U. S. NUCLEAR REGULATORY COMMISSION

OFFICE OF NUCLEAR REACTOR REGULATION

FINAL SAFETY EVALUATION FOR TOPICAL REPORT

WCAP-16182-P/NP, REVISION 3, "WESTINGHOUSE BWR CONTROL ROD CR 99

LICENSING REPORT - UPDATE TO MECHANICAL DESIGN LIMITS"

WESTINGHOUSE ELECTRIC COMPANY

PROJECT No. 700

1.0 INTRODUCTION

By letter dated November 10, 2009, Westinghouse Electric Company (Westinghouse) submitted topical report (TR), WCAP- 16182-P-A/WCAP-16182-NP-A, Revision 1, "Westinghouse BWR Control Rod CR 99 Licensing Report - Update to Mechanical Design Limits," dated October 2009 (References 1 and 14). This revision provided updated design requirements for the Westinghouse Generation 3 (Gen 3) control rod blades (CRBs) that increase their service life to the Revision 0 of the TR that was approved by the U.S. Nuclear Regulatory Commission (NRC) (Ref. 2). As a result of the NRC staff requests for additional information (RAIs) and audits Westinghouse submitted Revision 2 of WCAP-16182-P with further enhancement of the design requirements and additions to the analysis options in the methodology by letter dated November 3, 2015, (Ref. 3). As a result of the NRC staff RAIs and audit of Revision 1 and Revision 2 of the WCAP-16812-P TR in May 2016, Westinghouse submitted Revision 3 of WCAP-16182-P (Ref. 4). Supplemental information was submitted by Westinghouse in References 5, 6, and 7 as responses to the NRC staff RAIs.

This TR presents a set of design requirements for the Westinghouse boiling water reactor (BWR) control rods based on which a set of measurable criteria is established. These requirements and criteria form a set of design bases for Westinghouse control rods for use in BWRs. The TR also evaluates the CR 99 design against the measurable criteria to ensure that the design meets the design bases for Westinghouse control rods for BWRs.

Pacific Northwest National Laboratory (PNNL) was a consultant to the NRC during this review. As a result of the reviews of the TR by NRC staff and PNNL consultants, RAI questions were sent to Westinghouse. Westinghouse responded to the RAI questions in References 5, 6, and 7. PNNL submitted a technical evaluation report to the NRC on the results of its review (Ref. 8).

The main technical issue of this review was Westinghouse's need to increase the stress limits above the stress limits established in the approved Revision 0 in order to accommodate the higher design loads associated with a higher mechanical end of life (MEOL). Westinghouse could not use the Revision 0 design bases because the Revision 1 stresses were higher than the Revision 0 design basis stress limits. Westinghouse needed to justify the stresses that they wanted under Revision 1 loading conditions. The NRC allows applicants to define novel stress limits within their design bases, but adequate justification for those limits is required. This issue was resolved by Westinghouse making significant changes to its analysis methodology and to its design bases. Westinghouse moved to sophisticated nonlinear finite element analysis methods that are compliant with American Society of Mechanical Engineers *Boiler and Pressure Vessel Code* (ASME BPVC) (Ref. 9) rules for plastic analysis. Article NB-3000 of ASME BPVC, Section III, Division 1, Subsection NB covers the rules for designing Class 1 components, and this draft Safety Evaluation (SE) refers to that article as NB-3000.

Section 2.0 of the SE describes regulatory evaluation of the TR in terms of the applicable regulations and review criteria. The applicable regulations are appropriate General Design Criteria (GDC) of Appendix A to Title 10 of the *Code of Federal Regulations* (10 CFR). Regulatory guidance for the review of above is provided in NUREG-0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants" (SRP), Section 4.2, "Fuel System Design" (Ref. 10).

Section 3.0 of this SE describes the history of this review, which included a number of audits, RAI questions, and significant revisions of the original submittal to address the technical issues that were raised during the review. Key issues and developments are noted as they occurred during this review, to help explain the progression from Revision 1, to Revision 2, and to Revision 3.

