US-APWR

3rd Pre-Application Review Meeting

Advanced Accumulator

November 29, 2006

Mitsubishi Heavy Industries, Ltd.

Meeting Attendants

- **Hiroshi Hamamoto (Responsible for System Design)**
  - Deputy Chief Engineer
  - Water Reactor Engineering Department
    Nuclear Energy Systems Engineering Center
  - Mitsubishi Heavy Industries, LTD.
- **Hiroshi Sano (Responsible for Advanced Accumulator Design)**
  - Engineering Manager
  - Water Reactor System Engineering Section
    Nuclear Energy Systems Engineering Center
  - Mitsubishi Heavy Industries, LTD.
- **Michitaka Kikuta (Responsible for LOCA Analysis)**
  - Engineering Manager
  - Safeguard System Engineering Section
    Nuclear Energy Systems Engineering Center
  - Mitsubishi Heavy Industries, LTD.
- **Tadashi Shiraishi (Responsible for Test Program)**
  - Research Engineering Manager
  - Thermal System Laboratory
    Takasago Research & Development Center
  - Mitsubishi Heavy Industries, LTD.

Objectives of Meeting

➢The purpose of the meeting is to:

✓Assure that the Topical Report (TR) of Advanced Accumulator for the US-APWR meets all four criteria to be accepted for review

Reference ; USNRC NRR Office Instruction LIC-500 Rev.3
Processing Requests for Reviews of Topical Reports

✓Present information to the NRC on the scope, purpose, and methodology of proposed TR for the Advanced Accumulator for the US-APWR to ensure NRC's expectations for TR are met

✓Provide an opportunity for the NRC to explain its process, schedule, expectations, and to provide candid feedback to MHI

Outline of Presentation

1. US-APWR will adopt an Advanced Accumulator (ACC) which incorporates automatic flow switching from a large flow rate for refill to a small flow rate for reflood
2. Performance requirements for both flow rates were selected based on Target PCT
3. Two design requirements for flow damper
   - Flow Resistance coefficient for large flow (refill)
   - Switching ratio for small flow (reflood)
4. ACC design was confirmed by four scale model tests
   - Principle and performance of ACC were confirmed
   - Empirical correlation for flow rate coefficient was formulated
   - Scalability to actual plants was also confirmed

5.Justification of ACC design will be confirmed by LOCA analysis for US-APWR

Item 1 to 4 will be discussed in this presentation and item 5 will be explained later at topical report of LOCA analysis

CONTENTS

1. Introduction

- The Advanced Accumulator (ACC) design will be included in the US-APWR
- The US-APWR's ACC is incorporated into the safety system design in order to provide the low pressure injection function of conventional Emergency Core Cooling Systems (ECCS) using accumulator and the safety injection pump
- This arrangement simplifies the configuration of the ECCS

1. Introduction

- Details of ACC will be presented in the topical report for review and approval by the United States Nuclear Regulatory Commission (USNRC)
- MHI will explain the outline of the topical report (function, principles, requirements and characteristics, testing and verification, etc.) of ACC

The following is corresponding to section of the topical report

2. Characteristics of ACC

- **Contents**

2.1 Function of ACC

➢ECCS injection during large break LOCA

Step1: Core Refilling

Inject the water rapidly with large flow to fill the lower plenum and downcomer of the reactor vessel in a short time

Step2: Core Reflooding

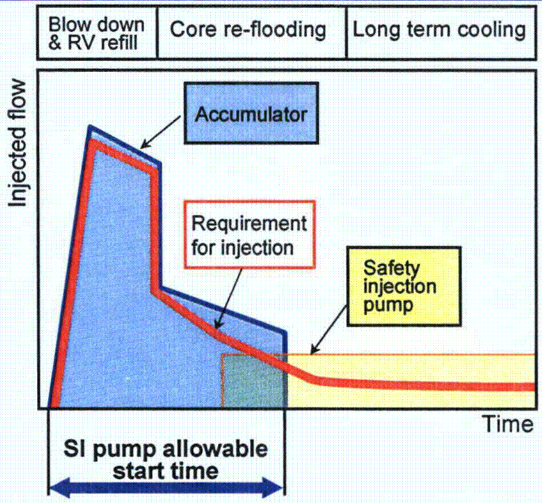
Recover the core water level using the water head in the downcomer. ECCS injection keeps the high water level in the downcomer and re-floods the core immediately

Step3: Long Term Cooling

After core reflooding is completed, inject water to compensate for the water reduction due to evaporation by decay heat in order to maintain reflooded condition of the core

2.1 Function of ACC

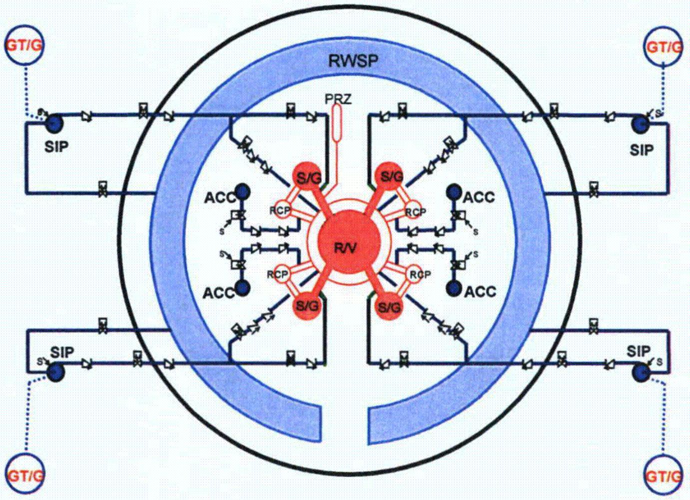
- ➢ Automatic switching of injection flow rate by flow damper
- ➢ Integrated function of low head injection system
- ➢ Long-lasting injection of ACC allows more time for safety injection pump to start



Item	US Current 4 Loop Plant	US-APWR
Step1 Core Refilling	• Accumulator System	• Accumulator System
Step2 Core Reflooding	• Low Head Injection System • High Head Injection System	• Accumulator System • High Head Injection System
Step3 Long term cooling	• Low Head Injection System • High Head Injection System	• High Head Injection System

2.1 Function of ACC

➢ Configuration of ECCS



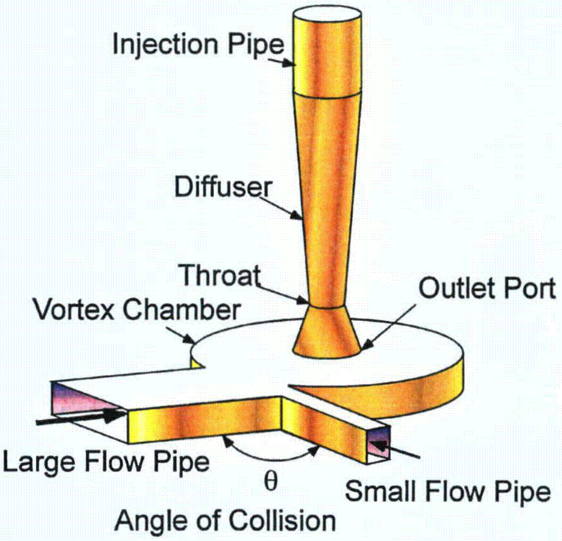
RV: Reactor Vessel
SG: Steam Generator
RCP: Reactor Coolant Pump
PRZ: Pressurizer
S: Safety Injection Signal
ACC: Advanced Accumulator
SIP: Safety Injection Pump
RWSP: Refueling Water Storage Pit
GT/G: Gas Turbine Generator

- ✓ Four ACCs are installed and each ACC connects to one Reactor Coolant System (RCS) cold leg
- ✓ Four High Head Injection subsystems are installed and inject water following ACC injection
- ✓ Low Head Injection system is not installed

2.2 Principle of ACC

➢ Mechanical Configuration of Flow Damper

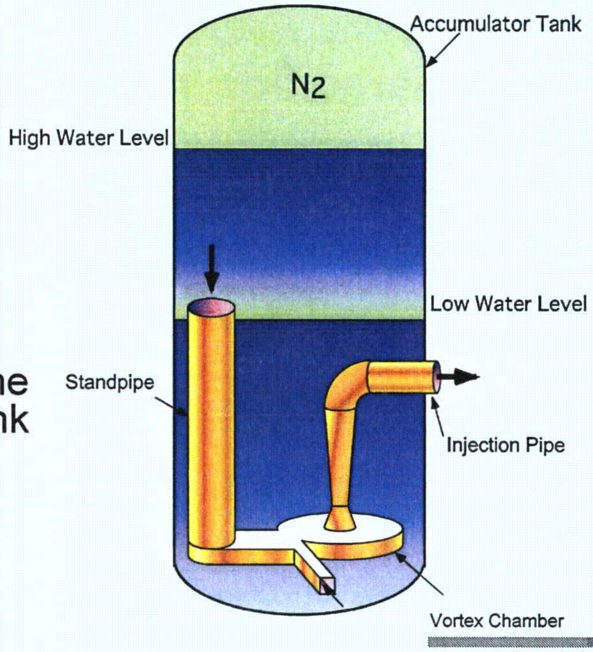
- Small flow pipe tangentially attached to the vortex chamber
- Large flow pipe radially attached to the vortex chamber
- The throat portion is provided at the outlet of the vortex chamber to form the strong vortex during small flow
- Diffuser is provided to recover the pressure drop during large flow



2.2 Principle of ACC

➢Structure of ACC

- Vortex Chamber at bottom of Accumulator Tank
- Standpipe connected to vortex chamber
- Inlet port of standpipe at the middle of Accumulator Tank
- Outlet pipe of vortex chamber connected to injection pipe



