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.:	**70-8027**
SRP Section:	**03.12 - ASME Code Class 1, 2, and 3 Piping Systems and Piping Components and Their Associated Supports**
Application Section:	**3.12**
Date of RAI Issue:	**07/15/2015**

Question No. 03.12-3

NRC Bulletin (BL) 88-11 and SRP Section 3.12 discuss the potential for stresses induced by thermal stratification in the pressurizer (PZR) surge line (SL). In particular, BL 88-11 requested the establishment of a program that would monitor the surge line for the effects of thermal stratification beginning with hot functional testing (HFT). APR1400 DCD Tier 2, Section 3.12.5.10 states that the APR1400 conforms with BL 88-11, but the APR1400 DCD does not include the description of a program to implement monitoring of the PZR SL consistent with BL 88-11 and SRP Section 3.12 (as was included in other design certification applications that have been reviewed by the NRC).

1. Please confirm that the structural integrity evaluation of the APR1400 PZR SL includes consideration of thermal stratification and thermal striping to ensure that fatigue and stresses are in compliance with applicable code limits.
2. The presentation in DCD Tier 2, Section 3.12.5.10 on thermal stratification with regard to the PZR SL is rather general. Please revise the DCD to describe APR1400 PZR SL features and operational procedures that address the structural integrity issues raised by NRC Bulletin 88-11 in minimizing SL stratification.
3. According to BL 88-11, thermal stratification occurs in the PZR SL during heatup, cooldown, and steady-state operations of the plant. Please discuss whether a monitoring program is planned to verify the design transients used in the structural design of the surge line or how this verification will take place. Describe the program, testing, and its implementation, consistent with BL 88-11 and SRP Section 3.12, that will demonstrate that stratification temperature measurements for the APR1400 PZR SL will be within acceptable analyzed limits, that there will not be unanalyzed thermal cycles, and that piping thermal deflections result in no adverse consequences (such as contacting the pipe whip restraints). In addition, add, or provide a technical justification for not including, HFT activities in DCD

Section 14.2 to monitor the PZR SL stratification, which should continue at least during the first cycle of plant operation.

4. Given that PZR SL monitoring is the responsibility of a COL licensee, please discuss (with DCD revisions such as COL items as appropriate) what these responsibilities would be.

Response - (Rev. 1)

Response to No. 1

The structural integrity evaluation of the APR1400 PZR SL includes consideration of thermal stratification and thermal striping as follows:

The stresses and fatigue due to the thermal stratification in the APR1400 PZR SL are evaluated as described in the section 3.12.5.10 of APR1400 DCD Tier 2 as follows:
The stratified-flow-induced curvature of the piping and local stresses due to a temperature gradient are obtained from finite element analyses. These analyses provide the local effects and pipe rotations for an unsupported pipe segment. A stratified flow thermal hydraulic model with the top half of the fluid at hotter temperature and the lower half of the fluid at colder temperature is used to determine the pipe wall temperature based on the thermal-hydraulic conditions. Heat transfer and structural thermal stress analyses are performed using the ANSYS computer program to determine the rotations and local stresses. Rotations are considered to act over all horizontal portions of the pipe. The resulting bending moments are calculated in the piping analysis with the ADLPIPE computer program by allowing the pipe to thermally expand unconstrained and by then applying a set of equal and opposite displacements at the rigid support points. Local stress effects due to top-to-bottom thermal gradients are also considered to act over all horizontal sections of pipe. For ASME Class 1 piping, gross bending stresses due to stratification are considered as secondary stresses, while local stresses due to thermal gradients are considered as peak stresses.

In addition, the local stresses and crack growth due to thermal striping in the APR1400 PZR SL are also evaluated. The thermal striping is characterized by the frequency and amplitude of the fluid temperature fluctuation and the heat transfer coefficient at the interface between the hot/cold fluid and the wall. The amplitude and frequency used as input values are determined from the previous experimental data of open literatures. The finite element analyses are used to obtain temperature distribution and stress intensity factors at axially cracked pipe wall. The results of heat transfer analysis shows that the thermal striping effect is greatly reduced as the distance from the inner surface of the pipe increases. This tendency indicates that the thermal gradient due to striping effect is very local. Three crack depths are analyzed to ensure that stress intensity factor, $K_{I,}$ is decreasing as a function of depth. The local stresses due to temperature distribution through the wall thickness are calculated in accordance with the formula provided in ASME Section III, NB-3653.2 and are lower comparing to those local stresses calculated on the conservative assumption for stress and fatigue analyses that the stratification interface is always horizontal and stable without mixed zone due to thermal striping. The assumption is applied to the above stratified flow thermal hydraulic model with the top half of the fluid at hotter temperature and the lower half of the fluid at colder temperature. Therefore, those higher local stresses are used to evaluate the stresses and fatigue.

