AUDIT SUMMARY
FOR REVIEW OF AP1000 SPECIALIZED SEISMIC OPTION REPORT

LOCATION:

This audit was conducted June 7 – 9, 2016 at:

Westinghouse Electric Company
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BACKGROUND:

The Westinghouse Electric Company (WEC) AP1000 plant Design Control Document (DCD), Revision 19 was certified by the U.S. Nuclear Regulatory Commission (NRC) on December 30, 2011. A Specialized Seismic Option (SSO) for the AP1000 standard design has been developed by WEC for use in locations with seismic levels typically seen in portions of the western United States and certain other countries. The purpose of the SSO is to extend the range of applicability of the AP1000 standard design, by including an enhanced seismic spectra (ESS) into the AP1000 plant design.

On December 18, 2015, the staff accepted for review, the WEC SSO report. The SSO report provides approach, methods, and changes necessary to adapt the AP1000 plant design to a future combined license (COL) applicant's site with site conditions addressed in the report. Moreover, the SSO report provides specific exemptions and departures from the AP1000 DCD Revision 19 to support a future AP1000 COL application in locating an AP1000 plant at a site that meets the appropriate site conditions.

In support of the staff's ongoing review, an audit of WEC's SSO documents that support the SSO report's evaluations and conclusions was performed.

REGULATORY AUDIT BASES:

- Title 10 *Code of Federal Regulations* (10 CFR) Part 50, Appendix A, General Design Criterion 2, "Design Bases for Protection Against Natural Phenomena"
- 10 CFR Part 50, Appendix S, "Earthquake Engineering Criteria for Nuclear Power Plants"
- 10 CFR 52.47(a)(27) and SECY-93-087, "Policy, Technical, and Licensing Issues Pertaining to Evolutionary and Advanced Light-Water Reactor (ALWR) Designs"
- 10 CFR 50.55a
- Standard Review Plan (SRP) Sections 3.9.2, 3.9.3, 3.7, 3.8, 3.10, 4.2, and 19

AUDIT TEAM AND TEAM ASSIGNMENTS:

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AUDIT SUMMARY:

The audit started with safety and entrance briefings provided by WEC and NRC, respectively. Following the safety and entrance briefings, WEC presented an overview of the SSO report. This overview covered topics related to the nuclear island (NI) modeling and analysis approach, in-structure response spectra (ISRS) for key locations, structural design enhancements, component evaluation, piping systems, and seismic margin assessment.

Subsequent to WEC's overview, the staff started the review of selected reports and calculations. Specifically, the staff focused on reports and calculations related to:

- the development of seismic design parameters including the SSO ESS and associated time histories;
- seismic analyses of NI structures;
- structural demand and capacity evaluations of AP1000 critical sections;
- NI non-linear stability analysis and associated sets of time histories, containment stress and stability analyses; and
- seismic margin calculations.

The staff engaged WEC in constructive and informative discussions on technical issues related to the calculations and SSO report and shared the staff's perspectives as they are related to relevant staff guidance documents in the subject areas. At the conclusion of the audit, the staff and WEC agreed on a list of audit action items, some of which have been developed into requests-for-additional-information (RAIs). The more significant issues discussed during the audit are described below.

STRUCTURAL ENGINEERING INPUT

SSO ESS and Associated Time Histories

The staff reviewed HSP-GW-G1-004, Revision 0, "The Certified Seismic Design Response Spectra for the Enhanced Seismic Plant," which describes the applicant's development of the SSO ESS. The ESS were developed based on the Regulatory Guide (RG) 1.60, "Design Response Spectra for Seismic Design of Nuclear Power Plants," spectral shapes and the spectrum described in [

]. The peak ground acceleration of the ESS [ ], as compared to 0.3 g for the AP1000 Certified Seismic Design Response Spectra (CSDRS). The ESS are defined with [ ] on the log-log scale. The ESS are broadband response spectra enveloping the AP1000 CSDRS from [ ]. Therefore the staff found the ESS acceptable because they envelop the AP1000 CSDRS which has been certified with AP1000 standard plant DCD Revision 19 and thus satisfy the Appendix S of 10 CFR Part 50 requirement.

