fuel burnups. In the final SE approving the PAD5 methodology, the NRC staff assessed this model and found it to be acceptable based on the low values of helium solubility predicted by the model and the large upper and lower uncertainty bounds.

The NRC staff assessed the applicability of the helium solubility model to the requested rod-average burnup extension limit consistent with the prior assessment in the SE approving the PAD5 methodology. Fuel pellets in rods containing pressurized helium are assumed to absorb a portion of the helium atmosphere. Further, the extent of helium dissolution is calculated based on initial fuel density while assuming the dissolution process is complete at the beginning of fuel irradiation. In other words, helium content within the fuel is assumed to be at saturation for the given fuel density. From this perspective, the helium content within the fuel due to dissolution decreases with burnup, and it is expected to do so monotonically (minor variations due to temperature changes notwithstanding). Therefore, the low values of helium solubility predicted at low burnups will be even lower at higher burnups, while the large upper and lower uncertainty bounds, which were developed from the lower burnup data, will also be applied. Because the predicted helium solubility will continue to be small and the large uncertainty bounds continue to ensure at least a 95 percent probability with 95 percent confidence, the NRC staff finds the helium solubility model to be applicable to the requested rod-average burnup extension limit of **[ ]**

The helium production model assumes helium is produced at a rate of 0.3 atoms per 100 fissions, and the release model assumes that all the helium above the current solubility level is released to the void volume. In the SE approving the PAD5 methodology, the NRC staff found these assumptions to be reasonable. In the scope of the current review, the NRC staff finds these assumptions remain reasonable; helium production is not expected to increase with burnup, and it is conservative to assume all helium above the current solubility level is released. Therefore, the NRC staff finds the helium release model to be applicable to the requested rod-average burnup extension limit of **[ ]**

Per Westinghouse's response to RAI-1, the PAD5 helium solubility and release models are dependent on local burnup effects. The NRC staff notes that, while these models are based on local burnup, they are calibrated to and validated with rod-average data. Therefore, the NRC staff finds there is no need for a local burnup limit due to this model.

*Cladding Diametral Growth and Steady-State Creep*

The cladding diametral creep model in PAD5 is the sum of the deformation due to thermal creep, irradiation enhanced creep, and irradiation induced diametral growth. The cladding thermal creep model is a function of temperature, effective stress, and total fast neutron fluence. The cladding irradiation creep model is also a function of these phenomena, in addition to fast neutron flux. The cladding diametral growth model in PAD5 is a function of fast neutron fluence and, for Optimized ZIRLO™, also **[ ]** In the SE approving the PAD5 methodology, the NRC staff assessed these models and found them to be acceptable based, in part, on the demonstration that the models predict creep with no bias and the acceptability of the upper and lower uncertainty bounds in ensuring at least 95/95 predictions.

In assessing the applicability of these models to the requested burnup extension limit, the NRC staff noted the cladding creep comparisons in the PAD5 database did not appear to include data beyond **[ ]** rod-average burnup. The NRC staff therefore requested in RAI-7 that Westinghouse justify applicability of the models for rod-average burnups beyond 62 GWd/MTU. Westinghouse's response stated irradiation effects on cladding creep saturates at lower fluence, and the response also indicated additional cladding creep data is available in the response to RAI-9 of the PAD5 TR for burnups greater than **[ ]** Westinghouse's response to RAI-1 indicates this value is local burnup, and the NRC staff notes this **[ ]**

The NRC staff examined the additional cladding creep data available in the response to RAI-9 of the PAD5 TR and noted the following. First, these data were given consideration in the NRC staff's SE approving the PAD5 methodology (within the scope of the 62 GWd/MTU rod-average burnup limit) and found to demonstrate the models give reasonable predictions of cladding creep without bias with respect to dependent phenomena (i.e., temperature, stress, or fast neutron fluence). Second, the data at higher burnups show best-estimate predictions and an uncertainty consistent with the data from lower burnups, which indicates the upper and lower uncertainty bounds found acceptable by the NRC staff in the SE approving the PAD5 methodology are also applicable to the proposed range of extended burnup. Third, the data at higher burnups continue to demonstrate no discernable adverse trends with respect to predictive capability. Based on these observations, the NRC staff finds the cladding creep models in PAD5 to be applicable to the requested burnup extension limit of **[ ]** rod-average burnup.

Per Westinghouse's response to RAI-1, the PAD5 diametral growth and steady-state creep models are dependent on local burnup effects. The NRC staff notes that, while these models are based on local burnup, the available PAD5 database by which they are validated exceeds local burnups of **[ ]** which bounds the requested equivalent rod-average burnup extension limit of **[ ]** Therefore, the NRC staff finds there is no need for a local burnup limit due to this model.

*Fuel Rod Axial Growth*

While fuel rod axial growth influences the rod internal pressure, it is also significant in its own right. Therefore, the NRC staff's assessment of Westinghouse's fuel rod axial growth models is provided separately in Section 3.2.1.10 of this SE.

*Fuel Temperature Distribution*

While the fuel temperature distribution influences rod internal pressure, it is also significant in its own right. Therefore, the NRC staff's assessment of Westinghouse's fuel temperature distribution models is provided separately in Section 3.2.1.6 of this SE.

*Conclusions Regarding Fuel Rod Internal Pressure Evaluations*

The acceptance criteria for precluding fuel system damage due to excessive fuel rod internal pressure do not change with higher burnups. The overall effect of higher burnups on fuel rod internal pressure is expected to result in overall higher rod internal pressures. Westinghouse anticipates that, for most plants, **[**

**]** and this acceptance criterion would be evaluated on a cycle-specific basis. Additionally, Westinghouse will demonstrate the fuel rod internal pressure criteria are met on a plant-specific basis as part of the standard reload analysis. The NRC staff finds this reasonable.

However, the NRC staff notes the available validation data for a number of models are sparse at higher burnups **[** **]** and the staff could not conclude the acceptability of the models to the requested rod-average burnup extension limit outside the scope of the present review (i.e., on a generic basis). Therefore, the NRC staff finds that PAD5 is acceptable for evaluating rod internal pressures up to the requested rod-average burnup extension limit within the scope of the methodology presented in WCAP-18446-P/ WCAP-18446-NP, Revision 0, and the additional constraints imposed by this SE. This conclusion is based on the acceptability of the models discussed above, the constancy of the rod internal pressure acceptance criteria with higher burnups, and the plant-specific analyses that will be performed as part of standard reload analyses to ensure continued compliance with regulatory requirements, conformance to applicable fuel design limits, and adherence to guidance.

### 3.2.1.2 Fuel Rod Clad Stress

The design basis for fuel rod cladding stress is to ensure the fuel system will not be damaged due to excessive fuel rod cladding stress. The maximum cladding stress intensities, excluding pellet-cladding interaction-induced stress (discussed separately in Section 3.2.1.4 of this SE), will be evaluated based on American Society of Mechanical Engineers (ASME) *Boiler and Pressure Vessel Code* (BPVC) guidelines.

Fuel rod cladding strain evaluations determine limiting stress loads from several PAD5 inputs. Chiefly among these are **[**

**]** all of which are discussed below.

*Rod Internal Pressure*

Higher burnups will lead increased rod internal pressures. The NRC staff's assessment of rod internal pressure regarding higher burnups and the expected increase is discussed above in Section 3.2.1.1 of this SE.

*Cladding Diametral Growth and Steady-State Creep*

The NRC staff's assessment of cladding diametral growth and steady-state creep regarding higher burnups is discussed above in Section 3.2.1.1 of this SE.

*Cladding Yield Strength and Ultimate Tensile Strength*

Cladding yield strength (YS), also known as the elastic limit, is the amount of stress fuel cladding can experience before being permanently deformed. Ultimate tensile strength (UTS) is the amount of stress fuel cladding can withstand before necking occurs, and the rod is considered to have failed due to potential loss of hermeticity. These mechanical properties are known to be impacted by irradiation (i.e., fluence), with YS and UTS increasing (i.e., due to material hardening) with increasing irradiation. PAD5 contains correlations for YS and UTS for cold worked stress relief annealed (SRA) Zircaloy, SRA ZIRLO, and partially recrystallized Optimized ZIRLO in irradiated and unirradiated conditions. The same correlations are used across all three claddings for irradiated YS and UTS. An irradiation hardening model is also included in PAD5 to calculate a smooth transition from the unirradiated YS and UTS to the irradiated YS and UTS. In the NRC staff's SE approving the PAD5 methodology, the irradiated YS and UTS correlations were found acceptable based on comparisons to FRAPCON and Westinghouse cladding data.

The NRC staff examined the same comparisons and Westinghouse cladding data to assess the applicability of the YS and UTS correlations to higher burnups. Figure 6.3-1 of the PAD5 TR presents comparisons of cladding hardening data versus fast neutron fluence. The NRC staff noted the PAD5 models predict irradiation hardening reasonably well and that the effects of irradiation hardening appear to **[** **]** This effect is also observed in (1) the separate raw YS and UTS data versus fluence curves respectively presented in Figure 6.5-2 and Figure 6.5-3 of the PAD5 TR and (2) the separate raw YS and UTS data versus fluence curves respectively presented in Figure 2.5-6a and Figure 2.5-6b of WCAP 18446-P/WCAP-18446-NP, Revision 0. The results suggest **[**

**]** As discussed in Section 3.1.4.6 of this SE, **[**

**]** The NRC staff further notes that a number of conservatisms have been incorporated into the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology (e.g., such as with respect to the prediction of cladding rupture under LOCA conditions, as discussed below in Section 3.3 of this SE). Therefore, the YS and UTS correlations should continue to predict reasonably well up to the requested rod-average burnup extension limit. Section 6.5 of the PAD5 TR indicates the data within these plots are for ZIRLO and Optimized ZIRLO up to rod-average burnups of at least **[**

**]** Based on this, the NRC staff finds the PAD5 irradiated YS and UTS correlations are applicable to the requested rod-average burnup extension limit for the ZIRLO and Optimized ZIRLO claddings.

Per Westinghouse's response to RAI-1, the PAD5 YS and UTS correlations are dependent on local cladding fluence. The NRC staff notes that, while these correlations are based on local cladding fluence, the available PAD5 database by which they are validated exceeds equivalent local burnups of **[** **]** which bounds the requested equivalent rod-average burnup extension limit of **[** **]** Therefore, the NRC staff finds there is no need for a local burnup limit due to this model.

### *Conclusions Regarding Fuel Rod Clad Stress*

The acceptance criterion for precluding fuel system damage due to excessive fuel rod cladding stress does not change with higher burnups. The overall effect of higher burnups on stress is expected to be a **[** **]** Westinghouse anticipates that, for most plants, **[** **]** Regardless, Westinghouse will demonstrate the clad stress acceptance criteria are met on a plant-specific basis as part of its standard reload analysis. Therefore, the NRC staff finds that PAD5 is acceptable for evaluating cladding strain up to the requested rod-average burnup extension limit because of the acceptability of the models discussed above, because the clad stress acceptance criteria does not change with higher burnups, and because plant-specific analyses will be performed as part of standard reload analyses to ensure continued compliance with regulatory requirements and adherence to guidance.

### 3.2.1.3 Fuel Rod Cladding Strain

The acceptance criterion for this fuel rod design basis is the fuel cladding must not fail due to excessive cladding strain. This criterion is assumed to be met as long as the total tensile strain (total elastic plus plastic tensile strain due to uniform cylindrical fuel pellet deformation) remains below 1 percent during Condition I and II events.

Westinghouse states that an incremental burnup extension may lead to an **[** **]** WCAP-18446-P/WCAP-18446-NP, Revision 0, restricts extended burnup assemblies to the core periphery, which is expected to result in less demanding service conditions with lower TCS values. Westinghouse will perform plant-specific evaluations as part of its reload analyses to ensure that TCS remains below 1 percent. Fuel assemblies intended to reach extended burnups may potentially experience slightly different power histories which could affect the behavior of TCS. Westinghouse presented evidence that the **[** **]** (discussed further in Sections 3.2.2 and 3.3.3 of this SE). However, any differences in the power histories and their effect on TCS should ultimately be captured and verified to be acceptable in Westinghouse reload analyses.

In the SE approving the PAD5 methodology, the NRC staff assessed Westinghouse's cladding strain models and found them to be acceptable. Within WCAP-18446-P/WCAP-18446-NP, Revision 0, there are no proposed changes to the models, methodology, or design criteria associated with clad strain to accommodate an incremental burnup extension. Therefore, the NRC staff examined the cladding hoop strain results from ramp tests in the PAD5 TR to assess the adequacy with which PAD5 can predict cladding strain during transients in the range of the requested burnup extension.

The NRC staff noted that Figure A.2.4-2 and Figure A.2.4-4 of the PAD5 TR contain very few **[                                   ]** data in the range of the requested rod-average burnup extension. The paucity of data makes it difficult to conclude that PAD5 can acceptably predict TCS at the burnups of interest on generic basis. However, within the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology higher burnup assemblies are placed on the core periphery. The fuel rods in these assemblies will be in their third cycle and are expected to have low initial powers (e.g., **[              ]** as seen in Table 4.7-1 of WCAP-18446-P/WCAP-18446-NP, Revision 0). As a result, these fuel rods will not have high transient power increases, and the resulting TCS values are expected to remain relatively low. The NRC staff's review of Westinghouse's response to RAI-1 of the PAD5 TR noted that the ramp test data available at higher burnups are representative of the peak rod-average powers expected for the higher burnup assemblies (e.g., **[                ]** Additionally, as discussed above in Section 3.2.1.1 under "Fission Gas Bubble Swelling," both pellet thermal expansion and fission gas swelling are necessary to fully account for the cladding permanent hoop strain observed in ramp test data. Regarding fission bubble gas swelling, the NRC staff ultimately concluded PAD5 could acceptably model this phenomenon for the application scope specified in WCAP-18446-P/WCAP-18446-NP, Revision 0. Therefore, given that the ramp test data is representative of peripheral fuel assembly power during transients, the lower TCS values that will result from the lower power peripheral assemblies, and the acceptable modeling of the underlying phenomena that contribute to hoop strain, the NRC staff finds the PAD5 methodology can reasonably predict transient cladding strain up to the requested rod-average burnup extension limit within the scope of the methodology described in WCAP-18446-P/WCAP-18446-NP, Revision 0.

*Conclusions Regarding Fuel Rod Cladding Strain Evaluations*

The NRC staff determined that PAD5 is acceptable for evaluating TCS because of the acceptability of the models discussed above, because any increase in TCS due to higher burnup is expected to be small, and because WCAP-18446-P/WCAP-18446-NP, Revision 0, only permits extended burnup assemblies on the periphery where the local power is relatively low. Additionally, plant-specific analyses will be performed as part of standard reload analyses to ensure continued compliance with regulatory requirements and adherence to guidance.

#### 3.2.1.4 Pellet-Cladding Interaction

As discussed by Westinghouse in Sections 3.1.2 and 3.1.4 of WCAP-18446-P/WCAP-18446-NP, Revision 0, the fuel cladding must not fail due to pellet-cladding interaction (PCI) or pellet-cladding mechanical interaction (PCMI). These interactions can occur when the pellet and cladding contact each other, which may result in damage to the cladding. As discussed in Chapter 4.2 of the SRP (Reference 13), the difference between PCI and PCMI is subtle; PCI is generally the result of stress-corrosion cracking due to fission-product-driven embrittlement of the cladding, whereas PCMI is primarily a stress-driven failure mechanism. The PCI design criterion is assumed to be satisfied by meeting two other design criteria: the one percent clad strain criterion and the fuel overheating criterion. It was determined in WCAP-17642-P-A, Revision 1, that meeting these two other design criteria is an acceptable means of demonstrating compliance with the PCI design criterion.

Westinghouse provided further discussion of PCMI in connection with its assessment of the control rod ejection accident in Section 5.1.2 of WCAP-18446-P/WCAP-18446-NP, Revision 0, which describes how the PCMI failure threshold in RG 1.236 is expressed in terms of a peak radial average fuel enthalpy rise versus excess cladding hydrogen content. Because Westinghouse would apply applicable failure criteria recommended in the NRC staff's regulatory guidance, the NRC staff finds this approach to be acceptable with respect to the control rod ejection accident.

*Fuel Radial Relocation*

Previous versions of the PAD code accounted for fuel radial relocation in thermal calculations, but PAD5 accounts for fuel radial relocation in both thermal and PCMI calculations. In the SE approving the PAD5 methodology, the NRC staff assessed this model and found it to be acceptable based, in part, on the ability of PAD5 to provide reasonable predictions of cladding strain.

Given the limited **[ ]** available in the PAD5 database for rod-average burnups in excess of 62 GWd/MTU (see Section 3.2.1.3 of this SE), the NRC staff examined the broader validation of the fuel radial relocation model to assess its applicability to the requested rod-average burnup extension limit. Validation of the model is provided in the PAD5 TR and is based on fuel temperature data for open gap conditions and ramp test cladding diameter change data for both open- and closed-gap conditions. The NRC staff noted the available data either exceed the requested rod-average burnup extension limit or are representative of it. Additionally, the data are reasonably predicted and exhibits uncertainties consistent with the data from rod-average burnups below 62 GWd/MTU. Therefore, the NRC staff finds the model remains applicable to **[ ]** rod-average burnup.

Per Westinghouse's response to RAI-1, the PAD5 fuel radial relocation model is dependent on local burnup effects. The NRC staff notes that, while this model is based on local burnup, the available data within the PAD5 database by which the model is validated exceeds local burnups of **[ ]** which bounds the requested equivalent rod-average burnup extension limit of **[ ]** Therefore, the NRC staff finds there is no need for a local burnup limit due to this model.

*Conclusions Regarding Pellet-Cladding Interaction Evaluations*

Westinghouse has not proposed any changes to this design criterion, or the methodology used to demonstrate compliance with the PCI design criterion. The NRC staff has determined that the PCI design criterion may continue to be satisfied by demonstrating compliance with the one percent clad strain and fuel overheating criteria. These criteria are discussed further in Sections 3.2.1.3 and 3.2.1.6, respectively, of this SE. Therefore, based on the evaluations in these SE sections and the discussion above, Westinghouse's evaluation of PCI with an incremental burnup extension is acceptable.

#### 3.2.1.5 Fuel Cladding Oxidation and Hydriding

The corrosion design criteria for fuel assemblies are that fuel damage must not occur due to excessive cladding oxidation and hydriding. Fuel damage due to these phenomena is precluded by placing limits on cladding oxidation thickness and hydrogen pickup limits. These limits are 100 microns and **[ ]** respectively.

Fuel rod corrosion and hydriding evaluations depend on steady-state oxidation (with potentially enhanced corrosion effects at higher burnups) and cladding steady-state hydrogen concentration. Consideration is also given to the mechanical strength of the cladding in response to hydrogen pickup.

*Cladding Steady-State Oxidation and Potentially Enhanced Clad Corrosion*

Westinghouse evaluates oxidation in PAD5 using fuel-cladding-dependent models that have been approved by the NRC in the WCAP-12610-P-A & CENPD-404-P-A, Addendum 2-A TR (Reference 28).[2] The applicable fuel claddings consist of Zircaloy-4, ZIRLO, and Optimized ZIRLO. The approval of the PAD5 methodology included upper and lower uncertainty bounds for the corrosion models for these cladding alloys. Additional discussion related to the evaluation procedures utilizing the corrosion models are found in the PAD5 methodology.

The NRC staff assessed the applicability of these corrosion models to the requested rod-average burnup extension limit. Figure 2.5-3 of WCAP-18446-P/WCAP-18446-NP, Revision 0, presents raw cladding oxide thickness data as a function of rod-average burnup for ZIRLO and Optimized ZIRLO claddings. These data encompass the requested rod-average burnup extension limit but are not compared to PAD5 predictions. It is also not clear from these figures whether these data were part of the database used to perform the fitting of the ZIRLO and Optimized ZIRLO corrosion models and develop the uncertainty bounds as presented in WCAP-12610-P-A & CENPD-404-P-A, Addendum 2-A.

Westinghouse's response to RAI-6 indicates the Optimized ZIRLO data from Figure 2.5-3 was not included in the formulation of the corrosion models in WCAP-12610-P-A & CENPD-404-P-A, Addendum 2-A, but confirmation of the upper uncertainty bound with this data was performed in the PAD5 TR, and comparisons to predicted oxide thicknesses were presented in the response to RAI-3c of the PAD5 TR. The comparisons demonstrate a clear trend of **[**

**]** for the burnups of interest. The response to RAI-3b of the PAD5 TR also demonstrates the continued applicability of the upper uncertainty bound. Because overprediction of oxide thickness is conservative and the upper uncertainty bound remains applicable, the NRC staff finds the Optimized ZIRLO corrosion model predictions to be acceptable.

Regarding the ZIRLO corrosion model, Westinghouse's response to RAI-6 did not address whether the data presented in Figure 2.5-3 were utilized in formulating the corrosion model or confirming the upper uncertainty bound. However, Figure 2.2-10 of WCAP-12610-P-A & CENPD-404-P-A, Addendum 2-A, provides a large amount of predicted oxide thickness comparisons for ZIRLO across a nearly identical range of TRD (rod-average burnups of approximately **[** **]**) and clearly demonstrates the same trend of **[** **]** as observed in the Optimized ZIRLO data. Figure 2.2-6 of WCAP-12610-P-A & CENPD-404-P-A, Addendum 2-A, also demonstrates the applicability of the upper uncertainty bound for this data. Because overprediction of oxide thickness is conservative and the upper uncertainty bound remains applicable, the NRC staff finds the ZIRLO corrosion model predictions to be acceptable.

Per Section 3.3.2, "Zircaloy-4 Cladding," of the PAD5 TR, WCAP-17642-P-A, Revision 1, current fuel designs do not employ Zircaloy-4 cladding, and Zircaloy-4 cladding fuel will not be used in fuel designed to achieve burnups greater than **[** **]** Therefore, the NRC staff did not assess the applicability of the Zircaloy-4 corrosion model to the requested rod-average burnup extension limit. Based on the discussions provided above, the NRC staff finds the ZIRLO and Optimized ZIRLO cladding corrosion models acceptable for use up to rod-average burnups of **[** **]**

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[2] Note that WCAP-12610-P-A & CENPD-404-P-A, Addendum 2-A, refers to a single document that Westinghouse cross-listed as both a WCAP and CENPD report.

Per Westinghouse's response to RAI-1, the PAD5 fuel cladding corrosion models are dependent on local burnup effects. The NRC staff notes that, while these models are based on time at local temperature (which is based on local power), the available data within the PAD5 database by which the models are validated exceed the requested rod-average burnup extension limit of **[ ]** Therefore, the NRC staff finds there is no need for a local limit due to this model.

*Cladding Steady-State Hydrogen Concentration*

Westinghouse evaluates hydrogen content in PAD5 using a single model for the Zircaloy-4, ZIRLO, and Optimized ZIRLO fuel claddings. The model and its applicability to these fuel claddings has been approved by the NRC in the WCAP-12610-P-A & CENPD-404-P-A, Addendum 2-A, TR; Westinghouse indicates therein that the hydrogen absorption in ZIRLO and Zircaloy-4 is comparable, while Optimized ZIRLO is either equivalent or less. The approval of the PAD5 methodology included an upper uncertainty bound for this model. Additional discussion related to the evaluation procedures utilizing the hydrogen content model is found in the PAD5 methodology.

The NRC staff assessed the applicability of this model to the requested rod-average burnup extension limit. Figure 2.5-5 of WCAP-18446-P/WCAP-18446-NP, Revision 0, presents raw cladding hydrogen content data as a function of rod-average burnup for ZIRLO and Optimized ZIRLO claddings. These data include the requested rod-average burnup extension limit but are not compared to PAD5 predictions. It is also not clear from these figures whether these data were part of the database used to perform the fitting of the ZIRLO and Optimized ZIRLO hydrogen concentration model and develop the uncertainty bounds as presented in WCAP-12610-P-A & CENPD-404-P-A, Addendum 2-A.

Westinghouse's response to RAI-8 indicates the Optimized ZIRLO data from Figure 2.5-5a and Figure 2.5-5b were not included in the formulation of the hydrogen concentration model in WCAP-12610-P-A & CENPD-404-P-A, Addendum 2-A, but comparisons to predicted hydrogen concentration and confirmation of the upper uncertainty bound were presented in the response to RAI-3d of the PAD5 TR. The comparisons demonstrate reasonable predictions of hydrogen concentration in ZIRLO cladding and a conservative tendency to overpredict hydrogen concentrations in Optimized ZIRLO. These results are also consistent with Westinghouse's justification for the model's applicability to multiple cladding alloys, as discussed above. The hydrogen concentration data presented in the response to RAI-3d of the PAD5 TR for Optimized ZIRLO are within the range of the existing database and Figure-2.5-5b; therefore, the upper uncertainty bound continues to remain applicable for Optimized ZIRLO. Because hydrogen concentration is conservatively predicted for Optimized ZIRLO, and because the upper uncertainty bound remains applicable, the NRC staff finds the hydrogen concentration model to be applicable up to the requested rod-average burnup extension limit for the Optimized ZIRLO cladding.

However, the NRC staff noted that a number of hydrogen concentration datapoints presented in Figure 2.5-5b for ZIRLO **[ ]** at higher burnups and are outside the range of predicted and measured ZIRLO hydrogen concentration data presented in the response to RAI-3d of the PAD5 TR. It is also not clear what burnups the ZIRLO data within the response to RAI-3d of the PAD5 TR correspond to. Therefore, based on the information provided, the NRC staff could not confirm the continued applicability of the hydrogen concentration model to the requested rod-average burnup extension limit for ZIRLO cladding. Therefore, consistent with the discussion in Section 3.1.4.5 of this SE, and as required by

Limitation and Condition 10, applicability of the hydrogen concentration model for ZIRLO cladding should be justified on an application-specific basis.

Per Section 3.3.2, “Zircaloy-4 Cladding,” of the PAD5 TR, WCAP-17642-P-A, Revision 1, current fuel designs do not employ Zircaloy-4 cladding, and Zircaloy-4 cladding fuel will not be used in fuel designed to achieve burnups greater than **[ ]** Therefore, the NRC staff did not assess whether the hydrogen absorption in Zircaloy-4 remained comparable with ZIRLO to the requested rod-average burnup extension limit, and the acceptability of the hydrogen concentration model to this burnup limit for ZIRLO and Optimized ZIRLO, as discussed above, should not be considered as implicit approval of the model for Zircaloy-4.

Per Westinghouse’s response to RAI-1, the PAD5 fuel cladding steady-state hydrogen concentration model is dependent on local burnup phenomena. The NRC staff notes that the model is dependent on cladding oxidation, which is dependent on local time at local temperature. However, the data available within the PAD5 database by which the oxidation models are validated (as discussed above under “Steady-State Cladding Oxidation”) exceed the requested rod-average burnup extension limit of **[ ]** Therefore, the NRC staff finds there is no need for a local limit due to this model.

*Continuing Degradation of Mechanical Strength Due to Higher Hydrogen Pickup*

The acceptance limit for cladding hydrogen concentration, or “pickup,” has already been established to be that the best-estimate, volume-average hydrogen concentration level in the most limiting clad axial node will be less than or equal to **[ ]** at the end of fuel operation. While it is expected that proceeding to higher burnups will result in an increase in cladding corrosion and therefore an increase in hydrogen pickup, the hydrogen pickup limit of **[ ]** remains applicable. This helps ensure that the degradation of mechanical strength due to higher hydrogen concentrations is not a concern, and the NRC staff finds this acceptable.

*Conclusions Regarding Fuel Cladding and Hydriding Evaluations*

Westinghouse has not proposed any changes to the upper limits for clad oxidation and hydriding. An increase in burnup will result in increasing cladding corrosion, which may challenge these limits. Westinghouse will evaluate the maximum cladding oxidation and hydriding on a plant-specific basis as part of its standard reload analysis to ensure that these limits are not exceeded. The limits ensure that fuel rods will not fail due to cladding corrosion. By not proposing any changes to the upper tolerance limits, Westinghouse maintains an adequate level of assurance with respect to preventing excessive cladding corrosion. The primary difference with a burnup extension is the amount of margin between the maximum calculated cladding corrosion and the upper tolerance limit.

The NRC staff has determined that Westinghouse’s evaluation of fuel clad oxidation and hydriding is acceptable because of the acceptability of the models discussed above, the maintenance of previously acceptable upper tolerance limits for corrosion and hydrogen concentration, and the performance of cycle- and plant-specific evaluations to ensure that these limits are not exceeded.

### 3.2.1.6 Fuel Temperature

The acceptance criteria for maximum fuel temperature is that the fuel rods will not fail due to fuel centerline melting for Condition I and II events, and the fuel rod centerline temperature shall not exceed the fuel melt temperature during Condition I and II operation, accounting for degradation of the melt temperature. Westinghouse has not proposed any changes to this acceptance criteria.

*Fuel Melting Point*

PAD5 contains fuel temperature melting point models for $UO_2$, $UO_2$-$Gd_2O_3$, and $UO_2$-$Er_2O_3$ fuels. In the SE approving the PAD5 methodology, the NRC staff found these models acceptable for up to **[ ]** based, in part, on conservative performance comparisons to FRAPCON and applicability of a 95/95 upper uncertainty bound on fuel centerline temperature predictions. The models contain a burnup-dependence and exhibit a reduction in fuel melting temperature with increasing burnup.

The NRC staff noted the fuel melting point comparisons of PAD5 and FRAPCON demonstrate that PAD5 continues to conservatively predict the fuel melting temperature (with respect to FRAPCON) up to the requested rod-average burnup limit extension. The NRC staff also observed that PAD5 reasonably predicts fuel centerline temperatures up to the requested rod-average burnup limit extension such that the 95/95 upper uncertainty bound remains applicable (discussed below under "*Fuel Thermal Conductivity*"). Based on this, the NRC staff finds the PAD5 fuel melting point model is applicable to rod-average burnups up to **[ ]**

Per Westinghouse's response to RAI-1, the PAD5 fuel melting point model is dependent on local fuel pellet burnup. Westinghouse's response to RAI-1 indicates data for local burnups greater than 90 GWd/MTU were used to develop the fuel melting point model and provided a reference for this data. The NRC staff examined the referenced data and notes the data in excess of 90 GWd/MTU is sparse. However, the amount of referenced data available up to local burnups of **[ ]** is reasonable, and this local burnup bounds the equivalent requested rod-average burnup extension limit. Therefore, the NRC staff finds there is no need for a local limit due to this model.

