TRANSIENT AND ACCIDENT ANALYSES AS PART OF THE APR1400 DESIGN CONTROL DOCUMENT AUDIT

JULY 14, 2015 – SEPTEMBER 30, 2015

Korea Hydro and Nuclear Power Co., Ltd. (KHNP)
and Korea Electric Power Corporation (KEPCO)

APR1400 DESIGN CERTIFICATION
Docket No. 52-046

Location: NRC Headquarters
Two White Flint North
11545 Rockville Pike
Rockville, MD 20852-2738

KHNP Washington DC Center
8100 Boone Blvd. Suite 620
Vienna, VA 22182

Purpose:

The purposes of this audit are for the staff to: (1) gain an understanding of Advanced Power Reactor 1400 (APR1400) supporting calculations and analyses to reach a reasonable assurance finding and (2) review related documentation and non-docketed information to evaluate conformance with the Standard Review Plan (SRP) or technical guidance.

Background:

On March 5, 2015, the U.S. Nuclear Regulatory Commission (NRC) accepted the design certification application for docketing for the APR1400 submitted by Korea Hydro and Nuclear Power Co. (KHNP) (Reference 1). The staff initiated Phase 1 of the application design certification review on March 9, 2015.

The NRC staff determined that efficiency gains would be realized by auditing the documents supporting the calculations presented in the design control document (DCD) in lieu of requests for additional information (RAIs) asking the applicant to docket the calculation files. The purpose of this audit is to allow the NRC technical staff to gain an understanding of the supporting calculations to better focus staff inquiries to the applicant. During the audit and other interactions with the applicant, detailed RAIs may be developed, which would be part of future formal correspondence.

Regulatory Audit Basis:

Title 10 of the *Code of Federal Regulations* (10 CFR) 52.47(a)(3)(i), states that a design certification application must contain a final safety analysis report (FSAR) that includes a description of principal design criteria for the facility. An audit is needed to evaluate the safety conclusions that need to be made regarding Chapter 4, 5, and 9, of the APR1400 DCD and identify detailed information related to the applicant's principal design criteria.

Enclosure

The NRC staff must have sufficient information to ensure that the acceptable risk and adequate assurance of safety can be documented in the NRC staff's safety evaluation report (SER).

This regulatory audit is based on the following:

- 10 CFR Part 50 Appendix A, General Design Criteria (GDC):
    - GDC 10, "Reactor Design," 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.
    - GDC 11, "Reactor Inherent Protection," the reactor core and associated coolant systems shall be designed so that, in the power operating range, the net effect of the prompt inherent nuclear feedback characteristics tends to compensate for a rapid increase in reactivity.
    - GDC 20, "Protection System Functions," the protection system shall be designed to: (1) initiate automatically, the operation of appropriate systems including the reactivity control systems, to assure that specified acceptable fuel design limits are not exceeded as a result of anticipated operational occurrences and (2) sense accident conditions and to initiate the operation of systems and components that are important to safety.
    - GDC 25, "Protection System Requirements for Reactivity Control Malfunctions," requires the protection system to be designed to assure that specified acceptable fuel design limits (SAFDL) are not exceeded for any single malfunction of the reactivity control systems; therefore, a single malfunction of the control rod drive system (CRDS) should not result in exceeding SAFDL.
    - GDC 26, "Reactivity Control System Redundancy and Capability," requires that control rods are capable of reliably controlling reactivity changes to assure that under conditions of normal operation, including anticipated operational occurrences, and with appropriate margin for malfunctions such as stuck rods, specified acceptable fuel design limits are not exceeded.
    - GDC 27, "Combined Reactivity Control Systems Capability," requires the reactivity control systems to 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," requires the reactivity control systems to 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.

  - GDC 29, “Protection against Anticipated Operational Occurrences,” requires that the reactivity control system be designed to ensure an extremely high probability of accomplishing its safety functions in the event of anticipated operational occurrences; hence, failure of non-safety-related systems should not prevent the control element drive mechanisms (CEDMs) from performing its safety function.

  - GDC 62, “Prevention of Criticality in Fuel Storage and Handling,” requires that criticality in the fuel storage and handling system shall be prevented by physical systems or processes, preferably by use of geometrically safe configurations.

- 10 CFR 50, Section 50.61, prescribes specific requirements for fracture toughness for protection against pressurized thermal shock events. 10 CFR 50.61(c)(1)(iv)(B), requires the best estimate neutron fluence, in units of 1019 n/cm2 (E greater than 1 MeV), at the clad-base-metal interface on the inside surface of the vessel at the location where the material in question receives the highest fluence for the period of service in question. As specified in this paragraph, the end of life fluence for the vessel beltline material is used in calculating KRTPTS.

- 10 CFR 52.6, “Completeness and Accuracy of Information,” requires, in pertinent part, an applicant for a standard design certification to provide complete and accurate information in all material aspects.

- 10 CFR 50.46a, “Acceptance Criteria for Reactor Coolant System Venting Systems,” Criterion (c): “The vent system must be designed to ensure that:

  (1) The vents will perform their safety functions; and

  (2) There would not be inadvertent or irreversible actuation of a vent.”

