Thermal hydraulic behavior analysis of VANAM-M3(ISP-37) experiment using CINEMA code

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1. Introduction

ISPs(International Standard Problems) are problems determined by OECD/NEA to compare experimental and analytical results as part of reactor safety studies. Through these problems, it is possible to determine the accuracy of the accident simulation and analysis results by the analysis code and and improve the insufficient parts.

The ISP-37, VANAM-M3 experiment, is to measure the thermal hydraulic behavior and aerosol removal ability inside the containment when steam and aerosol particles are injected into the containment through the SRV(Safety relief valve) of the pressurizer, and compare it with the calculation results of the analysis code.

The Battelle model containment of VANAM-M3, which simulates the PWR containment building, is constructed of reinforced concrete as shown in Figure 1, has a total area of 626 m^3, and consist of several compartments in a cylindrically symmetrical shape[1, 2]. Steam and aerosols are injected from compartments R3, R5 and R9. In the first stage of the experiment, steam was injected through R5 to simulate the steam flowing through the SRV of the pressurizer, and then, steam was injected into the R3 compartment to consider the reaction of the coolant with the core melt. The experiment was carried out in six steps as follows[3].

Phase 1: Initial containment wall heating [4680 sec ~ 61920 sec]

Phase 2: The first steam and aerosol injection [61920 sec ~ 65628 sec]

Phase 3: Natural condensation [65628 sec ~ 81720 sec]

Phase 4: The second steam and aerosol injection [817200 sec ~ 83304 sec]

Phase 5: Injection of steam in R3 compartment [83304 sec ~ 90936 sec]

Phase 6: Injection of steam in R5 compartment [90936 sec ~ 108000 sec]

Through this experiment, geometrical effects of multi-compartments, atmospheric stratification, atmospheric mixing by natural circulation, heat transfer of structures, condensation of walls, distribution and sedimentation of aerosols, etc. can be studied. In addition, a comparative study to verify the accuracy of the experiment can be performed [3].

In this study, the behavior of aerosols was not considered, and the tool used for the analysis is CINEMA(Code for Integrated severe accident Evaluation and MAnagement), which is an safety analysis code that analyzes various major phenomena inside the containment building. In this study, using the thermal hydraulic behavior data inside the VANAM-M3 containment building, comparative evaluation and analysis of the results were performed with the calculation results of the CINEMA code.

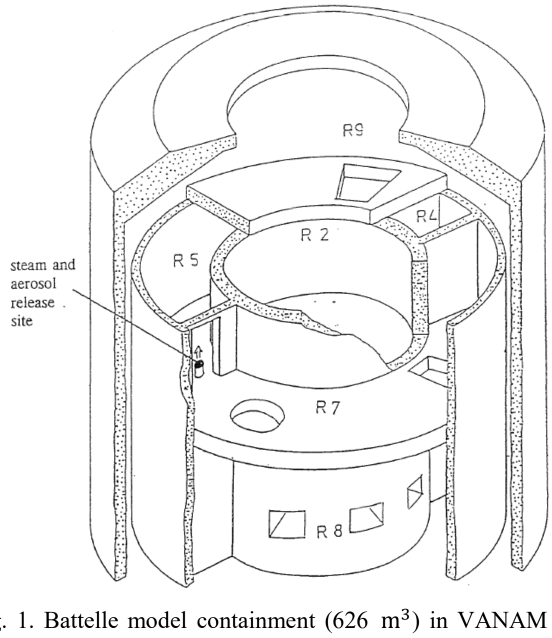

Fig. 1. Battelle model containment (626 m^3) in VANAM test configuration [1]

2. Methods and Results

2.1 Nodalization of VANAM-M3 containment

In order to analyze the VANAM-M3 experiment using the CINEMA, the containment building was divided into 11 compartments and 5 sumps, and the internal structure of the containment building was divided into 32 and the external structure into 15. The flow path between the compartments was configured as shown in Figure 2. The injection of steam is injected at R5, R94 and R3 as shown in Figure 2, and in this case, the calculation was performed without considering the injection of aerosol particles to evaluate only the thermal hydraulic behavior.