*Fuel Thermal Conductivity and Continuing Degradation of Fuel Thermal Conductivity*

Figure A.2.1-15 of the PAD5 TR contains comparisons of predicted and measured fuel centerline temperatures for burnups within the range of the requested extended burnup limit. The results show good agreement, and there is sufficient data presented to conclude that the PAD5 methodology can adequately predict fuel temperature, accounting for the reduction in fuel thermal conductivity with burnup. The high-burnup data provided in WCAP-17642-P-A, Revision 1, follows similar trending and spread as the data within already-approved ranges of burnup, and the upper uncertainty bound therefore remains applicable. The NRC staff therefore finds the PAD5 fuel thermal conductivity model to be applicable to the requested rod-average burnup extension limit.

Per Westinghouse's response to RAI-1, the PAD5 fuel thermal conductivity model is dependent on local fuel pellet burnup. The NRC staff notes that, while the model is dependent on local burnup, the model was calibrated using rod-average burnup data up to **[ ]** This exceeds the requested rod-average burnup extension limit of **[ ]** Therefore, the NRC staff finds there is no need for a local limit due to this model.

*Conclusions Regarding Fuel Temperature Evaluations*

The PAD5 methodology includes a power-to-melt evaluation that ensures the expected power history is bounded by a limiting power history. This evaluation conservatively models several factors which could be affected by increased burnups including **[**

**]** To ensure that the power-to-melt evaluation bounds the expected power history, Westinghouse will perform cycle- and plant-specific evaluations as part of its routine reload safety analysis.

The NRC staff determined that PAD5 is acceptable for modeling fuel temperature under the requested incremental rod-average burnup extension because of the acceptability of the PAD5 models (discussed above) and because cycle- and plant-specific evaluations will be performed to ensure compliance with the relevant regulations and safety limits.

### 3.2.1.7 Clad Free Standing

The purpose of this criterion is to preclude fuel system damage due to excessive fuel cladding stress. Specifically, the criterion precludes the possibility of instantaneous collapse of the fuel rod cladding onto the fuel pellet due to compressive differential pressure across the cladding wall.

*Conclusions Regarding Clad Free-Standing Evaluations*

The most limiting condition for clad free standing is when the rod internal pressure is at a minimum and the core ambient pressure is at a maximum, usually a static value. The minimum rod internal pressure occurs at BOL, and thus the limiting condition of clad free standing is also BOL. Therefore, this criterion is unaffected by a change in maximum burnup, as the rod internal pressure will not decrease to pressures below those found at BOL.

The NRC staff determined that the PAD5 methodology is acceptable for modeling the critical collapse pressure of the cladding onto the fuel because the limiting condition occurs at BOL (conditions for which the PAD5 methodology is already approved), and degradation of cladding material properties at higher burnups would not be sufficient to create a new limiting condition.

### 3.2.1.8 Fuel Clad Fatigue

The acceptance criteria for ensuring fuel system damage will not occur due to fatigue is a fatigue life usage factor less than 1.0 to prevent reaching the material fatigue limit. This usage factor is assessed with consideration of a safety factor of 2 on stress amplitude or a safety factor of 20 on the number of fatigue cycles, whichever is more limiting. In the PAD5 methodology, the impact on fatigue damage is assessed using a **[**

**]** The Langer-O'Donnell fatigue model is used to determine the relationship between strain and fatigue cycles-to-failure.

Fatigue is driven by the accumulated effects of cyclical strains associated with daily load following. It is expected that higher burnups will result in increased fuel clad fatigue due to a larger number of strain cycles inherent to longer core residency times. However, the fatigue damage analyses utilized by Westinghouse will assess cyclical stresses far in excess of those expected of fuel in actual operation and yield bounding fatigue damage results, even with consideration of the longer residency times associated with higher burnups. This is because power reactors primarily operate at full-power steady-state conditions and do not experience the daily cyclical load following considered in the fatigue assessments.

#### *Conclusions Regarding Fuel Clad Fatigue Evaluations*

The Westinghouse design basis and acceptance limit incorporate significant margin to ensure that fuel clad will not fail due to fatigue. Westinghouse does not propose any changes to the acceptance criteria for fuel clad fatigue and believes that most licensees will be able to accommodate any impacts of the burnup limit extension with available margins. Plant-specific application must demonstrate that the fuel clad fatigue acceptance criteria are satisfied and that any reduction in available margin does not result significant safety concerns.

The NRC staff has determined that Westinghouse's evaluation of fuel clad fatigue is acceptable for the requested rod-average burnup extension limit because fuel clad fatigue is evaluated as part of the standard reload analysis procedure, any loss of margin will be accounted for, and the fatigue damage assessments will be bounding when considering the expected actual operational conditions of the fuel.

### 3.2.1.9 Fuel Clad Flattening

Fuel clad flattening is a fuel rod failure mode that can occur when inter-pellet gaps form and create a space the cladding can collapse down into the space. Inter-pellet gaps may be formed by radiation-induced material changes in the pellets, such as densification. The Westinghouse acceptance criteria for this fuel rod failure mode is that clad flattening will not occur.

Westinghouse's technical basis for fuel rod clad flattening is discussed in WCAP-13589-A, "Assessment of Clad Flattening and Densification Power Spike Factor Elimination in Westinghouse Nuclear Fuel" (Reference 29). Clad flattening depends on several design and physical events happening within a given period of time. The first of these is fuel pellet hangup, then the formation of an axial gap in the fuel stack due to fuel densification below the hung-up pellet, followed by cladding creep into the axial gap. Pellet hangup has generally been attributed to a combination of pellet cocking (i.e., a tilted misalignment) and cladding creep. Thus, fuel design parameters important to clad flattening are fuel-to-cladding gap, initial fuel rod fill pressure, fuel densification, pellet cocking, and cladding creep rate.

Per WCAP-13589-A and the NRC staff's associated SE, Westinghouse demonstrated the fuel manufacturing process employed, including among other things a combination of higher initial fill gas pressures with low densification fuel, produces a stable fuel design with a significant lack of axial gaps. Specifically, axial gaps greater than **[ ]** can lead to cladding collapse. WCAP-13589-A indicates that a **[ ]** margin in axial gap formation exists for Westinghouse fuels. The NRC staff also notes that the reduction in fuel pellet volume due to densification reaches its greatest extent early in life, between **[ ]** rod-average burnup (as seen in Figure 2-16 of WCAP-10851-P-A and the response to RAI-1 of WCAP-18446-P/WCAP-18446-NP, Revision 0). At higher burnups, the fuel pellet volume is increasing beyond its as-fabricated volume. Therefore, the likelihood of axial gaps forming that are large enough facilitate cladding collapse is largely precluded.

*Conclusions Regarding Fuel Clad Flattening Evaluations*

Westinghouse is not proposing to change clad flattening acceptance criteria, and the NRC staff has determined that this acceptance criteria will remain acceptable at the increased burnups within the scope of WCAP-18446-P/WCAP-18446-NP, Revision 0, because it ensures fuel cladding failure by flattening is largely precluded. Westinghouse demonstrates compliance with the acceptance criteria by fabricating fuel pellets in such a manner as to preclude the formation of axial gaps large enough for clad flattening. The technical basis for this determination is documented in WCAP-13589-A. It is shown that Westinghouse fabrication methods limit axial gap formations to lengths considerably less than what is required for clad flattening. While higher burnups will lead to longer residence times, the NRC staff finds that the axial gap length threshold for clad flattening will not be exceeded for these longer residence times due to the significant margin to that threshold and the fuel volume shrinkage reaching its peak early in life. Therefore, the NRC staff determined that Westinghouse's evaluation of fuel clad flattening is acceptable for the requested rod-average burnup extension limit of **[ ]**

### 3.2.1.10 Fuel Rod Axial Growth

The design-basis acceptance limit for fuel rod axial growth is the fuel system will not be damaged due to excessive axial interference between the fuel rods and the fuel assembly structure. In particular, the fuel rods shall be designed with sufficient clearance between the fuel rod and the top and bottom nozzles of the assembly in order to accommodate any growth of the fuel rod.

*Potentially Enhanced Rod Growth*

Higher burnups are expected to result in increases of fuel rod axial growth. Fuel rod axial growth is discussed above in Section 3.1.4.4 of this SE. In short, Westinghouse's design process is intended to reasonably assure rod growth remains within tolerable limits. However, ZIRLO cladding is more limiting than Optimized ZIRLO cladding with respect to rod growth, and **[**

**]** Ultimately, per the methodology presented in WCAP-18446-P/WCAP-18446-NP, Revision 0, Westinghouse will confirm on a plant-specific basis that the PAD5-calculated rod growth precludes excessive axial interference between the fuel rods and support structures. The NRC staff notes Figures 2.5-4a and 2.5-4b of WCAP-18446-P/WCAP-18446-NP, Revision 0, and the response to RAI-5 demonstrate the PAD5 model predicts ZIRLO and Optimized ZIRLO rod growth data within the upper 95/95 uncertainty bound across the request rod-average burnup extension range.

*Conclusions Regarding Fuel Rod Axial Growth Evaluations*

The NRC staff determined that Westinghouse's assessment of fuel rod axial growth is acceptable because the PAD5 model is expected to adequately model the fuel rod axial growth in the range of the requested rod-average burnup extension and the fuel rod axial growth will be confirmed on a plant-specific basis to ensure there is no excessive contact forces between the rod and support structures.

### 3.2.1.11 Fuel Clad Wear

Fuel clad wear caused by contact with grid support structures, mid-grids and intermediate flow mixing grids, is limited to **[** **]** This limitation will persist into the range of extended burnup. Numerous factors, described in Section 3.1.11 of the TR, can affect fuel clad wear. Most notably are **[** **]** all of which exacerbate grid-to-rod fretting due to the increased fuel residence time characteristic of higher burnups. Higher burnups can also cause dimensional changes in the assembly which could lead to additional cladding wear.

Section 3.1.11 of WCAP-18446-P/WCAP-18446-NP, Revision 0, TR describes how Westinghouse performed tests using the 17x17 OFA design to assess clad wear. **[** **]** is within acceptable guidelines. The results of these tests support Westinghouse's conclusion that fuel clad wear will remain within allowable limits under extended burnup conditions. The NRC staff finds this reasonable.

*Conclusions Regarding Fuel Clad Wear*

The NRC staff determined that Westinghouse's assessment of fuel clad wear is acceptable up to the requested rod-average burnup extension limit because the fuel clad wear design limit is not being changed and testing indicates acceptable performance.

### 3.2.1.12 Conclusions Regarding Fuel Rod Performance

In the NRC staff's final SE approving the PAD5 methodology, the NRC staff included the following Limitation and Condition restricting applicability of the PAD5 code and methodology to:

> Rod-average burnups up to 62 GWd/MTU for all approved types of cladding.

In Section 3.1 of WCAP-18446-P/WCAP-18446-NP, Revision 0, Westinghouse requested modification of this Limitation and Condition in order to accommodate a burnup extension. Specifically, Westinghouse requested the PAD5 Limitation and Condition be revised as follows:

> Rod-average burnups up to **[** **]** for all approved types of cladding.

The preceding subsections of this SE document the NRC staff's assessment of the PAD5 methodology for applicability to the requested rod-average burnup extension limit. Per these discussions, the NRC staff could not conclude that the burnup range of applicability can be acceptably extended for all models on a generic basis, including in particular the **[** **]** models. This was due to the sparse **[** **]** data available at higher burnups and insufficient justification for extending the burnup range of applicability. Therefore, the NRC staff does not approve Westinghouse's requested modification to the Limitation and Condition in the PAD5 SE that would increase the burnup limit applicable to the PAD5 methodology from 62 GWd/MTU to the requested rod-average burnup extension limit of **[** **]** on a generic basis. However, based on the discussions presented in the preceding subsections, the NRC staff concludes that the PAD5 fuel performance code adequately models fuel rod phenomena and adequately quantifies the associated uncertainties such that PAD5 may be acceptably applied up to the requested rod-average burnup extension limit of **[ ]** within the scope of the application methodology described in WCAP-18446-P/WCAP-18446-NP, Revision 0. This position is reflected in Limitation and Condition 4. Generic NRC approval of an extension to the burnup range of applicability for the PAD5 methodology beyond the limits specified in WCAP-17642-P-A, Revision 1, may necessitate additional data and justification, particularly for the models/phenomena noted above.

### 3.2.2 Nuclear Design Methods and Application

The nuclear designs methods referenced in Section 3.2, “Nuclear Design Methods and Application,” of WCAP-18446-P/WCAP-18446-NP, Revision 0, are PARAGON, PHOENIX-P, and ANC. Westinghouse is seeking to extend the range of applicability for these codes to the requested rod-average burnup extension limit. Nuclear design methods provide solutions to the neutron transport equation, cross-section data, power distributions, peaking factors, reactivity calculations, and other neutronic parameters. This information is essential in evaluation of the performance of high-burnup fuel.

PARAGON and PHOENIX-P are both two-dimensional, multi-group transport theory codes. These codes solve neutron transport equations and provide homogenized, two-group cross-sections for nodal calculations and feedback models. Westinghouse indicates in Section 3.2.1, “Background,” of WCAP-18446-P/WCAP-18446-NP, Revision 0, that PARAGON generally provides better flux solution results compared to PHOENIX-P, but PHOENIX-P is used in a special geometry to generate appropriately weighted constants for the baffle and reflector regions. PARAGON and PHOENIX-P provide nuclear data as an input to core simulator codes, such as ANC. PARAGON is described in more detail in its associated TR, WCAP-16045-P-A, Revision 0, “Qualification of the Two-Dimensional Transport Code PARAGON” (Reference 30) and PHOENIX-P in WCAP-11596-P-A, “Qualification of the PHOENIX-P/ANC Nuclear Design System for Pressurized Water Reactor Cores” (Reference 31).

ANC is an advanced nodal code used for two-dimensional and three-dimensional neutron diffusion calculations. ANC provides information for safety analysis calculations, power distributions, peaking factors, critical boron concentrations, control rod worths, reactivity coefficients, peaking factors, pin powers, and other neutronics parameters. ANC is described in more detail in WCAP-10965-P-A, “ANC: A Westinghouse Advanced Nodal Computer Code” (Reference 32). This code is typically coupled with either PARAGON or PHOENIX-P to create a coupled neutronic core design system, as demonstrated in the validation bases documented in the TRs respectively describing these lattice codes, WCAP-16045-P-A and WCAP-11596-P-A.

Westinghouse has not proposed any changes to the above codes, asserting the mechanisms for depletion when increasing the maximum rod-average burnup from 62 GWd/MTU to **[ ]** are identical to those needed below 62 GWd/MTU. While the NRC staff finds this is conceptually true in that neutronic codes can be considered as computational engines for generating nuclear data for a given reactor core configuration, the neutronic conditions characteristic of higher burnup cores (e.g., due to shifting flux spectrums from increased buildup of fission product isotopes and heavier loadings of neutron poison) could exercise the code in heretofore unassessed ways. Therefore, the potential exists that these codes could generate unrealistic results from models (e.g., as a result of simplifications made during implementation of the methodologies or using models outside the application range for which they were designed). This and any existing nonzero trends in predictive error would have a direct impact on quantified uncertainties at higher burnups. Additionally, parameters considered in neutronics codes are only validated for specific ranges. An increase in burnup, among other changes in nuclear design, may require parameter values beyond the currently validated range of the methodology. Validation of codes and methods to the requested rod-average burnup extension limit will provide assurance of continued performance and applicability. Therefore, the NRC staff examined the neutronic methods in two areas most likely to be stressed by application to an extended burnup range: (1) accuracy in predicting buildup and depletion of major uranium and plutonium isotopes and (2) capability of modeling increased critical boron concentrations.

Regarding uranium and plutonium isotopes, the concentrations of these isotopes change with burnup, and accurate prediction is indicative of appropriate generation of cross-sections and other nuclear data necessary for downstream methods. The NRC staff examined the isotopic concentration (buildup and depletion) validation bases of the PARAGON and PHOENIX-P codes, as presented in WCAP-16045-P-A and WCAP-11596-P-A, respectively. Isotopic concentration validation for both codes was performed using Saxton and Yankee Rowe isotopic data for actinides. The NRC staff noted that for many of the isotopes assessed in the validation bases, both codes reasonably predict the isotopic concentrations across the available rod-average burnup range (approximately **[ ]**) with no obvious biases or trend in increasing uncertainty. The NRC staff noted that for several isotopes (**[ ]**), there appears to be **[ ]** However, the available data is too limited to determine whether this is a consistent outlier or the beginning of a trend. The NRC staff requested additional information to discern the nature of a possible trend in RAI-10.

Westinghouse's response to RAI-10 provided additional validation ranging from the extent of the existing validation bases' burnup range to **[ ]** These additional results indicate there is no **[ ]** and the quantified uncertainty is consistent with that of the original validation data. While the available data does not bound the requested rod-average burnup extension limit, the NRC staff finds the consistency in the data up through the provided burnup range is sufficient to conclude the codes will continue to reasonably predict isotopic concentrations of these actinides for the requested burnup range of interest (i.e., **[ ]** rod-average burnup). This is because the determination of isotopic concentrations in these codes is effectively a tallying of production and removal through various nuclear reactions (e.g., fission, absorption, decay, etc.) based on generated cross-sections and decay constants obtained from raw nuclear data; errors inherent in this tallying process or cross-section generation scheme would have cumulative effects with accumulated burnup that will manifest as an observable trend of increasing predictive uncertainty. Such a trend has not been identified. Therefore, based on the discussion above, the NRC staff finds Westinghouse's response acceptable.

Concerning critical boron concentrations, in developing a core design capable of achieving individual rod-average burnups of **[ ]** it is expected that the core-average enrichment will increase slightly, resulting in additional excess reactivity. There are numerous ways to hold down excess reactivity in a core. These include soluble boron and various burnable absorbers designs. Presence of these neutron absorbers will affect core performance and may affect the predictive capability of neutronics codes such as PARAGON and PHOENIX-P, the validation basis for which includes limited data for critical boron concentrations up to 3392 ppm. The NRC staff inquired in RAI-9 whether significant changes to the critical boron concentration will be required to accommodate the above nuclear design changes. Westinghouse responded by indicating that slight variations in critical boron concentrations are expected but will be within current cycle-to-cycle variations. Westinghouse's response also identified that the maximum critical boron concentration of any core design is limited by chemistry considerations, as well as the minimum required boron concentrations in safety systems and the moderator temperature coefficient, which are limited by TS. Without changes to TS, Westinghouse stated that current reactor coolant system boron concentrations will remain largely unchanged. Effectively, Westinghouse's response indicates (1) it does not anticipate a significant change in critical boron concentration, and (2) it believes the PARAGON and PHOENIX-P codes have sufficient capability to analyze the expected ranges of critical boron concentration to support the application scope of WCAP-18446-P/WCAP-18446-NP, Revision 0. The NRC staff finds Westinghouse's response to be reasonable for the following reasons. First, the chemistry and TS considerations mentioned in Westinghouse's response help establish limits on allowable boron concentrations to preclude undesirable operating conditions from occurring (e.g., positive moderator temperature coefficient, insufficient shutdown margin, possible boron precipitation during postulated design-basis events, etc.). Second, should the development of a core design demonstrate the need for critical boron concentrations in a range outside that of current core designs, this would necessitate (as identified by Westinghouse) changes to plant TS and/or changes to the approved ranges of PARAGON and PHOENIX-P, which would require NRC review and approval.

In further support of the continued applicability of existing approved neutronic methods, Westinghouse provided comparisons of example core designs to illustrate the **[**

**]** rod-average burnup core designs. These comparisons are presented in Section 3.2.3, "Example Nuclear Designs," and Section 3.2.4, "Similarity to Current Nuclear Designs," of WCAP-18446-P/WCAP-18446-NP, Revision 0. These comparisons are also provided to illustrate anticipated fuel management strategies.

The NRC staff examined the comparisons in Section 3.2.3 and Section 3.2.4 of WCAP-18446-P/WCAP-18446-NP, Revision 0, when performing the assessments of the neutronic codes discussed above. While the comparisons are of different simulations as opposed to code-to-code comparisons against higher-order methods, they do serve to illustrate the performance behavior of the neutronic codes when designing higher burnup cores and whether the results are consistent with the expected behavior of higher burnup cores. In particular, the NRC staff notes **[**

**]** This is expected. The NRC staff also noted **[**

**]** which is also an expected result due to the **[**

**]** Given the consistency of the simulated core behavior with the expected behavior of higher burnup cores designed within the constraints imposed by the Westinghouse methodology, the NRC staff has additional confidence in the Westinghouse nuclear design codes.

*Conclusions Regarding Nuclear Design Methods*

Based on the discussion provided above, the NRC staff finds the Westinghouse nuclear design codes PARAGON, PHOENIX-P, and ANC are applicable to core nuclear designs within the scope of the methodology presented in WCAP-18446-P/WCAP-NP, Revision 0.

### 3.2.3 Thermal-Hydraulic Design

Section 3.3 of WCAP-18446-P/WCAP-18446-NP, Revision 0, describes the applicability of Westinghouse's thermal-hydraulic (T/H) design methods at higher burnup. The T/H design methods include DNB correlations, subchannel codes, statistical methods for determining the DNB ratio (DNBR) limit, rod bow penalties, and T/H analyses as inputs for transient analysis methodologies. A complete list of the referenced TRs is found in Section 3.3 of the TR.

Westinghouse asserts that its T/H codes and methods are applicable at higher burnups with no changes necessary. This is due to the limited impact of burnup on DNB correlations. DNB correlations used by PWRs are primarily dependent on local coolant conditions, rod power, and rod bow. Local T/H conditions relevant to DNB prediction, including pressure, flow, quality, and heat flux, are not explicitly dependent upon burnup. Small dimensional changes to coolant channels, such as due to rod bow, can affect the coolant conditions, as discussed later in this section. WCAP-18446-P/WCAP-18446-NP, Revision 0, only permits extended burnup assemblies to be loaded in the core periphery, where the relative assembly power is low. By limiting extended burnup assemblies in power, these assemblies will not be limiting with respect to many acceptance criteria, including DNB.

Fuel rod bowing is burnup-dependent and potentially reduces the flow area between adjacent fuel rods, making the rods more susceptible to DNB. Rod bowing is accounted for by incurring a burnup-dependent DNBR penalty. The burnup-dependence of the rod bow DNBR penalty is only significant up to the maximum burnup of the first cycle, about 33 GWD/MTU, when the assembly power is typically highest. Beyond this burnup, the credit taken for lower assembly power typically outweighs the rod bow penalty. Therefore, an increase in maximum assembly burnup affecting only extended burnup assemblies on the core periphery will have no effect on the rod bow DNBR penalty.

DNB propagation is a phenomenon in which a fuel rod experiencing DNB balloons due to high cladding temperature and rod internal pressure. The ballooned cladding reduces the surrounding flow area, causing adjacent rods to also experience DNB. The acceptance criterion for Westinghouse's DNB propagation methodology is independent of burnup. DNB propagation is not expected to be a concern with the extended burnup assemblies allowed under WCAP-18446-P/WCAP-18446-NP, Revision 0, because extended burnup assemblies are limited to locations on the core periphery where they will not be DNB-limiting.

*Conclusions Regarding Thermal-Hydraulic Design*

The NRC staff has determined that Westinghouse's T/H codes and methods are applicable up to the requested rod-average burnup extension limit because the DNB correlation and DNBR determination methodology are largely independent of burnup, the rod bow DNBR penalty methodology is limited by fuel rods within existing burnup limits with higher rod powers, and the fact that DNB is not expected to occur in low-power peripheral assemblies during any non-LOCA event. Furthermore, Westinghouse will **[**

**]**

## 3.3 Loss-of-Coolant Accident Analysis Methods

Section 4 of WCAP-18446-P/WCAP-18446-NP, Revision 0, describes Westinghouse's proposed methodology for analyzing fuel operating in the incremental burnup range (i.e., a rod-average burnup range between 62 GWd/MTU and **[ ]**) for the spectrum of postulated LOCAs.

The NRC staff's evaluation of Westinghouse’s proposed methodology for addressing the impacts of increased fuel burnup on the postulated LOCA addresses the following topics:

- An introduction to fuel fragmentation, relocation, and dispersal (FFRD) during a postulated LOCA
- Westinghouse’s proposed treatment of FFRD during a postulated LOCA
- Regulatory considerations associated with fuel rods in the extended burnup region
- Westinghouse’s proposed adaptations to existing physical models within its LOCA methodologies to address fuel rods in the extended burnup region
- Westinghouse’s proposed methodology for confirming non-rupture of fuel rods in the incremental burnup range during a LOCA
- A demonstration analysis Westinghouse performed to illustrate application of the proposed methodology for confirming non-rupture of fuel rods in the incremental burnup range

Each of these topics is discussed below in the following sections of this SE.

### 3.3.1 Fuel Fragmentation, Relocation, and Dispersal During a Postulated LOCA

The behavior of standard fuel designs incorporating uranium dioxide pellets at low-to-moderate burnups has been studied extensively under both normal operation and accident conditions. For instance, the potential for fuel pellets to experience cracking under operating conditions, and for these cracked pieces of the pellet to reorient has long been recognized. Additionally, as discussed in a 1983 report published by Kernforschungszentrum Karlsruhe (KfK) (Reference 33), experiments performed at a German research reactor using irradiated fuel pellets with burnup values up to 35 GWd/MTU demonstrated a potential for fragmentation at or around the time of rod burst during a simulated LOCA heatup transient.

In light of relevant information available in 2015, the NRC staff identified in SECY-15-0148, “Evaluation of Fuel Fragmentation, Relocation and Dispersal Under Loss-of-Coolant Accident (LOCA) Conditions Relative to the Draft Final Rule on Emergency Core Cooling System Performance During a LOCA (50.46c)” (Reference 34), no imminent safety concern with respect to operation at fuel burnups less than or equal to 62 GWd/MTU. However, SECY-15-0148 identified the potential for fuel to become increasingly susceptible to FFRD at burnups beyond 62 GWd/MTU, further noting that advancements in fuel design or fuel management strategies could affect FFRD susceptibility. SECY-15-0148 stated that, as needed, future regulatory action could be initiated if information is developed that would motivate the adoption of additional requirements to address FFRD.

More recently, according to Research Information Letter (RIL) 2021-13, “Interpretation of Research on Fuel Fragmentation, Relocation, and Dispersal at High Burnup” (Reference 35), significant attention on FFRD phenomena was spurred by a test intended to simulate high-burnup fuel under LOCA conditions. In test IFA-650.4, performed at the Halden reactor in 2006, significant FFRD was observed on a rodlet with an average burnup of over 90 GWd/MTU. Subsequently, continued additional testing regarding FFRD phenomena has been conducted by both the NRC and the international reactor safety community, and test results available at its time of publication (i.e., December 2021) are summarized in RIL 2021-13.

While recognizing the complexity of the underlying phenomena and associated limitations in the present understanding thereof, RIL 2021-13 identifies simple, conservative, empirical thresholds based on the conservative interpretations at which FFRD phenomena have been experimentally observed, namely:

- Fine fuel fragmentation is observed to begin at approximately 55 GWd/MTU pellet-average burnup

- Fuel relocation is observed to begin at a cladding strain of approximately 3 percent

Maintaining cladding integrity under conditions where fuel fragmentation and dispersal could occur is one means to obviate a detailed analysis of these phenomena and their downstream impacts on plant equipment relied upon for the protection of public health and safety.

### 3.3.2 Overview of Westinghouse's Proposed Treatment of FFRD in a LOCA

Westinghouse states in Section 4.2.3 of WCAP-18446-P/WCAP-18446-NP, Revision 0, that the simplest approach for addressing problematic impacts of FFRD on safety analyses is to preclude fuel dispersal. By maintaining fuel rods in the incremental burnup range at sufficiently low power levels, Westinghouse seeks to demonstrate to a high level of confidence that its cladding will not burst during postulated events. The specific approach Westinghouse proposes in WCAP-18446-P/WCAP-18446-NP, Revision 0, for the LOCA event would confirm the non-rupture of fuel rods with rod-average burnups in the incremental burnup range of 62 GWd/MTU – **[** **]** using a version of the FULL SPECTRUM LOCA™ (FSLOCA™) evaluation model (Reference 36) that has been modified as described in Section 4 of WCAP-18446-P/WCAP-18446-NP, Revision 0, and which is evaluated in Section 3.3.4 of this SE.

Two key points are evident from the discussion thus far:

- The approach proposed by Westinghouse does not address FFRD over the full range of susceptible burnups defined in RIL 2021-13.

- The gap between the lower burnup threshold addressed in WCAP-18446-P/WCAP-18446-NP, Revision 0 (i.e., rod-average burnup of 62 GWd/MTU) and the burnup threshold for fuel fragmentation identified in RIL 2021-13 (pellet-average burnup of 55 GWd/MTU) is larger than it appears because of the different axial extents over which the burnup is averaged.

The NRC staff's review of the methodology presented in WCAP-18446-P/WCAP-18446-NP, Revision 0, included potential impacts of the use of incremental burnup fuel on the dispersal of fuel below the burnup range requested in the topical report. With respect to the potential for fuel dispersal at rod-average burnups less than 62 GWd/MTU, in its response to RAI 26, Westinghouse provided example calculations suggesting that, for typical input values representative of PWRs, the currently existing potential for fuel dispersal in the event of a LOCA occurring near the end of a fuel cycle **[**

**]**

The proposed analysis methodology and associated NRC staff evaluation only addresses fuel dispersal in the requested burnup range. Demonstration of compliance with 10 CFR 50.46 requires analysis of all the fuel assemblies in the core, regardless of burnup. Therefore, fuel assemblies with a burnup less than 62 GWd/MTU will continue to require analysis to demonstrate compliance with applicable rules and regulations. Licensees may utilize current approved methodologies to evaluate fuel assemblies for burnups up to 62 GWd/MTU.

While RIL 2021-13 identified 55 GWd/MTU as a threshold for the onset of fine fragmentation which could result in fuel dispersal in the event of clad failure of sufficient size, it did not thoroughly discuss the consequences of fuel dispersal. Due in part to the information provided by RIL 2021-13, the NRC staff have convened a Phenomena Identification and Ranking Table (PIRT) panel to investigate the impacts of fuel dispersal, which is expected to complete in the spring of 2024. This PIRT is intended to better understand the potential impacts and state of knowledge of fuel dispersal and to potentially guide future research efforts as needed to better understand the related phenomena. Since this PIRT is focused on the impacts of fuel dispersal regardless of burnup, the results could potentially be of interest for all fuel greater than 55 GWd/MTU local burnup. If the NRC identifies information as a result of this research that challenges the current NRC position that fuel dispersal is not a significant safety issue for burnups below 62 GWd/MTU, then the NRC will take appropriate regulatory action regarding methodologies currently approved for these burnups.

