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CFD Analysis of Flow Distribution in Containment during LOCA and its Comparison with GOTHIC

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1. Introduction

In order to prevent further damage to the environment in the event of a nuclear power plant accident, ensuring the integrity of the containment building is an important issue. Since the Fukushima accident, a passive safety system, which operates passively when the active safety system is inoperable, such as during station black out accident, is being introduced to improve the safety of nuclear power plant. Among the passive safety system, the Passive Containment Cooling System (PCCS) is installed on the wall of containment to remove vapor mass and energy in order to maintain the pressure of the containment building below the design limit. [1]

For a reliable PCCS design, it is essential to evaluate the performance of PCCS by analyzing the nuclear power plant pressure and temperature (P/T) behavior during the accidents. The P/T analysis of containment building is performed using GOTHIC 8.2. [2] Since the GOTHIC is lumped parameter code, GOTHIC has a limit to multi-dimensional flow analysis. In this study, for this reason, the vapor distribution at the beginning of the LOCA was analyzed using ANSYS-CFX 16.2 [3] and its results were compared with GOTHIC results to confirm the reliability of the GOTHIC P/T analysis results.

2. CFD calculation modeling

In this study, the vapor flow distribution of the initial LOCA situation in the containment was analyzed prior to the heat transfer analysis such as wall condensation with non-condensable gas. The geometric model for the analysis is based on the APR+ data provided by KHNP. The APR+ is a next generation reactor model that enhances safety and stability while maintain the basic structure of APR 1400. Therefore, the concrete wall thickness of APR+ is thicker than APR1400 by about 1m, and quadrant isolation design is applied. The containment building is 46.63m in inside diameter and 77.19m in height and consists of nuclear steam supply system, reactor coolant system, reactor pressure vessel, steam generator, reactor coolant pump, pressurizer, turbine and generator as shown in Fig. 1.

After simplifying the geometry of the APR+ reactor, the analysis area was set by adding four PCCS around the inner wall of the containment building as shown in Fig. 2. In this calculation, since the wall heat transfer is not considered, the mesh is generated only for the fluid region inside the containment building. For the CFX calculation, 763,235 meshes are used as presented in Fig. 3.

Fig. 1. Conceptual design of APR+ [4]

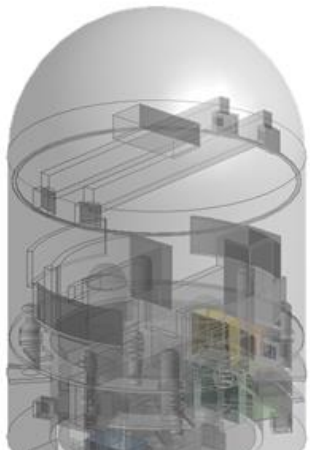


Fig. 2. Geomtry of APR+ for the CFX calculation

In this analysis, the pump suction line break accident in steam generator room #2 was assumed, and the mass and energy for the discharged coolant is as shown in Fig.4. In the case of LOCA, flashing phenomena occurs due to instantaneous discharge of the two-phase fluid. However, in this analysis, it is assumed that the discharged coolant is only released to saturated steam with maintained total energy.

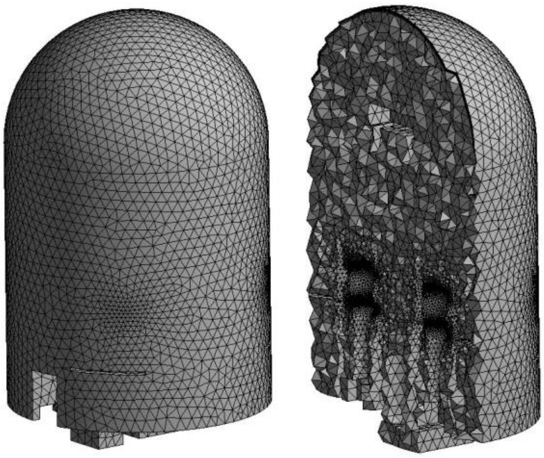
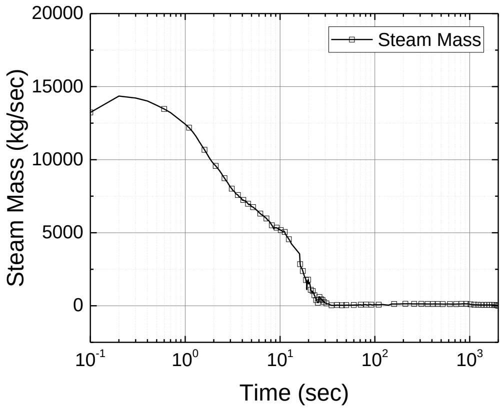
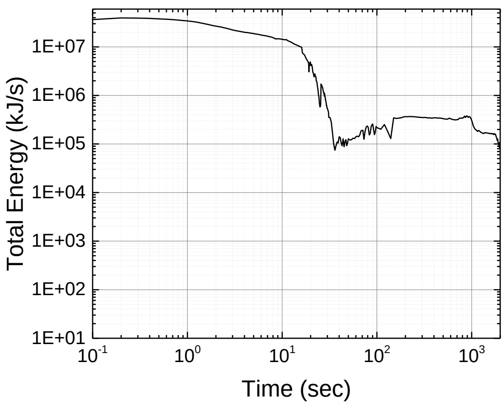