2.2 Principle of ACC

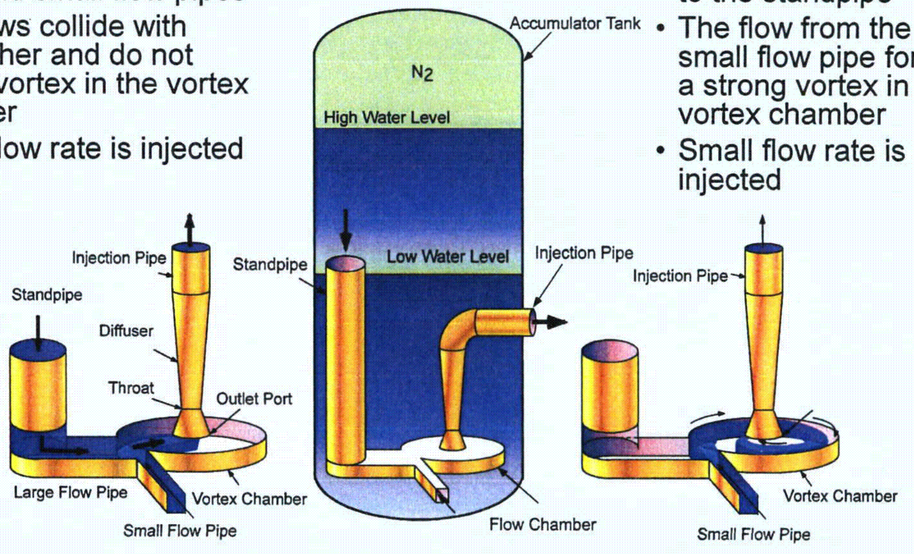
➢ Characteristics of ACC

✓**At high water level**

- Water comes into both large and small flow pipes
- The flows collide with each other and do not form a vortex in the vortex chamber
- Large flow rate is injected

✓**At low water level**

- Water stops flowing to the standpipe
- The flow from the small flow pipe forms a strong vortex in the vortex chamber
- Small flow rate is injected



(b) Large Flow Rate (RV Refilling) (a) Water Levels in Accumulator Tank (c) Small Flow Rate (Core Reflooding)

2.2 Principle of ACC

➢ Characteristics of ACC (cont.)

✓At large flow rate

- Cavitation at the throat affects flow rates
- Cavitation factor and Reynolds numbers are the key parameters to determine flow rates

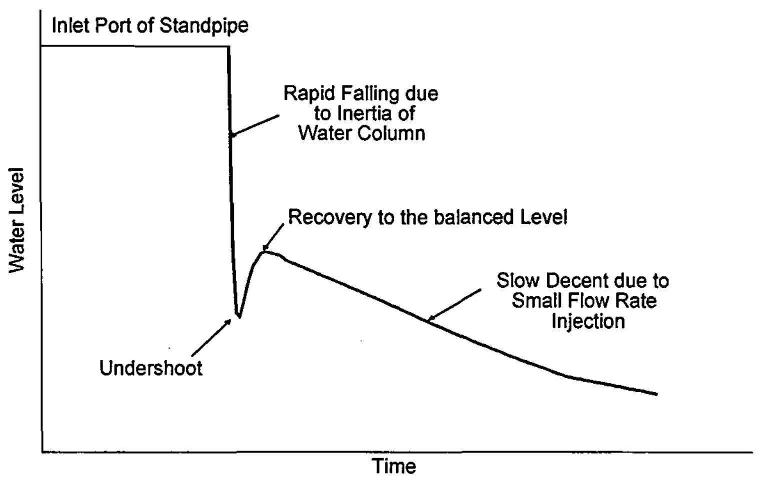
✓At small flow rate

- Strong and steady vortex flow is formed in the vortex chamber
- Large pressure drop exists along the radius of the vortex chamber

2.2 Principle of ACC

➢ Characteristics of ACC (cont.)

✓Switching flow rate



Water Level in Standpipe (schematic chart)

- Inertia of water column makes water surface undershoot below the balanced level
- Water surface recovers to the balance level

2.3 Requirements for Performance of ACC

Fundamental safety requirements

Limit the Peak Clad Temperature (PCT) under 2200°F (1200°C) during large LOCA

Function of ACC during LB LOCA

Step1: Refill the lower plenum and downcomer immediately during refilling period following reactor coolant blow down

Step2: Establish the core reflooding condition by maintaining the downcomer water level after refilling the core

Performance requirements for ACC

Requirements for large flow injection from step1 function

Requirements for small flow injection from step2 function

Assume related parameters

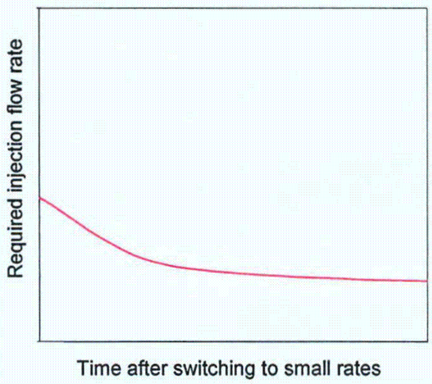
Design requirements for ACC

2.3 Requirements for Performance of ACC

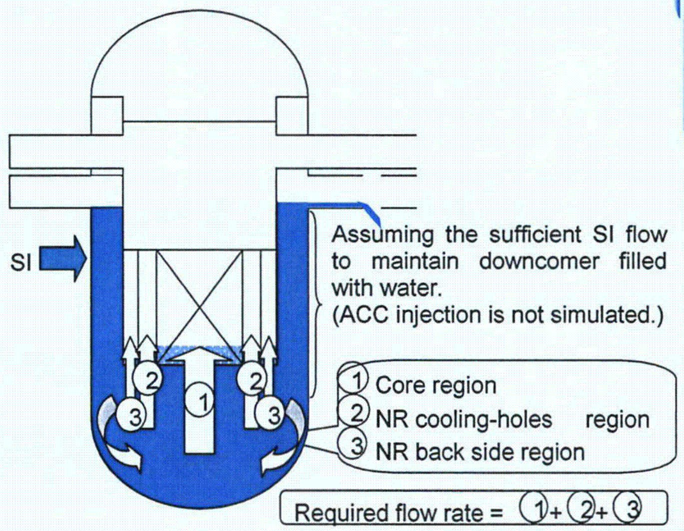
- **Performance requirements for large flow Rate (Refilling)**
  - ✓The water volume for large flow injection in ACC should cover the lower plenum and downcomer regions of reactor vessel
    - The lower plenum and the downcomer are filled with water as rapidly as possible during refilling period

2.3 Requirements for Performance of ACC

- **Performance requirements for small flow rate (Reflooding)**
  - ✓ Downcomer should be filled with ECCS water
  - ✓ Required flow rate is calculated by the hypothetical LOCA analysis by Appendix K model with Japanese decay heat model



Required ECCS injection flow rate



2.3 Requirements for Performance of ACC

- **Design requirement for large flow injection**
  - ✓ PCT depends on over all resistance coefficient of the accumulator system
  - ✓ Over all resistance coefficient is summing up resistance coefficient of flow damper resistance coefficient and pipe of injection (Flow damper :K_D, Pipe of injection line :K_P)
  - ✓ K_P depends on routing of injection line.
  - ✓ K_D was selected to achieve the target PCT under 1800°F (1000°C)
  - ✓ The design requirement for large flow injection is $\mathbf{K_D}$

2.3 Requirements for Performance of ACC

- **Expected large flow characteristics**
  - ✓ Assume major parameters
    - Water volume of large flow injection
    - Initial gas volume
    - Initial gas pressure

      Notes;

      1. Water volume satisfies performance requirements. Details are discussed in section 3.1
      2. Other parameters are set based on experience for conventional plant
  - ✓ Calculate large flow injection
    - Typical depressurization of RCS is assumed
    - Calculate flow rate of large flow injection

2.3 Requirements for Performance of ACC

- **Expected large flow characteristics (cont.)**
  - ✓ Calculation method

$$P_{gas} - P_{inj} = K \cdot \rho \frac{U^2}{2} - \rho g (H_t - H_p)$$

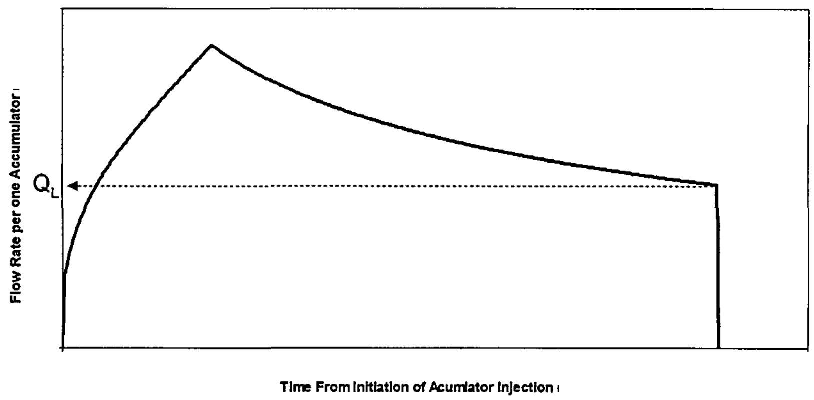
$$P_{gas} = \left(\frac{V_{gas0}}{V_{gas}} \right)^{\kappa} \cdot P_{gas0}$$

$$\frac{dV_{gas}}{dt} = A \cdot U$$

P_{gas}	: Accumulator gas pressure
P_{gas0}	: Initial accumulator gas pressure
V_{gas}	: Accumulator gas volume
V_{gas0}	: Initial accumulator gas volume
P_{inj}	: Pressure at the injection point (RCS pressure)
K	: Resistance coefficient of ACC system
H_t	: Water level elevation of ACC
H_p	: Elevation of the injection point
U	: Velocity in injection pipe
A	: Cross section inside of the injection pipe
g	: Gravity acceleration
t	: Time
ρ	: Density of water
κ	: Adiabatic exponent

2.3 Requirements for Performance of ACC

- **Expected large flow characteristics (cont.)**
  - ✓ Calculation of large flow characteristic



Expected flow rate at the end of large flow injection from the calculation results: Q_L gpm
(Resistance coefficient of ACC injection line: K_D+K_P)

2.3 Requirements for Performance of ACC

- **Design requirements for small flow injection**
  - ✓ Required small injection flow rate: Q_S
    - Required ECCS injection flow rate at flow switching
  - ✓ Large injection flow rate: Q_L
    - Expected flow rate at the end of large flow injection
  - ✓ Design requirement
    - Flow-switching ratio from large to small flows: Q_L/Q_S
    - Q_L/Q_S to achieve required small injection flow rate
    - Design requirement is set to R with margin. ($R < Q_L/Q_S$)

