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Preliminary Analysis of Ex-vessel Debris Bed Coolability according to Bed Geometry

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1. Introduction

During the late phase of severe accidents in PWRs (Pressurized Water Reactors), the molten corium may be discharged into the reactor cavity if the lower head of the reactor vessel is failed. The cooling and stabilization of the discharged molten corium in the reactor cavity is important to suppress further accident progression such as molten core-concrete interaction which can cause the containment failure and significant release of radioactive material outside the containment.

The strategy of pre-flooding of coolant into a reactor cavity for ex-vessel corium cooling and stabilization was adopted for the most operating Korean NPPs. It is expected that the molten corium breaks up in the water pool, and accumulated on the cavity floor in the form of a particulate debris bed. Also, it can be coolable. However, if the molten corium reaches the cavity floor without the completely break-up, or the debris bed is re-melted, a continuous molten pool is produced on the floor and it leads to MCCI.

Through the recent research results [1], One of the most important parameters is the debris bed geometry. KAERI is plan to perform the experiment to develop the representative models of the multi-dimensional geometrical configuration of the debris bed and dryout criteria. [2] KAERI also is developing the module for the ex-vessel debris coolability. In this study, it is performed the preliminary analysis of ex-vessel debris bed coolability according to bed geometry such as the porosity, the bed shape, and the debris bed particle size.

2. Description of Model

2.1 simplified ex-vessel debris bed coolability module [3]

So far, the cooling process of the ex-vessel corium debris can be divided into four categories which are melt jet breakup, particle dynamics, debris bed formation, and the bed cooling (Fig.1). When the molten corium release from the RPV and goes into the water, the melt jet may break and will fragment simultaneously. The fragmented particles fall into the cavity floor and accumulate on the cavity floor in the form of a debris bed. The heat generated by the debris bed can be removed by natural circulation of coolant through the porous bed.

The simplified ex-vessel debris bed coolability module which covers the melt jet break-up, debris bed sedimentation, debris bed formation and its cooling is under development. Two modules, DEJET and DECOOL, were developed. The initial failure condition was either from the user input or from the other code. DEJET deals with both the melt jet break-up and debris bed sedimentation. The results of the DEJET module, which are the debris particle size distribution, the particle temperature and mass, and the cake temperature and mass if the breakup length is longer than the pool height, are provided to the DECOOL module. DECOOL deals with the debris bed formation and cooling. The detailed models of DEJET are described in ref. 3.

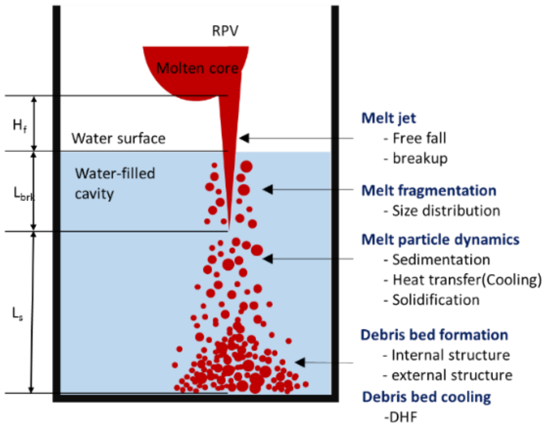

Fig. 1. Scenario of melt outflow from RPV and formation of particulate debris in pre-flooding cavity

2.2 DECOOL models

The cooling limitation of the debris bed is often used as the DHF (dryout heat flux), which is defined by the maximum heat flux through the bed without dryout. Most of the debris coolability studies have assumed a cylindrical debris bed shape in which the bed is flooded either through its top or bottom surface. The realistic debris bed geometry has not been considered at all in classical analyses. Recently, the geometry of the debris bed has become an important parameter because it determines which type of flooding mode is possible for the infiltration of water into the pores of the bed.

