Non-Proprietary

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.:	**199-8223**
SRP Section:	**03.08.01 – Concrete Containment**
Application Section:	**03.08.01**
Date of RAI Issue:	**09/08/2015**

Question No. 03.08.01-8

10 CFR Part 50.44(c)(5) provides the regulatory requirements for analyzing an accident release of hydrogen generated from 100 percent fuel clad-coolant reaction accompanied by hydrogen burning. Standard Review Plan (SRP) 3.8.1, Section II.4.K and Regulatory Guide (RG) 1.216, "Containment Structural Integrity Evaluation for Internal Pressure Loadings Above Design-Basis Pressure," provide guidance for demonstrating the structural integrity of the containment in accordance with the requirements in 10 CFR 50.44.

The staff reviewed Section 3.8.1.3, "Loads and Load Combinations," of the DCD and noted that hydrogen generation pressure load due to fuel-clad and water interaction is included. However, DCD Sections 3.8.1.4 and 3.8.1.5 do not describe the design and analysis procedures, and the acceptance criteria for this loading condition. Regulatory Guide 1.216, Position 2, "Combustible Gas Control Inside Containment," states that containment should be evaluated for the pressure arising from the fuel cladding-water reaction, hydrogen burning, and post-accident inerting. In accordance with 10 CFR 50.44, SRP 3.8.1 and RG 1.216, the applicant is requested to provide a description of the design and analysis approach, and the acceptance criteria for the structural evaluation of this loading condition. If the approach is different from the criteria presented in SRP 3.8.1 and RG 1.216, then provide the technical basis for this difference.

Response – (Rev. 1)

The safety of containment under the combustible gas load (P_s) condition, which includes hydrogen generation pressure load due to 100 percent fuel-clad and water interaction (P_{g1}) accompanied by hydrogen burning (P_{g2}), is assessed and demonstrated to comply with the allowable values in ASME CC-3720. The pressure from the hydrogen generation event including P_{g1} and P_{g2} is determined by using the adiabatic, isochoric, complete combustion (AICC) pressure evaluation. Based on the results of this evaluation, the upper-bound value for the pressure load as a result of slow deflagrations of hydrogen produced from 100 percent metal-water reaction is 109 psig which is larger than 45 psig described in Reg. Guide 1.216. The pressure (P_{g3}) resulting from post-accident inerting does not exist in APR1400 and thus, this pressure did not considered in this assessment.

A pressure load due to the hydrogen burning under the hydrogen mass equivalent to 100% metal-water reaction is evaluated from the AICC condition. The AICC pressure gives the bounding load for the deflagration inside the containment during the severe accident because of no heat loss and complete combustion. Deflagration is combustion with the sub-sonic speed relative to the unburned gas. If the flame speed is smaller than the speed of sound the pressure build-up inside the containment is uniform, therefore, the loads show quasi-static behavior. In contrast, the dynamic combustion load can be generated if the deflagration-to-detonation transition (DDT) is possible to be occurring, however, we can exclude the dynamic combustion load because the evaluation of the possibility of the flame acceleration and DDT inside the containment indicates no chance to DDT.

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Figure 1 Transient AICC Pressure

In Reg. Guide 1.216, for concrete containments, the acceptance criteria are limited to demonstrating that the liner strains satisfy the Factored Load Category requirements presented in ASME Code, Section III, Division 2, Subarticle CC-3720.

Under these conditions, the loadings should not produce strains in the containment liner plate in excess of the limits established in ASME CC-3720. Allowable strains for factored loads considering membrane only are 0.005 cm/cm in compression and 0.003 cm/cm in tension. Allowable strains for factored loads considering combined membrane and bending are 0.014 cm/cm in compression and 0.010 cm/cm in tension.