Section 4.0 of this SE describes the technical review in detail. The two main issues in this review were the design bases, discussed in Section 4.2, and the design evaluation, discussed in Section 4.3. A number of specific technical issues were raised throughout the course of this review, and they are listed and discussed in Section 4.4.

Section 5.0 of the SE lists surveillance plans and Section 6.0 provides the conclusions.

2.0 <u>REGULATORY EVALUATION</u>

Regulatory framework and guidance for the review of fuel system designs and reactivity control systems are GDC 10, GDC 26, GDC 27, and GDC 35 within Appendix A to 10 CFR Part 50. GDC 10 establishes specified acceptable fuel design limits (SAFDLs) that should not be exceeded during any condition of normal operation, including the effects of anticipated operational occurrences (AOO). GDC 26 requires two independent reactivity control systems of different design principles including control rods capable of reliably controlling reactivity changes to assure that under conditions of normal operations, including AOOs SAFDLs are not exceeded. GDC 27 and GDC 35 establish requirements for combined reactivity control system capability and emergency core cooling capability under postulated accident conditions.

Regulatory guidance for the review of fuel system design and adherence to the GDC listed above is provided in NUREG-0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants" (SRP), Section 4.2, "Fuel System Design" (Ref. 10).
In accordance with SRP Section 4.2, the objectives of fuel system safety review are to provide assurance that:

- The fuel system is not damaged as a result of normal operation and AOOs,
- 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, and
- Coolability is always maintained.

Westinghouse has established the following design requirements based on its mechanical, operational, physics, and material acceptance criteria:

- Based on the applicable material and operational acceptance criteria, the control rod will be compatible with control rod drive (CRD) system, coupling device, fuel, fuel channels, and rod handling equipment.
- Mechanical, physics and operational criteria will satisfy the design requirement such that rod worth and transient operation (e.g., SCRAM and free fall velocity) are consistent with the plant safety analyses.
- Based on material, mechanical and operational criteria, the control rod is expected to have mechanical stability and materials choices such that mechanical function is maintained throughout the life of the control rod.
- Based on the physics criteria, the control rod is designed such that currently used tools can monitor core power distribution and burn-up
- Material criteria satisfy the design requirement that total life cycle dose due to its use (activation product dose, direct dose, and disposal dose) is minimized.
- The design and manufacture of the control rod fulfill applicable codes and standards, including applicable parts of the ASME BPVC.

3.0 BACKGROUND HISTORY AND ISSUE RESOLUTION

The initial TR under review was WCAP-16182-P, Revision 1, dated October 2009 (Refs. 1 and 14). The two key issues that came out of the initial review of the TR were a lack of information about the structural analyses and the use of novel stress-based design criteria. The lack of information about structural analysis is a common issue. It has become typical that TRs like this one do not contain sufficient information to determine if finite element analyses have been conducted in a reasonable manner. It is often easiest to schedule audits of internal calculation packages and interactive reviews of finite element analyses than to request applicants or licensees to provide sufficient documentation through RAI questions. Westinghouse's use of novel design criteria is more unusual, and it was ultimately the one technical issue that proved to be the most challenging to resolve.

The first round of RAI questions asked Westinghouse for more details of the finite element analyses (Questions 8-10) and to justify its new novel von Mises based design criteria (Question 15). Westinghouse provided a response to the first round of RAI questions in LTR-NRC-11-15, Revision 1, dated June 6, 2011 (Ref. 5). The RAI responses provided some useful information about the finite element models (FEMs), but Westinghouse indicated that it preferred to host an audit rather than provide input and output files for review. The key issues surrounding the finite element analyses were still not clear at this point because there was not enough information available to the review team. On the issue of the novel von Mises design criteria, the RAI response referenced the German Nuclear Safety Standards Commission code (KTA 3103 (Ref. 11)), but the answer did not provide a sufficient justification for mixing the ASME BPVC with the German KTA code. There was also an issue that the general design requirements of the Revision 1 TR stated that the CR-99 met ASME BPVC design rules. This was seen as a logical contradiction within the TR that needed to be remedied – one section of the TR declared that the design criteria was ASME BPVC, but in a different section the TR defined stress criteria that were more permissive than ASME BPVC.

