In-vessel Downstream Effect Tests for the APR1400

Non-proprietary

July 23, 2013 KHNP-CRI



APR1400-K-A-EC-13003-NP

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Introduction

KHNP issued APR1400-K-A-I(RA)-13001-P "Test Plan for Invessel Downstream Effect of the APR1400" to address the plant specific in-vessel downstream issue.

□ PWROG works on in-vessel downstream effects have been reviewed

- U.S.NRC SER for WCAP-16793-NP Revision2
- Common test protocol (LTR-SEE-I-09-34)
- □ The QA program complies with 10 CFR part 50 Appendix-B, 10 CFR Part 21, and ASME NQA-1-2008 and 1a-2009.

Objective

□ Objective of in-vessel downstream effect tests

- Obtain test data on pressure drop through a mock-up FA
- Demonstrate that a sufficient driving force is available to maintain an adequate flow rate
- Confirm that the long-term core cooling capability is adequately maintained in the APR1400

LOCA Scenarios (1/4)

□ Three LOCA scenarios are chosen

- Core flow rate and its direction affect the behavior of debris in the core
- Break location affects the driving force of injected ECCS water

LOCA scenario	Core flow direction	APR1400 flow rate	Flow rate/ FA*	Remark
HL Break	Upward	4,940 gpm	20.5 gpm	Max. safeguard flow rate of four(4) SI
CL Break	Upward	792.5 gpm	3.29 gpm	Boil-off flow rate at 1,200 sec
CL Break after HLSO	Downward	2,470 gpm	10.25 gpm	Max. safeguard flow rate of two(2) SI

* 1/241 of the maximum flow rate for the APR1400

LOCA Scenarios (2/4)

- □ Hot-leg break
 - Driving force reaches its peak before the flow begins to spill over the shortest SG tubes in the cold-leg side



CHNP

LOCA Scenarios (3/4)

□ Cold-leg break

 Driving force is the manometric balance between the liquid in the downcomer and the core



LOCA Scenarios (4/4)

□ Cold-leg break after hot-leg switch over (HLSO)

 Driving force reaches its peak when the flow begins to spill over the shortest SG tubes in the hot-leg side



Acceptance Criteria

□ Available driving head for each LOCA scenario

$$dP_{avail} = dP_{dz} - dP_{flow}$$

where dP_{dz} = pressure head due to liquid level between core inlet and outlet dP_{flow} = pressure head due to flow losses in the RCS = $(k/A^2 * w^2) / (288 * \rho_1 * g_c)$

TS

- Hot-leg break
 - $dP_{avail} = [$
- Cold-leg break
 - $dP_{avail} = [$]^{TS}
- Cold-leg break after HLSO

 $dP_{avail} = [$]

Test Facility (1/2)

Test column

- Mock-up FA of PLUS7 : ¹/₂ full length
- Same components : top/bottom nozzle, p-grid, top/bottom grid,
 - 4 mid grids (Full length of PLUS7 has 9 grids)
- Debris mixing tank
 - Transparent cylindrical shape : 1,880 L (45.6 % of the minimum IRWST water/FA)
 - Heater/chiller are installed to control water temperature
 - A stirrer is installed to prevent debris settling
- Recirculation System
 - One recirculation pump, one flow meter
 - Flow rate can be adjustable
- **Control and Monitoring System**
 - Control : water flow rate, water temperature
 - Record : flow rate(1), temperature(4), differential pressure(5)



Test Conditions (1/3)

Initial conditions

- Room temperature
 - **♦ 22** °C ± 1 °C
 - Lower water temperature covers post-LOCA core conditions since the water density is high, and the pressure drop is increased in the test condition.
- Atmospheric pressure
 - The system pressure has negligible effect on fluid compared to water temperature.
- Constant flow rate
 - ✤ HL break condition (Upward) : 77.6 lpm ± 5%
 - CL break condition (Upward) : 12.5 lpm ± 5%
 - ✤ CL break after HLSO (Downward) : 38.8 lpm ± 5%

Test Conditions (2/3)

D Bypass Debris Types and Amounts per FA

Debris type	Specific type	Debris generated in containment	Assumed bypass debris (kg)	Per FA* (g)
Fibrous	NUKON	0	0	0
	Latent fiber	7.5 lbs (3.4 kg)	3.4	14.1
Particulate -	Coating debris	3.1 ft ³ (232.6 kg)	232.6	965.2
	Latent particle	92.5 lbs (41.95 kg)	41.95	174
Reflective metal insulation		114 ft ³	0	0
Chemical compounds		416.7 lbs (189 kg)	189	784.2

* 1/241 of the assumed bypass debris amount

Test Conditions (3/3)

D Test matrix

TS

Test Procedures (1/3)

- □ Select a flow rate : 77.6 lpm (HL break) or 12.5 lpm (CL Break)
- □ Set water temperature : 22 °C
- **Π** Prepare particulate : SiO₂ (10μm±5μm)
 - Add all particulates first
 - Allow system to equilibrate for 30 min. minimum



Silica powder (SiO₂)



After addition



Test Procedures (2/3)

Prepare fiber : NUKON

Grind a boiled and dried NUKON for 8 seconds

Description	Specified Value	Range	
Fiber length<500µm	77%±10%	67%-87%	
500µm≤fiber length≤1000µm	18%±10%	8%-28%	
Fiber length≥1000µm	5%±10%	0%-15%	

- Add fiber in 10 g increments
- Wait for at least 20 minutes (1 loop volume through test loop)
- Repeat until all fiber has been added
- Allow at least 100 minutes (5 turnovers of the test loop volume)



Grinded fiber debris





Test Procedures (3/3)

□ Prepare chemical : ALOOH

- Add ALOOH in 50 g (or 300 g, 385 g) increments
- Wait for at least 60 minutes (3 loop volume through test loop)
- Record time and dP
- Repeat until all ALOOH has been added



AlOOH powder



Water mixing



Test Results for Shin-Kori 3&4(1/2)

□ Hot-leg break

- 8 Tests had been run to evaluate hot-leg breaks
- p:f ratio ranged from 0.5:1 to 126:1
- Limiting result occurred at p:f ratio = 1:1
- Meet the acceptance criteria([] kPa) with sufficient margin : [] kPa

ΤS

[dP result (77.6 lpm, particle/fiber/chemical:100g/100g/300g)]



Test Results for Shin-Kori 3&4(2/2)

□ Cold-leg break

- 4 Tests had been run to evaluate cold-leg breaks
- p:f ratio ranged from 1:1 to 126:1
- Limiting result occurred at p:f ratio = 10:1
- Meet the acceptance criteria ([] kPa) with enough margin : [] kPa

[dP result (11.4 lpm, particle/fiber/chemical:500g/50g/300g)]



ΤS

Summary

- KHNP planes in-vessel downstream effect tests of the APR1400 to confirm the plant specific effects on FA during post-LOCA with debris-laden.
- □ Will use conservative test approach
 - Actions are taken to prevent settling
 - All fiber are introduced as "fines"
 - No credit is taken for filtering effect of strainer bed

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□ The QA program complies with 10 CFR part 50 Appendix-B, 10 CFR Part 21, and ASME NQA-1-2008 and 1a-2009.