It is confirmed from the evaluation results that fatigue and stresses are in compliance with the ASME Code limits considering thermal stratification and thermal striping and that stress intensity factor, ΔK_I, remains below the threshold for fatigue crack growth given in ASME Section XI, Appendix C and starts to decrease as the depth of crack increases.

Response to No. 2

The APR1400 pressurizer surge line features and operational procedures address the structural integrity issues raised by NRC Bulletin 88-11 in minimizing surge line stratification.

- The surge line piping is routed to ensure that sufficient flexibility exists to minimize resistance to uniform thermal growth and the thermal deformation due to stratified flow loadings. The surge line has the horizontal section between the vertical take-off at top of the hot leg and vertical leg at the bottom of the pressurizer. The horizontal section is sloped downward at a minimum rate of 1/16 inch per foot from the pressurizer.
- The nozzle and surge line from the hot leg are upward vertical and of sufficient length to prevent the colder hot leg fluid from entering the surge line beyond the take-off. During the normal power operation, a continuous bypass spray flow is maintained to further suppress turbulent penetration from the hot leg flow.
- The pressurizer versus hot leg temperature differential is limited during heatup below the design temperature differential of 188.9 ℃ (340 ˚F). Also, the pressurizer heaters are used to maintain a required pressure and temperature during the initial heatup. The pressurizer level is maintained at a predetermined level (outsurge) during the plant heatup by the charging and letdown flow controls, which can limit the colder hot leg fluid insurge.

Responses to No. 3 & 4

The APR1400 design conforms with NRC Bulletin 88-11 and SRP Section 3.12 pressurizer surge line requirements as follows:

- The stratification test for the surge line piping layout for Younggwang Nuclear Power Plant Unit 3 (YGN 3) was done as part of the YGN 3 pre-core hot functional test. The measurements taken during the test verified the assumptions and methodology of the surge line design basis both from a thermal-hydraulic and structural standpoint. The measurements included both the circumferential and axial temperature gradients and the pipe displacements. The surge line for APR1400 has the almost same operational procedure and piping layout as those for YGN 3 of OPR1000 as shown in Figures 1 and 2 and was also tested during Shin-Kori Nuclear Power Plant Unit 3 (SKN 3) pre-core hot functional test. Only the pipe displacements were measured from the SKN 3 test because it was confirmed from the YGN 3 test that there are the relationships between pipe temperatures, curvatures, and displacements which form the basis of the design analysis. The pipe displacements measured from the SKN 3 test verified the design of surge line for APR1400.
- The first COL applicant will implement the monitoring program during preoperational testing and continue to monitor by using the fatigue monitoring system during the first cycle of operation to verify the design transients used in the structural design of the surge line (COL 3.12(8)). The monitoring program includes the real-time measurements of the surge line displacements and temperatures at several major locations and plant data such as hot leg and pressurizer temperatures, pressurizer pressure and level, charging and letdown flows, as well as the status of reactor coolant pumps, pressurizer heaters, and spray valves.

- The test to monitor the surge line stratification will be performed as described in DCD Tier 2, Section 14.2.12.1.51, “Pre-Core Reactor Coolant System Expansion Measurements” and Section 14.2.12.1.140, “Pre-Core Pressurizer Surge Line Stratification Test.”

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Figure 1 Surge Line Piping Layout for OPR1000 such as YGN 3

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Figure 2 Surge Line Piping Layout for APR1400 such as SKN 3

Impact on DCD

DCD sections 3.12.5.10, 3.12.7 and 14.2.12.1.51 and Table 1.8-2 will be revised as indicated in the Attachment. A new DCD section 14.2.12.1.140 will be inserted as indicated in the Attachment.

Impact on PRA

There is no impact on the PRA.

