REVISED RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

APR1400 Design Certification

Korea Electric Power Corporation / Korea Hydro & Nuclear Power Co., LTD

Docket No. 52-046

RAI No.:	**155-8167**
SRP Section:	**06.02.05 – Combustible Gas Control in Containment**
Application Section:	**6.2.5**
Date of RAI Issue:	**08/18/2015**

Question No. 06.02.05-1

10 CFR 52.44(c)(1) requires that a standard design certification applicant must ensure a mixed atmosphere in containment during design-basis and significant beyond design-basis accidents. A mixed atmosphere means that the concentration of combustible gases in any part of the containment is below a level that supports combustion or detonation that could cause loss of containment integrity.

Acceptance Criteria 4 of Standard Review Plan (SRP) Section 6.2.5, “Combustible Gas Control in Containment,” and Regulatory Position C.3 of Regulatory Guide (RG) 1.7, “Control of Combustible Gas Concentrations in Containment,” Revision 3 state that all containment types should have an analysis of the effectiveness of the method used for providing a mixed atmosphere and that this analysis should demonstrate that combustible gases will not accumulate within a compartment or cubicle to form a combustible or detonable mixture that could cause loss of containment integrity.

APR1400 Design Control Document (DCD), Tier 2, Section 6.2.5.3 states that mixing is achieved by natural convection processes. In addition, DCD, Tier 2, Section 19.2.3.3.2.2 states that the APR1400 hydrogen control analyses were performed using the Modular Accident Analysis Program (MAAP) to determine hydrogen mixing, distribution, and combustion inside containment. KHNP’s “Severe Accident Analysis Technical Report,” APR1400-E-P-NR-14003-P, Revision 0, provides the results of these MAAP analyses and describes that the containment model consisted of 36 nodes.

In order for the staff to reach a conclusion of reasonable assurance that the requirements for mixing are met, the staff needs to review the calculation which demonstrates mixing in containment during and following an accident that releases an equivalent amount of hydrogen as would be generated from a 100 percent fuel clad-coolant reaction, either on the licensing docket or in the electronic reading room. The calculation should include:

- Hydrogen distribution and deflagration to detonation transition (DDT) potential for at power operation analysis for each of the 36 nodes, and at least 5 scenarios, showing the hydrogen, oxygen, and steam concentration for all nodes. Identify and address any nodes where the hydrogen concentration is greater than 10%. Identify and address any nodes with DDT potential, quantitatively and or qualitatively.

- The hydrogen generation curves versus time for each of the scenarios analyzed.

- The assumptions for crediting the hydrogen mitigation system. For example, provide the performance of the passive autocatalytic recombiners (PAR) and/or hydrogen igniters (HI). Include the PAR efficiency, number and locations of PARs and HIs credited.

- The criteria for the selection of the accident scenarios.

- DCD Tier 2, Figures 19.2.3-3 through 19.2.3-6 are labelled with scenario success criteria abbreviations. For each selected scenario, identify the mitigation systems or equipment credited, and to what extent. Elaborate on the success criteria for each scenario. For example, does HI credit all 8 igniters? Does 3WV credit both three way valves as being aligned to relieve in the steam generator compartments? A table of scenarios with corresponding assumptions with credited mitigating systems would be helpful.

This question is based upon material found in DCD Tier 2 Sections 6.2.5 (Combustible Gas Control in Containment), 19.2.3 (Severe Accident Mitigation), Tier 1 Section 2.11.4 (Containment Hydrogen Control System), and the Severe Accident Analysis Report, APR1400-E-P-NR-14003-P, Rev. 0.

Response – (Rev. 3)

a) Based on MAAP analysis on hydrogen distribution, the concentration of hydrogen, oxygen, and steam for all nodes in the selected 5 accident scenarios are shown in Figure 1 through Figure 15. The description of the 5 scenarios is given in Table 1. The nodes whose hydrogen concentration exceeds 10% are found in the figures. As addressed in Section 4.2 of the Severe Accident Analysis Report (APR1400-E-P-NR-14003-P, Rev.0), DDT possibilities are estimated for the nodes with hydrogen exceeding 10% according to the SOAR methodology (Reference 6 of the Severe Accident Analysis Report). DDT indices for all nodes in the 5 accident scenarios are shown in Figure 16. Details of FA and DDT assessments are addressed in Ref. 2 of this response. Ref. 1 and 2 of this response will be placed in the electronic reading room from 15.11.23 to 16.02.22 for the staff's review.