The three-dimensional finite element (FE) model for safety evaluation during the combustible gas load condition is based on the structural analysis model for section design. The FE program is used for the nonlinear analysis of the containment structure. The full FE model includes the entire prestressed concrete containment structure which consists of the concrete wall and dome, the liner plate, rebars, and tendons. The solid and shell elements are used for concrete and liner plate, respectively. In addition, the rebars and tendons are modeled as truss elements. Material nonlinear models for steel and concrete are constructed on the basis of the design code and a few references. For simulating the cracking behavior of concrete, the smeared crack model is adopted and the tension stiffening effect and their interaction are also taken into consideration. The reinforcement in concrete structures is provided by means of rebars. With this modeling approach, the concrete behavior is considered independently of the rebars. Therefore, in the concrete modeling, tension stiffening is required in the smeared crack model to simulate load transfer across cracks through the rebar to consider the effects of the reinforcement interaction with concrete.

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The steel is assumed to be a linear elasto-plastic model. The stress-strain curves for the reinforcing steel and tendons are based on the ASME code-specified minimum yield strengths. An elastic-plastic and a piece-wise linear stress-strain relationship above yield stress is used for the reinforcing steel and tendons. The maximum temperature during the hydrogen generation is 350°F and the degradation of concrete and steel material properties at this temperature is conservatively applied thru all of analysis phases.

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Impact on DCD

DCD Tier2, Section 3.8.1.4.12 will be revised, as indicated in the attached markup.

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

There is no impact on any Technical, Topical, or Environmental Report.

The liner anchorage system is analyzed, which includes calculating the force and deflection at anchorage points. The design of the liner anchorage conforms with the force and displacement allowables in Subarticle CC-3730 of Section III of the ASME Code.

For the structural design of containment liner plates, the stresses at formworks are calculated for basemat liner, shell liner, and dome liner, respectively. The lowest ratio of allowable stress to induced stress for each part is shown in Table 3.8-12 as margins of safety for the design.

3.8.1.4.11 Ultimate Pressure Capacity

The ultimate pressure capacity (UPC) of the containment is evaluated based on the design results of the structure. The UPC is estimated based on attaining a maximum global membrane strain away from discontinuities of 0.8 percent. This strain limit is applied to the tendons, rebars, and liner. When the pressure capacity contribution is calculated from the tendons, the above-specified strain limit is applied to the full range of strain. The UPC analysis is performed considering material nonlinear behaviors for the reinforced concrete.

The stress-strain curves for the reinforcing steel and tendon are based on the code-specified minimum yield strength. An elastic-plastic and a piece-wise linear stress-strain relationship above yield stress is used for the reinforcing steel and tendon, respectively. The stress-strain curves are developed for the design basis accident temperature.

The ultimate pressure capacity of the containment is a pressure of 1.269 MPa (184 psi) at which the maximum strain of the liner plate and horizontal tendon is approximately 0.8 percent.

Combustible Gas Control Inside Containment

3.8.1.4.12 ~~Severe Accident Capability~~

~~The safety of the containment under severe accident conditions is assessed and demonstrated to conform with the allowable values in Subarticle CC-3720 of the ASME Code.~~

~~Based on the results of the analyses, all of the tendons and rebars are still in the elastic stage. At the maximum pressure loading level of the critical severe accident scenario, the~~

Section 3.8.1.4.12 is substituted as the contents on page 3 (See Page 3)

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~~liner plate strains at the cylindrical wall base, mid-height wall, and penetration regions do not reach the limit strain of the allowable values.~~

3.8.1.4.13 Design Summary Report

A design summary report for the containment structures is presented in Appendix 3.8A where the design of representative critical sections of the structures is described.

The evaluation considering the deviations of as-procured or as-built construction to the design is performed with the acceptance criteria described in Subsection 3.8.1.5.

3.8.1.5 Structural Acceptance Criteria

The allowable stresses, strains, forces, displacements and temperatures for the containment structures including the liner are defined based on the requirements given in Article CC-3000 of the ASME Code. When the containment structure is subjected to the load combinations described in Table 3.8-2, the allowable stresses, strains, forces or displacements specified below are not exceeded in order that:

a. The containment is essentially elastic under service load conditions.

b. General yielding of the reinforcing steel does not develop under factored primary load conditions.

c. The leak-tight integrity of the liner is maintained.

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Under these conditions, the loadings should not produce strains in the containment liner plate in excess of the limits established in ASME CC-3720. Allowable strains for factored loads considering membrane only are 0.005 cm/cm in compression and 0.003 cm/cm in tension. Allowable strains for factored loads considering combined membrane and bending are 0.014 cm/cm in compression and 0.010 cm/cm in tension.

