Commissioning Experience for Reactor and Primary Cooing System of Jordan Research and Training Reactor (JRTR)

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The primary cooling system is designed to cool the heat generated from the core of a pool-type research reactor (JRTR, Jordan Research and Training Reactor). The system penetrates the pool and is connected to the reactor. The reactor and pool should be kept clean as a caution during commissioning because re-cleaning or disassembling and re-assembling will require additional time and cost. Thus, the reactor, fluid equipment, instruments and pipes should be fabricated based on the cleaning procedure in accordance with the requirements of the related code and standard. The reactor and primary cooling system should be installed using the installation procedure because the interface between the reactor assembly and the related system including the fluid system, platform, pool door, instruments, detector conduits, and pool covers inside the pool is considerably complicated. After the primary cooling system is installed in the reactor and pool, system flushing is performed to remove any dust, particles, or other foreign matter using closed and open flushing methods. After the flushing and required CATs (Construction Acceptance Test) are completed and the demineralized water is filled in the pool and system, the SPT (System Performance Test) including measuring the system flow rate and pressure loss and checking the function of the pumps, valves, and system alarms can be started. Because the control valve is not used in the safety system, the pressure loss of the system is adjusted by replacing the system orifice plates with the planned procedure to meet the system flow rate during the SPT. The PST (Pre-Service inspection Test), which is a prerequisite for developing an in-service test program can be performed after the results of SPTs satisfy the acceptance criteria of the tests.

1. Introduction

JRTR (Jordan Research and Training Reactor) was developed for various neutron applications and training. JRTR is an open pool-type research reactor, which consists of the reactor assembly and the related fluid systems inside the pool. The fluid systems are designed for adequate cooling of the heat generated from the reactor core [1], purifying the pool and primary cooling system, and providing a good shielding barrier for many kinds of radio-nuclides from the reactor core [2]. Before starting the normal operation of JRTR, the reactor assembly, the related systems, pool, and instruments should be installed, flushed, and inspected. In addition, the systems should be tested to check whether they are operating well according to the performance requirements. In this paper, the methodology and procedure for the installation, flushing, and commissioning tests of JRTR are described.

2. Fluid System and Instrument

2.1. System description

The PCS circulates demineralized water to remove the heat produced in the core. The heat is transferred to the cold water of the Secondary Cooling System (SCS) through the PCS heat exchangers. The PCS flow is returned to the pool through the PCS discharge header. The pool inlet PCS pipe is branched to cool the grid plate. The pool water flows through the upper guide structure, core and outlet plenum, and then returns to the PCS. The PCS circuit is provided external to the RSA. The system consists of two parallel 50% capacity pumps and heat exchangers, a decay tank, siphon breakers, flap valves, flow orifices, strainers, PCS discharge header, all necessary interconnecting pipes, valves, and instruments.

A reactor outlet PCS pipe is connected to the decay tank. The outlet pipe of the decay tank is split into two inlets of the PCS pumps. Each pump outlet is connected with the inlet of each heat exchanger. Two heat exchanger outlets are joined into one common pool inlet PCS pipe to return the cooling water to the reactor pool. During normal operation, some of the cooling water flows into the reactor pool through the grid plate nozzle. The other flows to the pool bottom through the PCS discharge header. Then the suction force of the PCS pump drives down the pool water from the UGS and the downward flow goes through the core. The coolant is directed to the vertical decay tank through the reactor outlet PCS pipe. The decay tank is designed to provide enough transit time to ensure that the N-16 activity sufficiently decreases before the coolant leaves the shielding room of the decay tank [3]. Hence, the radiation level in the PCS equipment room is kept much lower than that in the decay tank room. The coolant discharged from each PCS pump transfers the heat generated in the reactor to the SCS through each PCS heat exchanger. After passing through the heat exchangers, the cooled primary coolant comes to the grid plate nozzle and to the bottom of the reactor pool through the PCS discharge header [4]. After the PCS pumps stop, the PCS flow rate is slowly decreased by the inertia force of flywheels attached to PCS pump shafts, and then the flap valves installed on the reactor outlet PCS pipe inside the reactor pool are passively opened. The openings of these valves provide flow paths for the natural circulation from the flap valves through the core and the UGS to remove the core decay heat. The PCS also provides system parameters on the OWS such as the flow rate, temperature, reactor pool level, pressure, and valve positions.

