Non-Proprietary

Performance Verification of APR1400 Safety Injection Tank -Fluidic Device

- Design Requirements for Fluidic Device
- VAPER Test Facility & Fluidic Device
- Test Conditions & Test Results
- Uncertainty Analysis
- Issues Identified by the NRC Staff
- Summary

Design Requirements for Fluidic Device K Factor

- The following requirements were drawn from hypothetical LBLOCA analysis and conservative assumptions:

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VAPER Test Facility (1/3)

- Full-Scale SIT & FD
  - I.D. : 2.74 m (8.0 ft)
  - Height : 11.9 m (39.0 ft)
  - Volume : 68.13 m^3 (68.13 ft^3)
- Air Compressor
  - Max P: 5.0 MPa (725 psi)
- **Final Goal**
  - **Verification of the pressure loss coefficient (K-Factor) of Fluidic Device**, which is used to evaluate SI water injection flow rate in safety analysis code

VAPER Test Facility (2/3)

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VAPER Test Facility (3/3)

- Geometrical differences between VAPER SIT-FD and APR1400 SIT-FD

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Dimensions of Fluidic Device

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	Standard FD	FD-S*
Dia. of Vortex Chamber		
H. of Vortex Chamber		
W. of Supply Nozzle		
W. of Control Nozzle		
Angle btw. Nozzles		
I.D. of Throat		
Height of Stand Pipe		
I.D. of Stand Pipe		

* FD-S : Fluidic Device for Sensitivity of H. of Stand Pipe & Manufacturing Tolerances

Test Matrix & Conditions (1/7)

Test ID	Objectives	Remark
Case-01	Repeatability of Standard Design FD	4 Tests (One Low Press. Test)
Case-02	Effect of Water Inventory (or Stand Pipe Height)	3 Tests
Case-03	Effect of Manufacturing Tolerance (Expected Max. Values)	Height of Vortex Chamber (3 Tests)
Case-04		Height of Vortex Chamber & Width of Control Nozzle (3 Tests)

Test Matrix & Conditions (2/7)

	Reference Condition [VAPER Tests]	APR1400 SIT Condition
SI line outlet pressure		
Initial SIT gas pressure		

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Test Matrix & Conditions (3/7)

	Reference Condition [VAPER Tests]	APR1400 SIT Condition
SI water volume for large flow		
SI water volume for small flow		
Initial SI water temperature		

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Test Matrix & Conditions (4/7)

- Case-01 Tests
  - Reference test for standard Fluidic Device
  - Three tests to check the repeatability
  - One low pressure test to check its sensitivity

Test ID	Initial SIT Pressure [kPa(g), (psig)]	Initial SIT Water Level [m (ft)]	Initial SIT Temperature [°C (°F)]
Case-01-01			
Case-01-02			
Case-01-03			
Case-01-04			

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Test Matrix & Conditions (5/7)

- Case-02 Tests
  - To check the sensitivity of the stand pipe height

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Test Matrix & Conditions (6/7)

- Case-03 Tests
  - To check the sensitivity of the vortex chamber height

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Test Matrix & Conditions (7/7)

- Case-04 Tests
  - To check the sensitivity of the control nozzle width

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11th Pre-application Meeting

Test Results: SIT & Stand Pipe Levels

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$$h_{SIT} = \frac{(\rho_w - \rho_{air})gH - \Delta P}{(\rho_w - \rho_{air})g}$$

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Case-01 Tests

Case-01~04

Test Results: SI Water Injection Flow Rate

$$W_{SI}(t) = \rho_w A_{SIT} \frac{h_{SIT}(t) - h_{SIT}(t+\Delta t)}{\Delta t}$$

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Repeatability !!!

Reproducibility !!!
(Manufacturing Tolerance)

Test Results: Fluidic Device K Factor

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Repeatability !!!

Reproducibility !!!
(Manufacturing Tolerance)

11th Pre-application Meeting

Test Results: Fluidic Device K Factor

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Effect of Air Discharge on FD K Factor (1/3)

- The discharge flow rate of the air can be evaluated from the change rate of the total air mass.

$$W_{air}(t) = \frac{m_{air}(t) - m_{air}(t+\Delta t)}{\Delta t}$$

$$m_{air}(t) = \rho_{air}(t) V_{air}(t)$$

Effect of Air Discharge on FD K Factor (2/3)

- The air discharge begun at about 100 sec for Case-01, and reached its maximum at about 120 sec.

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Effect of Air Discharge on FD K Factor (3/3)

- Fluidic Device K Factor was not sensitive to the air discharge flow during 100~120 sec period.

