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Preliminary MARS-KS Analysis of OPR1000's Scaled Thermal-Hydraulic Facility, URILO-II

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1. Introduction

To ensure the safety and reliability of nuclear power plants, it is ideal for integral effect test (IET) facilities to be designed with the same shape as the reference plant. However, due to budget, space, and technological limitations, these facilities are often scaled down from the reference design. These scaled-down IET facilities have been utilized for decades to evaluate the thermal margins or performances at LOCA and safety systems for various reference plants. It has been important to accurately capture the timings of various thermal-hydraulic phenomena in IET facility design, and thus, most major facilities maintain the same height as the reference plant to maintain a matching time ratio [1–7]. Although 1/1 height facilities can provide reliable experimental data, their large scale and high operational demands make it difficult to modify the design or add new systems for testing or educational purposes. To facilitate a broader range of experimentation encompassing new technologies and concepts, as well as academic and educational initiatives, there is a need for IET facilities that are both more compact and versatile.

The overall purpose of this study is to conduct integral effect tests of various new nuclear safety technologies and provide educational opportunities through experimentation and observation. In contrast to existing large-scale IET facilities, the new IET facility have been designed to be more compact and versatile while still accurately simulating the thermal-hydraulic (TH) phenomena of nuclear power plants. The reference nuclear power plant for this study is the Optimized Power Reactor 1000 (OPR1000), which is a 1000MW-class PWR nuclear power plant and the most common type of operating nuclear power plant in Korea. To achieve the purpose, the IET facility, named UNIST Reactor Innovation LOop-II (URILO-II), has been designed to reduce the reference to 1/8 in height and 1/10 in diameter [8]. The key design feature of this IET is to use a Freon instead of water as the working fluid having advantages that it can be tested under much lower pressure, temperature, thermal power condition.

The development of a more compact and versatile IET facility with educational purpose has the potential to not only improve the safety of nuclear power plants but also advance the field of nuclear safety research. By enabling a wider range of experimentation on new technologies and concepts, the IET facility can facilitate the identification and implementation of innovative safety measures that may not have been possible with previous large-scale IETs. Furthermore, the use of the Freon as a simulant fluid may have implications for the design and operation of nuclear power plants, as it could lead to the development of more efficient and cost-effective systems.

When conducting experiments with Freon for scaling, it is essential to assess the degree of similarity and distortion in experimental results, as different fluids are used. In this paper, we introduce design of URILO-II and conduct preliminary TH code analysis to figure out the scaling matching.

2. Methods and Results

2.1 Description of URILO-II facility

The designed URILO-II, based on scaling analysis, is illustrated in Figure 1. The loop configuration comprises a reactor pressure vessel (RPV), four reactor coolant pumps (RCPs), a pressurizer, two steam generators (SGs), a hot-leg, and a cold-leg. Both the RPV and SGs are equipped with sight glasses to enable observation of internal phenomena. During transient states, the thermal-hydraulic phenomena occurring in the core and SG U-Tubes will be visualized, facilitating phenomena and distortion analyses. The flow area and axial elevation have been designed according to the geometric ratio.

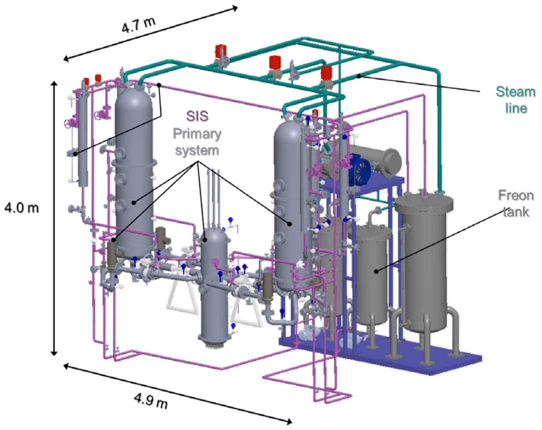

Fig. 1. Schematic design of URILO-II [8].

As shown in Table 1, the normal operating conditions were derived by single and two-phase flow scaling analysis based on Ishii's three level scaling method from previous study [8]. URILO-II operates at a pressure of 2.65 MPa, the full power of 1.7MW, a core inlet temperature of 61 ℃, and an outlet temperature of 75 ℃. The thermal power of the actual simulation to be manufactured will be 0.12 MW (7% of full power), which is a sufficient condition for the decay heat simulation with considered heat loss.

This facility is set to be manufactured next year, and upon completion of design verification experiments, it will be utilized for testing various passive safety systems and advanced technologies based on the 4th Industrial Revolution, as well as for educational and training purposes for nuclear engineering students.

In scaling analysis results from previous study [8], the similarity of two-phase flow natural circulation can secure the same phenomenon because the important dimensionless numbers (Subcooling number, Phase change number, Drift flux number, Froude number, and Exit quality number) are matched to near 1 with the reference. In addition, the friction number and the orifice number can be similarly matched by applying an appropriate flow restriction according to the pressure drop when constructing the experimental facility.

For single-phase circulation, which is an important phenomenon in the early stages of accident situations, the Richardson number – representing the ratio of buoyancy due to temperature differences to fluid inertia – is well-matched at 1.0. However, due to the low heat transfer rate of freon fluid, the fluid and solid heater transfer will be somewhat not matched with OPR1000. Therefore, single-phase natural circulation will be expected to coexist with a portion of two-phase, and the actual degree of distortion was preliminary accessed with MARS-KS analysis.

