Coolability analysis of initial ex-vessel molten corium for pre-flooding strategy

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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 prevent further accident progression such as molten core-concrete interaction.

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 jet is completely fragmented in the water pool, and accumulated on the cavity floor in the form of a particulate debris bed. Also, it can be cool down. However, if the molten corium reaches the cavity floor without completely breaking up or the debris bed is re-melted, a continuous molten pool, which is called "cake," is produced on the floor, and it can lead to a MCCI [1].

KAERI is developing the module for the ex-vessel debris coolability [1, 2]. In this study, the module was validated on the initial cooling model by comparing the analysis results with FARO experiment [3].

2. Description of Model

2.1 simplified ex-vessel debris bed coolability module [2]

So far, the cooling process of the ex-vessel corium debris can be divided into four categories which are melt jet breakup, the particle dynamics, the debris bed formation, and the debris bed cooling (Fig.1). In the pre-cavity strategy, when the discharged molten corium from the RPV goes into the water, the melt jet will fragment. 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. The detailed models of each phenomenon were described in the Refs 1, and 2.

In this study, to analysis the initial ex-vessel molten corium coolability, we seek to solve the unsteady one-dimensional heat conduction equation even during the formation of the debris bed.

$$\rho_{eff} c_{eff} \frac{\partial T_{bed}}{\partial t} = \frac{\partial}{\partial z}\left(k_{eff} \frac{\partial T}{\partial z}\right) + S \qquad (1)$$

where, $\rho_{eff} = (1-\varepsilon)\rho_{bed}$, $c_{eff} = (1-\varepsilon)c_{bed}$, $k_{eff} = (1-\varepsilon)k_{bed}$, S are density, specific heat, thermal conductivity of porous media, and source term [4].

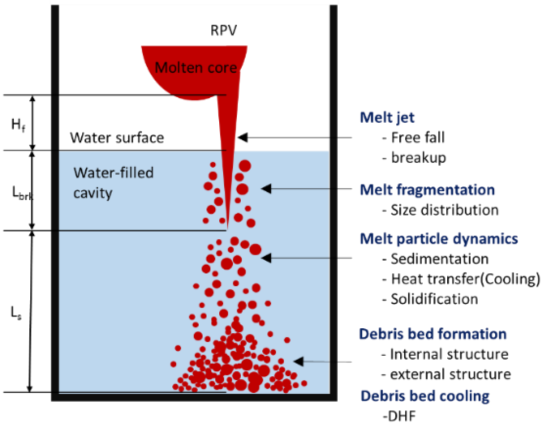
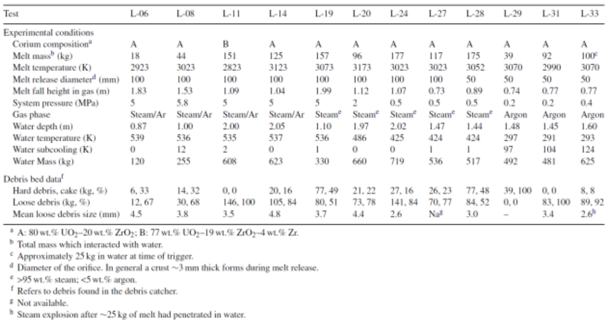


Fig. 1. Scenario of melt outflow from RPV and formation of particulate debris in pre-flooding cavity [1]

2.2 Benchmark problem : FARO experiment

To verify the analysis model and to improve it, FARO tests were selected as a benchmark problem. The FARO tests were designed to study the integral corium melt jet/water mixing and quenching behavior using UO2 based melt under prototypical conditions. 12 tests were performed that involved quenching of 18-177 kg corium melts in saturated and subcooled water [3]. The table 1 summarized the main experimental conditions and debris bed data.

Table I. FARO test conditions and results [3]