Non-Proprietary

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Figure 1 Mole Fraction of Hydrogen for LLOCA

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Figure 2 Mole Fraction of Steam for LLOCA

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Figure 3 Mole Fraction of Oxygen for LLOCA

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Figure 4 Mole Fraction of Hydrogen for SLOCA

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Figure 5 Mole Fraction of Steam for SLOCA

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Figure 6 Mole Fraction of Oxygen for SLOCA

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Figure 7 Mole Fraction of Hydrogen for SBO

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Figure 8 Mole Fraction of Steam for SBO

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Figure 9 Mole Fraction of Oxygen for SBO

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Figure 10 Mole Fraction of Hydrogen for TLOFW

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Figure 11 Mole Fraction of Steam for TLOFW

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Figure 12 Mole Fraction of Oxygen for TLOFW

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Figure 13 Mole Fraction of Hydrogen for MLOCA base case

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Figure 14 Mole Fraction of Steam for MLOCA base case

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Figure 15 Mole Fraction of Oxygen for MLOCA base case

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Figure 16 DDT index for all nodes of each scenario

- Sensitivity analysis

  * MLOCA-H2-AHFSP0-MCCI

  Since the safety case of MLOCA-H2-AHFSP0-MCCI has similar results to LLOCA-H2-AHFSP0-MCCI, it is described in the appendix of the calculation note, instead of in the calculation body. Details of analysis results are presented below;

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Figure 17 Mole Fraction of Hydrogen for MLOCA-H2-AHFSP0-MCCI

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Figure 18 Mole Fraction of Oxygen for MLOCA-H2-AHFSP0-MCCI

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Figure 19 Mole Fraction of Steam for MLOCA-H2-AHFSP0-MCCI

- Sensitivity Analysis

  * TLOFW-H2-0HFSDP3-MCCI

  The 3-way valve is the device which prevents hydrogen concentration in the IRWST during high pressure scenarios. The MAAP code allows for the modeling of two discharge points for the RCS effluents. The two IRWST compartments, where the RCS effluents are discharged through the spargers, were designated as the two discharge points for the base analysis. Half of the effluent from each RCS line is normally discharged into each of the two IRWST compartments. For the LOFW cases, Nodes 26 and 28 are designated as the two release compartments. However, for the 3-way valve operating case, the upper SG #2 compartment, Node 7, where the discharge nozzle of the 3-way valve is located, was designated as the release compartment, instead of the IRWST compart

  A sensitivity analysis was performed to review the operation time of the 3-way valve. The timing for manual operation of the 3-way valve is 30 minutes after the onset of core damage. The sensetivity case analyzed manual operation of the 3-way valve at 10 minutes after core damage. Details of analysis results are presented below;

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Figure 20 Mole Fraction of Hydrogen for TLOFW-H2-0HFSDP3-MCCI (3 way valve operated 10 minutes after core)

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Figure 21 Mole Fraction of Oxygen for TLOFW-H2-0HFSDP3-MCCI (3 way valve operated 10 minutes after core)

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Figure 22 Mole Fraction of Steam for TLOFW-H2-0HFSDP3-MCCI (3 way valve operated 10 minutes after core)

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Table 1 Accident Scenarios Employed in MAAP Analysis

b) The hydrogen generation curve for each scenario is given in Figure 23. The figure shows the hydrogen generation at in-vessel and ex-vessel. The total mass of hydrogen is also illustrated.

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Figure 23 Hydrogen Generation Curve of Each Scenario

c) The hydrogen mitigation system, consisting of passive autocatalytic recombiners (PARs) and hydrogen igniters (HIs), is installed inside the containment building. PARs that are evenly spaced inside the containment building handle accident sequences in which the hydrogen release rate is expected to be low or moderate. Whereas, HIs protect PARs in case of an extremely unlikely accident involving rapidly released hydrogen and function to maintain the containment building's integrity by promoting hydrogen combustion, as they are installed near the hydrogen release points. The hydrogen mitigation system in the APR1400 consists of 30 PARs and 8 igniters whose locations are shown in Table 2. The size and type of each PAR and assumed PAR efficiency employed in MAAP analyses are also addressed. The Framatome-ANP GmbH PAR model was used for hydrogen analysis, and they are assumed to be 25% degraded by cable fire and iodine vapor. For detailed information regarding PAR modeling, the MAAP user manual for the PAR model used is attached as Ref. 3.

