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.:	**528-8709**
SRP Section:	**14.02- Initial Plant Test Program**
Application Section:	**14.02**
Date of RAI Issue:	**11/14/2016**

Question No. 14.02-70

General Design Criterion (GDC) 19 in Appendix A to 10 CFR Part 50 states that, "A control room shall be provided from which actions can be taken to operate the nuclear power unit under normal conditions..." Normal operating conditions include the shutting down of a reactor; therefore, since the residual heat removal (RHR) system is one of several systems involved in the normal shutdown of all reactors, this system must be operable from the control room.

The guidance for the review of the design requirements for the RHR system are provided in NUREG-0800, Branch Technical Position (BTP) 5-4. NUREG-0800, BTP 5-4, "Design Requirements of the Residual Heat Removal System," Section 5, "Test Requirements" for boron mixing states:

> "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. Comparison with the performance of previously tested plants of similar design may be substituted for these tests."

In RG 1.68, Appendix A, Section A-4t, "Low-Power Testing" states:

> "Perform natural circulation tests of the reactor coolant system to confirm that the design heat removal, boron mixing plant cool down/depressurization, and stable natural circulation conditions are maintained throughout the test or by comparison of the plant's reactor coolant system hydraulic data to a reference prototype plant of similar design and configuration (PWR)."

In DCD Table 14.2-7, the DC applicant cross referenced DCD Subsection 14.2.12.4.22 to RG 1.68, App. A, Section 4t, which identified this test has a low power test. The CE System 80+ DCD Section 14.2.12.4.23, “Natural Circulation Test,” included in Step 5.2 the test acceptance criteria (in DCD Chapter 5, Appendix 5d) to confirm adequate boron mixing during natural recirculation flow. The NRC staff requests the DC applicant add similar test acceptance criteria to the APR1400 DCD Section 14.2.12.4.22 “Natural Circulation Test,” to be consistent with the NRC regulatory basis and this CE System 80+ test.

Additionally, as acknowledged by KHNP in the revised response to RAI 91-7867, Question 14.02-7 (ML16182A597), the NRC staff requests that the words "(First-of-a-Kind Test)" be deleted from the title of the test listed in 14.2.12.4.22.

In the DC applicant’s response to RAI 384-8100, Question 05.04.07-03 (ML16077A291), the DC applicant stated:

> “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 [reactor vessel upper head] 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.”

The NRC staff determined that the DC applicant did not adequately justify use of BNL-NUREG-41512 to not perform boron mixing. The NRC staff determined that the DC applicant should verify sufficient boron mixing to cooldown the reactor from hot standby to hot shutdown conditions when the Shutdown Cooling System (SCS) is placed in-service. The DC applicant should consider revising the natural circulation test to include other SSCs to safely complete this test and verify boron mixing and natural circulation can be used to cooldown the reactor from hot standby to hot shutdown conditions with suitable test acceptance criteria to place the SCS in-service.

Response

The purpose of this additional information on the APR1400 natural circulation cooldown boron mixing test is to establish the ability of the APR1400 Reactor Coolant System (RCS) to rapidly and completely mix an injected quantity of concentrated borated water through the RCS during natural circulation conditions. The determination is based on the similarity between the APR1400 RCS design and the Palo Verde Unit 1 (PVNGS) RCS design, and the applicability of the PVNGS boron mixing test results to the APR1400. The results obtained from the PVNGS test programs were used to project the expected RCS boron mixing for the APR1400. In addition, the RCS design data for each plant was compared to show the similarity.

A boron mixing test was conducted as part of the PVNGS natural circulation cooldown test on January 24, 1986. The test involved adding a predetermined amount of borated water using the charging pumps to the reactor coolant system during natural circulation and then monitoring the primary system boron concentration at discrete locations as mixing occurred. The test result showed that the RCS boron mixing delay time (defined as the time required for the injected boron to be completely mixed in the RCS beyond the end of the boron injection time) during natural circulation was conservatively evaluated as six minutes for each loop.

The mechanisms responsible for successful boron mixing include the boron injection stream velocity, cold leg velocity, reactor vessel flow paths, steam generator tube length differential and the RCS coolant volume. The APR1400 mechanisms and associated design parameters were then compared to PVNGS. The expected boron mixing for the APR1400 was then assessed based upon the similarities to PVNGS.

(1) Cold Leg Mixing

The cold leg fluid flow is characterized as turbulent flow due to a high Reynolds number value. Turbulence will cause the boron to be circulated cross sectionally in the cold leg eliminating any possible stratification of boron concentration there. The APR1400 shows a Reynolds number of 2.7×10^6, well exceeding the threshold number of 10,000. This result assures that the APR1400 cold leg flow will be turbulent in nature and the boron mixing process will benefit from the turbulence in the same manner that the PVNGS boron mixing did.