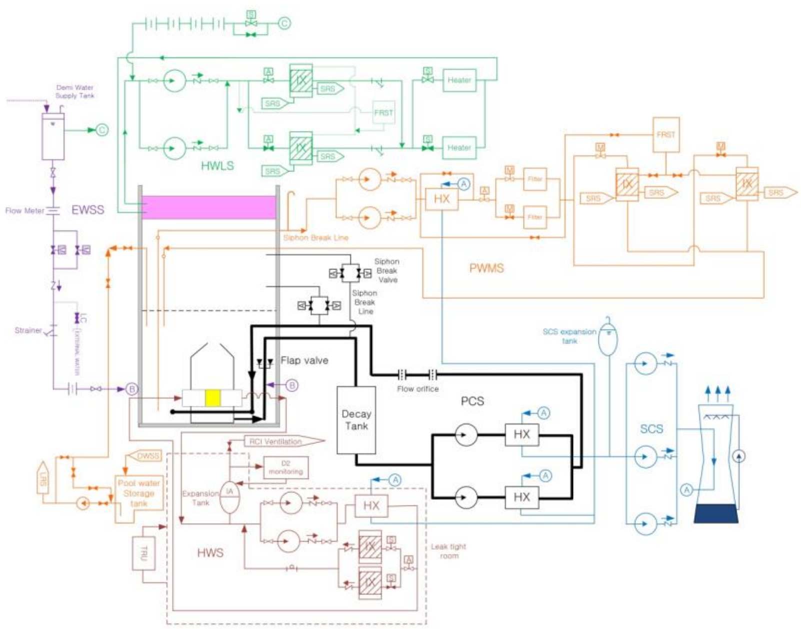

FIG. 1. Flow Diagram of Reactor Cooling and Connected Systems (Open Flushing)

2.2. Commissioning Test for PCS and instruments

After the PCS is installed in the reactor and pool, the system flushing is performed to remove the dust, particles, or other foreign matter using closed and open flushing methods. Before the PCS is connected to the reactor structure assembly (RSA) and in-pool pipes, the closed flushing is performed by installing a temporary bypass piping as shown in *Fig 2*. To check whether the pressure loss of the system is changed or not, the temporary pressure gages are installed between the inlet and outlet of PCS strainer, PCS pumps, and PCS heat exchangers. PCS pumps are used alternately to re-circulate after the demineralized water is supplied from the demineralized water supply tank to the system and the air of the system is fully vented. If the pressure losses increase and the strange materials are expected to be found, the flushing work is stopped and the temporary mesh of PCS strainer is checked (*Fig. 3*). The location of the PCS strainer is determined for convenience of the flushing and the procedure of the disassembly and assembly is considered in advance during the system design. Because the system pressure loss is changed during the flushing, the time of the system operation is controlled to protect the PCS pumps.

The flow design is shown in *Fig. 4*. The thermal design flow (TDF) is determined as the minimum flow to cool the core and supply for the thermal-hydraulic analysis during normal operation and a safety analysis during an accident. A safety analysis had been carried out using the initial primary cooling water flow rate based on the minimum flow rate and uncertainty of the instrument. The results of the safety analyses for the design basis events using lower limit of the TDF are ensured that the minimum CHFR is greater than the design limit and no fuel failures are predicted. The TDF is also used for the LCO (Limiting Conditions for Safe Operation and Surveillance Requirements) and the PCS flow rate shall be maintained as more than the minimum flow rate. When the PCS flow rate decreases below the TDF, the operator should shut down the reactor. Thus, the design target flow of the PCS pump is a BEF (Best Estimate Flow) to satisfy the TDF. However, the PCS flow is determined based on the pressure loss of the system, which is the calculated value and can be determined as the real value after measuring the values during the SPT. During the closed flushing, the pressure loss of the system decreases due to exclusion of the core. Because the pressure loss is decreased as soon as the closed flushing is started, the operator checks that the flow rate approaches the maximum design flow, which is related to the pump NPSH and pump run out. While the initial flushing is performed, the pressure loss of the system starts to increase due to dust or foreign matter. If the flow approaches toward TDF, the valve control, the pump stop and strainer mesh cleaning are conducted for the PCS flow to be kept between the TDF and maximum design flow rate during the flushing.

