Coolability Analysis of Ex-vessel Corium in OPR1000 pre-flooded reactor cavity

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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, 3] called COCCA(Code of ex-vessel Corium Coolabiligy Analysis). In this study, the effectiveness of the pre-flooding strategy according to 6 accident scenarios was evaluated for OPR1000. In addition, the effectiveness of the preflooding strategy for LBLOCA accidents was evaluated by linking CSPACE and COCCA.

2. Analysis Results

2.1 Code of ex-vessel corium coolability analysis (COCCA)

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-flooding 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 COCCA which covers the melt jet break-up, debris bed sedimentation, debris bed formation and its cooling is under development. The models used in the COCCA code are summarized in Table1. The detailed models of each phenomenon were described in the Refs 1 to 4.

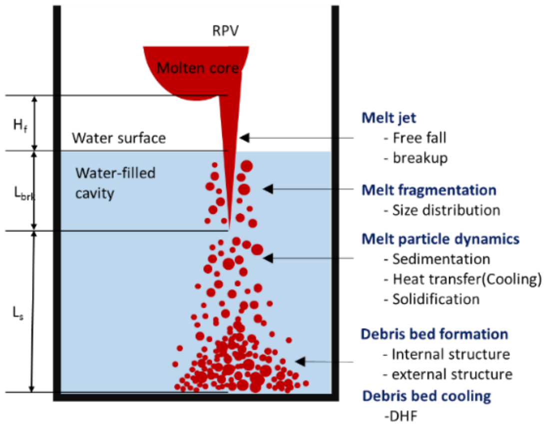

Fig. 1. Scenario of melt outflow from RPV and formation of particulate debris in pre-flooding cavity [1]

Table1.models used in the COCCA code

Phenomena		Models
fragmentation	Jet Breakup model	Saito*, Epstein
	Particle distribution model	TROI distribution
Corium coolability	Particle debris bed shape	Cylindrical model*, conical model, DEFCONS’s model
	Particle debris bed cooling	1-D transient analysis*[4]
	Pressure drop model	Modified Ergun Eq. *, Schmidt, Tung and Dhir
	DHF model	Lipinski 0-D model*, Schmidt

2.2 Evaluation of pre-flooding strategies for 6 scenarios

Six scenarios were derived through Lv.2 PSA analysis for the OPR1000 nuclear power plant [5,6]. Severe accident analysis was performed using MELCOR 2.2 version, and the RV failure time and pressure were calculated in Table.2. [7]

Analysis was performed using COCCA as the corium property condition of Table 3 and the cavity condition of Table 4. It was confirmed that the ex-vessel molten corium was cooled stably under the conditions of Table 4 when Epstein correlation was used for the jet break-up length model.

Table2.RV pressure when the RV failed [5]

Scenario	SBO-T4	SBO	TLOFW	SGTR	SLOCA	LLOCA
RV pressure[MPar]	1.5	1.6	1.7	1.6	1.9	0.2
Temperature[K]	2600	2600	2700	2700	2300	2400

Table3. Corium properties

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
Emssivity		0.79
Decay heat	W/kg	200

Table4. Cavity conditions

Variable	Unit	value
Particle diameter	mm	1 to 3
Pool height	m	5.858
Free fall height	m	1
Pool temperature	K	373
Cavity pressure	bar	1
Failure diameter	m	0.3
Debris bed shape	-	Cylindrical shape
Cavity area	m2	55

2.3 Evaluation of pre-flooding strategies LBLOCA accidents by linking CSPACE and COCCA.

In order to estimation of the pre-flooding strategies in OPR1000 using COCCA, several inputs are needed, such as the debris temperature, properties, RV pressure, cavity information, etc. SPACE code is a general-purpose thermal-hydraulic system code based on two-fluid, three-field model. COMPASS code simulates the mechanical and thermal behavior of fuels and reactor vessel internal structures during the core damage at given thermal-hydraulic boundary condition. CSPACE is developed by coupling COMPASS and SPACE.[8]. When CSPACE and COCCA are linked, COCCA can be received in-vessel information from CSPACE

The code was developed so that CSPACE and COCCA could be linked in real time. COCCA receives the information in Fig. 2 from reactor vessel failure.

Figure 3 shows the corium release flow rate of CSPACE and the corium release flow rate received by COCCA. It was confirmed that the data was received well from COCCA.

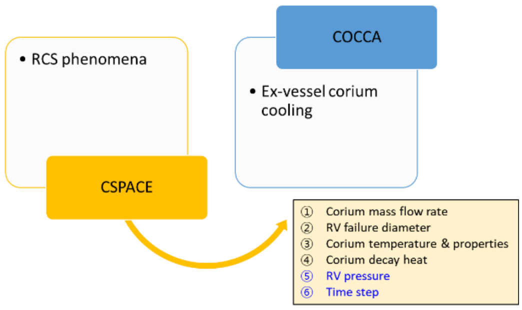

Fig. 2. CSAPCE and COCCA linkage

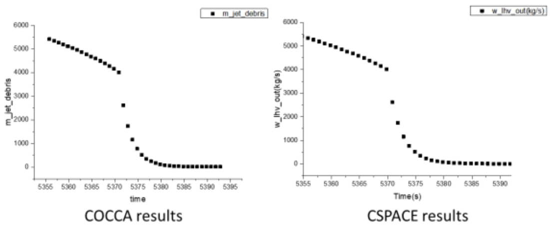

Fig. **3**. COCCA and CSPACE corium release rate

Analysis of the LBLOCA accident [8] is being performed. As mentioned above, from RV failure, COCCA receives RV internal information and corium information received from CSPACE. The ex-vessel corium coolability analysis is performed under the information received from CSPACE and the cavity conditions in Table 4. If we use Epstein correlation for obtaining the jet break-up length, the molten jet is completely fragmented under the table 3 conditions. In addition, the particle debris bed could be sufficiently cooled as shown in Fig.4.

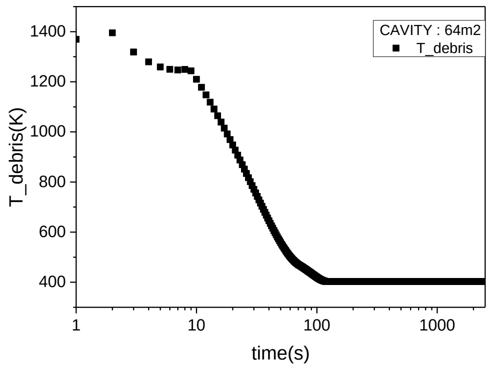

Fig. **4**. Debris coolabilty analysis results.

3. Conclusions

An evaluation of the pre-flooding strategy for the OPR1000 nuclear power plant was performed. Results may vary depending on various variables and cavity conditions in the power plant. In this paper, analysis was performed under the conditions of Table 4, and it was confirmed that the corium was cooled stably under the conditions of Table 4.

ACKNOWLEDGMENTS

This work was supported by the Korea Institute of Energy Technology Evaluation and Planning (KETEP) grant funded by the Korean government (Ministry of Trade, Industry, and Energy) (No. 20193110100090).

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