US-APWR

Reactor Vessel Lower Plenum 1/7 Scale Model Flow Test Plan

Non-proprietary Version

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1. INTRODUCTION

MHI is currently planning to carry out an experiment associated with the reactor internals for the US-APWR in order to confirm the characteristics related to the lower plenum design configurations. It is believed that this test will not change the design significantly, and conclusively, it is not planned to use and refer the outcome of the new test to the Design Control Document for the US-APWR.

To response to the NRC's interest in the test, an outline of the test plan has been submitted to NRC (MHI Ref.: UAP-HF-07040) and the NRC's staffs are invited to observe the test in the near future. Corresponding to the NRC's request for additional information regarding the test plan, this document presents more details of the plan for the US-APWR reactor vessel lower plenum 1/7 model flow test.

2. TEST PURPOSE

The US-APWR reactor internals are designed for the core with 14 ft -257 fuel assemblies. Although the design of an integrated lower core support system exists as a standard design of 14 ft core reactor for Westinghouse 3XL/4XL, there is no operating experience with the 257 fuel assemblies. The elimination of the core instrumentation system from the bottom region of the vessel simplifies the structures of the vessel lower plenum.

The purpose of this test is to confirm the following characteristics related to the lower plenum design configuration of the US-APWR.

(1) Hydraulic characteristics
- Core inlet flow distribution
- Inlet flow distribution for cooling the Neutron Reflector (NR)
- Pressure loss of the vessel down-comer, lower plenum and lower core support plate

(2) Flow-induced vibration (FIV) of the structures in the lower plenum

(3) Core inlet temperature distribution with a non-uniform coolant condition between primary loops

3. TEST EQUIPMENT

3.1 Test Loop

- The region of the US-APWR to be simulated in the test model is identified in Figure 3-1.
- Four sets of Inlet pipes simulating 4 loops of the US-APWR are included in the test loop as shown in Figure 3-2.

3.2 Model of Vessel and Internals

- Vessel and lower internals are simulated in 1/7 scale as shown in Figure 3-3. Comparison of dimensions between the actual plant and the test model are shown in Table 3-1.
- Lower head of the vessel is made of acrylic resin to provide visualization of the flow.
- Test vessel is set in up-side down to easy access to lower plenum region. This reversal condition makes no affect on flow simulation because the flow inside a PWR reactor is the forced convective flow and there is no free surface, then the effect of gravity can be neglected.

4. TEST CONDITIONS

4.1 Flow Condition

- The test will be conducted at room temperature.
- Flow rate for the hydraulic testing will be determined to simulate the dynamic pressures or pressure loss of the US-APWR.
- Flow rate for the flow-induced vibration tests will be set to maintain the reduced velocity (U/ fn D) [1] simulating the flow-induced vibration response of the US-APWR.
- Comparison of the coolant flow parameters between the actual US-APWR plant and the tests is summarized in Table 4-1.

4.2 Scaling Rule

- In the selection of the scale size of the model and temperature condition, a non-dimensional analysis has been performed. One of the requirements to simulate the hydraulic phenomena is to assure that the Reynolds number (Re) is larger than 1×10^4 that maintains the developed turbulent flow condition. An additional key parameter in the simulation of flow-Induced vibration response is the reduced velocity (U/fn D)[1].
- The results of the non-dimensional analysis are summarized in Table 4-2. It is concluded that the 1/7 scale model to be tested under room temperature will be sufficient to maintain the turbulent flow condition and to accurately simulate the flow-induced vibrations.
- Scaling effects on the measuring parameters are summarized in Table 4-3.

5. MEASURMENT APPROACH

5.1 Hydraulic Test

- Measurement system for the hydraulic characteristics is shown in Figure 5-1.
- Types and locations of the sensors used for the hydraulic test are summarized in Table 5-1.
- Core and NR inlet flow distribution will be measured using venturi flow meters

(hereafter called as venturi). The venturi is depicted in Figure 5-2. The locations of venturies are identified in Figure 5-3.

- Pressure loss of the vessel down-comer, the lower plenum and the Lower Core Support Plate (LCSP) will be measured by static pressure taps as presented in Figure 5-4.

