Design of the Fuel Test Loop in the HANARO

B. S. SIM, C. Y. LEE, J. Y. KIM, D. Y. CHI

Hanaro Center, Korea Atomic Energy Research Institute
P.O.Box 105, Yusong, Taejon, 305-600, Korea
Tel : +82-42-868-2278 Fax : +82-42-868-8364
E-mail : bssim@nanum.kaeri.re.kr

Abstract

The paper describes the design development with high pressure Fuel Test Loop for both of PWR and CANDU type fuel testing under simulated power reactor conditions in the HANARO reactor. The Fuel Test Loop consists of In-pile Test Section(IPS) and Out-Pile System(OPS). The IPS is connected to the OPS by means of which the system pressure, the system temperature and the water quality are controlled and regulated. Power reactor requirements are generally applicable to the Fuel Test Loop and have been applied judiciously. In many respects the Fuel Test Loop is analogous to a direct cycle power reactor. As such it is appropriate to place the normal heat sink outside the the reactor coolant pressure boundary. The design of the Fuel Test Loop is completed except some parts of the FTL and the equipments of the OPS are under fabrication. Also the safety analysis report was submitted to the Korea Institute of Nuclear Safety(KINS) to get the license of installation and operation of the Fuel Test Loop.

1. Introduction

The HANARO Fuel Test Loop(FTL) is a self-contained circuit that supports nuclear reactor fuel experiments. One of two types of reactor fuel is placed within the HANARO Large Hole(LH) experimental hole as shown in fig. 1 and irradiated in a manner that supports the experiment's objectives.

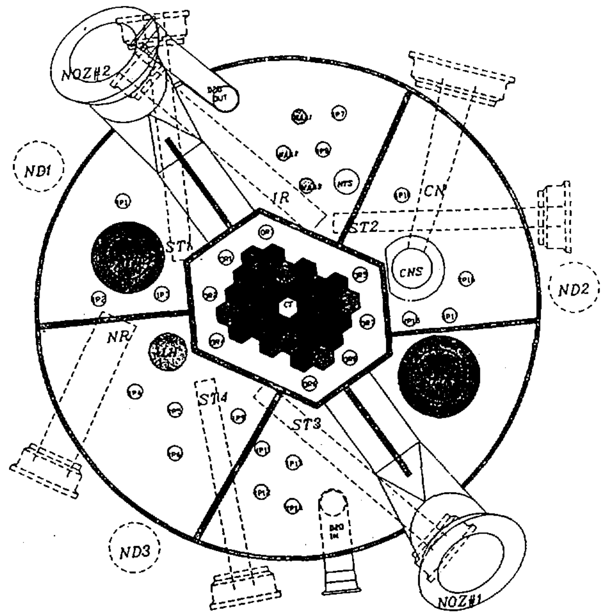

Fig.1 HANARO core configuration

The test fuel is of the Pressurized Light Water Reactor (PWR) type or of the Pressurized Heavy Water Reactor(CANDU) type. The FTL accommodates normal process conditions for temperature, pressure, flow and water chemistry found on each reactor's primary system. (refer to table 1)

Table. 1 Design and Operation Parameters of Fuel Test Loop

Parameters		CANDU	PWR
IPS & OPS Temparature		354.5℃	354.5℃
Design Pressure	OPS	17.24 MPa	17.24 MPa
	IPS	11.03 MPa	17.24 MPa
IPS Max. Operation Conditions	Genarated Heat	800 kW	690 kW
	Inlet Temparature	281℃	316℃
	Outlet Temparature	290℃	328℃
	Outlet Temparature	10 MPa	15.5 MPa
	Flow Rate	17.21 kg/s	10.25 kg/s
Fuel Bundle, O. D.		99.7 mm (37 rods excluding fin length)	79.1 ×79.1 mm (6×6, 32 rods)
IPS Flow Tube I. D.		103.4 mm	80.62×80.62 mm 89.76×89.76 mm

Typical Values of the major nuclear conditions for HANARO FTL in normal operation are given below.

