DESIGN AND INSTALLATION OF FUEL TEST LOOP IN HANARO

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Abstract. FTL is a test facility which could conduct a fuel irradiation test at HANARO. The fuels can be tested in the IR1 irradiation hole of HANARO under commercial power plant operating conditions. The equipment installation was completed in March 2007. At present, the commissioning of the FTL is being conducted. The FTL will be used for the irradiation test of high burn-up PWR fuels and an advanced fuels. In this paper, the design and installation of the FTL are introduced.

1. Introduction

The FTL (Fuel Test Loop) is a facility which could conduct a fuel irradiation test at HANARO (High-flux Advanced Neutron Application Reactor) [1]. The FTL is composed of an IPS (In-Pile test Section) and an OPS (Out Pile System). 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 OPS contains process systems which are necessary to maintain the proper fluid conditions. The FTL simulates commercial NPPs' operating conditions such as their pressure, temperature and neutron flux levels to conduct the irradiation and thermo-hydraulic tests. The conceptual design of the FTL was started at the end of 2001 and both the basic and detailed design had been finished by March 2004. At present, a safety analysis report for the license and an IPS mock-up test for a verification of the design concept have been prepared. The installation of the FTL was finished successfully in March 2007. The commissioning of the FTL will be conducted by 2008. The FTL will be used for the irradiation test of high burn-up PWR fuels after the commissioning is completed. The FTL will also be used for an advanced fuel irradiation test and could maximize the usage of HANARO. In this paper, the design and installation of the FTL are introduced.

2. Design

The fuel test loop provides the test conditions of a high pressure and temperature similar to those of commercial PWR and CANDU reactors. 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 ASME B31.1 Power Piping code. The safety system for the FTL is designed based on Anticipated Operational Occurrences (AOOs) and Design Basis Accidents (DBAs). Inadvertent closure of the loop isolation valves, loss of a normal forced cooling, safety relief valve discharge and a loss of class IV power are assumed as the AOOs [2][3]. Loss of coolant accident and a reactivity insertion accident are considered as the DBAs. Accident analyses ensure that the FTL meets the design criteria of the Depart from Nucleate Boiling Ratio (DNBR) and Peak Cladding Temperature (PCT) and that it has a sufficient emergency core cooling capability. Fig. 1 shows the schematic diagram of the FTL.

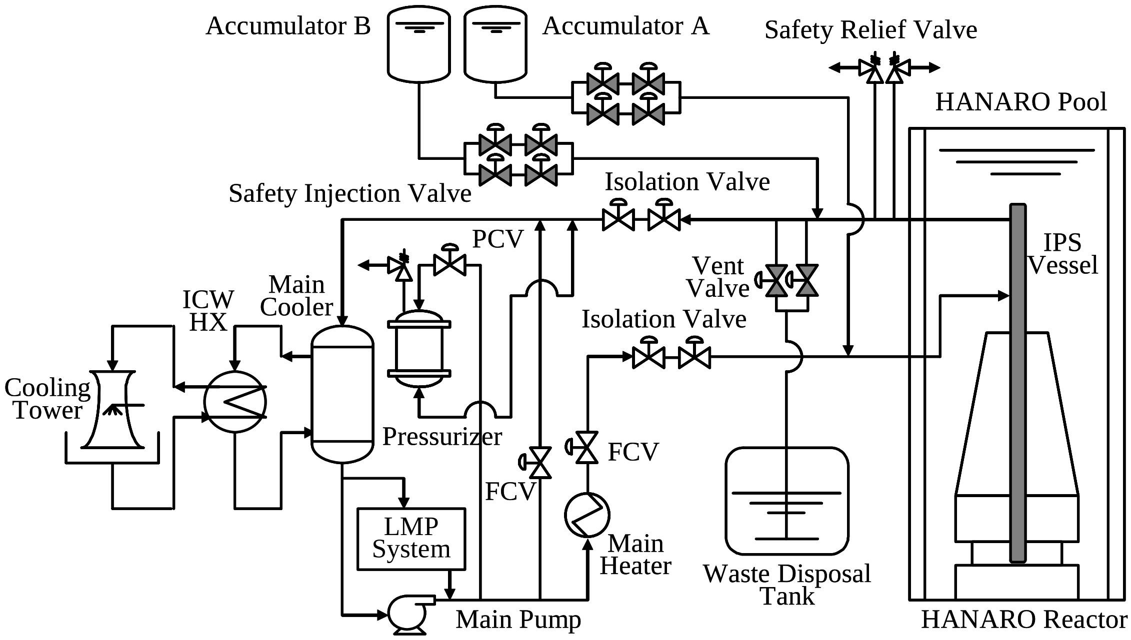

FIG. 1. Schematic diagram of the FTL.

