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.:	**275-8294**
SRP Section:	**04.02 – Fuel System Design**
Application Section:	**4.2**
Date of RAI Issue:	**10/27/2015**

Question No. 04.02-2

GDC 2 requires that SSCs important to safety are designed to withstand the effects of earthquakes without the loss of capability to perform their safety functions. The design bases for these SSCs shall reflect: (1) the severity of the historical reports, with sufficient margin to cover the limited accuracy, quantity, and time period for the accumulated data, (2) appropriate combinations of the effects of normal and accident conditions with the effects of the natural phenomena, and (3) the importance of the safety functions to be performed. SRP Section 4.2 Appendix A (II) (5) provides review guidance regarding the combination of loads in order to meet GDC 2.

Technical report APR1400-Z-M-NR-14010-P analyzes SSE, pipe rupture, and IRWST discharge load cases. Section 6.2.6 discusses evaluation results based on a combination of the loads; however, it is unclear how the loads were combined. Additionally, Section 6.2.6 points to Table 6-2, which does not appear in the technical report.

Staff request the applicant clarify the methodology used to combine the loads, and update the technical report as necessary, including the addition of Table 6-2.

Response

In Table 6-1 of technical report APR1400-Z-NR-14010-P, the combination method for SSE, pipe rupture and IRWST discharge load is applied as follows:

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Because the description in Section 6.2.6 is related to Table 6-1; and Table 6-2 is an editorial error, it will be corrected as follows (see the attachment):

- Modify Table 6-1 to Table 6-2,
- Add a new Table 6-1, stress intensities and limits for PLUS7 fuel rod, etc.

Attachment: KNF Response to RAI APR1400 DC RAI 275 SRSB 8294 (Q2)_Markup.

Impact on DCD

There is no impact on the DCD.

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 Report

Technical Report of APR1400-Z-M-NR-14010-NP will be revised reflecting the modification.

The fuel rod bending stress can be computed through this moment. This calculation is iterated at each fuel rod section.

The axial stress from bending and friction, the hoop stress from the differential pressure and the axial stress from differential pressure are combined to evaluate the stress intensity.

6.2.5 Nozzle Stresses

As discussed above, the axial and lateral loads are generated during seismic and pipe rupture accidents. These loads are transmitted to the fuel assemblies through the top and bottom nozzles, except for loads related to pressure or flow in the core, and the lateral loads between grids of adjacent fuel assemblies.

Moments and axial loads at the ends of the guide thimbles are applied to the nozzles through the intersections between guide thimble and nozzles. In addition, the reaction forces between the nozzles and the fuel alignment plate or core support plate are calculated using the equilibrium of the nozzles. Using all forces and moments acting on the nozzles, the stresses on the nozzles are calculated.

6.2.6 Analyses and Results

The stress for fuel assemblies is calculated using the fuel assembly deflection shape that represent the most severe stress conditions, such as seismic and pipe rupture accidents. The analysis method for these conditions is described below:

In the seismic analysis, each node or element of the fuel assembly model in the detailed core model undergoes a peak displacement, moment, and shear at any time separately during a seismic event. The time when the maximum values occur and the deflection shape of the fuel assembly model at that time are recorded. Due to the fuel assembly model with eleven elements and twelve nodes, a total of thirty-three fuel assembly deflection shapes are derived as a result of the core analysis. Thirty-three cases consist of deflection shapes at peak displacement (10 cases), at peak moment (12 cases), and at peak shear (11 cases). Similar to seismic events, the analysis for pipe rupture events is also performed and a total of thirty-three cases are generated.

For these events, the core analyses for two orthogonal directions in the horizontal plane are performed, and the fuel assembly deflection shapes at each direction are derived. The stress for each component at each direction is independently calculated using the deflection shapes. The maximum stress, which is calculated by combining maximum value for each conditions and directions by the SRSS method, is compared with the stress criteria for each component as described in Section 7.

