In-vessel Downstream Effect Tests for the APR1400

Non-proprietary

July 23, 2013

KHNP-CRI

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Introduction

- KHNP issued APR1400-K-A-I(RA)-13001-P “Test Plan for In-vessel 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

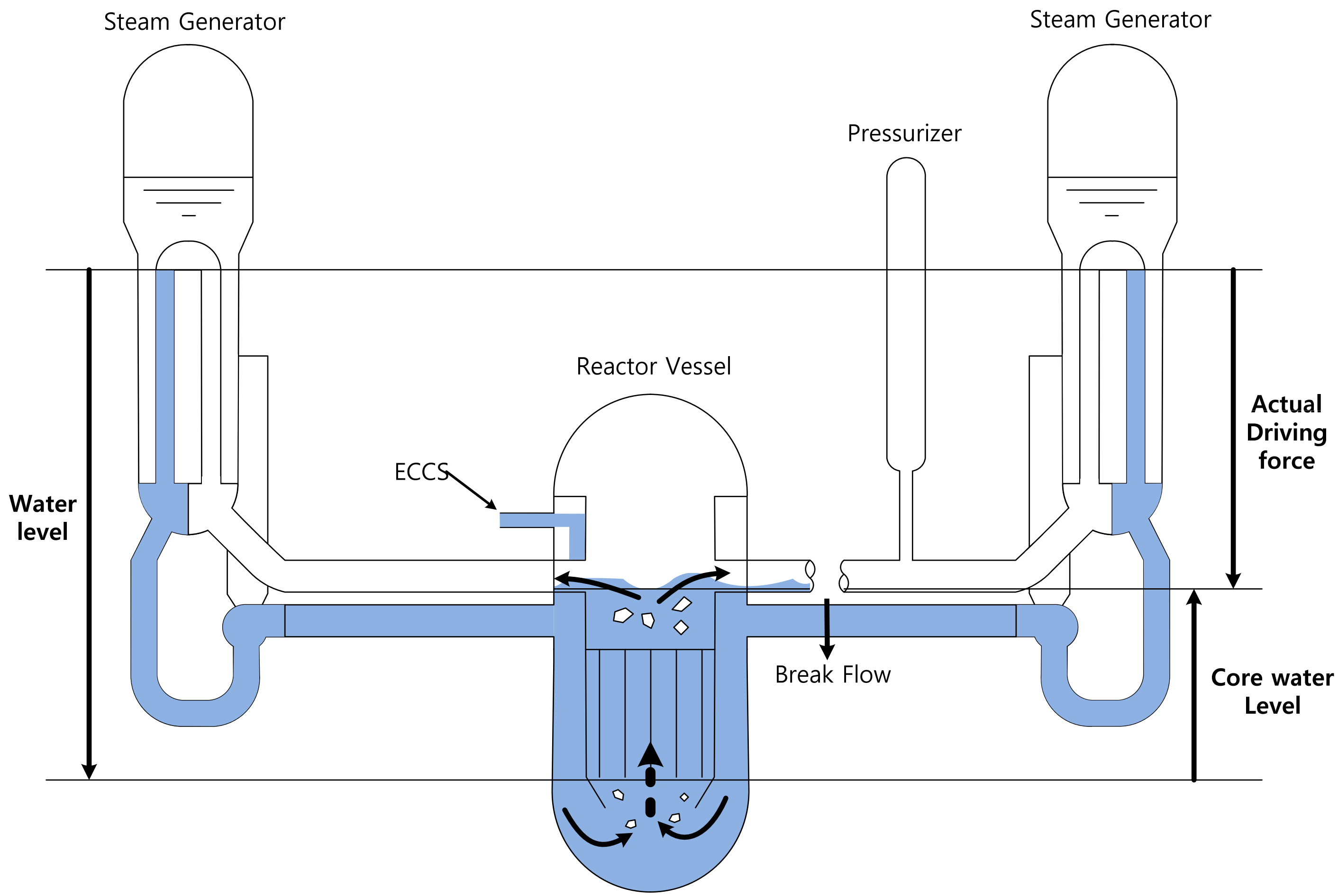
LOCA scenario	Core flow direction	APR1400 flow rate	Flow rate/ FA*	Remark
HL Break	Upward	4,940 gpm	20.5 gpm	Max. safeguard flow rate of four(4) SI
CL Break	Upward	792.5 gpm	3.29 gpm	Boil-off flow rate at 1,200 sec
CL Break after HLSO	Downward	2,470 gpm	10.25 gpm	Max. safeguard flow rate of two(2) SI