2.1. OPS

The OPS contains a pressurizer, a cooler, a heater, pumps, and a purification system which are necessary to maintain the proper fluid conditions. In addition, the OPS contains an engineered safety system that could safely shutdown both the HANARO and the FTL if an accident occurs. 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 circulating water cooler. The main circulating pump provides the motive power to circulate the FTL coolant within the loop. After a pump discharge, an in-line heater provides the capability to increase the temperature for a startup and for a positive temperature control. A pressurizer is provided to establish and maintain the coolant pressure for the test fuel type. A purification and de-gasification system is provided for maintain the coolant inventory and the chemistry conditions. 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. In addition, the OPS contains an electrical system and an Instrumentation and Control (I&C) System.

2.1.1. Process systems

The OPS contains the following process systems [1].

- 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
- Test loop 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 design parameters of the main cooling system are given by Table 1.

Table 1. Design parameters of the main cooling water system.

Design parameters	PWR Type	CANDU Type
Maximum Temperature	350 ℃	350 ℃
Maximum IPS pressure	17.5 MPaA	17.5 MPaA
Maximum OPS pressure	17.5 MPaA	17.5 MPaA
Operation flow	1.60 kg/sec	1.63 kg/sec

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 will perform the following nuclear safety related functions;

- Remove the IPS decay heat when normal forced cooling is unavailable,
- Provide emergency cooling water to the IPS subsequent to anticipated operational occurrences (AOOs) or design basis accidents (DBAs),
- Provide emergency makeup water for emergency cooling of the IPS subsequent to breach of the main cooling water pressure,
- Protect the emergency cooling water system from over-pressurization events.

The emergency cooling water system will also perform the following non-nuclear safety functions;

- Charge the accumulators with nitrogen and maintain the charged pressure,
- Monitor the normal level of accumulators.

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.

2.1.2. I&C system

The I&C system for the FTL is divided into a safety control system and a non-safety control system [4]. The I&C system has the following functions;

- Maintaining of 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,
- Data acquisition from the test fuel and process operation.

The safety control system is used for controlling the safety related FTL process systems and a shutdown of the HANARO reactor against abnormal operating conditions [5]. 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 FTL process systems such as the main cooling water system, the intermediate cooling water system, etc. The data acquisition system collects and stores the signals from the in-pile instruments (SPND, Thermocouple, LVDT, etc.) installed in the IPS, and generates the irradiation data. Fig. 2 shows the overall control system configuration for the FTL.