2.4 Expected Characteristics of ACC

➤ **Bases for calculating the injection characteristics**

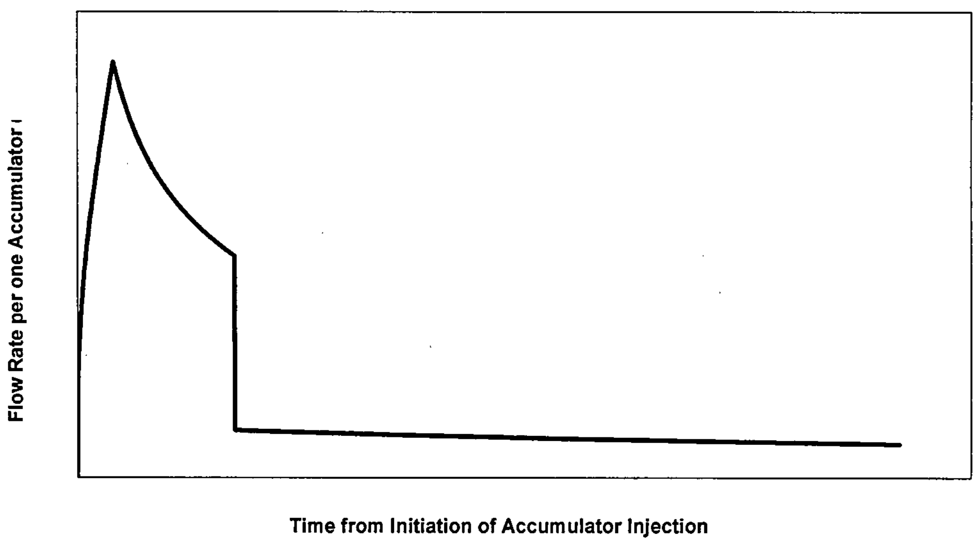
✓ Give major parameters

- Water volume of large flow injection
- Initial gas volume
- Initial gas pressure
- Resistance coefficient of flow damper in large flow injection: K_D
- Resistance coefficient of accumulator injection piping and valve expected for flow damper: K_P
- Flow-switching ratio: R

✓ Confirm the performance expected

2.4 Expected Characteristics of ACC

➤ **Calculation of expected performance**



3. Detailed Design of As-installed ACC

Contents

3.1 Design Basis and Specification of ACC

➢ Goals to perform the function

✓Refilling process (large flow injection)

- Immediately inject the water equivalent to the volume of the downcomer and lower plenum of RV to attain reflooding

✓Reflooding process (small flow injection)

- Continues injecting water following the refilling process to maintain downcomer water level
  - The duration of small flow injection is associated with Safety Injection (SI) pump capacity. The small flow injection needs to be continued until SI Pumps take over.

3.1 Design Basis and Specification of ACC

➢ Basis of volume of ACC

✓ Assumption

(a) Injection flow from the ACC on the broken cold-leg spills to containment

⬇

The number of ACC to achieve core injection is three.

(b) 1/3 of the total injection flow from the three ACCs on the intact legs spills due to the ECCS bypass phenomenon based on the previous 4 loop plant analysis.

⬇

2/3 of total ACC injection flow achieves core injection.

✓ Basis of water volume of large flow injection: V_L

$$V_L = V_R \; / \; 3^{(a)} \; / \; (2/3)^{(b)}$$

V_R: Total volume of the downcomer and the lower plenum

3.1 Design Basis and Specification of ACC

➢Basis of volume of ACC (cont.)

✓Basis of small flow injection volume

- Decide the expected duration of small flow injection reflected on Safety Injection (SI) pump capacity
- Water volume of small flow injection is decided by both the expected duration and the small flow rate of ACC

3.1 Design Basis and Specification of ACC

➢ Basis of volume of ACC (cont.)

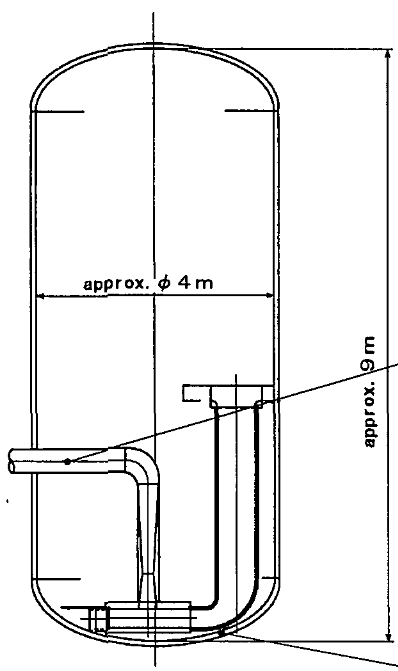
- ✓ Volume of ACC is decided by summing up following volumes
  - Water volume of large flow injection
  - Water volume of small flow injection
  - Gas space and dead water volume

Specification of ACC

Type:	Vertical cylindrical
Number:	4
Volume:	3,180 ft^3 (90 m^3)

The validity of the volume will be confirmed in ECCS analysis for the US-APWR

3.2 Structure of ACC



Outline drawing of ACC

➢ Major dimensions of ACC

- ✓ Total height approx. 30ft (9m)
- ✓ Inner diameter approx.13ft (4m)

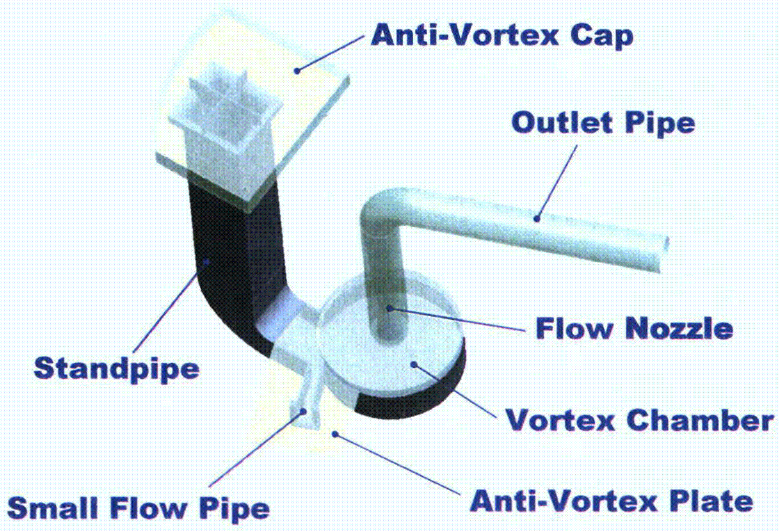
Outlet pipe ; drawn from the upper side of the flow damper

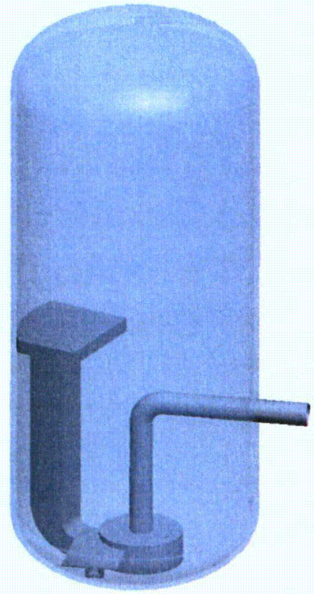
Dead water volume is less than the case of drawn out from the bottom

Flow Damper

3.3 Structure of the flow Damper

➢ Structure of the flow damper



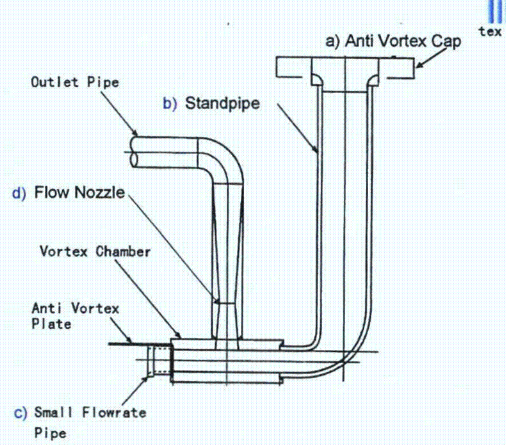


Flow Damper

3.3 Structure of the flow Damper

➢ Detailed structure of the flow damper

a)	The anti-vortex cap installed on the inlet port of the standpipe prevents the formation of a vortex and gas entrainment into the flow damper just before the flow switching to improve flow-switching characteristics
b)	The inlet of the standpipe is set at the water level for switching flow rate from large to small flows
c)	The small flow pipe is tangentially connected to the vortex chamber and designed to reduce energy loss in it
d)	The throat is provided to increase flow resistance during small flow, and the diffuser to recover pressure during large flow in the outlet pipe which is smoothly connected to the injection pipe



4. Confirmation Test Program of ACC

➢Contents

4.1 The Confirmation Tests

- The design requirements and specifications of ACC for the US-APWR that were discussed in section 2 and 3 are the same as that for the Japanese APWR
  - The core output and the size of the reactor vessel that are main parameters to determine the design requirements, and the specifications of ACC are the common to both the Japanese APWR and the US-APWR
- Therefore, the confirmation test program of ACC that had been done for the Japanese APWR is applicable to the US-APWR