The three-dimensional finite element (FE) model for safety evaluation during the combustible gas load condition is based on the structural analysis model for section design. The FE program is used for the nonlinear analysis of the containment structure. The full FE model includes the entire prestressed concrete containment structure which consists of the concrete wall and dome, the liner plate, rebars, and tendons. The solid and shell elements are used for concrete and liner plate, respectively. In addition, the rebars and tendons are modeled as truss elements. Material nonlinear models for steel and concrete are constructed on the basis of the design code and a few references. For simulating the cracking behavior of concrete, smeared crack model is adopted and the tension stiffening effect are also taken into consideration. The reinforcement in concrete structures is provided by means of rebars, with this modeling approach, the concrete behavior is considered independently of the rebars. Therefore, in the concrete modeling, the tension stiffening is required in the smeared crack model to simulate load transfer across cracks through the rebar which consider the effects of the reinforcement interaction with concrete. The steel is assumed to be a linear elasto-plastic model. The stress-strain curves for the reinforcing steel and tendons are based on the ASME code-specified minimum yield strengths. An elastic-plastic and a piece-wise linear stress-strain relationship above yield stress is used for the reinforcing steel and tendons.

For the structural analysis under the combustible gas load, the dead load is applied first and then the pressure load is incremented until the pressure from this event is reached. Since the duration of the loading is much larger than the period of the structure, the static analysis methods are adequate for structural integrity evaluation under the combustible gas load. Based on the results of the analyses, all of the tendons and rebars are still in the elastic stage. At the maximum pressure loading level of the combustible gas load condition, the liner plate strains at the cylindrical wall base, mid-height wall, and penetration regions do not reach the allowable limit strain values of membrane only load and combined membrane and bending load.

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Application Section:	**03.08.01**
Date of RAI Issue:	**09/08/2015**

Question No. 03.08.01-10

According to 10 CFR 52.47(a)(23), applications for light-water reactor (LWR) designs shall include a description and analysis of design features for the prevention and mitigation of severe accidents. Standard Review Plan (SRP) 3.8.1, Section II.4.K and Regulatory Guide (RG) 1.216, "Containment Structural Integrity Evaluation for Internal Pressure Loadings Above Design-Basis Pressure," provide guidance for demonstrating the structural integrity of the containment in accordance with the requirements in 10 CFR 52.47(a)(23). In accordance with RG 1.206 and RG 1.216, the description of the evaluation for containment pressure integrity under the more likely severe accident challenges is normally described in Section 19 of the applicant's DCD. DCD Section 19.2.3.1.2, "Containment Pressure Limits" states that the containment structural integrity evaluation is described in Subsection 3.8.1.4.12.

The staff reviewed Section 3.8.1.4.12, "Severe Accident Capability," of the DCD and noted that additional information is needed in order for the staff to complete its safety review of the containment. The staff noted that information such as a description of the severe accidents that are being evaluated, the loads that are selected, the mathematical models that are being used, analysis approach and results are not included in the application. Regulatory Guide 1.216, Position 3, "Commission's Severe Accident Performance Goal," describes the methods acceptable for demonstrating that the containment can maintain its role as a reliable, leak-tight barrier for approximately 24 hours following the onset of core damage. In accordance with 52.47(a)(23), SRP 3.8.1 and RG 1.216, the applicant is requested to provide a description of its severe accident analysis approach in Section 3.8.1.4.12 of the DCD, and explain how it compares to the approach described in Regulatory Guide 1.216, Position 3.

Response - (Rev. 1)

This response is limited to Regulatory Guide (RG) 1.216, Position 3, "Commission's Severe Accident Performance Goal".

For a description of how the application conforms to the guidance of RG 1.216, Position 1, “Containment Structural Integrity Evaluation for Internal Pressure Loadings Above Design-Basis Pressure,” please refer to the revised response to RAI 129-8085, Question No. 03.08.01-5. In the this response, the ultimate pressure capacity (UPC) of the prestressed concrete containment is described. This description includes a discussion regarding the finite element (FE) model, FE analysis method, and the acceptance criteria of RG 1.216, Position 1.

