AUDIT PLAN FOR REVIEWING THE KEPCO/KHNP TOPICAL REPORT "KCE-1 CRITICAL HEAT FLUX CORRELATION FOR PLUS7 THERMAL DESIGN" (APR1400-F-C-TR-12002-P REV.0) IN THE BACKDROP OF RAI 3-7443 RESPONSE
January 21–22, 2015

APR1400 DESIGN CERTIFICATION
Korea Hydro and Nuclear Power, Co, Ltd. (KHNP)
Project No. 0782

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

Purpose:

The purpose of the audit is to review the applicant's data, calculations, and supporting documents to gain in-depth understanding of the KEPCO/KHNP analyses, documentation, computer codes, assumptions, and uncertainties related to Topical Report "KCE-1 Critical Heat Flux Correlation for PLUS7 Thermal Design" (APR1400-F-C-TR-12002-P).

Background:

The U.S. Nuclear Regulatory Commission (NRC) staff plans to audit KHNP/KEPCO's submittal material supporting safety review activities related to the KEPCO/KHNP Topical Report "KCE-1 Critical Heat Flux Correlation for PLUS7 Thermal Design" (APR1400-F-C-TR-12002-P). The audit will also give NRC staff the opportunity to identify and verify the information that will have to be docketed to support the licensing basis and regulatory activities for the APR1400 design. Performing this audit will help staff finalize its assessment of the applicant's response to RAI 3-7443 and complete the safety review of the KEPCO/KHNP Topical Report.

Regulatory Audit Bases:

1. SRP Section 4.4 (Thermal and Hydraulic Design)
2. SRP Section 15.0.2 (Review of Transient and Accident Analysis Methods)

This audit follows the guidelines in Office of New Reactors (NRO) Office Instruction NRO-REG-108 (Revision 0), "Regulatory Audits."

Regulatory Audit Scope:

The objective of the audit is to resolve the outstanding issues in the applicant's response to NRC RAI 3-7443 issued to support the safety review of the KEPCO/KHNP Topical Report "KCE-1 Critical Heat Flux Correlation for PLUS7 Thermal Design" (APR1400-F-C-TR-12002-P). The proposed audit is an opportunity to resolve all outstanding safety concerns about the topical report, so that a draft safety evaluation report (SER) can be written. This audit plan formalizes the specific concerns that the staff has already communicated to the applicant through the May 1, 2014, public meeting and the September 23, 2014, teleconference. A written summary of the staff assessment of the applicant's response to all 18 RAI 3-7443 questions was also

shared with the applicant to facilitate the teleconference. After the teleconference, staff decided to conduct an audit to minimize the need for subsequent supplemental RAIs.

The following aspects of the applicant's RAI 3-7443 response and the KEPCO/KHNP Topical Report "KCE-1 Critical Heat Flux Correlation for PLUS7 Thermal Design" (APR1400-F-C-TR-12002-P) will be of special interest to the NRC staff during the proposed audit.

1) Addressing the non-conservative regions and trends in the critical heat flux (CHF) test data would be critical. The most significant of them is the sharp data reversal between 1400 psia and 1750 psia. Some apparent ways of addressing it may include taking more test data to fill the non-conservative gap; changing the form of the correlation to fit the data better; or excluding the 1400-1750 psia range from approval. Therefore, the applicant needs to justify the applicable pressure range for the KCE-1 correlation. Any data analyses performed to support the applicant's position need to be included in the audit material. Hereunder are some relevant details.

   a) The staff had asked the applicant to justify using the KCE-1 correlation at pressures between 1400 and 1750 where the non-conservative trend is observed. The RAI response does not discuss the pressure range between 1400 psia and 1750 psia and no justification is provided for the use of KCE-1 correlation below 1750 psia. If the applicant does not need to use the KCE-1 correlation in this range, then it will be limited to pressures above 1750 psia. If the applicant needs to use the KCE-1 correlation between 1400 psia and 1750 psia, it would need to justify its use given the non-conservative trend in the data within this range.