The staff also reviewed HSP-GW-G1-005, Revision 0, "The Design Ground Motion Time History for the Specialized Seismic Option Project." Synthetic acceleration time histories were developed to envelop the ESS following the SRP Section 3.7.1, [

] event. The staff noted that Figures 5-8 through 5-13 of this report provide [ ] time histories. Since the acceleration time histories, not the velocity and displacement time histories, are used in the seismic analyses, the staff requested during the audit that the applicant clarify [ ] was performed on the acceleration time histories. During the audit, the applicant confirmed that the time histories were generated using [

].

The power spectral density (PSD) comparison presented in Figure 3-10 of the SSO report and in the reviewed calculations only covers frequencies up to [ ], which is much lower than the zero period acceleration (ZPA) frequency [ ] associated with the design response spectra (i.e., the ESS). During the audit, the staff noted that the PSD should be evaluated up to a frequency that is consistent with the design response spectra (e.g. [ ] in this case) to ensure appropriate estimation of the PSD over the entire frequency range of interest. The staff requested the applicant to submit their acceleration time histories for a staff confirmatory analysis, which will assess whether the time histories meet the SRP acceptance criteria with a focus on their power sufficiency. The request for time histories also included the four additional sets of time histories used for the non-linear stability analysis of the NI structures.

Seismic Analyses of NI Structures

WEC performed mode superposition time history analyses of the NI structures to obtain the ISRS needed in the analysis and design of seismic subsystems. WEC's analysis captured the response of modes up to [ ] (i.e., the ZPA frequency for the SSO) and neglected the [ ]. Based on the staff feedback, during the audit WEC performed additional mode superposition time history analyses to consider modes up to [ ] in order to verify the accuracy of their mode superposition analysis results. WEC provided ISRS comparisons at the AP1000 six key locations for the [ ] and the [ ] mode superposition time history analyses. The staff reviewed these comparisons during the audit, and confirmed there are negligible differences in results between the two cutoff frequencies. On this basis the staff found that WEC's implementation of the mode superposition time history analysis method considering modes up to [ ] produced sufficiently accurate results.

Structural Demand and Capacity Evaluations of AP1000 Critical Sections

During the audit, the staff confirmed that the design evaluations for the SSO were performed for all the AP1000 Revision 19 critical sections. The SSO report includes a summary of these evaluations including markups to DCD tables showing required versus provided reinforcement. However the staff requested WEC to clarify missing tables in the DCD markups for some of the critical sections. WEC clarified that no changes were necessary for such critical sections due to [ ] due to the ESS relative to the AP1000 Revision 19 [ ]. Per staff's request, WEC committed to include these tables in the SSO report and associated description indicating that no change was necessary due to the [ ] for these cases. Additionally, and in contrast to the above cases, for the cases where reinforcement changes were necessary (e.g., cases where the provided reinforcement increased in the SSO relative to the AP1000 Revision 19) the staff requested WEC to provide the technical basis that demonstrate adequate member ductility as per code requirements. In response to the staff request, WEC committed to address the technical basis for the provided reinforcement in the SSO report.

NI Non-linear Stability Analysis and Associated Sets of Time Histories

The staff reviewed HSP-1000-S2C-004, Revision 0, '[ ] Analysis for ESS," which describes the applicant's [ ] of the NI structures with five sets of acceleration time histories, one of which is the set of design time histories. The 2D model consists of three concentrated stick models (ASB, CIS and SCV) supported by a rigid beam representing the common basemat. The 2D model is in the plane of east-west (EW) direction and the vertical direction. The analysis was performed using the ANSYS program. A [ ] at the bottom of the basemat is incorporated in the model to consider the effect of sliding and uplifting. Design level earthquake (ESS) and review level earthquake (1.67×ESS) were used in the nonlinear stability analyses, both considering an increase with a factor of 1.1 to be consistent with the factor of safety in the SRP guidance on stability evaluation. The EW direction is the direction along the shorter horizontal dimension of the NI structures. Although the SSO report correctly points out that the longer direction (North-South) is more stable against overturning, the effect of neglecting the 3D input motions to a 3D structure is not immediately clear due to the effect of load-path dependency shown in a non-linear analysis. During the audit, the staff discussed internally whether a 2D analysis is acceptable, and determined that the 2D analysis is acceptable because (a) an application of the 100-40-40 rule for consideration of the three components of the input motion would result in about an 8 percent increase in the resultant shear load in the horizontal direction, and (b) this level of increase is not expected to significantly increase the [ ] and [ ], both of which are determined to be very small.