Fig. 3. Mesh of APR+ for the CFX calculation



(a) Discharged mass flow rate



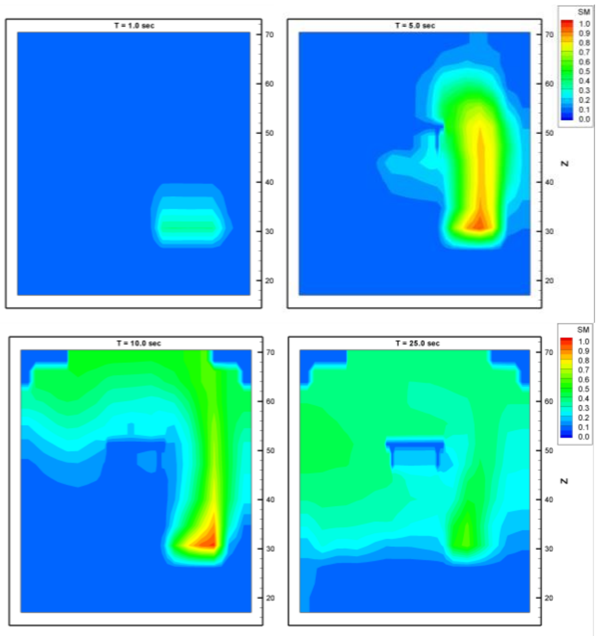
(b) Discharged energy

Fig. 4. M/E for containment analysis

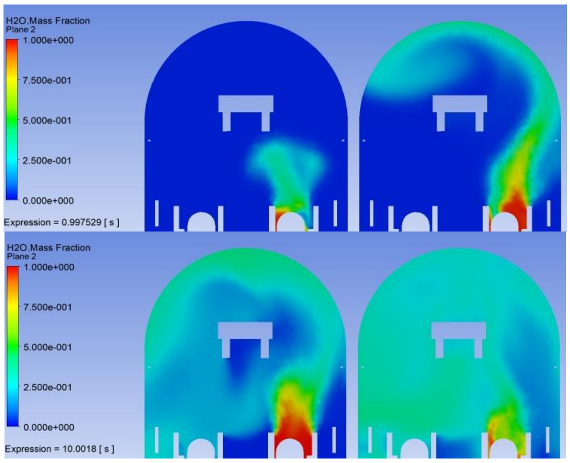
Since hear transfer is not considered in this analysis, the boundary conditions of all walls including PCCS are modeled as adiabatic wall. Discharged steam is injected in the form of saturated steam at the lower part of steam generator room #2, and the *k-ω* SST model is used for the turbulence model. The initial pressure and temperature inside the containment building were set as 1atm, 300K.

3. CFD calculation results

In order to analyze the detailed flow field inside the containment vessel, the analysis was carried out using 20% and 100% M/E. The temperature, pressure and vapor mass fraction of each compartment were obtained through analysis, and the flow above the operating floor was analyzed. The CFX analysis results of vapor flow field above the operating floor are compared with GOTHIC analysis results as shown in the following figures. (Figs. 5 ~ 8)

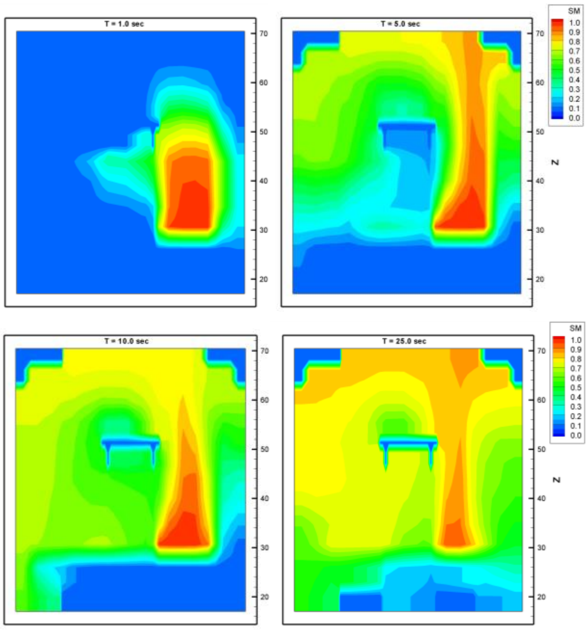


(a) GOTHIC (1s, 5s, 10s, 25s)