A second round of RAI questions was asked as a follow up to some of the first round of RAI questions. The audit to review finite element analyses had not been performed yet, so the reviewer's understanding of the FEA was limited, but it appeared that Westinghouse did not perform any structural analyses of the control blade under seismic loading conditions. Westinghouse responded to the follow-up RAI questions in LTR-NRC-12-48 (Ref. 6) with a description of an elastic-plastic fatigue analysis that was associated with operational basis earthquake (OBE) and safe shutdown earthquake (SSE) seismic loads. The analysis was not done according to ASME BPVC, and it was not clear that the evaluation of seismic loads was sufficient to demonstrate safety.

The first audit occurred on August 22, 2012, at the Westinghouse Twinbrook Office, Rockville, Maryland. Westinghouse provided access to some finite element analyses of the CR-99 control blade design. However, these analyses were not the correct finite element analyses of record for the TR. Due to some logistics problems, Westinghouse was not able to make the correct model files available for review during this audit. The NRC review team decided to review the available models to best make use of the audit time.

The analyses that were made available at the first audit seemed to demonstrate that the CR-99 would meet ASME BPVC design requirements using standard ASME BPVC stress limit definitions (stress intensity). It was not necessary for the NRC staff to accept the proposed novel design criteria because the CR-99 could be approved based ASME BPVC stress limits. This path to resolution was discussed and agreed upon with Westinghouse, and NRC staff provided a list of information needed to complete the review at the first audit.

The most important item that the NRC requested was for Westinghouse to provide a formal summary of the correct analyses of record on the docket. Westinghouse was to use both the standard ASME BPVC methodology and Westinghouse's proposed von Mises design basis to provide a side-by-side comparison of the two design bases. The expectation was that the CR-99 would pass the ASME BPVC stress limits, so it would not be necessary for NRC to decide if the novel von Mises stress limits were acceptable or not.

A second important open item topic that came out of the first audit was the need for Westinghouse to explain its intended design basis. Specifically, Westinghouse stated during the audit that failing the pressure boundary of the control blade (through-wall cracking) was permissible under Westinghouse design philosophy. However, this is not consistent with ASME BPVC NB-3000 design rules. NB-3000 provides rules for pressure vessel design, and the rules do not permit any local failure of the pressure boundary under design basis loading. Revision 0 of the TR used NB-3000 design rules. The NRC staff understanding of Westinghouse's position was that Westinghouse was proposing a novel set of design criteria that was based on NB-3000, but it also permitted gross plastic deformation of the control blade and local failure of the pressure boundary under certain loading conditions. A more detailed and formal explanation of Westinghouse's position regarding local through-wall failure of the control blade was requested.

Westinghouse responded to the open items of the August 2012 audit with LTR-NRC-12-67, dated September 2012 (Ref. 7). This document addressed 9 open items that were composed at the audit. The response was problematic because the structural analyses of record demonstrated that the CR-99 did not meet the basic ASME BPVC NB-3000 stress limits. The worst case analysis exceeded the ASME BPVC limit by 26 percent, and had a design margin on the proposed von Mises limit of just 1 percent. Westinghouse also provided an additional collapse load analysis that showed that the loading state was close to the collapse load. Westinghouse's response to the open items of the first audit derailed the resolution path that was discussed at the first audit. The formal response made it clear that the stresses in the CR-99 control blade would be much higher under the revised loading limits, much higher than NRC had approved before for the CR-99, and potentially higher than other control blades.

A second audit was conducted on December 5, 2013, at the Westinghouse Twinbrook Office, Rockville, Maryland. It was originally planned for two days. The goal was to resolve the key technical issues, particularly the proposed higher stress limits. Due to availability of Westinghouse staff, the audit was discontinued at noon on Day 1 and Day 2 was cancelled. This audit did not resolve any of the outstanding issues.