In addition to the design time histories, four additional sets of time histories were also used in the non-linear stability analyses. These time histories were generated by adjusting seed records from the earthquake events: [ ]. The staff's review of this report found that the applicant's spectral matching procedure follows [ ]. However, the staff found that the PSD of the time histories were estimated using a method involving [ ]. Therefore, the staff requested the applicant to

provide a technical justification for the adequacy of the method used for estimating the PSDs of the 4 additional sets of time histories or estimate the PSDs using the strong motion duration as described in SRP 3.7.1 Revision 4, Appendices A and B.

Containment stress and stability analyses

In the SSO, the [ ] is changed from [ ] for the certified AP1000 plant design condition to [ ] for the SSO. Based on the information in the SSO report, the technical basis for this change was not clear to the staff. During the audit, WEC indicated that the change in [ ] was necessary so that the stresses associated with the [ ] are within acceptable limits. During the audit the staff reviewed the SSO [ ]. Per staff request, WEC provided an additional SSO calculation referenced in the [ ] that documented the [ ] evaluation for the SSO. These calculations were specific to the [ ] and did not provide a clear indication of the effects of the change. To further clarify the effects for the [ ] change in the [ ], WEC provided comparisons of SSO [ ] and [ ]. These comparisons showed that given the increased ESS seismic demands, changing the [ ], enables the [ ]. During the audit WEC also proposed markups to the SSO report to indicate that with the change of [ ] remain within allowable stresses. The staff found the proposed markups to be acceptable and did not find any new issues during the audit related to the [ ].

The staff also examined additional containment stress calculations available during the audit. These calculations showed that the structural integrity of the containment vessel continues to be maintained in the SSO [ ]. While the staff did not find new issues related to the containment stress calculations, the staff noted that there is no description in the SSO report related to such evaluations performed for the SSO other than the [ ]. The staff requested WEC to include a summary of such evaluations and respective conclusions in the SSO report. In response to the staff request, WEC committed to issue a supplemental response to RAI-SSO-002 to describe the containment stress evaluations, associated conclusions, and respective proposed markups for the SSO report.

Seismic Margin High Confidence Low Probability of Failure (HCLPF) Calculations

The staff reviewed HSP-PRA-GSR-002, Revision 0, "[ ] calculations for the Specialized Seismic Option Project," which describes the applicant's seismic fragility evaluations for structure, system, and components (SSCs) relative to the ESS. Fragility evaluations were conducted for all SSCs listed in DCD Table 19.55-1, "Seismic Margin Parameters and HCLPF Values." From a review of the SSO report, the staff determined that the justification for certain [ ] in HCLPF capacity could not be determined from the information provided (e.g., the [ ] could not account for the stated HCLPF capacity). Therefore, the staff audited the detailed seismic margin calculations to confirm the assumptions made for the seismic margin evaluations were appropriate. During the audit, the staff conducted a detailed review of the calculations for a limited sample of structures including the [ ]. The staff confirmed that the calculations provided sufficient basis for the respective HCLPF capacities

reported in the SSO report and concluded that the methodologies used for the seismic fragility evaluations were consistent with those used for the AP1000 certified design.

During the audit, the staff also reviewed the justification for differences in [ ] between the SSO and AP1000 certified design. The staff focused on the [ ] to understand the source of the variation. The applicant explained how the [ ] is calculated and explained the differences between the SSO and AP1000 certified design. The staff determined that the [ ] is determined consistent with EPRI NP-6041, "A Methodology for Assessment of Nuclear Power Plant Seismic Margin." Additional topics related to the seismic margin HCLPF capacities that were discussed at the audit are documented in RAIs.

