The Effect of Presence of Irradiation Rig on Research Reactor Core Flow Distribution

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1. Introduction

One of major purpose of research reactor is to irradiate various materials for commercial and research applications such as medical isotopes [1]. Research reactor is open-pool type and core is cooled by single phase downward forced convection flow. The core has 22 fuel assemblies (FA) which are composed of 21 fuel plates. Inside the core, 5 irradiation holes are surrounded by FAs. During on-power loading of irradiation holes, overall core flow is affected by change in flow resistance of the irradiation hole. If the core flow is maldistributed, thermal margin of research reactor is significantly reduced [2]. Therefore, scattered flow velocity of assemblies should be higher than certain value [3] and distributed within 5 % range. This study investigated the effect of the presence of the irradiation rig on the core flow distribution. Flow velocity of FA and fission moly assembly (FM) were measured with and without irradiation rig in real-scale test facility.

2. Method and Results

2.1 Calibration of FA and FM simulator

Core simulator was designed to realize core hydraulic characteristics of actual research reactor and also allow flow measurement [4]. Core simulator was manufactured in real-scale because Reynolds number of research reactor core flow is not located in completely turbulent flow regime. Flow measurement adopts indirect methodology to guarantee high accuracy without flow distortion; estimating mass flow rate from measuring pressure drop. Pressure taps were machined at interval for standard fuel assembly (SFA), follower fuel assembly (FFA), and FM simulator. To obtain pressure drop correlation of FA and FM, single channel experiment was performed separately in advance of core flow experiment. Concept of single channel experiment is simulating the core flow as a single flow path to calibrate FA and FM. Test section of each assembly type was manufactured e.g. guide tube and grid plate. For all FA and FM simulators, pressure drop correlation was developed in the form of equation 1.

$$\dot{m}_{fuel,i} = a\Delta P_i^b \tag{1}$$

Where, $\dot{m}_{fuel,i}$ is mass flow rate of assembly $[kg/s]$, ΔP_i is pressure drop along narrow rectangular channel $[Pa]$.

2.2 Real-scale test facility

After single channel experiment, FA and FM simulators were loaded in the core box, which is enclosed by water tank to mimic open-pool condition. To simulate flow from pool water management system (PWMS), pipe distributor was connected to the bottom of the water tank. Core simulator was connected to test facility with 2 inlet and 2 outlet pipes (Figure 1). Real-scale irradiation rig mockups were loaded on irradiation holes as shown in Figure 2. Rig mockup can be removed by withdrawing dedicated equipment.

Table I Core inlet boundary conditions

Parameter	Value
Core inlet mass flow rate	565 kg/s
Core inlet flow ratio	1: 1
PWMS mass flow rate	~7 kg/s
Core inlet temperature	35 ℃

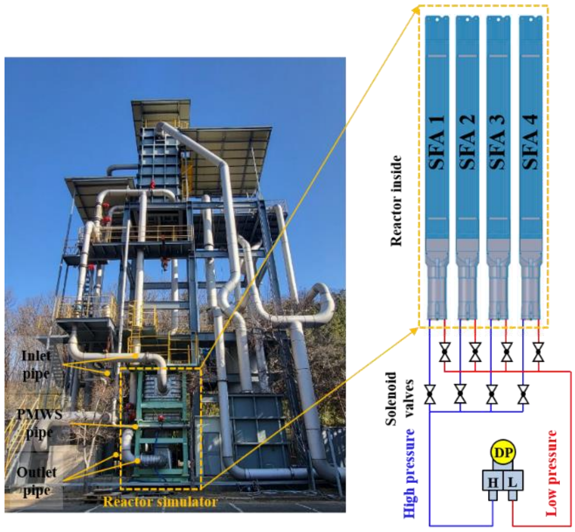

Fig 1 Photo of ROAR (with schematic of relay system)

To investigate hydraulic features of research reactor, real-scale test facility named ROAR (Real-scale hydraulic test loop of advanced research reactor) was constructed [5]. ROAR consists of primary cooling system (PCS) pumps, immersion heaters, and control valves to implement the core inlet hydraulic boundary conditions (Table I). Due to insufficient number of differential pressure (DP) transmitters, relay system was adopted to measure DP of FA and FM in parallel. In the relay system, pressure signal is blocked or passed through by manipulation of solenoid valves, which are controlled by microcontroller unit. During the sequential measurement, fluctuation of inlet boundary conditions was small enough to assume steady state.