5.2 Flow-Induced Vibration Test

- A block diagram of flow-induced vibration measurement is shown in Figure 5-5.
- Types and locations of the sensors used for flow-induced vibration measurement are summarized in Table 5-2.
- Vibrations of the diffuser plates will be detected using accelerometers as shown in Figure 5-6.
- Stress fluctuations on the support columns will be measured using strain gauges as presented in Figure 5-6.
- Pressure fluctuations will be monitored by pressure transducers as shown in Figure 5-4.

5.3 Core Inlet Temperature Distribution Test

- Temperature distributions at the core inlet will be measured by thermo couples.
- Allocation and the number of thermo couples are summarized in Table 5-3. And the address mapping of the measuring positions in the core inlet is shown in Figure 5-7.

6. TEST PROCEDURE AND EVALUATIONS

The test matrix is shown in Table 6-1. The procedure of each test including the evaluation process is as follows.

6.1 Hydraulic Test

(1) Calibration and validation check

a. Prior to the installation

The coefficient of dischange for each venturi will be determined by the calibration test prior to the installation of the venturies in the test vessel.

b. Daily check of sensor validation

As a daily procedure, in each testing day, after the last test, an additional test with the first testing conditions will be conducted to confirm the validity of the sensors by examining the results between the first test and the repetitive test. The procedure is presented in Figure 6-1.

(2) Test without diffuser plates

The 1st test will be performed without the diffuser plate assemblies. The orifice sizes of LCSP flow holes are identical. Basic flow behaviors in lower plenum without the diffuser plate will be observed by the Particle Image Velocimetry (PIV) method. Pressure loss and core inlet flow distributions will be also measured to be a reference data for the successive tests.

(3) Test with diffuser plates

The 2nd test will be conducted with the diffuser plates in the lower plenum. The orifice sizes of LCSP flow holes are still same. The same kinds of measurements as those of the above test (2) including flow visualization observation will be obtained to confirm the effect of diffuser plates on the pressure loss and the core inlet flow distributions.

(4) Test with optimized LCSP flow hole

The 3rd test will be carried out with the diffuser plates and LCSP flow holes with optimized orifice distribution. In the optimized design, the flow holes in the peripheral region have larger orifices than those of the inner region because the pressure of the peripheral region is relatively lower in the lower plenum due to the effect of down-comer flow. The core inlet flow distribution and pressure loss with the optimized orifices will be confirmed in this test.

6.2 Flow-Induced Vibration Test

(1) Calibration and validation check

Relation between static loads on the diffuser plates and strains of the columns will be measured before testing. Validation of the sensors will be confirmed in each testing day in the manner as shown in Figure 6-1.

(2) Tapping test

Natural frequencies and vibration modes of the diffuser plate assemblies will be measured by tapping tests. Tapping tests will be performed both in air and in water to confirm the effect of hydraulic dynamic mass effect.

(3) Flow-Induced vibration

a. Check for Abnormal Vibrations

Relations of flow rates and rms values of vibration response (dynamic strains of the diffuser plate support columns) in log-log scale will be produced to confirm no abnormal vibration like a resonance with vortex shedding or fluid elastic instability.

b. High cycle fatigue evaluation

High cycle fatigue due to the flow induced vibration of the diffuser plate support columns will be evaluated from the measured strain amplitude. It will be confirmed that the fluctuating stress does not exceed the limit for 10^{11} cycles on the ASME design fatigue curve.

6.3 Core Inlet Temperature Distribution Test

(1) Calibration and daily check of thermo couples

Each thermo couple will be calibrated before the installation. Data deviations of all thermo couples will be examined in the calibration test before and after the testing to assure the sensors' reliability.

(2) Measurement of temperature distribution at core inlet

To simulate a non-uniform coolant condition between the primary loops, hotter fluid will be supplied to one of the loops, while other loops have fluid with room temperature. Time-averaged temperature distribution at the core inlet will be evaluated by the thermo couples.

7. QUALITY ASSURANCE PROGRAM

This test will be performed under the quality assurance program of Takasago R&D Center that satisfies 10 C.F.R. Part50 Appendix-B and is approved by Nuclear Energy Systems Quality and Safety Management Department of MHI.

8. SCHEDULE

The currently planned schedule of the test is summarized in Table 8-1.