MECHANICAL ENGINEERING INPUT

The audit basis is to confirm that design analyses follow the requirements of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, as required by 10 CFR 50.55a, and are consistent with the descriptions in the AP1000 SSO report. This regulatory audit is also needed for safety evaluations regarding SSCs that described in the AP1000 SSO report.

During the audit of AP1000 SSO, the Mechanical Engineering Branch staff reviewed a sample of calculation packages of AP1000 components, component supports, piping and pipe supports, [ ]. The audit supports the staff's reviews of the AP1000 SSO Report. In general, the NRC staff found that the design calculation packages incorporate the acceptable methodologies and provisions (i.e., analysis methods in Regulatory Guide (RG) 1.92, "Combining Modal Responses and Spatial Components in Seismic Response Analysis," and damping values in RG 1.61, "Damping Values for Seismic Design of Nuclear Power Plants,") specified in the certified AP1000 DCD Revision 19 and therefore, meet the methodologies in the topical report and ASME code requirements. During the audit, the staff shared the audit observations and had discussions with the applicant regarding the calculation packages. Some staff's audit observations may result in a request for additional information. The audit observations are as follows:

Stress Analyses of Components and Component Supports

The staff reviewed Document HSP-MV20-Z0R-016, "[ ], for the Specialized Seismic Option Project," Revision 0, and found that the calculation was performed for Service Level D load combinations, however it did not include stress calculations for load combinations of Service Levels A, B, and C. Since the [ ], in accordance with ASME Code Section III requirements, full ASME Code stress analyses need to be performed to include the stress calculations of Service Levels A, B and C load combinations of these nozzles and supports. In response to NRC staff's finding, WEC responded that stress calculations of Service Levels A, B, and C will be performed in the detailed design phase in accordance to AP1000 DCD Revision 19 providing full ASME stress analysis to meet ASME Code Section III requirements. The staff finds that WEC's response addressed the staff's observation, and is considered acceptable.

Stress Analyses of Piping and Piping Supports

The staff reviewed Section 2.4 of Document HSP-SGS-PLR-030, "Piping Stress Analysis Report for [ ] for the Specialized Seismic Option Project," Revision 0. This section indicated there are [ ] for this calculation. The staff requested that the applicant provide a clarification how these [ ] impact the piping stress analyses. The applicant stated that the listed [ ] in Section 2.4 were for [ ]. These items had no impact to the calculations. The staff found that the applicant response acceptable.

In review of Document HSP-SGS-PLR-030, "Piping Stress Analysis Report for [ ], for the Specialized Seismic Option Project," Revision 0, the staff questioned that the guidance of RG 1.122, "Development of Floor Design Response Spectra for Seismic Design of Floor-Supported Equipment or Components" for the broadening of the response spectrum to account for the uncertainties was appropriately considered. It appeared that the piping stress calculation does not have ESS loading cases for upper bound, normal and lower bound to address the uncertainties. Staff requested the applicant provide a discussion in the topical report, and stress calculations of ESS loading cases of upper bound, normal and lower bound to address the components and piping accounting for uncertainties in the structural frequencies. In response to the staff request, the applicant stated that the broadening of response spectrum to account for the uncertainties was considered conforming to RG 1.122. The models of piping stress analyses were developed with ESS loading cases of upper bound, normal and lower bound. The staff found the applicant response acceptable. In addition, the applicant is requested to provide a discussion in the SSO report that the uncertainties are addressed accordingly. The staff will review the added discussion of this audit item in the next revision of the SSO report. **This audit item is considered a confirmatory item.**

Section 2.4 of Document HSP-RCS-PLR-010, "Piping Analysis Report for [ ] for the Specialized Seismic Option Project," Revision 0, indicated that there were [ ] for the calculation. The applicant stated that these [ ] had no impact to the calculations. The staff found that the applicant response acceptable.