Since the methodology presented in WCAP-18446-P/WCAP-18446-NP, Revision 0, precludes fuel cladding failure to a **[** **]** in the 62 GWd/MTU – **[** **]** burnup range, it is not expected for the conclusions of the PIRT (and any related follow-up research efforts) to conflict with the staff's findings related to WCAP-18446-P/WCAP-18446-NP, Revision 0. It should be noted that the NRC staff's approval of WCAP-18446-P/WCAP-18446-NP, Revision 0 does not imply any consideration about the acceptability of fuel dispersal for fuel cladding below 62 GWd/MTU peak rod average burnup, only that the use of incremental burnup fuel **[**

**]**

### 3.3.3 Regulatory Considerations Associated with Extended Burnup Region

In Section 4.2.1 of WCAP-18446-P/WCAP-18446-NP, Revision 0, Westinghouse explains its strategy for determining compliance with the requirements of 10 CFR 50.46 for fuel in the extended burnup range. In particular, Westinghouse stated as follows that the **[**

**]**

- (b)(1) peak cladding temperature
  Referencing as a basis its FSLOCA TR (Reference 36), Westinghouse stated that fuel assemblies with **[** **]** Westinghouse further stated in WCAP-18446-P/WCAP-18446-NP, Revision 0, that the cladding temperature **[** **]**

**[**

**]**

- (b)(2) maximum local oxidation
  Westinghouse stated that a **[**
  **]** for similar reasons to those expressed above for peak cladding temperature. In particular, Westinghouse stated that fuel rods in the extended burnup region would **[**
  **]**

- (b)(3) core-wide oxidation
  Similarly to the discussion for maximum local oxidation, Westinghouse stated that the **[**
  **]** Westinghouse further stated that the calculation of core-wide oxidation in analyses performed using the FSLOCA evaluation model is generally calculated under the conservative assumption that **[**
  **]**

- (b)(4) coolable core geometry
  Westinghouse stated that a coolable core geometry is ensured by compliance with acceptance criteria (b)(1) and (b)(2), and conservatively accounting for grid deformation due to combined seismic and LOCA loads for inboard (i.e., non-peripheral) fuel assemblies.

- (b)(5) long-term cooling
  Westinghouse stated that the proposed incremental burnup extension does not impact the methodology used for demonstrating adequate long-term core cooling.

Considering the characteristics of existing reactor core and fuel designs to which the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology is applicable, the NRC staff finds Westinghouse's argument reasonable that **[**

**]** Nevertheless, the NRC staff notes that the methodology applied by Westinghouse will explicitly compute values for the cladding temperature and oxidation for each node of rods simulating fuel in the incremental burnup range. While Westinghouse has not defined these outputs as **[** **]** for the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology, implementation of the WCAP-18446-P/WCAP-18446-NP, Revision 0, would not exempt licensees from the requirement to satisfy the 10 CFR 50.46 acceptance criteria for fuel in the extended burnup range. Therefore, any calculated failure to satisfy 10 CFR 50.46 acceptance criteria would remain unacceptable, irrespective of whether cladding rupture has been calculated to occur. Furthermore, in addition to the discussion Westinghouse provided for acceptance criterion (b)(4), the NRC staff further considers the assurance of cladding non-rupture to be an effective approach for the prevention of fuel dispersal, which helps support a conclusion that the requirement for maintaining coolable core geometry in 10 CFR 50.46(b)(4) is satisfied.

Originally, Westinghouse had proposed, based upon engineering insights, that **[** **]** should be evaluated using the methodology in WCAP-18446-P/WCAP-18446-NP, Revision 0. However, in response to RAI 13, Westinghouse proposed a modified approach stipulating the performance of independent cladding rupture calculations for conditions with **[** **]** The NRC staff found Westinghouse's modified approach consistent with the approach the NRC staff accepted in its review of the FSLOCA evaluation model in WCAP-16996-P-A, Revision 1. In that review, as well as the present review, the NRC staff found that **[** **]** would satisfy the requirement expressed in GDC 35 that abundant emergency core cooling be provided for scenarios involving either only onsite or only offsite electrical power availability. Originally, Westinghouse had also proposed **[** **]** incorporated conservatisms, as identified in RAI 12, the approach did not appear to be fully consistent with 10 CFR 50.46(a)(1) in that it could neither be considered realistic with accounting for uncertainty or in conformance with Appendix K to 10 CFR Part 50. In response to RAI 12, Westinghouse elected to **[** **]** from WCAP-18446-P/WCAP-18446-NP, Revision 0. The NRC staff found **[** **]** to be an acceptable means for satisfying 10 CFR 50.46(a)(1). **[** **]** further resolved the NRC staff's request in RAI 18 that Westinghouse provide adequate evidence of the **[** **]**

In Section 4.2.2 of WCAP-18446-P/WCAP-18446-NP, Revision 0, Westinghouse explains its position concerning how the proposed methodology would address compliance with the acceptance criteria in the proposed 10 CFR 50.46c rulemaking (Reference 37). While the NRC staff considered research findings associated with the proposed 50.46c rulemaking in evaluating the proposed methodology against the applicable acceptance criteria in 10 CFR 50.46, the NRC staff did not evaluate the proposed methodology against the actual acceptance criteria in the proposed 50.46c rule. The 50.46c rule remains under deliberation by the Commission, and its acceptance criteria are not in effect at the present time. Because Westinghouse proposed the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology as a means to determine compliance with the acceptance criteria in proposed rule 10 CFR 50.46c, the acceptability of which is not evaluated in this SE, the NRC staff has introduced Limitation and Condition 11, which stipulates that this SE has neither evaluated nor approved WCAP-18446-P/WCAP-18446-NP, Revision 0, as a method for determining compliance with the acceptance criteria in proposed rule 10 CFR 50.46c.

While the NRC staff did not evaluate the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology with respect to satisfying the requirements of the proposed 10 CFR 50.46c rulemaking, as discussed in RAI 25, the NRC staff did request that Westinghouse address how research findings described within the 10 CFR 50.46c rulemaking have been factored into Westinghouse's conclusion that existing requirements in 10 CFR 50.46 have been satisfied. In particular, the 10 CFR 50.46c rulemaking package discusses research findings associated with the potential for degraded cladding performance during a LOCA due to several mechanisms that may not be adequately accounted for in existing evaluation models, including hydrogen-enhanced beta-layer embrittlement, cladding inner diameter oxygen ingress, and breakaway oxidation. If not accounted for adequately, these potential degradation mechanisms could impact the ability of a licensee to demonstrate compliance with the coolable core geometry requirement in 10 CFR 50.46(b)(4).

In response to RAI 25, Westinghouse provided an extended discussion that is summarized in the bulleted list below:

- The research findings supporting the 10 CFR 50.46c rulemaking were addressed for fuel in the extended burnup range in Section 4.2.2 of WCAP-18446-P/WCAP-18446-NP, Revision 0, TR and in its voluntary submittal from May 2021 (Reference 4). The WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology requires that fuel assemblies in this category be placed at peripheral core locations. As discussed in Section 4.2.2 of WCAP-18446-P/WCAP-18446-NP, Revision 0, Westinghouse stated that,

    - Cladding embrittlement concerns are minimized for fuel in the extended burnup region because, as discussed above, these fuel rods are not expected to **[** **]** during the LOCA heatup transient.

    - Oxygen ingress concerns are minimized for fuel in the extended burnup region because, as discussed in Section C.3.B of Draft RG 1.224, an acceptable approach to account for oxygen ingress is to use twice the oxidation on the exterior of the cladding for unruptured cladding locations for fuel with a local exposure exceeding 30 GWd/MTU. As discussed above, because the **[** **]** would be expected during a LOCA.

    - Breakaway oxidation concerns are minimized for fuel in the extended burnup region because the **[** **]**

- No additional action is necessary for fuel in the core that complies with existing burnup limits because reactor core designs involving fuel in the proposed extended burnup region would be **[** **]** Fuel assemblies operating within existing burnup limits may be placed at the core interior. For such assemblies, Westinghouse stated that fuel rod initialization assures that the parameters of importance for analyzing the LOCA event are conservatively treated. For example, Westinghouse included Figures 3.2-1 through 3.2-8 in WCAP-18446-P/ WCAP-18446-NP, Revision 0, which illustrate the impact of the proposed incremental burnup extension on core designs Westinghouse deemed representative. Westinghouse stated that no significant increase in **[** **]** (other than the core center assembly, which would be precluded from hosting an extended burnup assembly by the restriction Westinghouse subsequently imposed in its May 2021 voluntary supplement (Reference 4)).

    Westinghouse further stated that **[** **]** cited in Westinghouse's May 2021 voluntary supplement (which Westinghouse intends to incorporate as Section 3.2.4 of WCAP-18446-P/WCAP-18446-NP, Revision 0) include (1) an enrichment limit of 5 weight percent uranium-235, (2) the limitation requiring placement of fuel assemblies exceeding current burnup limits on the core periphery, and (3) **[** **]**

> Westinghouse formally incorporated the first two of these constraints as limitations on the methodology in Section 7.1 of WCAP-18446-P/WCAP-18446-NP, Revision 0.

Based upon information summarized above, Westinghouse concluded that its proposal to permit operation with fuel in the extended burnup range, in accordance with WCAP-18446-P/ WCAP-18446-NP, Revision 0, and incorporated limitations, would not exacerbate the potential for the identified degradation mechanisms to affect compliance with 10 CFR 50.46.

The NRC staff agrees with the conclusions Westinghouse drew from the evidence discussed above in its response to RAI 25, both for peripheral fuel assemblies in the extended burnup region and for fuel assemblies operating within existing burnup limits that may be placed in interior core positions. For peripheral assemblies, the NRC staff agrees that the non-limiting conditions experienced during the LOCA heatup transient would limit the potential for the identified degradation mechanisms to contribute to unacceptable cladding failure modes. For fuel assemblies operating within existing burnup limits that may be placed in interior core positions, the NRC staff considers the analysis performed by Westinghouse to provide reasonable assurance that future core designs following the proposed incremental burnup extension will **[** **]** The NRC staff further notes that Westinghouse included limitations in the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology to ensure that the effective core design constraints on fuel enrichment and fuel assembly placement necessary to provide confidence in this conclusion will be maintained. As such, the NRC staff finds that Westinghouse has acceptably addressed the research findings referred to in RAI 25 that are associated with the 10 CFR 50.46c rulemaking for the purpose of demonstrating compliance with existing regulatory requirements in 10 CFR 50.46.

### 3.3.4 Proposed Evaluation Model Updates for Analyzing Fuel in Extended Burnup Region

Regarding the evaluation of fuel in the extended burnup region, Westinghouse recognized the need for certain updates to its existing calculational approaches, affecting both analytical models and the associated analysis procedures. In particular, WCAP-18446-P/ WCAP-18446-NP, Revision 0, describes a new evaluation model for analyzing extended-burnup fuel that is based on Westinghouse's most advanced LOCA evaluation model, the FSLOCA evaluation model. The modifications to this method described in WCAP-18446-P/WCAP-18446-NP, Revision 0, apply solely to the analysis of fuel in the extended burnup region and do not affect the approved FSLOCA evaluation model described in WCAP-16996-P-A, Revision 1 (Reference 36).

As discussed in Section 3.1 of WCAP-16996-P-A, the FSLOCA evaluation model is served by the system thermal-hydraulic code WCOBRA/TRAC-TF2. The WCOBRA/TRAC-TF2 code models two-phase flow with a three-field approach (i.e., gas, continuous liquid, and entrained liquid). The code applies four continuity equations (i.e., including non-condensable gas), three momentum equations, and two energy equations (i.e., the continuous and entrained liquid fields are assumed to be in thermal equilibrium). The WCOBRA/TRAC-TF2 system code further incorporates the capability to model the vessel component with a subchannel formulation.

Additionally, as discussed in the executive summary of WCAP-16996-P-A, the fuel performance data input to the WCOBRA/TRAC-TF2 code for the FSLOCA evaluation model will be from the PAD5 code, which ensures that known impacts of thermal conductivity degradation and other phenomena are incorporated.

### 3.3.4.1 Incorporation of Approved Fuel Performance Methods in Safety Analyses

While the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology requires fuel-related inputs from the PAD5 fuel performance code, some licensees' existing analyses of the LOCA event may currently rely upon legacy or ad hoc interim methods for determining fuel-related inputs. To account for the effects of increased fuel burnup rigorously, Westinghouse committed in its proposed Limitation 7 in Section 7.1 of WCAP-18446-P/WCAP-18446-NP, Revision 0, to incorporate modern PAD5 models and methods into the plant-specific licensing basis for most fuel and safety analysis. However, Westinghouse permitted an exception for existing LOCA analysis, which, due to concerns, the NRC staff requested additional justification for in RAI 28.b.

In response to RAI 28.b, Westinghouse justified Limitations 7's proposed exclusion of the LOCA analysis from the requirement to use PAD5 for fuel-related inputs by stating that the analysis to be performed using the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology is **[**

**]** Westinghouse stated that, with respect to thermal conductivity degradation, initial assessments were provided by affected licensees pursuant to 10 CFR 50.54(f). Westinghouse further stated that licensees using Westinghouse LOCA evaluation models have since incorporated thermal conductivity degradation into their licensing basis analyses in accordance with requirements of 10 CFR 50.46(a)(3) via various approaches (e.g., the 10 CFR 50.46 reporting process, application of plant-specific evaluation models, or adoption of generically approved methods incorporating corrections for thermal conductivity degradation, such as the FSLOCA evaluation model). Westinghouse observed that one of the ad hoc interim approaches used by licensees, a version of the PAD4 code with a modification to activate modeling of thermal conductivity degradation (i.e., PAD4+TCD) **[**

**]**

The NRC staff's review of Westinghouse's response to RAI 28.b considered that the interim approaches implemented by licensees provided assurance that the imposition of additional near-term regulatory measures was not necessary to address the thermal conductivity degradation issue described in several NRC information notices issued from 2009 to 2012 (Reference 38), (Reference 39), (Reference 40). However, these interim approaches, some of which have now been in place for over a decade, have generally not undergone formal review and approval as providing acceptable modeling of thermal conductivity degradation and the full range of fuel performance issues that could affect the LOCA and other postulated events. Therefore, the NRC staff did not incorporate into Limitation and Condition 7 of this SE the exception that Westinghouse had proposed adding for the LOCA. As a result, licensees implementing the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology must include the LOCA among the set of analyzed events for which fuel-related inputs will be provided by PAD5, absent acceptable plant-specific justification for alternative approaches to be supplied during the implementation review for the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology.

### 3.3.4.2 Phenomena Relevant to Burnup Extension

As described in Section 4.3 of WCAP-18446-P/WCAP-18446-NP, Revision 0, Westinghouse assessed phenomena relevant to the analysis of fuel in the extended burnup region by considering the results of two PIRT exercises:

- the Westinghouse PIRT supporting the FSLOCA evaluation model in Section 2.3 of WCAP-16996-P-A, Revision 1 (Reference 36)

- an NRC-sponsored PIRT documented in NUREG/CR-6744 (Reference 41) and NUREG-1749 (Reference 42)

Considering the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology's objective of demonstrating non-rupture of cladding, Westinghouse's assessment of previous LOCA PIRTs focused upon phenomena associated with the fuel rod and core. Westinghouse stated that many of these fuel- and core-related phenomena from previous LOCA PIRTs would apply to calculations associated with cladding rupture, but that some phenomena may be of more (or less) direct importance. Relevant phenomena from the two PIRTs Westinghouse considered are identified and discussed below in Table 1 and Table 2. The goal of Westinghouse's assessment of these phenomena was to determine whether existing analytical code models are adequate to support the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology or whether model improvements would be necessary. The NRC staff has included an evaluation of Westinghouse's approach for each item in these tables, frequently via reference to other sections of this SE.

Table 1: PIRT Phenomena from WCAP-16996-P-A, Revision 1,
Considered in WCAP-18446-P/WCAP-18446-NP, Revision 0

| Phenomenon | Disposition |
|---|---|
| Fuel Rod | |
| Stored energy | Westinghouse stated that in the FSLOCA evaluation model, fuel conductivity is modeled as **[** **]** Westinghouse stated that stored fuel energy is important to the methodology for calculating cladding rupture in WCAP-18446-P/WCAP-18446-NP, Revision 0, and that the approach is discussed in Section 4.7.3.2.1 of the TR. The NRC staff agrees with Westinghouse's conclusion that stored energy has an important influence on cladding rupture through its effect on cladding temperature, among other things. As discussed below in Sections 3.3.4.3 and 3.3.5.3 of this safety evaluation, the NRC staff found Westinghouse's modeling of parameters significant to the determination of stored energy to be acceptable within the context of the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology. |

| Phenomenon | Disposition |
|---|---|
| Cladding oxidation | Westinghouse stated that while cladding oxidation is generally highly important for LOCA analysis, it is **[** **]** described in WCAP-18446-P/WCAP-18446-NP, Revision 0, because **[** **]** for fuel rods in the extended burnup region. As discussed above in Section 3.3.3, the NRC staff found Westinghouse’s arguments concerning high-temperature cladding oxidation to be reasonable within the context of the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology.<br>With regard to oxidation arising from pre-transient corrosion, Westinghouse stated that approved corrosion models determined to **[** **]** for ZIRLO and Optimized ZIRLO cladding have been incorporated into the PAD5 code. As discussed in Section 3.1 of WCAP-18446-P/WCAP-18446-NP, Revision 0, Westinghouse determined that no updates are required to the modeling approaches used in PAD5. As discussed above in Section 3.2.1.5, the NRC staff found Westinghouse’s proposed modeling approach for pre-transient corrosion of ZIRLO and Optimized ZIRLO to be acceptable within the context of the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology. |
| Decay heat | Westinghouse stated decay heat is a significant energy source that influences the cladding heatup rate. The decay heat model in the WCOBRA/TRAC-TF2 code is derived from the ANSI/ANS 5.1-1979 standard (Reference 43). Westinghouse identified that the proposed incremental burnup extension would apply the decay heat model beyond the range for which it had previously been validated and addressed the issue in Section 4.6 of WCAP-18446-P/WCAP-18446-NP, Revision 0. As discussed below in Section 3.3.4.5, the NRC staff found Westinghouse’s proposed modeling approach for decay heat during a LOCA to be acceptable within the context of the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology. |
| Cladding deformation | Westinghouse stated that the modeling of cladding deformation and rupture are highly important for the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology. Westinghouse identified that cladding deformation can affect thermal-hydraulic conditions in the channel(s) surrounding a fuel rod (e.g., cladding swelling can lead to flow area obstruction and flow redirection) as well as affecting conditions inside the fuel rod (e.g., rod internal pressure). Westinghouse discussed cladding deformation and rupture models in Sections 4.4.2 and 4.4.3 of WCAP-18446-P/WCAP-18446-NP, Revision 0. As discussed below in Section 3.3.4.3, the NRC staff found Westinghouse’s proposed modeling approach for cladding deformation to be acceptable within the context of the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology. |
| Core | |
| Critical heat flux | Westinghouse stated that the WCOBRA/TRAC-TF2 code has been assessed against experimental critical heat flux data and demonstrated to **[** **]** As such, Westinghouse concluded that **[** **]** As discussed above in Section 3.2.3, the NRC staff found Westinghouse’s proposed modeling approach for critical heat flux (also referred to as DNB) to be acceptable within the context of the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology. |

| Phenomenon | Disposition |
|---|---|
| Post-critical-heat-flux heat transfer/Steam cooling | Westinghouse stated that its proposal to operate with fuel in the extended burnup region is not expected to significantly affect heat transfer behavior. Westinghouse stated that this heat transfer behavior is **[** **]** The NRC staff agrees with Westinghouse's assessment of phenomenon importance; while the thickness of the oxide layer may increase with burnup, **[** **]** are not expected to vary significantly. |
| Rewet/$T_{min}$ | Westinghouse stated that, as discussed in Section 29.1.8 of WCAP-16996-P-A, Revision 1, the FSLOCA evaluation model **[** **]** The NRC staff agrees with Westinghouse's assessment of phenomenon importance; while the thickness of the oxide layer may increase with burnup, **[** **]** are not expected to vary significantly. |
| Heat transfer to a covered core | Westinghouse stated that heat transfer to a covered core does not impact the PIRT rankings for the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology because cladding rupture for fuel in the extended burnup region would not occur when the core is covered. The NRC staff agrees with Westinghouse's determination of phenomenon importance, while noting that the fact that rupture would not occur during core coverage does not immediately imply a lack of significance. Nevertheless, considering the arguments discussed above concerning **[** **]** the NRC staff agrees that the importance of heat transfer to a covered core is not expected to vary significantly. |
| Radiation heat transfer | Westinghouse stated that the PIRT rankings and treatments associated with radiation heat transfer are not affected by the proposed incremental burnup extension. The NRC staff agrees with Westinghouse's assessment of phenomenon importance; while the thickness of the oxide layer may increase with burnup, the **[** **]** important to radiation heat transfer are not expected to vary significantly. |
| 3-D flow/<br>Core natural circulation | Westinghouse stated that the effects of multidimensional flow are captured by the core nodalization scheme, which uses separate assembly groupings to model the radial flow distribution in the core. Westinghouse stated that for cladding rupture calculations, a bounding approach is used to define the initial condition for fuel rods of interest, as discussed in Section 4.7.3.2.1 of WCAP-18446-P/WCAP-18446-NP, Revision 0. Considering the evidence of **[** **]** presented by Westinghouse, which was evaluated above in Sections 3.2.2 and 3.3.3, the NRC staff considers it reasonable that the importance of this phenomenon would not be significantly affected by the proposed incremental burnup extension. |
| Void generation/<br>Void distribution | Westinghouse stated that the PIRT rankings and treatments associated with void generation and void distribution are not affected by the proposed incremental burnup extension. Considering the evidence of **[** **]** presented by Westinghouse, which was evaluated above in Sections 3.2.2 and 3.3.3, the NRC staff considers it reasonable that the importance of this phenomenon would not be significantly affected by the proposed incremental burnup extension. |

| Phenomenon | Disposition |
|---|---|
| Entrainment/ Deentrainment | Westinghouse stated that the PIRT rankings and treatments associated with entrainment and deentrainment are not affected by the proposed incremental burnup extension. Based upon its engineering judgment, the NRC staff considers it reasonable that the importance of this phenomenon would not be significantly affected by the proposed incremental burnup extension. |
| Flow reversal/Stagnation | Westinghouse stated that flow reversal and stagnation in the core is varied by the sampling of models in the FSLOCA evaluation model, including the break area for split breaks, break discharge coefficients, and component flow resistances. Westinghouse stated that, while the analysis of fuel in the extended burnup region does not influence flow reversal and stagnation behavior, these phenomena must be accounted for in the WCAP-18446-P/ WCAP-18446-NP, Revision 0, methodology. Westinghouse stated that Section 4.7.3.2.2 of the TR describes how the analytical approach accounts for the uncertainty in these phenomena. As discussed below in Section 3.3.5.3, when Westinghouse **[ ]** the NRC staff deemed review of the information contained in Section 4.7.3.2.2 of WCAP-18446-P/WCAP-18446-NP, Revision 0, unnecessary. Beyond this, considering the evidence of **[ ]** presented by Westinghouse, which was evaluated above in Sections 3.2.2 and 3.3.3, the NRC staff considers it reasonable that the importance of this phenomenon would not be significantly affected by the proposed incremental burnup extension. |
| Flow resistance | Westinghouse stated that, similarly to the discussion for the flow reversal and stagnation phenomenon above, while the variation of flow resistance must be accounted for, it is not affected by the extension of the method into the extended burnup region. Based upon the evidence of **[ ]** discussed above as well as its engineering judgment, the NRC staff considers it reasonable that the importance of this phenomenon would not be significantly affected by the proposed incremental burnup extension. |
| Water storage in barrel/baffle region | Westinghouse stated that the PIRT rankings and treatments associated with water storage in the barrel/baffle region are not affected by the proposed incremental burnup extension. Based upon its engineering judgment, the NRC staff considers it reasonable that the importance of this phenomenon would not be significantly affected by the proposed incremental burnup extension. |

Table 2: PIRT Phenomena from NUREG/CR-6744 and NUREG-1749
Considered in WCAP-18446-P/WCAP-18446-NP, Revision 0

| Phenomenon | Disposition |
|---|---|
| Plant Transient Phenomena | |
| Gas pressure and rod free volume | Westinghouse stated that the fuel rod initialization is based on the PAD5 fuel performance code and asserted that the WCOBRA/TRAC-TF2 models were assessed for high-burnup fuel in RAIs 36-39 associated with WCAP-16996-P-A, Revision 1. The NRC staff agrees with the importance of gas pressure and rod free volume to determining cladding rupture behavior. The NRC staff has evaluated the PAD5 models for determining fuel rod internal pressure above in Section 3.2.1.1.<br>The NRC staff found that, although revisions to the FSLOCA evaluation model during the staff's review extended its applicability to fuel beyond its first operating cycle, the previous review of WCAP-16996-P-A did not formally |

| Phenomenon | Disposition |
|---|---|
| | review and approve the WCOBRA/TRAC-TF2 models for the incremental burnup extension requested in WCAP-18446-P/WCAP-18446-NP, Revision 0. However, as discussed particularly in response to RAI 38, models exist in FSLOCA for these phenomena during the transient phase of the LOCA, and a comparison is made to results from PAD5 to ensure reasonable agreement at initialization. The most significant aspects of operation with fuel at increased burnup are thus captured in the PAD5 modeling used to initialize fuel rods prior to the transient. Therefore, the NRC staff considers Westinghouse's modeling approach to reasonably incorporate transient modeling of gas pressure and rod free volume within the context of the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology. |
| Cladding temperature | Westinghouse stated that parameters important to the calculation of cladding temperature are already captured in the FSLOCA evaluation model. As discussed further in Sections 3.3.5.3 and 3.3.5.6, the NRC staff agrees that the fuel rod cladding temperature has a significant influence on the tendency of cladding to rupture during a postulated LOCA and that the requisite models exist in the previously reviewed and accepted FSLOCA evaluation model. |
| Burst criteria | Westinghouse stated that the cladding burst criterion is highly important since it directly relates to a **[ ]** for the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology. Westinghouse described its approach for modeling cladding rupture in Section 4.4.3 of WCAP-18446-P/WCAP-18446-NP, Revision 0. The NRC staff agrees with the importance of this phenomenon to the **[ ]** considered in the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology. Westinghouse's modeling of burst criteria is discussed further below in Sections 3.3.4.3 and 3.3.5.3 of this SE. |
| Location of burst | Westinghouse stated that, while the prediction of cladding rupture is important, the particular burst location is not, since the occurrence of rupture on fuel in the incremental burnup range would not satisfy the acceptance criteria in WCAP-18446-P/WCAP-18446-NP, Revision 0. The NRC staff finds Westinghouse's rationale acceptable, since the method is intended to assure avoidance of rupture, thereby preempting the need to assess impacts of cladding rupture. |
| Time-dependent gap-size heat transfer | Westinghouse stated that it discussed an assessment of the gap conductance modeling in WCOBRA/TRAC-TF2 in Section 4.4.1 of WCAP-18446-P/WCAP-18446-NP, Revision 0, and that cladding deformation in WCOBRA/TRAC-TF2 is discussed in Section 4.4.2 of WCAP-18446-P/WCAP-18446-NP, Revision 0. The NRC staff agrees with the importance of this phenomenon for assessing cladding rupture and has documented its review of Westinghouse's approach below in Section 3.3.4.3. |
| Transient Fuel Rod Phenomena | |
| Heat resistance in the gap | Westinghouse stated that, as discussed above, gap conductance in WCOBRA/TRAC-TF2 is discussed in Section 4.4.1 of WCAP-18446-P/WCAP-18446-NP, Revision 0. The NRC staff agrees with the importance of this phenomenon for assessing cladding rupture and has documented its review of Westinghouse's approach below in Section 3.3.4.3. |
| Heat resistance in the oxide | Westinghouse stated that heat resistance in the oxide layer can increase stored energy at the onset of a LOCA, and that the associated potential for an increase in stored energy is addressed conservatively, as discussed in Section 4.7.3.2.1 of WCAP-18446-P/WCAP-18446-NP, Revision 0. The NRC staff's review found that Westinghouse has incorporated acceptable modeling of the oxide layer, including a conservative estimation of its thermal conductivity, as discussed in Section 4.2.2 of WCAP-18446-P/ WCAP-18446-NP, Revision 0, and an overall |

| Phenomenon | Disposition |
|---|---|
| | conservative treatment of stored energy, as discussed in 4.7.3.2.1 of WCAP-18446-P/WCAP-18446-NP, Revision 0. |
| Cladding oxidation magnitude | Westinghouse stated that the magnitude of cladding oxidation is of **[** **]** The NRC staff agrees with this position, as discussed above in Section 3.3.3 of this SE. Westinghouse added that the FSLOCA evaluation model further assumes that the pre-existing oxidation layer expected to be present on fuel cladding **[** **]** The NRC staff recognizes the **[** **]** as a modeling conservatism. |
| Size of burst opening | Westinghouse indicated that, because the occurrence of cladding rupture would not satisfy the acceptance criteria in WCAP-18446-P/WCAP-18446-NP, Revision 0, the specific modeling of the burst opening size would not be significant to the proposed methodology. The NRC staff finds Westinghouse's rationale acceptable since the method is intended to prevent rupture and thereby preempt the need to assess the impacts of cladding rupture. |
| Burst criteria | As discussed above, Westinghouse stated that the cladding burst criterion is highly important since it directly relates to a **[** **]** for the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology. Westinghouse described its approach for modeling cladding rupture in Section 4.4.3 of WCAP-18446-P/NP. The NRC staff agrees with the importance of this phenomenon to the **[** **]** considered in the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology. Westinghouse's modeling of burst criteria is discussed further below in Sections 3.3.4.3 and 3.3.5.3 of this SE. |
| Time of burst | Westinghouse stated that the time of burst is not significant to the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology because the occurrence of burst would represent a failure to satisfy the acceptance criteria of the proposed methodology. The NRC staff finds Westinghouse's rationale acceptable, since the method is intended to prevent rupture and thereby preempt the need to assess the impacts of cladding rupture. |

### 3.3.4.3 Fuel Rod Models in WCOBRA/TRAC-TF2

In Section 4.4 of WCAP-18446-P/WCAP-18446-NP, Revision 0, Westinghouse describes the modeling of fuel rods in the WCOBRA/TRAC-TF2 code. The fuel rod models applied by Westinghouse are intended to capture the important phenomena described in Section 4.3 of WCAP-18446-P/WCAP-18446-NP, Revision 0, and evaluated in the previous section of this SE. Section 4.4 describes five primary models that are discussed in turn below:

- pellet-to-cladding gap conductance model
- cladding deformation
- cladding rupture
- fuel rod initialization
- FGR

*Pellet-to-Cladding Gap Conductance Model*

In Section 4.4.1 of WCAP-18446-P/WCAP-18446-NP, Revision 0, Westinghouse stated that the pellet-to-cladding gap conductance model is discussed in Section 8.3.2 of WCAP-16996-P-A, Revision 1, as well as the response to part 3 of RAI 37 of that review. Because the modeling approaches in <u>W</u>COBRA/TRAC-TF2 and PAD5 **[**

**]**

In response to RAI 20, including Figures 20-1 and 20-2, Westinghouse provided additional evidence to support its finding that there is **[**

**]**

The NRC staff's review of Westinghouse's modeling of gap conductance for the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology relies significantly upon the NRC staff's previous review of Westinghouse's discussion of the modeling of gap conductance in the FSLOCA evaluation model. In particular, the NRC staff's review of WCAP-16996-P-A, Revision 1, found that Westinghouse had presented adequate evidence in its response to FSLOCA RAI 37 to demonstrate that, after calibration of the fuel average temperature to acceptably match the PAD5-calculated value, **[** **]** The NRC staff's conclusion further relies upon the additional evidence provided in Westinghouse's response to RAI 20, which demonstrated **[** **]** On this basis, the NRC staff found Westinghouse's modeling of the pellet-to-cladding gap heat conductance to be acceptable in support of calculations with the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology.