4.1 The Confirmation Tests

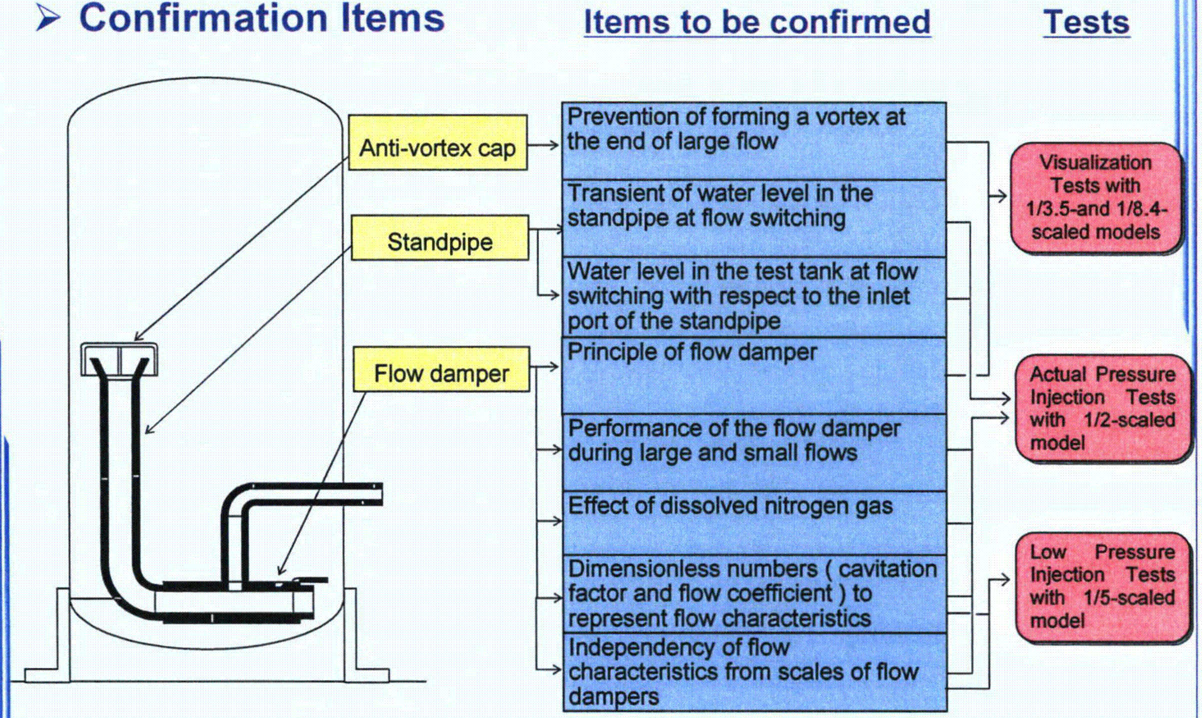
- Confirmation tests were carried out to examine whether the expected performance was achieved by the operational principle of ACC and to discuss the performance requirements.

  The test program was conducted as a joint study among five utilities* and MHI.

* Hokkaido Electric Power Co., Kansai Electric Power Co., Shikoku Electric Power Co., Kyushu Electric Power Co., and Japan Atomic Power Company.

4.1 Purpose of the Confirmation Tests

- Confirmation Items



➢ Four kinds of scale models were made

- ✓ Demonstration of switching flow (1/8.4 scale visualization tests)
- ✓ Confirmation of sharp shutoff of flow into the standpipe (1/3.5 scale visualization tests)
- ✓ Acquisition of the flow rate characteristics at low pressures (1/5 scale visualization and low pressure injection tests)
- ✓ Confirmation tests at actual plant pressures (1/2 scale actual pressure injection tests)

(1) 1/8.4 scale tests

1/8.4 scale tests

➢ Objectives

Demonstration of switching flow

- ✓ Confirmation of operational principle of the flow damper
  - Visualizing the characteristics of flows in the flow damper and the standpipe during large flow injection, flow switching from large to small, and small flow injection
  - Observing the characteristics of flow in the vortex chamber and switching flow
- ✓ Confirmation of behavior of water level in the standpipe at flow-switching
  - Visualizing behavior of water level in the standpipe at flow-switching

4.2 Detailed Description of Tests and Results

1/8.4 scale tests

➢ Test apparatus

- ✓The test apparatus consisted of an ACC model, an exhaust tank and an injection pipe
- ✓The scale of the flow damper was 1/8.4
  (The scale selected to be movable to anywhere for demonstration)
- ✓The vortex chamber was in an upright position
- ✓The front panel was made of transparent acrylic resin (standpipe and the flow damper were observed)

4.2 Detailed Description of Tests and Results

1/8.4 scale tests

➢ Test conditions

- ✓There was no special requirement for the test conditions
- ✓The following conditions were employed for simplicity
  - Pressure in the ACC was slightly lower than 0.1MPa (14psi)
  - Pressure in backpressure tank was atmospheric pressure

➢ Parameters measured during test

- ✓Flows were visualized in the ACC, the standpipe, the small flow rate pipe and the vortex chamber
- ✓Flow rate was measured and displayed on a screen
- ✓Pressure in the ACC was monitored

➢ Measuring equipment

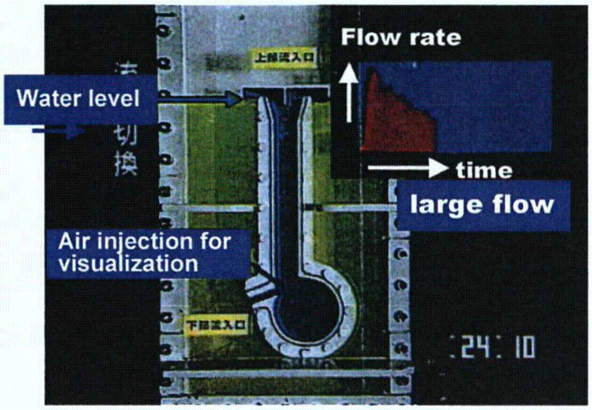
- ✓Pressure gauges
- ✓Flow meter
- ✓Flow switching was confirmed with flow rate transient on a screen