   b) Including the conservative dataset at the edge of the range of operation (at 1400 psia) may make the correlation appear more conservative than it actually would be within the range of operation, and would possibly lead to an effectively less conservative departure from nucleate boiling ratio (DNBR) limit within the range of operation. The staff did not find Figures 8-1 and 8-2 in the RAI 3-7443 response helpful in that regard. In the RAI 3-7443 Question 8 response, KHNP referenced a method for combining non-poolable data to generate a 95/95 limit. The staff needs to understand the technical basis for the approach during the audit.

   c) The applicant needs to provide the data analysis details in the audit to support its position on the potentially non-conservative sub-region at pressures near 1750 psia, qualities near 0.1, and local mass fluxes near 2 Mlbm/hr-ft^2, as identified in RAI 3-7443 Question 9.

2) The applicant needs to demonstrate that the heat losses from the test section were duly accounted for in their CHF test data, for the entire range of the tested bundle power. Besides the RAI question, KHNP agreed to meet this requirement in the May 1, 2014, meeting under "Test Acceptance Criterion" (ML14154A030). So far, the applicant has not been able to quantify or bound the heat losses from the CHF test section. A [ ]^{TS} heat balance was observed at very low bundle power, low inlet temperature, low pressure, and low flow rate conditions, while bundle powers up to an order magnitude higher, temperatures up to [ ]^{TS}, flow rates up to [ ]^{TS}, and pressures up to [ ]^{TS} were involved in the test range. Ignoring the heat losses through the test section would be non-conservative, as it would make CHF look higher than it actually is. Therefore, the applicant should either (a) justify the applicability of the [ ]^{TS} heat balance criterion

observed at low power and low temperature conditions over the entire domain of CHF test conditions; or (b) bound the heat losses and factor them into the correlation. The applicant may furnish the documentation showing how the heat loss question was addressed in the previous rod bundle CHF test programs at Columbia University's Heat Transfer Research Facility (HTRF). Any supporting analysis has to treat the heat losses as a bias in the test data due to the test section configuration that necessarily leads to a higher and non-conservative CHF value, and not as a cumulative measurement uncertainty due to the loop instrumentation. The staff also needs to understand how the [ ]TS were used in data reduction. The following two references cited in the RAI 3-7443 response are of special interest for the audit.

a) [ ]TS

b) [ ]TS

3) The applicant should provide the qualification status documentation for the HTRF for the CHF tests for PLUS7 fuel design. The documents should show details of the quality assurance (QA) program, test procedures, test acceptance criteria for the test facility, and the instrumentation calibration records or the approved methodology that was followed to perform and track the instrumentation calibration. There is a lack of documentation in the Topical Report (TR) about whether and how frequently the instrumentation calibrations were performed at this test facility. Considering the significance of accurately measuring the mass flow rate and inlet/outlet conditions in the overall computation of the critical heat flux and its subsequent design application, it is important to establish that the calibration of related instruments were performed following an approved test procedure and quality assurance program. As cited in the RAI 3-7443 response, the [ ]TS is of special interest for the audit. Including the documentation of any QA audit or inspection conducted for HTRF during other CHF test programs would also be valuable in this regard.

4) As agreed in the May 1, 2014, meeting regarding "Source of Uncertainty," (ML14154A030), the applicant needs to provide information about the overall experimental uncertainty involved in the CHF measurements/calculations to address SRP Section 4.4 Acceptance Criterion #1. This should also include the fabrication uncertainties and computational uncertainties (in using the TORC code), beside the measurement uncertainties due to instruments. The computational uncertainties would be driven by the TORC code parameter selection and heat losses. Any unaccounted for heat losses would pose a bias in the TORC code's prediction of the minimum departure from nucleate boiling ratio (MDNBR) location as the local conditions and fluid properties are computed based on energy conservation. No sources were identified and no discussion was provided in the TR for the fabrication uncertainties due to manufacturing tolerances, which could potentially affect the inlet mass flux and other test parameters. The uncertainties between the measured and predicted values reflected by the KCE-1 correlation are not a part of this concern as they would be covered under the 95/95 limit of the correlation. The applicant may consider including [ ]TS, in the audit, if it could facilitate the staff's question about the overall experimental uncertainty.