9. REFERENCE

(1) Robert D. Blevins, "Flow-Induced vibration, "VAN NOSTRAND REINHOLD COMPANY, 1977, 2.2.2 Reduced velocity, Dimensionless Amplitude

Table 3-1 Test Model Dimensions

	Actual Plant	Test Model	Scale Ratio
Inlet loop diameter			1/7
Distance from Inlet nozzle center to core barrel bottom			1/7
Vessel inside diameter			1/7
Core barrel outer diameter			1/7
LCSP flow holes for F/A **Numbers** **Diameter**			 1/7
Diffuser plate assembly support columns **Numbers** **Diameter**			 1/7

Table 4-1 Coolant Flow Parameters

	Actual Plant	Hydraulic Test	FIV Test
Temperature	550.6 deg. F (288 deg. C)	Room temp	Room temp
Pressure	2,250psig (15.5 MPa)		
Density	46.8lb/ft^3 (750kg/m^3)		
Nominal Loop Flow Rate	TDF 112,000gpm (25,400 m^3/h)		

∗: Correction of fluid mass density ratio to maintain the dynamic pressure level.

Table 4-2 Related Non-dimensional Parameters for Scaling

	Related Non-dimensional Parameter	Test Requirement	Actual Plant (Approximately)	Test Condition (Approximately)	Test Adequacy
Hydraulic Test	$Re=UD/\nu$ *	$Re >>10^4$ (Highly developed turbulence)			Adequate
Flow-Induced Vibration	$Ur = U/ fn\, D$ *	Ur model =Ur plant			Adequate

*: D is typical length or diameter of the diffuser plate support column in this case.

Table 4-3 Scaling Rule for Measuring Parameters
(Scale= 1/N, Flow velocity is maintained)

	Dimension Analysis	General Scale Effect	Ratio in This Test
Length	L	1/N	1/7
Mass	M	$1/N^3$	1/343
Time	T	1/N	1/7
Area	L^2	$1/N^2$	1/49
Volume	L^3	$1/N^3$	1/343
Velocity U	LT^{-1}	1/1	1/1
Dynamic Pressure &Pressure Loss	$ML^{-1}T^{-2}$	1/1	1/1
Hydraulic Force	MLT^{-2}	$1/N^2$	1/49
Stress	$ML^{-1}T^{-2}$	1/1	1/1
Strain	1	1/1	1/1
Natural Frequency: fn	T^{-1}	N	7
Displacement	L	1/N	1/7
Acceleration	LT^{-2}	N	7

Table 5-1 Measurement Items for Hydraulic Test

Measurement Items	Sensor Type	Locations	Number of Sensors
Core Inlet Flow Distributions	Venturi (Figure 5-2)	Figure 5-3	
N/R Inlet Flow Distributions	Venturi	Figure 5-3	
Pressure Loss	Static Pressure Taps	(Figure 5-4)	

Table 5-2 Measurement Items for Flow-Induced Vibration Test

Measurement Items	Measuring Parts	Sensor Location (Angle)	Sensing Direction	Sensor ID	Number of Sensors
Strain					
Acceleration					
Pressure Fluctuation					

LCSP : Lower Core Support Plate

Table 5-3 Measurement Items for Core inlet Temperature Distribution Test

Measurement Items	Sensor Type	Locations	Number of Sensors
Core Inlet Temperature Distributions	Thermo Couples		
Inlet Loop Temperature	Thermo Couples		

Table 6-1 Test Conditions

ID	Structures in Lower Plenum	LCSP Flow Hole Orifice	Loop Flow Rate	HYDRAULIC			FIV	TEMP
				PIV	Inlet Flow Distribution	Pressure Loss	Acc. strain	

Table 8-1 Schedule of Reactor Vessel Lower Plenum (1/7 Scale Model Flow Test)

Year	2007									2008		
Month	4	5	6	7	8	9	10	11	12	1	2	3
Test Plan (2006/9-10)												
Equipment Design (2006/11-2007/4)												
Existing test facility inspection and maintenance Manufacturing & Setting												
Hydraulic Test -Measurement System Set up -Test without Diffuser Plates -Test with Diffuser Plates -Core Inlet Flow Holes Optimization												
FIV Test -Measurement System Set Up -Test												
Core Inlet Temp. Distribution Test -Measurement System Set Up -Test												