4.2 Detailed Description of Tests and Results

1/8.4 scale test

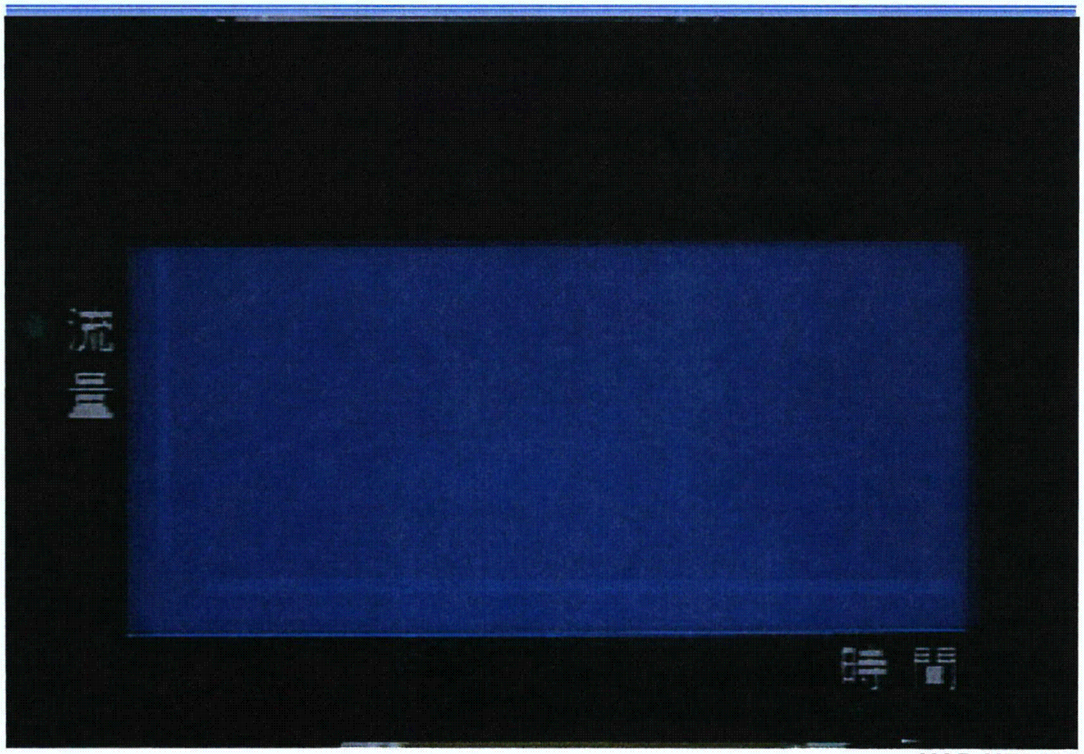
➢ Test results and discussions

✓ Characteristic of flow just before flow switching from large to small

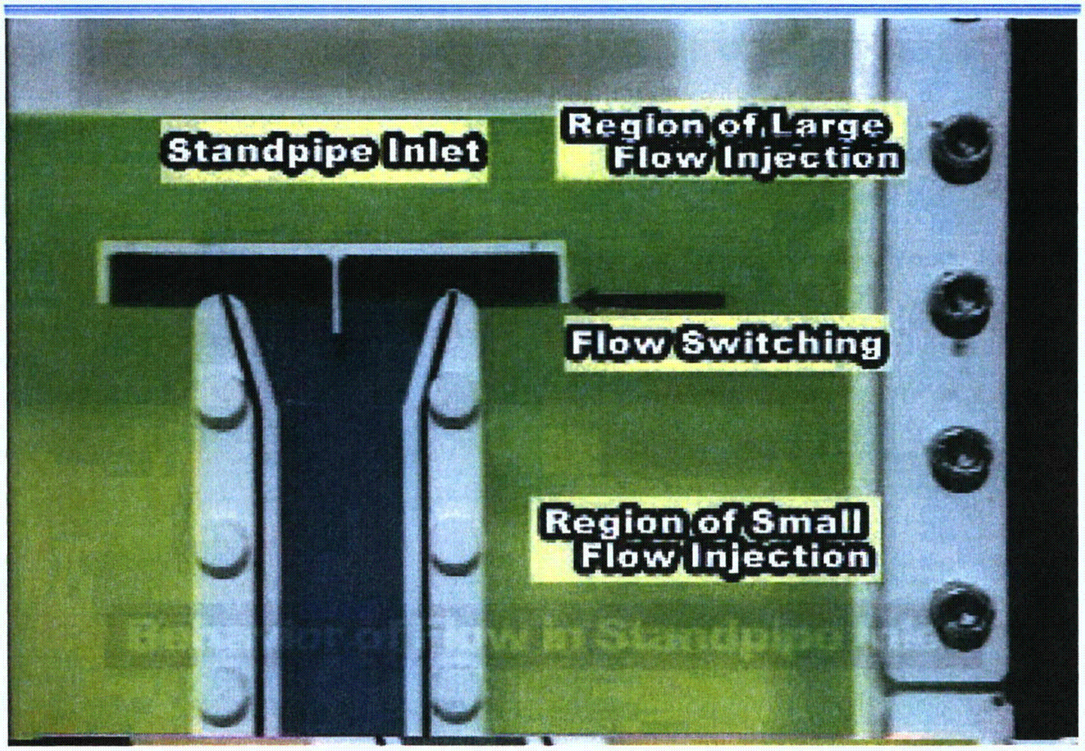


24.10 seconds after initiation of the test

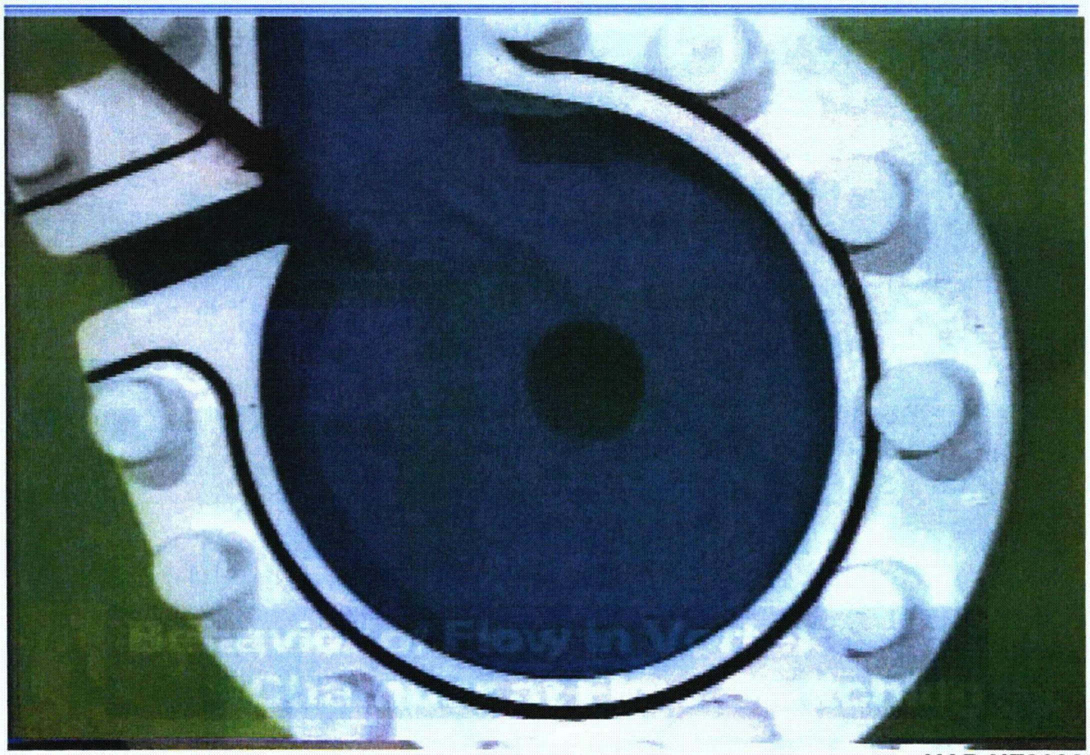
Principle of ACC



Switching Flow



Flow in Vortex Chamber



➢ Discussions and summary

1/8.4 scale tests

✓ Basic performance of the flow damper was confirmed as follows:

(1) When water level was higher than the top of the standpipe (large flow injection)

- Flows from the standpipe and the small flow pipe collided with each other in the vortex chamber and directly went to the outlet port
- Vortex was not formed in the vortex chamber
- Resistance was small and large flow rate came off

(2) When water level was lower than the top of the standpipe (small flow injection)

- Flow from the standpipe stopped and only the flow from the small pipe came into the vortex chamber
- Strong and steady vortex was formed
- Resistance was large and small flow rate came off

1/8.4 scale tests

(3) During the flow switching

- Water level in the standpipe temporarily undershot due to inertia of water column in it
- Water level recovered soon and flow in the standpipe stopped so that the water level was maintained in it
- Gas did not enter through the standpipe to the vortex chamber

1/3.5 scale tests

(2) 1/3.5 scale tests

➢ Objectives

✓Confirmation of sharp flow switching and prevention of vortex formation at the inlet port of the standpipe with an anti-vortex cap

- The ACC design utilizes the anti-vortex cap at the top of the standpipe to prevent formation of a vortex and gas entrainment during flow switching
- Without the anti-vortex cap, it was foreseen that gas entrainment affected the flow, and flow rate could not be smoothly switched

1/3.5 scale tests

➢ Test apparatus

✓The test apparatus consisted of a standpipe, a test tank, a pump and an injection pipe

✓The anti-vortex cap was made of transparent acrylic resin so as to observe the characteristics of a vortex at the inlet of the standpipe

✓The scale of the inlet port of the standpipe was 1/3.5 for easy observation

4.2 Detailed Description of Tests and Results

1/3.5 scale tests

➤ Test conditions

- ✓Froude numbers were used to simulate the flow conditions at the time of switching flow rates
- ✓Pressure in Accumulator Tank :atmospheric pressure
- ✓Anti-vortex Cap with Skirt :(1) attached and (2) not attached

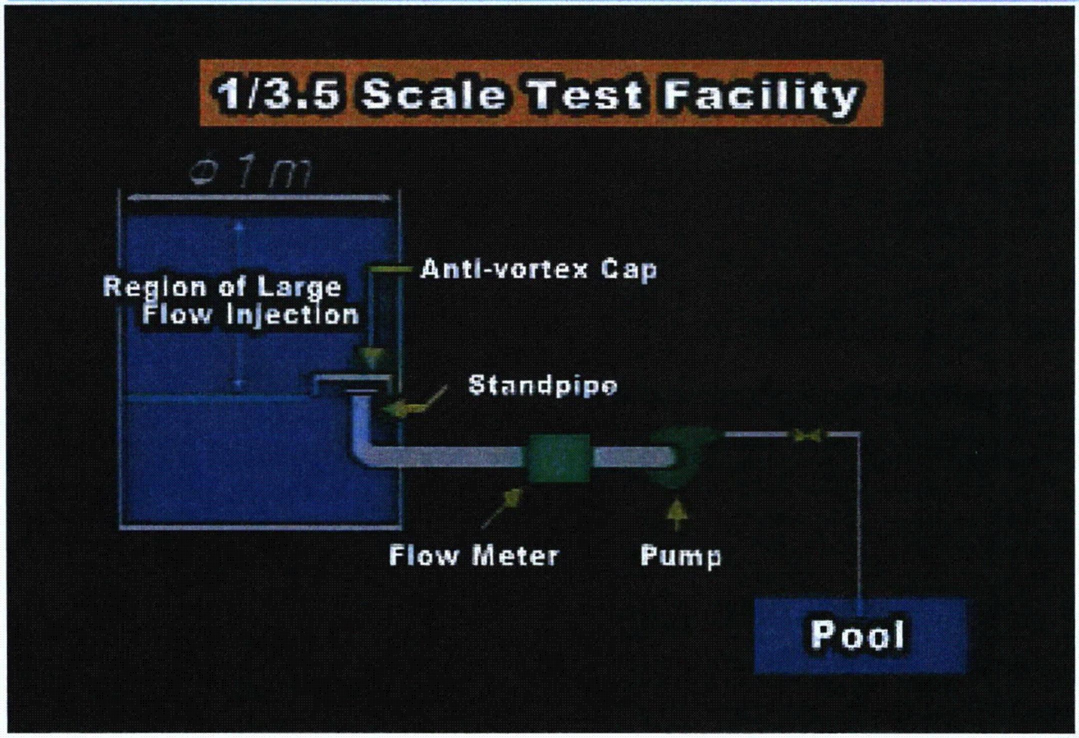
➤ Parameters measured during test

- ✓Transients of flow rate
- ✓Water level in the tank

➤ Measuring equipment

- ✓Electro-magnetic flow meter
- ✓Ruler attached on the sidewall of the tank

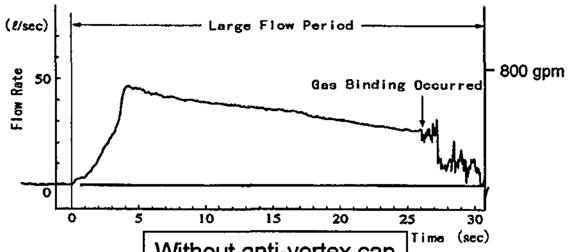
Anti-vortex cap



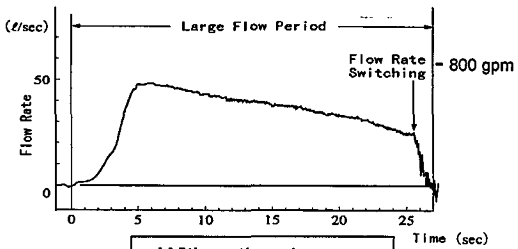
4.2 Detailed Description of Tests and Results

- Test results and discussions (Flow Characteristics)

1/3.5 scale tests



Without anti-vortex cap



With anti-vortex cap

✓Gas leakage started at 26 seconds

✓Fluctuation of flow rate was generated for several seconds

✓Took up to five seconds for flow rate to decrease to zero after the fluctuation

✓Flow rate came to zero in approx. one second from 25.5 seconds

✓Flow rate switched more quickly than that in the case without the anti-vortex cap

4.2 Detailed Description of Tests and Results

1/3.5 scale tests

➢ Discussions and summary

✓Effectiveness of the anti-vortex cap was confirmed, using 1/3.5-scaled model of the inlet port of the standpipe

- It was confirmed that the anti-vortex cap makes sharp switching of flow and prevents gas entrainment

(3) 1/5 scale tests

1/5 scale tests

➢Objectives

✓Confirmation of operational principle of flow damper

- Visualizing flow in the vortex chamber during large flow injection, flow switching from large to small and small flow injection

✓ Confirmation of performance during large and small flows

- Evaluating cavitation factor and flow rate coefficient during large and small flows
- The flow characteristics obtained by the tests were compared with the results of 1/2 scale tests to confirm the validity of applying the similarity design method.

