Parametric Analyses of MCCI for SMART Using MELCOR

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1. Introduction

A variety of issues in a severe accident have been raised more after the Fukushima accident in Japan. When a reactor vessel fails to retain corium in a vessel due to any reason, efficient actions have to be conducted for protecting the integrity of containment. In order to do that, it is important to understand how corium will move and interact with others in containment. MCCI (Molten-Corium Concrete Interaction) is one of the most important issues in the view of corium behavior inside the containment. Understanding the MCCI is important in a phenomenological point of view. Furthermore, the effects from main variables have to be analyzed for design certificate of a nuclear power plant in a practical point of view.

SMART (System-integrated Modular Advanced ReacTor) is chosen as the reference reactor in this paper. The project for the exportation to Saudi Arabia is in progress.

In severe accident management strategy of advanced pressurized water reactors such as APR1400 (Advanced Power Reactor 1400 MWe) and SMART, filling the cavity with water is preceded for retaining the corium in vessel through external reactor vessel cooling (ERVC). According to the step of strategy, there is a high possibility that the water level in the cavity is maintained at the level of the cold leg bottom.

The objective of this paper is to analyze the results of the MCCI phenomena from varying with main conditions after the ERVC condition of SMART.

2. Methods

MELCOR is a fully integrated, engineering-level computer code that models the progression of severe accidents in light water reactors [1]. MELCOR-version 1.8.6 developed by Sandia National Laboratories is used in this study. For the MCCI problem, the effects of heat transfer, concrete ablation, cavity shape change, and gas generation are included in MELCOR, using models taken from the CORCON-Mod3 code [2].

MCCI input model of SMART was developed by modifying that of APR1400. A specific plant of SMART-PPE (Pre-Project Engineering), whose core thermal-power is 365 MW, is adopted for the analyses. The containment of SMART is modeled with 43,891 m^3 of free volume. The cavity, whose height is relatively lower than that of APR1400, is modeled based on the design of SMART-330 (SDA granted).

The composition and mass of corium are quoted from a research about IVR-ERVC (in-vessel retention through external reactor vessel cooling) for SMART under the conservative assumption that all the corium in the IVR-ERVC strategy is dropped into the cavity [3]. The composition and mass of corium are shown in Table I. The MCCI simulations started in the condition that the inputted corium was located on the cavity under the coolant. In addition, containment spray systems and containment cooling systems are not simulated in the analyses.

Table I: Corium Composition and Mass

Layer	Contents	Mass (ton)
Metal	Fe	16.0
	Zr	2.8
Oxide	UO2	18.6
	ZrO2	3.7

3. Results

3.1 Base Case

The layer of light oxide (LOX) was separated from that of heavy oxide (HOX) at the initial period. After that, the concrete ablation under the bottom of heavy oxide layer caused its density decrease. Due to the decrease of density, the layer floated on the metal layer (MET). Mass of the heterogeneous mixture layer of light oxides and metals (LMX) continuously increased due to concrete ablation. Fig. 1 shows the initial inversion of metal and oxide layers.

The ablation rate after 11 days became higher than the initial rate because the independent metal layer was finally mixed with the layer of light oxides and metals. It also caused the small peak in the temperature variation as shown in Fig. 2.