HANARO reactor characteristics for the HANARO FTL channels :

- LH hole Diammeter : 150mm
- Fast Neutron (> 0.82 Mev) : 6.62×10^{11} n/cm^2.sec.
- Thermal Neutron (< 0.625 ev) : 9.77×10^{13} n/cm^2.sec

2. The In-pile Section (IPS)

The IPS provides a pressure boundary enclousre to be utilized for insertion and removal of fuel test bundles into the HANRO reactor LH tube structure. There are two IPS designs one for PWR fuel testing and the other for CANDU fuel testing. The IPS must be designed to provide the capability to test PWR and CANDU fuel at normal operating conditions. Both pressure tube assemblies (PWR and CANDU) are to fit into one spool piece weldment, which is mechanically bolted to the LH tube structure. The piping from the OPS (Out-pile System) support system is connected directly to the HANARO IPS at the spool piece inlet and outlet. Coolant from the OPS passes through the connecting pipe through the HANARO pool, enters the IPS through the inlet nozzle, then enters the region inside the pressure tube through annulur solts, passing downward within in annulus between pressure tube and the flow tube to the bottom of the flow tube. There it makes a 180° turn, entering the flow tube, flowing vertically upward past a fuel bundle, and exiting the flow tube through annulur solts. The spool piece collects this flow and guides it to the outlet nozzle, where it exits the spool piece retuning to the OPS through a connecting pipe through the HANARO pool. The closure head and fuel bundle assembly for the IPS must provide closure and a pressure boundary for both the PWR and CANDU pressure tube assembly (fig. 2). The IPS assembly then forms a portion of the pressure boundary for the Fuel Test Loop, and must be designed to meet the intent of sections III, Devision 1 of the ASME B & PV code.

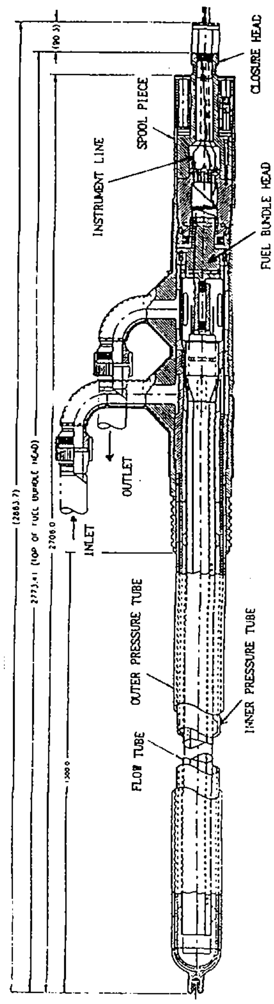

Fig. 2 IPS Assembly

The IPS assembly consits of six majer subassemblies : the spool piece, pressure tube (PWR or CANDU), flow tube (PWR or CANDU), fuel bundle head, closure head and support structure. The pressure tube, flow tube and the closure head assembly fit together in a concentric axial assembly, with the components being held together with dual pins. This closure head secures the entire assembly within the spool piece. The pressure boundary is also established by an upper and lower mechanical seal, the upper seal between the spool piece and fuel

bundle head, and the lower seal between the spoolpiece and pressure tube.
The closure head maintains the pressure boundary by clamping the fuel bundle assembly within the spool piece by direct contact, thus maintaining closure of the upper seal and by fuel bundle head transmitting closure head force required to clamp the lower seal to the pressure tube and spool piece, isolating the Fuel Test Loop system from the HANARO pool.
For instrumentation, provision for a total of 22 hard lines has been designed into the IPS. The fuel experimenter can incorporate neutron and other pressure and temperature sensors up to the limit of 22 total sensors.

3. The Out-pile System (OPS)

The OPS of HANARO FTL was designed to meet the operation conditions for CANDU and PWR. The OPS's functional requirements are as follows :

- it provides the correct experimental conditons for testing with respect to pressure, thermo-hydraulics, nuetronics and water chemistry.
- it provides safety function i.e emergency cooling water supply, component cooling water supply, waste disposal system, isolation valve of main cooling system, and for safety instrumentation, automatic safety action on loop etc. ...

The FTL piping and Instrumentation Diagram (P&ID) is as shown,fig 3.

3.1 Main Cooling Water (MCW) System

The MCW circuit start at IPS outlet, through the pool penetration, through redundant fast-closing outlet isolation valves, through a cooler to remove heat generated in the test section, through a circulation pump, through a heater to maintain test section temperature, through redundant fast-closing inlet isolation valves, and into the IPS inlet.

The MCW shall perform the following functions :

- Establish and maintain the design process condition to the IPS during normal test reactor modes of operation
- Provide automatic isolation to isolate the IPS from the non-nuclear safety portion of the MCW on loss of normal forced cooling or pipe rupture events.

