論 文 の 内 容 の 要 旨

論文題目　Investigation of Debris Bed Coolability and Re-Criticality under the Self-Leveling Behavior of Mixed Solid Particles
（固体粒子のセルフレベリングによるデブリ冷却と再臨界に関する研究）

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In a postulated core-disruptive accident (CDA) in Japan sodium-cooled fast breeder reactor (JSFR), the debris bed will be piled up to form a conical shape on a core support structure in the lower inlet plenum of the reactor vessel. The in-vessel retention (IVR) of CDA is of prime importance in enhancing safety characteristics of JSFR. In the heat-removal phase, IVR failure is dominated by thermal boundary failures. One of the main factors inducing thermal boundary failure is the incompleteness of stable coolability due to the debris bed exceeding the coolable limit.

In order to achieve the stable and effective cooling of debris bed with decay-heat removal, its thickness should be suppressed below the coolable limit by the enhancement of debris dispersion. For this purpose, the multi-layer debris tray is introduced to the JSFR design, on which the debris will migrate from the upper-layer tray to the lower tray, in cases where the coolable-limit thickness is exceeded. The preliminary evaluation by DEBNET code suggests that the relocated molten material would be stably cooled in the reactor vessel by fragmentation and debris-dispersion on the multi-layer debris tray, and the phenomena of thermal boundary failure due to the incompleteness of stable cooling could be avoided by the installation of the multi-layer debris tray. Even the result from the simulating calculation has uncertainty, the behavior of self-leveling will still be initialized to help the debris bed particles re-distributing and suppressed the height of debris bed again. The effectiveness of self-leveling behaviors on stable cooling for the debris bed has also been investigated in order to give further robustness to the present CDA scenario from the viewpoint of achieving IVR.

However, these previous analysis on the debris bed coolability and the probability of re-criticality is under the assumption of the debris bed with homogeneous distribution.

In the real situation, the debris bed is a mixed-density debris bed. Therefore, when these mixed-density debris particles start to re-distribute during the phenomena of self-leveling, a debris bed with heterogeneous distribution will be formed. Furthermore, the heavier fuel particles would possibility form a stratified distribution, because , compared with the lighter structure particles, the heavier fuel particles will tend to sink to the bottom of the debris bed during the self-leveling. Under this condition, the capability of coolability and the probability of re-criticality could deviate from the original prediction which is based on the assumption of homogeneous distribution. Therefore, the objective of this study is to clarify in which conditions the debris bed will obtain stable cooling considering the effect of debris bed particle stratification during self-leveling on the generation of criticality. To achieve this goal, both the neutronics model and CFD-DEM model should be built up for the final reactor scale study.

For the aspect of building neutronics model, through the neutronics calculation to evaluate the k-eff eigenvalue on three alternative configurations, it was found that the debris bed with a stratified distribution or centralized distribution have higher probability to attain the status of re-criticality, compared with the debris bed with homogeneous distribution. Therefore, it depicted that, if the mixed-density debris bed formed a stratified distribution during the self-leveling, the probability of re-criticality will higher than the previous expectation whose concerning is based on the homogenous distribution.

For the aspect of building CFD-DEM model, after a series of the sensitivity studies, CFD-DEM model had been verified by experiments under the cases of mixed-density particles bed. The verified CFD-DEM model can correctly track the heavy particles movement in the light particles bed with the water-injection. In addition, since the experiments is for simulating g phenomena of self-leveling in JSFR and have done the non-dimensional analysis, the verified CFD-DEM model is with the capability to be applied on it.

Finally, the reactor scale case of 35% of JSFR total fuel inventory is chosen for being applied on the neutronics model and CFD-DEM model at the same time. The mixed-density debris bed is set as the stratified distribution, because it can compared the result with the previous study using the homogeneous distribution. When the self-leveling is processing, the temperature and the position information of these debris particles are successfully collected, and the k-eff eigen value shows a trend of decreasing. Therefore, self-leveling effect had been quantitively confirmed, even under a case of stratified distribution.