To perform safe shutdown earthquake (SSE) and branch line pipe break (BLPB) analyses for the fuel assembly, the fuel assembly deflected shapes, axial loads and grid impact forces obtained from the RCS and RVI analyses as well as the geometries and the material properties of the fuel assembly and reactor internals models are prepared.

Stresses for ~~fuel assembly components~~ fuel rod are calculated based on the SSE, BLPB and IRWST data and compared to their stress limits in Table 6-1. For fuel rods, it was found that the fuel rod stress intensities occurring due to deflected shapes are smaller in all cases than hoop stresses. As the hoop stress was compared to the limits for the fuel rod, the design margins of over [ ]^{TS} and approximately [ ]^{TS} from the primary membrane stress and the primary membrane and bending stress points of view, respectively.

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[ ]

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Table 6-1 Stress Intensities and Limits for PLUS7 Fuel Rods

Table 6-2

~~Table 6-1~~ Stress Intensities and Limits for PLUS7 Fuel Assembly Components

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After Modification

Table 6-1 Stress Intensities and Limits for PLUS7 Fuel Rods

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Table 6-2 Stress Intensities and Limits for PLUS7 Fuel Assembly Components

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Question No. 04.02-3

GDC 2 requires that SSCs important to safety are designed to withstand the effects of earthquakes without the loss of capability to perform their safety functions. The design bases for these SSCs shall reflect: (1) the severity of the historical reports, with sufficient margin to cover the limited accuracy, quantity, and time period for the accumulated data, (2) appropriate combinations of the effects of normal and accident conditions with the effects of the natural phenomena, and (3) the importance of the safety functions to be performed. SRP Section 4.2 Appendix A Section (II) (1) provides guidance regarding the review of input load analyses. It specifically addresses the situation in which earthquake loads are large enough to produce a nonlinear fuel assembly response.

Figure A.2-6 of APR1400-Z-M-NR-14010-P demonstrates that the PLUS7 fuel assembly design exhibits nonlinear behavior, with a natural frequency that varies with vibrational amplitude. This has caused the staff to question the adequacy of the linear lateral vibrational model used in the analysis to model fuel assembly behavior.

Staff requests the applicant provide justification for the use of a linear fuel assembly model to represent the PLUS7 fuel assemblies and update the technical report, if necessary.

Response

The fuel assembly (FA) seismic/LOCA methodology in Technical report APR1400-Z-M-NR-14010-P was prepared based on CENPD-178-P, Rev. 1-P (CENPD-178). Section 6.2.4.2 of CENPD-178 describes that one purpose for pluck impact simulation is to validate the fuel assembly modelling technique. Similar to CENPD-178, the linear model that represents the PLUS7 FAs was developed considering nonlinear characteristics at large amplitude and verified through comparison of the pluck impact test and pluck impact simulation. The comparison results clearly show that the model provides good agreement with the test data. Detailed information is described as follows:

Pluck simulation model

Figure 04.02-3-1 shows a simplified beam model and a pluck impact simulation model for a fuel assembly. Nodes are located at grid center elevations and are connected to each other with beam elements. Each span weight is lumped at grid node and a rotational spring is attached at the end of each fuel assembly.

Using the force equilibrium equation with a torsional spring at each end, the normalized deflection shape of the model is expressed in terms of two non-dimensional parameters, α_1 and α_2. The optimized values are obtained by minimizing the difference in the lateral defection between the test result and the model as shown in Table 04.02-3-1. Using two non-dimensional parameters, α_1 and α_2, and fuel assembly 1st mode natural frequency from the lateral vibration test, beam rigidity (EI) and two rotational spring stiffnesses (K_L, K_U) are calculated, respectively.