To remove foreign material from the system, the valves are designed and installed to perform the draining and venting of the system easily. Whenever the flushing is performed, the vibration, noise, and leakage of the PCS pump, heat exchanger, and pipes are checked to protect the equipment. When the differential pressure of the PCS strainer maintains a stabilized state for 30 minutes, the closed flushing is completed. After the PCS is connected to the RSA and PCS discharge header, open flushing can be started, as shown in *Fig. 1*. Before operating two PCS pumps simultaneously, each pump is used alternately to decrease the flow rate of the PCS because the differential pressure of system is abruptly changed while foreign materials and dust accumulate in the PCS strainer and decay tank. When PCS pump operation during 30 minutes under normal operation conditions is possible, two PCS pumps can be simultaneously used to flush the entire PCS.

After the flushing and the required Construction Acceptance Test (CAT) are completed and the demineralized water is filled in the pool and system, a System Performance Test (SPT) is performed. Because the control valve is not used in the safety system, the pressure loss of the PCS is adjusted by replacing the system orifice plates with the planned procedure to meet the system flow rate during the SPT. The allowable band of the PCS flow including the measurement uncertainty and the margin for the flow that decrease during operation is checked by controlling the flow orifice during the start-up test (*Fig. 4*). The cavitation of the pump is created and a subsequent collapse of vapor bubbles occurs in areas where the pressure locally drops to the fluid vapor pressure. The extent of cavitation depends on how low the pressure is in the pump. Thus, the NPSH (Net Positive Suction Head) margin is checked to protect the pump.

NPSH margin = NPSHa / NPSHr (1)

NPSHa (Available NPSH) = $(H_a + H_s) - (H_{vp} + H_v + H_L)$ (2)

Here, H_a: *Atmosphric pressure head*

H_{vp} : *Vapor pressure head of pump suction*

H_v : *Velocity head of pump suction*

H_v : *Statcic head of pump suction*

H_L : *Friction loss head of pump suction*

NPSHr (Required NPSH) : minimum absolute pressure that has to be present at the suction side of the pump to avoid cavitation

After the PCS pumps stop for a normal or abnormal operation, the PCS flow rate is slowly decreased by the inertia force of the flywheels attached to PCS pump shafts to remove the residual heat before the flow inversion by the natural circulation. During a LOOP (loss off-site accident), the coast down flow is used to remove the residual heat, and is utilized as information of the safety analysis. The validity and consistency of the designed coast down flow rate for a JRTR PCS pump are evaluated using a simulation software package, the modular modeling system (MMS) [5].

$$\frac{d\dot{m}}{dt} = \frac{1}{(L/A)}\left((P_e - P_l - \rho K_{dz}) - k_{fr}\dot{m}|\dot{m}|\right) \quad (3)$$

Here, $\dot{m}$: *coolant flow rate*

L/A :*equivalent inertia length for the system*

P_e : *the pressure at the entering port*

K_{dz} : *elevation rise*

k_{fr} : *flow resistance*

$$I\frac{d\omega}{dt} + C\omega^2 = 0 \quad (4)$$

Here, I : *the moment of inertia of the pump flywheel*
ω :*the pump angular velocity*
C : *the proportional constant*

