US-APWR

Neutron Reflector Reflooding Test Plan

Non-proprietary version

July, 2007

MITSUBISHI HEAVY INDUSTRIES, LTD.

TABLE OF CONTENTS

1. INTRODUCTION

MHI is currently planning to carry out an experiment associated with the neutron reflector for the US-APWR in order to confirm a model in large break LOCA code. It is believed that this test will not change large break LOCA code, it is not planned to use and refer to the outcome of the new test in the DCD.

To response to the NRC's interest in the new test, outline of the test plan has been submitted to NRC (MHI Ref.: UAP-HF-07041) and the NRC's staffs are invited to see 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 reflooding test of the neutron reflector for the US-APWR.

In addition, a neutron reflector flooding test for the Mitsubishi Advanced Pressurized Water Reactor (APWR) in Japan had been performed [1].

2. TEST PURPOSE

Fig.1 shows an overview of the neutron reflector (NR) for the US-APWR.

The neutron reflector is located between the core barrel and core, and forms the core cavity. The purposes of the NR are to increase structural reliability by eliminating bolts in the high neutron fluence region, to reduce neutron irradiation of the reactor vessel, and to improve neutron utilization and thus the fuel cycle cost.

The NR consists of ten thick stainless steel blocks. The NR is cooled by coolant through the flow holes in the blocks to prevent excessive stress and thermal deflections of the blocks due to the heat generated inside this steel structure by absorbing gamma radiation.

The NR has a high heat capacity because of the large metal volume. Therefore, heat release from the NR may affect the reflooding rate in the reflooding phenomena during a large break LOCA. The WCOBRA/TRAC code, which will be used for safety analysis, is able to model the NR as a separate channel with a heat structure that is similar to the AP600 model and has been approved by NRC. The reflooding test of the NR for the US-APWR is planned to confirm the thermal hydraulic modeling of a flow hole in the NR using the WCOBRA/TRAC code that will be reported in topical report of large break LOCA. The test has been planned as a separate effect test focused on the thermal hydraulic impact of a single flow hole.

3. TEST EQUIPMENT

3.1 Conceptual Drawing

A schematic diagram of the test loop is shown in Fig.2. Flooding water is supplied to the test section from the flooding water feed line and is boiled by heated metal in the test section. The two-phase flow flows out to the upper plenum where the liquid part of the two-phase flow is separated and drained to the liquid storage tank. The mist flow discharged from the upper plenum is separated into droplets and steam flow at the separator in the gas-liquid separation tank. The steam flows out to the steam line through a steam flow meter measuring the steam flow rate.

3.2 Configuration of Test Section

Fig. 3 shows a structural drawing of the test section with full scale for the single flow hole. Also, the main dimensions of the test section are shown in table 1 and below. The measurement items are described later.

As the behavior of the gas-liquid two-phase flow is affected by gravity, the shape of flow path and heat capacity of the NR metal, the inner diameter and height of the NR flow hole are same as the US-APWR, and the material of test section is same as the US-APWR. Also the outer diameter is derived from the average heat capacity of the NR metal per a flow hole, which is intended to model the NR consistent with the modeling in the ECCS analysis using WCOBRA/TRAC for the US-APWR. One flow hole and surrounding metal is the average for the entire NR.

The NR for the US-APWR has more than [ ] channels. The test section simulates only one channel representative of the performance of the entire NR, which the results will be scaled up conservatively for generated steam and droplet. The scaled up effect has been evaluated by [ ].

The test section metal is wrapped in thinner thermo-cement and sheath heater and then insulation in order to warm up and maintain the initial metal temperature which simulates the temperature at starting of reflooding. The heater is turned off simultaneously with starting of flooding in order to simulate the effect of metal heat release of heat sink to the fluids in the flow hole.

3.3 Test Loop

The test loop consists of the following equipment as shown in Fig.2.

-Test section simulating a flow hole of the NR
-Gas-liquid separation tank to separate droplets and measure the liquid mass transient ejected through the flow hole
-Liquid storage tank to measure the quantity of the liquid ejected through the flow hole
-Feed water tank and feed water pump that supply flooding water as forced injection
-Heaters in feed flooding water line and feed water tank to set the flooding water temperature
-Steam line and pressure control valve to maintain the system pressure

The feed water tank and the pump are installed in the lower portion of the test section. The liquid storage tank, the gas-liquid separation tank, and the steam flow meter, where liquid mass transient and steam flow rate are measured, are installed nearby the test section outlet.