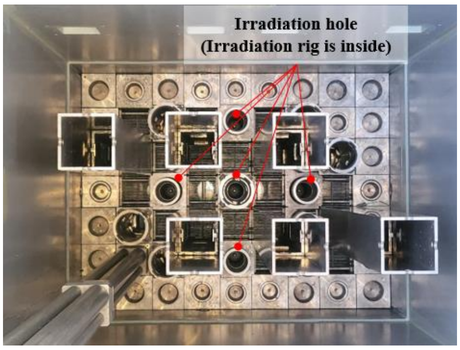

Fig 2 Research reactor core simulator

2.3 Test result

To investigate the effect of presence of the irradiation rig on the core flow distribution, rig mockup in the center irradiation hole was removed. As indicator for evenly distributed flow, flow nonuniformity U_{flow} is defined as equation 2.

$$U_{flow} = \left|(v_{avg} - v_i)/v_{avg}\right| \times 100\ \% \qquad (2)$$

Where, v is flow velocity $[m/s]$, subscript avg means assembly averaged, i is serial number of assemblies. Flow nonuniformity and measuring uncertainty are summarized in Figure 3 and 4. Conservatively, flow nonuniformity and measuring uncertainty can occur simultaneously in actual research reactor. Nevertheless, flow nonuniformity of each assembly type still satisfies the criteria ($< 5\ \%$) regardless of presence of irradiation rig. Average flow velocity is compared for each type of assembly in table II. When the rig was removed, flow velocity of each type was slightly decreased, but was still larger than design value with enough margin.

Table II Average flow velocity (dimensionless form)

	$\frac{v_{avg,w/o\ rig}}{v_{avg,w/rig}}$
SFA flow	0.996
FFA flow	0.999
FM flow	0.991

Increase of mass flow rate of irradiation hole is estimated indirectly by subtracting assembly flow from total PCS flow. This value indicates mass flow rate of gap channel, which has no contribution to cool either fuel plates or FM targets. When the rig was removed, mass flow rate of gap channel was 2.7 % increased due to flow path enlargement. However, considering the fact that research reactor core is parallel channel system, the effect of the presence of irradiation rig was diffused out to numerous surrounding flow channels.

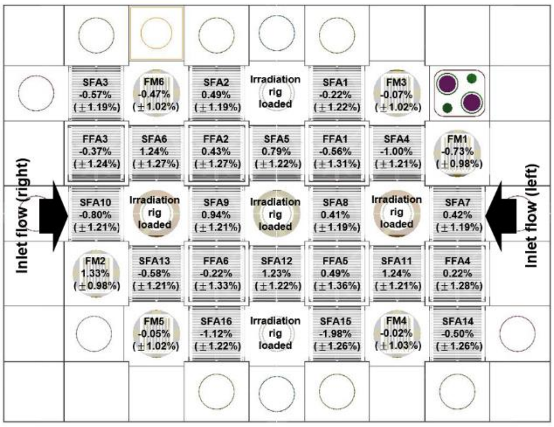

Fig 3 Core flow distribution (rig loading)

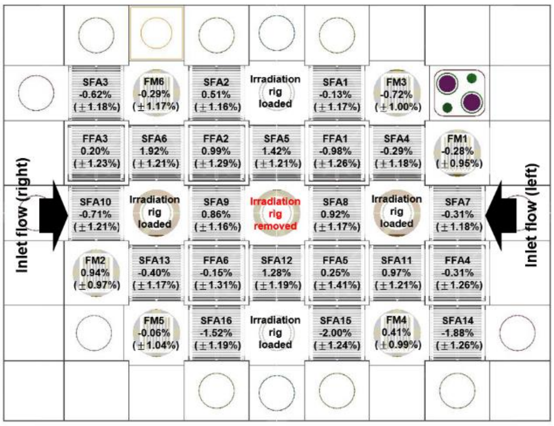

Fig 4 Core flow distribution (rig removal)

3. Conclusion

Research reactor core flow was successfully measured for irradiation rig removal condition in real-scale test facility, ROAR. It was found that even when the rig was removed from the irradiation hole, design criteria for flow velocity and distribution of FA and FM were satisfied. Obtained data will be used for supporting thermal-hydraulic safety analysis results obtained from hot channel method.

REFERENCES

[1] C. Park, B.C. Lee, J.S. Ryu, Y.S. Kwon, Overall Design Features and Key Technology for KJRR, Transactions of the Korean Nuclear Society Autumn Meeting, October 29-30, 2015, Gyeongju, Korea

[2] S.K. Park, Introduction to Safety Analysis Approach for Research Reactors, Transactions of the Korean Nuclear Society Autumn Meeting, October 27-28, 2016, Gyeongju, Korea

[3] KAERI, 2022, Kijang Research Reactor Thermal Design Flow, KJ-033-KC-387-024

[4] KAERI, Design and Fabrication of Core Flow Distribution Test Mockup for Kijang Research Reactor, to be published

[5] D.K. Hwang, et.al., 2023, Plant-scale experiments of an air inflow accident under sub-atmospheric pressure by pipe break in an open-pool type research reactor, Nucl. Eng. Technol.