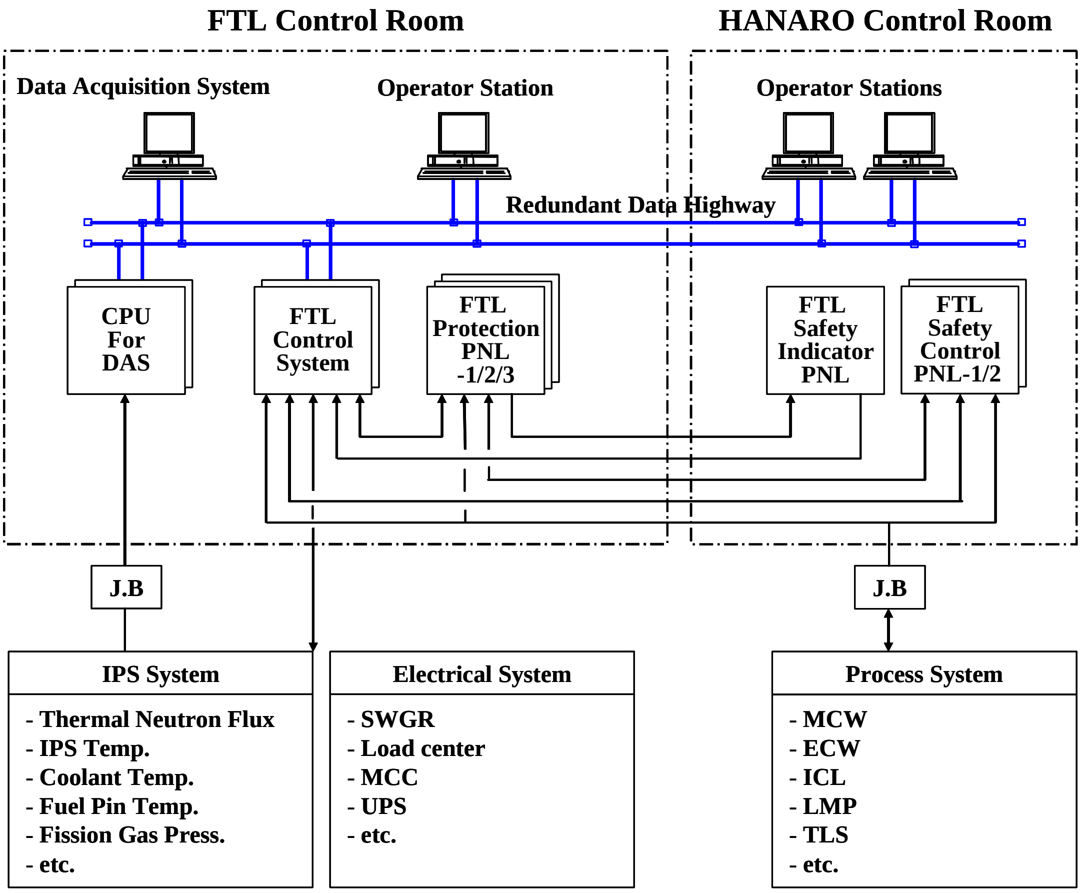

FIG. 2. Overall control system configuration.

The safety related control panels are classified as Quality class “Q” and Seismic category “I”. The protection panels are installed in the FTL control room located at the first floor of the reactor hall. The safety control panels and the safety indicator panels are installed in the HANARO control room. Fig. 3 shows a signal flow diagram of the safety related control panels. The safety related control panels were designed with the following safety regulation of IEEE std-603 to ensure the system’s reliability;

- Single failure criterion,
- Redundancy,
- Independence,
- Diversity,
- Fail-safety design,
- Manual initiation,
- Channel checks,
- Channel bypass,
- Identification of protective action,
- Interface with non safety related system,
- Equipment qualification,
- etc.

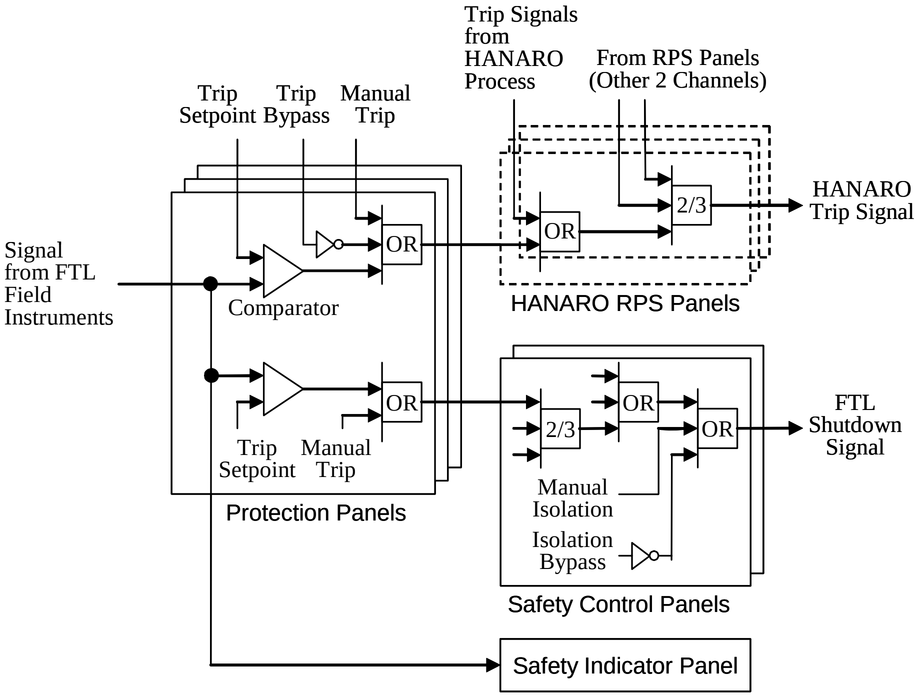

FIG. 3. Signal flow diagram of the safety related control panels.