5) KHNP's description of the application of the Tong Factor (Fc) in the TR and the RAI 3-7443 response to correct the non-uniform heat flux data is very confusing. The NRC staff does

not understand most of the discussion provided in the RAI 3-7443 response. It is not clear how the applicant calculated and applied the Tong Factor and how it demonstrates conservatism. [

]TS." It is not clear how the effect of axial power was [ ]TS and what the logic was. The staff is unable to understand the philosophy behind Figures 6-1, 6-2, 6-3, and 6-4 of the response, that present Tong Factor as [

]TS The applicant should consider including in the audit material any relevant reference(s) cited in RAI 3-7443 Question 7 response, to bring clarity to the Tong Factor discussion. An updated Table A-3 with an additional column for the computed Tong Factors will address several staff questions.

6) The applicant has not justified testing a single axial profile and explained why the inlet/bottom or outlet/top peaked power profiles were not included in the test matrix. The applicant also has not described how well the tested cosine power distribution represents the actual profile that would be experienced during the operation of the PLUS7 fuel geometry. There are no supporting statements provided in the RAI response or in the topical report. As a matter of fact, the RAI response projects the "*actual axial power distribution expected to be experienced during the operation of PLUS7 fuel cores*," as a non-tested profile. The staff needs to understand the relevance of the tested non-uniform profile to the actual profile expected in the PLUS7 fuel geometry.

7) Even though, the staff will not review the application of the TORC code and plans to handle it through conditions and limitations of the SER, the computational uncertainties involved in using the TORC code are still a part of the staff review, in order to address SRP Section 4.4 Acceptance Criterion #1. Hereunder are some of the typical staff concerns about the TORC code parameters and nodalization.

   a) No justification is provided for selecting [ ]TS axial nodes for the TORC code. Was any sensitivity analysis conducted to justify the number of nodes? KHNP should provide a sensitivity analysis of the nodalization to demonstrate convergence. This information is also expected to shed some light on TORC code's computational uncertainty.

   b) What does "Yes/No" mean for the "Consistency with design constitutive relations" column title, as reported in Table 15-1 of the RAI 3-7443 response? The staff is concerned as to why, according to Table 15-1, the applicant does not see a need to provide the justification for most of the TORC input parameters. The reference cited in the RAI response as well as the topical report (CENPD-161-P-A; "TORC Code, A Computer Code for Determining the Thermal Margin of a Reactor Core," April 1986) needs to be made available during the audit.

   c) How sensitive are the TORC results to the specified thermal diffusion co-efficient (TDC) and how was the TDC value of [ ]TS validated? How was it concluded that the value that corresponded to a 26-inch grid spacing would be conservatively applicable to PLUS7 CHF data taken with a 15.7 inch spacing? In essence, the staff wants to understand the uncertainties computing the CHF value that is associated with the selection of various TORC code parameters, such as TDC.

   d) Section 6 reports that the reactor analysis is to be performed with the design inverse Peclet number (1/Pe = 0.0101) which is equivalent to a TDC = 0.038 applied to the

Westinghouse PWR for fuel assembly with "R" mixing vane grid design. The staff has concern about using a different TORC parameter for safety analysis than the one used for data reduction and correlation development. The applicant needs to justify this approach.

8) According to the RAI response, the CETOP-D code uses a different model to calculate the transport properties and a different numerical scheme to solve conservation equations than the TORC code. What would be the justification of using the KCE-1 correlation with CETOP-D code, as its different properties module and different numerical scheme would entail additional computational uncertainties while the staff is still trying to understand the computational uncertainties involved in using the TORC code that was used for the correlation development? The staff considers this review to be limited to the use of the KCE-1 correlation with the TORC code. Statements about the use of KCE-1 in CETOP-D would fall outside of the current review. Nevertheless, the applicant should include the Technical Report APR1400-F-C-NR-12001, "Thermal Design Methodology" as a part of the audit material.