- 10 CFR 50.46(b)(5): “After any calculated successful initial operation of the emergency core cooling system, the calculated core temperature shall be maintained at an acceptably low value and decay heat shall be removed for the extended period of time required by the long-lived radioactivity remaining in the core.”

- 10 CFR 50.68: “Criticality Accident Requirements,” prescribes specific requirements for preventing criticality event in fresh and spent fuel storage.

- RG 1.206, Subsection 4.6.2: “Applicants should provide failure mode and effects analyses of the CRDS in tabular form, with supporting discussion to delineate the logic employed."

- RG 1.206, Section C.I.4.6, "Function Design of Reactivity Control Systems."
- RG 1.206, Section C.I.5.4.1, "Reactor Coolant Pumps."
- RG 1.206, Section C.I.5.4.12, "Reactor Coolant System High Point Vents."
- SRP Section 5.4, "Reactor Coolant System Component and Subsystem Design."
- SRP Sections 4.6 and 15.0, "Introduction - Transient and Accident Analyses."
- SRP Section 4.6, page 4.6-9, point 1: "The review evaluates the SAR to ascertain that failure modes and effects analyses have been completed to determine that the CRDS (not the individual drives) is capable of performing its safety-related function following the loss of any active component."
- SRP Subsection 5.4.12, "Reactor Coolant System High Point Vents."

Regulatory Audit Scope:

The NRC staff will conduct this audit in accordance with the guidance provided in NRO-REG-108, "Regulatory Audits" (Reference 2). The staff intends to review information, documents and supporting calculations related to the reactor, reactor coolant system and connecting systems, and auxiliary systems described in APR1400 DCD Tier 2, Chapters 4, 5 and 9, specifically Subsections 4.3, 4.6, 5.4.1, 5.4.12 and 9.1.1. The following are areas which the NRC staff intends to review during this audit:

- In Section 4.3, the staff needs information to assess: (1) DIT/ROCS Code Benchmarking with ENDF/B-IV Cross Section Library; (2) DIT/ROCS code benchmarking analyses for PLUS7 fuel design with gadolinium loading patterns; (3) control rod depletion and the approach to estimate the change in the differential control rod worth; (4) reactor vessel fluence calculation; and (5) Monte Carlo N-particle (MCNP) adjoint function calculation.
- In Section 4.6, the staff needs information to assess: (1) isolation of essential and non-essential components; (2) combined performance of the reactivity control systems and its relation to the other sections in Chapter 15; and (3) related Chapter 14 performance tests of the CEDMs.
- In Section 5.4.1, the staff needs information to assess the reactor coolant pump (RCP) design and associated operational performance issues. The staff needs information regarding: (1) injection water flow path within the pump seals packages and the associated leak-off configuration; (2) pump and motor bearings types (3) the performance tests and analyses that shows the minimum margin of 22 ^F for seal cooling water in the loss of component cooling water to RCPs case; (4) detailed description of the anti-rotation devices, and (5) the robust test

program that verifies the performance of the seal to withstand adverse station black out (SBO) conditions.

- In Section 5.4.12, the staff needs information to assess the reactor coolant gas vent system (RCGVS) and its performance. The staff needs information to clarify the use of the RCGVS during startup and any potential impacts on post-accident conditions; path to the reactor drain tank; functions of the pressurizer and the reactor vessel closure head portions of the RCGVS; potential breaks in the pressurizer vent line; the performance evaluation of the RCGVS and RCGVS instrumentation.

- In Section 9.1.1, the staff needs information to assess the applicant's burnup credit analysis methodology for spent fuel pool criticality safety analyses and code benchmarking methodologies for depletion codes, TRITON, and three-dimensional criticality analysis code KENO-VI with ENDF/B-VI cross sections. The staff needs information to verify that the overall approach is consistent with the guidance in DSS-ISG-2010-01, "Staff Guidance Regarding the Nuclear Criticality Safety Analysis for Spent Fuel Pools." and other relevant reports based on which the applicant used to develop the burnup credit analyses for the APR1400 design.

<u>Documents and Information Necessary for the Audit</u>:

The following documents are to be made available to the NRC staff, either at the KHNP Washington, DC Center, or in the electronic reading room. This is not a comprehensive list of documents that the staff will be reviewing as part of the audit, as there may be a need to review additional data and calculations supporting the basis for these documents. Appropriate handling and protection of proprietary information shall be acknowledged and observed throughout the audit.

- Calculation and documentation in Section 4.3 related to: (1) the code benchmarking methodology for both the depletion code, discrete integral transport (DIT), and three-dimensional reactor core analysis code ROCS; (2) estimated control rod worth loss due to depletion of B-10 when using the full-strength control element assemblies (CEA) as regulating rods; (3) the best estimate of reactor vessel fluence; and (4) the neutron flux adjoint function, which is used in the Core Protection Calculator System and the Core Operating Limit Supervisory System of the APR1400 reactor.