In case of fuel assembly frequency and damping, the FA 1st and 3rd modes of vibration are the key parameters in pluck impact simulation. To simulate the pluck impact test, the FA 1st and 3rd mode frequency in air at room temperature was chosen to [ ]^{TS}, respectively. And the 1st mode critical damping ratio for large amplitudes is [ ]^{TS}. The damping parameters were calculated using the following equations, which is normally referred to as Rayleigh damping and commonly used in nonlinear-dynamic analysis:

$$[C] = \alpha[M] + \beta[K]$$

$$\alpha = \frac{4 f_1 f_3 (f_1 c_3 - f_3 c_1)}{f_1^2 - f_3^2} \; and \; \beta = \frac{(f_3 c_3 - f_1 c_1)}{\pi (f_3^2 - f_1^2)}$$

Pluck impact test

In order to provide information on the lateral fuel assembly impact loads, pluck impact tests are performed with the PLUS7 FA in the reactor end support condition. Solid constraints that simulate the core shroud are placed so that the appropriate gap (150 mils) exists between the constraints and the grids with the fuel assembly in an un-deflected position. The fuel assembly is then displaced horizontally away from the solid constraints and released. The impact forces and duration times are recorded using load cell and LVDTs before and after impact. A schematic of the test arrangement is shown in Figure 04.02-3-2.

Pluck impact simulation

In order to validate and verify nonlinear characteristics of the fuel assembly model, a simulation was performed for the pluck impact test using the fuel assembly model and the simulation results were compared with the test results.

To simulate the multi-grid impact test, the impact spring elements were used at grid 4 through 10. A gap between the un-deflected position of the fuel assembly and impact surface is set to 150 mils which is the same as test condition. The initial displacement shape was determined by applying a lateral force at grid 6, which is to simulate the pluck impact test. Test and simulation results at various displacements are shown in Figure 04.02-3-3. The analysis results in Figure 04.02-3-3 correlate well with the test results within an acceptance range and are more conservative than the test results. The comparison of impact velocity and impact force characteristics of the simulation and test results at grid 6 is shown in Figure 04.02-3-4.

Table 04.02-3-1 Fuel Assembly deflection shape
(Comparison of test result and model result)

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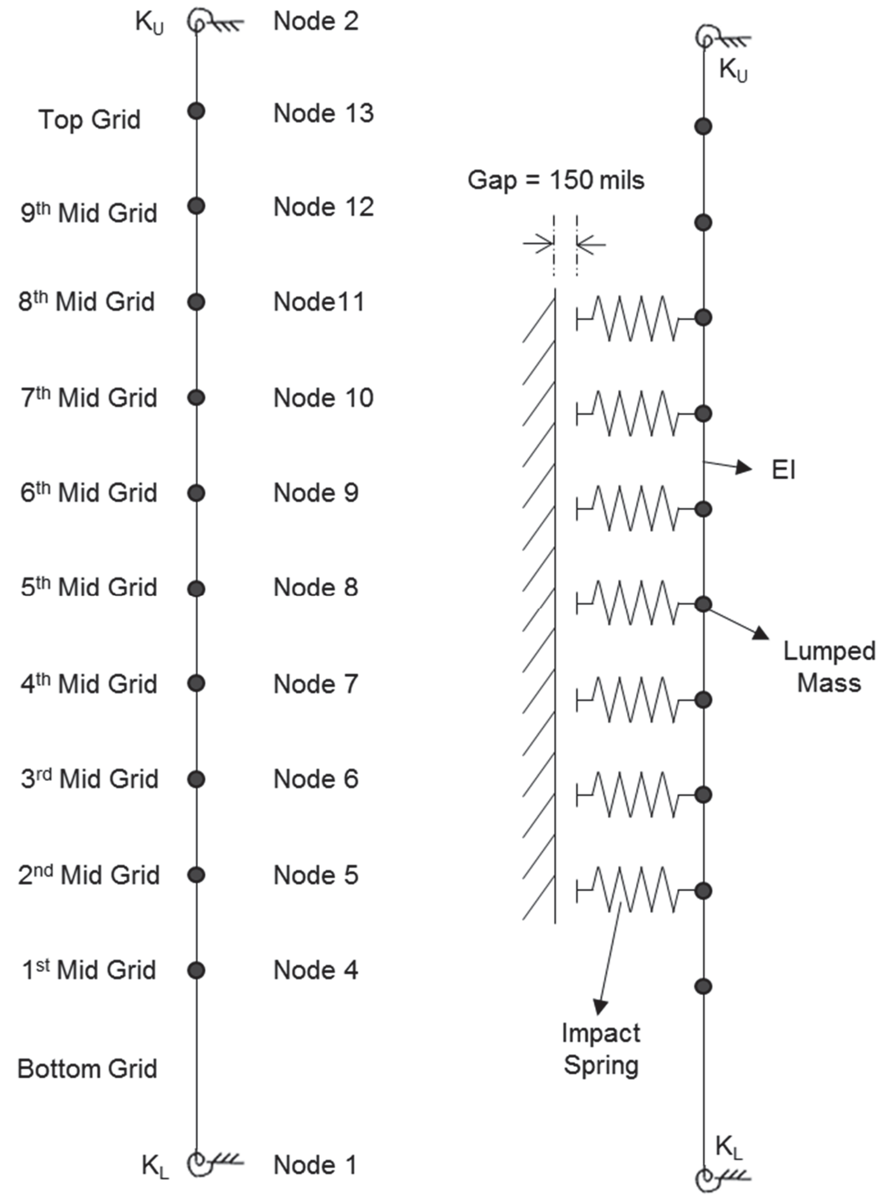

