Introduction of Research Activities on Ex-vessel Debris Bed Cooling in the Pre-flooded Reactor Cavity

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1. Introduction

A postulated severe accident of ex-vessel corium release into a pre-flooded reactor cavity adopted as the SAM (severe accident management) strategy for Korean PWRs (pressurized water reactors) is represented in Fig. 1 [1]. A particulate debris bed is likely to be formed on the cavity floor by melt jet fragmentation during FCI (fuel-coolant interaction), and its long term coolability should be secured for the containment integrity. The debris bed coolability is highly dependent upon two-phase pressure drop characteristics through the bed [2, 3] and its geometrical configuration [3-8] as well. Comprehensive experimental and analytical works have been carried out on the ex-vessel debris bed cooling in the pre-flooded reactor cavity are introduced in this paper.

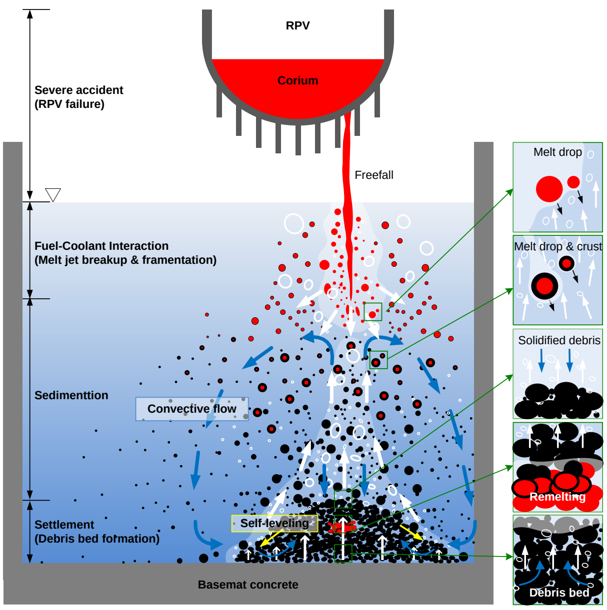

Fig. 1. A schematic of ex-vessel corium release into a pre-flooded reactor cavity

2. Experimental Study

Three main experimental facilities were established as shown in Fig. 2. DEFCON (DEbris bed Formation and COolability experimeNt) and DEFCON-S are the ex-vessel debris bed formation test facilities while two phase pressure drop facility is for the debris bed coolability estimation in terms of DHF (dryout heat flux).

DEFCON is a large scale integrated test facility to investigate the effects of 'steam spike' in the early phase of FCI, 'convective flow' created in the water pool, and 'self-leveling (flattening)' of the bed. A particle heating system can accommodate 1000 kg of metallic particles and heat the particles up to 1000°C by electrical heating. STS particles are used as the corium debris simulants, and typically 300 kg of particles are released through a 50 mm nozzle by gravity to a pre-flooded water tank (2 m×2 m×4 m). The steam production from the debris bed is simulated by air injection from 49 air supply block-load cell assemblies installed at the bottom of the water tank. Particles shape and size distribution, water pool depth and decay heat power density of the bed are considered as the main experimental variables. Recently, the tests using heated particles below 1000°C are ongoing, and accordingly the temperatures of particles and water pool are considered as additional variables. The bed shape changes are recorded by several cameras with back lightning, and the instant shapes after the 1st phase of particle sedimentation and 2nd phase of self-leveling are quantified by image processing as exemplified in Fig. 3.

Fig. 2. Experimental facilities

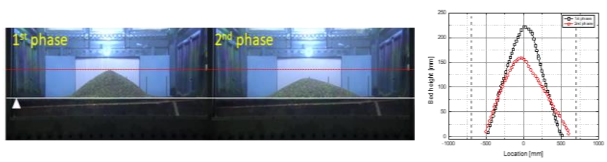

Fig. 3. Quantification of debris bed shape

DEFCON-S is a small scale facility constructed recently to perform various tests using heated particles with a focus on the 'steam spike' phenomenon and its effect on the initial particle dispersion. Typically 5 kg of STS particles is heated in a graphite crucible by induction heating and then released through a 20 mm nozzle by gravity to a pre-flooded water tank (0.6 m×0.6 m×0.7 m). As with DEFCON facility, the particle heating temperature is restricted below 1000°C due to jamming (sintering) between the metallic particles.

