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.:	**384-8100**
SRP Section:	**05.04.07 – Residual Heat Removal (RHR) System**
Application Section:	**SRP 5.4.7**
Date of RAI Issue:	**02/01/2016**

Question No. 05.04.07-3

NSSS (nuclear steam supply system) Natural Circulation Cooling Analysis

NRC Standard Review Plan (SRP) Branch Technical Position (BTP) 5-4, “Design Requirements for Residual Heat Removal Systems,” Section B, "Branch Technical Position," Subsection 5, “Test Requirements,” states, in part, that:

“The preoperational and initial startup test program shall be in conformance with Regulatory Guide 1.68. The programs for PWRs shall include tests with supporting analysis to (1) confirm that adequate mixing of borated water added before or during cooldown can be achieved under natural circulation conditions and permit estimation of the times required to achieve such mixing, and (2) confirm that cooldown under natural circulation conditions can be achieved within the limits specified in the emergency operating procedures.”

RG 1.68, “Initial Test Programs for Water-Cooled Nuclear Power Plants” provides guidance on the initial test program that includes the following requirements:

- General Design Criterion (GDC) 1, “Quality standards and records” of Appendix A, “General Design Criteria for Nuclear Power Plants” to 10 CFR Part 50 states, in part, that structures, systems, and components important to safety shall be tested to quality standards commensurate with the importance of the safety functions to be performed.

- Criterion XI, “Test Control,” of Appendix B, “Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants,” to 10 CFR Part 50 states, in part, that a test program shall be established to assure that all testing required to demonstrate that SSCs will perform satisfactorily in service is identified and performed in accordance with written test procedures, which incorporate the requirements and acceptance limits contained in applicable design requirements.

DCD Subsection 5.4.7.3.1.3, “Conclusions,” states, in part that:

“The NSSS natural circulation cooling analysis results demonstrate that a cooldown and depressurization to the shutdown cooling system (SCS) entry conditions are achievable within the BTP 5-4 requirements. It is concluded that the NSSS can be cooled and depressurized to the SCS entry conditions with the restrictive assumptions of BTP 5-4.”

However, in DCD Section 14.2.12.4.22, Section 5.0, Acceptance Criteria, the DC applicant states:

5.1 The natural circulation power-to-flow ratio is less than 1.0.

The NRC staff could not identify any information in DCD Section 5.4.7 related to the natural circulation power-to-flow ratio of less than 1.0 being an adequate test acceptance criterion in DCD Section 14.2.12.4.22. In addition, the staff performed a search of applicable DCD Chapters 4, 5, 15, and 16 including technical reports without identifying any information of natural circulation, boron and thermal stratification, and appropriate margin to SAFDLs related to power to flow ratio.

Please provide additional information in DCD Sections 5.4.7 and 14.2.12.4.22 to address and justify meeting NRC SRP BTP 5-4, Section B, Branch Technical Position, Subsection 5, “Test Requirements.”

Please provide the documents related to the natural circulation analysis and test including a discussion of the relationship of the above conditions with respect to the reactor power conditions at the initiation of the test.

Response

The natural circulation test addressed in DCD Section 14.2.12.4.22 is performed to confirm the design heat removal capability of the RG 1.68, Appendix A, Subsection 4.t requirements. This test is performed at end of power ascension test with the initial condition of more than 80% of thermal power to get enough decay heat for the test. The reactor is tripped and hot standby condition is maintained with all reactor coolant pumps (RCPs) running. For the test, all RCPs are tripped and the plant is maintained at a stable condition, within the emergency operating guideline limits, for at least 30 minutes.