*Cladding Deformation*

Westinghouse discussed cladding deformation in Section 4.4.2 of WCAP-18446-P/WCAP-18446-NP, Revision 0. In the discussion therein, Westinghouse stated that the modeling of cladding deformation in WCOBRA/TRAC-TF2 is described in Section 8.4.1 of WCAP-16996-P-A, Revision 1, and that its modeling of cladding deformation considers both elastic and high-temperature creep deformation. Westinghouse stated that the model has been **[**

**]**

Upon consideration of the experimental results in the references from **[** **]** cited by Westinghouse, the NRC staff found that relevant physical insights have been established. However, as is typical of cladding rupture tests, the referenced experimental results contain some variability and do not necessarily provide a complete, consistent picture across all potential conditions relevant to the application of the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology. The NRC staff concludes that Westinghouse has acceptably addressed these reasonable limitations through the **[**

**]**

*Cladding Rupture*

Westinghouse discussed cladding rupture in Section 4.4.3 of WCAP-18446-P/WCAP-18446-NP, Revision 0, focusing on three primary topics: (1) the effect of hydrogen uptake in the cladding, (2) the cladding rupture models in the WCOBRA/TRAC-TF2 code, and (3) cladding deformation due to rupture.

(1) First, in Section 4.4.3.1 of WCAP-18446-P/WCAP-18446-NP, Revision 0, Westinghouse discussed how hydrogen uptake in zirconium-alloy claddings tends to **[**

**]**

**[** **]** that must be assessed against for the proposed incremental burnup extension.

As shown in Table 4.4-1 and Figures 4.4-2 through 4.4-6 of WCAP-18446-P/ WCAP-18446-NP, Revision 0, Westinghouse assessed rupture temperature data collected from experiments with ZIRLO, Optimized ZIRLO, zirconium-4, and a small amount of zirconium-2 cladding. While WCAP-18446-P/WCAP-18446-NP, Revision 0, applies only to fuel clad with ZIRLO and Optimized ZIRLO, Westinghouse **[** **]** The experiments Westinghouse considered involved cladding specimens in various conditions, including as-fabricated, pre-hydrided, and irradiated. Westinghouse stated that the database presented in WCAP-18446-P/WCAP-18446-NP, Revision 0, includes specimens with **[** **]** for zircaloy-2 and zircaloy-4, and **[** **]** for ZIRLO and Optimized ZIRLO. Westinghouse stated that the **[** **]** in the database significantly exceed the expected values associated with the incremental burnup extension, which would result in a **[** **]**

Westinghouse pared down the available data in Figure 4.4-6 of WCAP-18446-P/ WCAP-18446-NP, Revision 0, to isolate the results most relevant to fuel in the incremental burnup range. Considering this data, Westinghouse concluded that **[** **]** Westinghouse therefore considered measured data from both of these sources to be appropriate to perform validation of its modeling of cladding rupture temperature. Additionally, based upon data in Figures 4.4-7 and 4.4-8 in WCAP-18446-P/WCAP-18446-NP, Revision 0, Westinghouse concluded that the cladding rupture strain as a function of **[** **]**

The NRC staff agreed with Westinghouse's position that the potential for hydrogen embrittlement should be considered when validating cladding rupture modeling approaches to assure conservatism for fuel rods in the incremental burnup range. Based upon the physical arguments and data presented by Westinghouse in Section 4.4.3.1 of WCAP-18446-P/WCAP-18446-NP, Revision 0, the NRC staff further agreed that it is appropriate to consider rupture data from pre-hydrided and irradiated specimens for this purpose.

(2) Second, in Section 4.4.3.2 of WCAP-18446-P/WCAP-18446-NP, Revision 0, Westinghouse discussed the cladding rupture models included in the WCOBRA/TRAC-TF2 code, further citing Section 8.4.1 of WCAP-16996-P-A, Revision 1. Westinghouse stated that the database used to derive the WCOBRA/TRAC-TF2 cladding rupture model considers experiments with **[** **]** However, as discussed above, Westinghouse identified the need to validate its model against **[** **]** In performing this validation, Westinghouse recognized, as depicted in Figure 4.4-9 of WCAP-18446-P/WCAP-18446-NP, Revision 0, the potential for its correlation to **[** **]** Therefore, Westinghouse originally proposed in WCAP-18446-P/WCAP-18446-NP, Revision 0, to use a model developed by

**[**

**]**

In RAI 11, the NRC staff questioned Westinghouse’s proposed use of a **[**

**]** for determining the occurrence of cladding rupture in the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology. Under such an approach, even when Westinghouse’s proposed model were to predict no fuel rod rupture, a substantial fraction of the thousands of fuel rods in a reactor core could in fact have experienced rupture, potentially leading to a significant dispersal of fuel fragments.

Westinghouse responded to RAI 11 by alluding to the **[** **]** from the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology (as discussed above in Section 3.3.3 of this SE) and noting its desire to focus upon the proposed **[** **]** Westinghouse acknowledged that, for the FSLOCA evaluation model, which is also **[** **]** However, for WCAP-18446-P/WCAP-18446-NP, Revision 0, Westinghouse proposed **[** **]** Westinghouse stated that its revised rupture curve for WCAP-18446-P/WCAP-18446-NP, Revision 0, would **[** **]** In particular, Westinghouse pointed out that its revised curve would maintain the general trends exhibited by the **[**

**]**

The NRC staff's review found Westinghouse’s revised approach reasonable but noted that figures referred to in the RAI 11 response had not been included therein. In response to RAI 11.2, Westinghouse provided the omitted figures, further including additional experimental data for fuel rods with **[** **]** The expanded dataset better characterizes fuel rods in the incremental burnup range which may have **[** **]** Westinghouse stated in its response to RAI 11.2 that **[** **]** avoidance of which is a fuel rod design criterion. Figures 11-1 through 11-3 in Westinghouse’s response to RAI 11.2 demonstrate the **[** **]** the NRC staff finds the proposed rupture temperature curve to be acceptable for use with the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology.

(3) Third, in Section 4.4.3.3 of WCAP-18446-P/WCAP-18446-NP, Revision 0, Westinghouse discussed the modeling of cladding deformation due to rupture. In Figures 4.4-13 and 4.4-14 of WCAP-18446-P/WCAP-18446-NP, Revision 0, Westinghouse further plotted a comparison of its model predictions of the cladding circumferential strain as a function of rupture temperature. Considering that the avoidance of cladding rupture for fuel rods within the incremental burnup range is a **[** **]** for the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology, the NRC staff sought clarification in RAI 22

on the rationale for including the modeling of rupture strain within WCAP-18446-P/WCAP-18446-NP, Revision 0. In response, Westinghouse clarified that the information in Section 4.4.3.3 of WCAP-18446-P/WCAP-18446-NP, Revision 0, was included for completeness and that the modeling of cladding rupture strain is not relevant to the analysis of fuel in the incremental burnup range in accordance with the proposed methodology. Based upon Westinghouse's response to RAI 22 that the cladding rupture strain model would not be relied upon in WCAP-18446-P/WCAP-18446-NP, Revision 0, analyses, the NRC staff did not perform a technical review of, nor make a regulatory conclusion concerning, the information in Section 4.4.3.3 of WCAP-18446-P/WCAP-18446-NP, Revision 0.

*Fuel Rod Initialization*

In Section 4.4.4 of WCAP-18446-P/WCAP-18446-NP, Revision 0, Westinghouse described the process by which fuel rods are initialized. For the FSLOCA evaluation model, Westinghouse stated that fuel rods are calibrated to the **[** **]** determined by the PAD5 fuel performance code. Westinghouse further stated that **[** **]** Westinghouse observed that WCOBRA/TRAC-TF2 predictions for fuel rods with rod-average burnups between **[** **]**

The NRC staff finds it acceptable that Westinghouse follow the FSLOCA evaluation model's fuel rod initialization procedure for calculations performed with the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology. These two analysis methods have similar objectives; and, as evaluated further in Section 3.3.5.3 of this SE, the use of **[** **]** of cladding rupture, which is the relevant **[** **]** for the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology. Assuring **[** **]** further provides assurance that realistic fuel inputs are used in safety analyses.

*Fission Gas Release*

In Section 4.4.5 of WCAP-18446-P/WCAP-18446-NP, Revision 0, Westinghouse discussed its basis for concluding that the **[** **]**

In reaching this conclusion, Westinghouse considered information from tests intended to model fuel rod behavior during a postulated LOCA, including tests conducted in the **[** **]**

- [
  ]

Westinghouse further discussed LOCA simulations performed using the WCOBRA/TRAC-TF2 code for fuel rods in the incremental burnup range. For fuel rods that Westinghouse identified as [

]

In its review of Westinghouse's proposed approach for transient FGR, the NRC staff requested further information in RAI 24 on topics such as (1) Westinghouse's statements that [ ] would not occur during a LOCA, in light of the results of the demonstration analysis included in Section 4.8 of WCAP-18446-P/WCAP-18446-NP, Revision 0, and (2) the limited data supporting Westinghouse's expectation that [ ] during a LOCA.

Westinghouse responded that its position that the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology [ ] is predicated upon constraints applied to the methodology, including the restriction that fuel bundles in the incremental burnup range must be placed on the core periphery. Westinghouse's response further clarified its perspective that, while the [ ] particularly with respect to fuel rods in the incremental burnup range located on the core periphery.

In response to the NRC staff's concern about limitations in the evidence supporting an expectation of [ ] for the fuel rods to be analyzed by the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology, Westinghouse's response reiterated the representativeness of the results but further proposed to implement a limitation on [ ] in cladding rupture calculations. In its response to RAI 24, Westinghouse suggested a [

] is based on releases described in RIL 2021-13 for fuel rod segments with an [ ]

In response to additional questions the NRC staff posed in RAI 24.2, Westinghouse further justified (1) its proposed [ ] and (2) its position that transient FGR is associated primarily with temperature increases, rather than significant temperature changes (i.e., also encompassing temperature decreases).

Regarding the **[** **]** Westinghouse's response to RAI 24.2 referred to research results from Capps et al. (Reference 47), Jernkvist (Reference 48), Une, et al. (Reference 49), (Reference 50), Turnbull (Reference 51), and Yueh (Reference 52). Among the important research findings Westinghouse cited in its response are the following:

- The initial burst of transient FGR has been attributed to the overpressurization of fission gas bubbles that leads to microcracking and interlinking of bubbles in the rim region of a fuel pellet.
- **[** **]**

Westinghouse further stated that the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology focuses upon fuel rods in the incremental burnup range that are characterized by **[** **]** the fission gas bubble overpressurization and microcracking phenomena identified in the above research findings.

Regarding the potential association of transient FGR with significant reductions in fuel pellet temperature, Westinghouse acknowledged that FGR models in the current generation of industry fuel performance codes are empirical. However, Westinghouse stated that it was **[** **]**

While Westinghouse recognized that there is some test data associated with **[** **]**

In light of the physical insights and experimental results Westinghouse discussed in response to RAIs 24 and 24.2, the NRC staff found Westinghouse's proposal to **[** **]**

The NRC staff's conclusion concerning the importance of transient FGR to the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology is ultimately based in large part upon Westinghouse's proposed restriction to limit fuel assemblies in the incremental burnup range to core peripheral locations, which **[** **]**

### 3.3.4.4 Thermal Properties of Fuel Rod Materials

In Section 4.5 of WCAP-18446-P/WCAP-18446-NP, Revision 0, Westinghouse discussed the modeling of the thermal properties of fuel rod materials in the WCOBRA/TRAC-TF2 code, referencing Section 11.4 of WCAP-16996-P-A, Revision 1. In Section 4.5.1 of WCAP-18446-P/WCAP-18446-NP, Revision 0, Westinghouse further discussed a proposed change to its modeling approach for the thermal conductivity of uranium dioxide.

Westinghouse stated that the thermal conductivity model for uranium dioxide in WCOBRA/TRAC-TF2 for applications such as the FSLOCA evaluation model accounts for the effects of burnup on thermal conductivity. However, for the purpose of performing analysis in accordance with the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology, Westinghouse indicated that the **[**

**]** as per comparison plots shown in Figures 4.5-1 and 4.5-2 from WCAP-18446-P/WCAP-18446-NP, Revision 0.

The NRC staff found Westinghouse's proposed approach to **[** **]** for thermal conductivity of uranium dioxide within the WCOBRA/TRAC-TF2 code in support of applications associated with WCAP-18446-P/WCAP-18446-NP, Revision 0, to be acceptable. The NRC staff finds this approach acceptable because (1) the NRC staff has **[**

**]** Finally, as explained above in Section 3.2.1.6 of this SE, the NRC staff's question in RAI 1 concerning the potential need for a local burnup limit to assure acceptable modeling of fuel properties sensitive to local burnup conditions, such as thermal conductivity, has been acceptably addressed.

#### 3.3.4.5 Kinetics and Decay Heat Models in WCOBRA/TRAC-TF2

Section 4.6 of WCAP-18446-P/WCAP-18446-NP, Revision 0, describes the reactor kinetics and decay heat model in WCOBRA/TRAC-TF2. This model tracks the heat sources resulting from fission product decay heat, fission heat, and actinide decay heat. These heat sources are significant contributors to cladding heating and are important in determination of the peak cladding temperature during a postulated LOCA.

The WCOBRA/TRAC-TF2 decay heat model was approved only for use up to an assembly average burnup of **[** **]** for modeling of various physical parameters. Extending these models to burnups greater than that requires an additional submittal, and that justification is provided in the present TR. Westinghouse has updated the figures of various relevant parameters to include data in the range of the incremental burnup extension. The figures include data related to fission fractions, beta-effective, prompt neutron lifetime, energy release, delayed neutron precursor group half-lives, and capture-to-fission ratios. The figures show that the WCOBRA/TRAC-TF2 model captures the expected trends associated with these parameters with no noticeable discontinuities that would suggest that the model is inadequate at modeling fuel rods in the incremental burnup range. The data presented shows that the

WCOBRA/TRAC-TF2 decay heat model demonstrates acceptable performance up to a rod-average burnup of **[** **]** showing no signs of degradation in predictive capability.

The decay heat model used in WCOBRA/TRAC-TF2 is based on the ANSI/ANS-5.1-1979 decay heat standard (Reference 43). This standard includes a neutron capture correction factor, which is determined by equation 11 in the standard. However, this equation is only applicable for fuel with a maximum operating time of 4 years, which can be exceeded in cores designed to operate for three 18-month cycles. Therefore, Westinghouse has provided justification demonstrating that the calculated neutron capture correction factor for such cycles under extended burnup conditions is acceptable. The justification includes **[** **]** neutron capture correction factors. In response to RAI 23 (Reference 6), Westinghouse provided figures demonstrating that WCOBRA/TRAC-TF2 **[** **]** therefore the NRC staff determined that the treatment of the neutron capture correction factor remains applicable under extended burnup conditions up to a peak rod-average burnup of **[** **]** Westinghouse compared the WCOBRA/TRAC-TF2 calculated normalized fission interaction frequency (NFIF) and a NFIF calculated with newer nuclear physics data. Westinghouse's analysis indicates that the newer nuclear physics data results in a higher NFIF, thus more conservative. As a result, Westinghouse has updated the coefficients used to calculate the NFIF in WCOBRA/TRAC-TF2. This update will result in higher calculated powers at lower moderator densities, thus being more conservative than the previous coefficients. The NRC staff determined that this change is acceptable because it results in a more conservative determination of the NFIF.

Westinghouse does not propose any changes to the approved methodology for gamma energy redistribution. The approved methodology is conservative and is not expected to be significantly impact by the proposed increase in maximum rod-average burnup.

The NRC staff determined that the proposed changes to the WCOBRA/TRAC-TF2 kinetics and decay heat models are acceptable because the proposed changes are updated to newer and more conservative data and demonstrate applicability at higher burnups.

Per Westinghouse's response to RAI-1, the decay heat model used in LOCA analyses is dependent on local fuel pellet burnup. Westinghouse indicated the decay heat is a function of the local powers achieved within a fuel pellet throughout operation, but for LOCA calculations, **[** **]** The NRC staff notes that the use of an **[** **]** is conservative with respect to how **[** **]** Additionally, as discussed in the paragraphs above, the **[** **]** used is conservative and Westinghouse presented data for the WCOBRA/TRAC-TF2 decay heat model up to a rod-average burnup of **[** **]** which bounds the requested rod-average burnup extension limit. Therefore, the NRC staff finds there is no need for a local limit for this model.

### 3.3.5 Proposed Methodology for Confirming Non-Rupture of Fuel Rod Cladding

In Section 4.7 of WCAP-18446-P/WCAP-18446-NP, Revision 0, Westinghouse described its proposed methodology for calculating fuel rod cladding rupture. This section of the NRC staff's SE describes the following key aspects of Westinghouse's proposed approach:

- the proposed range of break sizes to be addressed
- the basic calculational approach
- factors influencing the uncertainty of cladding rupture
- modifications to the **[** **]** for assessing fuel rod rupture
- the design-specific applicability of the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology
- adoption of burnup-dependent peaking factors

### 3.3.5.1 Proposed Range of Break Sizes

Westinghouse separately discussed in Section 4.7 of WCAP-18446-P/WCAP-18446-NP, Revision 0, its proposed treatment of small-break, intermediate-break, and large-break LOCAs.

While the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology splits the LOCA break spectrum into three regions, as discussed in Section 29.2.3 of WCAP-16996-P-A, Revision 1, the FSLOCA evaluation model is divided into only two regions, Region I (i.e., smaller breaks) and Region II (larger breaks). Westinghouse stated in Section 4.7 of WCAP-18446-P/WCAP-18446-NP, Revision 0, that the proposed methodology for determining whether fuel rods in the extended burnup region will experience cladding rupture **[** **]** In accordance with discussion in Section 4.7.3.1 of WCAP-18446-P/WCAP-18446-NP, Revision 0, Westinghouse defined the large-break LOCA for WCAP-18446-P/WCAP-18446-NP, Revision 0, synonymously with the "Region II" definition established in Chapter 29 of WCAP-16996-P-A, Revision 1.

Westinghouse based its expectation that **[** **]** upon both physical reasoning and its experience performing LOCA calculations using the FSLOCA evaluation model.

With respect to the physical behavior expected for small breaks, Westinghouse stated that the boiloff uncovery is typically **[** **]**

Regarding analytical calculations of various sizes of pipe rupture, in Figures 4.7-1 through 4.7-5 from WCAP-18446-P/WCAP-18446-NP, Revision 0, Westinghouse provided the results of sample LOCA calculations showing peak cladding temperatures for small, intermediate, and large breaks. The example calculations shown in these figures reflect Westinghouse's conclusion that **[** **]** During the review, the NRC staff further audited additional calculational results generated by Westinghouse for other PWRs, which confirmed the information Westinghouse provided in WCAP-18446-P/WCAP-18446-NP, Revision 0.

Nevertheless, in RAI 16, the NRC staff questioned whether the information provided by Westinghouse in WCAP-18446-P/WCAP-18446-NP, Revision 0, constitutes sufficient basis to conclude that **[** **]** within the scope of the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology. In response to RAI 16, Westinghouse acknowledged that, while compelling, the available evidence may not support complete generalization. Therefore, as an additional confirmation, Westinghouse stated that it will **[** **]** during implementation of the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology. Should any plants be identified where **[** **]**

The NRC staff found Westinghouse's proposal to focus the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology on **[** **]** to be acceptable based upon (1) the strong evidence observed during the NRC staff's review that **[** **]** and (2) Westinghouse's revision to the methodology in response to RAI 16 to apply the methodology to **[** **]** In this regard, the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology would be executed for **[** **]** which is described in Section 4.7 of WCAP-18446-P/WCAP-18446-NP, Revision 0, and further in WCAP-16996-P-A, while incorporating the updated models and other modifications described in WCAP-18446-P/WCAP-18446-NP, Revision 0, and associated submittals.

### 3.3.5.2 Basic Calculational Approach

Westinghouse originally proposed that the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology would allow for calculations to be performed using **[** **]** The NRC staff identified questions concerning the proposed **[** **]** including (in RAI 12) whether it would comply with requirements in 10 CFR 50.46(a)(1), and also (in RAI 14) whether results computed by the approach in a **[** **]** might be subject to significant variability which could challenge the approach's effectiveness. In response, Westinghouse elected to **[** **]** method from the methodology and rely solely upon the **[** **]** described in Section 4.7.3.1 of WCAP-18446-P/WCAP-18446-NP, Revision 0, that closely resembles the FSLOCA evaluation model in WCAP-16996-P-A, Revision 1, that has previously been found acceptable by the NRC staff for a related application. The NRC staff found that Westinghouse's **[** **]** acceptably resolves the concerns identified in RAIs 12 and 14.

In Section 4.7.3.1, Westinghouse described the **[** **]** as intended to be executed in a manner similar to the FSLOCA evaluation model, with the exceptions that:

- the updated code models described in WCAP-18446-P/WCAP-18446-NP, Revision 0, would be applied,
- **[** **]** subject to the conditions described above in the discussion of RAI 16,
- the analysis would consider only fuel in the incremental burnup range, and
- only a **[** **]** would be considered, namely margin to cladding rupture.

The NRC staff finds this framework for the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology to be acceptable because (1) it is based on the FSLOCA evaluation model that has previously been found to be acceptable for a similar application, (2) it would provide reasonable assurance of capturing all break sizes that could potentially be limiting, and (3) it would focus on an applicable **[ ]** sufficient to prevent the dispersal of fragmented fuel from rods in the incremental burnup range. In this capacity, the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology would complement a licensee's existing LOCA evaluation model(s) for demonstrating compliance with 10 CFR 50.46(b) acceptance criteria including the peak cladding temperature, maximum local oxidation, and core-wide oxidation. The NRC staff finds acceptable Westinghouse's position that **[ ]**

3.3.5.3 Factors Influencing Uncertainty of Cladding Rupture

In Section 4.7.3.2 of WCAP-18446-P/WCAP-18446-NP, Revision 0, Westinghouse identified **[ ]** during a postulated LOCA:

- **[ ]**

While cladding rupture is indirectly influenced by numerous additional uncertainties associated with physical phenomena (e.g., heat transfer, fluid flow), initial conditions, and equipment performance, these additional factors are not immediately related to the incremental burnup extension and are already acceptably considered in the FSLOCA evaluation model upon which the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology's **[ ]** is based.

With respect to the **[ ]** Westinghouse discussed in response to RAI 21 its proposed procedure for calibrating the initial fuel average temperature and rod internal pressure. As for the FSLOCA evaluation model, in the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology, fuel rods would be initialized using the PAD5 code. Westinghouse stated that **[ ]** are the same as used in the approved FSLOCA evaluation model. The NRC staff found Westinghouse's proposed treatment to be acceptable because it would add appropriate conservatism to the determination of the **[ ]** in a manner consistent with the existing FSLOCA evaluation model.

With respect to the second factor, Westinghouse stated that a number of parameters discussed in Section 4.7.3.2 of WCAP-18446-P/WCAP-18446-NP, Revision 0, are treated conservatively in order to predict a conservative peak cladding temperature. Among the parameters cited therein by Westinghouse which would conservatively impact the cladding temperature are the fuel rod-average temperature, the use of conservative peaking factors as a function of burnup, and the use of a **[ ]** for decay heat. Because a conservative prediction of the peak cladding temperature is also relevant to existing evaluation models for the LOCA event, a number of the features discussed in this regard are similar or identical to the treatment used for existing models, such as FSLOCA evaluation model. The NRC staff found Westinghouse's proposed treatments acceptable because they would add appropriate conservatism to the determination of the calculated peak cladding temperature.

With respect to the third factor, as discussed above in Section 3.3.4.3 of this SE in connection with the topic of [ ] in response to RAIs 11 and 11.2, Westinghouse revised its approach to incorporate additional conservatism. As a result of those changes to the model, which substantially increased its conservatism, the NRC staff obtained reasonable assurance that the prediction of whether cladding rupture would occur [ ] would be performed in an acceptable manner.

In Section 4.7.3.2.2, Westinghouse discussed the treatment of a number of additional significant parameters associated with the analysis of a LOCA. The context of the discussion is with respect to determining [ ] during the blowdown phase of a LOCA for the [ ] However, as discussed above in connection with RAIs 12 and 14, Westinghouse opted to remove from the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology. Therefore, the NRC staff did not perform a review of the information in Section 4.7.3.2.2.

### 3.3.5.4 Modifications to [ ] for Assessing Fuel Rod Rupture

As clarified in RAI responses submitted by Westinghouse, the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology proposes to use a [ ] The basic modeling approach used by Westinghouse, as discussed above, is similar to the FSLOCA evaluation model, but with modifications to address more rigorously the margin to rupture of fuel rods in the incremental burnup range.

In RAI 19, the NRC staff questioned the applicability of the existing [ ] for modeling fuel in the incremental burnup range. In RAI 19, the NRC staff observed that the [ ] are based upon the assumption that the analyzed reactor operating domain would be [ ] whereas for the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology, only the incremental burnup range of 62 GWd/MTU - [ ] is of interest. Hence, the NRC staff questioned whether considering [ ] representative of the [ ] would be appropriate, since [ ] range. Implementing a representative treatment of fuel rod burnup is fundamental to assuring an appropriate treatment for many parameters associated with the reactor core and fuel rods. Therefore, the NRC staff requested in RAI 19 that Westinghouse address the acceptability of the uncertainty approach for the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology and provide a demonstration of the [ ] methodology.

Westinghouse responded to RAI 19 by stating that the **[ ]** Westinghouse further indicated that, analogous to the FSLOCA evaluation model, the intent of the WCAP-18446-P/ WCAP-18446-NP, Revision 0, methodology is to preclude exceedance of the relevant acceptance criterion (i.e., in this case cladding rupture for fuel in the incremental burnup range) to a **[ ]** Westinghouse acknowledged that its proposed approach of **[ ]** could lead to WCAP-18446-P/WCAP-18446-NP, Revision 0, analyses being performed at conditions **[ ]**

In follow-up RAI 19.2, the NRC staff observed that an approach of **[ ]** during the portion of the operating cycle when fuel fragmentation and dispersal could occur. Furthermore, considering the 55 GWd/MTU local burnup threshold for fuel fragmentation conservatively established in RIL 2021-13, the NRC staff observed that Westinghouse's assumption that fuel rods below a rod-average burnup of 62 GWd/MTU need not be assessed for dispersal potential may lead to unrealistic results.

In response to RAI 19.2, Westinghouse revised its calculational approach to assume that the **[ ]** of all fuel rods residing in peripheral locations (i.e., the only permissible location for fuel rods in the incremental burnup range) would be **[ ]** these fuel rods would be assumed to **[ ]** Westinghouse stated that this assumption would introduce a conservative bias into its modeling approach. The NRC staff agrees with this statement, since Westinghouse would be assuming **[ ]** when higher peaking factors could exist.

With regard to **[ ]** of burnup-related phenomena, such as thermal conductivity degradation, Westinghouse identified that the approaches for determining its uncertainties may be found in Section 29 of WCAP-16996-P-A, Revision 1, as well as Table I in Appendix B therein. Westinghouse confirmed that the majority of the parameters in Table I are not burnup-related and listed them in Table 19-1 of its response to RAI 19. In Table 19-2, Westinghouse further included a list of parameters that are only important following cladding rupture, and hence, which are not relevant to the **[ ]** determined by the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology. Finally, Westinghouse included in Table 19-3 the remaining set of parameters that are burnup-related and which can influence the potential for cladding rupture.

The NRC staff reviewed the **[ ]** Westinghouse proposed for several phenomena to ensure they adequately correspond to the **[ ]** Following the modification Westinghouse proposed to the **[ ]** that is described in response to RAI 19.2, the NRC staff reached agreement with Westinghouse's conclusion that there is no further need to modify **[ ]** for other parameters discussed in its response to RAI 19.

The NRC staff finds the modifications to the **[ ]** proposed by Westinghouse in response to RAI 19.2 to be acceptable because the modified approach would provide a representatively conservative estimate of the **[ ]** for fuel rods in the incremental burnup range **[ ]**

### 3.3.5.5 Design-Specific Applicability of the WCAP-18446-P/WCAP-18446-NP, Revision 0, Methodology

In Section 4.1 of WCAP-18446-P/WCAP-18446-NP, Revision 0, Westinghouse proposed to apply the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology to all conventional Westinghouse and CE PWRs, while acknowledging that the FSLOCA evaluation model, on which the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology is based, has been approved at present only for Westinghouse 3- and 4-loop designs. In particular, as observed in RAI 15, the underlying FSLOCA evaluation model has not been approved for Westinghouse 2-loop and CE reactor designs. While these reactor designs share many features with Westinghouse 3- and 4-loop reactors, notable differences exist (e.g., different emergency core cooling system injection points, significant variations in accumulator injection pressure). Westinghouse did not provide sufficient information for the NRC staff to conclude that the relevant design differences would not affect any relevant conclusions in WCAP-18446-P/WCAP-18446-NP, Revision 0.