Table 2 PARs and Igniters Installed inside Containment. **TS**

d) Accident scenarios with variations of severe accident mitigation features available were used as a basis to cover a wide spectrum of accident conditions, including the representative level-1 PRA sequences with potential significance in-core damage frequencies. The analyzed accident sequences include 5 initiator types with a base case defined for each initiator type. For each initiator type, variations in the availability of accident mitigation systems are made such that their impact, if any, can be observed. The five initiator types are Large/Medium/Small break LOCA, Station Blackout, and Total loss of feedwater. These sequences represent the entire spectrum of severe accident conditions important to hydrogen accumulation and distribution in the containment. A more detailed description for the selection of the accidents in the analysis is given in Sections 4.1 and 3.1.2 of Reference 1of this response.

e) Table 1 illustrates the accident sequences selected in the analysis. Also the tables and description in Section 4.1 of Reference 1 to this response include more details. All 8 HI are assumed to be available. For the SBO and TLOFW case, both three way valves are assumed to be aligned to release the RCS to the SG compartment. Four POSRVs are assumed to be open for TLOFW and two are assumed to be open for SBO.

In addition, the technical report (APR1400-E-P-NR-1003-P) will be revised to reflect the current calculation results, and these three calculations will be added to the technical report references section.

1. "Hydrogen generation and control during severe accident," KEPCO E & C, Calculation Note 1-035-N389-101, Rev.03, Sep. 26, 2015.

2. "Assement of AICC Pressure Load due to Hydrogen Combustion in Containment," KEPCO E & C, Calculation Note 1-035-N389-102, Rev.01, April. 05, 2013.

3. "Analysis of local DDT potential in the APR1400 containment," KEPCO E & C, Calculation Note 1-035-N389-103, Rev.02, Oct. 28, 2014.

The editorial errors (RAI Figures 4, Figure 9 and Figure 12, Attachment 1 and 2) were identified and modified as a result of the conference call on Jan 12, 2017.

Impact on DCD

DCD Tier 2 Subsection 6.2.9 will be revised as shown in the Attachment 1

Impact on PRA

There is no impact on the PRA.

Impact on Technical Specifications

There is no impact on the Technical Specifications.

Impact on Technical/Topical/Environmental Reports

Technical report, APR1400-E-P-NR-14003-NP, will be revised as shown in the Attachment 2.

RAI 155-8167 Question 06.02.05-1_Rev.2

RAI 155-8167 Question 06.02.05-1_Rev.3

30. NEI 94-01, "Industry Guideline for Implementing Performance – Based Option of 10 CFR 50, Appendix J," Nuclear Energy Institute, July 1995.

31. ANSI/ANS 56.8, "Containment System Leakage Testing Requirement," American Nuclear Society, November 2002.

32. 10 CFR 20.1406, "Radiological Criteria for Unrestricted Use," U.S. Nuclear Regulatory Commission.

33. Regulatory Guide 4.21, "Minimization of Contamination and Radioactive Waste Generation: Life-Cycle Planning," U.S. Nuclear Regulatory Commission.

34. 10 CFR Part 50, Appendix A, General Design Criterion 52, "Capability for Containment Leakage Rate Testing," U.S. Nuclear Regulatory Commission.

35. 10 CFR Part 50, Appendix A, General Design Criterion 53, "Provisions for Containment Testing and Inspection," U.S. Nuclear Regulatory Commission.

36. 10 CFR Part 50, Appendix A, General Design Criterion 54, "Systems Penetrating Containment," U.S. Nuclear Regulatory Commission.

37. 10 CFR Part 50, Appendix J, "Primary Reactor Containment Leakage Testing for Water-Cooled Power Reactors," Option B, "Performance-Based Requirements," U.S. Nuclear Regulatory Commission.

38. ASME Section III, Division 2, Article CC 2520, "Fracture Toughness Requirements for Materials," The American Society of Mechanical Engineers.

39. ASME Section III, Division 1, Article NE 2300, "Fracture Toughness Requirements for Material," The American Society of Mechanical Engineers.

40. NUREG-0800, Section 6.2.1.2, "Subcompartment Analysis," Rev. 3, U.S. Nuclear Regulatory Commission, March 2007.

41. NRC RG 1.141, "Containment Isolation Provisions for Fluid Systems."

42. APR1400-E-P-NR-14003-P(Proprietary)&NP(Non-Proprietary) "Severe Accident Analysis Report", Rev.3 KHNP, December 2014

Deletion

RAI 155-8167 Question 06.02.05-1_Rev.3

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Figure 4-1 Mole Fraction of Hydrogen in the Dome Region for LLOCA (1 of 3)

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Figure 4-1 Mole Fraction of Hydrogen for LLOCA (1 of 3)