A third audit occurred on September 30 through October 2, 2014 (Ref. 12). One key agreement was that Westinghouse would perform stress analyses fully in accordance with ASME BPVC. The high stresses calculated for the CR-99 exceeded ASME PBVC basic stress limits, but the code has alternate rules that use nonlinear analysis methods that remove some of the conservatism of the basic stress limits. The CR-99 was expected to meet ASME BPVC design rules using the nonlinear methods. This would eliminate the need to use a novel von Mises stress criteria, which was a major sticking point in the review. Westinghouse also agreed that cracking of the control blade was not to be permitted under design basis loading conditions. The rules of ASME BPVC NB-3000 are defined to prevent material failure at the pressure boundary, so demonstrating the control blade meets NB-3000 rules provides an assurance that through-wall failures will not occur as a result of design basis loading.

As a result of NRC staff RAI questions and audits, Westinghouse issued Revision 2 of WCAP-16182-P in October 2015. This revision largely met the expectations of the NRC review team as Westinghouse followed the resolution path agreed to at the September-October 2014 (Ref. 12) audit. The structural analyses were performed according to ASME BPVC NB-3000 nonlinear analysis rules, and these new models needed to be reviewed at an audit because the TR did not contain enough information to determine if the analyses were done correctly. One issue that remained open was the seismic analysis of the CR-99, which did not appear to follow the ASME BPVC NB-3000 nonlinear analysis rules.

A fourth audit occurred on May 17 through 20, 2016, at Westinghouse's Rockville, Maryland offices (Ref. 13). The audit plan was written to identify NRC expectations from the previous audit (September 30 through October 2, 2014), and listed questions and discussion topics that were necessary to close out the open items that were not clearly resolved in Revision 2 of the TR. The review team reviewed the nonlinear finite element models and found most of them adhered to ASME BPVC NB-3000 rules and methodology with the exception of the seismic analysis. Westinghouse had attempted an alternate analysis methodology, but agreed to redo the analysis to conform entirely to the ASME BPVC methods.

Westinghouse issued Revision 3 of WCAP-16182-P in June 2016. This revision of the TR completely addressed all remaining open items. The seismic analysis was documented sufficiently and no further audits were needed.

4.0 TECHNICAL EVALUATION

4.1 Introduction

The objective of WCAP-16182-P, Revision 3, is to define higher loads and higher stress limits for the CR-99 control blade (BWR C, S, and D lattices) in order to define a MEOL that is longer than the one that was approved in Revision 0. Revision 3 incorporates the incremental changes made in Revision 1 and Revision 2. Few changes were made in Revision 3 relative to Revision 0 which was approved by the NRC staff in 2005 (Ref. 2). The major technical improvement is in the increase in loads and stress limits in Revision 3 relative to Revision 0.

Revision 0 used ASME BPVC NB-3000 basic stress limits as the design basis. Increasing the loads to the level proposed in the later revisions of the TR leads to stresses in the control blade that exceed ASME BPVC NB-3000 basic stress limits. This prompted Westinghouse to change the design basis in Revision 1 to effectively increase the stress limits above NB-3000. As discussed in Section 2.0, Westinghouse's von Mises stress limit approach in Revision 1 proved to be difficult to justify. Westinghouse did not have an experimental basis, such as control rod burst test data, to justify its proposed higher limits. Ultimately, Westinghouse chose to implement plastic stress analysis methods to demonstrate that the CR-99 meets the design rules of NB-3000 in Revision 2 and Revision 3. This provides a credible design basis that does not require further justification, per NRC's SRP Section 4.2 (Ref. 10).

The technical review covered issues that can be divided into three broad topics: the design bases, the design evaluation, and specific technical issues. These topics are discussed in more detail in the Sections 4.2, 4.3, and 4.4, of this SE, respectively.

