Establishment of a test facility to visualize debris transportation

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1. Introduction

According to a report by the NRC, SECY-12-0093, large amounts of debris can have a critical effect on long-term cooling performance when entering the reactor core. The main influencing factor is the fibrous debris in the core. This causes the accumulation in the bottom of the core to hinder the flow of cooling water. For the complete interpretation of Long Term Core Cooling (LTCC), authorized power plants must prove that no chemicals, debris or fibrous debris affect the long-term cooling performance of the fuel.

The background of the study is that after the LOCA (Loss of Coolant Accident) accident, debris, which introduced into the reactor core, is deposited under the fuel assembly to block the cooling water flow. So, it hinders the long-term cooling performance of fuel. In order to respond to the request of regulators such as the NRC in the United States, a facility is needed to visualize the phenomenon that can occur during post-LOCA by utilizing the similar size scaled test facility. In addition, it is necessary to prove whether the power plant operator can control the inflow of cooling water by blocking the lower part of the fuel assembly when a large amount of debris is present by utilizing this test facility. In order to solve the licensing problem, it is important to mimic the phenomenon occurring in the reactor without distortion. Scaling is required for the design and manufacture of test facility.

In this study, scaling was performed based on the amount of cooling water evaporated in the reactor, and an actual test facility was designed.

2. Methods and Results

2.1. General scaling factors

Since the evaporation in the reactor core is the most important factor for the flow rate at the bottom of the core, changes in the amount of cooling water flowing into the core have been studied. (Variation of water head, variation of Hot Leg and Cold Leg size, and variation of downcomer size)

Factors for controlling the amount of cooling water flowing into the reactor core (Circulation water tank and head difference in the reactor core, piping size of hot leg and cold leg, and size of downcomer) are the most important factors when performing scaling and should be defined as follows:

- ✓ A similarity group has been determined to preserve the phenomenon between the experimental device and the actual power plant
- ✓ Determining the local or overall major parts of the experimental setup
- ✓ Providing test specifications for experimental equipment
- ✓ Quantification of distorted scaling factors

Scaling method to be mainly used is Hierarchal Two-tier Scaling (H2TS) Methodology, and is known as the best method to express the importance of Boric Acid Precipitation and Long Term Cooling.[1]

The H2TS methodology can be used to determine the dimensions and operating conditions of the experimental setup. These scaling criteria are expressed by the ratio of model and prototype, material properties, and shape. The basis for determining the Scaling Criteria is as follows.

- ✓ Working fluid to be used in test equipment-buffered or unbuffered boric acid actually used in power plants
- ✓ Material to be used in this experimental device-The difference of each element due to the difference in material properties is maintained by scaling
- ✓ Operating pressure of the experimental device-The maximum pressure of the experimental device will be about 2 bar
- ✓ Length and time-The most important phenomenon that can appear in the experiment is the change in physical properties due to the difference in density between turbulence and fluid
- ✓ Fuel Assembly Geometry-Fuel rods and other structures that go into the fuel assembly. The phenomenon occurring in the lower plenum and downcomer plays the most important role in forming the flow.

2.2 Scaling sensitivity analysis by head water difference

This study analyzed the change in flow rate due to the water head difference, which is the most important factor, to simulate the flow rate of the cooling water flowing into the test facility. In addition, scaling has been performed according to the flow rate, and the dimensionless numbers that should be preserved and corresponding design factors are summarized as below. First, an aspect ratio that maintains the same length reduction ratio in all directions in order to preserve multi-dimensional phenomena. Second, Froude Number to preserve pressure drop by head. In particular, the reactor's free water surface differs from location to location during pump operation, preserving this effect. Third, Wall shear stress Number are examined and preserved. It is the same as the wall friction coefficient, and the pressure drop relationship, that is, Euler Number, can be preserved only if this number is preserved. Finally, Euler Number that preserves the geometric shape. This is a dimensionless number that is preserved by itself, if the variables listed above are preserved. However, if the geometry is not preserved, such as the fuel assemblies, the Euler Number is designed to be preserved. It is set so that it does not cause distortion in the entire flow field, so that modeling is possible.

Table. 1. Dimensionless number

Dimensionl ess	Equation	Constraint	Note
Geometric shape	$\frac{L}{d_H}$	Aspect Ratio	Multi-Dimensional Effect
Froude Number	$\frac{v^2}{gd_H}$	$v = \sqrt{L}$	L : 1/2.59 v : 1.601
Shear Stress	$\frac{\tau}{\rho v^2}$	$f = 1$	Re
Euler Number	$\frac{\Delta P}{(\rho v^2)/2}$	$\left(f\frac{l}{D}+K\right)\frac{1}{2}\rho V^2 = 1$	Friction Loss

2.3 Result of scaling sensitivity by water level difference

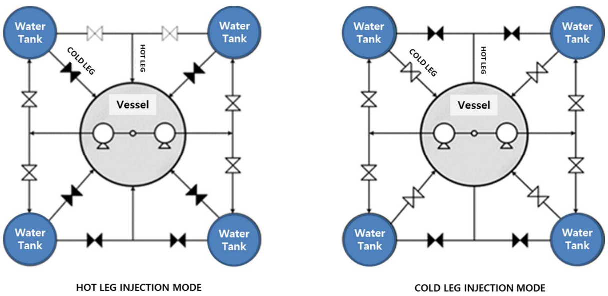

Fig. 1. In the case of Hot Leg Break and Cold Leg Break, the cooling water flow path

Two cases of Hot Leg Break and Cold Leg Break calculation results are shown in Fig.1. to simulate the flux of cooling water flowing into the experimental apparatus. In the hot leg break, coolant is injected in two directions, and in the cold leg break, coolant is injected in four directions to simulated pipe breaks. Using the verified code MARS, the size of the hot leg and cold leg, the diameter of the downcomer, and the coolant inflow due to the head difference have been examined. The nodalization for MARS-KS calculation is shown in Fig.2. As a result of MARS code, it can be seen that the flow that enters during cold leg break is increased in the form of almost linear due to head difference, and the change in flow rate increases as the K value changes. Also it can be seen that the Hot Leg Break has similar results.