In response to RAI 15, Westinghouse indicated that forerunner best-estimate evaluation models to the FSLOCA evaluation model, including the Code Qualification Document (CQD) (Reference 53) and Automated Statistical Treatment of Uncertainty Method (ASTRUM) (Reference 54), have previously been licensed for Westinghouse 2-loop and CE pressurized-water reactors. Westinghouse stated that there were **[**

**]** Westinghouse pointed out that the **[**

**]** Westinghouse further stated that an **[**

**]**

Westinghouse added that, **[**

**]** Therefore, Westinghouse proposed in its response to RAI 15 to **[**
**]** when considering the use of the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology for analyzing Westinghouse 2-loop and CE reactors.

While Westinghouse's past experience may indicate that the greatest potential for impacts associated with incorporating additional reactor designs into the methodology is with respect to **[** **]** the NRC staff finds it premature to limit the scope of review of the implementation of the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology at Westinghouse 2-loop and CE reactors solely to this area. An example alluded to previously in this safety evaluation is illustrative: the lower cover gas pressure of the safety injection tanks at some CE reactors could affect the relative importance of different break sizes. This example issue is at least partially addressed by the modification Westinghouse implemented to the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology in response to an NRC staff question in RAI 16. However, because a comprehensive review was not performed in connection with the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology and NRC staff's associated safety evaluation, a latent potential may remain for reactor design differences to impact the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology. Therefore, the NRC staff finds that the applicability of the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology must be confirmed in a future regulatory review for Westinghouse 2-loop and CE reactor designs (e.g., during a generic review to expand the applicability or a plant-specific review to implement the FSLOCA methodology). This stipulation is imposed in Limitation and Condition 6 in Section 4.0 of this SE.

### 3.3.5.6 Adoption of Burnup-Dependent Peaking Factors

As discussed in Sections 3.2.3, 3.2.4, and 4.7.3.2.1 of WCAP-18446-P/WCAP-18446-NP, Revision 0, the proposed methodology for confirming the integrity of fuel in the extended burnup range would not necessarily assume that extended burnup fuel would be operated with peaking factors, such as the heat flux hot channel factor ($F_Q(Z)$) and the nuclear enthalpy rise hot channel factor ($F_{\Delta H}^N$), that are initially at their current TS limits. Rather, Westinghouse proposed a safety analysis approach that would credit a projected reduction in the peaking factor of fuel rods as they undergo burnup over the normal operating cycle, which is not reflected in existing TS operating limits. As a general trend, which may be complicated by the presence of burnable neutron absorbers early in fuel life, peaking factors tend to decrease with burnup as enriched uranium in the fuel rods is gradually consumed by the neutron flux in the reactor core. The power of a fuel rod strongly influences the temperature transient its cladding would experience during a LOCA; the cladding temperature, in turn, strongly influences the hoop stress at which cladding rupture would occur. As an alternative to confirming the consistency of safety analysis peaking factor inputs for fuel rods in the incremental burnup range with applicable TS limits, Westinghouse proposed to confirm on a cycle-specific basis that each core reload design would abide by the burnup-dependent peaking limits necessary to assure non-rupture of fuel in the incremental burnup range.

In RAI 17, the NRC staff questioned whether the approach Westinghouse proposed in WCAP-18446-P/WCAP-18446-NP, Revision 0, complies with requirements in 10 CFR 50.36I(2)(ii) associated with the establishment of TS limiting conditions for operation of a nuclear reactor for, among other things, 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. As observed in RAI 17, crediting burnup-dependent peaking limits for fuel in the extended burnup range would appear to fall under 10 CFR 50.36(c)(ii) because the demonstration of fuel cladding integrity calculated in accordance with the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology would rely upon the plant operating in a manner that would limit the local power density of extended burnup fuel rods to assure the integrity of the fuel cladding during a postulated LOCA.

In response to RAI 17, Westinghouse argued that rod power burndown (i.e., the reduction in rod power as a function of burndown) is not a process variable, design feature or operating restriction. Westinghouse further argued that rod power burndown cannot be controlled in operation and further described its alternative approach of including criteria in the reload safety analysis checklist to limit fuel rod power burndown. However, the NRC staff did not obtain confidence that the proposed approach would yield a set of plant-specific TSs that would be capable of satisfying applicable requirements in 10 CFR 50.36.

In response to follow-up RAI 17.2, Westinghouse recognized that the WCAP-18446-P/ WCAP-18446-NP, Revision 0, methodology is intended to ensure that fuel cladding will remain intact as a fission product barrier during a LOCA. Westinghouse stated that, to address the requirements of 10 CFR 50.36, a maximum rod power limit specifically applicable to fuel assemblies during the period in which they are within the incremental burnup range would be added to the core operating limits report for licensees adopting the WCAP-18446-P/

WCAP-18446-NP, Revision 0, methodology. Westinghouse indicated that the specific core operating limits report item would be linked to the existing TS limiting condition for operation for the nuclear enthalpy rise hot channel factor, $F_{\Delta H}^{N}$ , that currently exists to protect against the occurrence of DNB. While this original purpose would continue to remain in effect, above 62 GWd/MTU, the revised limit would also protect against cladding rupture during a LOCA. Westinghouse stated that the required actions and completion times currently deemed acceptable for the DNB-based limit would apply equally to the new limit intended to protect against cladding rupture for extended burnup fuel, and that no need exists for additional surveillance requirements.

Finally, Westinghouse stated that the full-power $F_{\Delta H}^{N}$ limit could be scaled to reduced power by multiplying by the reciprocal of power (i.e., 1/P). Westinghouse stated that such a relationship is consistent with assumptions in the LOCA analysis because rod absolute power is the critical factor. While the NRC staff agrees with this position, the NRC staff notes that at very low power levels, the allowable peaking factor would undergo an unbounded, asymptotic increase. Therefore, establishing a maximum value for the peaking factor core operating limits report (COLR) limit at low powers may be appropriate.

The NRC staff's review of Westinghouse's proposed treatment of burnup-dependent peaking factors in RAIs 17 and 17.2 found that:

- Inclusion of a COLR limit to establish a burnup-dependent value for $F_{\Delta H}^{N}$ to prevent cladding rupture for peripheral fuel assemblies would be appropriate for licensees implementing the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology and wishing to credit power burndown.
- While scaling the burnup-dependent peaking factor limit to reduced powers may be appropriate, an appropriate maximum value for this peaking factor should be considered to address the potential for unbounded peaking factors at low power levels.
- While applying the departure from nucleate boiling-based $F_{\Delta H}^{N}$ limit only at burnups less than 62 GWd/MTU may be reasonable when assemblies with burnups exceeding 62 GWd/MTU are placed only on the core periphery (as required by the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology), neglecting the potential for DNB on high-burnup fuel assemblies may not be acceptable for other methods that allow interior placement of such assemblies.
- While the NRC staff finds Westinghouse's proposed approach for a burnup-dependent $F_{\Delta H}^{N}$ COLR limit to be acceptable in concept, specific limits must be reviewed for each plant and may be different than the sample Westinghouse provided in response to RAI 17.2 that was based upon the Westinghouse standard TSs in NUREG-1431. Due to the necessity of performing plant-specific review for such limits, the NRC staff imposes Limitation and Condition 12 that licensees implementing the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology describe and justify their proposed approach for implementing burnup-dependence into the $F_{\Delta H}^{N}$ operating limit or another acceptable alternative.

### 3.3.6 Demonstration Analysis for Non-Rupture of Cladding During a Postulated LOCA

Section 4.8 of WCAP-18446-P/WCAP-18446-NP, Revision 0, includes a demonstration analysis using the **[ ]** Westinghouse originally included in its methodology. However, as described in its response to RAI 12, Westinghouse subsequently proposed to remove this option from the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology. Therefore, the

NRC staff did not review the information provided in Section 4.8 of WCAP-18446-P/WCAP-18446-NP, Revision 0.

As described above in Section 3.3.5, in response to RAI 19, Westinghouse provided a demonstration of the **[ ]** which is the remaining allowable analysis approach in WCAP-18446-P/WCAP-18446-NP, Revision 0. The demonstration analysis in response to RAI 19 considered a Westinghouse 3-loop PWR. The demonstration analysis incorporated some revisions to the methodology that were not included in the original demonstration analysis in Section 4.8 of WCAP-18446-P/WCAP-18446-NP, Revision 0, including updated rupture temperature curves. However, other updates, such as the **[ ]** that were modified in subsequent RAI responses (e.g., RAI 19.2) are not included. The demonstration analysis performed by Westinghouse **[ ]** Westinghouse included several key calculated results for the demonstration analysis in a table and figures included in the RAI 19 response. Westinghouse stated that, in accordance with its response to RAI 24, a **[ ]** Although the check was not performed for the demonstration analysis, Westinghouse stated that the check will be conducted for any licensing analysis performed with the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology.

The demonstration analysis provided in response to RAI 19 does not fully reflect the final, modified WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology. However, because major features of the model were adequately demonstrated, the NRC staff considered the information therein responsive to the staff’s request that Westinghouse illustrate application of the proposed methodology. Therefore, the NRC staff considers RAI 19 resolved.

## 3.4 Non-LOCA Safety Analysis Methods

Section 5 of WCAP-18446-P/WCAP-18446-NP, Revision 0, describes Westinghouse’s proposed methodology for analyzing fuel operating in a rod-average burnup range between 62 GWd/MTU and **[ ]** for non-LOCA safety analyses.

The NRC staff’s evaluation of Westinghouse’s proposed methodology for analyzing the impacts of operating with fuel in the incremental burnup range on non-LOCA safety analyses addresses the following topics:

- Westinghouse’s proposed treatment of events (anticipated operational occurrences (AOOs) and accidents) that are dependent upon core-average effects and events that are dependent upon local effects in the fuel rods

- Westinghouse’s evaluation of control rod ejection (CRE) accidents and the applicability of RG 1.236 acceptance criteria to WCAP-18446-P/WCAP-18446-NP, Revision 0,

- Westinghouse’s evaluation of the LOCA mass and energy release for containment integrity analyses

### 3.4.1 Anticipated Operational Occurrences and Accidents

Sections 5.1.1 and 5.1.2 of WCAP-18446-P/WCAP-18446-NP, Revision 0, discuss Westinghouse's proposed evaluation of non-LOCA transients and accidents and reactivity-initiated accidents, respectively.

Westinghouse separates non-LOCA transients and accidents into two categories of events. The first category includes those events that are dependent solely on core-average effects. Westinghouse indicates that these events are analyzed to address core-wide or systems-based criteria such as loss of shutdown margin, margin to hot leg saturation, overpressurization of the reactor coolant system (RCS), overpressurization of the secondary system, or overfilling of the pressurizer. An incremental burnup extension may impact **[** **]**

The second category includes those events that are dependent on local effects in the fuel rods. Methodologies for these events model one or more hot rods and predict fuel enthalpy, DNBR, fuel temperature, and cladding temperature. Westinghouse does not propose any changes to the acceptance criteria associated with these events or parameters.

The NRC staff has determined that Westinghouse's evaluation of non-LOCA transient analysis is acceptable. Through (1) the model assessments described above and (2) the establishment an acceptance criterion requiring that **[** **]** for fuel rods in the incremental burnup range, Westinghouse provides adequate assurance that no new phenomena beyond the capability of its existing, approved evaluations models would affect the safety analysis for non-LOCA transients and accidents. Slight changes in **[** **]** to analyze the first category of events will not affect the predictive capability of these codes. **[** **]** are not expected to be significantly different from 62 GWd/MTU to **[** **]** rod-average burnup, such that the codes used to model these phenomena would not need to be adjusted. Likewise, the codes used to analyze the second category of events have been individually approved for use at a higher burnup (again, either generically or within the application scope of WCAP-18446-P/WCAP-18446-NP, Revision 0). Westinghouse is assuring an acceptable level of safety by not proposing any changes in the acceptance criteria for these events.

#### 3.4.1.1 Control Rod Ejection

RG 1.236 provides guidance for analysis of the CRE accident for PWRs and control rod drop accidents for boiling-water reactors. RG 1.236 provides acceptable methods and procedures for analyzing these accidents, analytical limits for demonstrating compliance with GDC 28, and fuel cladding failure thresholds. RG 1.236 is applicable up to a maximum fuel rod-average burnup of **[** **]**

A CRE accident is postulated to occur due to the failure of a control rod drive mechanism housing, which allows a control rod to be rapidly ejected from the reactor by the RCS pressure. The rapid ejection results in a power excursion and may cause the reactor to become prompt critical. The power excursion is limited by fuel temperature feedback and the accident is terminated when the reactor trips, typically on high neutron flux, high positive flux rate, or low RCS pressure. If a rod ejection were to occur, the nuclear design of the reactor and limits on control rod insertion will limit any potential fuel damage to acceptable levels. Cladding failure can result from the core power excursion and the highly peaked power distribution near the ejected rod location.

**[** **]** Extended burnup fuel is not expected to be significantly impacted by CRE in the present application due to the **[** **]** and are thus less susceptible to DNB and cladding failure. Westinghouse will perform analyses as part of its standard reload analysis, and as part of the methodology specified in WCAP-18446-P/WCAP-18446-NP, Revision 0, will confirm that **[** **]** The methods used to analyze CRE have been approved for extended burnup analyses in other sections of this SE.

The NRC staff has determined that Westinghouse's evaluation of CRE analyses is acceptable because Westinghouse **[** **]** Additionally, the codes used to analyze CRE for extended burnup fuel have been shown to maintain adequate predictive capability up to a rod-average burnup of **[** **]** Furthermore, Westinghouse's analyses will ensure that the cladding for fuel rods with a burnup greater than 62 GWd/MTU **[** **]**

### 3.4.2 Containment Integrity Analyses

Section 5.2 of WCAP-18446-P/WCAP-18446-NP, Revision 0, discusses the effects of the requested rod-average burnup extension on the containment integrity analyses. These analyses consider the mass and energy released to containment from a LOCA or steam line break event.

#### 3.4.2.1 Short-Term LOCA Mass and Energy Releases

Short-term LOCA mass and energy (M&E) releases are used to determine the maximum differential pressure within sub-compartments inside the containment building for purposes of assessing structural integrity. Short-term LOCA events such as these are typically analyzed using 1-to-3 second durations and the results are generally dictated by the mass flux at the piping break. Westinghouse indicates that, given the nature of these events, the fuel products and specific aspects of the fuel performance do not influence the short-term LOCA M&E release; the parameters that influence the M&E release are the break location, the corresponding temperature of the fluid in the ruptured pipe, the size of the pipe break, and the initial RCS pressure. Westinghouse therefore asserts that any changes in core design to allow for changes in cycle length at higher burnups for an average core would not impact these analyses.

The NRC staff finds this approach to be reasonable for short-term sub-compartment analyses. While achieving higher burnups and longer fuel cycles will necessitate an increase in core-average enrichment and may result in slightly higher peaking factors for some assemblies, the amount of energy within the reactor coolant at any given point of nominal operation is limited by operational limits on the plant (e.g., reactor coolant system loop or average temperature limits). In other words, due to the short time period of concern, reactor coolant system conditions are more significant than those of the reactor core for sub-compartment analysis. Furthermore, while an on-average greater mass of the uranium-235 isotope might exist in the core, the core's performance at any point is "throttled" to maintain operation at the specific licensed power level for a longer period of time. The envisioned operating conditions are thus expected to be consistent for existing 62 GWd/MTU core designs and the proposed **[** **]** core designs. Given the brief duration considered for the short-term LOCA M&E release, the maximum M&E that could be potentially released will be constrained by what is instantaneously available within the coolant (i.e., negligible energy transfer from fuel to coolant to the break), and the consistency in operating conditions with burnup ensures the M&E release will be consistent across core designs for a given break size and set of initial RCS conditions.

### 3.4.2.2 Long-Term LOCA Mass and Energy Releases

Containment integrity analyses for long-term LOCA M&E release consider the long-term integrity response of the containment, the maximum sump temperature, and general equipment qualification. Within the Westinghouse suite of codes and analysis methods, there are three licensed methodologies for performing long-term M&E release analyses:

1. WCAP-10325-P-A, “Westinghouse LOCA Mass and Energy Release Model for Containment Design March 1979 Version.” (Reference 55)
2. WCAP-17721-P-A. “Westinghouse Containment Analysis Methodology - PWR LOCA Mass and Energy Release Calculation Methodology.” (Reference 56)
3. CENPD-132P, Revision 1, “Calculative Methods for the C-E Large Break LOCA Evaluation Model” (Reference 57)

Westinghouse asserted no changes are needed for these methodologies and provided justification for the continued applicability to the requested rod-average burnup extension limit. The NRC staff’s assessment of each of these methodologies is discussed below.

*WCAP-10325-P-A*

The WCAP-10325-P-A methodology models an average core for the generation of long-term LOCA M&E releases and conservatively maximizes the rate of energy transfer from the core to the coolant and out of the break. Pellet and cladding interactions and rod burst are not modeled. Westinghouse indicates this is because these phenomena would retard the release of energy stored in the fuel to the coolant and out the break flow. However, other fuel thermal-mechanical properties that pertain to determining fuel stored energy and release are modeled (e.g., fuel rod inside and outside diameter, flow area through the core, peaking factors, pellet density, rod internal pressure, etc.). Of specific note is that the methodology considers the burnup where the highest fuel temperature during the proposed cycle would occur.

Westinghouse indicates WCAP-10325-P-A does not have any burnup limitation defined, but the fuel performance methodology that supplies fuel performance calculation results as input for the M&E release (i.e., PAD5) does have a burnup limitation. Westinghouse indicates that use of a fuel performance methodology approved for up to **[                    ]** rod-average burnup will enable the WCAP-10325-P-A methodology to provide conservative long-term LOCA M&E releases that are applicable up to **[                    ]** for use in the containment integrity analyses. The NRC staff finds this to be reasonable; the WCAP-10325-P-A methodology’s conservative maximization of the rate of energy release from the fuel to the coolant to the break size is not dependent on burnup. Additionally, the estimation of the fuel stored energy itself is provided as input from an external fuel performance methodology, and the staff has found this methodology acceptable for use up to the requested rod-average burnup extension limit within the scope of WCAP-18446-P/WCAP-18446-NP, Revision 0, specifically PAD5. See Section 3.2 of this SE for further discussion.

Regarding decay heat, Westinghouse indicated the decay heat generated in the core is included in the total energy released to containment in the WCAP-10325-P-A methodology, and that this is done to maximize the long-term containment pressures and temperature response. The decay heat model used is the ANSI/ANS 5.1-1979 standard plus 2-sigma uncertainty. Westinghouse notes that the standard provides flexibility to model burnups to **[**

**]** The NRC staff examined the WCAP-10325-P-A decay heat methodology and observed the decay heat release rates are divided between the fast fission of uranium-238 (8 percent) and thermal fission of uranium-235 (92 percent). Due to the high decay heat power of uranium-238 fission products, this simplified split is generally conservative compared to explicitly accounting for the lower decay heat power of other fissile elements and isotopes (e.g., plutonium-239). However, the NRC staff noted the decay heat model does not assume infinite operating time but instead assumes approximately 3.17 years of continuous full-power operation (with additional flexibility to account for plant-specific conditions). The NRC staff also noted the decay heat model utilizes a neutron capture factor taken directly from Table 10 of the ANSI/ANS 5.1-1979 standard, but the neutron capture factors listed in Table 10 are only applicable to a maximum operating time of 4 years. As noted in Section 4.6.2 of WCAP-18446-P/WCAP-18446-NP, Revision 0, the applicability range of Table 10 from the ANSI/ANS 5.1-1979 standard could be exceeded for various nuclear designs (e.g., fuel assemblies operated through three 18-month cycles). This also means the assumed cumulative full-power operating time of 3.17 years (assumed in the standard to occur continuously) will be exceeded. As a result, based upon the information provided during the review, the NRC staff could not conclude the decay heat model in WCAP-10325-P-A is appropriate for rod-average burnups to **[** **]** The NRC staff therefore introduced Limitation and Condition 13, which requires that Westinghouse provide adequate justification, either through a plant-specific implementation submittal or TR supplement, that the decay heat model in WCAP-10325-P-A is applicable to the requested rod-average burnup extension limit (e.g., demonstrate that the decay heat model is conservative with respect to decay heat curves produced from more detailed methods) or update the decay heat model inputs to assume a full-power operation and use a neutron capture correction factor appropriate (bounding or representative) for the cycle lengths of the nuclear design. With this Limitation and Condition, the staff finds the decay heat model in WCAP-10325-P-A acceptable for use within the methodology described in WCAP-18446-P/WCAP-18446-NP, Revision 0.

*WCAP-17721-P-A*

The WCAP-17721-P-A methodology uses the WCOBRA/TRAC code, and the initial core stored energy is biased high for the LOCA M&E release calculations. Just like WCAP-10325-P-A, the methodology in WCAP-17721-P-A models an average core, does not have any limitations defined with respect to individual rod-average burnup, and utilizes data from calculations performed by a fuel performance methodology that possesses a burnup limitation (i.e., PAD5). Additionally, Westinghouse noted that **[**

**]** Westinghouse indicates no changes are therefore needed for this methodology to perform long-term LOCA M&E release calculations for containment integrity analyses. The NRC staff finds this to be reasonable; the WCAP-17721-P-A methodology focuses on modeling the long-term M&E release of the RCS and the reactor core with a stored energy that is conservatively biased high. The initial fuel conditions and estimation of the fuel stored energy at the time of the break are provided as input from an external fuel performance methodology that the staff has found acceptable for use up to the requested rod-average burnup extension limit within the scope of WCAP-18446-P/WCAP-18446-NP, Revision 0, specifically PAD5. See Section 3.2 of this SE for further discussion.

Regarding decay heat, Westinghouse indicated the decay heat generated in the core is included in the total energy released to containment in the WCAP-17721-P-A methodology, and that this is done to maximize the long-term containment pressures and temperature response. The decay heat model used is the ANSI/ANS 5.1-1979 standard plus 2-sigma uncertainty. Westinghouse notes that the standard provides flexibility to model burnups to **[**

**]** The NRC staff assessed the WCOBRA/TRAC decay heat model (which is utilized in WCAP-17721-P-A) in Section 3.3.4.5 of this SE and found it acceptable with one exception. In particular, the NRC staff found Westinghouse's proposed implementation of equation 11 for the neutron capture correction factor from the ANSI/ANS 5.1-1979 standard under extended burnup conditions may lead to operating times in excess of the stated 4-year operating time identified in the standard. Therefore, the NRC staff imposed Limitation and Condition 14 to require that licensees implementing the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology adequately justify that use of the proposed neutron capture correction factor is acceptable or provide a modified approach for incorporating the effects of neutron capture for operating times beyond 4 years. The NRC staff also notes here the model does not assume infinite operating time but instead utilizes plant-specific cycle-dependent decay heat curves based on the ANSI/ANS 5.1-1979 standard plus 2-sigma uncertainty.

*CENPD-132P*

The CENPD-132P methodology is based on fuel-related inputs from a hot rod. Westinghouse indicates the fuel temperatures used are based on a bounding fuel centerline temperature versus linear heat rate over the entire fuel cycle. Westinghouse also states that, as with WCAP-10325-P-A, no burnup limit is listed for this methodology, but the fuel performance data used as input is generated by a fuel performance methodology that does have a burnup limit (i.e., PAD5). The implication is that use of a fuel performance methodology approved for up to **[** **]** rod-average burnup will enable the CENPD-132P methodology to provide conservative LOCA M&E releases that are applicable up to **[** **]** for use in containment integrity analyses. The NRC staff finds this to be reasonable; the CENPD-132P methodology does not model the fuel. Instead, the initial fuel conditions and estimation of the fuel stored energy at the time of the break are provided as input from an external fuel performance methodology that the NRC staff has found acceptable for use up to the requested rod-average burnup extension limit within the scope of WCAP-18446-P/WCAP-18446-NP, Revision 0, specifically PAD5. See Section 3.2 of this SE for further discussion.

Regarding decay heat, Westinghouse indicated the decay heat generated in the core is included in the total energy released to containment in the CENPD-132P methodology, and that this is done to maximize the long-term containment pressures and temperature response. Westinghouse did not identify the decay heat model used in CENPD-132P but indicated that **[**
**]** The NRC staff assessed the decay heat methodology described in CENPD-132, Supplement 4-P-A (Reference 58) and noted it is **[**

**]** The NRC staff further noted that **[**
**]**

than the ANSI/ANS 5.1-1979 standard plus 2-sigma uncertainty. Given the assumption of **[ ]** and **[ ]** compared to the ANS-1979 standard plus 2-sigma uncertainty, the NRC staff finds this acceptable.

### 3.4.2.3 Steamline Break Mass and Energy Releases

The short-term steamline break M&E releases are used to assess short-term pressure increase transients within sub-compartments inside or outside the containment building for purposes of assessing structural integrity during a postulated secondary-side pipe rupture. Short-term analysis of steamline breaks typically involves a duration of 1-10 seconds, and the results are generally dictated by mass flux at the piping break. Westinghouse indicates that, given the nature of these events, the fuel products and specific aspects of the fuel performance do not influence the short-term steamline break M&E release; the parameters that influence the M&E releases are the break location, the corresponding temperature and quality of the fluid in the ruptured pipe, the size of the pipe break. Westinghouse therefore asserts that any changes in core design to allow for changes in cycle length at higher burnups for an average core would not impact these analyses.

The NRC staff finds this logic to be reasonable. Similar to the NRC staff's assessment for short-term LOCA M&E releases, achieving higher burnups and longer fuel cycles will necessitate an increase in core-average enrichment and may result in slightly higher peaking factors for some assemblies, but the amount of energy within the secondary system for any given point of nominal operation is limited by the operational rating of the plant. The secondary-side operating conditions for a core designed to meet the proposed **[ ]** rod-average burnup extension limit will be consistent with those of existing 62 GWd/MTU core designs. Given the brief duration of the short-term analysis performed for steamline breaks, the maximum amount of M&E that could be potentially released will be constrained by what is instantaneously available within the steam supply system (i.e., negligible energy transfer from fuel to coolant to steam generator to the break), and the consistency in operating conditions with burnup ensures the M&E release will be consistent across core designs for a given break size and set of initial RCS conditions.

Regarding long-term steamline break M&E releases, Westinghouse indicates the computer codes and methods approved for these analyses remain applicable, and any impact from burnup increase will be **[ ]** The following three computer codes are used for long-term steamline break M&E release analyses:

1) LOFTRAN (Reference 59) (Reference 60)
2) RETRAN (Reference 61)
3) SGNIII (Reference 62) (Reference 63)

Regarding the LOFTRAN and RETRAN methodologies, these are not tied to any specific fuel performance limit or fuel design. Westinghouse indicates these methodologies assume bounding reactivity feedback modeling to conservatively bound plant operation at the end of the core life. However, given that these methods analyze **[ ]** The NRC staff assessed these methodologies and found Westinghouse's position reasonable; LOFTRAN and

RETRAN utilize simplified “lumped fuel” core models to calculate heat flow to the reactor coolant, and they use neutron point kinetics for reactivity feedback. The core power distribution and nuclear peaking factors are provided by an external code (e.g., ANC). For steamline breaks, heat transfer from the reactor core to the reactor coolant is maximized. Both codes also use the ANSI/ANS-5.1-1979 decay heat standard with 2-sigma uncertainty to determine bounding decay heat inputs. The NRC staff therefore finds the continued use of LOFTRAN and RETRAN acceptable for assessing secondary-side long-term steamline break M&E releases.

Regarding SGNIII, Westinghouse indicates that no changes are needed to the methodology to support a core-wide fuel burnup limit due to the methodology’s overall conservatism. However, Westinghouse did not provide a basis for this conclusion, particularly with regard to accommodating the potential for increased decay heat and core stored energy in the increased burnup regime. The NRC staff requested additional justification in RAI-27. Westinghouse’s response indicated the decay heat is produced using the ANS-5 1971 decay heat curve assuming infinite irradiation time. The NRC staff noted the 1971 decay heat curve is conservative with respect to the 1979 and 2005 curves, and the assumption of infinite irradiation time adds additional conservatism. The NRC staff therefore finds the approach to decay heat reasonable. Regarding core stored energy, Westinghouse’s response clarified that the parameters which establish the initial core stored energy in SGNII are provided as inputs to the code and are based on a specific fuel burnup. Because analyses at increased burnup conditions would adjust these inputs, the NRC staff finds this is also reasonable. Furthermore, in accordance with Limitation and Condition 7, these fuel-related inputs would be derived from analyses using Westinghouse’s PAD5 code. Based on the discussion above, the NRC staff finds the continued use of SGNIII acceptable for assessing secondary-side long-term steamline break M&E releases.

### 3.4.2.4 Containment Integrity Response

In Section 5.2.4 of WCAP-18446-P/WCAP-18446-NP, Revision 0, Westinghouse indicates the containment codes that analyze the long-term LOCA containment response for overall peak pressure and the long-term steamline break response for overall peak containment pressure and temperature utilize the M&E releases from these specific transients as an input, and they do not model the peak rod-average burnup directly. Therefore, no methodology changes will be needed for the containment response models for a full core with higher burnup. Because the M&E releases are inputs to the containment response methodologies and these will be updated/adjusted in response to the **[ ]** rod-average burnup nuclear designs, the NRC staff finds this acceptable.

However, the NRC staff noted that in Section 7.2, “Implementation of Burnup Extension,” of WCAP-18446-P/WCAP-18446-NP, Revision 0, Westinghouse stated the incremental burnup extension does not impact any of the containment analyses. This statement seems inconsistent with the discussions provided within this section of the SE that articulate a potential increase in decay heat and core stored energy, which will have a direct impact on containment response analyses of record. Westinghouse clarified in the response to RAI-29 that the text in question was written with respect to the acceptability of the existing methodology, not the results from the generation of M&E releases or the subsequent containment response. The incremental burnup extension does not impact any of the containment analyses methodologies or codes. The NRC staff finds this response acceptable; all M&E release analyses for an incremental burnup extension will use fuel performance data as analysis inputs that are provided by PAD5, which is the most up-to-date NRC-approved fuel performance code that is currently available within Westinghouse.

## 3.5 Radiological Consequence Analysis

Section 6 of WCAP-18446-P/WCAP-18446-NP, Revision 0, (Reference 1) describes the effects of the incremental burnup extension on the radiological consequence analyses for design-basis accidents. Based upon the NRC staff concerns raised during the initial acceptance review (Reference 2,3) and audit (Appendix A of this SE), Westinghouse provided a voluntary supplement (Reference 4) which significantly altered Section 6. With the exception of Section 6.5, “References,” the supplement completely replaces the original text of Reference 1.