- Provide signal to the HANARO reactor protection system to trip HANARO on low flow, low pressure, or low temperature in the IPS or MCW.

3.2 Emergency Cooling Water (ECW) System

The ECW circuit consist of redundant emergency cooling water accumulators, redundant emergency cooling water pumps, redumdant cooling heat exchangers, and associated piping, valve, and instrumentation.

The ECW shall perform the following functions :

- provide reactor coolant pressure boundary inventory control to preclude accidents with significant offsite dose consequences.
- provide emergency cooling water to the IPS subsequent to Anticipated Operational Occurrences (AOO) or Design Basis Events (DBE)
- Remove IPS decay heat when normal forced cooling is unavailable.

3.3 Component Cooling Water (CCW) System

The CCW circuit consists of redundant component cooling water pumps, and associated piping, valve, and instrumentation.

The CCW shall perform the following functions :

- transfer heat from pool and FTL Room 1 concrete penetration to the HANARO pool.
- transfer decay and sensible heat from the ECW system, via the ECW coolers and ECW pump coolers, whenever normal forced cooling is unavailable.

3.4 Letdown, Makeup and Purification (LMP) System

The LMP controls the volume, water purity and chemical characteristics of the MCW. The LMP cools and processes a portion of the MCW flow and returns this flow to the MCW or to the waste disposal tank. The LMP system must accommodate the requirements of both CANDU and PWR cycle.

The LMP shall perform the following functions :

- maintain the MCW system inventory by providing redundant and diverse makeup for both cycles.
- purify the MCW to Technical Specification values and maintain activity levels by removing ionized contaminated material and particles.
- provide chemical additon capability to maintain the MCW fluid conditons.

3.5 The others

The others OPS consists of :

- Waste Disposal and Transfer(WST) System
- Intermediate Cooling Water(ICL) System
- Test Loop Sampling (TLS) System
- Radiation Monitoring (RMS) System
- Associated instrumentation and controls

