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Analysis for Coolability Models of Molten Corium Concrete Interaction

Sang Ho Kim, Jong Hwa Park, Hwan Yeol Kim, Rae-Joon Park
Thermal Hydraulic and Severe Accident Research Division, KAERI, 989-111 Daedeok-daero, Yuseong-gu, Daejeon
**Corresponding author: sangho@kaeri.re.kr*

1. Introduction

There are various means to prevent a core melt accident and cool a corium inside a reactor vessel for protecting the integrity of a reactor vessel. In case that a reactor vessel is broken, a corium has to be cooled on a cavity for preventing the failure of containment isolation resulting in the release of radioactive materials to the outside environment. When a corium is not sufficiently cooled on a cavity, a molten corium ablates a cavity bottom which consists of concrete and steel liner. Molten corium concrete interaction (MCCI) which is a complex thermo-chemical phenomenon has been analyzed and studied continuously for reducing the uncertainty of the modeling. One of the issues in the MCCI phenomenon is the coolability of corium. Under the condition that the water on the upper surface of the corium layer exists, the heat transfer between the corium layer and the water has a profound effect on the overall ablation.

The purpose of this paper is to identify current coolability models on the upper surface and analyze the effects of cooling mechanisms on the total energy transfer.

2. Coolability Models in Codes

In this chapter, the coolability models in the main codes were identified and reviewed.

2.1 MELCOR2.2

MELCOR is a fully integrated, engineering-level computer code that models the progression of severe accidents in light water reactors. For the analysis of MCCI, the heat transfer, concrete ablation, cavity shape change, and gas generation are simulated in MELCOR, using models taken from the CORCON-Mod3 code [1].

Water on the top of the corium layer can cool the upper part of corium and the crust can be formed. At the interface between the top water and corium layer, a critical heat flux is calculated by a system pressure. The temperature difference of corium interface and saturated water determines a boiling regime according to the calculated critical heat flux. In the nucleate boiling regime, Rohsenow correlation was used. In the film boiling regime, the heat transfer model was set based on Berenson model. In the transition boiling regime, the heat flux value is calculated from the linear interpolation with critical heat flux and the heat flux at the Leidenfrost point. The total heat flux is improved by the gas agitation on the surface of the corium layer and the subcooled water condition.

Two cooling mechanisms of melt eruption and water ingression are included in the MELCOR version 2.2. The new models cited from CORQUENCH code can be used optionally [2]. The melt eruption transfers mass from the melt layer to the debris layer. The transfer rate is wholly proportional to the gas sparging velocity. Water ingression is modeled by a dryout heat flux. The crack temperature is estimated by Lister formula [3].

2.2 MAAP5

MAAP is a modular accident analysis program that simulates various severe accident sequences [4]. In the MCCI analysis, steam from a water pool overlying core debris is modeled. The major logic transfers heat at a rate by the critical heat flux unless the surface temperature is high enough for film boiling. If the debris surface temperature is high enough, the total heat flux is calculated by considering radiation interchange and the user-specified film-boiling heat transfer coefficient. Water ingression can be modeled by Lister-Epstein model or parametric model. Melt eruption is modeled by Ricou-Spalding correlation with single coefficient (E0).

2.3 ASTEC-V2

All the models included in the MCCI module MEDICIS that is part of the integral code ASTEC-V2 devoted to simulation of severe accidents in light water reactors [5].

The radiation heat flux towards the water pool and the dry-out heat flux contributed to the simulation of the penetration of the water into the crust through cracks. The top crust temperature is assumed to be saturation temperature. The temperature distribution between the top interface and the crust center are linearly interpolated as the crust center has the temperature 300 K higher than the saturation temperature. The bottom of the crust has the solidification temperature.

The mass flow rate of corium jet for melt eruption is also proportional to mainly the superficial gas rising velocity.

2.4 SACAP

SACAP is a severe accident analysis code developed by Future and Challenge technology in Korea. Recent coolability models for MCCI are included in the code.

3. Analysis Method

The MELCOR version 2.2 was used to analyze and compare the effects of cooling mechanisms on the total energy transfer in a MCCI condition.