In Document HSP-RCS-PLR-010, "Piping Analysis Report for [ ] for the Specialized Seismic Option Project," Revision 0, the staff found that [ ] were included in the calculation packages. The NRC staff noted that when the fatigue analysis is performed, it needs to be performed for all systems and components with ESS enhancements. The applicant provided a DCD mark-up that referenced and existing COL application commitment in the appendix of SSO topical report to have full ASME code stress analyses including the fatigue analyses performed in according to ASME Section III. The staff reviewed the DCD mark-ups and found the applicant response acceptable.

[ ] Evaluation

For [ ], the results are presented based on the revised model (which are [ ] deviated from the original) subjected to ESS response spectra for loads and stress. In the calculation, the damping values were not specified. During the audit, WEC stated that the damping values used are based on those used for AP1000 Revision 19, that is, [ ] that is consistent with Table 3.7.1-1 damping values in AP1000 DCD Revision 19.

The staff reviewed the [ ] calculations HSP-1101-SHC-001, Section 4.2 where the method of modal combination was not specified. WEC later clarified that [ ] methodology is used to combine closely spaced frequencies. This is the same methodology used in generic AP1000 calculation [ ] which supports DCD Revision 19. WEC also clarified that the [ ] method is also used for [ ] in Calculation HSP-1150-SHC-010 where no methodology was included. This is acceptable method in accordance with RG 1.92.

During the audit, the staff asked the basis for use of additional [ ] factor for load combination when including load cases. WEC clarified that the factors applicable for design are based on AISC-N690 (as stated in [ ]) using [ ]. A factor of [ ] is used for conservatism. WEC reiterated that this is the methodology used in the certified AP1000 DCD Revision 19 calculation [ ]. The staff later confirmed the factors [ ] with N690-1994 Code and concluded that the use of [ ] is conservative and acceptable.

During auditing of the [ ] calculation, the staff asked what multimode factor was used for equivalent static analysis. WEC stated that a multi-mode factor of [ ] is used for the equivalent static evaluation to consider flexible response. This is the same methodology used in the generic AP1000 calculation [ ] which support Tier 2 DCD Revision 19. WEC also stated that the generic AP1000 calculation results are [ ] between ESS and CSDRS. The [ ] evaluation results include the multi-mode factor since the generic AP1000 calculation equivalent static results already consider a multi-mode factor of [ ]. However, the [ ] method did consider the modification of [ ] due to the ESS condition. The staff may need additional information on this topic, leading to an RAI.

Equipment Seismic Qualifications

In Section 4.5.1 of the SSO report, WEC stated that it plans to perform the seismic qualification in [

]. However, Appendix A6.5 provides DCD Section 3.10 markups for the Option where ESS is defined in revised Subsection 3.7.1.1 and DCD Appendix 3I is eliminated from Section 3.10 for hard rock high frequency (HRHF) requirements as the ESS [ ] shown in Figure 4-4 of the SSO report (also see DCD Figures 3I.1-1 and 3I.1-2). During the audit, the staff discussed with WEC whether Appendix 3I should be eliminated since components and equipment in the ESS program are primarily designed to resist the high frequency vibratory seismic motion. WEC stated that for the SSO, the seismic qualification of the safety-related equipment is a COL applicant responsibility as stated in Section 4.5.1 of the SSO report, and that the information provided in Appendix 3I was to allow the COL applicant to perform this task. The staff considers that WEC provided adequate information for the COL applicant to perform equipment qualification using the seismic event ESS condition. This is a COL item as stated in the SSO report.

REACTOR SYSTEMS INPUT

Fuel Assembly Structural Response to Externally Applied Loads

WEC staff presented information related to the natural frequencies for the AP1000 fuel assembly as compared with the acceleration response spectrum for the SSO conditions. WEC provided a [ ] analysis to demonstrate that the fuel integrity would remain unchallenged under the SSO spectrum. NRC staff expressed some concerns regarding this [ ] approach and stated that the staff would need to review this approach in detail if it were to be used by WEC as a basis for compliance with General Design Criterion 2 in terms of the fuel assembly structural response. WEC then presented a [ ] analysis methodology which relied on [ ] to demonstrate fuel integrity. The staff noted that this approach was in line with previously approved WEC applications. At the conclusion of the audit, WEC committed to choosing an approach to the fuel assembly structural response to externally applied loads analysis and communicating that approach back to the NRC staff.