(a) simplified beam model (b) pluck impact simulation model

Figure 04.02-3-1 Simplified beam model and pluck impact simulation model

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Figure 04.02-3-2 Fuel assembly lateral impact test arrangement

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Figure 04.02-3-3 Pluck impact simulation results

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(a) Initial deflection vs. Impact force (b) Initial deflection vs. Impact velocity

(c) Impact force vs. Impact velocity

Figure 04.02-3-4 Comparison of test and simulation model results

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Impact on DCD

There is no impact on the DCD.

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 Report

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

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Question No. 04.02-4

GDC 2 requires that SSCs important to safety are designed to withstand the effects of earthquakes without the loss of capability to perform their safety functions. The design bases for these SSCs shall reflect: (1) the severity of the historical reports, with sufficient margin to cover the limited accuracy, quantity, and time period for the accumulated data, (2) appropriate combinations of the effects of normal and accident conditions with the effects of the natural phenomena, and (3) the importance of the safety functions to be performed. SRP Section 4.2 Appendix A Section (III) (1)-(2) provides review guidance regarding determination of strength for various fuel assembly components.

Section 6.2 of APR1400-Z-M-NR-14010-P states that the principle of the stress analysis methodology is that there is a direct relationship between the deflection shape of the fuel assembly model and the strains in the structure. The staff is concerned because this is not necessarily true because the linear model used in the methodology offers only an approximation of the fuel bundle deflection shape.

Staff requests the applicant justify the use of a linear method to calculate the stresses on fuel assembly components and update the technical report, if necessary.

Response

The principle of the stress analysis methodology in Section 6.2 of APR1400-Z-M-NR-14010-P was prepared based on Section 8.2 of CENPD-178-P, Rev. 1-P (CENPD-178).

As it is known, a fuel assembly has a non-linear characteristics due to the complexity of its structure but the linear method was conservatively used for the stress analysis on fuel assembly components as follows:

Load-deflection curve

The PLUS7 fuel assembly lateral stiffness characteristics were obtained from lateral stiffness tests conducted in air at room temperature as described in Section A.3 of APR1400-Z-M-NR-14010-P. A schematic of the test arrangement is shown in Figure 04.02-4-1. The lateral loads were incrementally applied and removed at the fifth, sixth, and seventh grids independently. As shown in Figures 04.02-4-2 through 04.02-4-4, the load versus deflection characteristics are nonlinear due mainly to fuel rod slippage. Due to nonlinear characteristics with softening load-deflection curve, the use of a linear method is more conservative for the stress calculations.

