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MEMORANDUM TO: Michael D. McCoppin, Chief
Licensing Branch 2
Division of New Reactor Licensing
Office of New Reactors

FROM: Tomeka Terry, Project Manager /RA/
Licensing Branch 2
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Office of New Reactors

SUBJECT: AUDIT REPORT OF STRUCTURAL AND SEISMIC DESIGN
SUPPORTING CHAPTER 3, "DESIGN OF STRUCTURES,
SYSTEMS, COMPONENTS, AND EQUIPMENT," OF THE
ADVANCED POWER REACTOR 1400 DESIGN CONTROL
DOCUMENT

The U.S. Nuclear Regulatory Commission (NRC) staff conducted an audit of the Chapter 3, Sections 3.7 "Seismic Design," and 3.8 "Design of Category I Structures," of the Korea Hydro & Nuclear Power Co., Ltd. (KHNP) Advanced Power Reactor (APR1400) design certification application on June 20, 2016 through June 24, 2016. The audit was conducted at the Westinghouse Electric Company facilities in Rockville, Maryland, on June 20, 2016 through June 24, 2016, and subsequently at NRC Headquarters in Rockville, Maryland. The purpose of the audit was to gain a better understanding of the design and analysis methods of structures and to confirm the design approach used by KHNP to reach a reasonable assurance finding.

The audit plan can be found in the Agencywide Documents Access and Management System under Accession No. ML16152A010 dated June 17, 2016. Enclosed is the audit report.

Docket No.: 52-046

Enclosures:

1. Audit Report
2. List of Attendees
3. List of Documents Audited

cc w/encl: See next page

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 CHAPTER 3, "DESIGN OF STRUCTURES, SYSTEMS, COMPONENTS, AND
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 CONTROL DOCUMENT DATED: 12/26/2017

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APR1400 DESIGN CONTROL DOCUMENT CHAPTER 3,

“DESIGN OF STRUCTURES, SYSTEMS,

COMPONENTS AND EQUIPMENT”

AUDIT REPORT

JUNE 20 – 24, 2016

1.0 SUMMARY

The U.S. Nuclear Regulatory Commission (NRC) staff conducted an audit of the Chapter 3, Sections 3.7 “Seismic Design,” and 3.8 “Design of Category I Structures,” of the Korea Hydro & Nuclear Power Co., Ltd., (KHNP) Advanced Power Reactor (APR) 1400 Design Certification Application design control document (DCD). The audit was conducted at the Westinghouse Electric Company facilities in Rockville, Maryland, on June 20–24, 2016, and subsequently at NRC Headquarters in Rockville, Maryland. The staff conducted the audit in accordance with the NRC’s Office of New Reactors (NRO) Office Instruction NRO-REG-108, “Regulatory Audits.” The audit plan, dated June 17, 2016, is in the NRC’s Agencywide Documents Access and Management System under Accession No. ML16152A010.

2.0 BASIS

This audit was conducted in order for the staff to gain a better understanding of the design and analysis methods of structural and seismic structures and supporting calculations and analysis to reach a reasonable assurance finding, and review related documentation and non-docketed information to evaluate conformance with the Standard Review Plan and other related guidance. The topics centered on the subjects of structural and seismic methodologies discussed in several requests for additional information, as outlined in the audit plan.

This regulatory audit is based on the following:

- Title 10 of the *Code of Federal Regulations* (10 CFR) 52.47(a)(9)
- 10 CFR Part 50 Appendix B
- General Design Criteria 1, 2, 4 and 5 of 10 CFR Part 50, Appendix A
- 10 CFR Part 50 Appendix S
- 10 CFR Part 100.23 Appendix A

3.0 OBSERVATIONS AND RESULTS

Staff audited a multitude of documents, including calculations and draft responses to Request for Additional Information (RAI), and had many technical discussions. The following list details the outcome for each audit plan item.

Enclosure 1

Section 3.7:

1. The compatibility of the power spectrum density (PSD) functions with the certified seismic design response spectra (CSDRS) - RAI 182-8160, Question 3.7.1-1

KHNP will revise the justification for its use of low pass filtering on the CSDRS time histories with corner frequencies lower than 50 Hz. A draft was shown to the staff during the audit and the staff reviewed.

2. The methods used to estimate the PSD for the CSDRS and the hard rock high frequency (HRHF) time histories - RAI 182-8160, Question 3.7.1-3.

NRC will send KHNP a feedback on the revised response to RAI Question 3.7.3-1, which will include a request for justification for the use of 33 Hz as the criteria to determine flexible/rigid tanks.

