Numerical analysis on temperature distribution in the reactor internals of SMART

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1. Introduction

Korea Atomic Energy Research Institute (KAERI) has developed a new advanced integral reactor named SMART (System-integrated Modular Advanced ReacTor) since 1996. The SMART is one of energy conversion systems and an advanced integral pressurized water reactor (PWR) of a small size. Its main purposes are electricity generation and sea water desalination [1]. Figure 1 presents layout of SMART reactor vessel and the flow directions by pumps [2]. The SMART has a compact size and no large pipe systems penetrate the reactor vessel, which is different from a commercial loop-type pressurizer water reactor. It contains its reactor coolant and major primary circuit components in the reactor pressure vessel. All the main components such as steam generator inlet (SGI) region, eight stream generators (SGs), four reactor coolant pumps (RCPs), core, flow mixing header (FMH) assembly, and flow skirt are located in the reactor vessel.

2. Research methods

2.1 Flow domain configurations and meshing

The reactor assembly and the coolant flow directions are shown in Figs. 1. The reactor flow of 2,090 kg/s and approximately 15 MPa discharges to the steam generator, admits to flow mixing header assembly and flow skirt, goes upward through the core, and enters the pumps. The 8 steam generators are located with equal spacing at the annulus between the steam generator inlet region and the flow mixing header assembly. The 8 steam generators absorb the 330 MW heat energy in the coolant water. By the heat energy, the water in tubes of steam generators is changed to the super heated steam. The core generates 330 MW heat as much as the absorbed heat in the steam generators. These two parts consist of many pipes and rods. In the present study, the 8 steam generators and the core are assumed into porous media. The pipes for flow detour and the pressurizer are excluded in the present calculation.
Figure. 2. shows the numerical grids in the SMART reactor for this study. They are generated using GAMBIT grid generator. For grid dependency test, a grid refinement study was performed using two different mesh distributions of approximately 9 millions grids with both structured and unstructured cells and 20 millions grids with only unstructured cells.

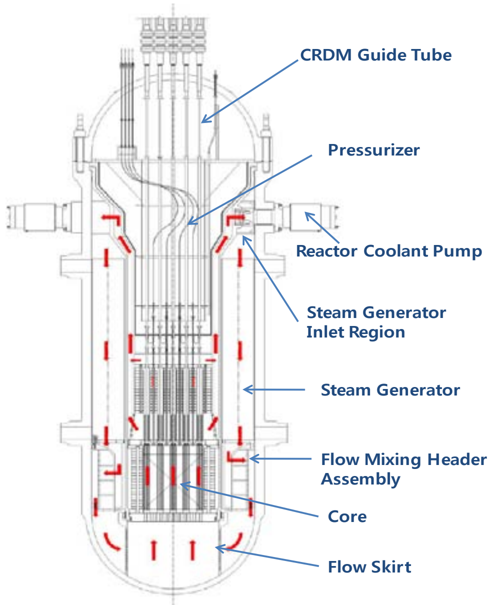

Figure 1. Layout of SMART reactor vessel [2].

2.2 Grid independency test

9M and 20M grids are presented in Fig. 2. H and W are the maximum height and the maximum width of the reactor, respectively. The relative pressure (P*) and relative velocity (U*) are the normalized values which mean that 0 is the minimum and 1 is the maximum in the whole system. The static pressure distributions for 20M grids are similar to those for 9M grids. Although the local velocity magnitudes are slightly different at y/H=0.21 in flow mixing header assembly, the results for 20M grids are similar to those for 9M grids in the most regions. The difference is caused by that local vortexes were differently generated by a size of grids in a chamber of the flow mixing header assembly.
A size of 20M grids was selected for further study, because the differences in results between 9M and 20M are rather small.

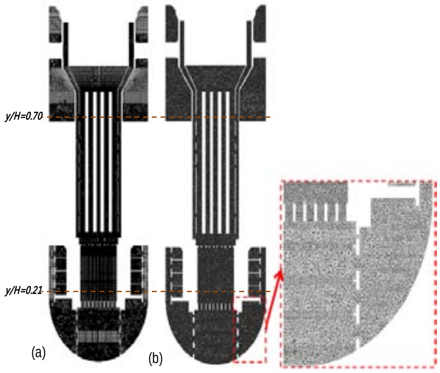

Figure 2. Mesh shapes and grid numbers:
(a) 9 millions; (b) 20 millions

3. Results and discussion

3.1 Results under nominal operation

The working flow through the steam generators admits to the flow mixing header assembly. This assembly is to spread out the flow uniformly once more. The water in a pair of steam generators directs to each floor in the flow mixing header assembly. In other words, the water divides evenly from the first to the fourth floor. Thus, the velocity magnitude is different locally in each floor. The main design purpose of this flow mixing header assembly is to mix the water flow from a steam generator with the others in case that one of the steam generator is broken down. It is related to temperature distribution toward the reactor core. We will deal with this event in following section.
The mixed water passes the flow skirt for spreading more uniformly, goes upward through the core, flows through the upper internals, and enters the pumps again in a loop. The SMART has many internals, which cause the varied velocity distributions and different temperature distributions in one closed system.
In the system, the temperature changes occur mainly in the steam generators and the core. It is because the core generates the 330MW heat energy and the eight steam generators absorb the 330MW heat as much as the heat generated by the core.

3.2 Temperature distributions by broken-down steam generator

Figure 3 presents temperature distributions when a pair of steam generators is broken down. In the figures, a red solid circle indicates a broken steam generator location and the number is the floor location from the first to the fourth.

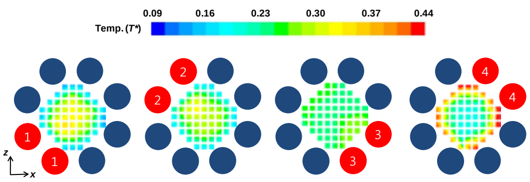

Figure 3. Temperature distributions
on the cross-section at y/H=0.17.

4. Summary

The present study investigated thermo-hydrodynamics in the SMART, which was one of the nuclear reactors developed by KAERI. We calculated the pressure, the velocity, and the temperature under nominal operation and to predict non-uniform temperature distributions in the inlet of core generated by the cases of broken-down steam generator. The conclusions can be summarized as follows.
1. In the system, the temperature changes occurred in the steam generators and the core because the core generated 330 MW heat energy and the eight steam generators absorbed 330 MW heat. At the inlet of core, the non-uniform temperature distributions were generated by unmixed thermal flow with an event case of a broken steam generator. In all the cases, the hot water is located in one side, because the water in each floor is divided half and half toward opposite directions. The high temperature positions appeared in the core center when the broken-down steam generator was related to the first floor, while in the outside when it was related to the fourth floor. The narrowest hot region was yielded when the steam generator related to the fourth floor was broken down.
2. The high temperature positions when a pair of steam generators is broken down are similar to those of superposition when each steam generator of the same pair is broken down. The normalized temperature for the broken pair connected to the 4th floor is ranged narrower than that for the broken single of steam generator.

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