For a description of how the applicant conforms to the guidance of RG 1.216, Position 2, “Combustible Gas Control Inside Containment,” please refer to the response to RAI 199-8223, Question No. 03.08.01-8. In this response, the safety of containment under the combustible gas load (P_s) condition is described. The description includes a discussion regarding the FE model, FE analysis method, and the acceptance criteria in RG 1.216, Position 2. The detailed description of the combustible gas load is also found in the revised response to RAI 129-8085, Question No. 03.08.01-1(c). In order to avoid confusion, the title of Subsection 3.8.1.4.12 in DCD Tier 2 was changed from “Severe Accident Capability” to “Combustible Gas Control Inside Containment” in RAI 199-8223, Question No. 03.08.01-8.

A discussion regarding RG 1.216, Position 3, is as follows.

Based on RG 1.216 Regulatory Position 3.1 a, selection of accident sequences based on a Level 1 probabilistic risk assessment (PRA) study is made. The more likely severe accident sequences to be analyzed for the containment performance are selected using a combination of deterministic and probabilistic approaches.

The top ten dominant sequences contributing to the core damage frequency (CDF) are selected from the Level 1 PRA results. Accident initiators for these sequences include station blackout (SBO), large break LOCA (LLOCA), small break LOCA (SLOCA), loss of feedwater (LOFW), and steam generator tube rupture (SGTR). These ten sequences account for 87.6% of the cumulative CDF. The applicant believes this to be an acceptable approach to identifying the more likely severe accident challenges since the probabilistic sequences and the dominant sequences from the deterministic approach are included. Details regarding the identification of the more likely severe accident challenges are given in Section 3.1.2 of “Containment Performance Analysis”, 1-035-N389-501, Rev. 04, which has been provided in the ERR.

Regarding RG 1.216 Regulatory Position 3.1 b, the selected sequences are analyzed with cavity flooding system (CFS) and emergency containment spray backup system (ECSBS) availability by using MAAP4.0.8. The pressure response for each sequence is summarized as follows: the SBO event peak pressure was 98.70 psia and peak temperature was 325°F (Table A-2, p. 239 in calculation note 1-035-N389-501, Rev.4); for the LLOCA event, 112 psia and 332°F (Table A-2, p. 239 in calculation note 1-035-N389-501, Rev.4); for the LOFW event, 105 psia and 330°F (Table A-2, p. 239 in calculation note 1-035-N389-501, Rev.4), respectively.

With regard to Regulatory Position 3.1(c), the development of the finite element models of the containment uses the approach described in Regulatory Position 1 (see RAI 129-8085 Question 03.08.01-5). A similar approach was also discussed in RAI 199-8223 Question 03.08.01-8, which is related to Regulatory Position 2. As the limitations described in Regulatory Position 3.1(c), all of the material properties, based on the enveloped temperature which covers the expected accident temperatures for each severe accident scenario, is conservatively used. In addition, an event which can cause the dynamic pressure transient inside the containment, such as the global hydrogen burning due to flame acceleration and deflagration-to-detonation transition is not expected during the severe accidents. Therefore, the dynamic effects are not included in calculating the response of containment.

Consequently, the MAAP study for the selected more likely severe accident sequences indicates that the pressure build-up inside the containment is bounded by a peak pressure of 112 psia (LLOCA) during the 24-hour period following the onset of core damage. A constant temperature of 350°F, which bounds the transient response to a LLOCA, is conservatively employed as the temperature loading.

The maximum pressure and temperature occur after the initial 24-hours of the onset of core damage. These parameters are enveloped by the maximum pressure and temperature, which occur during the initial 24-hour period, as illustrated by the pressure curves of the three sequences (in calculation note 1-035-N389-501, Rev.4). Therefore, the containment is capable of providing a barrier against the uncontrolled release of fission products for the more likely severe accident challenges, in accordance with RG 1.216 Regulatory Position 3.2 a.

Impact on DCD

The response to RAI 199-8223, Question No. 03.08.01-8 provides changes to the DCD, as discussed in this response.

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

There is no impact on any Technical, Topical, or Environmental Report.