The correlations, which determine the debris bed shape and DHF, are very limited although some groups have proposed models. KAERI plans to perform a debris bed formation and coolability test to propose an empirical correlation for the debris bed shape and DHF. The current status of the DECOOL is shown in Fig. 2. The debris bed shape is assumed as a conical shape. When the angle is 90°, the debris bed becomes a cylindrical debris bed. The heat transfer in the debris bed and cake is calculated with Eqs. 1 and 2:

$$Q_{bed} = A_{bed}h - Q_{decay} - Q_{btm} \qquad (1)$$

$$Q_{cake} = Q_{MCCI} + Q_{btm} - Q_{decay} \qquad (2)$$

, where Q_{bed} is the heat transfer in the debris bed; A_{bed} is the top surface area of the bed; Q_{decay} is the decay heat; Q_{btm} is the heat input at the debris bed bottom from the cake; Q_{MCCI} is the heat released by a MCCI, and h is the heat transfer coefficient, which is determined by comparing the effective heat transfer coefficient and DHF to a smaller value. Here, the Lipinski model was used to obtain the DHF value [4].

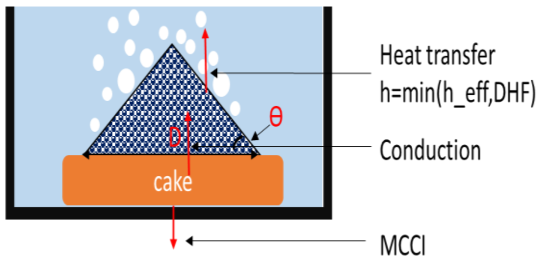

Fig. 2. Heat transfer in the debris bed and cake

2.3 Analysis results and discussion

To investigate how the debris bed temperature changes depending on the debris bed geometry, a preliminary analysis was performed. The main parameters are the porosity, the angle of the debris bed and the particle diameter. The melt properties and initial failure condition such as the failure diameter and corium temperature, and pressure, etc. were obtained through the accident scenario analysis using MELCOR 1.8.6. Code [3, 5]. Properties of ex-vessel corium are summarized in table II. The initial conditions of the pool and the cavity are in table III. We assumed that pool height is 5.858 m, free fall height is 1m, and the failure diameter in reactor vessel is 0.2 m. Also the pool temperature assumes the saturation temperature at 1 bar.

Table II: Melt properties [6]

Material property	Unit	value
Material		70% UO_2 and 30%ZrO_2
Density liquid	Kg/m^3	8000
Cp-liquid	J/kg/K	510
Cp-solid	J/kg/K	450
Tsolidus	K	2840
Tliquidus	K	2870
Latent heat	J/kg	320000
Emissivity		0.79
Decay heat	W/kg	80

Table III: Initial conditions

Variable	Unit	value
Particle diameter	mm	1-10
Pool height	m	5.858
Free fall height	m	1
Pool temperature	K	373
Cavity pressure	bar	1
Failure diameter	m	0.2
Mass in LVH	ton	130
Corium temp	K	2600
Pressure difference	bar	9

Decay heat	W/kg	100

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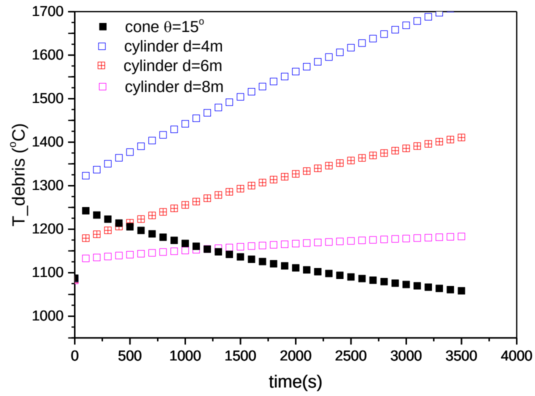

Fig. 3. Debris bed temperature with various shape

Figure 3 shows the evolution of the debris bed temperature over time with different bed shapes. The debris bed temperature decreases only in the case of the conical shape also shown by the experimental studies in the COOLOCE program at VTT [1]. They showed that the debris coolability for five beds compared to a top-flooded cylinder bed increased by up to 70 %. The reason is the larger surface area for heat transfer and the flooding modes which determine the DHF. It indicates that the debris bed geometry and the flooding modes are key parameters to determine the coolability of the debris bed. In future work, KAERI is planning to propose an empirical correlation for the debris bed shape and DHF.

3. Conclusions

The preliminary analysis was performed to investigate the effect of the debris bed geometry on the ex-vessel debris bed coolability. It is observed that the debris bed shape is one of the important parameters to determine the coolability of the debris bed. Thus, KAERI is planning to conduct the experiment to propose the representative models of the multi-dimensional geometrical configuration of the debris bed and dryout criteria

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