3. The adequacy of the methodology; and results for analyzing the effects of HRHF input ground motion on the standard plant - RAI 183-8197, Question 3.7.2-1.

KHNP provided draft markups to Technical Report 14004, addressing the items related to HRHF evaluation. The staff found the markups to be adequate. Further, the staff indicated that the markups describing the applicant's conclusion of the adequacy of the design to CSDRS relative to HRHF based on a comparison to allowable steel stresses (for the Containment Internal Structure), are adequate pending favorable results of the in-process HRHF analysis (i.e., 16 mode solution).

4. The adequacy of the method used to calculate the ground contact ratio - RAI 183-8197, Question 3.7.2-4.

KHNP will revise its RAI response with respect to the information related to the Emergency Diesel Generator Building (EDGB)/ Diesel Fuel Oil Tank (**DFOT**) to (a) clarify that the fixed-base analysis refers to **ANSYS** fixed-base transient analysis, (b) include final results and remove preliminary results (in the response and associated markups to TeR 14006), and (c) revise the markups to Section A.4.1.1 in TeR 14006 to replace the expression "rigid springs" by "relatively stiff spring" and remove the sentence referring to fixed-base analysis.

5. Consideration of hydrodynamic masses (e.g., in-containment refueling water storage tank (IRWST), auxiliary feedwater (AFW), and the Fire Hazards Analysis (FHA) tank masses) in the seismic analysis - RAI 226-8235, Question 3.7.2-5.

The item was resolved, KHNP will revise the RAI response to remove the paragraph that discusses the American Society of Civil Engineers 4-98 water compressibility criteria because it did not convey what KHNP intended to say.

6. Consideration of embedment effects in the structure –soil-structures interaction (SSSI) analyses - RAI 226-8235, Question 3.7.2-6.

KHNP will perform SSSI analyses with consideration of embedment.

7. The adequacy of the finite element models used in the seismic analysis - RAI 252-8299, Question 3.7.2-7.

KHNP will perform sensitivity study using fixed-base analysis with coupled containment structure (CS) and internal structure (IS) to evaluate the effects on the response. Alternatively KHNP will include a commitment in the DCD to ensure that the detailed design of the connection will be performed to be consistent with the modeling assumptions. In addition, KHNP indicated that the frequencies for the aforementioned slabs (provided in Question 3.8.3-5 related input), need revision. KHNP will provide the revised slab frequencies.

8. The consideration of accidental torsion in the seismic analysis - RAI 252-8299, Question 3.7.2-8.

Regarding the accidental torsion calculation, technical report 1-350-C304-001, Revision 4 for the EDGB/DFOT, referenced the AB calculation 9-320-C307-001 as input to the accidentals torsion calculation instead of the calculation for the EDGB soil-structure interaction (SSI) analysis. KHNP will revise the reference.

9. The adequacy of the analysis methods used for seismic Category I structures with the inclusion of all the soil cases that contribute to the determination of the in-structure response spectra (ISRS) - RAI 252-8299, Question 3.7.2-9.

Two approaches for addressing the S05 ISRS exceedance for the EDGB/DFOT were discussed. The applicant will consider these approaches and any others and present a revised response to the RAI at the appropriate time.

10. Modeling of flexible floors and walls in the reactor containment building (RCB) and the auxiliary building (AB) - RAI 252-8299, Question 3.7.2-10.

11. The applicant is to provide comparisons of ISRS at the center of AB walls, obtained from ANSYS coarse model and SASSI model that demonstrate consistent results between the two models. This is to be provided for a subset of the walls identified in the response to Question 3.7.2-10 (e.g., 5 walls), converging the frequency range for the walls identified in the response (e.g., low frequency, mid frequency, and high frequency). Alternatively, the applicant is to provide an approach to be described in the DCD, for performing local analysis of walls for which an ISRS at the center of the wall is to be developed for equipment design/analysis purposes.

12. Consideration of soil/sidewalls separation effects and implementation of SSI methodologies - RAI 252-8299, Question 3.7.2-11.

Staff audited the documentation related to the NQA1 verification and validation (V&V) for (ACS) SASSI, which met the staff's expectation. KHNP will describe the ACS SASSI V&V to NQA1 requirements in its response to RAI 252-8299, Question 3.7.2-11, and benchmark problem coverage of APR1400 parameters of interest.