4.2 Design Bases

The design bases that were established in Revision 0 of the TR were ASME BPVC NB-3000 basic stress limits. These stress limits are defined on the basis of stress intensity and are calculated using FEMs that assume elastic material behavior. The Section 4.2 of SRP (Ref. 10) states that stress limits that are obtained by methods similar to ASME BPVC are acceptable, while other stress limits must be justified. In this case, Revision 0 used ASME BPVC values so no further justification was required, but Revision 1 proposed novel stress limits that used von Mises stress instead of stress intensity. Per the SRP, this change required justification, but the TR did not contain any justification. The novel von Mises stress limits were difficult to justify for a number of reasons. Ultimately, Westinghouse abandoned the von Mises stress limits proposed in Revision 1, and changed to ASME BPVC plastic evaluation limits starting in Revision 2.

The new design bases in Revision 2 and Revision 3 define load limits, which are specified to be some fraction of the load that would cause the structure to collapse. Nonlinear finite element analysis is used to determine the collapse load. Service Level A loads are restricted to 2/3 of the collapse load. **[** **]** Service Level D loads are permitted to be 90 percent of the collapse load. These load limits and the finite element analysis methodology used to implement these load limits are generally in agreement with NB-3000 rules. **[** **]** This difference only affects the amount of safety margin that is required of the structure, so is not a significant safety concern. The control blade is not required by NRC to be designed to meet NB-3000 rules, or maintain NB-3000 margins. **[** **]**

A fundamental technical issue is that Westinghouse has used the design rules of NB-3000 to demonstrate safety for the CR-99 which is not Class 1 components and consequently results in a very conservative MEOL assessment when compared to other design rules such as the German KTA code. One reason for this is that ASME BPVC uses the Tresca (Maximum Shear Stress) failure criterion rather than the von Mises failure theory, which is more appropriate for ductile materials, like steel. Another source of conservatism is that the NB-3000 basic stress limits are calculated on an elastic basis, and therefore do not account for the redistribution of stress in a structure undergoing plastic deformation. It was reasonable for Westinghouse to look for an avenue for reducing conservatism to increase the MEOL of the CR-99, but defining new Design Bases (without having specific mechanical test data to support a new design basis) was a significant technical challenge.

As an example of the difficulty in defining new Design Bases, Westinghouse stated during the first audit that control blade cracking under mechanical loading was permissible under design basis loading. This was a radical change from the Revision 0 TR design basis, which ensured that the pressure boundary maintained its integrity under all design-basis loading scenarios. Allowing the pressure boundary to fail under design basis loads, such as during seismic loading, opened up the possibility of completely failing the control blade through crack propagation or ductile failure. New evaluation methods needed to be devised to demonstrate safety in a scenario where significant through-wall cracks were present. During this review process, Westinghouse prepared new, sophisticated nonlinear models to demonstrate that cracks would not propagate under seismic loading. The review staff needed to enlist the help of additional material scientists to assist in the review of the crack propagation calculations. In the end, it was easier for Westinghouse to back away from proposing novel design criteria and pursue options within the ASME BPVC to achieve its MEOL goal.

This review finds that the new Design Bases defined in Revision 3 of the TR are appropriate for maintaining safety of the CR-99 during its service life. Westinghouse's interpretation of NB-3000 in regards to Service Level B collapse load limits does not strictly adhere to ASME BPVC design limits, but the difference is only in the amount of margin against collapse. Westinghouse design criteria has a slightly lower safety margin at Service Level B, but this is reasonable because control blades are not Class 1 components and do not need to be designed with margins that are equal to NB-3000 rules.

4.3 Design Evaluation

The original (Rev. 0) design evaluation was performed using linear elastic finite element models. Stresses were linearized and compared to NB-3000 stress intensity limits. All analysis methods were in accordance with ASME BPVC. The design evaluation of Revision 0 was a typical, standard approach.

The Revision 1 design evaluation used a similar methodology, but changed from stress intensity stress limits to von Mises stress limits. This change is not permissible under ASME BPVC, so the Revision 1 design evaluation was either incorrect or required justification. The early phases of the review process focused on trying to understand Westinghouse's intent, to determine if the finite element analyses of the design evaluation needed to change to be consistent with the TR, or if the TR needed to be changed to be consistent with the design evaluation.