To confirm whether the coast-down flow rate satisfies the required values for a safety analysis during SPT, the electrical power supplied to two PCS pumps is cut off at the same time as shown in *Fig.5*. The measured coast down flow is confirmed to be well above the value required by the safety analysis.
After the residual heat has been sufficiently reduced by the coast-down flow rate with the flywheel, the flap valves installed on the reactor outlet PCS pipe inside the reactor pool are passively opened. The opening of these valves provides flow paths for the natural circulation from the flap valves through the core and the UGS to remove the core decay heat. As shown in *Fig. 6,* the flow direction across the flap valve of the natural circulation is the same as that of the normal pump operation. However, the flap valve should be open to provide the flow path during natural circulation mode, and closed to prevent the core by-pass flow during normal operation mode. When the PCS pumps are operating and the flow across the flap valve increases higher than the design criteria for closing the flap valve, the flap valves are designed to be closed. When the PCS pumps stop, the flap valve is designed to be passively opened by the pressure difference across the flap valve utilizing the disc weight and weight balance in the flap valve. A test was conducted to verify the performance at the manufacturer's experiment facility.

$$\Delta P_{flap\,valve} = k \frac{1}{2} \rho v^2 \qquad (5)$$

Here, k : *the resistance coefficient of flap valve*
v :*the velocity through the flap valve*

Four flap valve position switches are installed at each flap valve and tested to verify the closing of the flap valves during a power operation, and their opening during natural circulation mode. A RPS (Reactor Protection System) reactor trip by a not- fully closed flap valve signal is provided and tested when an inadvertent opening of the flap valve reduces the core flow due to a bypass flow through the not-fully closed flap valve. The opening time of the flap valves is also checked and compared based on the acceptable range.

Because the purpose of the PCS is to provide the necessary primary coolant flow to the reactor core and spaces to install instruments for actuation and control signals to the RPS, RRS (reactor regulating system), PAMS (Post Accident Monitoring System), and so on, the primary cooling water pressure, flow rate, temperature, pool level, and valve position are measured and tested to give the operator a complete picture of the system's condition. The alarm and discrepancy of the instruments are also checked during the SPT.

The PST (Pre-Service inspection Test) is a prerequisite for developing the in-service test, which is performed for the KEPIC MN components of PCS pumps, siphon break valves, and flap valves in according to the KEPIC MO. The PST is performed after the results of the SPTs satisfy the acceptance criteria of tests.