4.2 Detailed Description of Tests and Results

1/5 scale tests

➢Test apparatus

✓The test apparatus consisted of a tank, a flow damper, a standpipe, an injection pipe and an exhaust tank

✓The flow damper with a wall made of transparent acrylic resin was installed outside of the test tank to observe the characteristics of flow in the flow damper

✓The scale of the flow damper was 1/5 so that several models could be installed and tested at pressures lower than 0.9MPa

4.2 Detailed Description of Tests and Results

➢ Test method

1/5 scale tests

✓ **For visualization**

- The flow in the chamber was recorded using a video camera and observed

✓ **For acquisition of flow rate characterisitcs**

- Pressures in the test tank, the injection pipe and the exhaust tank, and water levels in the test tank and the standpipe were measured and recorded by PC, then flow rate coefficient and a cavitation factor were calculated

➢ Parameters measured during test

✓ Water level, pressure and temperature in Test Tank

✓ Water level in Stand Pipe

✓ Pressure in Injection Pipe

✓ Flow in Vortex Chamber was observed and recorded

➢ Measuring equipment

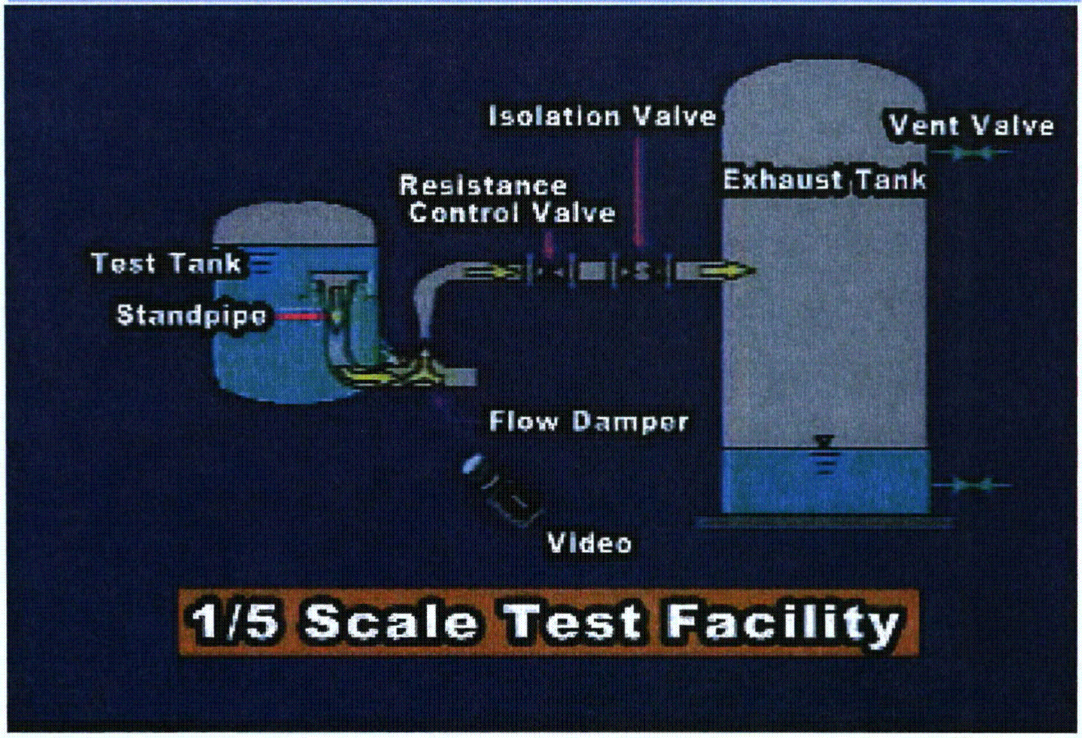
✓ Level gauges*

✓ Pressure gauges

✓ Thermocouples

*Flow rate was calculated from water level in the test tank

Low pressure tests

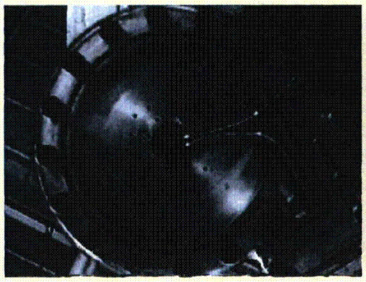


4.2 Detailed Description of Tests and Results

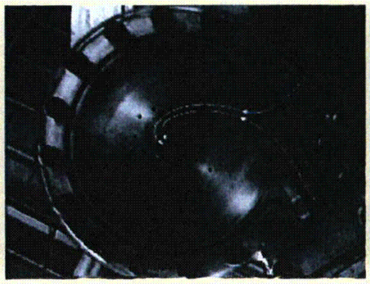
➢ Results of visualization test

1/5 scale test

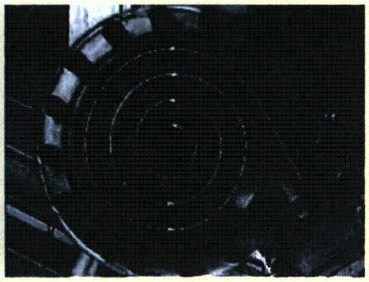
Large Flow



Flow Switching



Small Flow



Large Flow
- Both large and small flows collided with each other in the chamber
- The resultant combined flow went straight to the outlet port

Flow Switching
- It showed transient from large to small flows
- Vortex promptly began to form

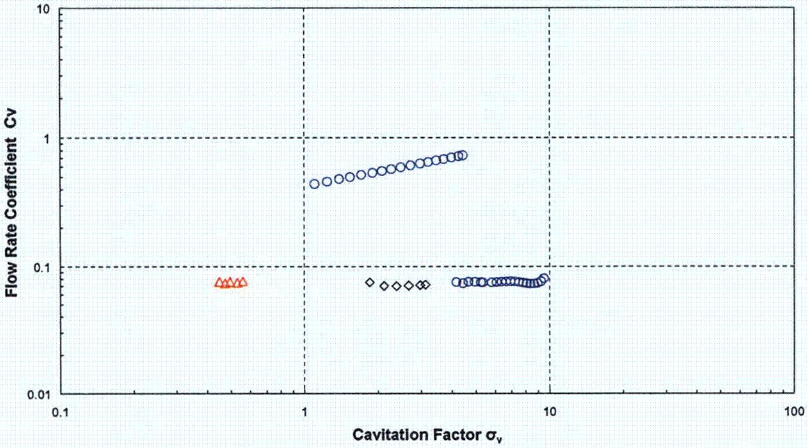
Small Flow
- Small flow tangentially entered in the chamber
- Strong and steady vortex formed in the chamber

4.2 Detailed Description of Tests and Results

➢ Test results of flow characteristics

1/5 scale tests

✓Data can be characterized by dimensionless numbers



A flow rate coefficient and a cavitation factor are defined as follows;

$$C_v = \frac{1}{\sqrt{K_D}}$$

$$K_D = \frac{(P_A + \rho g H) - \left(P_D + \frac{\rho V_D^2}{2} + \rho g H'\right)}{\frac{\rho V_D^2}{2}}$$

$$\sigma = \frac{P_D + P_{at} - P_v}{(P_A + \rho g H) - \left(P_D + \frac{\rho V_D^2}{2} + \rho g H'\right)}$$

K_D :Resistance coefficient of flow damper
P_A :Test tank pressure (Pa)
ρ :Density of water (kg/m3)
G :Acceleration of gravity (m/sec2)
H :Distance between water surface and center of flow damper (m)
H' :Distance between centers of chamber and measuring point P_D (m)
P_{at} :Atmospheric pressure (Pa)
P_v :Vapor pressure of water (Pa)
P_D :Static pressure in injection pipe (Pa)
V_D :Velocity in injection pipe (m/sec)
σ_v :Cavitation factor

4.2 Detailed Description of Tests and Results

1/5 scale tests

➢ Discussions and summary

✓ Confirmation of the principle of the flow damper

- During large flow injection
  - A vortex was not formed in the vortex chamber
- During flow switching from large to small
  - A flow to the outlet port formed a vortex in approx. one second after the start of flow switching
  - It was also confirmed that the flow rate smoothly switched in a short time
- During small flow injection
  - Swirling flow quickly traveled to the outlet port, and a strong and steady vortex was formed in the chamber

4.2 Detailed Description of Tests and Results

1/5 scale tests

➢ Discussions and summary (cont.)

✓ Confirmation of performance

- The data can be characterized by the dimensionless numbers (flow rate coefficient and cavitation factor)
- The experimental data of flow-switching ratio met the design requirement
- The characteristic curve of small flow injection showed that a flow rate coefficient was independent of a cavitation factor

4.2 Detailed Description of Tests and Results

(4) 1/2 scale tests

1/2 scale tests

➢ **Objectives**

✓ Confirmation of expected performance

- Resistance coefficient of the flow damper at large flow injection
- Flow-rate ratio at flow-switching from large to small

✓ Confirmation of the flow characteristics

- The flow rates obtained by the tests were characterized by the dimensionless numbers (flow rate coefficient and cavitation factor)

✓ Confirmation of the water level when switching flow

✓ Evaluation of the effect of dissolved nitrogen gas

- Conducting tests to evaluate the effect of dissolved gas under water

4.2 Detailed Description of Tests and Results

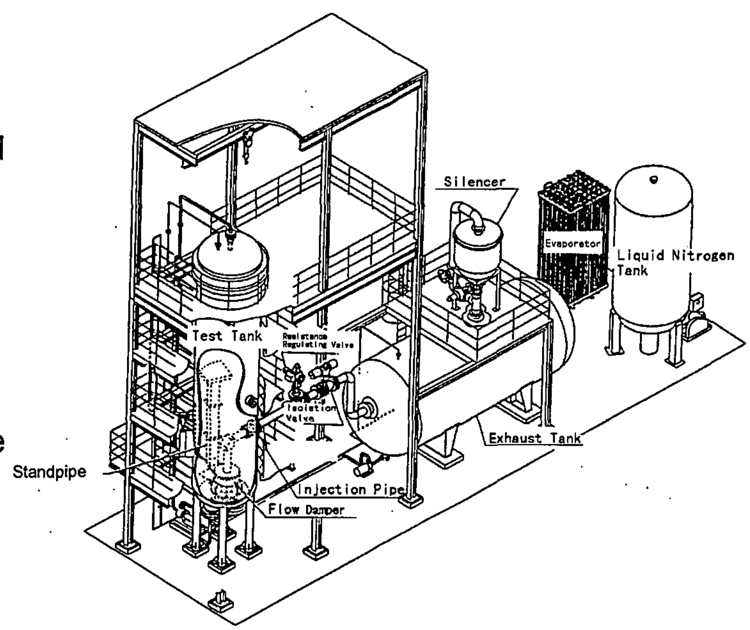
1/2 scale tests

➢ Test facility

✓ The test facility consisted of a test tank, a flow damper, an injection pipe and an exhaust tank