The Revision 2 design evaluation changed from linear elastic FEMs to nonlinear perfectly-plastic finite element models, using an analysis methodology that is defined in ASME BPVC NB-3000. There was no longer any need to linearize stresses with this analysis methodology;

the design criteria became loads instead of stresses. The analysis procedure is implemented by defining a structural finite element model with a bilinear material model. The initial behavior of the material is elastic, and that continues until the yield strength is reached. Then the material behaves in a perfectly-plastic manner, meaning the tangent modulus has zero slope, or zero strain-hardening. A perfectly plastic material model allows a structure to support a load beyond its yield limit, as long as the load can be redistributed. As the load increases, this type of structural model reaches a point where it can no longer redistribute the load, and the structure subsequently collapses. Using finite element analysis methods, the collapse load for a structure can be determined by increasing the loads until the numerical model can no longer converge to a solution. The last load step that successfully converges is considered the collapse load. NB-3000 load limits are defined as a fraction of the collapse load. For example, Service Level A loading conditions are limited to 2/3 (or 67%) of the collapse load. In practice, finite element models are used to determine the loads that would cause collapse, in order to demonstrate that the design basis loads are at least a certain margin below the collapse limit.

Westinghouse's Revision 2 models were reviewed during the fourth audit (May 2016) and all models were found to be appropriate, with no errors. Only one design evaluation change was required in Revision 3, which was the seismic loading analysis. The Revision 2 version of the analysis was not performed according to ASME BPVC, and Westinghouse agreed to revise the model to bring it into full compliance.

A preliminary version of the Revision 3 seismic analysis was reviewed during the fourth audit. Westinghouse was advised about what to document in the TR to avoid having another audit to review the Revision 3 seismic analyses. Westinghouse included sufficient information in the TR that the reviewers could determine that the new seismic analysis was appropriate, and no further review of the FEMs was necessary.

This review finds that the Revision 3 design evaluation is appropriate for demonstrating that the design bases are met. Westinghouse's design evaluation was performed in accordance with ASME BPVC. The FEMs were reviewed sufficiently to confirm that they are error-free and of appropriate quality.

4.4 Specific Technical Issues and Resolution

This review covered many specific technical issues. All of them were adequately addressed through the audit process or as changes to the models of the design evaluation or changes documented in the TR. This section lists the issues and identifies how they were resolved.

Design Requirements

Section 4.0 (Table 4-1) of the TR defines the design requirements. In Revision 1, it was not clear whether Westinghouse considered it a design requirement to design the CR-99 control blade in accordance with ASME BPVC NB-3000. Revision 3 of the TR clarifies the design requirements by stating "Although the control rod is not classified as a Class 1 component, the structural qualification is based on stress criteria defined in ASME III Subsection NB-3200."

Mechanical Analyses

The finite element analyses used to demonstrate compliance with the mechanical design criteria were reviewed during the fourth audit, and were found to be performed according to NB-3000 rules. At the end of the fourth audit, Westinghouse had a preliminary analysis of the seismic load case, and that model was also reviewed. Westinghouse included enough information about the seismic analysis in Revision 3 that no further review of the mechanical analyses was necessary. All of the mechanical analyses were found to be adequate and support the increase in MEOL that Westinghouse is seeking.

Maximum Channel Distortion

The seismic loading conditions were not documented in Revision 1. The TR was updated starting in Revision 2 to include the maximum channel deflection limit.

Residual Stresses Caused by B_4C Swelling

Loads caused by B_4C swelling were not included in all analyses in Revision 1, but by Revision 3 all possible B_4C swelling loads were included in the design evaluation.

Mechanical Stress/Strain Data for Irradiated Material

When Westinghouse moved to nonlinear stress analysis methods, they also began to use irradiated material properties. The irradiated material data was reviewed and references to the data were included in Revision 3 of the TR.