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

LOCA Scenarios (2/4)

❑ Hot-leg break

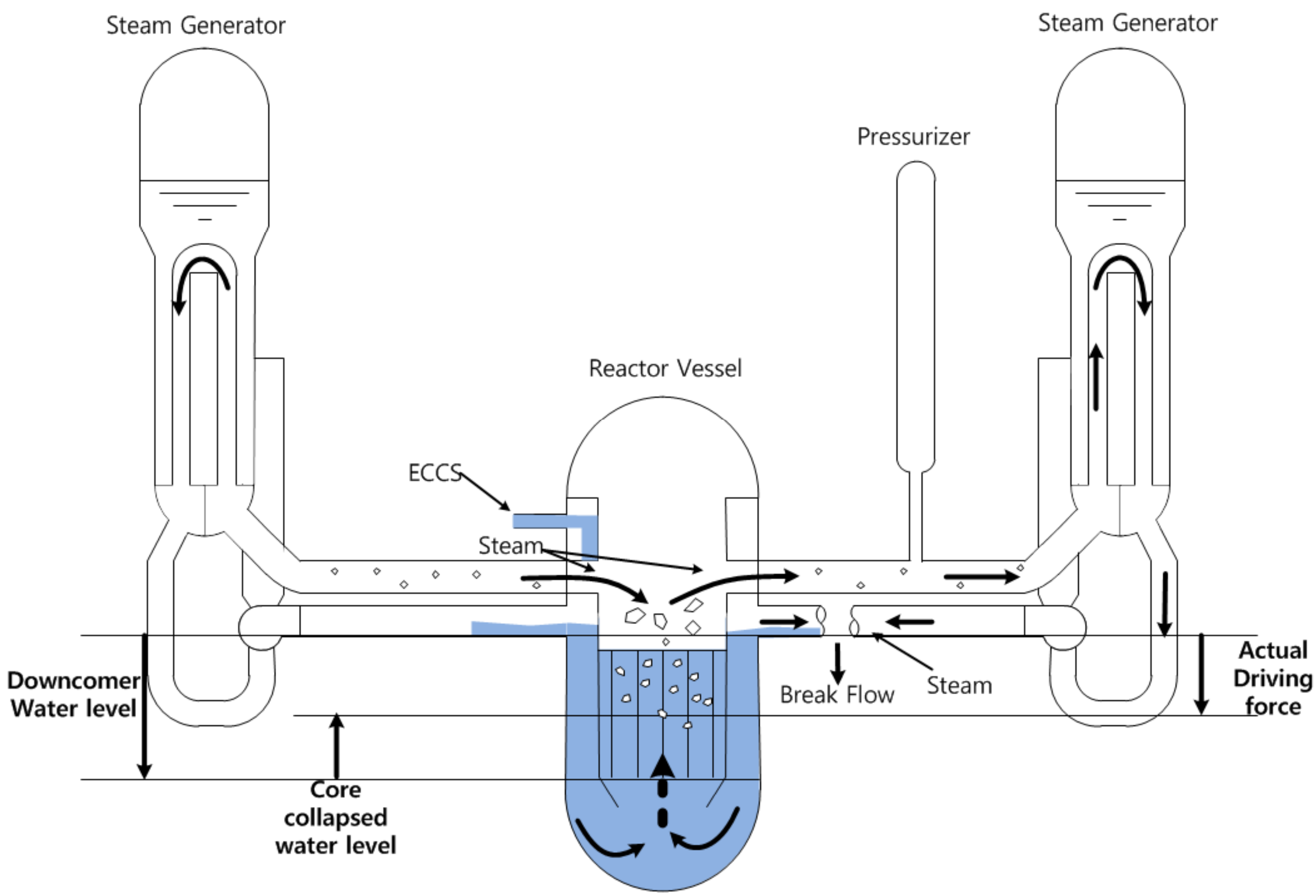
- Driving force reaches its peak before the flow begins to spill over the shortest SG tubes in the cold-leg side



