4.2 DEVELOPMENT OF FUEL TEST LOOP IN HANARO

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ABSTRACT

KAERI have developed a fuel test loop facility to conduct the fuel irradiation test at HANARO. Maximum 3 pins of fuel can be tested in the IR-1 irradiation hole of HANARO under commercial power plant operating conditions. The integral system performance test with mock-up fuels under a high temperature is being performed. The FTL will be used for an advanced fuel irradiation test and could maximize the usage of HANARO.

INTRODUCTION

The FTL (Fuel Test Loop) is a facility which can conduct a fuel irradiation test at HANARO. The FTL simulates commercial NPPs' operating conditions such as their pressure, flow, temperature, neutron flux levels and chemical conditions to conduct the irradiation and thermo-hydraulic tests. The conceptual design of the FTL was started at the end of 2001 and the detailed design had been finished by March 2004. The equipment installation of the FTL was successfully completed in March 2007. The commissioning of the FTL is being performed since April 2007. The FTL will be used for the irradiation test of advanced PWR fuels after its commissioning is completed. In this paper, the characteristics and commissioning of the FTL facility are introduced.
CHARACTERISTICS OF FTL FACILITY

Process systems [1,2,3,4]

The FTL provides the test conditions of a high pressure and temperature similar to those of commercial PWR and CANDU reactors. The FTL is composed of an OPS (Out Pile system) and an IPS (In-Pile test Section). The OPS is composed of a process system and an I&C (Instrumentation and Control) system. The IPS is to be loaded into the IR-1 position in the HANARO core. The FTL coolant is supplied to the IPS at the required temperature, pressure and flow conditions that are consistent with a test fuel. The nuclear heat added within the IPS is removed by the main cooling water. The main system of the FTL is designed by ASME Boiler & Pressure Vessel Section III code and its subsidiary system is designed by ASME Boiler & Pressure Vessel Section VIII code and the ASME B31.1 Power Piping code.

Fig. 1. Schematic diagram of the FTL.

The process system contains several equipments such as a pressurizer, a cooler, a heater, pumps, and a purification system which are necessary to maintain the proper fluid conditions. The nuclear heat generated within the IPS is removed by the main circulating water cooler. The main circulating pump provides the motive power to circulate the coolant within the loop. After a pump discharge, an in-line heater provides the capability to increase the temperature for a start-up and for a positive temperature control. A pressurizer is provided to establish and maintain the coolant pressure for the test fuel type. The process system includes the following systems.
- Main cooling water system
- Emergency cooling water system
- Penetration cooling water system
- Letdown, makeup, and purification system
- Waste storage and transfer system
- Intermediate cooling water system
- Sampling system
- IPS inter-space gas filling and monitoring system
- Miscellaneous systems

The main cooling water system controls and regulates the system pressure, temperature and flow rates of the coolant. It removes the fission and gamma heat of the IPS for a normal operation. The emergency cooling system is provided to maintain the experimental fuel cooling conditions in the event of an anticipated operational occurrence or the design basis accidents. The emergency cooling water system will inject the emergency cooling water directly from an accumulator to the main cooling water system if a line break accident occurs. The emergency cooling water system consists of two accumulators, safety injection valves, depressurization vent valves, and associated pipes. Accumulator A and B are connected by the safety injection pipes to the hot and cold legs of the main cooling water system respectively. The waste storage tank is connected by the depressurization vent pipe to the hot leg. As shown in figure 1, the pipes are designed as two trains for a redundancy. Each train has two valves in series because the accumulators and the waste storage tank should be completely isolated from the main cooling water system for a normal operation. All the equipment of the emergency cooling water system is designed as nuclear safety class 2. Seismic and electrical design is associated with the nuclear safety classification. The coolant of the accumulators is pressurized with nitrogen gas. The accumulators supply emergency coolant to the IPS for about 30 minutes. To prevent an injection of nitrogen into the IPS, the water level is measured with 3 sensors and the safety injection valves are closed if a low level trip occurs. The low level trip is actuated by the 2 out of 3 logic. The safety injection and depressurization valves are a solenoid-operated valve and the stroke time is 0.2 second.