The 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 measurement 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 reactor trip parameters from the FTL are as follows;

- Low flow rate of the IPS inlet main cooling water,
- High flow rate of the IPS inlet main cooling water,
- High temperature of the IPS outlet main cooling water,
- Low pressure of the inlet main cooling water,
- High pressure of the inlet main cooling water,
- High-High pressure of the IPS inner/outer vessel inter-space gap,
- High-High radiation of the IPS outlet main cooling water.

The safety control panels are composed of two independent panels, and they have some manual switches and relays in each panel for controlling 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. The safety control panels receive the trip signals from the protection panels when transient excursions of a process condition from the IPS main cooling water occur at unacceptable set point levels as follows;

- Low-Low flow rate of the IPS inlet main cooling water,
- High flow rate of the IPS inlet main cooling water,
- High-High temperature of the IPS outlet main cooling water,
- Low-Low pressure of the inlet main cooling water.

The ‘2 out-of 3’ concept is also applied to the safety control panels to satisfy the reliability of the overall plant. If any of the above input signals comes from the protection panels, the safety control panels automatically send the output command signals to the following control devices for a safe cooling down of the fuel temperature after a HANARO shutdown;

- Close the IPS inlet/outlet main cooling water isolation valves,
- Open the accumulator discharge isolation valves,
- Open the emergency cooling water isolation valves.

The FTL safety indicator panel receives the following analog signals to supervise the vital process status in the HANARO control room together with the FTL control room;

- Pressure of the IPS inlet main cooling water,
- Flow rate of the IPS inlet main cooling water,
- Temperature of the IPS outlet main cooling water,
- Pressure of the IPS inner/outer vessel inter-space gap,
- Radiation of the IPS outlet main cooling water.

The safety related control panels were qualified by the IEEE std-323, Qualifying Class 1E equipment for nuclear power generating stations, and the IEEE std-344, Guide for a seismic qualification of class 1E electric equipment for nuclear power generating stations. 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 measurement 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 generates the reactor trip signal. The HANARO RPS panels have a ‘2 out-of 3’ local coincidence logic for a reliability assurance. The FTL safety indicator panel receives the following analog signals to supervise the vital process status in the HANARO control room together with the FTL control room.

2.2. IPS

The IPS is to be loaded into the IR-1 position in the HANARO core [6][7]. This implies that the environment around the IPS is subjected to a high neutron flux (Thermal neutron flux: 1.2×10^{14} n/cm^2/sec, Fast neutron flux: 1.6×10^{14} n/cm^2/sec). The IPS can accommodate up to 3 pins of fuel and has instruments such as thermocouple, LVDT and SPND to measure a fuel’s performance during a test. The IPS is composed of the IPS head, outer pressure vessel, inner pressure vessel, 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 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. 4 shows a schematic diagram of the IPS inlet flow.

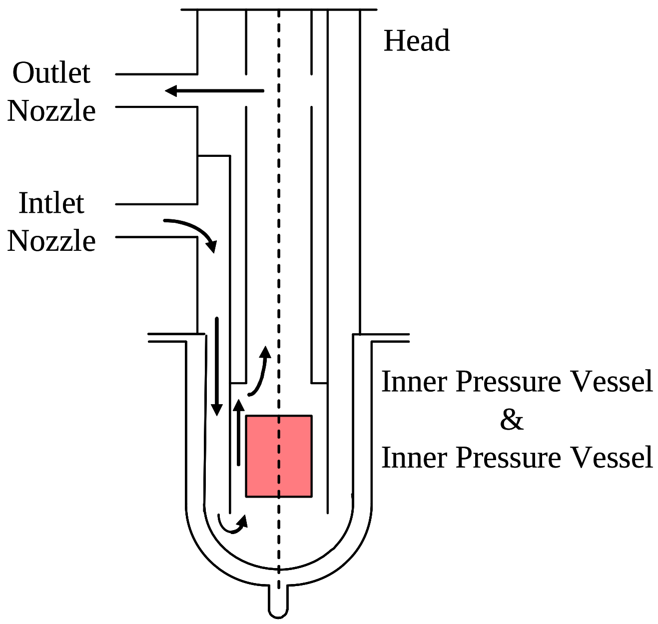

FIG. 4. Schematic diagram of the IPS inner flow.

