Transactions of the Korean Nuclear Society Autumn Meeting
Changwon, Korea, Oct 19-21, 2022

Uncertainty analysis for severe accident of CANDU reactor by using CAISER code

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1. Introduction

There is a limited number of severe accident codes for CANDU reactor in the world. Moreover, the validation works for the CANDU severe accident has not been performed as much as that of PWR reactor. Hence, it is difficult to validate the newly developing codes by comparing with experimental data or code-to-code comparison. So, it is important to perform relevant uncertainty and sensitivity study for the newly developing codes, together with the model comparison between the existing severe accident codes. KAERI is participating in the CRP task 2.6 (CANDU-6) with CAISER (Candu Advanced Integrated SEveRe) [1]. CAISER is a detailed severe accident analysis code for CANDU reactor, which has been developing at KAERI, from the demands about more accurate and realistic severe accident codes in the PHWR safety analysis

2. Severe accident codes and plant modeling

2.1 Severe Accident Code Identification

For the severe accident simulation for CANDU reactor, CAISER (Candu Advanced Integrated Severe accident analysis code) has been utilized, which has been developed at Korea Atomic Energy Research Institute (KAERI). The CAISER code simulates core degradation phenomena occurring in a calandria tank, and it consists of two main modules: A fuel rod degradation module and a fuel channel degradation module. The fuel rod degradation module simulates the severe accident phenomena in a fuel channel, which includes a core uncovery, fuel rods heatup, hydrogen generation due to steam-Zr oxidation, fuel rods slumping, fuel rods melting and relocation, and thermal interaction of relocated molten mass with a pressure tube or a calandria tube. The fuel channel degradation module simulates the overall severe accident phenomena in a calandria tank, including the sagging of a fuel channel, debris bed formation caused by a fuel channel failure, the molten pool formation, and the calandria tank failure. Each module is tracking mass and energy changes for the main components, which are fuel, cladding, pressure tube, calandria tube in a fuel rod degradation module, and debris bed, metallic and oxidic corium pools in a fuel channel degradation module. These two modules are closely interconnected to simulate phenomena both in a fuel channel and in a calandria tank at the same time.

In the CAISER code, the coolant in a fuel channel has been simulated by utilizing the existing thermal hydraulic system code, MARS [2], which has 1-dimensional node for a fuel channel in a flow direction. The fuel rod degradation module in the CAISER code simulates the solid parts in a fuel channel and MARS deals with the coolant in a fuel channel. Hence, the two codes are designed to communicate the relevant variables at every time step. That is, the CAISER code sends the convective heat transfer rate to MARS, while it receives the coolant temperature and the convective heat transfer coefficient from MARS. As shown in the above governing equations in a fuel channel, the CAISER code considers all kinds of heat and mass transport, including the oxidational exothermal reaction, the material relocation due to melting and the slumping.

The detailed modeling for CAISER code has been described in the previous document [1] with the simulation of CS28-1 experiment.

2.2 Plant Nodalization

CASIER analyzes the accident progression inside a fuel channel by utilizing the fuel rod degradation module. Accordingly, the fuel channel degradation module should communicate information with the corresponding fuel rod degradation module. That is, the calculation of the fuel rod degradation module should be repeated as many times as the number of nodes in a calandria tank because each node of the fuel channel degradation module has an independent power and thermal-hydraulic boundary condition. After all the nodes of the fuel channel degradation module receive information from the corresponding fuel rod degradation modules, the fuel channel degradation module is computed. Then each node of the fuel channel degradation module sends information to the corresponding fuel rod degradation modules and it proceeds to the next time step. In the CAISER code, the coolant in a fuel channel has been simulated by utilizing the existing thermal hydraulic system code, MARS code, which has 1-dimensional node for a fuel channel in a flow direction.

Since the accident progression inside a fuel channel is calculated by utilizing the fuel rod degradation module, the fuel channel degradation module should communicate information with the corresponding fuel rod degradation module. That is, the calculation of the fuel rod degradation module should be repeated as many times as the number of nodes $[I, J]$ because each node of the fuel channel degradation module has an independent power and thermal-hydraulic boundary condition. After all the nodes of the fuel channel degradation module receive information from the corresponding fuel rod degradation modules, the fuel channel degradation module is computed. Then each node of the fuel channel degradation module sends information to the corresponding fuel rod degradation modules and it proceeds to the next time step. Figures 1 and illustrate a modeling appraoch for a fuel channel and nodalization scheme for the fuel channel degradation module employed in CAISER. Figure 2 shows the nodalization for the CANDU-6 reactor with M-CAISER