List of Documents Reviewed

1. HSP-1000-S2C-060, Revision 0, "Time History Analysis of [ ] for the Specialized Seismic Option Project."
2. HSP-1200-S2C-002, Revision 0, "[ ] Analysis."
3. HSP-GW-G1-004, Revision 0, "The Certified Seismic Design Response Spectra for the Enhanced Seismic Plant."
4. HSP-GW-G1-005, Revision 0, "The Design Ground Motion Time History for the Specialized Seismic Option Project."
5. HSP-1000-S2C-004, Revision 0, "[ ] for ESS."
6. HSP-1000-S2C-030, Revision 0, "[ ] Analysis of [ ]."
7. HSP-PRA-GSR-002, Revision 0, "[ ] calculations for the Specialized Seismic Option Project."
8. HSP-1278-S3C-001, Revision 0, "[ ] Design – [ ]."
9. HSP-1010-S2C-004, Revision 0, "[ ] Analyses for [ ]."
10. HSP-1200-CCC-122, Revision 0, "[ ]."
11. HSP-1200-CCC-119, Revision 0, "[ ] Design."
12. HSP-1208-CCC-003, Revision 0, "Design of [ ]."
13. HSP-1000-S2C-088, Revision 0, "[ ] Response Spectra for [ ]."
14. HSP-MV50-S2C-009, Revision 0, "Time History Analysis of [ ]."
15. HSP-MV50-S2C-006, Revision 0, "Stress evaluation for Load combinations of [ ]."

16. HSP-MV50-S2C-034, Revision 0, “Stress and Stability Evaluation of AP1000 [ ] for the Specialized Seismic Option Project.”
17. HSP-2101-S3C-002, Revision 0, “[ ].”
18. HSP-1150-SHC-010, Revision 0, "[ ] for the Specialized Seismic Option Project."
19. HSP-RCS-PLC-056, Revision 0, “[ ] for the Specialized Seismic Option Project: [ ].”
20. HSP-MI01-S3C-032, Revision 0, “[ ] for the Specialized Seismic Option Project – [ ].”
21. HSP-MI01-S3C-900, Revision 0, “[ ] for the Specialized Seismic Option Project.”
22. HSP-MV11-S3C-200, Revision 0, “[ ] for the Specialized Seismic Option Project.”
23. HSP-PH01-Z0C-007, Revision 0, “[ ] for the Specialized Seismic Option Project.”
24. HSP-MB01-Z0C-200, Revision 0, “[ ] for the Specialized Seismic Option Project.”
25. HSP-SS30-Z0R-200, Revision 0, “[ ] for the Specialized Seismic Option Project.”
26. HSP-1101-SHC-001, Revision 0, “[ ].”
27. HSP-MB01-Z0C-051 Revision 0, “[ ] for the Specialized Seismic Option Project.”
28. HSP-MV20-Z0R-016 Revision 0, “[ ] for the Specialized Seismic Option Project”
29. HSP-RCS-PLR-010 Revision 0, “[ ] for the Specialized Seismic Option Project.”
30. HSP-SGS-PLR-030, Revision 0, “Piping Stress Analysis Report for [ ] for the Specialized Seismic Option Project.”
31. HSP-RCS-PLR-030, Revision 0, “Piping Analysis Report for [ ] for the Specialized Seismic Option Project.”
32. HSP-SGS-PLR-040, Revision 0, “Piping Analysis Report for [ ] for the Specialized Seismic Option Project.”
33. HSP-RCS-PLR-050, Revision 0, “Piping Analysis Report for [ ] for the Specialized Seismic Option Project.”
34. HSP-GW-S3C-001, Revision 0, “[ ] for Component and Supports.”
35. HSP-PH01-Z0C-002, Revision 0, “[ ] for the Specialized Seismic Option Project.”

36. HSP-GW-GLR-001, Revision 0, “The Specialized Seismic Option Report,” September 2015 (Proprietary), and HSP-GW-GLR-002, Revision 0, “The Specialized Seismic Option Report,” September 2015 (Non-Proprietary).”