The outer pressure vessel is a 321 stainless steel of 5.0 mm thickness and has 9 SPNDs. Inner pressure vessel is a 321 stainless steel of 4.0 mm thickness and its upper part is designed collar form to prevent cooling water stagnation. Restraint of the IPS from self-weight and seismic loads is achieved by its support system. One is a box beam in a pool wall and the other is a bracket on top of the HANARO core. Fig. 5 shows the vertical cross-section of the IPS.

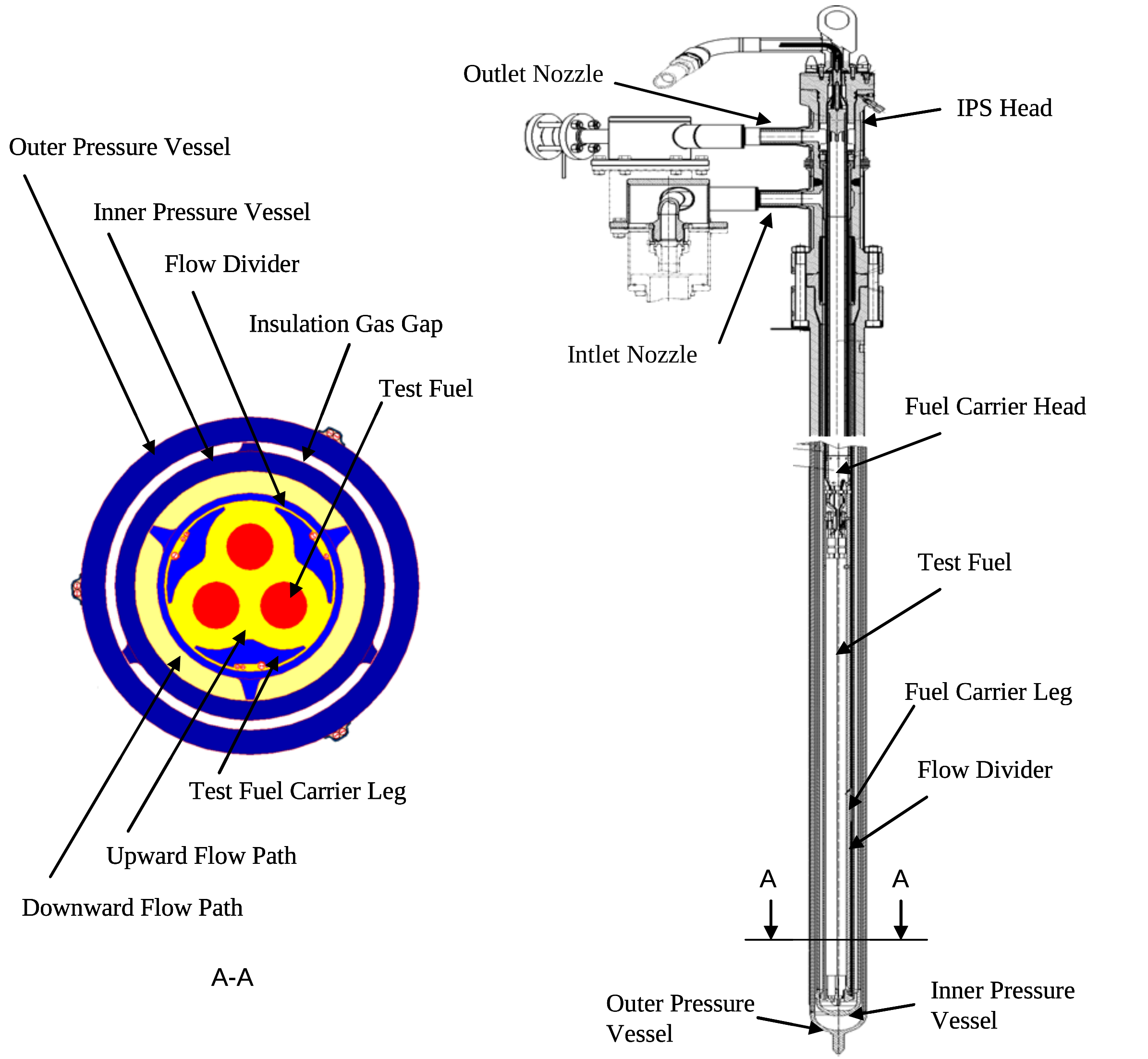

FIG. 5. Vertical cross-section of the IPS.