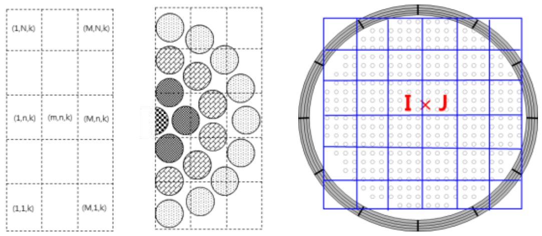

Fig.1 CAISER nodalization for core degradation

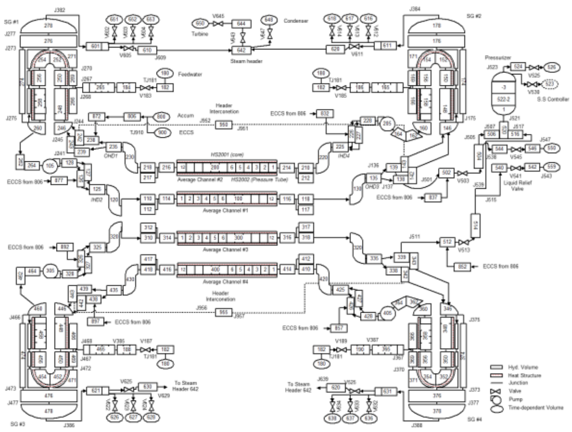

Fig.2 Plant nodalization of M-CAISER

3. Uncertainty Analysis Methodology

As uncertainty propagation methodology, statistical approach applying Monte-Carlo method has been used with 100 random samples. For response correlation / regression analysis methodology, Pearson`s and Spearman´s correlation coefficients has been used in the analysis.

For the uncertainty analysis, MOSAIQUE (Module for Sampling Input and QUantifying Estimator) code has been utilized, which was developed independently to facilitate the uncertainty analysis by KAERI (Korea Atomic Energy Research Institute). MOSAIQUE has two unique features. One is for its sampling input generation on which a spread sheet is utilized to easily assign an uncertainty parameter in the electronic input files. The other one is for the sampling calculations process in which a network of PCs in an intranet simultaneously performs each sampling calculation on multiple PCs.

4. Uncertainty Results

As The Figure-of Merit (FOM) of this uncertainty analysis has been defined as Hydrogen mass generation. The reference severe accident scenario is SBO (Station Black Out).

The hydrogen mass generation in a vessel has been displayed in Fig.3 for 100 sample runs. The CDF of hydrogen mass generation is shown in Fig. 4. The statistical analysis for the hydrogen mass generation is listed in Table 1.

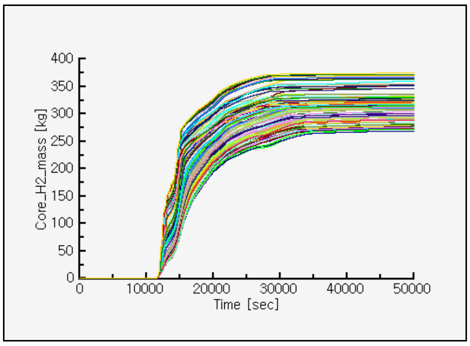

Fig.3 H_2 mass generation for 100 sample runs..

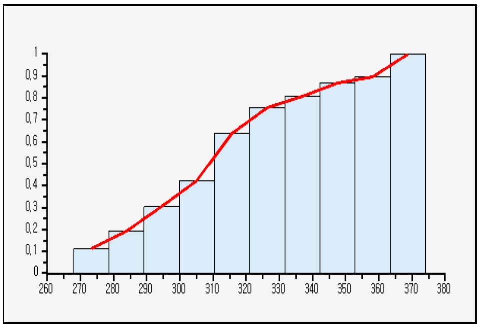

Fig.4 CDF for a H_2 mass genearation.

Table 1. Statistical results for a H_2 mass generation

H_2 generation (in-vessel) [kg]	
5th percentile	273.3
Median	314.3
95th percentile	370.6
S.Deviation	28.3
Mean	315.8

Sensitivity analysis for a hydrogen mass generation has been performed by using a Pearson’s correlation and a Spearman correlation, which are shown in Fig. 5. The factor “Vfactor_PT”, meaning the view factor between a fuel rods and a pressure tube, has a high value of Pearson coefficient, reflecting that it has a high sensitivity on a hydrogen mass generation in a core. For the hydrogen mass generation from a debris bed in a calandria tank, the parameter "db_porosity", meaning the porosity of a debris bed in a tank, has a high value of Pearson coefficient, reflecting that it has a high sensitivity on a hydrogen mass generation from a debris bed.

Fig.5 Sensitivity analysis results for H_2 mass generation

5. Conclusions

For the reference scenario of Station Black Out (SBO), the steady state and the transient calculation has been performed and the significant event times are secured. By using a Monte-Carlo method, an uncertainty analysis has been performed with 100 sample runs. The statistical data has been secured for the Figure of Merits. The sensitivity analysis has been performed by using a Pearson and a Spearman correlation for the Figure of Merits. The view factor between fuel rods and a pressure tube is shown to have the highest sensitivity on a hydrogen mass generation.

ACKNOWLEDGEMENTS

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korean Government (Ministry of Science and ICT) (No. RS-2022-00155244)

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