The NRC staff is actively working to update RG 1.183, “Alternative Radiological Source Terms for Evaluating Design Basis Accidents at Nuclear Power Reactors.” Many of the NRC staff’s concerns raised during the initial acceptance review centered around differences between Westinghouse’s proposed treatment of radiological source terms relative to the staff’s draft guidance. To address these differences, Westinghouse introduced Limitation #9 (adapted as Limitation and Condition 9 in this SE) which **[** **]** The benefit of this restriction would be to maintain consistency among the fleet as the NRC expects to publish revised guidance in this area. Nevertheless, the NRC staff reviewed the alternative source terms in Section 6 based upon the supporting technical bases.

Section 6 of WCAP-18446-P/WCAP-18446-NP, Revision 0, supplement (Reference 4) identifies typical design-basis accidents (DBAs) with associated radiological consequence analyses. The subsequent sections describe the effects of the incremental burnup extension on the radiological consequence analyses with respect to these six typical DBAs. While the listed postulated accidents are typical of CE and Westinghouse-designed nuclear power plants, there may be additional plant-specific accidents which have associated radiological consequence analyses. One example is the infrequent event with a single active failure included in several CE-designed plants. In the past, some CE licensees have bounded this class of infrequent event with a composite transient consisting of an inadvertent opening of an atmospheric dump valve with a loss of AC power (i.e., loss of forced circulation). This infrequent event is classified as a Condition III transient. As this event may predict fuel cladding damage, a radiological consequence analysis is provided in the plant’s licensing bases.

**[** **]** While not described in Section 6, this requirement to **[** **]** also applies to any non-LOCA events in a plant licensing basis for which fuel damage may be tolerated, including the infrequent events analyzed by licensees of CE-designed plants.

Section 6.1 states that the LOCA radiological consequence analyses are not dependent on the 10 CFR 50.46 emergency core cooling system performance demonstration, and that the fission product release assumed in these evaluations is based upon a major accident involving substantial meltdown of the core with subsequent release of appreciable quantities of fission products. The NRC staff agrees with this assertion and now commonly refers to this as the maximum hypothetical accident – LOCA (MHA-LOCA).

In Section 6.1 of the supplement to TR WCAP-18446-P/WCAP-18446-NP, Revision 0, Westinghouse addresses the potential impacts of the following items on the MHA-LOCA core-average source term and release timing:

- **[**

**]**

The NRC staff memorandum, dated May 13, 2020 (Reference 65), reviewed the applicability of RG 1.183 for higher burnups using the MHA-LOCA source term described in SAND2011-0128 and found it reasonable to extrapolate the report conclusions for fuel with **[ ]** peak rod-average. An additional NRC staff memorandum, dated July 20, 2021 (Reference 66), reported a staff's assessment of the impact FFRD would have on the RG 1.183 design-basis radiological consequence analyses involving significant core damage, concluding that RG 1.183 is bounding for the MHA-LOCA. Based upon the information presented in Section 6.1 and the two NRC staff memoranda, the NRC staff concludes the MHA-LOCA radiological consequence analyses following regulatory guidance provided in RG 1.183 remain appropriately bounding and therefore acceptable for incremental burnup extensions of **[ ]** peak rod-average for Westinghouse and CE PWRs.

Section 6 of WCAP-18446-P/WCAP-18446-NP, Revision 0, supplement describes the effects of the incremental burnup extension on the radiological consequence analyses for the steam generator tube rupture (SGTR), MSLB, Single RCP Locked Rotor (or Sheared Shaft), and CRE DBAs. **[**

**]** Note that licensees continuing to employ the RG 1.183 release fractions for the MSLB and Single RCP locked rotor events must remain within the applicability window defined in footnote 11 of the guidance.

For the CRE accident, WCAP-18446-P/WCAP-18446-NP, Revision 0, requires a demonstration that **[**

**]** Westinghouse stated that such an analytical demonstration is expected to be achievable due to the **[ ]** in the incremental burnup range, which must be placed on the core periphery. However, for fuel rods with burnups within existing limits (i.e., not exceeding 62 GWd/MTU), a limited number of which may be subject to failure during a CRE, Westinghouse is proposing to employ the steady-state fission-product-gap inventory fractions from **[ ]** Table 6-1 provides a comparison of steady-state radionuclide release fractions from RG 1.183,

**[** **]** and the latest NRC draft guidance DG-1389 (Reference 68). Based upon this comparison, the NRC staff finds the use of **[** **]** steady-state release fractions acceptable for the CRE accident.

Table 3: Comparison of PWR Steady-State Radionuclide Release Fractions

| Group | RG 1.183 (2000) | DG-1327 (2019) | DG-1389 (2022) |
|---|---|---|---|
| I-131 | 0.08 | 0.08 | 0.07 |
| I-132 | - - | 0.06 | 0.07 |
| Kr-85 | 0.10 | 0.36 | 0.40 |
| Other Noble Gases | 0.05 | 0.05 | 0.06 |
| Other Halogens | 0.05 | 0.05 | 0.04 |
| Alkali Metals | 0.12 | 0.49 | 0.20 |
| Range of Applicability | 62 GWd/MTU | 65 GWd/MTU | 68 GWd/MTU |

Section 6.2 states that rod ejection radiological consequence calculations must be **[** **]** These burnup-dependent transient FGR correlations have not been updated in the latest guidance, DG-1389 (2022). Furthermore, these correlations have been validated up to **[** **]** rod-average burnup. The NRC staff finds the use of the transient FGR correlations acceptable.

As stated in Section 6.3, a Fuel Handling Accident (FHA) involving fuel within the incremental burnup extension cannot be ruled out. As such, Westinghouse proposes a methodology for calculating plant-specific FHA radiological consequences for incremental burnup extension. Key inputs and assumptions for this new methodology are discussed below.

- **[** **]** the $F_{\Delta H}$ used to calculate the effective release fraction remains based on the TSs maximum allowable value. This approach is not a departure from plant's existing license bases and is therefore acceptable.

- **[** **]** Based upon the restriction that fuel assemblies which exceed 62 GWd/MTU must be placed on the core periphery (Limitation and Condition 8) and the core physics information provided in Section 3.2.4 of the supplement (Reference 4), the NRC staff finds the **[** **]** to be acceptable for this application.

- **[**

**]**

- **[** **]** to account for the incremental burnup increase. This approach is conservative, as the **[** **]** Continued use of the **[** **]** remains conservative, is not a departure from plant’s existing license bases, and is therefore acceptable.

- The cold rod internal pressure for the incremental burnup rods will be assessed **[** **]** Therefore, the **[** **]** used in the existing analysis remains appropriate. This approach is not a departure from plant’s existing license bases and is therefore acceptable.

- **[** **]** Based on the overall conservatism of the methodology, the NRC staff finds this assumption acceptable.

- **[** **]** Based on this conservative difference in anticipated releases, the NRC staff finds this assumption acceptable.

Following the steps outlined in Section 6.3, applicants would calculate effective radionuclide release fractions for incremental burnup extension fuel rods. If, for each radionuclide, the effective release fraction is smaller than the effective release fraction used in the docketed FHA radiological consequence analysis in the updated final safety analysis report (UFSAR), then the evaluation would conclude that the existing analyses remain bounding. If any of the radionuclide effective release fractions are larger than the effective release fractions used in the docketed FHA radiological consequence analysis in the UFSAR, then a more detailed dose calculation would be necessary to confirm that existing UFSAR analyses remain bounding. Westinghouse states that detailed analyses would be required to determine if the **[** **]** if applicable to the plant’s licensing basis. Westinghouse stated that additional margin could be obtained by **[** **]** Note that the analytical procedure for calculating plant-specific steady-state radionuclide release fractions has not changed in the most recent draft guidance[3] DG-1389. Westinghouse stated that this

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[3] Guidance for calculating Cs-134 and Cs-137 release fractions has been updated but does not necessarily impact FHA radiological consequence analyses.

**[ ]**

Following the methodology described above, licensees will explicitly address FHA radiological consequences as part of their license amendment request to implement the incremental burnup extension. Licensees are not required to demonstrate that existing UFSAR docketed analyses remain bounding and could introduce new bounding analyses following this methodology.

Finally, the example comparison provided in Section 6.3 of the supplement (assumptions #1 - #3) refers to sample numerical values as “conservative” for this example. It is not evident to the staff that these selections are inherently conservative. The example just illustrates the application of the methodology for “typical” values.

### 3.6 ADOPT Fuel Pellet Considerations

WCAP-18482-P-A, Revision 0, “Westinghouse Advanced Doped Pellet Technology (ADOPT) Fuel” (Reference 69), is an approved fuel pellet design that incorporates alumina and chromia dopants into the fuel matrix. ADOPT fuel pellets also have a higher theoretical density. WCAP-18446-P/WCAP-18446-NP, Revision 0, is also applicable to ADOPT pellets and is addressed in Appendix B to the TR.

Due to the higher theoretical density of ADOPT pellets, a fuel assembly may be slightly heavier, thus altering the mechanical response to dynamic forces. Overall, the net increase in fuel pellet weight is relatively small, especially considering the unfueled assembly weight is not expected to change. Therefore, there is little reason to expect any significant reduction in mechanical performance associated with ADOPT fuel pellets. Westinghouse confirmed this finding through seismic-LOCA calculations and determined that when compared to traditional $UO_2$ fuel pellets, the difference is **[ ]** The conclusion of this analysis is that the current methods and models are adequate for fuel designs with ADOPT fuel pellets. The NRC staff determined that the mechanical models are acceptable for use in assemblies with ADOPT fuel pellets in the range of extended burnup because the difference in reaction to dynamic forces between ADOPT and traditional $UO_2$ pellets is **[ ]**

ADOPT fuel pellets feature several performance improvements relative to traditional $UO_2$ pellets, such as a reduction in transient FGR and a higher melting point. Westinghouse takes no credit for these performance improvements in the range of extended burnup. There are three high-burnup phenomena for which Westinghouse provides further justification as to how ADOPT fuel pellets continue to adhere to the fuel rod performance conclusions described in Section 3.1 of the TR and Section 3.2 of this SE. Those characteristics are rim structure and its impact of FGR, rod growth, and fission gas swelling. The NRC staff reviewed these three characteristics and their associated sections in WCAP-18482-P-A. The NRC staff concluded that the differences in these characteristics do not necessarily reduce the predictive capabilities of the codes and methods used to model these characteristics because the methods do not need to be adjusted to accommodate ADOPT fuel pellets. The only parameters that are different when modeling ADOPT pellets compared to $UO_2$ pellets are higher initial fuel density and reduced rate of fuel densification. Altering these parameters to match ADOPT pellet characteristics will not impact the predictive capability of Westinghouse codes and methods and will result in more realistic modeling of ADOPT fuel pellets. The NRC staff also reviewed the fuel rod characteristics considered in Section 3.1 of WCAP-18446-P/WCAP-18446-NP, Revision 0, with respect to ADOPT fuel (i.e., in addition to the three characteristics upon which Westinghouse focused its assessment) and concluded that these characteristics of ADOPT fuel pellets are acceptably similar to those of standard $UO_2$ pellets within the incremental burnup range. The NRC staff further concluded that FFRD does not need to be addressed for ADOPT fuel pellets within the incremental burnup range because the methodology described in WCAP-18446-P/ WCAP-18446-NP, Revision 0, precludes FFRD by limiting extended burnup fuel assembles to the core periphery where their relative power is sufficiently low to reasonably preclude cladding rupture.

Appendix B.3.1 of WCAP-18446-P/WCAP-18446-NP, Revision 0, describes the impact of ADOPT fuel pellets on LOCA analyses. Westinghouse asserts that ADOPT fuel pellets present a minimal impact on LOCA analyses. ADOPT pellets are modeled explicitly in PAD5, which has been shown to be acceptable for modeling extended burnup fuel pellets in this section and earlier in the SE. Section 3.2.1.1 of this SE documents the staff's conclusion regarding the applicability of the PAD5 FGR model at burnups greater than 62 GWd/MTU. In short, the PAD5 model remains limited in its generic applicability up to a rod-average burnup of 62 GWd/MTU but has been shown to be acceptable within the scope of the present review up to **[ ]** ADOPT fuel pellets are expected to have a similar or reduced FGR compared to $UO_2$ pellets. Therefore, the NRC staff conclusions regarding the PAD5 FGR model are also applicable to ADOPT fuel pellets.

Appendix B.3.2 of WCAP-18446-P/WCAP-18446-NP, Revision 0, describes the impact of ADOPT fuel pellets on transient analysis methods. The NRC staff SE for WCAP-18482-P-A (Reference 69) concluded that existing non-LOCA acceptance criteria remain applicable to the ADOPT fuel pellet design. Furthermore, computer codes and methods used in the analysis of non-LOCA licensing basis events remain applicable for the ADOPT fuel pellet design. This SE has determined that the methodologies referenced within WCAP-18446-P/WCAP-18446-NP, Revision 0, acceptably model $UO_2$ pellets for extended burnup applications. ADOPT fuel pellets are generally expected to perform at least as well as $UO_2$ pellets. Therefore, the NRC staff has determined that the ADOPT fuel pellet design and transient analysis codes and methods used to model ADOPT fuel pellets are acceptable for use in extended burnup applications.

Appendix B.3.3 of WCAP-18446-P/WCAP-18446-NP, Revision 0, describes the impact of ADOPT fuel pellets on containment integrity analyses. The NRC staff SE for WCAP-18482-P-A (Reference 69) states that any impact to containment integrity analyses would be isolated to changes in the mass and energy released to containment due to a pipe rupture accident because Westinghouse's containment integrity analyses do not model the fuel. The NRC staff then concluded that no methodological changes are required for a full core ADOPT fuel design. An incremental burnup extension may have a small impact on decay heat and initial core stored energy which may slightly affect the results of a containment integrity analysis. ADOPT fuel pellets are expected to have the same response as $UO_2$ pellets at higher burnups for containment integrity analyses. Westinghouse's evaluation of containment integrity analyses is discussed in Section 5.2 of WCAP-18446-P/WCAP-18446-NP, Revision 0, and Section 3.4.2 of this SE. The NRC staff has determined that ADOPT fuel pellets will have minimal impact on containment integrity analyses compared to $UO_2$ pellets, adequately justifying the applicability of Westinghouse's containment integrity codes and methods for core designs with extended burnup ADOPT fuel pellets.

Westinghouse methods related to radiological consequence analysis may be conservatively applied to ADOPT fuel pellets with no fundamental change to the codes or methods. Westinghouse uses the 2011 ANS 5.4 standard methodology for calculating FGR. This standard is already applicable up to a rod-average burnup of 70 GWD/MTU. The standard is only applicable to conventional $UO_2$ pellets. ADOPT pellets have demonstrated **[** **]** Additionally, codes and methods used to determine radiological consequences of DBAs have previously been approved for use with ADOPT fuel pellets in WCAP-18482-P-A. Therefore, the NRC staff determined that application of the 2011 ANS 5.4 standard with ADOPT fuel pellets is conservative up to 70 GWd/MTU for use in radiological consequence analysis.

The NRC staff has determined that the codes and methods referenced in WCAP-18446-P/ WCAP-18446-NP, Revision 0, are applicable for ADOPT fuel pellets up to a rod-average burnup of **[** **]**

## 3.7 AXIOM Supplement

AXIOM cladding is a niobium-bearing zirconium alloy like the ZIRLO alloy, with reduced tin content to increase corrosion resistance like the Optimized ZIRLO alloy, and with vanadium and copper to improve resistance to hydrogen pickup. The AXIOM alloy is processed to be partially recrystallized annealed, similar to the Optimized ZIRLO cladding. AXIOM-clad fuel had been in commercial reactor test programs since 2002 domestically and in Europe, with burnups reaching 75 GWD/MTU. Westinghouse stated that the AXIOM alloy has demonstrated better in-reactor performance compared to the Optimized ZIRLO alloy, especially in high-duty operating environments.

Appendix C (Reference 12) of WCAP-18446-P/WCAP-18446-NP, Revision 0, describes the applicability of Westinghouse's cladding performance models to AXIOM cladding under an incremental burnup extension. These models were approved up to 62 GWd/MTU for AXIOM cladding as part of WCAP-18546-P-A (Reference 70). Westinghouse provided justification that the cladding performance models remain conservative and applicable to AXIOM cladding up to a peak rod-average burnup of **[** **]** with no modifications to the methods or models.

The WCAP-18546-P-A cladding performance models for cladding corrosion, hydrogen pickup fraction, fuel rod growth, and cladding creep all contain data beyond the requested range of extended burnup. This data demonstrates adequate model predictability for AXIOM cladding up to a peak rod-average burnup of **[** **]**

Westinghouse does not propose to revise any limits established in WCAP-18546-P-A. The NRC staff determined that the current limits for AXIOM cladding are acceptable because the limits were already established with consideration of high burnup. Because the models have been shown to be applicable up to a peak rod-average burnup of **[** **]** the respective limits are also applicable.

Westinghouse is maintaining the no-burst criterion for AXIOM cladding with respect to addressing the potential for FFRD in the incremental burnup range. This treatment and associated NRC discussion is found in Sections 3.3.1 and 3.3.2 of this SE. In short, Westinghouse is taking credit for the extended burnup assemblies being located in core positions with relatively low power such that they will not burst during LOCA conditions. This criterion and credit are also applied to extended burnup fuel rods with AXIOM cladding.

Cladding rupture and deformation are discussed in further detail in Section 3.3 of this SE. Westinghouse seeks to extend the discussion and conclusions related to the cladding deformation and rupture models in WCAP-18446-P/WCAP-18446-NP, Revision 0, to AXIOM cladding. Westinghouse has demonstrated that AXIOM cladding **[** **]** as modeled by the WCOBRA/TRAC-TF2 high-temperature creep model.

Westinghouse uses a burst temperature curve to establish a pressure-temperature region in which cladding may rupture. A bounding curve is used to mark the separation between the regions of no-rupture and rupture. This curve **[** **]** providing a high degree of confidence that AXIOM cladding will not rupture unless the limits established by the burst temperature curve are exceeded. Given the measures to be taken regarding the no-burst criterion described above and the data provided in Appendix C of WCAP-18446-P/WCAP-18446-NP, Revision 0, the NRC staff determined that AXIOM cladding is expected to perform adequately as long as extended burnup assemblies with AXIOM cladding are located in core positions with sufficiently low power as to preclude conditions that could lead to cladding rupture.

The NRC staff determined that the conclusions in WCAP-18446-P/WCAP-18446-NP, Revision 0, and this SE are also applicable to AXIOM cladding because the methods and models have been shown to adequately model the performance of AXIOM cladding and demonstrate that, under the constraints applied by WCAP-18446-P/WCAP-18446-NP, Revision 0, and this SE, AXIOM cladding will perform acceptably up to a peak rod-average burnup of **[** **]**

### 3.8 Applicability and Implementation

In Section 7 of WCAP-18446-P/WCAP-18446-NP, Revision 0, Westinghouse summarizes applicability conditions, self-imposed limitations, and supplemental analytical work required to implement the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology.

The NRC staff has incorporated the self-imposed imposed limitations Westinghouse has proposed in Section 7.1 of WCAP-18446-P/WCAP-18446-NP, Revision 0, in Section 4.0 of this SE, below. In some cases, the NRC staff has modified Westinghouse's proposed limitation, based upon its review, to assure the acceptability of the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology.

In Section 7.1.1 of WCAP-18446-P/WCAP-18446-NP, Revision 0, Westinghouse listed a number of fuel designs for which the proposed WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology would be applicable. The list was further expanded in response to RAI-3 to clarify the specific variants of each fuel assembly design that WCAP-18446-P/WCAP-18446-NP, Revision 0, would be applicable to. The NRC staff's review found this list of assembly designs to be acceptable for the incremental burnup range proposed in WCAP-18446-P/WCAP-18446-NP, Revision 0, because the assembly mechanical design evaluation methodology is comprehensive and will ensure the structural integrity of each assembly design is maintained. The WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology is generically applicable to the 17x17 OFA design and may be applied to all designs listed in Section 7.1.1 of WCAP-18446-P/WCAP-18446-NP, Revision 0, with additional justification, as discussed in Limitation and Condition 1 of this SE.

In Section 7.2 of WCAP-18446-P/WCAP-18446-NP, Revision 0, Westinghouse stated that implementation of the incremental burnup extension will require some new calculations and evaluations of various existing calculations. A summary of the implementation requirements described by Westinghouse is provided below in Table 4.

Table 4: Implementation Requirements for WCAP-18446-P/WCAP-18446-NP, Revision 0

| **Calculation** | **Description of Implementation Requirement** |
|---|---|
| Fuel Assembly Mechanical Design | Demonstration that the fuel assembly mechanical design criteria described primarily in Section 2 of WCAP-18446-P/WCAP-18446-NP, Revision 0, relevant RAI responses, and this safety evaluation are satisfied. |
| Fuel Rod Design | Demonstration that the fuel assembly mechanical design criteria described primarily in Section 3.1 of WCAP-18446-P/WCAP-18446-NP, Revision 0, relevant RAI responses, and this safety evaluation are satisfied. |
| Loss-of-Coolant Accident | Demonstration that fuel rods with rod-average burnup exceeding 62 GWd/MTU do not rupture in accordance with the methodology described primarily in Section 4.7 of WCAP-18446-P/WCAP-18446-NP, Revision 0, relevant RAI responses, and this SE. |
| Transient and Non-LOCA Accident Analysis | Evaluation to confirm that **[** **]**<br>Perform analysis demonstrating that the acceptance criteria in RG 1.236 are satisfied, including fuel cladding failure thresholds, allowable limits on damaged core coolability, radiological consequences, and reactor coolant system pressure. The evaluation for addressing allowable limits on radiological consequences relies upon **[** **]** |
| Containment Analysis | No specified implementation requirements. |
| Analysis Decay Heat Models | The decay heat models used for analyses not discussed within the TR will be evaluated accounting for fuel assemblies in the incremental burnup range. |
| Reload Safety Evaluation | The nuclear designs under the incremental burnup extension will be assessed to ensure no reload limits are violated. As discussed above in Section 3.3.5, per Limitation and Condition 12, licensees relying upon burnup-dependent peaking limit reductions are required to describe their proposed approach for implementing burnup-dependence into the $F_{\Delta H}^{N}$ operating limit or other acceptable alternative. |
| Radiological Consequence Analysis | Westinghouse introduced Limitation #9 which provides a self-imposed restriction on the **[** **]** described in Section 6. Limitation #9 restricts the use of the WCAP-18446-P/WCAP-18446-NP, Revision 0, radiological consequence analysis methodology **[** **]**<br>For the CRE event, licensees implementing the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology must **[** **]**<br>Licensees shall assess any changes to the inventory of radionuclides in the reactor core and determine impacts on plant-specific radiological consequences. When considering the effects of increased fuel burnup, as with any modification that could potentially affect the radiological consequence analysis, plants implementing the WCAP-18446-P/ |

| Calculation | Description of Implementation Requirement |
|---|---|
| | WCAP-18446-NP, Revision 0, methodology using older regulatory guidance (e.g., RG 1.195) for their current radiological consequence analyses should evaluate the applicability of their current licensing basis methods relative to updated regulatory guidance applicable to fuel assemblies operating at increased burnup. |
| Vessel Fluence | Evaluate existing analyses or perform a reanalysis accounting for the elevated fuel average burnup. |
| Spent Fuel Pool | Evaluate existing analyses or perform a reanalysis of spent fuel heat removal and time-to-boil calculations accounting for increased fuel burnup. |
| Dry Cask Storage | Beyond the scope of the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology. |
| Westinghouse Fuel Criteria Evaluation Process (FCEP) | Westinghouse stated that it will update the peak rod-average burnup limit associated with the application of the FCEP process that is documented in WCAP-12488-P-A (Reference 71) after a licensee has received a license amendment approving use of WCAP-18446-P/WCAP-18446-NP, Revision 0. In this regard, the NRC staff notes that, in accordance with Section 6.0 of WCAP-12488-P-A and its corresponding safety evaluation, the possibility of updates to permit extension of the FCEP process beyond the 60 GWd/MTU limit in place at the time of the approval of WCAP-12488-P-A was enabled up to a maximum value of **[ ]** without prior NRC staff approval. |

The NRC staff's review finds that the set of implementation requirements described in Section 7.2 of WCAP-18446-P/WCAP-18446-NP, Revision 0, and as summarized above in Table 4, constitutes a reasonable summary of the major plant analyses that would typically be expected to be evaluated or reperformed when implementing WCAP-18446-P/WCAP-18446-NP, Revision 0. In this sense, the NRC staff agrees with the generic implementation requirements proposed by Westinghouse. However, the NRC staff recognizes that individual licensees could have additional or plant-specific licensing basis requirements that must be considered when pursuing the implementation of an incremental fuel burnup extension. Therefore, the set of calculations described in Section 7.2 of WCAP-18446-P/WCAP-18446-NP, Revision 0, should not be construed as eliminating the need to consider what would otherwise be licensing basis requirements applicable to a given plant.

## 4.0 LIMITATIONS AND CONDITIONS

Based upon its review of WCAP-18446-P/WCAP-18446-NP, Revision 0, the NRC staff finds it necessary to impose certain limitations and conditions upon the proposed methodology to ensure acceptable implementation.

The limitations and conditions listed below include nine limitations proposed by Westinghouse in Section 7.1 of WCAP-18446-P/WCAP-18446-NP, Revision 0, as supplemented in its voluntary submittal dated May 13, 2021. The NRC staff has adopted these limitations and conditions in this SE as Limitations and Conditions 1-9, albeit in some cases in modified form; as such, the list of limitations and conditions in this SE supersedes the self-identified limitations Westinghouse included in Section 7.1 of WCAP-18446-P/WCAP-18446-NP, Revision 0.

*Limitations and Conditions*

1. The applicability of this TR is limited to all currently manufactured Westinghouse and CE fuel designs. The specific list of applicable designs is provided in Section 7.1.1 of

WCAP-18446-P/WCAP-18446-NP, Revision 0, TR. The fuel assembly mechanical design evaluation in Section 2.0 of the TR provides generic approval of the 17x17 OFA design for use at a fuel rod-average burnup of **[** **]** A fuel assembly mechanical design evaluation, consistent with Section 2.0 of the TR, is needed to apply the incremental burnup extension to the fuel assemblies other than the 17x17 OFA design described in Section 7.1.1 of the TR. The additional evaluations may be included as part of a plant-specific application, a supplement to WCAP-18446-P/WCAP-18446-NP, Revision 0, or a separate TR.

2. The applicability of this TR is limited to $UO_2$ or ADOPT fuel with ZIRLO, Optimized ZIRLO, or AXIOM cladding.

3. The applicability of this TR is limited to un-poisoned fuel, fuel with integral fuel burnable absorber (IFBA), and fuel with gadolinia. This limitation does not preclude the use of wet annular burnable absorber (WABA) or other discrete burnable absorbers during the lifetime of an assembly.

4. The maximum fuel rod-average burnup and fuel assembly average burnup permitted with this TR is **[** **]** While this TR does not constitute generical approval of the PAD5 methodology for rod-average burnups of **[** **]** PAD5 is approved for the requested rod-average burnup of **[** **]** when implemented within the WCAP-18446-P/WCAP-18446-NP methodology (Section 3.2.1.12).

5. A maximum of 5 weight percent fuel enrichment is permitted with this TR.

6. The WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology for LOCA rupture calculations may only be applied to the Westinghouse 2-loop PWR and CE PWR designs after (1) the FSLOCA EM is approved for these designs and (2) the WCAP-18446-P/WCAP-18446-NP methodology is confirmed to be applicable for these designs.

   Furthermore, the LOCA cladding rupture calculations for these designs **[** **]** for 3-loop and 4-loop PWRs. (Section 3.3.5.5)

7. The NRC staff's approval of the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology is based on the incorporation of PAD5 fuel performance models and methods into the plant licensing basis for all fuel and safety analyses. Use of alternative methods to support any fuel or safety analysis will require acceptable plant-specific justification during the implementation review.

8. Only rods in peripheral assemblies (i.e., assemblies with at least one face towards the core baffles) may exceed a rod-average burnup of 62 GWd/MTU. Fuel rods in assemblies with a half-face towards the baffles in CE-designed PWRs are limited to a maximum rod-average burnup of 62 GWD/MTU (similar to core interior assemblies).

9. **[** **]**

**[ ]**

10. Based on the data provided in Figure 2.5-5b of WCAP-18446-P/WCAP-18446-NP, Revision 0, this SE was unable to confirm acceptable performance of ZIRLO cladding with respect to the **[ ]** best-estimate hydrogen content pickup design limit or the predictive capability of the PAD5 hydrogen concentration model for ZIRLO cladding. Additional justification should be provided on an application-specific basis demonstrating (1) that ZIRLO cladding will **[ ]** is acceptable for rod-average burnups greater than 62 GWd/MTU (Section 3.1.4.5), and (2) the PAD5 hydrogen concentration model can acceptably predict the hydrogen content of ZIRLO cladding for rod-average burnups greater than 62 GWd/MTU (Section 3.2.1.5).

11. This SE has neither evaluated nor approved WCAP-18446-P/WCAP-18446-NP, Revision 0, as a method for determining compliance with the acceptance criteria in proposed rule 10 CFR 50.46c. (Section 3.3.3)

12. Each licensee implementing the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology shall describe and justify its proposed approach for implementing burnup-dependence for rods that exceed 62 GWd/MTU into the $F_{\Delta H}^{N}$ core operating limit or another acceptable alternative. (Sections 3.3.5.6 and 3.1.2.5)

13. When applying WCAP-10325-P-A as part of the methodology described in WCAP-18446-P/WCAP-18446-NP, Westinghouse must either (1) adequately justify the decay heat model in WCAP-10325-P-A is applicable up to the requested rod-average burnup extension limit (e.g., demonstrate the model is conservative with respect to decay heat curves generated from more detailed methods), either through a plant-specific implementation submittal or through a supplement to this TR, or (2) adjust the inputs of the decay heat model in WCAP-10325-P-A to assume a full-power operation time and use a neutron capture factor appropriate for the extended cycle length of the nuclear design. (Section 3.4.2.2)

14. When applying WCAP-17721-P-A as part of the methodology described in WCAP-18446-P/WCAP-18446-NP, Westinghouse must either (1) adequately justify that equation 11 in the ANSI/ANS 5.1-1979 decay heat standard for determining the effects neutron capture of neutron capture is adequate for operating times beyond 4 years or (2) adjust the neutron capture model to provide appropriate predictions for operating times beyond 4 years.