Original schedule planned in April

Updated Schedule

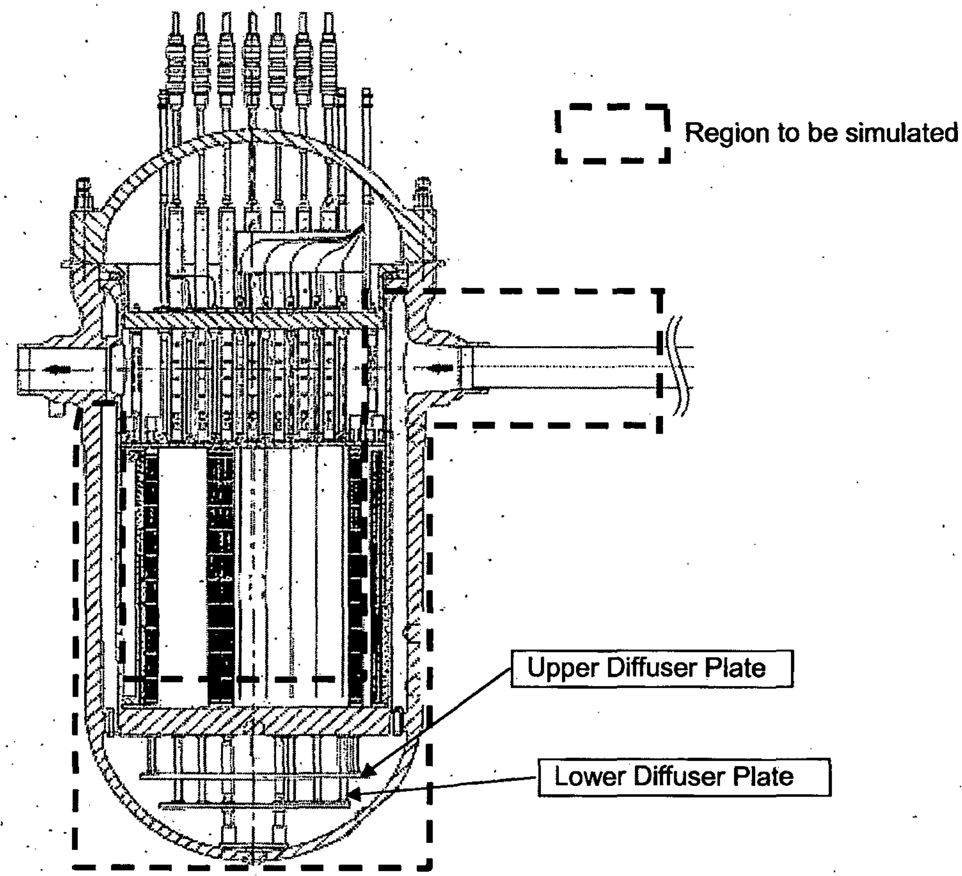

Figure 3-1 Scope of Simulation

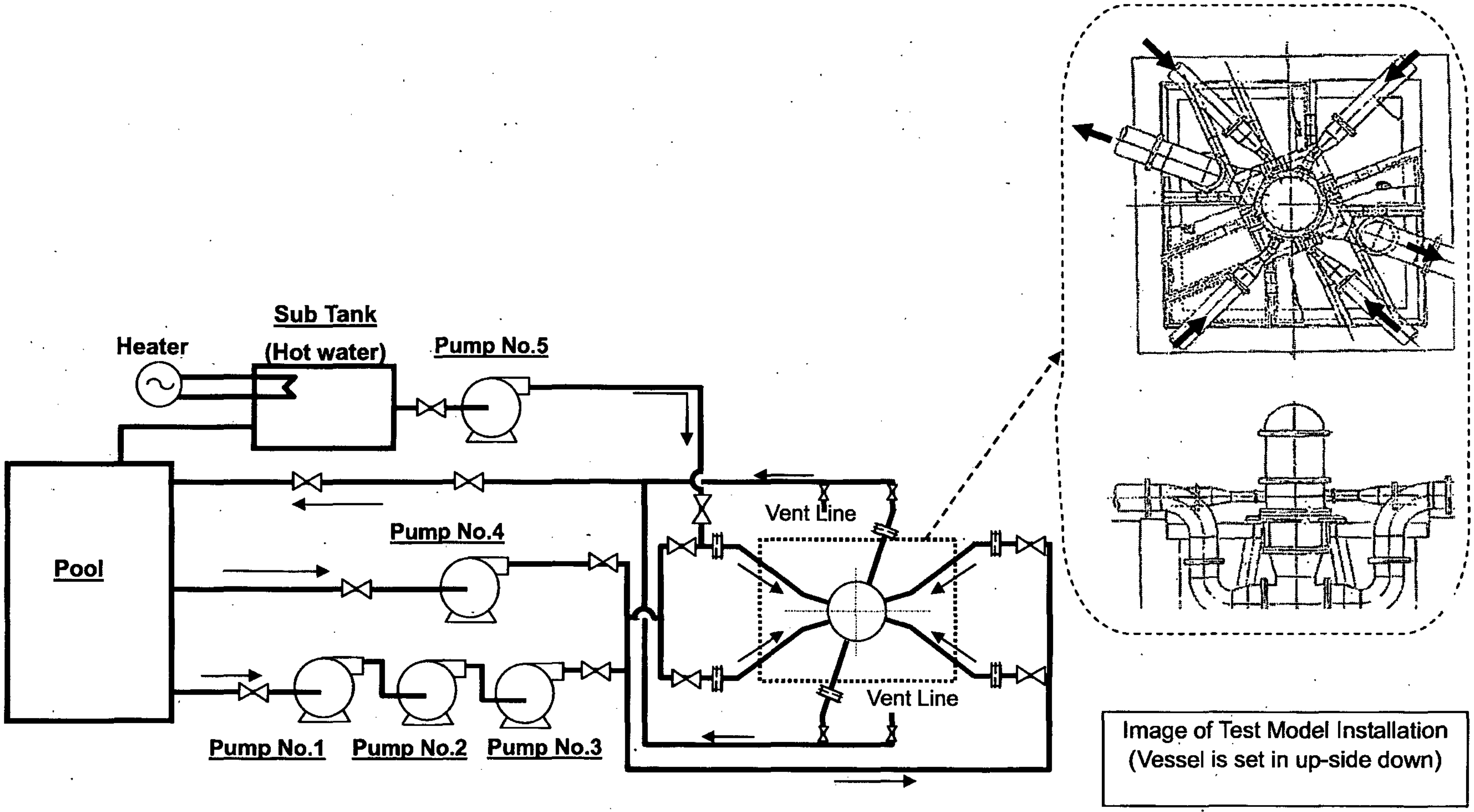