Test	L-06	L-08	L-11	L-14	L-19	L-20	L-24	L-27	L-28	L-29	L-31	L-33
Experimental conditions												
Corium composition[a]	A	A	B	A	A	A	A	A	A	A	A	A
Melt mass[b] (kg)	18	44	151	125	157	96	177	117	175	39	92	100[c]
Melt temperature (K)	2923	3023	2823	3123	3073	3173	3023	3023	3052	3070	2990	3070
Melt release diameter[d] (mm)	100	100	100	100	100	100	100	100	50	50	50	50
Melt fall height in gas (m)	1.83	1.53	1.09	1.04	1.99	1.12	1.07	0.73	0.89	0.74	0.77	0.77
System pressure (MPa)	5	5.8	5	5	5	2	0.5	0.5	0.5	0.2	0.2	0.4
Gas phase	Steam/Ar	Steam/Ar	Steam/Ar	Steam/Ar	Steam[e]	Steam[e]	Steam[e]	Steam[e]	Steam[e]	Argon	Argon	Argon
Water depth (m)	0.87	1.00	2.00	2.05	1.10	1.97	2.02	1.47	1.44	1.48	1.45	1.60
Water temperature (K)	539	536	535	537	536	486	425	424	424	297	291	293
Water subcooling (K)	0	12	2	0	1	0	0	1	1	97	104	124
Water Mass (kg)	120	255	608	623	330	660	719	536	517	492	481	625
Debris bed data[f]												
Hard debris, cake (kg, %)	6, 33	14, 32	0, 0	20, 16	77, 49	21, 22	27, 16	26, 23	77, 48	39, 100	0, 0	8, 8
Loose debris (kg, %)	12, 67	30, 68	146, 100	105, 84	80, 51	73, 78	141, 84	70, 77	84, 52	0, 0	83, 100	89, 92
Mean loose debris size (mm)	4.5	3.8	3.5	4.8	3.7	4.4	2.6	Na[g]	3.0	–	3.4	2.6[h]

[a] A: 80 wt.% UO_2–20 wt.% ZrO_2; B: 77 wt.% UO_2–19 wt.% ZrO_2–4 wt.% Zr.
[b] Total mass which interacted with water.
[c] Approximately 25 kg in water at time of trigger.
[d] Diameter of the orifice. In general a crust ~3 mm thick forms during melt release.
[e] >95 wt.% steam; <5 wt.% argon.
[f] Refers to debris found in the debris catcher.
[g] Not available.
[h] Steam explosion after ~25 kg of melt had penetrated in water.

2.3 Preliminary analysis results and discussion

Considering the melt mass, temperature, and the gases phase, we were first selected L-28 test as a benchmark problem. In the simulation, the Epstein's correlation [5] was used for the jet break up analysis. To simulate the debris bed shape as the test, the debris bed formation model was modified.

The experimental results of the mass of the cake and the particles, the particulate debris bed temperature (Fig.2), and the water temperature (Fig.3) were compared with the analysis results. When analyzed by the heat transfer model of Ref. 4, it was found that the initial debris bed temperature was 200 K higher than FARO results. The reason is that the minimum heat flux model was used as the heat transfer model for particle cooling during the sedimentation. We are modifying the heat transfer model. The heat transfer model is currently being improved. After improvement, the analysis results will be attached when revising the paper

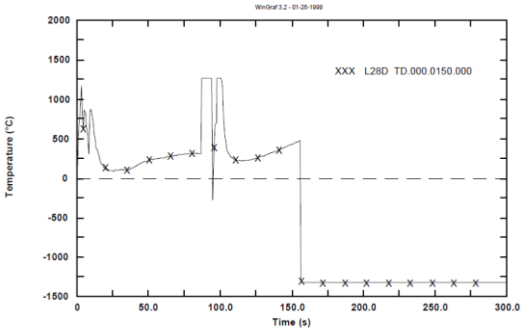


Fig. 2. Bottom of debris bed temperature [3]

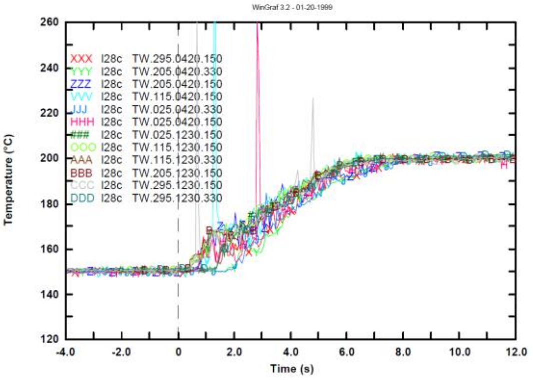


Fig. 3. Temperatures in the water region [3]

3. Conclusions

We are focusing on the development of the debris bed coolability analysis model. In this study, we tried to validate the cooability model and to improve it by comparing the analysis results with FARO test results. It is still underway to develop the debris bed heat transfer model. After developing 1-D analysis model, it will be expanded to analyze the local temperature of various shaped debris bed.

ACKNOWLEDGMENTS

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