The penetration cooling water system circulates the HANARO pool water to cool down the concrete penetration parts. The let down, make-up & purification system controls the volume, purification and chemical quality of the main cooling water. The waste storage and transport system collects the waste water and gas from the OPS and transports them to either the HANARO liquid radwaste system or the HANARO ventilation system for a normal operation. The waste storage tank also receives the discharges from the safety relief valves and the emergency coolant from the accumulators for a suppression of all the design basis events. The intermediate cooling water system transfers the fissile and pump heat to the HANARO secondary cooling system. The test loop sampling system monitors the water quality periodically. The IPS inter-space gas filling and monitoring system provides neon gas to the
pressure vessel gap and provides air gas to the in-pool pipe gap to insulate them from the pool water. The hydrogen control system supplies hydrogen gas to the de-gasfier to remove the solved oxygen in the cooling cooler. The test conditions for the fuel rest loop are given in Table 1.

Table 1. Test conditions in the FTL.

<table>
<thead>
<tr>
<th>Test conditions</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reactor operation cycle</td>
<td>9 cycles/year</td>
</tr>
<tr>
<td>Operation cycle length (EFPD/cycle)</td>
<td>28 days</td>
</tr>
<tr>
<td>Test rods</td>
<td>3 rods</td>
</tr>
<tr>
<td>LHGR</td>
<td>$\leq 320 \text{ W/cm}$</td>
</tr>
<tr>
<td>Peak to average heat rate</td>
<td>$\leq 1.16$</td>
</tr>
<tr>
<td>Fast neutron flux in cladding surface</td>
<td>$1.2 \times 10^{14} \text{n/cm}^2\cdot\text{sec}$</td>
</tr>
<tr>
<td>Coolant temperature</td>
<td>300 $\sim$ 308 $\degree\text{C}$</td>
</tr>
<tr>
<td>Coolant pressure</td>
<td>150 $\sim$ 159 $\text{kg/cm}^2$</td>
</tr>
<tr>
<td>Coolant velocity</td>
<td>1.37 $\sim$ 1.84 $\text{kg/s}$</td>
</tr>
<tr>
<td>B concentration</td>
<td>$\leq 1500$ ppm</td>
</tr>
<tr>
<td>Dissolved oxygen concentration</td>
<td>$\leq 0.1$ ppm</td>
</tr>
<tr>
<td>pH at 300 $\degree\text{C}$</td>
<td>5.5 $\sim$ 8.0</td>
</tr>
</tbody>
</table>

I&C systems [5,6]

The I&C system for the FTL is divided into a safety control system and a non-safety control system. The I&C system has the following functions;

- Maintaining the irradiation test conditions by an automatic control,
- HANARO trip and a FTL safe shutdown during transient or accident conditions,
- Satisfaction of the safety design requirements such as a redundancy, independency and single-failure criterion,
- Simultaneous operation of the FTL with HANARO.

The safety control system is used for controlling the safety related process systems of the FTL and a shutdown of the HANARO reactor from abnormal operating conditions. The non-safety control system consists of a computer control system and a data acquisition system. The digitalized computer control system controls and monitors all the field signals from the process systems such as the main cooling water system, the intermediate cooling water system, etc. The safety related control panels are classified as Quality class “Q” and Seismic category “I”. The safety related control panels were designed with the following safety regulation of IEEE std-603 to ensure a system’s reliability such as single failure criterion, redundancy, independence, diversity, fail-safety design, manual initiation, channel checks, channel bypass,
identification of protective action, interface with a non safety related system, equipment qualification, etc. The FTL protection panels composed of three channels receive the signals from the corresponding field instruments, and generate the HANARO trip signal and the FTL shutdown signal if the measured signal exceeds the trip setpoint. The HANARO trip signals from the protection panels are interfaced with the corresponding channels of the HANARO RPS (Reactor Protection System) panels which generate the reactor trip signal. The HANARO RPS panels have a ‘2 out-of 3’ local coincidence logic for a reliability assurance. The FTL safety control panels are composed of two independent panels, and they have some manual switches and relays in each panel to control the safety related process systems. The main purpose of the safety control panels is to supply the emergency cooling water to remove the heat from the test fuels after a reactor shutdown. Fig. 2 shows the overall control system configuration for the FTL.