Figure 3-2 Test Loop and Test Model

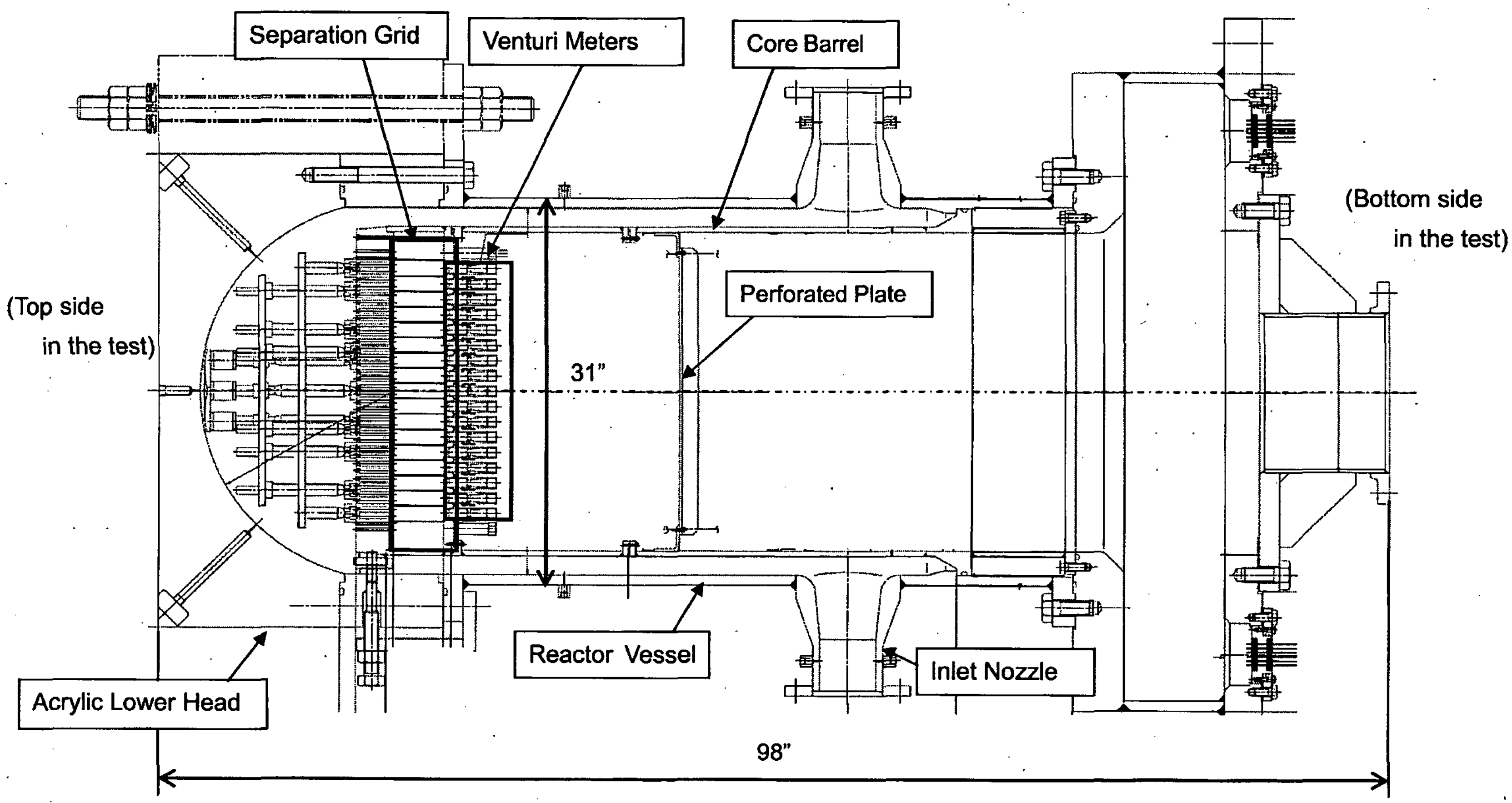

Figure 3-3 Model of Reactor Vessel and Lower Internals (1/7 Scale Model)