13. The adequacy of the method used for the seismic analysis of tanks - RAI 267-8301, Question 3.7.3-1.

KHNP proposed adding a new DCD section discussing the seismic analysis of tanks. The staff will review this addition at the appropriate time.

14. The separation of modal frequencies - RAI 267-8301, Question 3.7.3-5.

Section 3.8:

1. The method used for combining dynamic loads that include safety shutdown earthquake (SSE), loss-of-coolant accident (LOCA), and safety/relief valve actuation; the consideration of full or portion of live load for evaluating the seismic response forces - RAI 129-8085, Question 3.8.1-1.

KHNP provided a draft response markup for audit. Staff audited the content and found it to be technically acceptable.

2. The consideration of concrete cracking in the seismic analysis and design of the NI structures; the parameters affecting the prestress losses over the life of the plant - RAI 129-8085, Question 3.8.1-2.

KHNP provided a draft response markup for audit. Staff audited the content and found it to be technically acceptable.

3. The methodology for computing the ultimate pressure capacity of the containment - RAI 129-8085, Question 3.8.1-5.

KHNP will verify the dynamic load factor utilized, and explain a substantially reduced concrete tensile strength.

4. The description of the approach for analyzing the hydrogen pressure load due to fuel-clad and water interaction – RAI 199-8223, Question 3.8.1-8.

KHNP will include an explanation of reduced concrete tensile strength similar to RAI 129-8085, Question 3.8.1-5. Also, KHNP must explain the use of the dynamic load factor in this calculation.

5. The evaluation of the severe accident performance goal for the containment - RAI 199-8223, Question 3.8.1-10.

KHNP provided a draft response markup for audit. Staff audited the content and found it to be technically acceptable.

6. The design approach of various critical sections; and the V&V of the computer code - RAI 199-8223, Question 3.8.1-15.

Staff audited and verified the V&V for DARTEM code. Applicant provided draft markup of Table 3.8-1, which staff found technically acceptable. KHNP needs to show consistency with response to RAI 3.7.2-2 (Table 3.8A-40).

7. The criteria for the analysis and design of the penetrations - RAI 200-8225, Question 3.8.2-2.

Staff had provided feedback to the applicant in a public teleconference prior to the audit, no audit action was taken. KHNP will address staff feedback at a future date.

8. The methodology for analyzing the hydrodynamic pressure loads in the design and analysis of IRWST structure - RAI 208-8245, Question 3.8.3-1.
This item was deferred and no action was taken at the audit.

9. Loads and load combinations for the CIS - RAI 208-8245, Question 3.8.3-3.

KHNP is to review all loads and load combinations and include those applicable to the CIS.

10. The consideration of accidental thermal loads in the analysis and design of the CIS - RAI 208-8245, Question 3.8.3-4.

KHNP is to review all loads and load combinations and include those applicable to the CIS.

11. Slabs in CIS (decoupling, mass distribution, support/connection of slabs) - RAI 208-8245, Question 3.8.3-5.

KHNP will consider staff feedback given on a prior public teleconference. KHNP will explain how sliding connection is ensured and how friction forces are considered; explain whether same design approach is used for other floor slabs; and describe how minimum gap between steel beam/slab and containment is evaluated against relative displacements from seismic, thermal and LOCA. KHNP will also consider using the envelope of the vertical spectra at both ends of slab or provide justification for not doing so.

12. The adequacy of the concrete fill on top of the basemat liner - RAI 208-8245, Question 3.8.3-7.

KHNP provided a draft response markup for audit. Staff audited the content and found it to be technically acceptable.

13. The design and analysis approach of the leak chase channels in the containment liner plate, the IRWST, and the HVT liner plates - RAI 332-8382, Question 3.8.3-8.

KHNP will provide further justification for not including leak chase channel systems for the embedded containment floor and liner.

14. The inclusion of hydrodynamic load and dynamic soil pressure in loads generated by SSE - RAI 227-8274, Question 3.8.4-7.

KHNP to include similar description for EDGB and DFOT in the DCD, as done for the Auxiliary Building.

15. Waterproofing membranes and their effect on the shear resistance of the NI common basemat - RAI 255-8285, Question 3.8.5-4.

KHNP will evaluate the sliding stability and provide a response to RAI 255-8285, Question 3.8.5-4 at the appropriate time.

16. Construction sequence and differential settlement of foundation - RAI 255-8285, Question 3.8.5-7.

KHNP will provide moment diagram across the foundation; KHNP internal discussion is required for construction sequence. Differential settlement criteria needs to consider angular distortion (NRC Tech Rational Document, USACOE Manual, and American Society of Mechanical Engineers PVP Paper). KHNP will revise wording for combined operating license (COL) site-specific evaluation and COL item (regarding soil variations) and design margins.

