論 文 の 内 容 の 要 旨

Investigation on MCCI phenomena with multi-physics MPS simulation model
(MPS 解析モデルによる MCCI 現象に関する研究)

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As an important scientific issue of nuclear severe accident analysis, Molten Core-Concrete Interaction (MCCI) attracted serious concern of many researchers since 1970s. Researchers observed the evidence of gas generation and crust formation from the experiments before 1990s. In recent experiments, the major founding is that there is more efficient lateral ablation than that of the axial direction during the MCCI process. Besides the experimental research, several numerical simulation studies were also performed by using thermal hydraulic codes. Although most of the codes got reasonable results when they were validating against the experiments, it showed the big deviations in predicting the ablation shape of the stratified melt pool. According to the benchmark work of CCI-2 experiment, totally different ablation behaviors were observed from different codes based on different empirical interfacial models. In order to avoid the deviations from the empirical equations, some researchers tried to apply CFD method. Reasonable results were obtained but still have a lot of space to improve.

In this research, MCCI phenomena is analyzed by utilizing a developed MPS code with multi-physics models. In detail, heat transfer is directly calculated by energy equation; phase change is calculated based on the particle’s enthalpy and latent heat; natural circulation is simulated by the Boussinesq assumption; mixing process between concrete and corium is calculated by the mass diffusion; surface tension is simulated by the attractive force between particles; chemical heat release and the mass of gas generation is calculated according to the composition of the corium and concrete; the stirring process due to the gas generation is simulated by the movement of the bubble particles and their attractive force with the liquid particles in the melt pool.

In order to validate the heat transfer model and phase change model are applicable to calculate such molten metallic issue, a small functional experiment was performed. U-alloy

and gel wax were selected to emulate the molten corium and concrete. The ablation process was recorded by the high speed camera. Thermal couples were installed to measure the temperature. The motion of the molten u-alloy was visualized and temperature history was measured as the experimental data for code validation. By compare the experimental and the simulation results, the ablation behavior, deformation profile of the molten metal, and temperature history matched the experimental results, which suggested that the code may applicable to simulate the physical phenomena exists in an MCCI event. On the other hands, another two natural circulation experiment were simulated to validate the natural circulation model. The results shows that it can obtain the perfect data from pure heat conductivity or low Rayleigh number simulation, but there is some Deviation on high Rayleigh number flow condition' simulation because of the limitation of particle size.

CCI-2 experiment is simulated to validate the multi-physics models, which are developed for investigating the MCCI phenomena. Chemical reaction, gas generation and mass diffusion was considered in this simulation. Four cases with different models' combination were performed to discuss the models' effectivity. The ablation process is visualized from the simulation results: crust is formed at the beginning of the event due to the heat sink from the cold concrete.. The concrete is heated up by the crust and melted near the interface. New gas particles would generated during the concrete decomposition. The temperature of the melt pool shows a rapid decrease at the first 6 minutes of the event since it was cool down by the cold concrete. After the initial decrease, It shows a steady increase due to the thermal resistance from the generated crust. The crust is gradually re-melt within around half an hour. If the mixing process is assumed as infinity, new crust would generated by the liquid concrete particles, which cause the keep rising of the temperature. If the diffusion process is considered, the hot corium particle would invade the domain of liquid concrete and cause a rapid erosion, which result in a rapid decrease of the corium temperature due to the strong heat transfer. It supports the phenomena and explanation in the experiment. New crust is generated after around 20 minutes, and the temperature is stable and gradually increase in this period. The corium temperature increased after insert the chemical reaction model due to the heat release from the redox reaction. The mixture is more uniform after adding the gas generation model since the moving gas particles enhanced the stirring of the pool.

Key word: MCCI, MPS method, CCI-2 experiment, phase change, chemical reaction, gas generation.