Cracking and Local Depletion

The NRC staff raised the question about Westinghouse's use of average depletion values in its swelling calculations. The concern was that local depletion can cause higher local swelling, and thus higher localized swelling loads, than the average depletion values would predict. **[**

] This design feature is mentioned in the TR, but Westinghouse presented additional, more detailed material at one of the audits to fully address the reviewer's concerns.

Surveillance Plan

The NRC staff requested a surveillance plan for the CR-99 be instated due to the new, higher load limits. Westinghouse included the final version of the plan in Revision 3 of the TR. The surveillance plan will look for material integrity issues including cracking. One point to note is that the rods will be inspected for material integrity issues at 90% depletion, which could take ten or more years of service. NRC staff reviewed the surveillance plan internally and found it to be acceptable. The surveillance plan documented in Revision 3 fully resolves this issue. The surveillance plan is summarized in Section 5.0.

5.0 SURVEILLANCE PLAN

Westinghouse has been performing inspection on third generation of CR 99 control rods that were operating in two Swedish BWRs to almost 80% of their nuclear life and found no cracks. Westinghouse is committed to continue to inspect the leading rods at high exposures close to nuclear end-of-life (NEOL). The following inspection plan has been developed for D, C, and S lattice BWRs (Reference 4):

1. A minimum of two third (3rd) generation of CR 99 control rods shall be followed at operation in high duty locations in a D, C, and S-lattice US or international BWR.

2. Additional third (3rd) generation CR 99 control rods are operated in other US BWRs to a lower depletion than the two lead-depletion 3rd generation CR 99 control rods at the designated BWRs. Should other control rods at a domestic or international BWR become the highest depletion in the BWR fleet, they shall become the control rods inspected per this surveillance program.

3. The two lead-depletion control rods shall be irradiated, achieving as close to NEOL as practical (target minimum 90% of EOL).

4. For refueling outages in which the depletion of the lead 3rd generation CR 99 control rods are greater than 75% of design life, two highest depletion 3rd generation CR 99 control rods shall be visually inspected on all eight (8) faces on each control rod.

5. For the 3rd generation CR 99 rods inserted in the opposite lattice type as the lead depletion units, the two highest depletion control rods shall be visually inspected during outages where the control rods exceed 90% of design NEOL. These visual inspections shall be covering all eight faces of the control rod. For this surveillance program, the D and S lattice applications are considered equivalent, since the geometry of the absorber holes and absorber pins are identical.

6. If a material integrity issue is observed, Westinghouse shall arrange for additional inspection, if necessary, to determine root cause and recommend a revised lifetime limit to the NRC based on the inspections and other applicable information available.

7. Westinghouse shall report the results of the visual inspections of the 3rd generation control rods to the NRC within 12 months of the time when the inspections were performed.

6.0 CONCLUSIONS

1. Revision 3 of the TR (Reference 4) demonstrates that request for increased MEOL for the 3rd generation CR 99 control rods is justified and the staff approves the request.

2. The NRC staff has determined that the new design bases as presented in Revision 3 of WCAP-16182-P are appropriate. The design bases are plastic analyses that follow the rules of NB-3000 (Reference 9). The NRC staff has concluded that the new design bases demonstrate that the control blade will maintain its integrity throughout normal conditions of operation and safe shutdown earthquakes.

3. Though control blades are not actually Class 1 components, Westinghouse has applied the rules of NB-3000 to the control blade. NB-3000 is potentially more conservative than necessary for a BWR control blade. However, the NRC staff finds this appropriate.

4. Westinghouse design rules do not permit the control blade to fail its pressure boundary during design basis loading conditions. The NRC staff concludes that design rules do not allow a stress or loading state that would be expected to lead to failure of the pressure boundary.

5. The design bases deviate slightly from ASME BPVC NB-3000 rules for service level B limit load analysis, as described in TR Section 6.5. **[**

   ] The NRC staff has determined that this difference is not a safety concern, as both load limits ensure a safety margin against collapse, and therefore finds this acceptable.