9) The applicant's response does not address the possible overfitting of the KCE-1 correlation and the lack of a specific validation data base. The staff did not understand the applicant's statement that potential for overfitting is not expected in KCE-1 CHF correlation prediction. The RAI response does not provide an argument as to why the features of the KCE-1 correlation preclude overfitting of data. Best practices in fitting CHF correlations and previous experiments suggest that a certain percentage of the data points should not be used in the fitting process and should be used only in the validation process to ensure consistent behavior of the correlation. The NRC staff's own confirmatory analysis of the KHNP data suggests that if this were to happen, the 95/95 limit would increase. In the May 1, 2014, meeting regarding "Overfitting and Number of Test Data," (ML14154A030), KHNP promised to mark an additional column in the data table to identify which data points were included and which data points were excluded from the co-efficient development analysis. However, it has not been followed through in the RAI response. Is it because all data points were used in fitting the correlation?

10) The staff needs clarifications for the CHF Correlation data provided by the applicant in Table 10-1 in response to RAI 3-7443 Question 10 and its relation to Table A-3 in the topical report. Presenting a revised Table 10-1 with the missing CHFP and M/P columns in the audit will help.

In addition to the specific concerns documented in the above, hereunder are some general concerns about the RAI 3-7443 response that will also be discussed during the audit.

i. In several responses, the applicant made commitments to modify *"the appropriate subsection of the "A" version of the topical report upon approval [sic]"* to address the staff concerns. The applicant did not submit any marked-up changes for the staff's review, approval, and the future confirmatory action, which gives an impression that the applicant plans to meet the commitments by updating the TR after it will be approved by the NRC. In the staff's opinion, these mark-ups need to be submitted and verified in the revised version of the TR before the RAI could be closed and SER could be finalized. The staff would like to understand the applicant's position better, and how the change commitments will be tracked and verified.

ii. KHNP references an "assumption" numerous times in the RAI 3-7443 response emphasizing that the "assumption" makes the DNB calculation conservative. The NRC staff would like to discuss the assumption and understand how it makes the DNB calculations conservative. For instance, a better understanding the assumption is needed for the applicant's response to RAI 3-7443 Question 12 based on Figures 12-1 and 12-2. This will also address the May 1, 2014, meeting commitment by KHNP regarding "MDNBR Elevation Prediction," (ML14154A030). If the assumption is so critical, this would have to be elaborated within the topical report.

Logistics:

The staff proposes the audit take place in two steps. In the first step, the NRC staff would review the documents and information that the applicant provides at their local (Virginia) office. Some interaction with knowledgeable staff would be needed at this stage to be directed to the required information, but it is possible that some of this can be done and coordinated by telephone, if necessary. In the second step, once the staff has absorbed the collected information, the staff would return to directly interact with the applicant's staff to resolve any outstanding issues, as necessary. Detailed times and dates will be developed prior to the audit visit.

Information and Other Materials Needed for the Audit:

The NRC staff and the applicant have agreed that the audit will be conducted at the applicant's Washington Office Center in Vienna, Virginia. The following design documents should be available to the audit team at the time of the audit:

- All documents related to the areas identified in the audit scope. This should include all the documents cited or discussed in the RAI 3-7443 response, especially the ones that would support the resolution of questions and concerns summarized in the audit scope. The applicant should furnish the documents regardless of whether or not they are referenced in the TR. The proprietary versions of the documents, if applicable, would be needed for review during the audit.
- Other documents that the applicant deems necessary to support the review.

The applicant is requested to prepare a list of the documents to be made available during the audit, including the document titles, identifying numbers, and revisions.

Audit Team:

Syed I. Haider: Reactor Systems Engineer (NRO/DSRA/SCVB-SRSB)
Joshua Kaizer: Reactor Systems Engineer (NRR/DSS/SNPB)
Jim Steckel: Project Manager (NRO/DNRL/LB2)
Bruce Olson: Project Manager (NRO/DNRL/LB2)

Deliverables:

The audit team will issue a regulatory audit summary within 90 days after the completion of the audit that will be placed on the docket and in the Agencywide Documents Access and Management System (ADAMS). The audit outcome will be used to identify any additional information to be reviewed in a follow-on audit visit or submitted separately for making regulatory decisions. The audit will assist the NRC staff in resolving and closing the outstanding issues and preparing and issuing any further RAIs for the licensing review of the KEPCO/KHNP Topical Report "KCE-1 Critical Heat Flux Correlation for PLUS7 Thermal Design" (APR1400-F-C-TR-12002-P).