The design pressure of the test loop is approx. [ ] because the test focuses only on the reflood behavior during a large break LOCA.

Before flooding

The line to feed flooding water consists of the feed water tank with the pre-heater, the feed water pump, the liquid flow meter, and the heating device. Since the flooding water temperature of up to approx. [ ] is planned during the test at this time and the current feed water tank is an open air type, the temperature of the feed water tank is limited up to approx.[ ] as a maximum. The heating up to approx. [ ] is carried out by the heating device set near the inlet of the lower plenum.

The flooding water preheated in the feed water tank flows into the lower plenum, after the water is pressurized by the feed water pump and is heated by a heating device to the specified flooding water temperature. In the warm-up period prior to start of the flooding, the flooding water that flowed into the lower plenum returns to the feed water tank through the return line, and does not flow into the flow hole of test section due to water level control in the lower plenum.

The test loop is pressurized by supplying the steam from the boiler and is controlled to the constant specified pressure with the pressure control valve on the steam line.

The NR metal is heated to the specified temperature by the heater installed between the outer periphery of the NR metal and heat insulator.

Flooding period

The flooding is started with the water supplied into the flow hole portion by closing the solenoid operated valve on the return line. The flooding water removes the heat of the NR and boils in the flow hole. The thermal hydraulics behavior in the flow hole and metal heat release of the NR metal are measured by thermocouples and void sensors. The two-phase flow flows out to the upper plenum. The steam entrains a part of the droplets and flows into the gas-liquid separation tank, and the entrained droplets are separated by the cyclone type separator in the gas-liquid separation tank. The separated steam flows through an orifice type steam flow meter at the upper part of the gas-liquid separation tank and is discharged into the atmosphere together with the steam from the boiler. The separated droplets remain in the lower portion of the gas-liquid separation tank, and the droplet mass transient is derived from measuring the rise of the water level. The liquid mass that is not entrained by the steam in the upper plenum flows into the liquid storage tank from the bottom of the upper plenum. The liquid mass transient is derived from the liquid level change of the liquid storage tank.

Furthermore, the flow regime such as droplets behavior is observed at an observation port mounted in the upper plenum.

In the flooding period, the system pressure is maintained constantly by controlling the discharge steam flow rate into the atmosphere via the pressure control valve, even though the generated steam in the flow hole is added to the steam from boiler in the steam line.

4. TEST CONDITIONS

Test conditions are shown in table 2.

Thermal hydraulic behavior of the NR flow hole is affected by the flow conditions of flooding rate, flooding water temperature, initial metal temperature and pressure. Therefore, the number of test runs and test conditions (flooding rate, flooding water temperature, upper plenum pressure, initial metal temperature) including the range of test parameters will be determined appropriately based on an evaluation of large break LOCA analysis results with US-APWR plant parameters by WCOBRA/TRAC. A reproducibility test will be performed under appropriate test condition.

5. MEASURING AND CALIBRATION

5.1 Measuring

The main measurement items are shown in Fig. 3 and as follows.

<u>Measurement items in the NR flow hole</u>

(1) Fluid temperature in the NR flow hole

The fluid temperature nearby the inner wall of the flow hole is measured at a [ ] in the height direction.

(2) Metal temperature

The temperatures on the inner surface of the metal, its inside and its outer surface are measured at a [ ] in the height direction. The measurement height is the same as one of the fluid temperature. Two locations on the opposite faces are selected to confirm the circumferential temperature distribution.

(3) Void fraction in the NR flow hole

The void fraction is measured on the same cross-sectional surface as that of temperature measurement. A void sensor of conductance-type will be used.

(4) Differential pressure in the NR flow hole

The differential pressure is measured in the flow direction. The measurement is done at approx. [ ] length of the test section.

<u>Measurement items out of the NR flow hole</u>

(5) Outlet steam flow rate of the NR flow hole

The steam flow rate is measured by orifice type steam flow meter between the gas-liquid separation tank and the steam line.

(6) Outlet liquid mass transient of the NR flow hole

The liquid mass transient is derived from measuring of the liquid level change in the liquid storage tank and the gas-liquid separation tank.

(7) Flooding water flow rate to the NR flow hole

The flooding water flow rate is measured by liquid flow meter on the flooding water line.

(8) Pressure

The pressures are measure in the lower and upper plenums.

(9) Flow regime at the outlet of the NR flow hole

The behavior of the droplet ejecting from the flow hole is observed by using the video camera through the observation port glass installed in the upper plenum.