6. The new design evaluation finite element models were reviewed and found to be appropriate. No errors were found. The staff finds that the models had appropriate mesh density and were good implementation of modern nonlinear finite element analyses.

7. The NRC staff finds the surveillance plan listed in Section 5.1 acceptable.

7.0 REFERENCES

1. WCAP-16182-P, Revision 1, "Westinghouse BWR Control Rod CR 99 Licensing Report," October 2009 (Proprietary).

2. WCAP-16182-P-A, Revision 0, "Westinghouse BWR Control Rod CR 99 Licensing Report," March 2005 (Proprietary).

3. WCAP-16182-P, Revision 2, “Westinghouse BWR Control Rod CR 99 Licensing Report - Update to Mechanical Design Limits," October 2015 (Proprietary).

4. WCAP-16182-P, Revision 3, “Westinghouse BWR Control Rod CR 99 Licensing Report - Update to Mechanical Design Limits," August 2016 (Proprietary).

5. LTR-NRC-11-15 Rev. 1, “Response to the NRC’s Request for Additional Information RE: Westinghouse Electric Company Topical Report WCAP-16182-P-A, Revision 1, “Westinghouse BWR Control Rod CR 99 Licensing Report - Update to Mechanical Design Limits” (Proprietary),” June 2011.

6. LTR-NRC-12-48, “Response to the NRC’s Second Round Request for Additional Information RE: Westinghouse Electric Company Topical Report WCAP-16182-P-A, Revision 1, “Westinghouse BWR Control Rod CR 99 Licensing Report - Update to Mechanical Design Limits” (Proprietary),” June 2011.

7. LTR-NRC-12-67, “Resolution of Open Items from NRC Audit on WCAP-16182-P-A, Revision 1,“Westinghouse BWR Control Rod CR 99 Licensing Report – Update to Mechanical Design Limits” (Proprietary),” September 2012.

8. N. A. Klymyshyn, K. J. Geelhood and C. E. Beyer, “Technical Evaluation Report of the Topical Report WCAP-16182-P, Revision 3,” Pacific Northwest National Laboratory, January 2017.

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11. KTA 3103, “Shutdown Systems for Light Water Reactors,” SAFETY STANDARDS of the Nuclear Safety Standards Commission (KTA), March 1984.

12. Memorandum from J.L. Dean to A. J. Mendiola (USNRC), Regulatory Audit report –Review of TRs (1) WCAP-16182 Revision 1 Westinghouse BWR Control Rod CR 99 Licensing Report Update to Mechanical Design Limits Revision 1, October 2009 (ME2630) and (2) WCAP-15492-P-A Supplement 1 Revision 0 Material Changes for SVEA-96 Optime2 Fuel Assemblies, September 2010 (ME4700)," USNRC, December 7, 2014 (ADAMS Accession No. ML14325A846).

13. Memorandum from J.L. Dean to K. P. Hsueh (US NRC), "Regulatory Audit Report Review Of Topical Reports (1) Westinghouse Commercial Atomic Power -16182 Revision 2 Westinghouse Boiling Water Reactor Control Rod 99 Licensing Report Update To Mechanical Design Limits Revision 2, November 2015 (ME2630) And (2) Westinghouse Commercial Atomic Power -17769-P Revision 0 Reference Fuel Design Svea-96 Optima3 Fuel Assemblies, January 2014 (MF3367)," USNRC, July 26, 2016. (ADAMS Accession No. ML16201A077).

14. Response to NRC Request for Additional Information Re: Westinghouse Electric Company Topical Report (TR) WCAP-1 6182-P-A, Addendum 1, "Westinghouse BWR Control Rod CR 99 Licensing Report - Addendum 1, Updated Design Limits," dated November 6, 2008 (TAC No. MD7989) and Submittal of WCAP- 16182-P-A/WCAP- 16182-NP-A, Revision 1, "Westinghouse BWR Control Rod CR 99 Licensing Report - Update to Mechanical Design Limits," dated October 2009 (Proprietary/Non-Proprietary) (ADAMS Accession No. ML093240377).

Attachment: Resolution of Comments

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