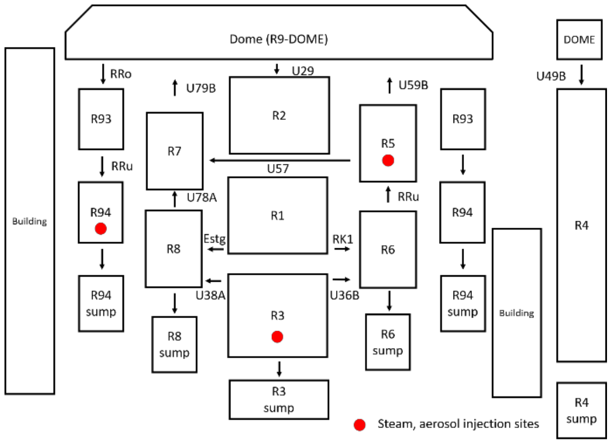

Fig. 2. Battelle model containment (626 m^3) in VANAM test configuration

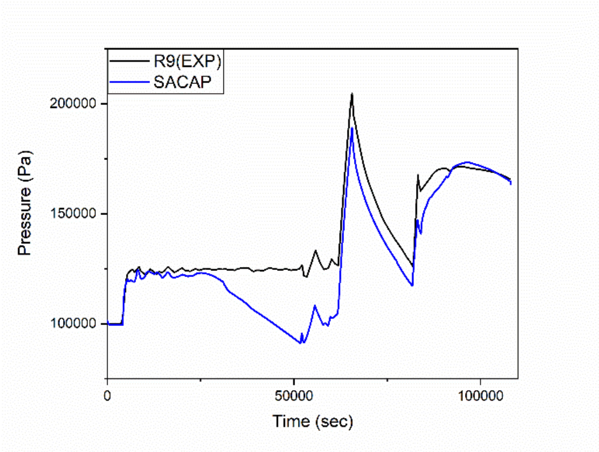

Fig. 3 Pressure in compartment R9-DOME

2.2 CINEMA calculation results

Figures 3 to 12 show the calculation results of the VANAM- M3 experiment using CINEMA and the comparison with the experimental results.

Figure 3 shows the pressure change with time in the R9-Dome compartment. In phase 1, the containment pressure is maintained at 1.25 bar by removing air from compartment R9.4 while heating the containment and injecting steam into the R5 compartment to adjust the initial boundary condition. In the CINEMA simulation result, the pressure showed a similar trend to that of the experiment until about 30,000 seconds, and then the pressure decreased after that. This calculation results can be thought of because the code calculated relative more condensation.

In phase 2, The first aerosol injection stage, the aerosol is injected through compartment R5 along with a mixture of air and water vapor, and the pressure rises to 2.05 atm. As a result of the CINEMA calculation, the increase in pressure is similar to the experimental result.

In the natural condensation phase, which is phase 3, since all injections are stopped, only the condensation of steam occurs and the pressure of the containment building is reduced, which was well simulated in CINEMA.

In the second aerosol injection stage, which is phase 4, aerosol containing steam is injected through the compartment R5, and the pressure increases at this time, and the CINEMA calculation result showed an increase similar to the experimental result. The CINEMA calculation results were similar to the experimental results even in the phase 5 and 6.

Figures 4 to 12 show the temperature change in each compartment. In the initial phase 1, aerosol containing steam is injected through R5. The aerosol injected into R5 then moves to R6, R7 and R9-Dome. As for the temperature of R5 predicted by CINEMA, the trend for each phase was the same, but the temperature increase was higher than that of the experiment. This can be interpreted that the water vapor escaping from R5 is small compared to the experiment. After that, looking at R6, which escaped from R5, the increase in temperature was high. This can be considered because the water vapor flowing from R5 to R6 did not go to R1 much. This can be confirmed by looking at the temperature graph of R1, and the temperature of R1 is significantly lower than the experimental value. In the case of R2 linked to R9-Dome, the trend of increasing and decreasing temperature for each phase was similar to the experimental result, but a lower temperature was predicted compared to the experimental result. On the other hand, in the case of R4, it was connected to the R9-Dome in the same way as R2, but it was confirmed that it showed a higher temperature than the experiment at the beginning of Phase 1. This can be confirmed by looking at the temperature graph of R1, and the temperature of R1 is significantly lower than the experimental value. In the case of R2 linked to R9-Dome, the trend of increasing and decreasing temperature for each phase was similar to the experimental result, but a lower temperature was predicted compared to the experimental result. On the other hand, in the case of R4, it was connected to R9-Dome in the same way as R2, but showed a higher temperature than the experiment at the beginning of Phase 1. In R3, the high splashing temperature was shown in the beginning of Phase 1 and in Phase 2, and in phase 5, the temperature increased in the same way as the experimental trend, and then the temperature decreased in phase 6, but higher temperature than the experimental result was predicted. In R9-Dome and R93, the temperature were predicted similar to the experimental results or slightly lower overall, and in R94, it showed a similar trend to that of R4.

There may be several reasons why the simulation results in each compartment show different values from the experimental results, but it is considered that the biggest reason is the large difference depending on the pipeline setting connecting the compartments. This can change the behavior of steam depending on the location of the pipeline attached to each compartment, and this can calculate the behavior of steam inside the containment differently from the actual phenomenon. Therefore, it is judged that sensitivity analysis with respect to the pipeline setting is necessary in the future. In addition, aerosol behavior of VANAM-M3 experiment will be performed in the future by linking with the SIRIUS code (Simulation of Radioactive nuclide Interaction Under Severe accident), which is the code that deals with the aerosol behavior and the thermal hydraulic behavior evaluation results of VANAM-M3 using CINEMA.