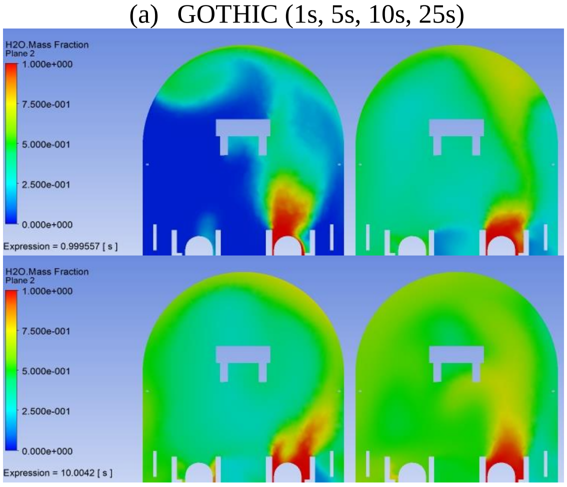


(b) CFX (1s, 5s, 10s, 25s)

Fig. 5. Analysis restults
(Vapor mass fraction; 20% M/E)

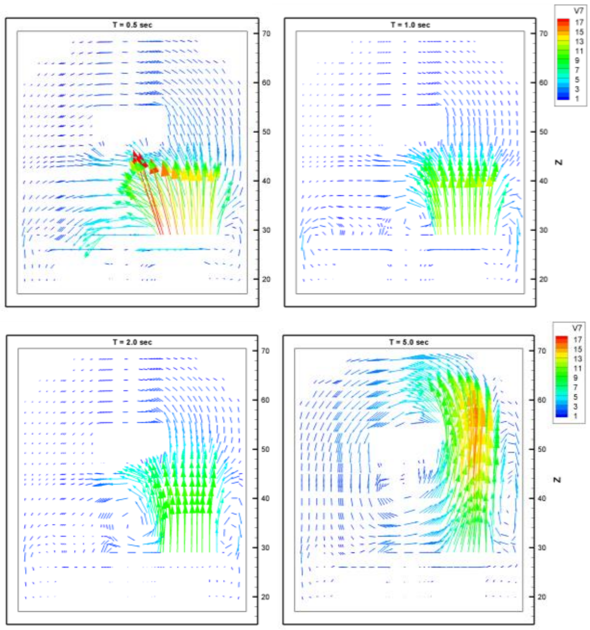


(a) GOTHIC (1s, 5s, 10s, 25s)

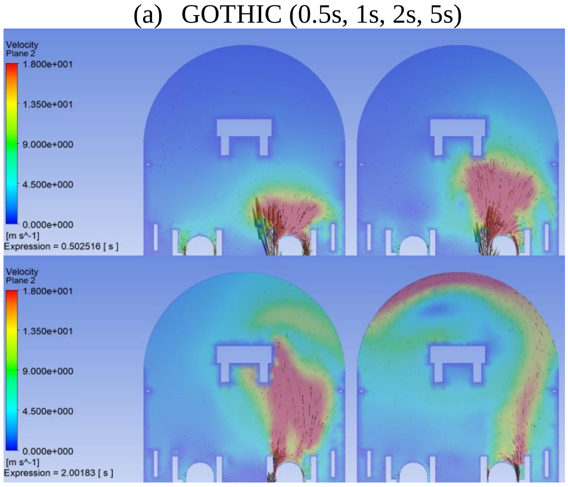


(b) CFX (1s, 5s, 10s, 25s)

Fig. 6. Analysis restults
(Vapor mass fraction; 100% M/E)



(a) GOTHIC (0.5s, 1s, 2s, 5s)



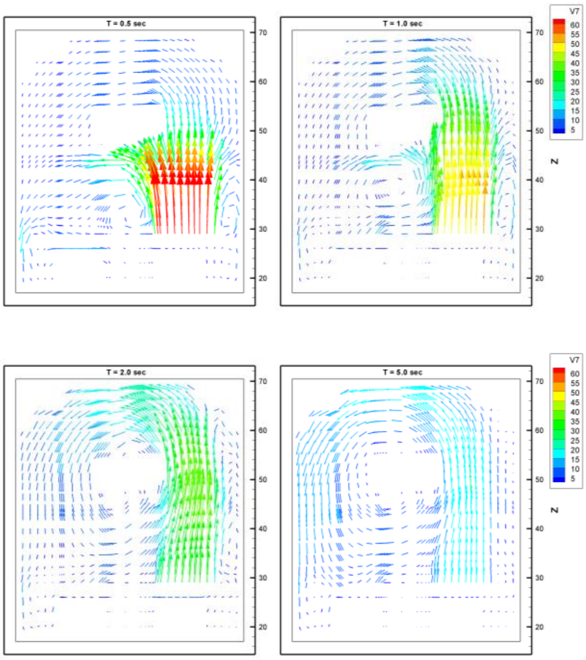
(b) CFX (0.5s, 1s, 2s, 5s)