The APR1400 has a design criterion indicating that a temperature increase during natural circulation shall be less than that of full power design conditions. The same degree of subcooling margin compared to full power design condition is automatically preserved after the reactor trip when the design criterion is met. The natural circulation test is performed to verify the design criterion. During the test, the power-to-flow ratio is calculated to verify the heat removal capability of NSSS under natural circulation condition is established. The power-to-flow ratio is defined as follows:

Power-to-flow ratio = $\frac{\Delta h_{NC}}{\Delta h_{100}} = \frac{Q_{NCC}/W_{NC}}{Q_{100}/W_{100}}$

where, Δh is the enthalpy rise across the reactor core,
Q is the thermal power or decay heat,
W is the mass flow rate.

The enthalpy rise is used instead of temperature increase to consider the pressure difference during the test.

Because the power-to-flow ratio is not used in any section of applicable DCD, the acceptance criteria on DCD Section 14.2.12.4.22 will be changed to as follows:

"5.1 Adequate natural circulation flow shall be maintained following trip of all RCPs.
5.2 The enthalpy rise at natural circulation condition is less that at design full power condition."

Also, DCD Sections 5.4.7.3.1 will be revised to incorporate the design criterion of the natural circulation as follows:

"The APR1400 is designed to have decay heat removal capability by natural circulation. The flow by natural circulation shall be enough that the temperature increase across the core during natural circulation is less than that of the full power design condition at the same core inlet temperature and pressure conditions."

The fuel integrity during the natural circulation is preserved by maintaining the subcooling margin of the RCS. DCD Section 5.4.7.3.1 shows that when the RCS subcooling margin is decreased to 15 ℃ (27 ˚F), the operator stops the RCS depressurization and begins to cooldown.

The boron mixing and cooldown to SCS entry condition by natural circulation is not a test item in initial test program of APR1400. The boron mixing and natural circulation cooldown tests were performed in 1980's in U.S. as required by NRC. The BNL-NUREG-41512, "Evaluation of Natural Circulation Cooldown Tests Performed at Diablo Canyon, San Onofre, and Palo Verde Nuclear Power Plants," concludes that adequate boron mixing could be achieved in less than one hour by natural circulation within the main flow path of the RCS and that relatively unborated water entering the RCS from the upper head and pressurizer will not have significant effect on criticality as long as the depressurization is conducted carefully to limit the size of possible void formation.

Palo Verde plants are of System 80 design which is the reference design of System 80+. APR1400, which has basically the same design as System 80+ design in thermal power and system configuration, is also evaluated to have adequate boron mixing capability during natural circulation operation.

The APR1400 EOG, which provides guidelines to mitigate a loss of offsite power or loss of forced circulation event, requires that when plant cooldown is required, boron concentration is periodically sampled and maintained within allowable boron concentration differences of

boron concentration throughout the RCS. A related boron concentration monitoring/control step in the APR1400 EOG, “Loss of Offsite Power/Loss of Forced Circulation,” is attached as follows:

Loss of Offsite Power/ Loss of Forced Circulation Recovery Guideline	Advanced Power Reactor 1400 Emergency Operating Guidelines	
	Revision 0.0	**Page <u>18</u> of <u>34</u>**

INSTRUCTIONS	**CONTINGENCY ACTIONS**
* 30. **IF** plant cooldown is desired, **THEN** ensure [adequate shutdown margin] is maintained in the RCS:	

a. Sample the RCS periodically for radioactivity and boron concentration.

b. Borate the RCS to maintain shutdown margin greater than [adequate shutdown margin].

c. Prevent boron dilution by pressurizer outsurge by **ALL** of the following:

1) Borate the entire RCS (including the mass in the pressurizer) to Cold Shutdown conditions.

2) Maintain pressurizer boron concentration within [allowable boron concentration difference] from RCS boron concentration by using main or auxiliary spray.

The APR1400 has the reactor coolant gas vent system (RCGVS) on reactor vessel upper head (RVUH) and the heat junction thermo-couples to measure the water level in the reactor vessel. When the void is formed in the RVUH region and the water level is decreased, the void is discharged from the RVUH and the boron mixing between the RVUH and main RCS loop is increased. Such operator action is described in DCD Section 5.4.7.3.1.1.