(2) Boron Injection Stream

The velocity of the boron injection stream is many times greater than the velocity of the flow through the cold leg. This assures that the concentrated borated water stream penetrates deeply into the flow field of the relatively slower moving cold leg flow. The projected APR1400 boron injection stream fluid velocity (via the CVCS charging pump) is greater than the value experienced during the PVNGS natural circulation boron mixing test. Thus, the APR1400 boron mixing is expected to exceed that demonstrated during PVNGS test results. The individual charging nozzle geometry is identical for the two plants.

When using the safety injection pumps to inject boron, the delivered safety injection flow will be greater than the charging flowrate which increases the boron mixing. The APR1400 Safety Injection System (SIS) uses four Direct Vessel Injection (DVI) nozzles located above the centerline of the cold and hot leg nozzles, but below the upper vessel flange. The safety injection fluid is injected directly into the reactor vessel downcomer above the elevation of the cold legs. The SIS fluid flows down the downcomer and mixes with the cold leg flow prior to enter the bottom of the core. The interior of the DVI nozzle provides a restricted flow area, having a smaller diameter than the safety injection line; hence, increasing the speed of injection flow. The APR1400 minimum safety injection flowrate exceeds the charging flowrate (per nozzle) by at least several orders of magnitude after the RCS is depressurized below SI pump shutoff head.

The high velocity of the charging flowrate or the safety injection flowrate assures deep penetration of the boron injection stream and thus a high degree of boron mixing in the cold leg and reactor core downcomer.

(3) Reactor Vessel Mixing

The APR1400 reactor vessel flow path contributes to boron mixing as the coolant passes through the inlet plenum, downcomer, and lower plenum. The reactor vessel arrangement and geometry is similar on the two plants. The changes in flow direction in the reactor vessel contribute to complete boron mixing. The coolant flows into the reactor vessel, turns down the downcomer, through a flow skirt, up through the core and then turns as it exits to the hot leg. The mixing of boron in the APR1400 reactor vessel (i.e., downcomer, lower plenum and core) is expected to be at least equal to that experienced during the PVNGS testing. The APR1400 PLUS7 fuel assemblies with the R-type split mixing vane spacer grids provides a specific enhancement to the coolant mixing in reactor core.

(4) Steam Generator Mixing

The effect of the steam generator tube length difference (i.e., shortest to longest tube) is to elongate the concentrated boron fluid and contribute to boron mixing as the fluid exits the steam generators. The larger the difference in steam generator tube lengths, the greater the contribution to boron mixing. The difference between the longest and the shortest steam generator tubes is 472 inches for the APR1400. The value for PVNGS is 430 inches. Thus, the APR1400 steam generators are expected to contribute to boron mixing to a similar degree as that demonstrated on PVNGS.

(5) RCS Volume Comparison

The total volume of borated water, at a given concentration, needed to increase the RCS boron concentration from a given concentration to a given target concentration, will be more in the case of an RCS of more volume. The APR1400 volume is about 20% more than PVNGS. Though an equivalent boron concentration increase will take longer in the APR1400 design than the PVNGS, the APR1400 boron mixing capability in the RCS will be equal to or greater than that demonstrated in the PVNGS test.

Boron mixing, under natural circulation cooldown conditions, was successfully demonstrated during the PVNGS test. Plant parameters that affect boron mixing are shown in Table 1, and a similarity comparison of the RCS geometry for the APR1400 and PVNGS is presented Tables 2, 3, and 4. The similarity of the APR1400 design and operation to PVNGS assures similar boron mixing. Therefore, it is evaluated that a boron mixing test is not required for APR1400.

Table 1 Comparison of Boron Mixing Capability Between the APR1400 and PVNGS

Parameter	APR1400	PVNGS
Boron injection stream velocity, ft/sec	- Charging nozzle: 12.4 (66.4 gpm) - DVI nozzle: 248 gpm/SI pump at 1,500 psia of RCS pressure	Charging nozzle: 11.6 (62.0 gpm)
Cold leg flow velocity, ft/sec	1.5 [1)]	1.4 [2)]
Cold leg flow Reynold number [3)]	2.7×10^6 [1)]	2.5×10^6 [2)]
SG tube length differential, in	472	430
Total RCS fluid volume, ft^3	16,079	13,027

1) RCS at 550 °F and 2200 psia (flow rate after 4 hours of hot standby operation, 3% of full power flowrate)
2) PVNGS boron mixing test results
3) Reynold number greater than 10^4 assures consistent turbulent flow