5.2 Calibration

(1) Before installation

Only the measuring instruments that have been calibrated should be used for the test. The calibration should be performed prior to the install in order to comprehend the measurement errors.

(2) In use check for data reliability

The data reliability will be checked periodically by following manner.

-Mass balance at a specific time

-Consistence between saturated pressure and saturated temperature for pressure and temperature

-Consistence between several in-kind measuring instruments such as pressure and temperature

(3) After final test

The removal of almost measuring instruments from test loop is so difficult. Therefore a specific test with the known state as fluid condition will be performed to obtained thermal hydraulic data by using the measuring instruments and the test loop. It will be confirmed that the data is consistent with before installation data

6. TEST PROCEDURE

The test procedure is shown below.

6.1 Preparation of Flooding System

(1) Filling the feed water tank with water
Accumulate pure water from the water purifying device into the feed water tank.

(2) Start of feed water pump
Start the feed water pump, and commence control with the feed water control valve to obtain the specified flow rate of the flooding water. Set the bypass manual valve to achieve circulation with the pump bypass line, because the flooding flow rate is low in comparison with the rated flow rate of the pump.

(3) Control of water level in lower plenum
Start control with the control valve in the return line so that the flooding water that has entered in the lower plenum does not flow into the flow hole and the water that has flowed into the lower plenum returns to the feed water tank.

(4) Start of heating of pre-heater in feed water tank
Switch on the pre-heater of the feed water tank. Control the temperature of the feed water tank during heating using the pre-heater. Because the tank is an air open type, the temperature to be set for the feed water tank will be approx. [ ] or under, so that boiling does not occur in the tank.

(5) Filling the liquid storage tank and the gas-liquid separation tank with water
Fill the liquid storage tank and the gas-liquid separation tank with water through the water filling line after the temperature in the feed water tank reaches the specified temperature. The water level should be a detectable level.

(6) Switching-on the heater of the heating device
Switch on the heater of the heating device in order to heat the feed water tank water from approx. [ ] to approx.[ ], if the flooding water temperature is approx.[ ] as a test condition. At this time, set an appropriate specific thermal dose using a manual silicon-controlled rectifier (SCR, Thyristor) for the heater of the heating device, and adjust the temperature using the set value of the feed water tank temperature for setting the flooding water flowing-in temperature.

(7) Flow of cooling water of the cooler
Adjust the cooling water flow rate supplied to the cooler on return line to prevent returning of flooding water of more than approx.[ ], if the flooding water temperature is approx.[ ].

6.2 Preparation of Steam System

(1) Start of boiler
Start the boiler and commence steam-flowing into the system.

(2) Setting of pressure
Control the pressure in the system with the pressure control valve mounted on the steam line to obtain the specified constant pressure.

(3) Heat trace
Start the heat trace for the liquid storage tank, the gas-liquid separation tank and the component from outlet of the test section to outlet of the steam flow meter.

6.3 Start of Heating of the Test Section

(1) Heating of test section
Start heating of the test section by switching on the heater of the test section. Carry out heating at this time up to the specified temperature with the silicon-controlled rectifier (SCR), by monitoring the temperature distribution in the axial direction of the test section.

(2) Temperature holding of test section
Manually adjust at the point when the specified temperature is reached, so that a constant temperature is maintained for a while. Monitor again in the axial distribution.

6.4 Start of Flooding

(1) Start of flooding
Close the solenoid-operated valve on return line connected to the lower plenum in order to start the flooding to the flow hole, and simultaneously shut off the power to the heater of the test section

(2) Monitoring items
Monitor pressure and temperature for anomalies during the flooding.

If there is any problem, stop the equipment immediately.

7. EVALUATION ITEMS OF TEST RESULTS

The test data will be evaluated for the following items to understand the sensitivity of the test conditions, such as flooding rate, flooding water temperature, initial metal temperature, and system pressure

-Generated steam mass transient
(Steam flow rate is converted to the mass transient)
-liquid mass transient in the liquid storage tank
-liquid mass transient in the gas-liquid separation tank
-Injected water mass transient
(Flooding water flow rate at flow hole inlet is converted to the mass transient)
-Fluid temperature of each cross-sectional nearby surface

-Metal temperature of each cross-section
-Void fraction of each cross-sectional nearby surface
-Differential pressure of test section portion

8. 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.

9. SCHEDULE

The currently planned schedule of the test is summarized in Table 3.