Impact on Technical Specifications

There is no impact on Technical Specifications.

Impact on Technical/Topical/Environmental Reports

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

The reactor vessel and piping segments away from the stratified zone are not affected by thermal stratification and are not considered in local stress determination. The maximum stress intensity extracted from three-dimensional finite element analysis is added to the ΔT_2 term of ASME Section III, NB-3653.2 Equation (11) without considering stress index.

3.12.5.10 Thermal Stratification

NRC Bulletin 79-13 (Reference 21) addresses the effect of thermal stratification that leads to the cracking of the feedwater line. The APR1400 feedwater lines are designed to minimize the thermal stratification. The feedwater lines are angled downward from the horizontal to minimize the potential for thermal stratification. This is also described in Subsection 5.4.2.1.2.1.3.

NRC Bulletin 88-11 (Reference 22) was issued in response to the results of an inspection of the surge line at Trojan that showed large, unexpected movements that closed available gaps between the line and pipe whip restraints. NRC Bulletin 88-11 requires that holders of operating licenses or construction permits establish and implement a program to provide reasonable assurance of the structural integrity of the surge line when subjected to thermal stratification in the pressurizer surge line.

This part should be replaced with the description on the page 3 of Attachment.

The APR1400 conforms with NRC Bulletin 88-11 pressurizer surge line requirements. Available data from construction plants have been evaluated and incorporated into the design of the APR1400. The design will continue to be assessed as new data become available and will be evaluated for applicability to the APR1400.

In response to NRC Bulletin 88-11, a test in a Korean nuclear power plant was performed to obtain operating plant data that were needed to characterize thermal stratification in the surge line. Data obtained at operating plants showed that temperature differences in the surge line walls due to thermal stratification were related to the mode of plant operation. These data confirmed that the maximum temperature differences in the surge line were bounded by the difference in temperature between the pressurizer and the hot leg. The APR1400 surge line is designed for the maximum temperature difference that is experienced between the pressurizer and the hot leg.

Piping systems subjected to stratified flow are evaluated for additional thermal stresses due to thermal stratification. Stratified flow exists when a hotter fluid flows over a colder one.

This condition induces a vertical thermal gradient, resulting in increased overall bending stresses and localized thermal gradient stresses. Stratified flow effects consist of (1) local stresses due to temperature gradients in the pipe wall, and (2) additional thermal pipe bending moments generated by the restraining effect of supports on the stratified-flow-induced curvature of the piping. The extent of stratification is reduced by sloping generally horizontal pipe runs and is mitigated by carefully selecting designs and operating procedures.

Structural evaluations are performed using elastic and/or simplified elastic-plastic analyses in accordance with the ASME Code, considering the applicable loadings in addition to the stratified flow loadings.

This part should be replaced with the description on the page 3 of Attachment.

The stratified-flow-induced curvature of the piping and local stresses due to a temperature gradient are obtained from finite element analyses. These analyses provide the local effects and pipe rotations for an unsupported pipe segment. A stratified flow thermal-hydraulic model with the top half of the fluid at hotter temperature and the lower half of the fluid at colder temperature is used to determine the pipe wall temperature based on the thermal-hydraulic conditions. Heat transfer and structural thermal stress analyses are performed using the ANSYS computer program to determine the rotations and local stresses. Rotations are considered to act over all horizontal portions of the pipe. The resulting bending moments are calculated in the piping analysis with the ADLPIPE computer program by allowing the pipe to thermally expand unconstrained and by then applying a set of equal and opposite displacements at the rigid support points. Local stress effects due to top-to-bottom thermal gradients are also considered to act over all horizontal sections of pipe. For ASME Class 1 piping, gross bending stresses due to stratification are considered as secondary stresses, while local stresses due to thermal gradients are considered as peak stresses.

3.12.5.11 Safety Relief Valve Design, Installation, and Testing

The design and installation of the safety valves and relief valves for overpressure protection are performed per the requirements in Appendix O of the ASME Code (Reference 23).

A static method with a conservative dynamic loading factor is used to calculate the discharge forces of safety valves and relief valves that use open vent stacks for discharging fluid directly into the air. Dynamic transient loads of fluid discharged from safety/relief

To be inserted into DCD Tier 2, section 3.12.5.10

The APR1400 pressurizer surge line features and operational procedures address the structural integrity issues raised by NRC Bulletin 88-11 in minimizing surge line stratification.