The thermal stratification on RCS loop during natural circulation is not expected based on the tests referred in BNL-NUREG-41512 which says that the boron mixing in main flow path of the RCS would be very rapid under natural circulation condition. However, flow in RVUH is stagnant and concern for the thermal stress during natural circulation is issued on Generic Issue 79. However, the NRC also issued the Generic Letter 92-02, “Resolution of Generic Issue 79, Unanalyzed Reactor Vessel (PWR) Thermal Stress during Natural Convection Cooldown,” which does not require generic or plant-specific actions for safety reason. Therefore, this issue is not addressed in DCD Section 1.9.3, “Generic Issues,” which presents proposed technical resolutions for USI and medium- and high-priority GSI identified in the NUREG-0933.

Impact on DCD

DCD Tier 2, Subsections 5.4.7.3.1 and 14.2.12.4.22 will be revised as shown in the attachment associated with 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 Reports.

The design condition of the SCS is taken at 96 hours after plant shutdown. At this point, the design basis is to maintain a 48.39 °C (120 °F) average refueling temperature with a CCW temperature of 35 °C (95 °F). Two SDCHXs and two SCPs are assumed to be in operation at the design flow. The SDCHX size is determined at this point because it requires the greatest heat transfer area due to the relatively small ΔT between primary fluid and component cooling water. The design input heat load at 96 hours is based on decay heat at 96 hours after reactor shutdown, assuming an average reactor core burnup of two fuel cycles. Additional energy input to the RCS from two SCPs running at design flow rate is also included with no credit taken for component energy losses to the external environment. The cooldown rate is limited to a maximum of 41.7 °C/hr (75 °F/hr) throughout the cooldown. A typical two-train cooldown curve is shown in Figure 5.4.7-1.

With the most limiting single active failure in the SCS, the RCS temperature can be brought to 93.3 °C (200 °F) within 24 hours following shutdown using one SCP and one SDCHX, assuming that the RCS pressure and temperature are reduced to SCS initiation conditions by other heat rejection means within 14 hours. A typical single-train cooldown curve is shown in Figure 5.4.7-2.

The SCS is designed using a philosophy of total physical separation of redundant trains so that the system can carry out its safety function assuming a single active failure during both normal and short-te
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The APR1400 is designed to have decay heat removal capability by natural circulation. The flow by natural circulation shall be enough that the temperature increase across the core during natural circulation is less than that of the full power design condition at the same core inlet temperature and pressure conditions.

Reasonable assurance of adequate sampling capability of the SCS is provided for all modes of SCS operation to verify boron concentration and fission product activity.

5.4.7.3.1 <u>Performance Evaluation Assuming the Most Limiting Single Failure and Only Onsite Power Available</u>

The results of a computer simulation of a natural circulation cooldown (NCC) of NSSS from normal operation to SCS entry condition are presented in this section. The simulation is in conformance with BTP 5-4 requirements. These requirements include the

4.2 Pressurizer pressure and level

4.3 Steam generator levels and pressure

4.4 RCS boron concentration

5.0 ACCEPTANCE CRITERIA

~~5.1 The natural circulation power-to-flow ratio is less than 1.0.~~

5.1 Adequate natural circulation flow shall be maintained following trip of all RCPs.

5.2 The enthalpy rise at natural circulation condition is less than at design full power condition.

14.2.12.4.23 Liquid Waste Management System Test

1.0 OBJECTIVE

1.1 To demonstrate that the operation of the liquid waste management system (LWMS) for collection, processing, recycling, and preparation of liquid waste for release to the environment is satisfactory. A list of LWMS subsystems is provided below:

- Floor drain subsystem
- Equipment waste subsystem
- Chemical waste subsystem
- Radioactive laundry subsystem

2.0 PREREQUISITES

2.1 The LWMS equipment, including all subsystem equipment, is operable in either manual and/or automatic modes, as desired.