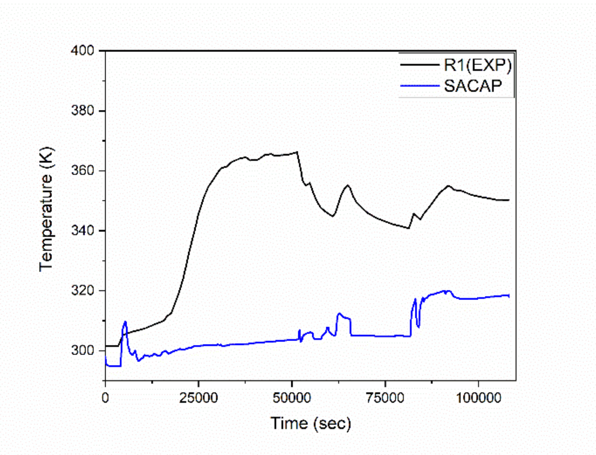

Fig. 4 Temperature in compartment R1

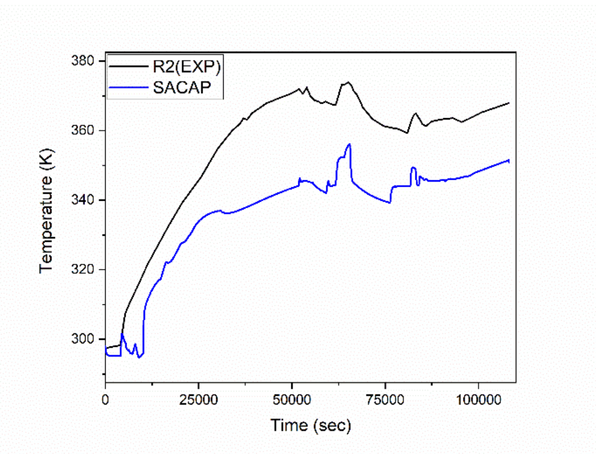

Fig. 5 Temperature in compartment R2

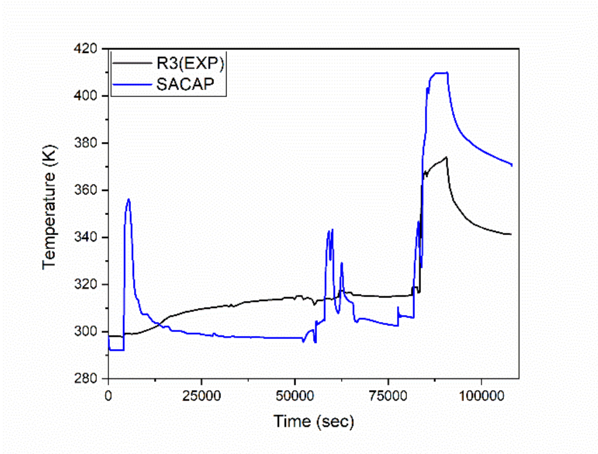

Fig. 6 Temperature in compartment R3

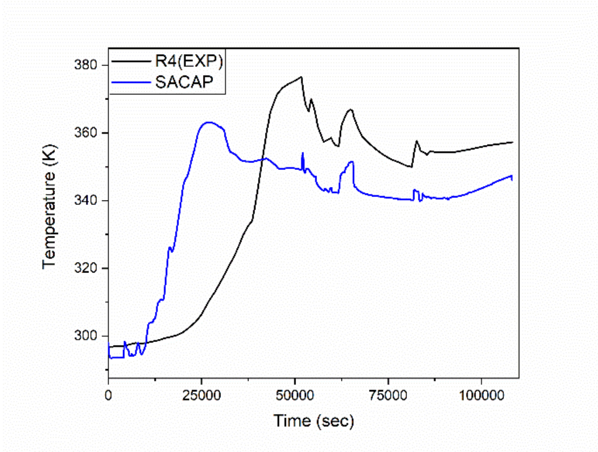

Fig. 7 Temperature in compartment R4

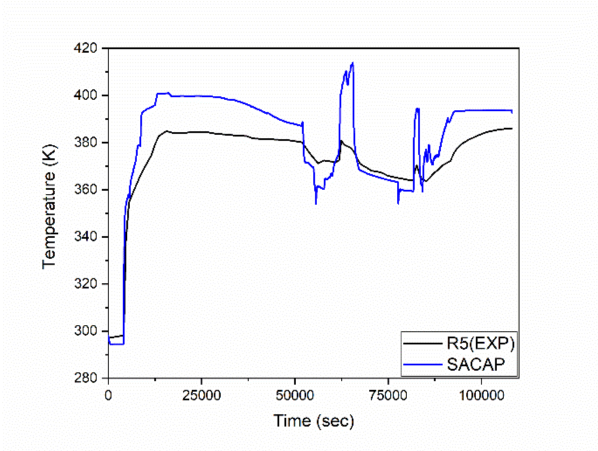

Fig. 8 Temperature in compartment R5

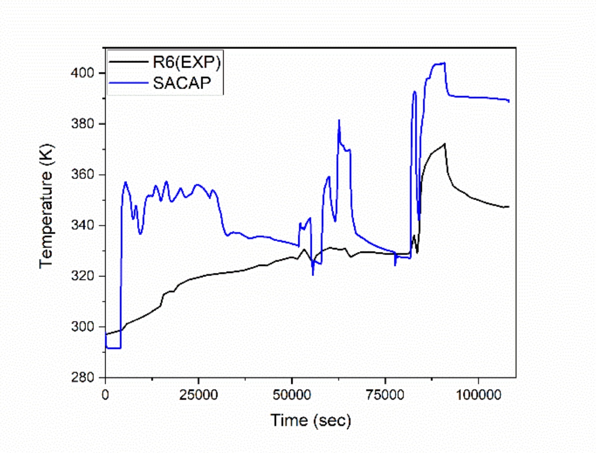

Fig. 9 Temperature in compartment R6

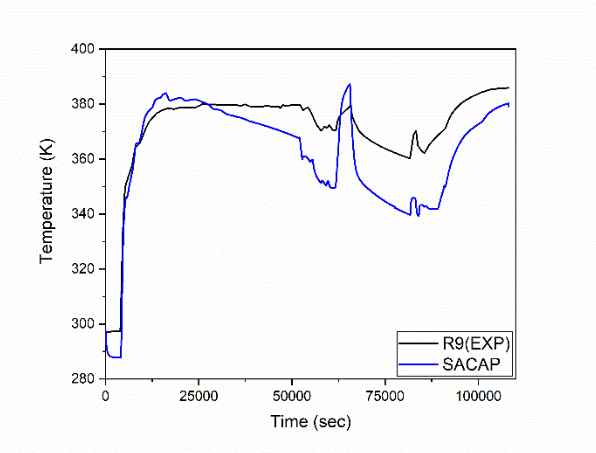

Fig. 10 Temperature in compartment R9-Dome

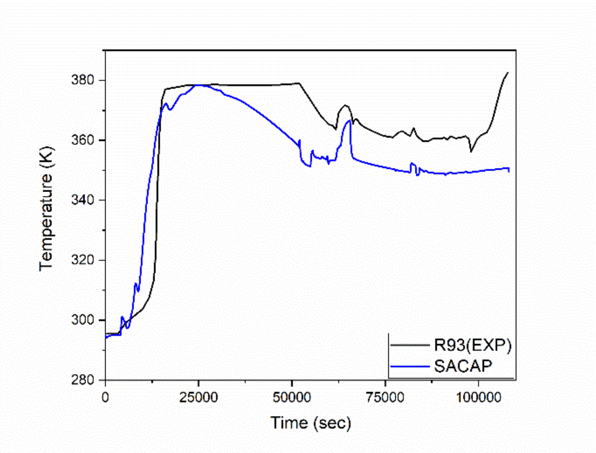

Fig. 11 Temperature in compartment R93

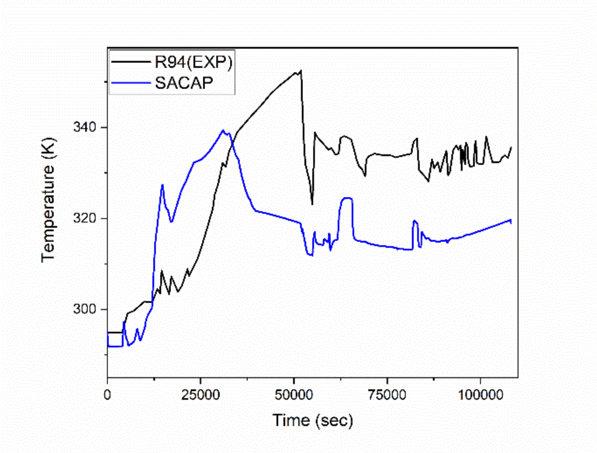

Fig. 12 Temperature in compartment R94

3. Conclusions

The thermal hydraulic behavior of VANAM-M3 was simulated using the CINEMA. As a results of the simulation, the trends for each phase were in good agreement with the experimental results. However, there were also compartments with different tendencies, which may be due to the condition of the pipeline connecting the compartments. In the future, the aerosol behavior inside the compartment will be simulated by linking the CINEMA thermal hydraulic behavior calculation results to the fission product behavior code SIRIUS code.

ACKNOWLEDGMENTS

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