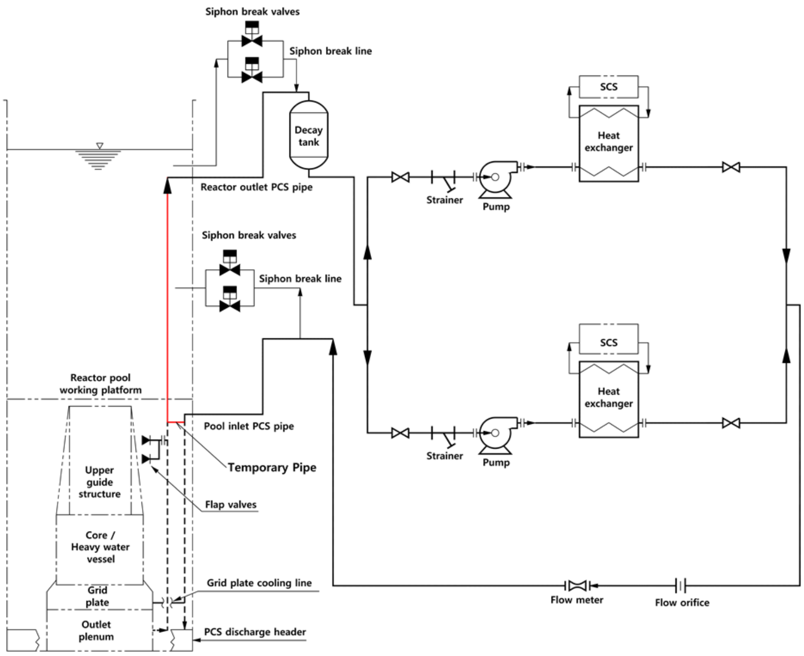

FIG. 2. Primary Cooling System for Closed Flushing

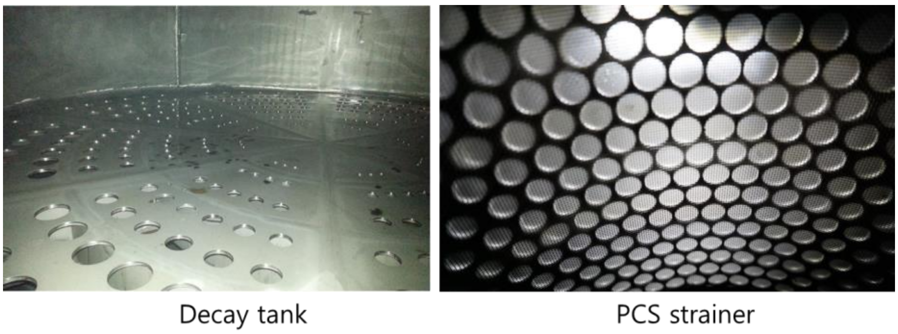

FIG. 3. Inspection Result of Decay Tank and PCS Strainer after Flushing

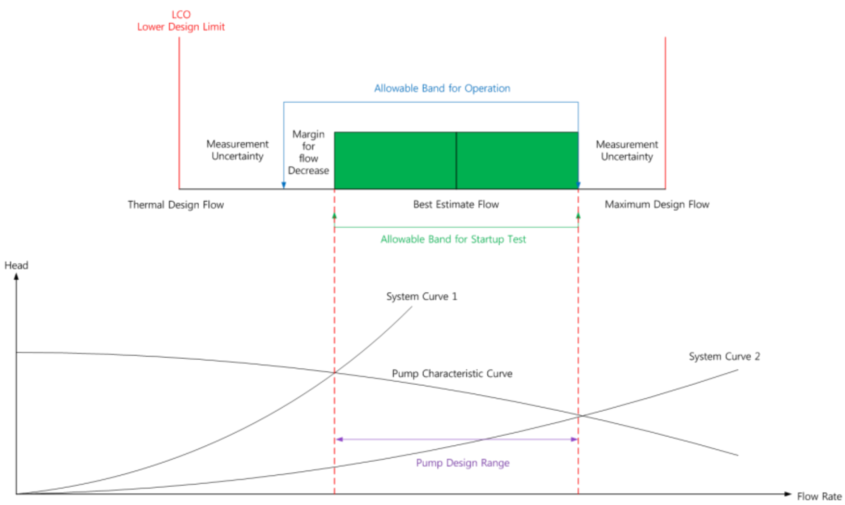

FIG. 4. PCS Pump curve and PCS flow design

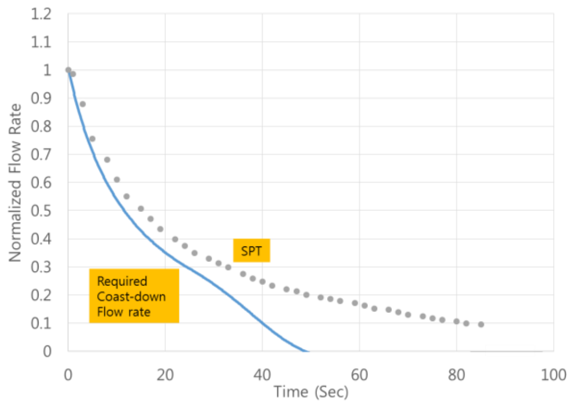

FIG. 5. Coast-Down Flow using Flywheel of PCS Pump

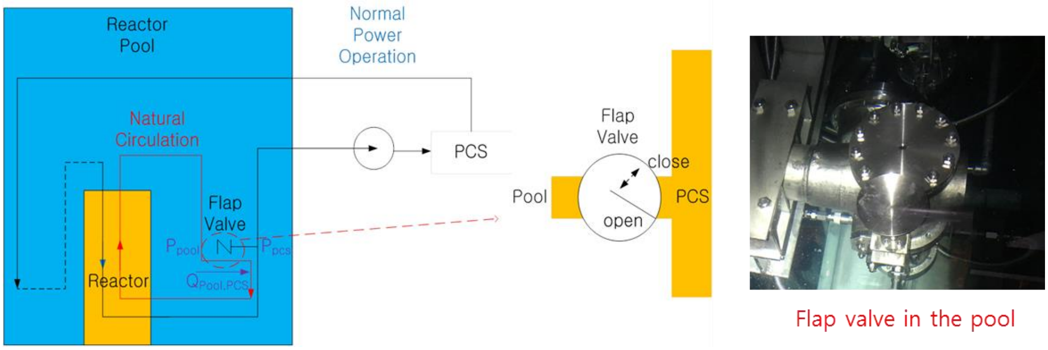

FIG. 6. Flap Valve installed in the Pool

3. Installation and Commissioning of Reactor Assembly

The reactor and primary cooling system are installed by following the installation procedure because the interface among the reactor assembly, the related system, platforms, pool door, Pneumatic Transfer System (PTS), I&C detectors, detector conduits, and pool cover inside the pool is considerably complicated (*Fig. 7*). The outlet plenum and grid plate are first installed and the alignment of beam ports is checked using a laser tracker. After the heavy water vessel is installed, the grid plate cooling line and the heavy water system (HWS) pipe are connected, and the helium leak test of the HWS is performed. Pool water is filled to perform a leak test of a beam port assembly. After draining of the pool water, the Control Absorber Rod (CAR) and Second Shutdown Rod (SSR) guide tubes, reflectors, dummy fuels, upper guide structure, CRDM (Control Rod Drive Mechanism), SSDM (Second Shutdown Drive Mechanism), and the working platform are installed utilizing the laser tracker and special tools. After the SPT for CRDM, SSDM, and pool door are implemented, the pre-service inspection including the visual inspection of the reactor component and HWV inner shell measurement are performed using an under-water camera and inner shell measurement tool.

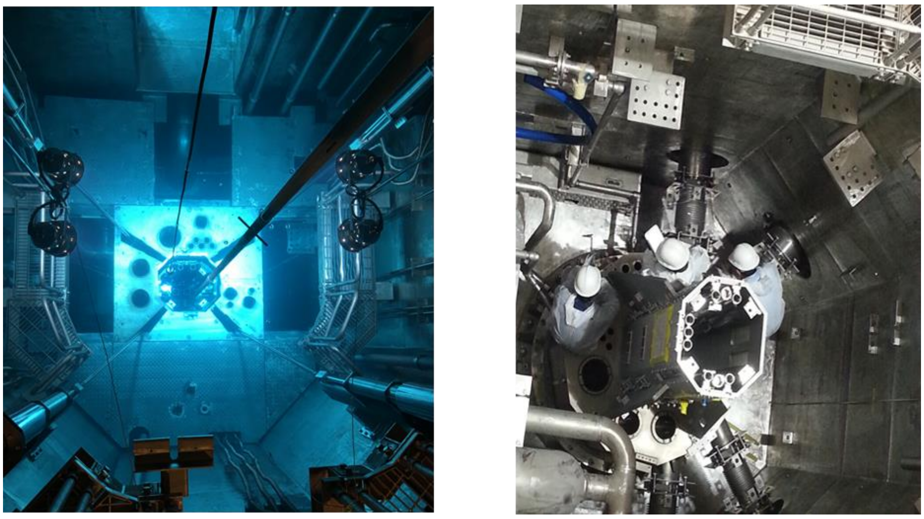

FIG. 7. Reactor assembly and the related system in the pool

4. Conclusions

Before starting normal JRTR operation, the reactor assembly, fluid system, and instruments were installed by following the interface procedures. Closed and open system flushing were performed to remove dust, particles, or other foreign matter in the system. After the flushing and required CAT are completed, the SPT including measuring the system flow rate and pressure loss and checking the function of pumps, valves, system alarms, CRDM, SSDM, and pool door were performed. It was shown that the SPT results satisfied the acceptance criteria. The PST for the system and PSI for the reactor assembly, which is a prerequisite for developing an in-service test and inspection program, were performed.

5. Acknowledgement

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6. References

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