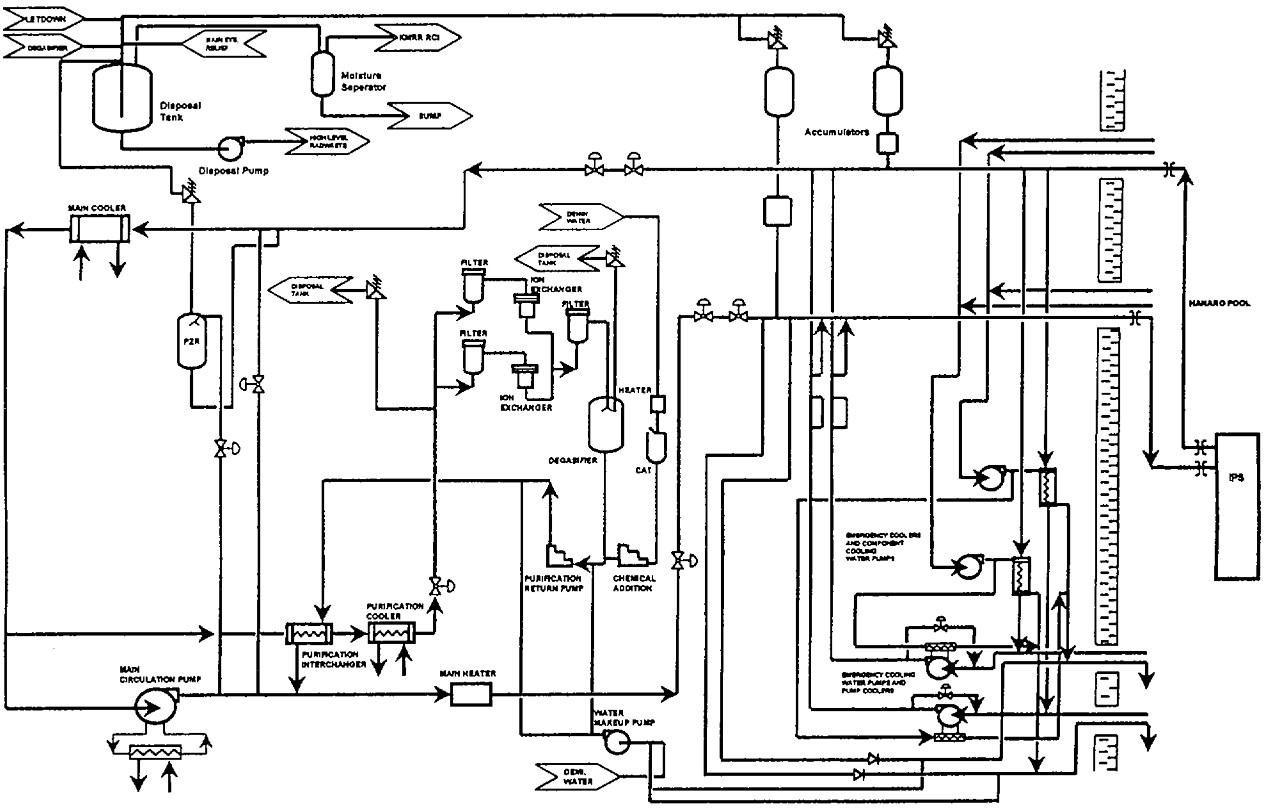

Fig. 3 HANARO FUEL TEST LOOP OUT OF PILE SYSTEM

4. Safety Analysis

4.1 Objective

The FTL safety analysis reviews the thermal and hydraulic responses to establish acceptable design and operation limits that ensure safety. It is intended to use the USNRC Standard Review Plan, to evaluate the FTL performance.
The main and emergency cooling systems for two sample fuel bundle are evaluated and proved. These two sample fuels are a 37 pin CANDU and a modified 32 pin PWR bundle.

4.2 Method

The safety performance requirements for the FTL are to be based on the Standard Review Plan used for US commercial power plants where applicable to the FTL. In particular, those accident event identified in chapter 15 of the SRP are to be analyzed. A review of the SRP chapter 15 was made, first to identify the applicable analyses, and second, to prioritize the events so that certain analyses could be considered bounded and removed from further consideration.

The RELAP5/MOD 3 computer code is used to perform the thermal and hydraulic analysis of the FTL. The calculation performed for the evaluation are defined from a review of chapter 15 of the SRP.
Two safety parameter were used for the safety accident analyses. For the Anticipated Operational Occurrence (AOO) accidents, it is required that the actual heat flux should not exceed the critical heat flux. For the Loss of Coolant Accidents(LOCA), the peak clad temperature of fuel rod should not exceed the allowable temperature.

4.3 Results

The calculation are based on the applicable SRP analyses for the FTL. The following limiting cases are derived from these calculations.

- Loss of flow – Isolation valve fail closure
- Inadvertent safety relief valve lift
- Failure of main cooling pump
- Large Break LOCA – Room 1 cold leg
- Small Break LOCA – Inpool cold leg

For the cases of AOO accident (ISV failure accident, stuck open SRV and Failure of MCW pump), the actual heat flux did not exeed the critical heat flux. The removal of the fuel decay heat was mainly depended by the flow of the emergency cooling pump. For the LOCA, the PCTs were lower than the analysis limit of 1310K. In the CANDU mode, the Room 1 LBLOCA was a limiting case. The PCT for the case mentioned above was 1291K. In the PWR mode, the PCT for the In-pool SBLOCA which was a limiting case for that mode was 1266K.

5. Present Status of HANARO FTL Construction

At present, the design of FTL were completed except the equipment vendor design document review and incorporation in detail design. The manufacturing of equipments such as vessels, coolers, pumps, valves and pipes is in progress. The construction and operaton pemits for HANARO FTL is underway by Korea Institute of Nuclear Safety (KINS).

6. Summary

The report describes the design, safety analysis and present status of the Fuel Test Loop at HANARO reserch reactor.
Installation of the Fuel Test Loop will be completed by 2001 and commission test will be carried out during 2002. This Fuel Test Loop will be useful for a wide range of irradiation experiments in relation to our power reactor fuel development program such as DUPIC (Direct use of spent PWR fuel in CANDU), CANFLEX (CANDU Flexibel fueling) and advenced PWR fuel.

7. References

1. Safety Analysis Report for Fuel Test Loop, Vol. 1, 1994
2. KMRR Fuel Test Loop Design Criteria, FL-070-DR-S001, 995
3. KMRR Fuel Test Loop IPS Design Specification, FL-300-RT-B001, 1995
4. B. E. Schmitt, RELAP5 Accident Analysis Calculation, 1995