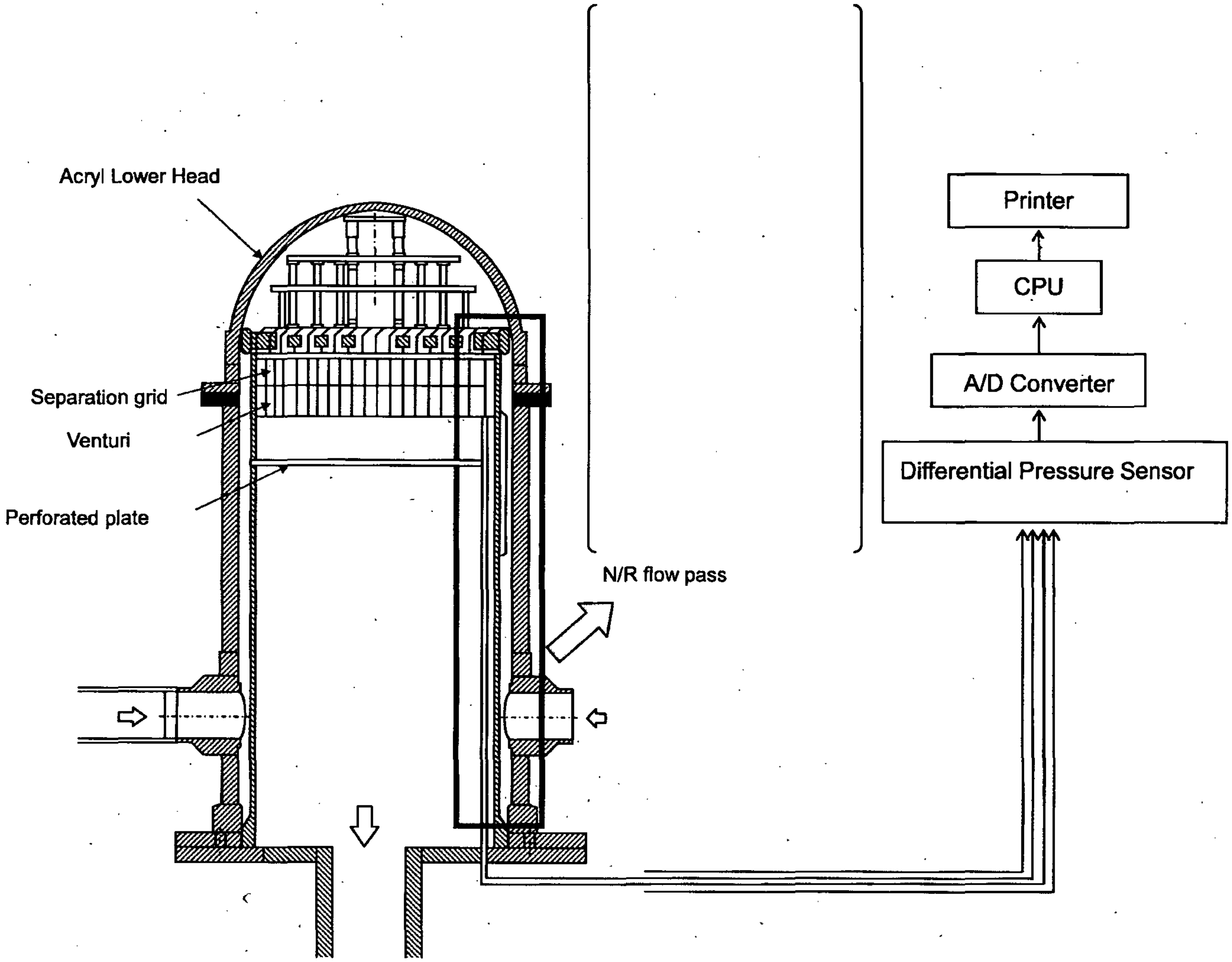

Figure 5-1 Hydraulic Measuring System

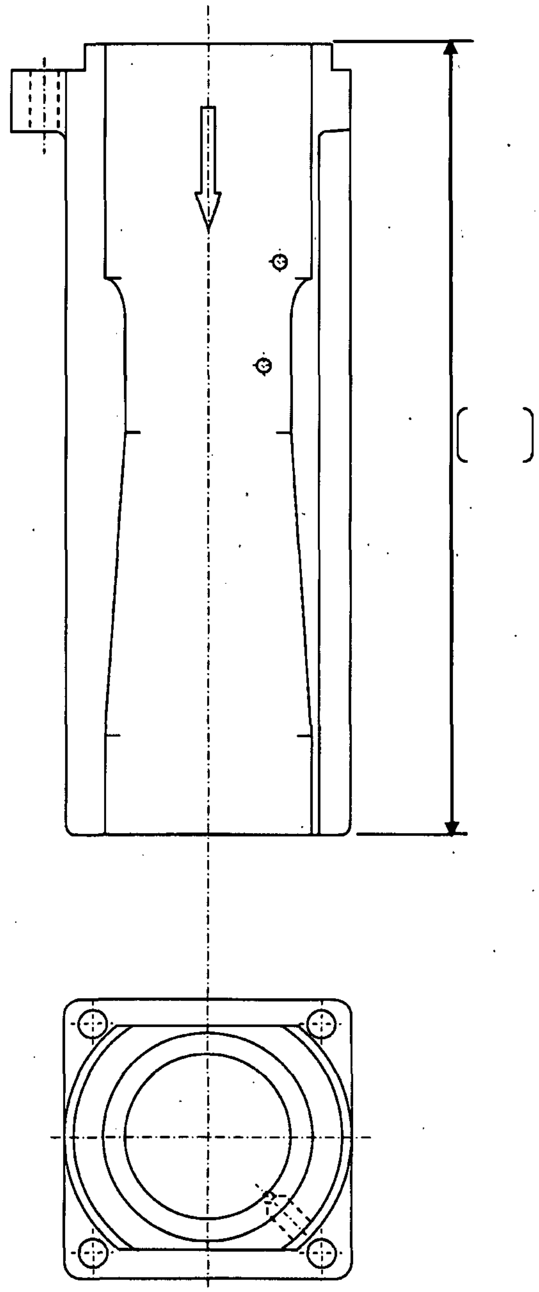

Figure 5-2 Venturi Flow Meter

Figure 5-3 Inlet Flow Distribution Measuring Locations