✓ Heights of the test tank and the standpipe were the full scales

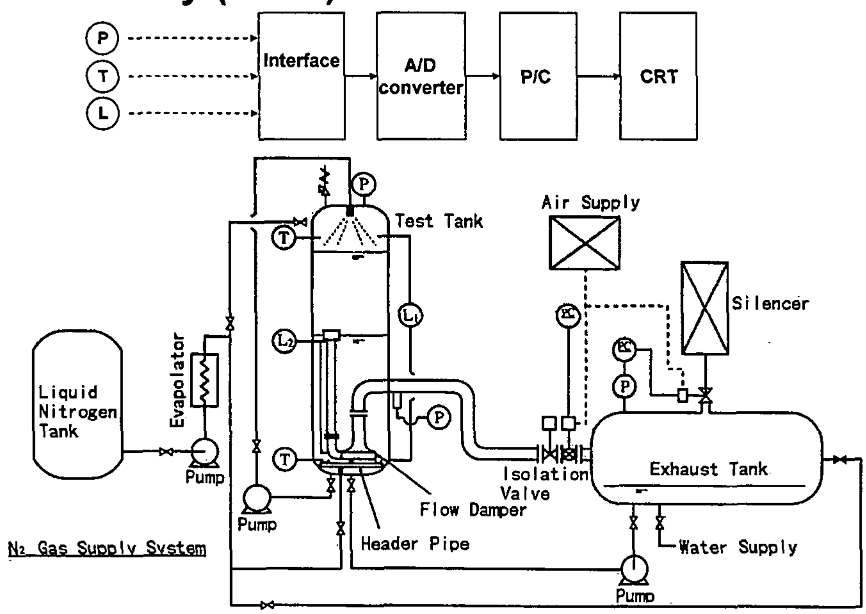
✓ The diameters of the test tank and the flow damper were 1/2 scales



4.2 Detailed Description of Tests and Results

1/2 scale tests

➢ Test facility (cont.)



Outline of the Test Facility

4.2 Detailed Description of Tests and Results

1/2 scale tests

➢ Test conditions for main cases

Test case	**Test Tank pressure** MPa (psi)	**Exhaust Tank pressure** MPa (psi)	**Objective**
Case1	4.04 (586)	0.098 (14)	Obtain data for ECCS performance evaluation during large LOCA
Case2	4.53 (657)	0.098 (14)	Obtain data for high pressure design
Case3	5.22 (758)	0.098 (14)	Obtain data for high pressure design
Case4	4.04 (586)	0.49 (71)	Obtain data for high backpressure

4.2 Detailed Description of Tests and Results

1/2 scale tests

➢ **Test conditions (cont.)**

✓ Resistance Coefficient of Injection Pipe : actual plant value

✓ Initial Water Level in Accumulator Tank : actual operating level

✓ Opening Time of Valve : Set as short as possible to get data at small cavitation factors

➢ **Parameters measured during test**

✓ Water level, pressure and temperatures in test tank

✓ Water level in standpipe

✓ Pressures in injection pipe and exhaust tank

➢ **Measuring equipment**

✓ Level gauges*

✓ Pressure gauges

✓ Thermocouples

*Flow rate was calculated from water level in the test tank

Construction of 1/2-scale model

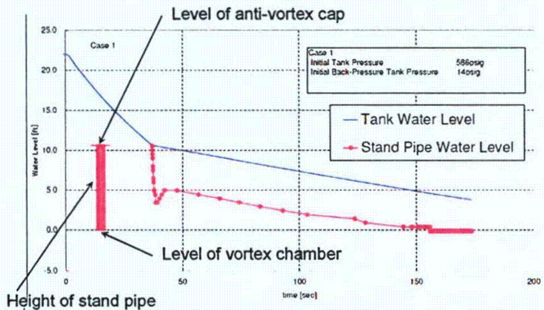
4.2 Detailed Description of Tests and Results

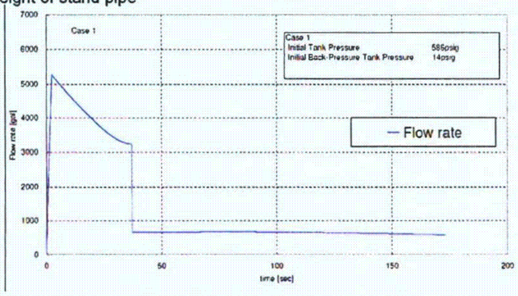
➢Test result of Case1

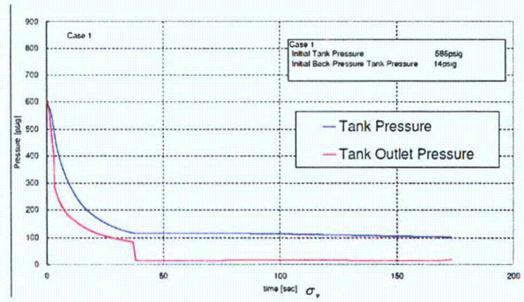
1/2 scale tests

(Initial Tank Pressure: 586psig , Initial Back-Pressure: 14psig)

✓ Water level was maintained in stand pipe at the flow switching
✓Flow rate sharply switched with water level at the top of stand pipe







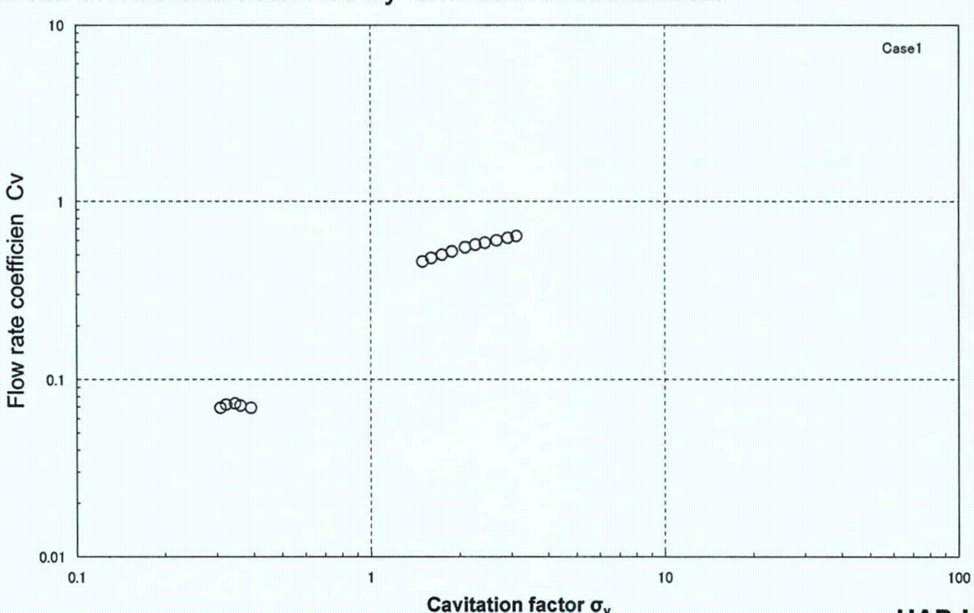
4.2 Detailed Description of Tests and Results

➢Test result of Case1 (cont.)

1/2 scale tests

(Initial Tank Pressure: 586psig , Initial Back-Pressure: 14psig)

✓Data can be characterized by dimensionless numbers

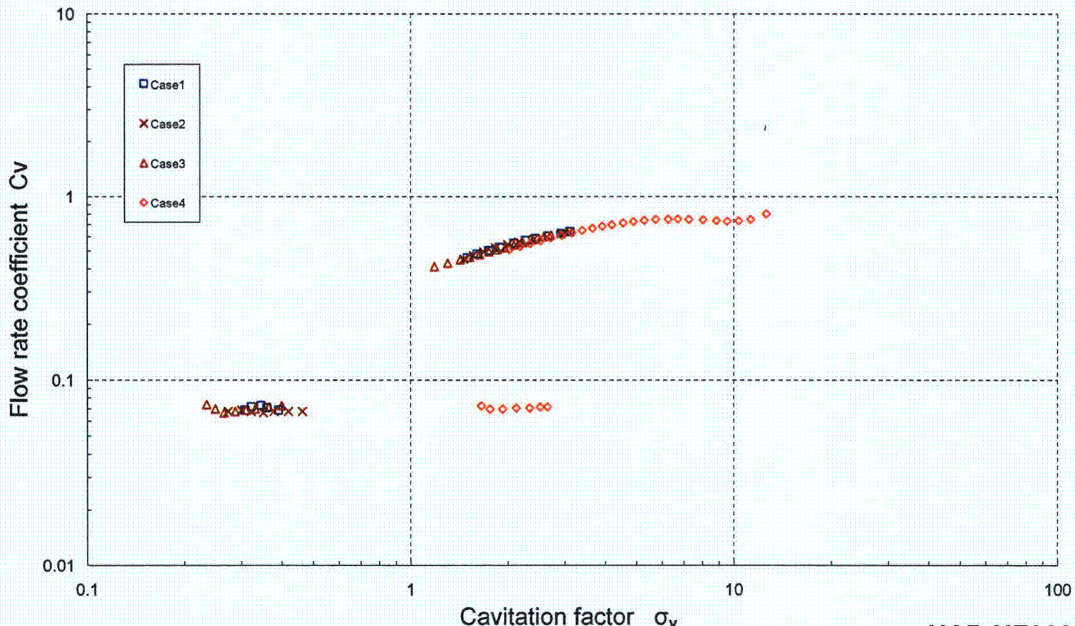


4.2 Detailed Description of Tests and Results

1/2 scale tests

➢Test result (cont.)