- The surge line piping is routed to insure that sufficient flexibility exists to minimize resistance to uniform thermal growth and the thermal deformation due to stratified flow loadings. The surge line has the horizontal section between the vertical take-off at top of the hot leg and vertical leg at the bottom of the pressurizer. The horizontal section is sloped downward at a minimum rate of 1/16 inch per foot from the pressurizer.
- The nozzle and surge line from the hot leg are upward vertical and of sufficient length to prevent the colder hot leg fluid from entering the surge line beyond the take-off. During the normal power operation, a continuous bypass spray flow is maintained to further suppress turbulent penetration from the hot leg flow.
- The pressurizer versus hot leg temperature differential is limited during heatup below the design temperature differential of 188.9 ℃ (340 ˚F). Also, the pressurizer heaters are used to maintain a required pressurizer and temperature during the initial heatup. The pressurizer level is maintained at a predetermined level (outsurge) during the plant heatup by the charging and letdown flow controls, which can limit the cooler hot leg fluid insurge.

The APR1400 design conforms with NRC Bulletin 88-11 pressurizer surge line requirements as follows:

- The stratification test for the surge line piping layout for Younggwang Nuclear Power Plant Unit 3 (YGN 3) was done as part of the YGN 3 pre-core hot functional test. The measurements taken during the test verified the assumptions and methodology of the surge line design basis both from a thermal-hydraulic and structural standpoint. The measurements included both the circumferential and axial temperature gradients and the pipe displacements. The surge line for APR1400 has the almost same operational procedure and piping layout as those for YGN 3 of OPR1000 and was also tested during Shin-Kori Nuclear Power Plant Unit 3 (SKN 3) pre-core hot functional test. Only the pipe displacements were measured from the SKN 3 test because it was confirmed from the YGN 3 test that there are the relationships between pipe temperatures, curvatures, and displacements which forms the basis of the design analysis. The pipe displacements measured from the SKN 3 test verified the design of surge line for APR1400.
- The first COL applicant will implement the monitoring program during preoperational testing and continue to monitor by using the fatigue monitoring system during the first cycle of operation to verify the design transients used in the structural design of the surge line (COL 3.12(8)). The monitoring program includes the real-time measurements of the surge line displacements and temperatures at several major locations and plant data such as hot leg and pressurizer temperatures, pressurizer pressure and level, charging and letdown flows, as well as the status of reactor coolant pumps, pressurizer heaters, and spray valves.

3.12.7 Combined License Information

COL 3.12(1) The COL applicant is to prepare design reports for ASME Class 1, 2, and 3 piping system in accordance with ASME Section III.

COL 3.12(2) The COL applicant is to design the piping exposed to wind and/or tornado, if any, to the plant design basis loads.

COL 3.12(3) The COL applicant is to perform fatigue evaluations of ASME Class 1 piping.

COL 3.12(4) The COL applicant is to perform stress evaluations for ASME Class 2 and 3 piping.

COL 3.12(5) The COL applicant is to perform fatigue evaluations of environmental impact on ASME Class 1 piping, using methods acceptable to the NRC at the time of evaluation.

COL 3.12(6) The COL applicant is to perform the piping stress analysis including the thermal stratification effect on the SCS suction line.

COL 3.12(7) The COL applicant is to determine maximum radial thermal expansion at its design temperature.

Insert.

COL 3.12(8) The first COL applicant will implement the monitoring program during preoperational testing and continue to monitor by using the fatigue monitoring system during the first cycle of operation to verify the design transients used in the structural design of the surge line.

3.12.8 References

1. ASME Boiler and Pressure Vessel Code, Section III, "Rules for Construction of Nuclear Facility Components," The American Society of Mechanical Engineers, the 2007 Edition with the 2008 Addenda.