Table 2 Comparison of Reactor Coolant System Geometry

Component	Flow Path Length, ft	Top Elevation, ft (a)	Bottom Elevation, ft (a)	Minimum Flow Area, ft^2	Volume, ft^3
	APR1400 (PVNGS)				
Hot Leg	14.10 (14.06)	2.39 (2.38)	-1.75 (-1.75)	9.62 (9.62)	137.26 (135.27)
Suction Leg	25.36 (24.32)	1.30 (0.58)	-9.98 (-9.97)	4.91 (4.91)	127.66 (119.38)
Discharge Leg	19.30 (19.30)	1.27 (1.25)	-1.27 (-1.25)	4.91 (4.91)	97.18 (94.74)
Pressurizer					
Liquid Level (full power)	-	43.74 (b)	-	50.07 (50.07)	1110 (900)
Surge Line	73.64 (69.44)	19.94 (b)	1.76 (1.75)	0.56 (0.56)	41.19 (38.82)
Steam Generator					
Inlet Plenum	4.74 (4.74)	6.71 (6.48)	-0.51 (-0.10)	19.07 (19.07)	434.56 (332.41)
Outlet Plenum	4.74 (4.74)	6.71 (6.48)	-0.51 (-0.10)	9.74 (9.74)	434.56 (332.41)
Tubes	67.91 (61.15)	37.89 (40.94)	6.71 (6.48)	0.002 (0.002) (c)	2147.0 (1634.2)
Reactor Vessel					
Inlet Nozzle	3.7 (3.7)	1.47 (1.4)	-1.47 (-1.5)	4.9 (4.9)	20.75 (21.7)
Downcomer	19.9 (21.4)	11.6 (11.7)	-22.6 (-22.6)	33.75 (33.8)	1,170.0 (1,157.1)
Lower Plenum	5.5 (3.2)	-20.6 (-20.5)	-25.9 (-25.9)	32.5 (32.5)	434.5 (430.2)
Active Core	12.5 (12.5)	-5.1 (-5.3)	-17.6 (-17.8)	60.8 (60.8)	815.7 (888.2)
Outlet Plenum	5.7 (5.7)	1.9 (2.1)	-2.7 (-2.4)	26.6 (26.6)	441.7 (459.4)
Top Head	3.2 (3.2)	19.9 (19.9)	12.7 (12.7)	7.8 (7.8)	468.2 (422.6)
Outlet Nozzle	4.0 (4.0)	1.87 (1.7)	-1.87 (-1.8)	9.6 (9.6)	42.75 (32.2)

(a) Reactor vessel nozzle centerline is the reference elevation 0.0 ft.
(b) Depends on individual plant surge line height
(c) Flow path area per tube

Table 3 Comparison of Reactor Coolant System Component
Thermal and Hydraulic Data (1/2)

Component	Data	
	APR1400	PVNGS
Reactor Vessel		
Rated core thermal power, MWt	3,983	3,800
Operating pressure, psia	2,250	2,250
Coolant outlet temperature, °F	615	621.2
Coolant inlet temperature, °F	555	564.5
Total coolant flow, 10^6 lbm/hr	166.6	164.0
Steam Generators		
Number of units	2	2
Primary side (or tube side)		
Operating pressure, psia	2,250	2,250
Inlet temperature, °F	615	621.2
Outlet temperature, °F	555	564.5
Secondary side (or shell side)		
Full-load steam pressure/temperature, psia/°F	1,000/545	1,070/552.9
Zero-load steam pressure, psia	1,100	1,170
Total steam flow per S/G, lbm/hr	8.97×10^6	8.45×10^6
Feedwater temperature, full power, °F	450	450

Table 3 Comparison of Reactor Coolant System Component Thermal and Hydraulic Data (2/2)

Component	Data	
	APR1400	PVNGS
Pressurizer		
Operating pressure, psia	2,250	2,250
Operating temperature, °F	653	655
Internal volume, ft^3	2,400	1,800
Reactor Coolant Pumps		
Number of units	4	4
Operating pressure, psia	2,250	2,250
Total dynamic head, ft	360	365
Rating and power requirements, kW	10,000	8,850
Pump speed, rpm	1,190	1,190
RCP heat input to RCS, MWt	24.6	23 to 26
Pipe size (inside dia.), in		
Hot leg	42	42
Cold leg (Suction/ Discharge leg)	30	30

Table 4. Comparison of Fuel Assemblies Mechanical Design Parameters

Design Feature	Data	
	APR1400	PVNGS
Fuel Assemblies		
Fuel rod array	Square, 16 × 16	Square, 16 × 16
Fuel rod pitch, in	0.506	0.506
Fuel rod to fuel rod, in	7.964 × 7.964	7.972 × 7.972
Total fuel weight, lb UO_2 (assuming all rod locations are fuel rods)	259.7×10^3	257.1×10^3
Number of grids per assembly	12	10

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 Reports

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