A two phase pressure drop test facility was set up to evaluate the DHF of the debris bed based on the two pressure drop measurements as the infiltrated water into the bed flows out as two phase flow. A cylindrical test section filled with the particles has 100 mm in inner diameter and 500 mm in height. Several single and two phase pressure drop measurements through the STS particle bed using air and/or water have been conducted and compared the existing models. The final goal is to perform the test using TROI particles, which are prototypic corium debris produced by FCI with no steam explosion, and to propose the most appropriate two phase pressure drop model applicable to the corium debris bed in a real accident situation.

3. Analytical Study

A lumped parameter code, COLAS (COrium cooLability of Analysis Simulator) is under development to evaluate the ex-vessel debris bed coolability in the pre-flooded reactor cavity. It consists of two modules of DEJET and DECOOL as shown in Fig. 4 [9, 10]. The melt jet breakup and particle sedimentation are dealt with in DEJET, and then the results of the size distribution, temperature and mass of the fragmented particles, the cake temperature and mass in case of incomplete met jet breakup are provided to DECOOL. Then, the debris bed formation and coolability is evaluated in DECOOL.

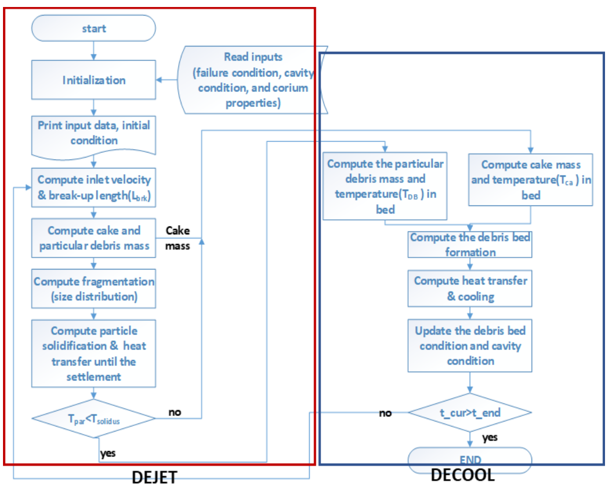

Fig. 4. COLAS analysis flow chart

Recently, COLAS has been updated by including a few improvements such as 2-D debris bed configurations based on the DEFCON experiments, two phase pressure drop models from the latest test results and 1-D debris bed heat transfer model. All of the models of debris bed shape and two phase pressure drop with DHF are integrated in COLAS. The code improvements are being made by doing some preliminary analyses for the ex-vessel corium release severe accident scenarios by coupling with integral severe accident code MELCOR [11, 12]. Moreover, the code validations are being performed with previous experimental results like COOLOCE experiment [13]. The COLAS code will be utilized as a stand-alone code for the evaluation of ex-vessel debris bed coolability and applied to Korean integrated severe accident code CINEMA (Code for INtegrated severe accident Evaluation and MAnagement).

4. Application to PSA and SAM Improvements

All research outputs from the experimental and analytical activities will be hopefully applied to improvements of the success criteria of EDC (ex-vessel debris cooling) stipulated in the Level-2 PSA (probabilistic safety assessment). In addition, they needs to be finally implemented into a SAMG by considering comprehensive aspects in the ex-vessel debris bed cooling with the adverse effects such as containment overpressurization induced by rapid steam production.

In order to refine the existing PSA for OPR-1000, basic top events and their branch probability criteria of the EDC/BMT (basemat melt through) DET (decomposition event tree) were reviewed with impact analyses, and BMT sensitivity analyses for the newly derived EDC factors (debris bed depth considering the porosity and the inclination angle of conical debris bed) were performed [14]. Now, rearrangement of the all EDC factors and assessment of their branch probability in the event tree are being conducted.

5. Conclusions

Recent experimental and analytical works on the ex-vessel debris bed cooling in the pre-flooded reactor cavity, and some efforts being made for the improvement of severe accident management are introduced in this paper. There are still many challenging issues to evaluate the ex-vessel debris bed coolability in a real accident situation. However, it is meaningful that we took a step forward to the ex-vessel debris cooling issue which have been hardly addressed in the existing integrated severe accident codes.

ACKNOWLEDGMENTS

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