2. ASME B31.1, "Code for Pressure Piping, Power Piping," The American Society of Mechanical Engineers, the 2010 Edition.

3. ASME B31.3, "Code for Pressure Piping, Process Piping," American Society of Mechanical Engineers, the 2010 Edition.

Table 1.8-2 (7 of 29)

Item No.	Description
COL 3.12(6)	The COL applicant is to perform the piping stress analysis including thermal stratification effects on SCS suction line.
COL 3.12(7)	The COL applicant is to determine maximum radial thermal expansion at its design temperature.
COL 3.13(1)	The COL applicant is to maintain quality assurance records including CMTRs on ASME Section III Class 1, 2, and 3 component threaded fasteners in accordance with the requirements of 10 CFR 50.71.
COL 3.13(2)	The COL applicant is to submit the preservice and inservice inspection programs for ASME Section III Class 1, 2, and 3 component threaded fasteners to the NRC prior to performing the inspections.
COL 5.2(1)	The COL applicant is to address the addition of ASME Code cases that are approved in NRC RG 1.84.
COL 5.2(2)	The COL applicant is to address the ASME Code cases, which are invoked for the ISI program of specific plant.
COL 5.2(3)	The COL applicant is to address the Code cases invoked for operation and maintenance activities.
COL 5.2(4)	The COL applicant is to address the material specifications, which are not shown in Table 5.2-2, as necessary.
COL 5.2(5)	The COL applicant is to specify the version of EPRI's, "Primary Water Chemistry Guidelines," that will be implemented.
COL 5.2(6)	The COL applicant is to address the actual, as-procured, fracture toughness data of the RCPB materials to the staff at a predetermined time by an appropriate method.
COL 5.2(7)	The COL applicant is to submit the actual, as-procured yield strength of the austenitic stainless steel materials used in RCPB to the staff at a predetermined time agreed-upon by the regulatory body.

Insert.

COL 3.12(8)	The first COL applicant will implement the monitoring program during preoperational testing and continue to monitor by using the fatigue monitoring system during the first cycle of operation to verify the design transients used in the structural design of the surge line.

14.2.12.1.51 Pre-Core Reactor Coolant System Expansion Measurements

1.0 ~~OBJECTIVE~~OBJECTIVES

1.1 To demonstrate that the reactor coolant system (RCS) components are free to expand thermally as designed during initial plant heatup and return to their baseline cold position after the initial cooldown to ambient temperatures

Insert

1.2 To demonstrate that surge line movements due to stratification are within design limits

2.0 PREREQUISITES

2.1 All construction activities have been completed on the RCS components.

2.2 Initial ambient dimensions have been set on the steam generator and reactor coolant pump (RCP) hydraulic snubbers, upper and lower steam generator and reactor vessels keys, ~~and~~ pressurizer keys, RCP columns and surge line supports.

2.3 Initial ambient dimensions for the steam generator, reactor vessel, pressurizer, RCP and ~~RCP~~ surge line supports have been recorded.

2.4 The instruments for the real-time measurements of the surge line pipe displacements at several major locations are installed.

3.0 TEST METHOD

3.1 Check clearances at hydraulic snubber joints, keys, and column clevises during heatup and record at 37.8 °C (100 °F) increments during heatup.

3.2 At stabilized conditions, record all steam generator, reactor vessel, pressurizer and RCP clearances.

3.3 Record the real-time surge line displacements and the plant data such as hot leg and pressurizer temperatures, pressurizer pressure and level, Insert.

14.2.12.1.140 Pre-Core Pressurizer Surge Line Stratification Test

1.0 OBJECTIVES

1.1 To demonstrate that the temperature measurements due to surge line stratification are within design limits during hot functional testing of the first APR1400 plant

2.0 PREREQUISITES

2.1 All required support systems such as CVCS, PLCS, and PPCS have been completed.

2.2 Pressurizer surge line insulation with removable plugs for instruments is installed.

2.3 The instruments for the real-time measurements of the surge line temperatures are installed at several major locations in the axial and circumferential directions.

3.0 TEST METHOD

3.1 Record the real-time surge line temperatures and the plant data such as hot leg and pressurizer temperatures, pressurizer pressure and level, charging and letdown flows, as well as the status of RCPs, pressurizer heaters and spray valves.

4.0 DATA REQUIRED

4.1 Surge line temperature time-history

4.3 Time-history plant data such as hot leg and pressurizer temperatures, pressurizer pressure and level, charging and letdown flows, as well as the status of RCPs, pressurizer heaters, and spray valves

5.0 ACCEPTANCE CRITERIA

5.1 Verification that surge line temperatures are within design limits

Insert.