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Uncertainty Analysis (1/5)

- **Uncertainty of FD K Factor** was analyzed at a **95% confidence level** in accordance with the guidelines of ISO[1)] & ASME [2)]
- Total uncertainty is obtained by the root sum square of the systematic and random uncertainties

$$U_{95} = \left[B^2 + P^2\right]^{1/2} = \left[B^2 + \left(t_{95} S_{\overline{X}}\right)^2\right]$$

1) Guide to the Expression of Uncertainty in Measurement (1995)
2) Test Uncertainty, ASME-PTC 19.1-1998 (1998)

Uncertainty Analysis (2/5)

- **Systematic uncertainty** was evaluated by the propagation of the elemental uncertainty sources

$$B_K = \pm\left[\left(\frac{\partial K}{\partial \Delta P}B_{\Delta P}\right)^2 + \left(\frac{\partial K}{\partial \rho_w}B_{\rho_w}\right)^2 + \left(\frac{\partial K}{\partial A_{Pipe}}B_{A_{Pipe}}\right)^2 + \left(\frac{\partial K}{\partial W_{SI}}B_{W_{SI}}\right)^2\right]^{1/2}$$

$$= \pm\left[\left(\frac{K}{\Delta P}B_{\Delta P}\right)^2 + \left(\frac{K}{\rho_w}B_{\rho_w}\right)^2 + \left(2\frac{K}{A_{Pipe}}B_{A_{Pipe}}\right)^2 + \left(2\frac{K}{W_{SI}}B_{W_{SI}}\right)^2\right]^{1/2}$$

$$B_{W_{SI}} \approx \pm\left[\left(\frac{\partial W_{SIT}}{\partial \rho_w}B_{\rho_w}\right)^2 + \left(\frac{\partial W_{SIT}}{\partial A_{SIT}}B_{A_{SIT}}\right)^2 + \left(\frac{\partial W_{SIT}}{\partial \Delta h}B_{\Delta h_{SIT}}\right)^2\right]^{1/2}$$

$$= \pm\left[\left(\frac{W_{SIT}}{\rho_w}B_{\rho_w}\right)^2 + \left(\frac{W_{SIT}}{A_{SIT}}B_{A_{SIT}}\right)^2 + \left(\frac{W_{SIT}}{h_{SIT}(t) - h_{SIT}(t+\Delta t)}B_{\Delta h_{SIT}}\right)^2\right]^{1/2}$$

Uncertainty Analysis (3/5)

Systematic Uncertainty

- SI water flow rate
- Fluidic Device K Factor

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Uncertainty Analysis (4/5)

- **Random uncertainty** of Fluidic Device K Factor was evaluated by multiplying the **standard deviation** with a **coverage factor** of the student *t*-distribution
  - Standard deviation was determined from the K Factors obtained for all tests

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Uncertainty Analysis (5/5)

- Total Uncertainty of Fluidic Device K Factor

$$U_{95} = \left[B^2 + P^2\right]^{1/2} = \left[B^2 + \left(t_{95} S_{\overline{X}}\right)^2\right]$$

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Summary of Fluidic Device K Factor

- The measured Fluidic Device K Factor meets the design requirements for both the large and small flow injection periods.

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Issues Identified by the NRC Staff (1/4)

- Issue 1: Complete Safety Injection Tank Fluidic Device Verification Test Results
  - Complete sets of graphs and/or tabulated test data will be provided on the request of the NRC staff.

Issues Identified by the NRC Staff (2/4)

- Issue 2: Effect of Cavitation

1. The effect of gaseous cavitation is described in section 5.2 of the topical report (APR1400-Z-M-TR-12003-P Rev.0).
2. The effect of vaporous cavitation is being investigated using a CFD analysis for a different SI water temperature.

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Issues Identified by the NRC Staff (3/4)

- Issue 3: Effect of Manufacturing Uncertainty of Facing Angle between the Supply Nozzle and Control Nozzle
  - CFD analysis will be performed.

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Issues Identified by the NRC Staff (4/4)

- Issue 4: Application of FD K-factor to Safety Analysis

1. The range of K-factors obtained from VAPER experiments including uncertainties was used to confirm whether it is within the K-factor design requirements.
2. The results of VAPER tests were used to confirm large break LOCA analysis code RELAP5/MOD3.3/K's predictive capability of observed flow injection behavior.
3. The test data were also used for nodalization development of SIT-FD.
4. The details of items 2 and 3 are described in the topical report (APR1400-F-A-TR-12004-P Rev.0) for large break LOCA evaluation model CAREM.

Summary

- Full scale tests were performed to verify the performance of APR1400 Fluidic Device
- Reproducibility of the performance of Fluidic Device
  - Performance was not sensitive to the changes in the initial SIT pressure & stand pipe height.
  - Performance was also not sensitive to the manufacturing tolerances examined.
- APR1400 Fluidic Device meets the design requirements for both the large and small injection periods.