LOCA Scenarios (3/4)

❑ Cold-leg break

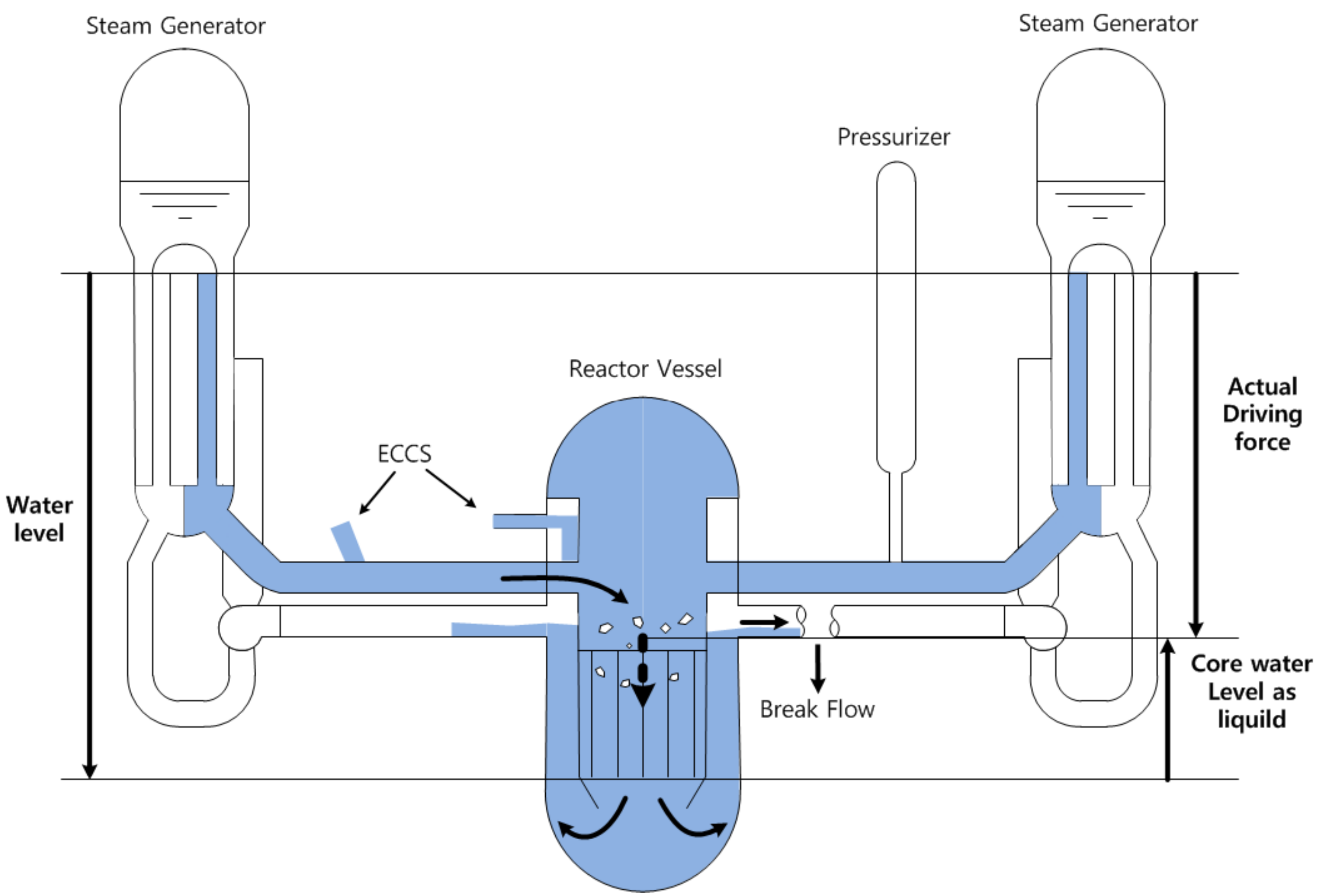
- **Driving force is the manometric balance between the liquid in the downcomer and the core**