Figure 5-4 Pressure Measurement Positions

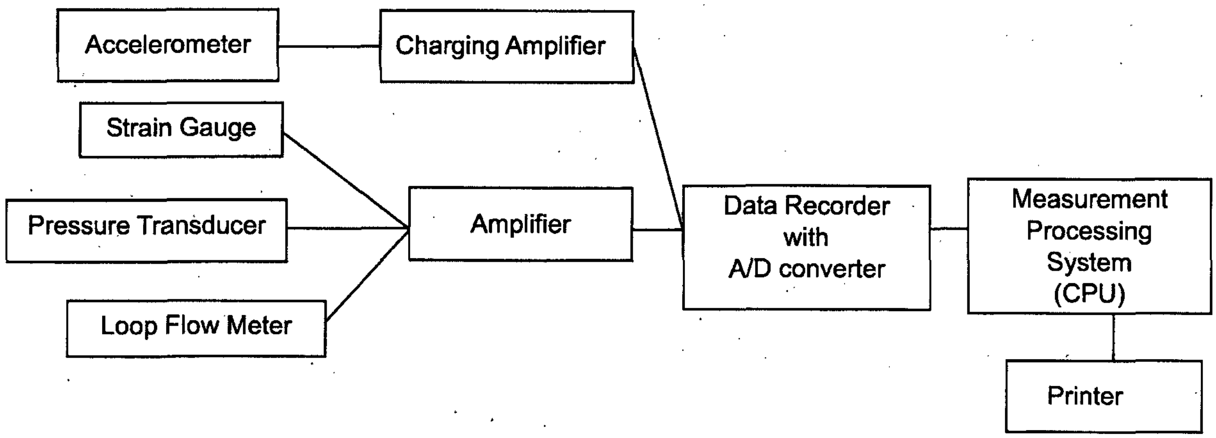

Figure 5-5 Flow-Induced Vibration Measurement Block Diagram