10. REFERENCE

[1] Kondo, Y. et al. , "Experimental Study of Thermal-Hydraulic Behavior of Coolant out of Neutron Reflector for APWR During Reflooding of Large Break LOCA", 11th International Conference on Nuclear Engineering, Tokyo, JAPAN, April 20-23, 2003, ICONE11-36033

Table 1 Configuration of test section and US-APWR

Table 2 Test conditions*

Table 3 Test schedule

Year	2007								
Month	4	5	6	7	8	9	10	11	12
Test plan (2006/9-2007/4)	■								
Design of test equipment (2006/10-2007/5)	■	■							
Preparation/ Installation of test equipment (2006/11-2007/8)	■	■	■	■	■				
Test									
Typical case test						■			
Sensitivity test							■	■	■ *

*: A detailed test schedule will be finalized at the end of August.

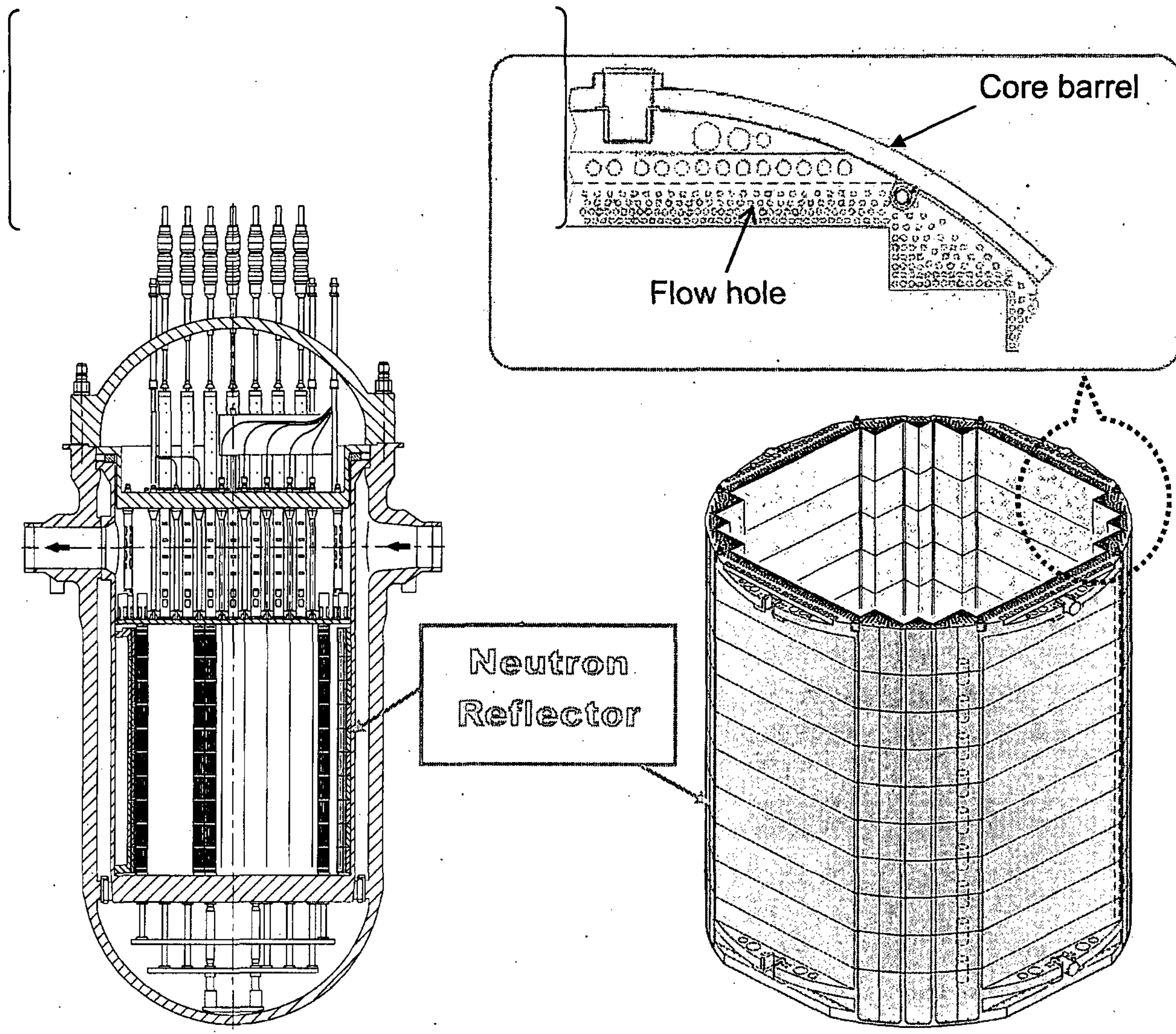
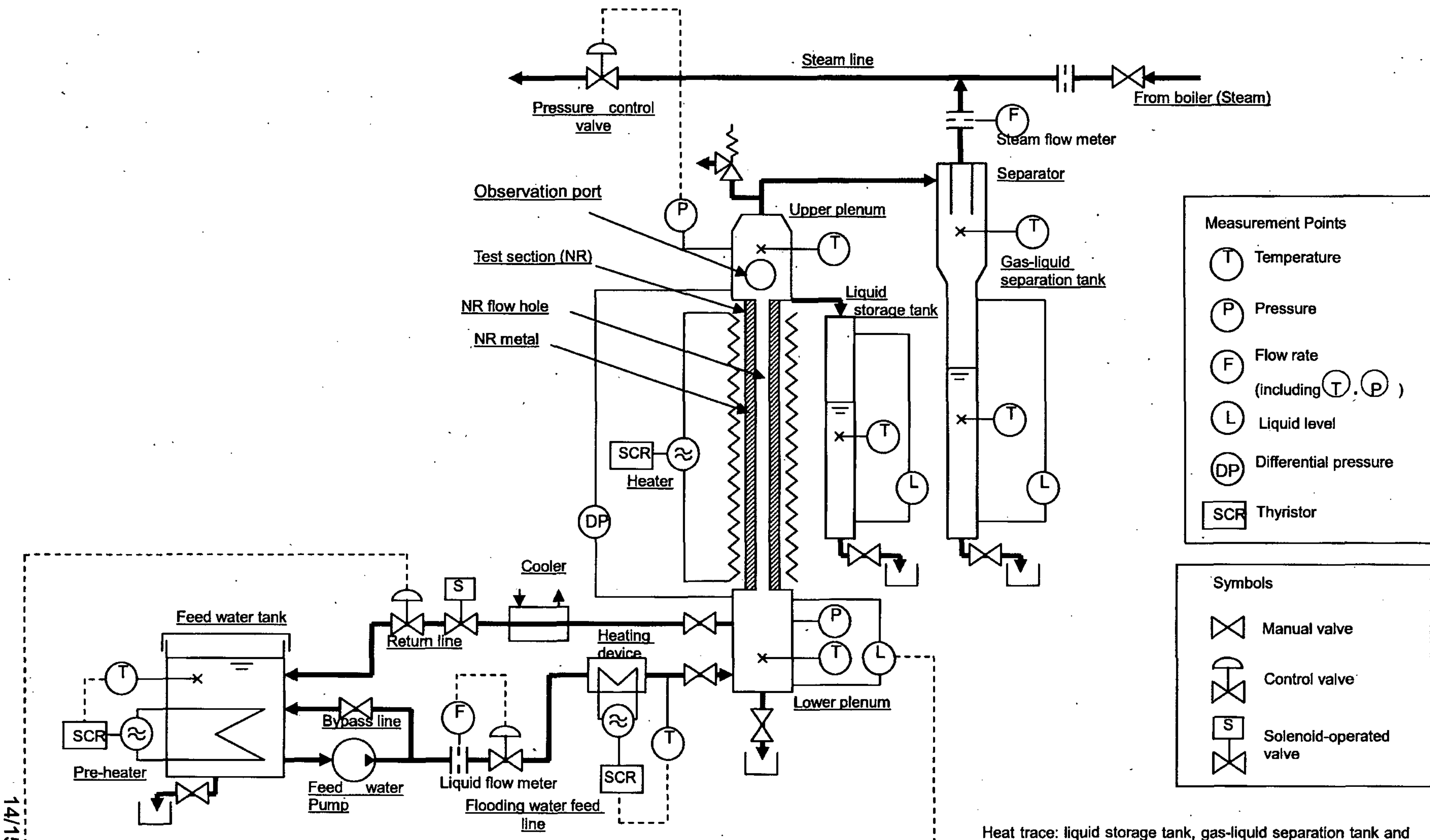


Figure 1 Neutron Reflector in US-APWR



Heat trace: liquid storage tank, gas-liquid separation tank and component from outlet of the test section to outlet of steam flow meter.

Figure 2 Schematic diagram of test loop

Figure 3 Test section