Table I: Normal operation conditions for OPR1000 and URILO-II

Parameter	OPR1000 (P)	Model (M)	Ratio (M/P)
Power (100%), MW	2815.0	1.7	1/1654
Pressure, MPa	15.514	2.65	1/5.9
Core inlet Temp., ℃	296.0	61.0	1/4.9
Core outlet Temp., ℃	327.3	75.0	1/4.4
Temperature diff., ℃	31.3	14.0	1/2.2
Inlet subcooling, kJ/kg	314.4	34.5	1/9.1

2.2 Preliminary Results of MARS-KS Analysis

A preliminary analysis was performed using the thermal-hydraulic analysis code MARS-KS to evaluate the operating conditions of the designed IET facility. The MARS-KS is the TH analysis code developed based on the RELAP5/MOD3.2.1.2 and the COBRA-TF, which has been used for nuclear power plant regulation in Korea. The modeling of this IET facility differs only in size and reactivity control from the actual reference and has the same shape and configuration, but the major difference was that Freon(R134a) was used instead of water as the working fluid. The thermal property file of R134a developed by Son and Bang [9] was used, which is required for MARS-KS analysis.

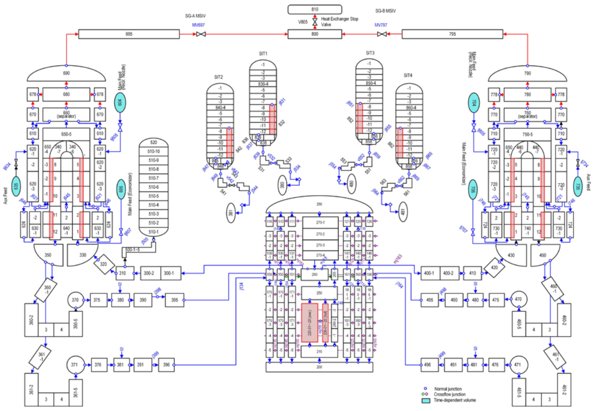

Fig. 2. MARS-KS nodalization of URILO-II facility for preliminary TH analysis.

According to the volume and length of the IET, the hydraulic component was modeled as shown in Fig. 2, and the primary system was set to maintain a pressure of 2.65 MPa as the design value. In the case of the secondary system, the R134a refrigerant operates at a pressure of 1.35 MPa, but in this preliminary analysis, the working fluid of the secondary system was simulated at 1.0 MPa and 40 ℃ with R134a. The pressure at the outlet of the pressurizer and the outlet pressure of the steam generator were inputted as the boundary conditions of the analysis. The heat structure was inputted to simulate the electric heating rods for the hot-channel and average channel in the core, and the heat transfer between the primary system and the steam generator u-tube was input to be removed by boiling on the secondary side.

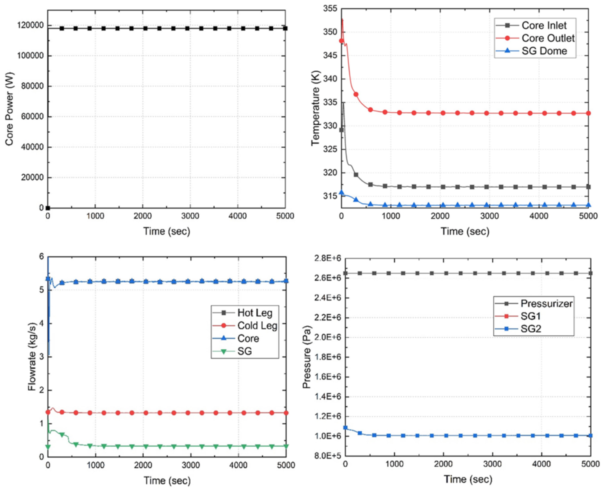

Fig. 3. Preliminary MARS-KS analysis results of URILO-II.

The analysis result with MARS-KS was shown in Fig. 3, and since the secondary side pressure and saturation temperature are lower than actual normal conditions, the core inlet temperature was analyzed to be about 15K lower. Due to the overall low core temperature, the specific heat capacity was lowered, so the temperature difference between the inlet and outlet of the core was 15.4 K, which was 1.4 K over from the design value of 14 K. The core flow rate was 5.2 kg/s, which was in good agreement with the design value. However, the MARS analysis result of URILO-II is still lacking in comparison with the current scale analysis value because the analysis instability of the secondary side and the verification of the properties of the Freon refrigerant are not complete.

Through the MARS-KS preliminary analysis, the analytical framework for URILO-II has been established. However, improvements regarding thermal properties and correlation modification of heat transfer coefficient of R134a are needed for more exact comparison. As a further works, by conducting analyses for normal operation and SBLOCA, and comparing the results with the reference, we expect to gain a more accurate understanding of the experiment facility's scaling accuracy.

3. Conclusions

In this paper, to confirm the design similarity of the OPR1000 scaled experiment facility, URILO-II, designed for education and research, we introduced the design details of URILO-II and conducted the initial analysis using MARS-KS. The MARS analysis results of URILO-II were still lacking in the verification due to fluid property values and need to further analysis. As a further work, we plan to compare the performance of URILO-II in normal operation and SBLOCA with OPR1000 to conduct design verification and determine the experimental scope.

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