- Calculation and documentation related to failure modes and effects analysis (FMEA) of the CRDS to verify that a failure in the CRDS does not prevent a reactor trip from occurring.

- KEPCO Design Specification, 11A60-FS-DS485, Rev. 02, "Design Specification for Reactor Coolant Pump Motors," issued November 11, 2014. The staff would like to review this document to verify if the design specification document addresses the vendor shop-tests mentioned in DCD Subsection 5.4.1.

- Calculations and documentation related to Subsection 5.4.12 for the reactor vessel closure head (RVCH) vent capacity and the capacity required to vent a noncondensible bubble from the RVCH; and the pressurizer vent capacity and the capacity required to cool down/depressurize the plant.

- Calculations and documents related to the overall approach used for spent fuel criticality safety analyses as described in Section 9.1. Calculations and documentation demonstrating consistency with the recommendations from the Kopp Memorandum and NUREG/CR-7109, if this approach is used.

Audit Team:

Shanlai Lu (Team Lead), NRO, Senior Reactor Systems Engineer
Alexander Velazquez-Lozada, NMSS, Thermal Engineer
Alexandra Burja, NRO, General Engineer
Hien Le, NRO, Reactor Operations Engineer
James Steckel, NRO, Project Manager
Peter Yarsky, RES, Senior Reactor Systems Engineer
Donald Carlson, NRO, Senior Project Manager

Applicant Contacts:

Christopher Tyree, KHNP
Harry Chang, KHNP

Team Assignments:

The following table identifies the NRC staff and their review areas.

Table-1. NRC On-site Review Team

Review Area	NRC Staff Name
Audit Team Lead	S. Lu
Computer Codes	A. Velazquez
Reactor Coolant System and Connecting Systems	H. Le/A. Burja
Criticality	P. Yarsky/D. Carlson/A. Burja
Project\Support	J. Steckel

Logistics:

The NRC staff and the applicant have agreed that the audit will be conducted via an electronic reading room and in the KHNP office in Vienna, VA. In support of this approach, the applicant has agreed to make knowledgeable staff available, along with relevant documentation, to support the staff's review and discussion of the materials.

The audit is scheduled for a period of three months and onsite audits will be scheduled as needed. The staff requests that all document titles identified by the NRC staff be available at the beginning of the audit in the electronic reading room and prior to any scheduled onsite audit.

The NRC staff will have internal meetings throughout the audit to discuss preliminary findings. A summary of the audit preliminary findings will be provided to the applicant for discussion. The document titles responsive to the audit areas are listed in the Information and Documents Necessary for the Audit section of this audit plan.

Special Requests:

The NRC staff requests that KHNP provide:

- Document titles responsive to the audit areas listed in Regulatory Audit Scope and Methodology section of this audit plan.
- Searchable electronic copies of the documents listed above.
- KHNP personnel to provide any necessary overviews of the APR1400 reactor; reactor coolant system and connecting systems; and auxiliary systems DCD information and related documents.

Audit Activities and Deliverables:

The NRC audit team review will cover the technical areas identified in the Documents and Information Necessary for the Audit section of this audit plan. Depending upon how much effort is needed in a given area, the NRC team members may be reassigned to ensure adequate coverage of important technical elements.

The NRC Project Manager will coordinate with KHNP, in advance of any audit activities, to verify specific documents and identify any changes to the audit schedule and requested documents.

The NRC staff acknowledges the proprietary nature of the information requested. All proprietary information will be handled appropriately throughout the audit. While the NRC staff will take notes, the NRC staff will not remove hard copies or electronic files from the audit site(s).

At the completion of the audit, the audit team will issue an audit summary within 90 days, that will be declared and entered as an official agency record in the NRC's Agencywide Documents Access and Management System (ADAMS) records management system. The audit outcome may be used to identify any additional information to be submitted for making regulatory decisions, and it will assist the NRC staff in the issuance of RAIs (if necessary) for the licensing review of APR1400 DCD Chapters 4, 5, and 9 and any related information provided in other chapters, in preparation of the NRC staff's SER.

If necessary, any circumstances related to the conductance of the audit will be communicated to James Steckel (NRC) at 301-415-1026 or via email at James.Steckel@nrc.gov.

An audit will be conducted for approximately three months from the NRC Headquarters via KHNP's electronic reading room; however the audit may also be carried out at KHNP's facilities in Vienna, VA, if the technical information is only retained in hard copy.

Follow-up audits at the NRC Headquarters via KHNP's electronic reading room (or at KHNP's facilities in Vienna, VA) may be necessary at various times.

References:

1. "Letter to Korea Hydro and Nuclear Power Co., Ltd., and Korea Electric Power Corporation – Acceptance of the Application for Standard Design Certification of the Advanced Power Reactor 1400," ADAMS Accession Number ML15041A455, issued March 4, 2015.

2. NRO-REG-108, "Regulatory Audits," ADAMS Accession Number ML081910260, issued April 2, 2009.

3. APR1400 Design Control Document, Revision 0, issued December 2014.