3. Installation

The equipment of the FTL were installed from July 2006 to March 2007. A 3-dimensional view of the OPS installation is shown in Fig. 6. The safety related components are installed in FTL room 1, and the non-safety related components are installed in FTL rooms 1 and 2. The safety barrier is installed between the safety related components and the non-safety related components in FTL room 1. The control system and data acquisition system are installed in the FTL control room located in the reactor hall.

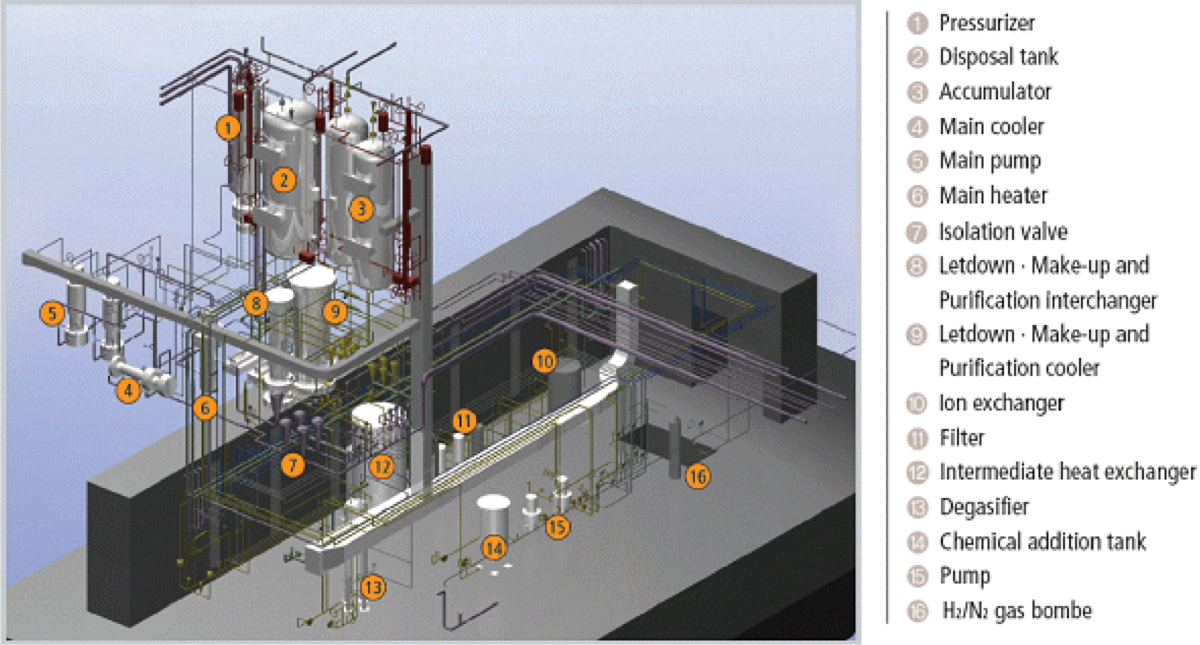

FIG. 6. 3-dimensional view of the OPS in the FTL room 1 & 2.

4. Conclusions

The design and installation for the FTL in HANARO were introduced. The FTL is a facility which could conduct a fuel irradiation test at HANARO. The FTL is composed of an IPS and an OPS. 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 OPS contains the process systems such as a main cooling system, an emergency cooling water system, a purification system, etc. which are necessary to maintain the proper fluid conditions. The application fields of the FTL are as follows.

- Nuclear fuel irradiation behavior test at the operating condition 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 commissioning of the FTL will be conducted by 2008. The FTL will be used for an irradiation test of high burn-up PWR fuels after the commissioning is completed. The FTL will also be used for the advanced fuel irradiation test and could maximize the usage of HANARO.

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