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Figure 4-1 Mole Fraction of Hydrogen in the Dome Region for LLOCA (2 of 3)

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Figure 4-1 Mole Fraction of Hydrogen LLOCA (2 of 3)

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Figure 4-1 Mole Fraction of Hydrogen in the Dome Region for LLOCA (3 of 3)

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Figure 4-1 Mole Fraction of Hydrogen for LLOCA (3 of 3)

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Figure 4-2 Mole Fraction of Hydrogen in the Dome Region for SLOCA (1 of 3)

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Figure 4-2 Mole Fraction of Hydrogen for SLOCA (1 of 3)

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Figure 4-2 Mole Fraction of Hydrogen in the Dome Region for SLOCA (2/3)

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Figure 4-2 Mole Fraction of Hydrogen in the Dome Region for SLOCA (3 of 3)

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Figure 4-2 Mole Fraction of Hydrogen SLOCA (3 of 3)

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Figure 4-3 Mole Fraction of Hydrogen in the Dome Region for SBO-3way valve (1 of 3)

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Figure 4-3 Mole Fraction of Hydrogen for SBO-3way valve (1 of 3)

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Figure 4-3 Mole Fraction of Hydrogen in the Dome Region for SBO-3way valve (2 of 3)

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Figure 4-3 Mole Fraction of Hydrogen for SBO-3way valve (2 of 3)

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Figure 4-3 Mole Fraction of Hydrogen in the Dome Region for SBO-3way valve (3 of 3)

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Figure 4-3 Mole Fraction of Hydrogen for SBO-3way valve (3 of 3)

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Figure 4-4 Mole Fraction of Hydrogen in the Dome Region for TLOFW-3way valve (1 of 3)

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Figure 4-4 Mole Fraction of Hydrogen for TLOFW-3way valve (1 of 3)

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Figure 4-4 Mole Fraction of Hydrogen in the Dome Region for TLOFW-3way valve (2 of 3)

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Figure 4-4 Mole Fraction of Hydrogen for TLOFW-3way valve (2 of 3)

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Figure 4-4 Mole Fraction of Hydrogen in the Dome Region for TLOFW-3way valve (3 of 3)

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Figure 4-4 Mole Fraction of Hydrogen for TLOFW-3way valve (3 of 3)

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62 Teodorczyc, A., Lee, J. H. S. and Knystautas R., 1988, Propagation Mechanisms of Quasi-detonations, 22nd Symposium International on Combustion. The Combustion Institute, Pittsburgh, PA, 1723-1731.

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64 NP-3878, Thomson, R. T., et al., 1988, "Large-Scale Hydrogen Combustion Experiments, Vol. 1: Methodology and Results," Electric Power Research Institute.

65 NUREG/CR-4905, Tieszen, S. R., et al., 1987, "Detonability of H2-Air-Dilutent Mixtures," SAND85-1263, Sandia National Laboratories, Albuquerque, New Mexico, July.

66 Tieszen, S. R., et al., 1993, "Hydrogen Distribution and Combustion," in Ex-Vessel Accident Review for the Heavy Water New Production Reactor (e.d. by K. D. Bergeron), SAND 90-0234, NPRW-SA90-3, Sandia National Laboratories.

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68 Valencia, L., and Wolf, L., 1990a, "Overview of First Results on H2-Distribution Tests at the Large Scale HDR-Facility," 2nd Int. Conf. on Containment Design and Operation, Toronto, October.

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71 Whitehouse, D. R., et al., 1994, "Combustion of Stratified Hydrogen-Air Mixtures in the 10.7 m3 CTF Cylinder," 3rd Int. Conf. on Containment Design and Operation, Toronto, October.

72 NUREG/CP-0105, Wolf, L., and Valencia, L., 1989, "Hydrogen Mixing Experiments in the HDR-Facility," Proceeding of the U.S. Nuclear Regulatory Commission, 17th Water Reactor Safety Information Meeting, Vol. 2.

KEPCO E&C, Calculation Note

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74 ~~KEPCO-ENC~~, “Hydrogen Generation and Control during Severe Accidents”, 1-035-N389-101, Rev.03, SEP. 26, 2015.

75 ~~KEPCO-ENC~~, “Assement of AICC Pressure Load due to Hydrogen Combustion in Containment”, 1-035-N389-102, Rev.01, April. 05, 2013.

76 ~~KEPCO-ENC~~, “Analysis of Local DDT potential in the APR1400 Containment”, 1-035-N389-103, Rev.02, Oct. 28, 2014.