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

$= (k/A^2 * w^2) / (288 * \rho_l * g_c)$

- **Hot-leg break**

  dP_{avail} = [ ]^{TS}

- **Cold-leg break**

  dP_{avail} = [ ]^{TS}

- **Cold-leg break after HLSO**

  dP_{avail} = [ ]^{TS}

Test Facility (1/2)

- Test column
  - Mock-up FA of PLUS7 : ½ 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 Facility (2/2)

❑ Test loop

TS

Test Conditions (1/3)

❑ Initial conditions

- Room temperature
  - ❖ 22 °C ± 1℃
  - ❖ 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)

❑ 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)

- Test matrix

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Test Procedures (1/3)

- ❑ Select a flow rate : 77.6 lpm (HL break) or 12.5 lpm (CL Break)
- ❑ Set water temperature : 22 °C
- ❑ Prepare particulate : SiO_2 (10μm±5μm)
  - Add all particulates first
  - Allow system to equilibrate for 30 min. minimum

Silica powder (SiO_2)

After addition

Test Procedures (2/3)

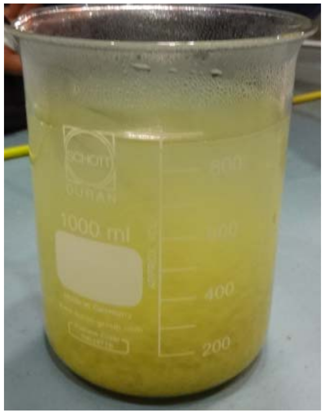
❑Prepare fiber : NUKON

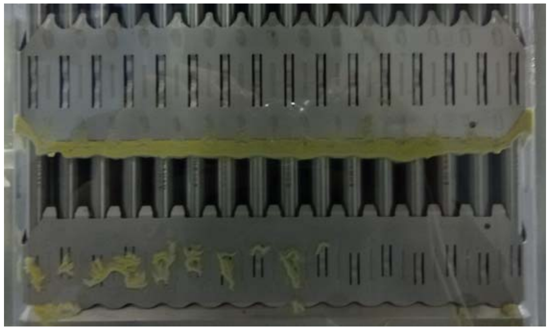
- **Grind a boiled and dried NUKON for 8 seconds**

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

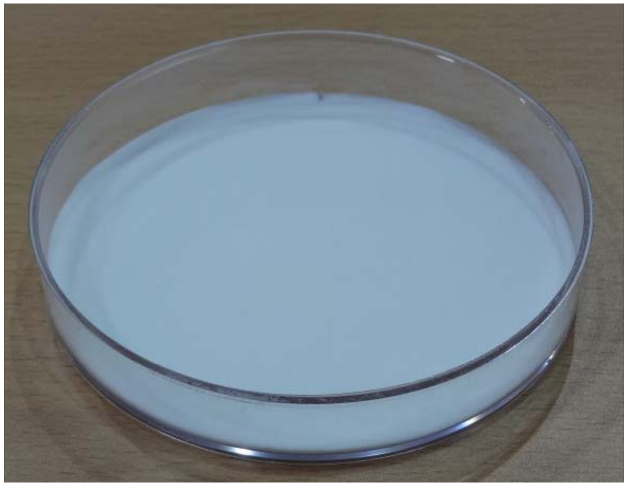

Water mixing


P-grid and bottom grid

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

[ ] TS

[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

TS

[ ]

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

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