Figure 5-6 Measuring Positions for Flow-Induced Vibrations

Figure 5-7 Core Inlet Temperature Measuring Locations

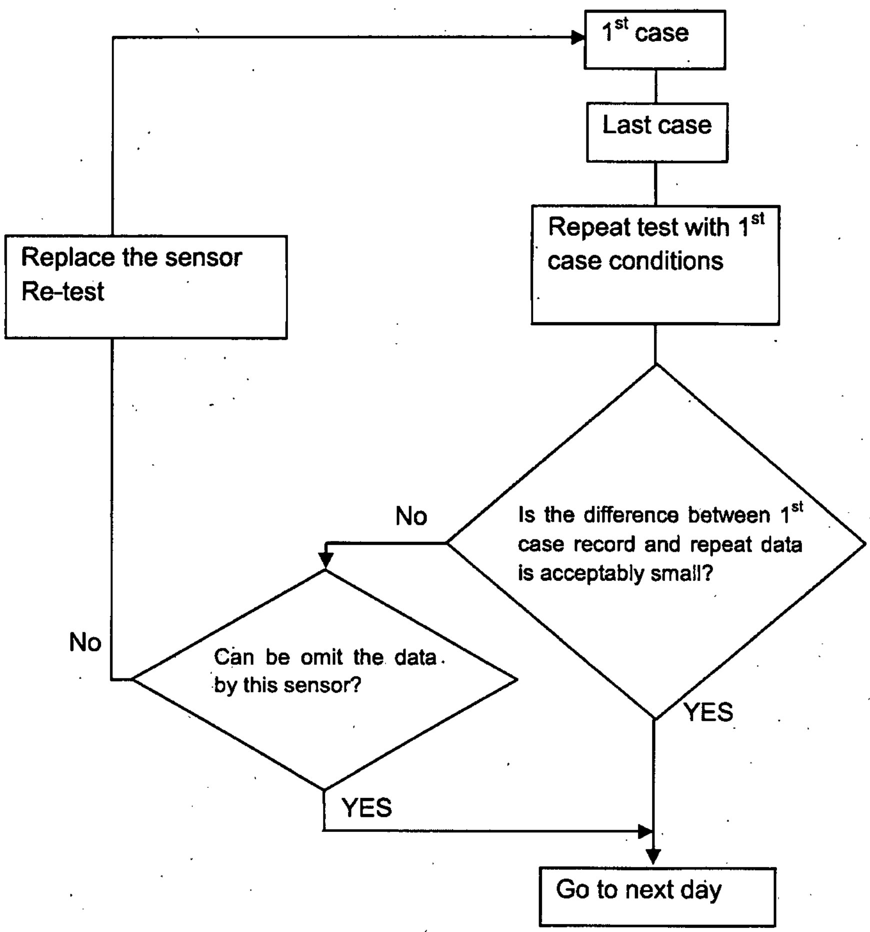

Figure 6-1 Daily Check of Data Repeatability