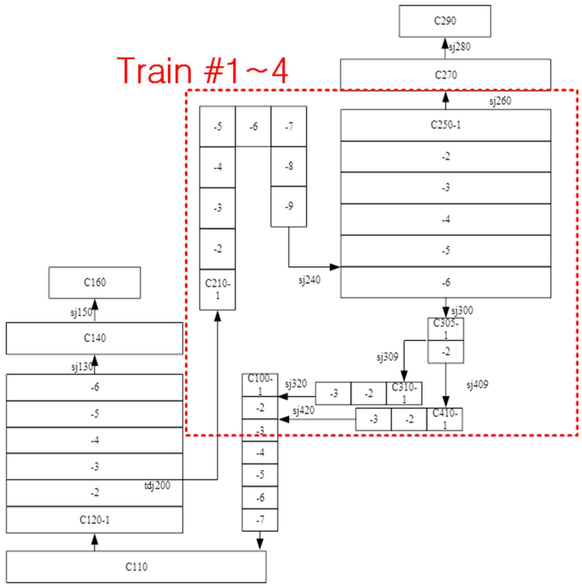

Fig. 2. Nodalization for MARS-KS calculation

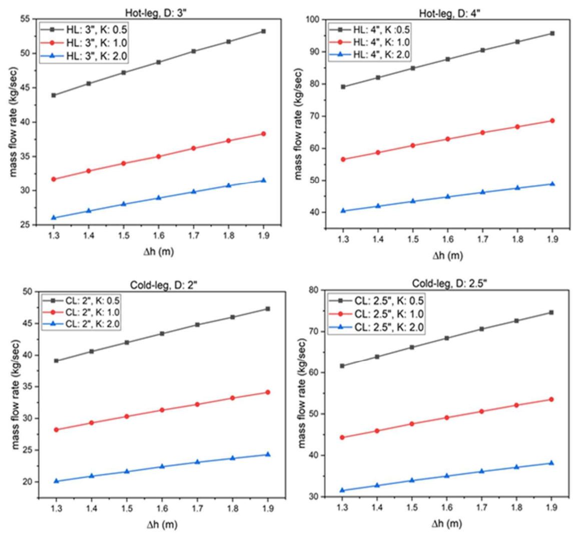

Fig. 3.The relationship between water level and flowrate according to K value change

3. Conclusions

The reactor core is made of acrylic material and is designed to visualize the flow and the movement / accumulation of debris (fiberglass) inside.

Scaling process has been analyzed and designed based on the inner diameter of the reactor core, which is

1.56m with 70mm thickness. As a result of the scaling analysis, the outer diameter of the downcomer has been determined to be 1.35m and the inner diameter to 1.31m. This value is very conservative, and the cooling water that is circulated through the core is corresponding to the amount of evaporation from the reactor core, and the values are from about 10 kg/s to 40 kg/s, respectively, which are considered to be the characteristics of each power plant.

The flow rate through the Hot Leg and Cold Leg cannot be adjusted by changing the diameter of the pipe, but a ball valve is installed for each pipe connected to the cooling water supply tank to control the K value and the velocity /discharge of flow.

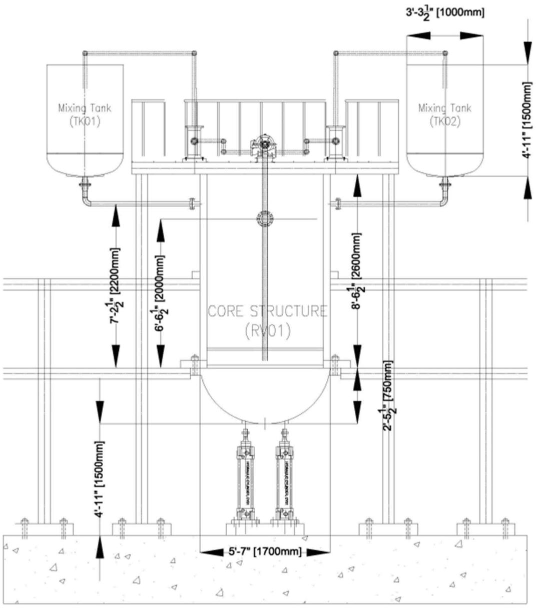

Fig. 4. Layout of test Facility (front view)

Fig. 5. Picture of the test Facility

4. ACKNOWLEDGMENTS

This work was supported by Development of Debris Transport Visualization in Reactor Vessel Test Facility for Nuclear Power Plants Safety of the Ministry of Science and Information and Communications technology (MSIT) grant funded by the Korea government Ministry of Knowledge Economy (No. 2018M2A8A1084229).

5. REFERENCES

[1] M., Kataoka, I., "Scaling Laws for Thermal-Hydraulic System Under Single Phase and Two-Phase Natural Circulation," Nuclear Engineering and Design, Vol. 81, pg. 411-425, 1984.