17. Short and long term settlements - RAI 255-8285, Question 3.8.5-9.

KHNP provided a draft response markup for audit. Staff audited the content and found it to be technically acceptable. KHNP to add new COL Item as per response to Question 3.8.5-7.

18. Checking of differential settlements by the COL applicant - RAI 255-8285, Question 3.8.5-18.

KHNP to provide justification for not including long term settlement (reference information or sufficient margin against acceptance criteria) in the future response to the RAI.

4.0 CONCLUSION

The summary of observations, as indicated above, was communicated to KHNP during the audit and reiterated at the exit briefing. The staff audited the seismic analysis and structural design, including reports, along with calculations supporting the applicant's RAI responses to the staff's RAIs. NRC staff identified further information needed to make regulatory findings. The staff and applicant agreed to continue to track issues discussed in the audit through the associated existing RAIs outlined previously.

LIST OF ATTENDEES

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John Vera	U.S. Nuclear Regulatory Commission (NRC)
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Sunguk Kwon	Korea Hydro & Nuclear Power Co., Ltd. (KHNP)

Jungho Kim	KHNP
Steven Mannon	AECOM
David Wagner	AECOM
Rob Sisk	Westinghouse

LIST OF DOCUMENTS AUDITED

- Artificial Time History Generation, Document No.: 1-300-C305-001
- Hard Rock High Frequency Time History Generation, Document No.: 1-300-C305-002
- SSSI Analysis, Document No.: 1-300-C305-011
- Containment Building Seismic Analysis, Document No.: 1-310-C305-011
- Seismic Analysis of Nuclear Island (NI) Structures Using Incoherent Ground Motion, Document No.: 1-310-C305-001
- Auxiliary Building Seismic Analysis, Document No.: 1-320-C305-001
- Emergency D/G Building Seismic Analysis, Document No.: 1-350-C305-001
- Seismic Analysis of Emergency Diesel Generator Building Using Incoherent Ground Motion, Document No.: 1-350-C305-002
- Containment Building-Analysis of NI Common Basemat, Document No.: 1-311-C304-001
- Containment Building IRWST Hydro-Dynamic Analysis, Document No.: 1-311-C305-001
- Containment Building-Analysis of Concrete Shell and Dome, Document No.: 1-316-C304-001
- Containment Building Ultimate Pressure Capacity, Document No.: 1-316-C304-005
- Containment Building Capacity Evaluation on Severe Accident (Global), Document No.: 1-316-C304-007
- Containment Building Capacity Evaluation on Severe Accident (Local), Document No.: 1-316-C304-007
- Containment Building Primary Shield Wall Analysis, Document No.: 1-317-C304-002
- Auxiliary Building Structure Analysis, Document No.: 1-320-C304-002
- Auxiliary Building Auxiliary Feedwater (AFW) Tank Hydro-Dynamic Analysis, Document No.: 1-323-C305-001
- Auxiliary Building Fire Hazards Analysis (FHA) Hydro-Dynamic Analysis, Document No.: 1-324-C305-001
- Emergency D/G Building Structure Analysis, Document No.: 1-350-C304-001
- Containment Building-Design of NI Common Basemat, Document No.: 1-311-C318-001
- Reactor Containment Building (RCB)-Design of Post-Tensioning System, Document No.: 1-316-C318-001
- RCB-Design of Shell & Dome Concrete Section, Document No.: 1-316-C318-002
- RCB-Design of Area Around Large Penetration, Document No.: 1-316-C318-003
- RCB-Design of Main Steam Line Penetration, Document No.: 1-316-C318-004
- Containment Building Primary Shield Wall Design, Document No.: 1-317-C318-001
- Auxiliary Building Basemat Design, Document No.: 1-321-C318-001
- Auxiliary Building AFW Tank Concrete Design for Local Loads, Document No.: 1-323-C318-006
- Auxiliary Building FHA Concrete Design for Local Loads, Document No.: 1-324-C318-005
- RCB Liner Palte In-containment Refueling Water Storage Tank Floor Liner Plan El. 81'-0", Document No.: 1-311-C123-011
- Standard Details-Stainless Steel Liner Sections & Details Sheet 2, Document No.: 1-300-C123-002
- Design-Specification-Piping Penetration Assembly, Document No.: 9-037-G407-001

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