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Figure 04.02-4-1 Fuel assembly lateral stiffness test arrangement

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Figure 04.02-4-2 Lateral load vs. deflection loaded at Grid 6

Figure 04.02-4-3 Lateral load vs. deflection loaded at Grid 5

Figure 04.02-4-4 Lateral load vs. deflection loaded at Grid 7

Impact on DCD

There is no impact on the DCD.

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 Report

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

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Question No. 04.02-8

GDC 2 requires that SSCs important to safety are designed to withstand the effects of earthquakes without the loss of capability to perform their safety functions. The design bases for these SSCs shall reflect: (1) the severity of the historical reports, with sufficient margin to cover the limited accuracy, quantity, and time period for the accumulated data, (2) appropriate combinations of the effects of normal and accident conditions with the effects of the natural phenomena, and (3) the importance of the safety functions to be performed. Additionally, GDC 27 requires that the reactivity control systems be designed to have a combined capability, in conjunction with poison addition by the ECCS, of reliably controlling reactivity changes to assure that under postulated accident conditions and with appropriate margin for stuck rods the capability SRP Section 4.2 (II)(1)(B)(viii) and Appendix A provides review guidance related to mechanical fracturing based on seismic and LOCA applied loads. It is also stated specifically that control rod insertability must be maintained.

Table 6-1 of technical report APR1400-Z-M-NR-14010-P presents stress intensities and limits for the PLUS7 fuel assembly components. Section 7.3 of the technical report discusses the faulted condition criteria used for calculating the stress limits for components other than the grids. These limits appear to be based on ASME Boiler and Pressure Vessel Code values for service level D. Service level D corresponds to “faulted” conditions, which could affect the ability to insert RCCAs, and therefore challenge GDC 27.

Staff requests the applicant clarify the proposed stress-strain limits and what level of damage could occur to the components based on those limits. If damage could occur to the guide tubes based on the limits, justify the limits via rod insertion tests to demonstrate control rod insertability. Update the technical report, as necessary, to capture these points.

Response

For the evaluation of guide tube stresses induced by the lateral displacements and the axial loads on fuel assembly during seismic and LOCA events, Appendix F of ASME Section III is used as the general stress criteria: 1) the general primary membrane stress intensity P_m shall not exceed the lesser of $2.4S_m$ and $0.7S_u$, 2) the primary membrane plus primary bending stress intensity P_m+P_b shall not exceed 150% of the limit for P_m. The proposed stress limit (i.e., 1.05 S_u) and the associated strain ($\varepsilon_{1.05}$) for the SRA ZIRLO guide tube are depicted in Figure 04.02-8-1.

Since the ASME stress criteria are based on an elastic analysis, the triangular strain energy density over yield stress can be converted to equivalent strain energy on the actual stress-strain curve as shown in the figure. Therefore, the actual strain ($\varepsilon'_{1.05}$) is slightly increased by the equivalent strain energy density and the resulting damage will be slightly greater than proportional permanent strain. The following considerations explain that the damage will not create an excessive deformation of the guide tube that would prevent control rod insertability.

- The loadings during the seismic and LOCA events are not a static load, but an oscillating dynamic load that will be diminished after several seconds, so the actual stress on the guide tube is lower than the one given by the static elastic analysis that is based on an instantaneous deflection,
- Only a portion of the guide tube’s cross section has stresses that exceed yield at a particular elevation,
- Only a limited portion of the axial length of the guide tube has stresses that exceed yield, and
- Strain hardening of the guide tube when loaded beyond yield increases the elastic stain range of the material, thereby decreasing the permanent deformation of the guide tube associated with a loading beyond yield.

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Figure 04.02-8-1 PLUS7 Guide Thimble Stress-Strain Relation

Impact on DCD

There is no impact on the DCD.

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 Report

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