A pressurized water reactor whose thermal power is 4000 MW is adopted as a reference plant for the analysis. The early breach of a reactor vessel was assumed based on the sequence analysis. In the initial state of the simulation, about 130 tons of molten oxides and about 80 tons of molten metals existed on the containment cavity under the assumption that all the corium was spread well. The initial cavity was a cylinder with a floor area of 80 m^2. The cavity consists of a basaltic concrete. The concrete has the properties: the solidus temperature is 1350 K, the ablation temperature is 1450 K, and the liquidus temperature is 1650 K.

Three cases were analyzed with the continuous supply of water on the top of the corium layer. In the first case, only the boiling heat transfer on the top of the crust was included. In the second case, the boiling heat transfer with the water ingression mechanism was assumed. In the third case, the boiling heat transfer with the melt eruption mechanism was assumed. All the specific models were used in the original code with default options.

4. Results

The corium pool was separated to three layers in the initial state of the simulation in the case 1. The lowest was a uranium oxide layer. The highest was a light oxide layer. A metal layer between the heavy oxide layer and the light oxide layer was oxidized in the first. Three layers were mixed based on the mixing criterion. It existed as a light mixture layer as shown in Fig. 1. In the case 1, a maximum of about 1.7 m of concrete was ablated by the corium pool. The initial temperature of the corium pool was 2843 K. It decreased to 1750 K after an hour. After ten hours, the corium temperature continuously fluctuated at the concrete ablation temperature.

Heat transfer rates from the upper corium surface to the top coolant in the cases were shown in Fig. 2. In the initial time, the heat transfer rate sharply decreased according to the decrease of the corium temperature. The crust was formed and broken continuously in Fig. 3, the heat loss to the top coolant fluctuated. In the case 3, the stable heat transfer through the crust was achieved.

5. Conclusion

The heat transfer by the water ingression mechanism was enhanced up to about 50 %. The enhancement effect of the heat transfer by the melt eruption mechanism was insignificant in this simulation condition. It has to be verified in various conditions.

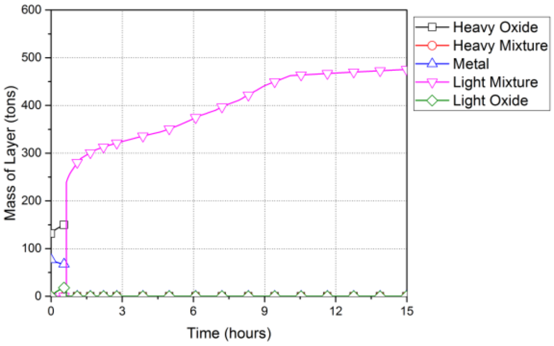

Fig. 1. Mass of Layer (Case 1)

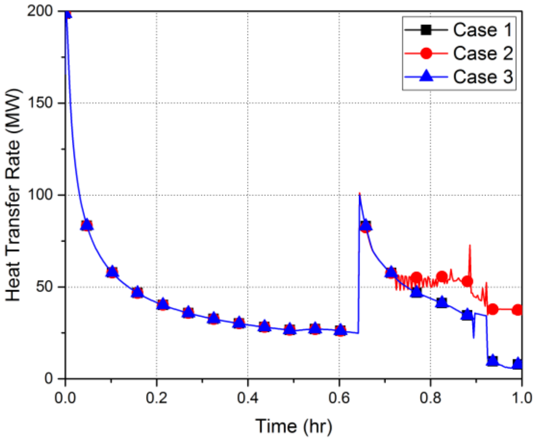

Fig. 2. Heat Transfer from Upper Corium Surface to Coolant

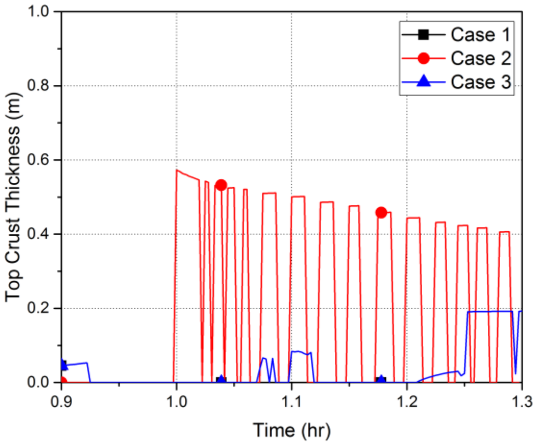

Fig. 3. Top Crust Thickness of the Upper Corium Layer in short term (Case 2: water ingression)

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