## 5.0 CONCLUSIONS

The NRC staff has reviewed WCAP-18446-P/WCAP-18446-NP, Revision 0, which describes Westinghouse's proposed methodology for assessing impacts of operating applicable Westinghouse fuel designs in an incremental burnup range from 62 GWd/MTU – **[ ]** on Westinghouse 2-, 3-, and 4-loop PWRs and CE PWRs. Within WCAP-18446-P/WCAP-18446-NP, Revision 0, Westinghouse has considered the suite of analyses that could be affected by the incremental burnup extension, including fuel assembly mechanical design, core and fuel rod performance, LOCA safety analyses, non-LOCA safety analyses, and radiological consequences. Based upon the evaluation documented above, the NRC staff has concluded that the WCAP-18446-P/WCAP-18446-NP methodology provides an acceptable approach for evaluating applicable fuel operation within the incremental burnup range, subject to the limitations and conditions specified in Section 4.0 of this SE.

Of particular significance is the limitation requiring placement of fuel assemblies operating in the incremental burnup range at peripheral core locations, which assures that the fuel assemblies will be operated at low power levels and generally remain non-limiting with respect to most safety analysis acceptance criteria. The NRC staff's acceptance of the methods described in WCAP-18446-P/WCAP-18446-NP, Revision 0, for the proposed application does not signify the NRC staff’s review and approval of these methods for other applications involving unrestricted placement of fuel assemblies with burnups greater than 62 GWd/MTU.

## 6.0 ABBREVIATIONS

| | |
|---|---|
| ADOPT | Advanced Doped Pellet Technology |
| AOO | Anticipated operational occurrences |
| ASME | American Society of Mechanical Engineers |
| ASTRUM | Automated Statistical Treatment of Uncertainty Method |
| BOL | Beginning of life |
| BPVC | Boiler and Pressure Vessel Code |
| CE | Combustion Engineering |
| COLR | Core operating limits report |
| CQD | Code Qualification Document |
| CRE | Control rod ejection |
| DBA | Design-basis accidents |
| DNB | Departure from nucleate boiling |
| ECCS | Emergency core cooling system |
| EOL | End of life |
| FCEP | Fuel Criteria Evaluation Process |
| FFRD | Fuel fragmentation, relocation, and dispersal |
| FGR | Fission gas release |
| FHA | Fuel Handling Accident |
| IFBA | Integral fuel burnable absorber |
| IFM | Intermediate flow mixers |
| LOCA | Loss-of-coolant accident |
| M&E | Mass and energy |
| MSLB | Main steam line break |
| NFI | Nuclear Fuels Industries |
| NFIF | Normalized fission interaction frequency |
| NRC | Nuclear Regulatory Commission |
| OFA | Optimized Fuel Assembly |
| PCI | Pellet-cladding interaction |
| PCMI | Pellet-cladding mechanical interaction |
| PCT | Peak cladding temperature |
| PIE | Post-irradiation examination |
| PIRT | Phenomenon identification and ranking table |
| PNNL | Pacific Northwest National Laboratory |

| | |
|---|---|
| RAI | Request for additional information |
| RCA | Rod control assemblies |
| RCCA | Rod cluster control assemblies |
| RCP | Reactor coolant pump |
| RCS | Reactor coolant system |
| SGTR | Steam generator tube rupture |
| SRA | Stress relief annealed |
| TCS | Transient cladding strain |
| TR | Topical report |
| TRD | Thermal reaction accumulated duty |
| TS | Technical specifications |
| UFSAR | Updated final safety analysis report |
| UTS | Ultimate tensile strength |
| WABA | Wet annular burnable absorber |
| YS | Yield strength |

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| | |
|---|---|
| Principal Contributors: | John Lehning<br>Kevin Heller<br>Brandon Wise |

Date: June 26, 2024

## APPENDIX A - U.S. NUCLEAR REGULATORY COMMISSION AUDIT

### BACKGROUND

By letter dated December 14, 2020 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML20350B834), Westinghouse Electric Company (Westinghouse) submitted Topical Report (TR) WCAP-18446-P/WCAP-18446-NP, Revision 0, "Incremental Extension of Burnup Limit for Westinghouse and Combustion Engineering Fuel Designs" (ADAMS Package No. ML20351A157) to the U.S. Nuclear Regulatory Commission (NRC) for review and approval. WCAP-18446-P/WCAP-18446-NP, Revision 0, presents a rationale and an application methodology for existing Westinghouse codes for analyses of PWR non-loss-of-coolant accident (LOCA) events identified in Chapter 15 of NUREG-0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants" (SRP), LOCA events, and nuclear design to burnups beyond the currently licensed limit of 62 GWd/MTU. WCAP-18446-P/WCAP-18446-NP, Revision 0, TR does not discuss increasing uranium-235 enrichment beyond the currently licensed limit of 5 weight percent, and therefore the burnup range requested by Westinghouse is limited to only a modest increase beyond the current licensing limit.

In January 2021, the NRC staff began an acceptance review of the TR and concluded that additional information was necessary before a formal review effort could begin. In a meeting with Westinghouse on February 11, 2021 (ADAMS Package Accession No. ML21042B315), the NRC discussed its acceptance review findings. Westinghouse indicated the necessary additional information identified by the NRC was available and could be readily compiled into a supplement which was submitted via letter dated (ADAMS Package Accession No. ML21134A146). The NRC subsequently accepted the TR for review (ADAMS Accession No. ML21053A412).

Because the initial submittal of the Westinghouse WCAP-18446-P/WCAP-18446-NP, Revision 0, TR required additional information for the NRC staff to begin its review, the NRC staff proposed to conduct a regulatory audit in an effort to increase efficiency, facilitate discussion, and clarify issues identified during the NRC staff's initial review. The audit was conducted virtually from April 8 through April 9, 2021. The audit was held in accordance with the U.S. NRC Office of Nuclear Reactor Regulation procedure as described in LIC-111, "Regulatory Audits," and under the guidance provided in LIC-500, Revision 9, "Topical Report Process." The audit was closed due to the proprietary nature of the information discussed. The information discussed during the audit was determined to be proprietary by the NRC staff. Based on the results of the audit, the NRC issued its requests for additional information via email dated December 15, 2021 (ADAMS Accession No. ML21344A076).

### REGULATORY AUDIT OBJECTIVES

The objective of this audit was to increase review process efficiency through direct interaction with Westinghouse's technical experts. More specifically, in preparation for the audit, Westinghouse made available, through their online document portal, a draft supplement document comprising additional information addressing concerns identified by the NRC staff during the acceptance review. The audit allowed the NRC staff to examine this supplemental document and obtain clarification on its contents, have extended discussions about differences in technical opinion, examine supportive documentation for the supplemental information and for the TR as submitted, and identify those areas of the review that need additional focus.

The list of participants for Day 1 is contained in the table below:

| **Name** | **Affiliation** |
|---|---|
| **Day 1** | |
| Paul Clifford | NRC |
| Kevin Heller | NRC |
| John Lehning | NRC |
| Elijah Dickson | NRC |
| Ekaterina Lenning | NRC |
| | |
| Uriel Bachrach | Westinghouse |
| Andrew Bowman | Westinghouse |
| Zeses Karoutas | Westinghouse |
| Jesse Klingensmith | Westinghouse |
| Jeffrey Kobelak | Westinghouse |
| James Laird | Westinghouse |
| Yun Long | Westinghouse |
| Ho Lam | Westinghouse |
| David Mitchell | Westinghouse |
| Mike Sivack | Westinghouse |
| Yixing Sung | Westinghouse |

The list of participants for Day 2 is contained in the table below:

| Name | Affiliation |
|---|---|
| **Day 2** | |
| Paul Clifford | NRC |
| Kevin Heller | NRC |
| John Lehning | NRC |
| Elijah Dickson | NRC |
| Ekaterina Lenning | NRC |
| | |
| Uriel Bachrach | Westinghouse |
| Jeffrey Kobelak | Westinghouse |
| James Laird | Westinghouse |
| Ho Lam | Westinghouse |
| Yun Long | Westinghouse |
| Nathaniel Mackereth | Westinghouse |
| David Mitchell | Westinghouse |
| Mike Sivack | Westinghouse |
| Yixing Sung | Westinghouse |

## REGULATORY AUDIT BASES

Regulatory guidance for the review of fuel system materials and designs and adherence to the Title 10 of the *Code of Federal Regulations*, Appendix A to Part 50, General Design Criteria (GDC) 10, “Reactor Design,” GDC 27, “Combined Reactivity Control Systems Capability,” and GDC 35, “Emergency Core Cooling,” is provided in SRP Section 4.2, “Fuel System Design.” In accordance with SRP Section 4.2, the objectives of the fuel system safety review are to provide reasonable assurance that: (1) the fuel system is not damaged as a result of normal operation and anticipated operational occurrences (AOOs), (2) fuel system damage is never so severe as to prevent control rod insertion when it is required, (3) the number of fuel rod failures is not underestimated for postulated accidents, and (4) coolability is always maintained. Regulatory guidance for the review of transient and accident analysis methods is provided in SRP Section 15.0.2, “Review of Transient and Accident Analysis Method.”

## DISCUSSION

During the acceptance review of the WCAP-18446-P/WCAP-18446-NP, Revision 0, the NRC staff identified four technical topics where additional information was required before a formal review could begin. These topics included:

1. Disposition of recent research findings concerning cladding embrittlement under LOCA conditions.

2. Support justifying the fuel fragmentation, relocation, and dispersal (FFRD) burnup threshold.

3. Addressing burnup-related phenomena pertinent to radiological consequence analyses (e.g., fragmentation induced fission gas release) and the data used in the analyses.

4. Discussion of monitoring and controlling applicable process variables.

Prior to the audit, the NRC discussed these concerns with Westinghouse, and Westinghouse indicated information speaking to the concerns was available and could be readily compiled into a supplement. A draft of the supplement was made available to the NRC staff during the audit. Seeking understanding of and alignment on the information presented in the draft supplement was necessary for the NRC staff to proceed further in its review efforts. Therefore, the first day of the audit was reserved for interactions between the NRC staff and Westinghouse regarding the supplement and its contents.

The discussions regarding the draft supplement and how it addressed the four technical topics of concern were beneficial. Regarding topics 1 and 2, the NRC staff obtained a better understanding of Westinghouse's technical position and provided Westinghouse a more detailed description of the NRC staff's concerns. The NRC staff explained that the basis for the concerns for topic 2 is due in part to recent findings from the NRC's Office of Nuclear Regulatory Research (RES). RES has been collating and examining data associated with the FFRD phenomena, and the results suggest FFRD can occur at burnups less than 62 GWd/MTU. Westinghouse indicated additional information could be supplied to further justify its chosen FFRD burnup threshold. While full resolution of the concerns for topics 1 and 2 was not achieved within the audit, the NRC staff did conclude sufficient information was available to allow the review to proceed.

Regarding topic 3, the NRC staff obtained enough information and clarity to identify a potential path to the resolution of the concerns. Section 6 of WCAP-18446-P/WCAP-18446-NP, Revision 0, provides discussion for performing various radiological consequence analyses (e.g., LOCA, fuel handling accident, etc.). Westinghouse's intent was to present a method that would be exercised on a plant-specific basis during implementation, particularly regarding addressing pertinent burnup-related phenomena, such as fragmentation-induced fission gas release. The NRC staff observed the approach and some of the data utilized were not consistent with the anticipated Revision 1 to Regulatory Guide 1.183. Westinghouse indicated understanding of the staff's concern, but also expressed apprehension due to the uncertainty of when RG 1.183, Revision 1, would be issued and the need to provide customers with a methodology in the interim. As a solution, Westinghouse proposed the **[** **]** in the WCAP-18446-P/WCAP-18446-NP, Revision 0, TR that would **[** **]** The NRC staff agreed this may be a viable path towards resolution of the concern but would require assessment of the **[** **]** to know for sure. This wording is to be provided in the submittal of the supplemental information document.

Regarding topic 4, the NRC staff identified a path that allowed for additional discussion of the concern while also allowing the review to proceed forward. Westinghouse indicated understanding regarding the NRC's audit discussion on the necessity of monitoring and controlling applicable process variables and that the justification presented in the TR for proceeding to an incremental burnup relies heavily on certain parameters that potentially qualify for this. Westinghouse expressed that, at present, its position is the core reload checklist and the physical limitations on core design make the monitoring and controlling of any incremental burnup-dependent parameters unnecessary. However, Westinghouse requested additional time to consider the matter internally, and the NRC staff indicated the question may be posed as a future request for additional information (RAI) in order to continue the discussion.

Day two of the audit was set aside to discuss any additional questions or technical concerns identified by the NRC staff during its review of the WCAP-18446-P/WCAP-18446-NP, Revision 0, TR to-date. Predominantly, the additional questions identified by the NRC staff were of clarification in nature. Westinghouse was responsive to these clarification questions, and the resulting discussion aided the NRC staff in understanding the submittal.

## EXAMINED AUDIT DOCUMENTS

1. "Draft Supplemental Submittal to Incremental Burnup Topical Report WCAP-18446-P/ WCAP-18446-NP," Revision 0-A, March 2021.

2. CN-LIS-20-26, Revision 0, "Burnup Extension: Cladding Rupture Calculation Method," Jeffrey Kobelak and Scott E. Fortune.

## CONCLUSION

The regulatory audit accomplished the objectives listed in Section 2.0 by allowing direct interaction with Westinghouse's technical experts. The NRC staff obtained clarification on the contents of the supplement, examined calculation notes supporting the supplement and the TR as-submitted, and discussed at-length differences in technical opinion. The clarifications and examined calculation notes helped the NRC staff's review. The discussions on the topics of concern allowed the NRC staff and Westinghouse to reassess positions and facilitate full resolution of these concerns during the review process via RAIs and audits. Additionally, the NRC staff concluded that the supplemental information drafted by Westinghouse provided sufficient information for the NRC staff's concerns to allow the review to continue forward. Following the audit, Westinghouse voluntarily submitted the supplemental information to support the NRC staff's review of the TR.

## NRC RESOLUTION OF COMMENTS TABLE

The table is a record of Westinghouse’s proprietary markup and voluntary comments contained in Enclosure 2 (ADAMS Accession No. ML24106A302 (Non-publicly available/Proprietary)) to the publicly available letter dated April 12, 2024 (ADAMS Accession No. ML24106A301) that Westinghouse submitted following the issuance of the draft SE issued by the NRC via letter dated February 26, 2024 (ADAMS Accession No. ML23278A058) for proprietary review, and Westinghouse’s amended proprietary markup and voluntary comments in Enclosure 2 (ADAMS Accession No. ML24152A302 (Non-publicly available/Proprietary)) submitted by Westinghouse via publicly available letter dated May 29, 2024 (ADAMS Accession No. ML24152A297). Table includes the NRC staff’s resolution. Comment page and line number refer only to the draft SE and will not correspond to the final SE as pages and line numbers have shifted.

**Table: Resolution of comments**

| Draft SE Page No. | Line No. | Comment Type | Westinghouse Suggested Revision | NRC Resolution |
|---|---|---|---|---|
| 1 | 37 | Proprietary Markup | Please mark proprietary as follows:<br>“... **[** **]** ... ” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 1 | 38 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[** **]** …” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 1 | 39 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[** **]** …” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 1 | 40 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[** **]** …” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 2 | 10 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[** **]** …” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 7 | 15 | Editorial | Please change “containment performance” to “radiological dose” | Comment acceptable. Change made. |

**Table: Resolution of comments (Continued)**

| Draft SE Page No. | Line No. | Comment Type | Westinghouse Suggested Revision | NRC Resolution |
|---|---|---|---|---|
| 7 | 25 | Proprietary Markup | Please mark proprietary as follows:<br>“… [<br>] …” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 8 | 7-9 | Proprietary Markup | Please mark proprietary as follows:<br>“… [<br>]…” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 8 | 12 | Proprietary Markup | Please mark proprietary as follows:<br>“… [<br>] …” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 8 | 14-15 | Proprietary Markup | Please mark proprietary as follows:<br>“… [<br>]” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 10 | 32-33 | Proprietary Markup | Please extend to mark proprietary as follows:<br>“… [<br>] …” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |

## Table: Resolution of comments (Continued)

| Draft SE Page No. | Line No. | Comment Type | Westinghouse Suggested Revision | NRC Resolution |
|---|---|---|---|---|
| 11 | 40-43 | Technical | Please modify this sentence as follows: "In this regard, any credit taken for power burndown for the incremental burnup fuel rods, whether implicit or explicit, should be consistent with or bounded by the proposed burndown associated with the core operating limits report item discussed below in Section 3.3.5.6 that is associated with preventing cladding rupture in a LOCA (accounting for any difference in rod versus assembly burnup, uncertainty application, etc.)."<br>The burndown assumed relative to rod bow is a **[** **]**<br>The basis is different than the proposed $F_{\Delta H}^{N}$ limit for the incremental burnup fuel rods to preclude rupture during a postulated LOCA. | Comment acceptable with the modifications added by the NRC staff for clarity to read:<br>"In this regard, any credit taken for power burndown to compensate for assembly bow, whether implicit or explicit, should be within the proposed burndown associated with the core operating limits report discussed below in Section 3.3.5.6 that is associated with preventing cladding rupture in a LOCA for fuel rods in the incremental burnup range (accounting for any different in rod versus assembly burnup, uncertainty application, etc.)." |
| 14 | 38 | Proprietary Markup | Please mark proprietary as follows:<br>"… **[** **]** …" | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |

## Table: Resolution of comments (Continued)

| Draft SE Page No. | Line No. | Comment Type | Westinghouse Suggested Revision | NRC Resolution |
|---|---|---|---|---|
| 15 | 12 | Amended Proprietary Markup | Please do not mark as proprietary information below that is publicly available:<br>“… best-estimate, circumferentially averaged …” | Initial comment in Enclosure 2 to ML24106A301 was rejected by the NRC staff because information does not meet the requirements of 10 CFR 2.390 (information is publicly available). Westinghouse amended its proprietary markup suggestion in the Enclosure 2 to ML24152A297 stating that the information is non-proprietary. |
| 15 | 22 | Editorial | Please change “WCAP-17642-P-A” to “WCAP-17642-P-A, Revision 1” | Comment acceptable. Change made. |
| 15 | 40 | Editorial | Please change “Mode” to “Model” | Comment acceptable. Change made. |
| 16 | 14-15 | Editorial | Please remove unnecessary close and open bracket for the proprietary markings | Comment acceptable. Change made. |
| 19 | 34-35 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[** **]**” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 21 | 40-41 | Amended Proprietary Markup | Please mark proprietary as follows:<br>“…very few data available within the extended burnup range, only **[** **]**” | Comment acceptable with the revised proprietary markings suggested by Westinghouse in Enclosure 2 to ML24152A297. Text marked as indicated below:<br>“…very few data available within the extended burnup range, only **[** **]**” |
| 22 | 1-2 | Proprietary Markup | Please extend to mark proprietary as follows:<br>“… **[** **]** …” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |

**Table: Resolution of comments (Continued)**

| Draft SE Page No. | Line No. | Comment Type | Westinghouse Suggested Revision | NRC Resolution |
|---|---|---|---|---|
| 22 | 9-10 | Amended Proprietary Markup | Please mark proprietary as follows:<br>"… few data available **[ ]** …" | Comment acceptable with the revised proprietary markings suggested by Westinghouse in Enclosure 2 to ML24152A297. Text marked as indicated below:<br>"…few data available **[ ]** …" |
| 22 | 13 | Proprietary Markup | Please mark proprietary as follows:<br>"… **[ ]** …" | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 22 | 15-17 | Proprietary Markup | Please mark proprietary as follows:<br>"… **[ ]** …" | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 22 | 19-21 | Proprietary Markup | Please mark proprietary as follows:<br>"… **[ ]** …" | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |

**Table: Resolution of comments (Continued)**

| Draft SE Page No. | Line No. | Comment Type | Westinghouse Suggested Revision | NRC Resolution |
|---|---|---|---|---|
| 23 | 3 | Amended Proprietary Markup | Please do not mark proprietary:<br>"… comparatively few data present …" | Initial comment in Enclosure 2 to ML24106A301 was rejected by the NRC staff; statement is non-proprietary per NRC staff judgment. Westinghouse amended its proprietary markup suggestion in the proprietary Enclosure 2 to publicly available letter ML24152A297 to indicate that the information is non-proprietary, and no proprietary markup is needed. |
| 23 | 24-25 | Proprietary Markup | Please remove proprietary markings | Comment acceptable. Proprietary markings removed. |
| 23 | 43-44 | Proprietary Markup | Please remove proprietary markings | Comment acceptable. Proprietary markings removed. |
| 24 | 13 | Editorial | Please change "rod-average burnup" to "local burnup" | Comment acceptable. Change made. |
| 26 | 14-15 | Proprietary Markup | Please mark proprietary as follows:<br>"… **[**<br>**]**" | Comment Acceptable - marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 27 | 13-14 | Amended Proprietary Markup | Please mark proprietary as follows:<br>"… sparse at higher burnups **[**<br>**]**<br>..." | Comment acceptable with the revised proprietary markings suggested by Westinghouse in Enclosure 2 to ML24152A297. Text marked as indicated below:<br>"… sparse at higher burnups **[**<br>**]** …" |
| 27 | 35-36 | Proprietary Markup | Please mark proprietary as follows:<br>"… **[**<br>**]** ..." | Comment acceptable - marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |

**Table: Resolution of comments (Continued)**

| Draft SE Page No. | Line No. | Comment Type | Westinghouse Suggested Revision | NRC Resolution |
|---|---|---|---|---|
| 29 | 24-26 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[** **]** ...” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 29 | 32-34 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[** **]** ...” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 29 | 46-48 | Amended Proprietary Markup | Please mark proprietary as follows:<br>“… contain very few **[** **]** data in the range of the requested rod-average burnup extension. The paucity of data ...” | Comment acceptable with the revised proprietary markings suggested by Westinghouse in Enclosure 2 to ML24152A297. Text marked as indicated below:<br>“…contain very few **[** **]** data in the range of the requested rod-average burnup extension. The paucity of data…” |
| 30 | 1 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[** **]** ...” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 30 | 6 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[** **]** ...” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 30 | 17 | Editorial | Please add a blank line prior to this line (consistent with formatting in balance of SER) | Comment acceptable. Change made. |

**Table: Resolution of comments (Continued)**

| Draft SE Page No. | Line No. | Comment Type | Westinghouse Suggested Revision | NRC Resolution |
|---|---|---|---|---|
| 30 | 37 | Editorial | Please change “WCAP-17642-P-A” to “WCAP-17642-P-A, Revision 1” | Comment acceptable. Change made. |
| 31 | 5 | Amended Proprietary Markup | Please mark proprietary as follows:<br>“… limited **[** **]** ...” | Comment acceptable with the revised proprietary markings suggested by Westinghouse in Enclosure 2 to ML24152A297. Text marked as indicated below:<br>“…limited **[** **]** …”. |
| 32 | 19-21 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[** **]** ...” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 32 | 31-32 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[** **]** ...” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 35 | 26 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[** **]** ...” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 35 | 36 | Editorial | Please change “WCAP-17642-P-A” to “WCAP-17642-P-A, Revision 1” | Comment acceptable. Change made. |

## Table: Resolution of comments (Continued)

| Draft SE Page No. | Line No. | Comment Type | Westinghouse Suggested Revision | NRC Resolution |
|---|---|---|---|---|
| 36 | 37-43 | Proprietary Markup | Please extend to mark proprietary as follows:<br>"… **[** **]** ..." | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 37 | 38 | Proprietary Markup | Please mark proprietary as follows:<br>"… **[** **]** ..." | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 37 | 39 | Proprietary Markup | Please mark proprietary as follows:<br>"… **[** **]** ..." | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 39 | 35-36 | Proprietary Markup | Please mark proprietary as follows:<br>"… **[** **]** ..." | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 39 | 36-37 | Amended Proprietary Markup | Please mark proprietary as follows:<br>"… sparse **[** **]** data available at higher burnups ..." | Comment acceptable with the revised proprietary markings suggested by Westinghouse in Enclosure 2 to ML24152A297. Text marked as indicated below:<br>"…sparse **[** **]** data at higher burnups…" |
| 39 | 48 | Editorial | Please change "WCAP-17642-P-A" to "WCAP-17642-P-A, Revision 1" | Comment acceptable. |

**Table: Resolution of comments (Continued)**

| Draft SE Page No. | Line No. | Comment Type | Westinghouse Suggested Revision | NRC Resolution |
|---|---|---|---|---|
| 41 | 21 | Proprietary Markup | Please mark proprietary as follows:<br>"… **[ ]** ..." | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 42 | 9-11 | Proprietary Markup | Please extend to mark proprietary as follows:<br>"… **[ ]** ..." | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 43 | 33-34 | Proprietary Markup | Please mark proprietary as follows:<br>"… **[ ]**" | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 44 | 47 | Technical | Suggest an update to include:<br>"… simple, empirical thresholds based on conservative interpretations at which FFRD phenomena which have been experimentally observed …" consistent with the characterization throughout the SE | Comment acceptable with slight modification added by the NRC staff (for clarity) to read:<br>"… simple, conservative, empirical thresholds based on the conservative interpretations at which FFRD phenomena have been experimentally observed, …" |
| 45 | 35 | Editorial | Suggest updating "interim" to "incremental" for consistency with the topical report and use throughout. | Comment acceptable. Change made. |
| 45 | 40-42 | Proprietary Markup | Please extend to mark proprietary as follows:<br>"… **[ ]** ..." | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |

**Table: Resolution of comments (Continued)**

| Draft SE Page No. | Line No. | Comment Type | Westinghouse Suggested Revision | NRC Resolution |
|---|---|---|---|---|
| 46 | 16 | Proprietary Markup | Please mark proprietary as follows:<br>“… [ ] ...” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 46 | 16 | Editorial | Please update units from “WG/MTU” to “GWd/MTU.” | Comment acceptable. Change made. |
| 46 | 21 | Editorial | Suggest updating “interim” to “incremental” for consistency with the topical report and use throughout. | Comment acceptable. Change made. |
| 46 | 22-23 | Proprietary Markup | Please mark proprietary as follows:<br>“… [ ]” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 46 | 29-31 | Proprietary Markup | Please mark proprietary as follows:<br>“… [ ] ...” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 46 | 35-36 | Proprietary Markup | Please mark proprietary as follows:<br>“… [ ]” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 46 | 37-41 | Proprietary Markup | Please mark proprietary as follows:<br>“… [ ]” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |

**Table: Resolution of comments (Continued)**

| Draft SE Page No. | Line No. | Comment Type | Westinghouse Suggested Revision | NRC Resolution |
|---|---|---|---|---|
| 46 | 44-45 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[**<br>**]** ...” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 46 | 47-48 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[**<br>**]**” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 47 | 3-5 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[**<br>**]**” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 47 | 7 | Editorial | Please change “FSLOCA” to “FSLOCA evaluation Model” | Comment acceptable. Change made. |
| 47 | 7-9 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[**<br>**]**” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 47 | 23-25 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[**<br>**]**” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |

**Table: Resolution of comments (Continued)**

| Draft SE Page No. | Line No. | Comment Type | Westinghouse Suggested Revision | NRC Resolution |
|---|---|---|---|---|
| 47 | 28 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[** **]** ...” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 47 | 39-40 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[** **]** ...” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 47 | 43 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[** **]**” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 47 | 46 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[** **]** ...” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |

**Table: Resolution of comments (Continued)**

| Draft SE Page No. | Line No. | Comment Type | Westinghouse Suggested Revision | NRC Resolution |
|---|---|---|---|---|
| 48 | 1-3 | Proprietary Markup | Please mark proprietary as follows:<br>"… **[** **]** ..." | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 48 | 7-12 | Proprietary Markup | Please mark proprietary as follows:<br>"… **[** **]** from WCAP-18446-P/WCAP-18446-NP, Revision 0. The NRC staff found **[** **]** to be an acceptable means for satisfying 10 CFR 50.46(a)(1). **[** **]** further resolved the NRC staff's request in RAI 18 that Westinghouse provide adequate evidence of the **[** **]**" | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 49 | 2-3 | Proprietary Markup | Please mark proprietary as follows:<br>"… **[** **]** ..." | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 49 | 9-11 | Proprietary Markup | Please mark proprietary as follows:<br>"… **[** **]** ..." | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 49 | 14-15 | Proprietary Markup | Please mark proprietary as follows:<br>"… **[** **]**" | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |

**Table: Resolution of comments (Continued)**

| Draft SE Page No. | Line No. | Comment Type | Westinghouse Suggested Revision | NRC Resolution |
|---|---|---|---|---|
| 49 | 19 | Proprietary Markup | Please mark proprietary as follows:<br>“… [<br>]” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 49 | 26-27 | Proprietary Markup | Please mark proprietary as follows:<br>“… [<br>] ...” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 49 | 31-33 | Proprietary Markup | Please mark proprietary as follows:<br>“… [<br>] …” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 49 | 38 | Proprietary Markup | Please mark proprietary as follows:<br>“… [<br>]” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 50 | 5-6 | Proprietary Markup | Please mark proprietary as follows:<br>“… [<br>]” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 50 | 20 | Editorial | Please change “FSLOCA” to “the FSLOCA evaluation model” | Comment acceptable. Change made. |

## Table: Resolution of comments (Continued)

| Draft SE Page No. | Line No. | Comment Type | Westinghouse Suggested Revision | NRC Resolution |
|---|---|---|---|---|
| 50, 51 | 51, 1-3 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[**<br>**]**” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 51 | 12-15 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[**<br>**]**” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 51 | 38 | Editorial | Please change “FSLOCA” to “the FSLOCA evaluation model” | Comment acceptable. Change made. |
| 52 | N/A | Proprietary Markup | Please mark proprietary as follows in the disposition of "Stored energy" in Table 1:<br>“… **[**<br>**]**” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |

**Table: Resolution of comments (Continued)**

| Draft SE Page No. | Line No. | Comment Type | Westinghouse Suggested Revision | NRC Resolution |
|---|---|---|---|---|
| 52 | N/A | Proprietary Markup | Please mark proprietary as follows in the disposition of "Cladding oxidation" in Table 1:<br>"… **[ ]** described in WCAP-18446-P/WCAP-18446-NP, Revision 0, because **[ ]** ..."<br>and<br>"... **[ ]** ..." | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 53 | N/A | Proprietary Markup | Please mark proprietary as follows in the disposition of "Critical heat flux" in Table 1:<br>"… **[ ]** As such, Westinghouse concluded that **[ ]**" | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |

## Table: Resolution of comments (Continued)

| Draft SE Page No. | Line No. | Comment Type | Westinghouse Suggested Revision | NRC Resolution |
|---|---|---|---|---|
| 53 | N/A | Proprietary Markup | Please mark proprietary as follows in the disposition of "Post-critical-heat-flux heat transfer/Steam cooling" in Table 1:<br>"… **[** **]** The NRC staff agrees with Westinghouse's assessment of phenomenon importance; while the thickness of the oxide layer may increase with burnup, **[** **]** ..." | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 53 | N/A | Proprietary Markup | Please mark proprietary as follows in the disposition of "Rewet /$T_{min}$" in Table 1:<br>"… **[** **]**<br>The NRC staff agrees with Westinghouse's assessment of phenomenon importance; while the thickness of the oxide layer may increase with burnup, **[** **]** ..." | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 53 | N/A | Proprietary Markup | Please mark proprietary as follows in the disposition of "Heat transfer to a covered core" in Table 1:<br>"… **[** **]** ..." | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |

**Table: Resolution of comments (Continued)**

| Draft SE Page No. | Line No. | Comment Type | Westinghouse Suggested Revision | NRC Resolution |
|---|---|---|---|---|
| 53 | N/A | Proprietary Markup | Please mark proprietary as follows in the disposition of "Radiation heat transfer" in Table 1:<br>"… **[** **]** ..." | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 54 | N/A | Proprietary Markup | Please mark proprietary as follows in the disposition of "3-D flow/Core natural circulation" in Table 1:<br>"… **[** **]** ..." | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 54 | N/A | Proprietary Markup | Please mark proprietary as follows in the disposition of "Void generation/Void distribution" in Table 1:<br>"… **[** **]** ..." | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 54 | N/A | Proprietary Markup | Please mark proprietary as follows in the disposition of "Flow reversal/Stagnation" in Table 1:<br>"... **[** **]** the NRC staff deemed review of the information contained in Section 4.7.3.2.2 of WCAP-18446-P/WCAP-18446-NP, Revision 0, unnecessary. Beyond this, considering the evidence of **[** **]** ..." | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 54 | N/A | Proprietary Markup | Please mark proprietary as follows in the disposition of "Flow resistance" in Table 1:<br>"… **[** **]** ..." | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |

## Table: Resolution of comments (Continued)

| Draft SE Page No. | Line No. | Comment Type | Westinghouse Suggested Revision | NRC Resolution |
|---|---|---|---|---|
| 55 | 3 | Editorial | Please change “FSLOCA model” to “the FSLOCA evaluation model” in the disposition of “Gas pressure and rod free volume” in Table 2 | Comment acceptable. Change made. |
| 55 | N/A | Proprietary Markup | Please mark proprietary as follows in the disposition of “Burst criteria” in Table 2:<br>“… relates to a **[ ]** ...” and “…phenomenon to the **[ ]** …” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 56 | N/A | Editorial | Please change “(b)(4)” to “(b)(2)” in the disposition of “Cladding oxidation magnitude” in Table 2. | Comment acceptable. Change made. |
| 56 | N/A | Proprietary Markup | Please mark proprietary as follows in the disposition of “Cladding oxidation magnitude” in Table 2:<br>“Westinghouse stated that the magnitude of cladding oxidation is of **[ ]** The NRC staff agrees with this position, as discussed above in Section 3.3.3 of this safety evaluation.<br>Westinghouse added that the FSLOCA evaluation model further assumes that the pre-existing oxidation layer expected to be present on fuel cladding **[ ]** The NRC staff recognizes the **[ ]** as a modeling conservatism.” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |

**Table: Resolution of comments (Continued)**

| Draft SE Page No. | Line No. | Comment Type | Westinghouse Suggested Revision | NRC Resolution |
|---|---|---|---|---|
| 56 | N/A | Proprietary Markup | Please mark proprietary as follows in the disposition of "Burst criteria" in Table 2:<br>"… relates to a **[ ]** ..." and<br>"… phenomenon to the **[ ]** …" | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 57 | 21-40 | Proprietary Markup | Please mark proprietary as follows:<br>"… **[ ]**" | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 57, 58 | 43, 1-9 | Proprietary Markup | Please mark proprietary as follows:<br>"… **[ ]**" | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 58 | 17-20 | Proprietary Markup | Please mark proprietary as follows:<br>"… **[ ]** The NRC staff's conclusion further relies upon the additional evidence provided in Westinghouse's response to RAI 20, which demonstrated **[ ]**" | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 58 | 32-47 | Proprietary Markup | Please mark proprietary as follows:<br>"… **[ ]**<br>Upon consideration of the experimental results in the references from **[ ]** ..." | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |

**Table: Resolution of comments (Continued)**

| Draft SE Page No. | Line No. | Comment Type | Westinghouse Suggested Revision | NRC Resolution |
|---|---|---|---|---|
| 59 | 1-3 | Proprietary Markup | Please mark proprietary as follows:<br>"… **[**<br>**]**" | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 59 | 13-25 | Proprietary Markup | Please mark proprietary as follows:<br>"… **[**<br>**]** ..." | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 59 | 32-34 | Proprietary Markup | Please mark proprietary as follows:<br>"… **[**<br>**]**" | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 59 | 37-42 | Proprietary Markup | Please mark proprietary as follows:<br>"… **[**<br>**]** for zircaloy-2 and zircaloy-4, and **[**<br>**]** for ZIRLO and Optimized ZIRLO. Westinghouse stated that the **[** **]** in the database significantly exceed the expected values associated with the incremental burnup extension, which would result in a **[**<br>**]**" | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 59 | 46-48 | Proprietary Markup | Please mark proprietary as follows:<br>"… **[**<br>**]**" | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |

**Table: Resolution of comments (Continued)**

| Draft SE Page No. | Line No. | Comment Type | Westinghouse Suggested Revision | NRC Resolution |
|---|---|---|---|---|
| 60 | 1-2 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[** **]**” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 60 | 16-18 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[** **]** However, as discussed above, Westinghouse identified the need to validate its model against<br>**[** **]**” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 60 | 20-21 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[** **]**” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 60 | 23-28 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[** **]**” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |

**Table: Resolution of comments (Continued)**

| Draft SE Page No. | Line No. | Comment Type | Westinghouse Suggested Revision | NRC Resolution |
|---|---|---|---|---|
| 60 | 30-31 | Proprietary Markup | Please mark proprietary as follows:<br>"… **[** **]** …" | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 60 | 38-49 | Proprietary Markup | Please mark proprietary as follows:<br>"Westinghouse responded to RAI 11 by alluding to the **[** **]** methodology from the WCAP-18446-P/WCAP-18446- NP, Revision 0, methodology (as discussed above in Section 3.3.3 of this SE) and noting its desire to focus upon the proposed **[** **]** Westinghouse acknowledged that, for the FSLOCA evaluation model, which is also **[** **]** However, for WCAP 18446-P/WCAP-18446-NP, Revision 0, Westinghouse proposed **[** **]** Westinghouse stated that its revised rupture curve for WCAP-18446-P/WCAP- 18446-NP, Revision 0, would **[** **]** In particular, Westinghouse pointed out that its revised curve would maintain the general trends exhibited by the **[** **]**" | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |

**Table: Resolution of comments (Continued)**

| Draft SE Page No. | Line No. | Comment Type | Westinghouse Suggested Revision | NRC Resolution |
|---|---|---|---|---|
| 61 | 3-10 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[** **]** The expanded dataset better characterizes fuel rods in the incremental burnup range which may have **[** **]** Westinghouse stated in its response to RAI 11.2 that **[** **]** avoidance of which is a fuel rod design criterion. Figures 11-1 through 11-3 in Westinghouse’s response to RAI 11.2 demonstrate the **[** **]** ...” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 61 | 19 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[** **]** ...” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 61 | 36-42 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[** **]** determined by the PAD5 fuel performance code. Westinghouse further stated that **[** **]** Westinghouse observed that WCOBRA/TRAC-TF2 predictions for fuel rods with rod-average burnups between **[** **]**” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |

**Table: Resolution of comments (Continued)**

| Draft SE Page No. | Line No. | Comment Type | Westinghouse Suggested Revision | NRC Resolution |
|---|---|---|---|---|
| 61 | 44 | Editorial | Please change “FSLOCA” to “FSLOCA evaluation model” | Comment acceptable. Change made. |
| 61 | 47-51 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[**<br>**]** of cladding rupture, which is the relevant **[** **]** for the WCAP-18446- P/WCAP-18446-NP, Revision 0, methodology. Assuring **[**<br>**]**<br>...” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 62 | 4-5 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[**<br>**]**” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 62 | 8-18 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[**<br>**]**” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 62 | 22-29 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[**<br>**]**” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |

## Table: Resolution of comments (Continued)

| Draft SE Page No. | Line No. | Comment Type | Westinghouse Suggested Revision | NRC Resolution |
|---|---|---|---|---|
| 62 | 32-33 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[** **]** …” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 62 | 35-36 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[** **]** …” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 62 | 39 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[** **]** …” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 62 | 42-43 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[** **]** …” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 62 | 47 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[** **]** …” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |

## Table: Resolution of comments (Continued)

| Draft SE Page No. | Line No. | Comment Type | Westinghouse Suggested Revision | NRC Resolution |
|---|---|---|---|---|
| 62 | 50 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[** **]** …” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 63 | 1-12 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[** **]** is based on releases described in RIL-2021-13 for fuel rod segments with an **[** **]**” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 63 | 15-16 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[** **]** …” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 63 | 20 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[** **]** …” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 63 | 28-32 | Proprietary Markup | Please mark proprietary as follows:<br>“**[** **]**” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |

## Table: Resolution of comments (Continued)

| Draft SE Page No. | Line No. | Comment Type | Westinghouse Suggested Revision | NRC Resolution |
|---|---|---|---|---|
| 63 | 36-37 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[**<br>**]** …” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 63 | 43-44 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[**<br>**]**” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 63 | 46-50 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[**<br>**]**” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 64 | 2-5 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[**<br>**]**” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 64 | 9-10 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[**<br>**]**” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 64 | 21 | Editorial | Please change “FSLOCA” to “the FSLOCA evaluation model” | Comment acceptable. Change made. |
| 64 | 24-31 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[**<br>**]** ...” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |

**Table: Resolution of comments (Continued)**

| Draft SE Page No. | Line No. | Comment Type | Westinghouse Suggested Revision | NRC Resolution |
|---|---|---|---|---|
| 64 | 34-35 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[**<br>**]** ...” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 64 | 38-43 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[**<br>**]**” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 64 | 39 | Editorial | Please change “WCAP-17642-P-A” to “WCAP-17642-P-A, Revision 1” | Comment acceptable. Change made. |
| 65 | 24-25 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[**<br>**]** ...” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 66 | 20 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[** **]** ...” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 66 | 35-36 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[**<br>**]**” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |

**Table: Resolution of comments (Continued)**

| Draft SE Page No. | Line No. | Comment Type | Westinghouse Suggested Revision | NRC Resolution |
|---|---|---|---|---|
| 63 | 28-32 | Proprietary Markup | Please mark proprietary as follows:<br>“[<br>]” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 66 | 41-42 | Proprietary Markup | Please mark proprietary as follows:<br>“… [<br>]<br>...” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 66, 67 | 46-50, 1-3 | Proprietary Markup | Please mark proprietary as follows:<br>“… [<br>]” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 67 | 9-10 | Proprietary Markup | Please mark proprietary as follows:<br>“… [<br>]” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 67 | 16-17 | Proprietary Markup | Please mark proprietary as follows:<br>“… [<br>] ...” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |

## Table: Resolution of comments (Continued)

| Draft SE Page No. | Line No. | Comment Type | Westinghouse Suggested Revision | NRC Resolution |
|---|---|---|---|---|
| 67 | 20-25 | Proprietary Markup | Please mark proprietary as follows:<br>"… **[** **]** ..." and "… **[** **]**" | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 67 | 28-34 | Proprietary Markup | Please mark proprietary as follows:<br>"… **[** **]** to be acceptable based upon (1) the strong evidence observed during the NRC staff's review that **[** **]** and (2) Westinghouse's revision to the methodology in response to RAI 16 to apply the methodology to **[** **]** In this regard, the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology would be executed for **[** **]** ..." | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |

## Table: Resolution of comments (Continued)

| Draft SE Page No. | Line No. | Comment Type | Westinghouse Suggested Revision | NRC Resolution |
|---|---|---|---|---|
| 67 | 42-49 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[** **]** The NRC staff identified questions concerning the proposed **[** **]** including (in RAI 12) whether it would comply with requirements in 10 CFR 50.46(a)(1), and also (in RAI 14) whether results computed by the approach in a **[** **]** might be subject to significant variability which could challenge the approach’s effectiveness. In response, Westinghouse elected to **[** **]** method from the methodology and rely solely upon the **[** **]** ...” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 68 | 1 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[** **]** ...” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 68 | 4 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[** **]** ...” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 68 | 9 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[** **]** ...” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |

**Table: Resolution of comments (Continued)**

| Draft SE Page No. | Line No. | Comment Type | Westinghouse Suggested Revision | NRC Resolution |
|---|---|---|---|---|
| 68 | 12 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[** **]** ...” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 68 | 18 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[** **]** ...” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 68 | 23-27 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[**<br>**]**” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 68 | 32-38 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[**<br>**]** during a postulated LOCA:<br>• **[**<br>**]** ...” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 68 | 44 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[** **]** ...” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |

**Table: Resolution of comments (Continued)**

| Draft SE Page No. | Line No. | Comment Type | Westinghouse Suggested Revision | NRC Resolution |
|---|---|---|---|---|
| 68 | 46 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[** **]** ...” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 68 | 50 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[** **]** ...” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |

**Table: Resolution of comments (Continued)**

| Draft SE Page No. | Line No. | Comment Type | Westinghouse Suggested Revision | NRC Resolution |
|---|---|---|---|---|
| 68, 69 | 46-50, 1-3 | Technical | Please update this paragraph as follows:<br>“With respect to the **[** **]** Westinghouse discussed in response to RAI 21 its proposed procedure for calibrating the initial fuel average temperature and rod internal pressure. As for the FSLOCA evaluation model, in the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology, fuel rods would be initialized using the PAD5 code. Westinghouse stated that **[** **]** are the same as used in the approved FSLOCA evaluation model. The NRC staff found Westinghouse’s proposed treatment to be acceptable because it would add appropriate conservatism to the determination of the **[** **]** in a manner consistent with the existing FSLOCA evaluation model.”<br>Section 4.7.3.2 of WCAP-18446-P describes the “Treatment for Uncertainty Contributors for Deterministic Rupture Calculations.” The text cited in the draft SE from Section 4.7.3.2.1 of WCAP-18446-P correspondingly was specific to the deterministic approach to the cladding rupture calculations. The deterministic approach **[** **]** per the response to RAI #12 in LTR- NRC-22-4, and it was noted therein that **[** **]** from the topical report. It was then clarified in the response to RAI #21 (LTR-NRC-22-4) that the “**[** **]**” | Comment acceptable. Change made. |

**Table: Resolution of comments (Continued)**

| Draft SE Page No. | Line No. | Comment Type | Westinghouse Suggested Revision | NRC Resolution |
|---|---|---|---|---|
| 69 | 8 | Proprietary Markup | Please mark proprietary as follows:<br>"… [ ] ..." | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 69 | 15 | Proprietary Markup | Please mark proprietary as follows:<br>"… [<br>] ..." | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 69 | 18 | Editorial | Please change "FSLOCA" to "the FSLOCA evaluation Model" | Comment acceptable. Change made. |
| 69 | 23 | Proprietary Markup | Please mark proprietary as follows:<br>"… [ ] ..." | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 69 | 26 | Proprietary Markup | Please mark proprietary as follows:<br>"… [ ] ..." | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |

## Table: Resolution of comments (Continued)

| Draft SE Page No. | Line No. | Comment Type | Westinghouse Suggested Revision | NRC Resolution |
|---|---|---|---|---|
| 69 | 31-32 | Proprietary Markup | Please mark proprietary as follows:<br>"… **[** **]** during the blowdown phase of a LOCA for the **[** **]**" | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 69 | 37 | Proprietary Markup | Please mark proprietary as follows:<br>"… **[** **]** ..." | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 69 | 40-41 | Proprietary Markup | Please mark proprietary as follows:<br>"… **[** **]**" | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 69 | 45 | Editorial | Please change "FSLOCA" to "FSLOCA evaluation model" | Comment acceptable. Change made. |
| 69 | 45-50 | Proprietary Markup | Please mark proprietary as follows:<br>"… **[** **]** for modeling fuel in the incremental burnup range. In RAI 19, the NRC staff observed that the **[** **]** are based upon the assumption that the analyzed reactor operating domain would be **[** **]** ..." | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |

## Table: Resolution of comments (Continued)

| Draft SE Page No. | Line No. | Comment Type | Westinghouse Suggested Revision | NRC Resolution |
|---|---|---|---|---|
| 70 | 1-3 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[** **]** representative of the **[** **]** would be appropriate, since **[** **]** ...” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 70 | 8 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[** **]** ...” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 70 | 10-11 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[** **]**” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 70 | 15-18 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[** **]** Westinghouse acknowledged that its proposed approach of **[** **]** could lead to WCAP-18446-P/WCAP-18446-NP, Revision 0, analyses being performed at conditions **[** **]**” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 70 | 20-21 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[** **]** ...” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |

**Table: Resolution of comments (Continued)**

| Draft SE Page No. | Line No. | Comment Type | Westinghouse Suggested Revision | NRC Resolution |
|---|---|---|---|---|
| 70 | 29-35 | Proprietary Markup | Please mark proprietary as follows:<br>"… **[** **]** of all fuel rods residing in peripheral locations (i.e., the only permissible location for fuel rods in the incremental burnup range) would be **[** **]** these fuel rods would be assumed to **[** **]**). Westinghouse stated that this assumption would introduce a conservative bias into its modeling approach. The NRC staff agrees with this statement, since Westinghouse would be assuming **[** **]** ..." | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 70 | 38 | Proprietary Markup | Please mark proprietary as follows:<br>"… **[** **]** ..." | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 70 | 44 | Proprietary Markup | Please mark proprietary as follows:<br>"… **[** **]** ..." | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |

**Table: Resolution of comments (Continued)**

| Draft SE Page No. | Line No. | Comment Type | Westinghouse Suggested Revision | NRC Resolution |
|---|---|---|---|---|
| 70 | 49-51 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[ ]** Westinghouse proposed for several phenomena to ensure they adequately correspond to the **[ ]**” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 71 | 1-3 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[ ]** that is described in response to RAI 19.2, the NRC staff reached agreement with Westinghouse’s conclusion that there is no further need to modify **[ ]** ...” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 71 | 6-10 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[ ]** proposed by Westinghouse in response to RAI 19.2 to be acceptable because the modified approach would provide a representatively conservative estimate of the **[ ]** for fuel rods in the incremental burnup range **[ ]**” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 71 | 29 | Editorial | Please change “FSLOCA” to “the FSLOCA evaluation model” | Comment acceptable. Change made. |

**Table: Resolution of comments (Continued)**

| Draft SE Page No. | Line No. | Comment Type | Westinghouse Suggested Revision | NRC Resolution |
|---|---|---|---|---|
| 71 | 32-41 | Proprietary Markup | Please mark proprietary as follows:<br>“… [<br>] Westinghouse pointed out that the [<br>] Westinghouse further stated that an [<br>] Westinghouse added that, [<br>] Therefore, Westinghouse proposed in its response to RAI 15 to [<br>] ...” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 71 | 47 | Proprietary Markup | Please mark proprietary as follows:<br>“… [ ] ...” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |

## Table: Resolution of comments (Continued)

| Draft SE Page No. | Line No. | Comment Type | Westinghouse Suggested Revision | NRC Resolution |
|---|---|---|---|---|
| 74 | 7 | Proprietary Markup | Please mark proprietary as follows:<br>"… **[** **]** ..." | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 74 | 14 | Proprietary Markup | Please mark proprietary as follows:<br>"… **[** **]** ..." | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 74 | 19-23 | Proprietary Markup | Please mark proprietary as follows:<br>"… **[** **]** that were modified in subsequent RAI responses (e.g., RAI 19.2) are not included. The demonstration analysis performed by Westinghouse **[** **]**" | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 74 | 25-26 | Proprietary Markup | Please mark proprietary as follows:<br>"… **[** **]**" | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 75 | 10,12 | Editorial | Please change "AOOs" to "non-LOCA transients and accidents" because Section 5.1.1 covers both AOOs (aka transients) and accidents. | Comment acceptable. Change made. |
| 75 | 14 | Editorial | Please change "dependent on" to "analyzed to address" | Comment acceptable. Change made. |

**Table: Resolution of comments (Continued)**

| Draft SE Page No. | Line No. | Comment Type | Westinghouse Suggested Revision | NRC Resolution |
|---|---|---|---|---|
| 75 | 17-19 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[**<br>**]**” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 75 | 28 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[** **]** ...” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 75 | 31 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[** **]** ...” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 75 | 32-33 | Proprietary Markup | Please mark proprietary as follows:<br>“**[** **]** ...” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 75 | 35 | Editorial | Please change “would need” to “would not need” for clarity (current text could be interpreted as changes are needed). | Comment acceptable. Change made. |

**Table: Resolution of comments (Continued)**

| Draft SE Page No. | Line No. | Comment Type | Westinghouse Suggested Revision | NRC Resolution |
|---|---|---|---|---|
| 76 | 3 | Editorial | Recommend changing “high neutron flux or high RCS pressure” to “high neutron flux, high positive flux rate, or low RCS pressure” because a reactor trip on high RCS pressure would not be expected for a rod ejection. | Proposed edit is acceptable. Change made. |
| 76 | 8-9 | Proprietary Markup | Please mark proprietary as follows:<br>“**[**<br>**]** ...” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 76 | 14-15 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[**<br>**]**” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 76 | 19-20 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[**<br>**]**” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |

**Table: Resolution of comments (Continued)**

| Draft SE Page No. | Line No. | Comment Type | Westinghouse Suggested Revision | NRC Resolution |
|---|---|---|---|---|
| 76 | 23-24 | Proprietary Markup | Please mark proprietary as follows:<br>“… [ ]” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 77 | 37 | Editorial | Recommend changing “energy release” to “release of energy” | Comment acceptable. Change made. |
| 78 | 11-14 | Proprietary Markup | Please extend to mark proprietary as follows:<br>“… [ ]” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 79 | 14-17 | Proprietary Markup | Please extend to mark proprietary as follows:<br>“… [ ]” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 80 | 41 | Proprietary Markup | Please mark proprietary as follows:<br>“… [ ]” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |

**Table: Resolution of comments (Continued)**

| Draft SE Page No. | Line No. | Comment Type | Westinghouse Suggested Revision | NRC Resolution |
|---|---|---|---|---|
| 81 | 11 | Technical | Please change "and assume infinite reactor operation" to "to determine bounding decay heat inputs." The decay heat in LOFTRAN and RETRAN is based on **[** **]** | Comment acceptable. Change made. |

**Table: Resolution of comments (Continued)**

| Draft SE Page No. | Line No. | Comment Type | Westinghouse Suggested Revision | NRC Resolution |
|---|---|---|---|---|
| 82 | 44-49 | Proprietary Markup | Please mark proprietary as follows:<br>“**[ ]** While not described in Section 6, this requirement to **[ ]** ...” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 83 | 12-21 | Proprietary Markup | Please mark proprietary as follows:<br>“**[ ]**” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 83 | 37-41 | Proprietary Markup | Please mark proprietary as follows:<br>“**[ ]**” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 83 | 46-48 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[ ]** Westinghouse stated that such an analytical demonstration is expected to be achievable due to the **[ ]** ...” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 84 | 2 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[ ]**” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |

## Table: Resolution of comments (Continued)

| Draft SE Page No. | Line No. | Comment Type | Westinghouse Suggested Revision | NRC Resolution |
|---|---|---|---|---|
| 84 | 4 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[ ]** ...” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 84 | 7, 12 | Editorial | Please update the date for DG-1389 (ML21204A065) from “2021” to “2022” consistent with the DG. | Comment acceptable. Date corrected. |
| 84 | 7 | Technical | Table B-1 of DG-1327 (ML18302A106) lists different fractions from Table 3 as follows: 0.09 should be 0.06 for I-132, 0.38 should be 0.36 for Kr-85, 0.09 should be 0.05 for Other Noble Gases, and 0.50 should be 0.49 for Alkali Metals | Comment acceptable. Change made. |
| 84 | 7 | Technical | Table 4 of DG-1389 (ML21204A065) lists a fraction of 0.06 for Other Noble Gases, versus 0.08 shown in Table 3 | Comment acceptable. The values were corrected per DG-1389. |
| 84 | 7 | Proprietary | The burnup level representing the maximum applicability of DG-1389 is not proprietary. | Comment acceptable. Change made. |
| 84 | 9-10 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[**<br>**]**” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 84 | 12 | Editorial | The date for DG-1389 (ML21204A065) should be updated from “2021” to “2022” consistent with the DG. | Comment acceptable. Change made. |

**Table: Resolution of comments (Continued)**

| Draft SE Page No. | Line No. | Comment Type | Westinghouse Suggested Revision | NRC Resolution |
|---|---|---|---|---|
| 84 | 20 | Proprietary Markup | Please mark proprietary as follows:<br>“**[** **]** ...” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 84 | 24-25 | Proprietary Markup | Please mark proprietary as follows:<br>“**[** **]**” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 84 | 28 | Proprietary Markup | Please mark proprietary as follows:<br>“... **[** **]** ...” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 84, 85 | 31-38, 1 | Proprietary Markup | Please extend to mark proprietary as follows:<br>“**[** **]**” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 85 | 3-6 | Proprietary Markup | Please mark proprietary as follows:<br>“**[** **]** to account for the incremental burnup increase. This approach is conservative, as the **[** **]** Continued use of the **[** **]** ...” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |

**Table: Resolution of comments (Continued)**

| Draft SE Page No. | Line No. | Comment Type | Westinghouse Suggested Revision | NRC Resolution |
|---|---|---|---|---|
| 85 | 10-12 | Proprietary Markup | Please mark proprietary as follows:<br>“... **[**<br>**]**<br>Therefore, the **[**<br>**]** ...” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 85 | 16-21 | Proprietary Markup | Please mark proprietary as follows:<br>“**[**<br>**]**” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 85 | 24-33 | Proprietary Markup | Please mark proprietary as follows:<br>“**[**<br>**]**” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 85 | 44-48 | Proprietary Markup | Please mark proprietary as follows:<br>“... **[**<br>**]** if applicable to the plant’s licensing basis. Westinghouse stated that additional margin could be obtained by **[**<br>**]**” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |

**Table: Resolution of comments (Continued)**

| Draft SE Page No. | Line No. | Comment Type | Westinghouse Suggested Revision | NRC Resolution |
|---|---|---|---|---|
| 86 | 1-3 | Proprietary Markup | Please mark proprietary as follows:<br>“... **[**<br>**]**” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 86 | 17 | Editorial | The title of the cited topical report should be updated to add “Fuel” at the end, i.e., “Westinghouse Advanced Doped Pellet Technology (ADOPT) Fuel” | Comment acceptable. Change made. |
| 86 | 46-47 | Proprietary | Please remove proprietary markings. | Comment acceptable. Proprietary markings removed. |
| 89 | 4-5 | Proprietary Markup | Please mark proprietary as follows:<br>“... **[**<br>**]** ...” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 89 | 10-11 | Proprietary Markup | Please mark proprietary as follows:<br>“... **[**<br>**]** ...” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |

**Table: Resolution of comments (Continued)**

| Draft SE Page No. | Line No. | Comment Type | Westinghouse Suggested Revision | NRC Resolution |
|---|---|---|---|---|
| 90 | N/A | Proprietary Markup | Please mark proprietary as follows in the description of implementation requirement of "Transient and Non- LOCA Accident Analysis" in Table 4:<br>"Evaluation to confirm that **[** **]**<br>Perform analysis demonstrating that the acceptance criteria in RG 1.236 are satisfied, including fuel cladding failure thresholds, allowable limits on damaged core coolability, radiological consequences, and reactor coolant system pressure. The evaluation for addressing allowable limits on radiological consequences relies upon **[** **]**" | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 90 | N/A | Proprietary Markup | Please mark proprietary as follows in the description of implementation requirement of "Radiological Consequence Analysis" in Table 4: "Westinghouse introduced Limitation #9 which provides a self-imposed restriction on the **[** **]** described in Section 6. Limitation #9 restricts the use of the WCAP-18446-P/ WCAP-18446-NP, Revision 0, radiological consequence analysis methodology **[** **]** For the CRE event, licensees implementing the WCAP-18446-P/WCAP-18446-NP, Revision 0, methodology must **[** **]**" | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |

## Table: Resolution of comments (Continued)

| Draft SE Page No. | Line No. | Comment Type | Westinghouse Suggested Revision | NRC Resolution |
|---|---|---|---|---|
| 91 | N/A | Proprietary Markup | Please mark proprietary as follows in the description of implementation requirement of “Westinghouse Fuel Criteria Evaluation Process (FCEP)” in Table 4:<br>“… **[ ]** …” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |
| 92 | 36 | Editorial | Please change “the cladding rupture calculations” to “the LOCA cladding rupture calculations” | Comment acceptable. Change made. |
| 92 | 47-50 | Proprietary | The text in limitation and condition #8 is non-proprietary. | Comment acceptable. Proprietary brackets removed. |
| 93 | 20-25 | Technical | Please add the following text to the L&C<br>“…its proposed approach for implementing burnup dependence for rods that exceed 62 GWd/MTU into the $F_{\Delta H}^{N}$ core operating limit…”<br>to be clear that the intent of this L&C is to ensure peaking factors used for the LOCA cladding rupture calculations are met. | Comment acceptable. Proposed text added. |
| 100 | N/A | Editorial | Consider adding DG-1327 and DG-1389 to the list of references | Comment acceptable. Change made. |

**Table: Resolution of comments (Continued)**

| Draft SE Page No. | Line No. | Comment Type | Westinghouse Suggested Revision | NRC Resolution |
|---|---|---|---|---|
| 104 | 42-46 | Proprietary Markup | Please mark proprietary as follows:<br>“… **[** **]** in the WCAP-18446-P/WCAP-18446-NP, Revision 0, TR that would **[** **]** The NRC staff agreed this may be a viable path towards resolution of the concern but would require assessment of the **[** **]** ...” | Comment acceptable – marked as proprietary information in the proprietary version and redacted proprietary information in the non-proprietary version of the final SE. |