Fig. 2. Overall control system configuration.

The data acquisition system collects and stores the signals from the in-pile instruments (SPND, Thermocouple, LVDT, etc.) installed in the IPS. The main measurement parameters are the centerline temperature of a test fuel, the neutron flux, the coolant temperature, the fission gap pressure, etc. The irradiation data can be monitored in office building located in reactor outside on a real time basis through the network.

**IPS(In-Pile test Section)**

The IPS including the test rig is to be loaded into the IR-1 position in the HANARO core. This implies that the environment around the IPS is subjected to a high neutron flux (Thermal
neutron flux: $1.2 \times 10^{14} \text{ n/cm}^2\text{-sec}$, Fast neutron flux: $1.6 \times 10^{14} \text{ n/cm}^2\text{-sec}$). The IPS can accommodate up to 3 pins of fuel and has instruments such as a thermocouple, LVDT and SPND to measure a fuel’s performance during a test. The IPS is composed of the IPS head, the outer pressure vessel, the inner pressure vessel, a flow divider and a test fuel carrier. Inlet nozzle and outlet nozzle for the main cooling water are located in the IPS head and insulated from the HANARO pool. Neon gas is filled into the gap between the outer pressure vessel and the inner pressure vessel to insulate the IPS from the HANARO pool. A flow divider divides the outlet cooling water from the inlet cooling water. The test fuel carrier is composed of a fuel carrier support stem (with 6 slots for the hot cooling water injection), a fuel carrier leg (3 legs are arranged through the 120° angles) and a fuel carrier head. Fig. 3 shows a schematic diagram of the IPS. The outer pressure vessel is a 321 stainless steel of a 5.0 mm thickness and has 9 SPNDs. Inner pressure vessel is a 321 stainless steel of a 4.0 mm thickness and its upper part is designed as a collar form to prevent a cooling water stagnation.

**Commissioning**

The equipment of the FTL was installed from July 2006 to March 2007. The commissioning was started from April 2007. The commissioning is performed with three stages. An individual system performance test under room temperature is performed in the first stage, and the integral system performance test with mock-up fuels under a high temperature is performed in the second stage, and finally the integral system performance test
with test fuels under a high temperature is performed in the third stage. The individual system performance test had been successfully completed. The integral system performance test with mock-up fuels under a high temperature is being performed. The passivation operation was performed at the starting point of the FTL operation under the high temperature condition. The integral system performance test with test fuels under a high temperature will be performed from December 2008. Figure 4 shows the pictures for the commissioning.

Fig. 4. Pictures for the commissioning.

CONCLUSIONS

KAERI have developed the FTL to conduct the fuel irradiation test at HANARO. The IPS which shall be loaded in the IR1 irradiation hole has a double pressure vessel and is designed to accommodate up to 3 pins of fuel. The application fields of the FTL are as follows;
- Nuclear fuel irradiation behavior test at the operating conditions of a commercial power plant,
- Fuel burn-up and mechanical integrity verification,
- Irradiation data generation for an analysis model,
- Technical improvement of a design and a fabrication for an advanced fuel development.

The FTL will be used for an irradiation test of advanced PWR fuels after its commissioning is completed in the end of 2008. The R&D for the irradiation test technologies will be progressed in the future.
REFERENCES