Fig. 7. Analysis restults (Velocity; 20% M/E)

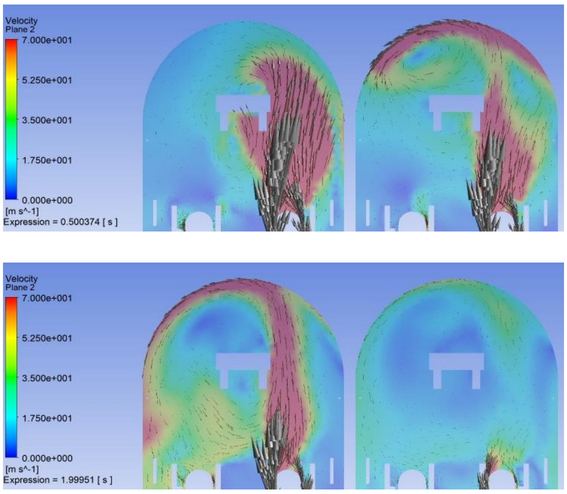
As a result of comparing the vapor mass fraction along the time, CFX results are analogous to GOTHIC results as shown in Figs. 5, 6. The vapor emitted by the accident rapidly rose due to the buoyancy effect and momentum. And then vapor diffused to upper part of the operating floor. However, as presented in Figs. 7, 8, the velocity results of the CFX at the beginning of the LOCA have discrepancy with results of GOTHIC. Since the break area of the CFX is fixed with small area, the vapor is discharged with a high velocity in CFX. However GOTHIC does not have the break area and the vapor is injected through the boundary in a large volume with a relatively small velocity. For this reason, there is a discrepancy in the analysis results at the initial phase of the accident; however the difference is reduced as the amount of injected steam decreased about 5 seconds after the accident.

There are many compartments inside the containment building, and since the compartments play an important role as passive heat sinks at the beginning of the accident, the vapor distribution of each compartment has an important influence on the initial heat removal.

Therefore, the CFX vapor mass fraction results of the SG room #1, SG room, #2, and regenerative Hx room were compared with GOTHIC results as shown in Fig. 9. As results of analysis, the vapor mass fraction results in both SG room and regenerative Hx room did not show significance discrepancy.



(a) GOTHIC (0.5s, 1s, 2s, 5s)

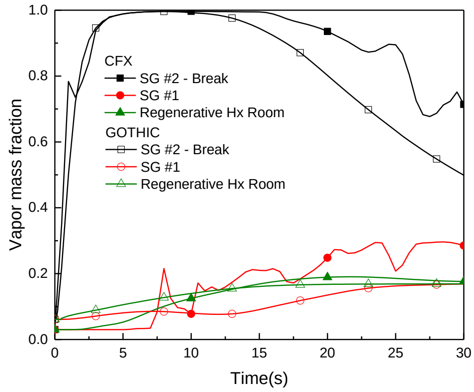


(a) CFX (0.5s, 1s, 2s, 5s)

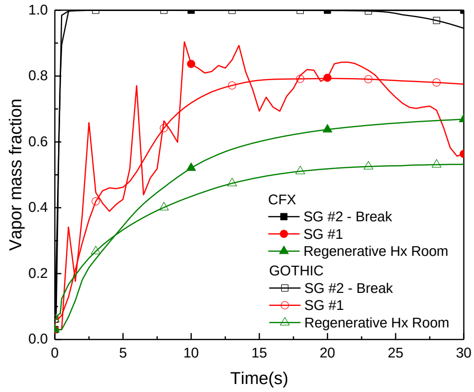
Fig. 8. Analysis restults (Velocity; 100% M/E)

4. Conclusions

In this study, the distribution of vapor flow field at the initial phase of LOCA was analyzed using CFX and the results were compared with the GOTHIC analysis results. Through comparison, it was confirmed that GOTHIC had a limitation as 1-D code in the initial velocity field analysis, but the difference was not large. Also, the reliability of GOTHIC when analyze the heat removal performance analysis of the passive heat sinks was confirmed through the CFX analysis of the vapor flow distribution inside the compartments.



(a) M/E 20%



(b) M/E 100%

Fig. 9. Vapor mass fraction analysis restults

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