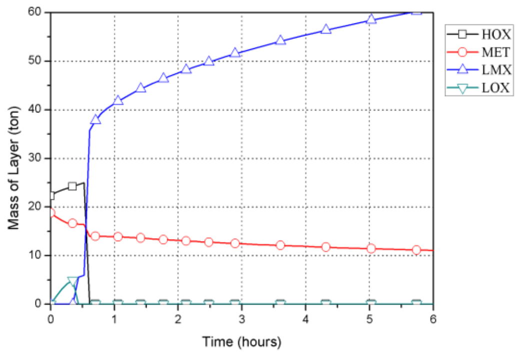

Fig. 1. Initial Layer Inversion of Metal and Oxide

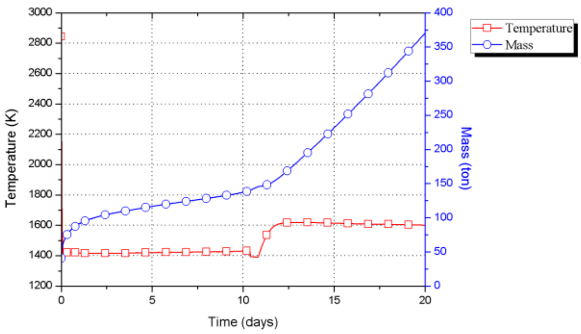

Fig. 2. Corium Mass and Temperature

3.2 Variation of Concrete Composition

The concrete of cavity in the base case had the same composition of the concrete used in APR1400. When the concrete composition was changed to limestone aggregate/common sand (LCS) concrete, the shape of concrete ablation was changed as shown in Fig. 3. It presented the appropriate ratio of axial to radial concrete ablation comparing with that of the APR1400 concrete as shown in a result of a previous MCCI experiment [4]. Furthermore, the generated CO2 in the case of LCS concrete was about 6.5 times larger than that in the case of APR1400 concrete.

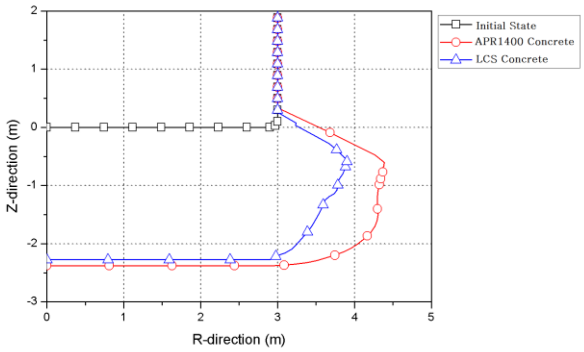

Fig. 3. Concrete Ablation from each Concrete Composition

3.3 Variation of Metal Amount

In a small modular reactor, main components of reactor coolant system are integrated inside a reactor pressure vessel. Accordingly, when core melt proceeds, the components and structure for coolant flow and heat transfer are heated and melted. The amounts of metals affect the progress of MCCI in the ex-vessel condition. In this subsection, the variation of iron amount was only considered rather than zirconium.

First of all, the case with 26 tons of iron delayed the direct contact of mixture layer of light oxides and metals with cavity concrete. It caused the decrease of cavity ablation altitude due to the presence of the metal layer between the mixture layer and cavity concrete.

Second, as the amount of iron in corium increased, more hydrogen and carbon-monoxide were generated. It was caused due to the delay of oxide interaction with cavity concrete as well as the chemical reactions of iron with steam and carbon-dioxide.

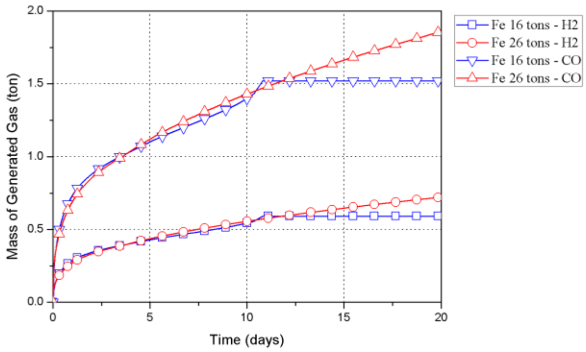

Fig. 4. Masses of Generated Gases

3.4 Variation of Coolant Supply Rate into Cavity

In the base case, the water level in the cavity was maintained at the bottom of feedwater line connected to steam generators as the water was continuously refilled into the cavity. In cases of the decreased coolant supply rates, the concrete ablation accelerated. According to that, more carbon-dioxide was generated. The standard CORCON-Mod3 model applied to heat transfer to overlying coolant including treatment of enhancements to the boiling curve still has some issues to be verified for simulating the effects of top flooding in a long-term phase of MCCI analysis.

4. Conclusions

MCCI simulations varying with main parameters in SMART were performed and analyzed using MELCOR in this study. The occurrence possibility of ex-vessel MCCI in SMART is much lower than that in large power plants due to larger heat transfer area and smaller thermal power in the condition of IVR-ERVC. In the analyses, the corium containing a large amount of iron has a higher risk for the integrity of containment in a long-term phase under the defined conditions. Specific models related with the variation analyses have to be reviewed more. This study does not consider the effects of containment cooling system in SMART; however, it will be reflected and analyzed later.

5. Acknowledgement

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