✓Data can be characterized by dimensionless numbers in common with cases 1 to 4



4.2 Detailed Description of Tests and Results

1/2 scale tests

Discussions and summary

➢ **Performance confirmation during large flow**

- ✓In case of LOCA condition, resistance coefficients met the design requirement
- ✓The results satisfied the performance goal

➢ **Performance confirmation during small flow (flow switching ratio)**

- ✓The flow-switching ratios met the design requirement
- ✓The results satisfied the performance goal

4.2 Detailed Description of Tests and Results

1/2 scale tests

Discussions and summary (cont.)

- **Water level when switching flow**
  - ✓It was confirmed that flow rate was switched at the expected water level
  - ✓Variation of water level of flow-switching was limited to a sufficiently small range

- **Undershoot of water level when switching flow**
  - ✓The undershoot of water level during the flow switching in each test was shorter than the height of the standpipe and sufficient margins were maintained to prevent gas entrainment

4.3 Scalability and Validity of Flow Rate Characteristics

- Dimensionless parameters
  - ✓ Navier-Stokes equation gives ;
    - Reynolds number that evaluates the effect of fluid viscosity
    - Froude number that evaluates the effect of gravity to free surface
  - ✓ Cavitation gives ;
    - Cavitation factor that evaluates the effect of generation of bubbles

- **A Reynolds number and a cavitation factor may affect flow rate characteristics of flow dampers**

- **A Froude number determines the time scale of transients of water levels in the accumulator tank and the standpipe**

4.3 Scalability and Validity of Flow Rate Characteristics

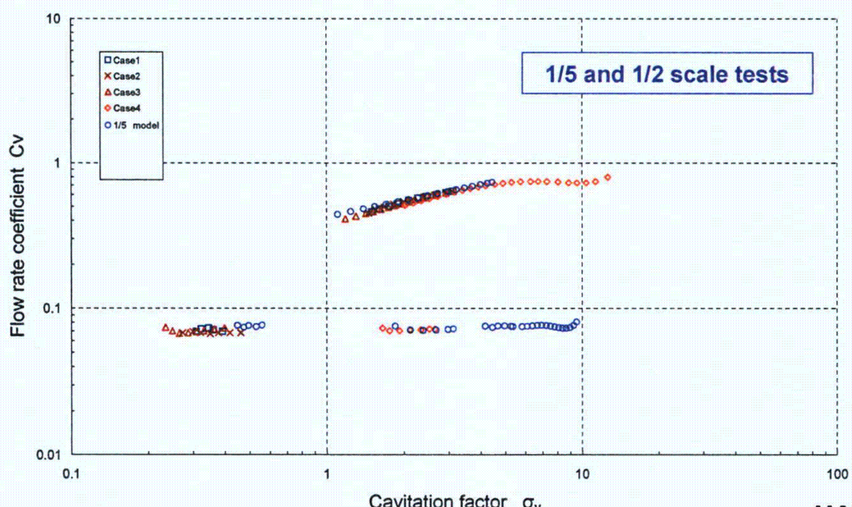
- **Reynolds numbers**
  - ✓ Actual plant : Re > 10^6
  - ✓ 1/2-scaled Model : Re > 10^6
  - ✓ 1/5-scaled Model : Re= 10^5 to 10^6

  Reynolds numbers were calculated with respect to the quantities at the throat

- **Cavitation factor**
  - ✓ Cavitation factors are common for the actual plant and the scale models

4.3 Scalability and Validity of Flow Rate Characteristics

- **Scalability**
  - ✓ Flow rate coefficients with respect to cavitation factors collapsed into two lines for large and small flow rates of both the 1/5- and 1/2-scaled models separately
  - ✓ Hence, the effect of Reynolds numbers, or friction, is negligible
  - ✓ Consequently, the measured flow rate coefficient can be applicable to the actual plant as a function of a cavitation number



4.3 Scalability and Validity of Flow Rate Characteristics

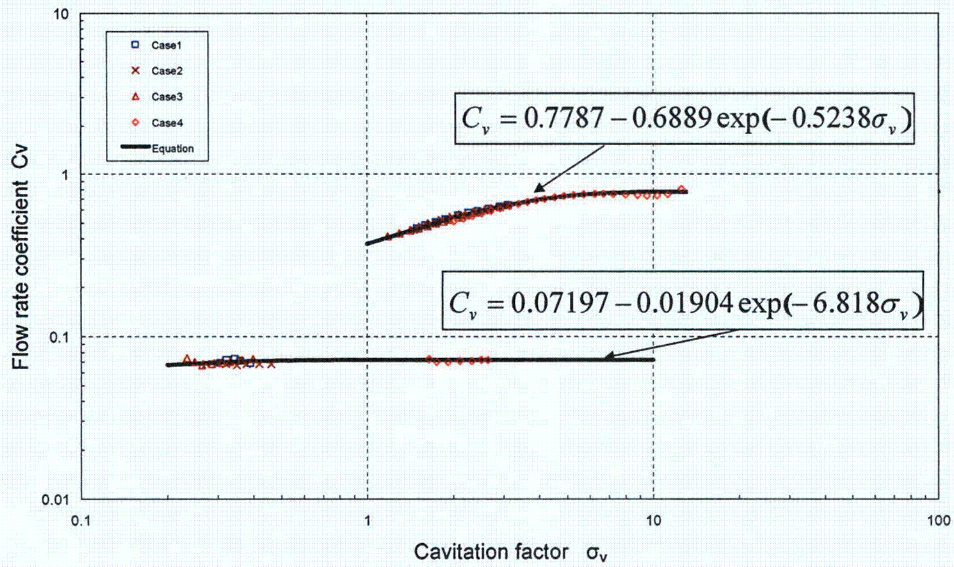
- **Validity of data for large flow injection**
  - ✓ Flow rate coefficient lessens as a cavitation factor gets smaller
    - It is reasonable because cavitation is stronger for a smaller cavitation factor
  - ✓ Flow rate coefficient approaches a constant value as a cavitation factor gets larger
    - It is reasonable because cavitation vanishes for a large cavitation factor
- **Validity of data for small flow injection**
  - ✓ Flow rate coefficient is independent of a cavitation factor
    - It is reasonable because flow rate is small, and the pressure at the throat is almost same as that in the exhaust tank which is larger than the vapor pressure

5. Concept and Justification of Safety Analysis Model

Contents

5.1 Characteristic Equations of Flow Rate for Safety Analysis

- Experimental formulae were derived separately for large and small flow rate injections by curve fitting using the data of 1/2-scale tests



5.2 Uncertainty of Characteristics Equations

- Estimation of uncertainty
  - ✓ Data of 1/2-scaled model were used to make the characteristic equations
  - ✓ Estimation of uncertainty was carried out in accordance with the Japanese version of "Measurement Uncertainty," Supplement on Instruments and Apparatus, Part 1, ASME Performance Test Codes, (ANSI/ASME PTC 19.1-1985) translated and printed by JSME, 1987
- Causes of uncertainty
  - ✓ Experimental errors
  - ✓ Instrumental errors
  - ✓ Manufacturing errors

5.3 Errors of Water Level for Switching Flow Rate

➢ Errors of switching level

- ✓ Displacement of water level at switching of flow rates from the elevation of the inlet port of the standpipe
- ✓ Water level at switching of flow rates was defined as an intersecting point of two curves of water levels for large and small flow injections

5.4 ACC Simulation Method for Safety Analysis

➢ Simulation Model

- ✓ Resistance coefficient K_D is calculated using the correlation between σ_v and C_v
- ✓ Correlation is incorporated into the LOCA analysis code and K_D is calculated at each time-step based on ACC water level

➢ Computational procedure for K_D

1) is calculated from the flow condition at flow damper

$$\sigma_v = \frac{P_D + P_{at} - P_v}{(P_g - P_D) - \frac{\rho V_D^2}{2} + \rho g H}$$

σ_v	:	Cavitation factor
P_{at}	:	Atmospheric pressure
P_D	:	Flow damper outlet pressure
P_g	:	Holding Gas pressure in accumulator
P_v	:	Vapor pressure
ρ	:	Density of water
g	:	Acceleration of gravity
H	:	Water level in accumulator from injection pipe
V_D	:	Velocity in injection pipe

5.4 ACC Simulation Method for Safety Analysis

➢Computational procedure for K_D (Cont.)

2) C_v is calculated using the following correlations :

For Large Flow-Rate: $C_v = 0.7787 - 0.6889\exp(-0.5238\sigma_v)$

For Small Flow-Rate: $C_v = 0.07197 - 0.01904\exp(-6.818\sigma_v)$

3) C_v is converted to K_D

$$K_D = 1/C_v^2$$

4) Total resistance coefficient is calculated by ;

$$K_{acc} = K_D + K_{pipe}$$

K_{acc} : Total resistance coefficient of accumulator and injection pipe

K_{pipe} : Total resistance coefficient of injection pipe

Note; Uncertainty of characteristics equations is considered to evaluate fuel cladding temperature conservatively in LOCA analysis

5.4 ACC Simulation Method for Safety Analysis

- For the US-APWR calculation, WCOBRA/TRAC with ASTRUM methodology which was approved by the NRC will be used for the large break LOCA analysis

- The empirical correlation discussed above will be incorporated to WCOBRA/TRAC code to model the advanced accumulator characteristics

6. Summary

- The Advanced Accumulator design has been validated by the four kinds of tests
- These tests and evaluations have demonstrated that the results of ACC testing are scalable
- The test data taken in these experiments covered the range of the expected applicability of the system installed in the US-APWR under design basis LOCA conditions

6. Summary

- The tests investigated the features of ACC, and demonstrated satisfactory performance of this component in accordance with its design
- Empirical flow coefficients developed from these test results are applicable for the US-APWR
- MHI will submit the topical report of ACC in January 2007