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Analysis of MCCI phenomena using CINEMA code

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1. Introduction

After the reactor vessel failure, the molten core is discharged into the containment. This molten core releases large amount of decay heat. If proper cooling process is not taken, it may trigger the basement melt-through. For this reason, understanding of MCCI phenomena is essential to cope with this.

So far, many experiments have been carried out to examine the physical behavior of MCCI phenomena. In the early stage of research on the MCCI phenomena, the following experiments were performed such as ACE (Thompson et al., 1997), SURC (Copus et al., 1990; Thompson et al., 1992a, 1992b), WETCOR (Blose et al., 1993), and MACE (Farmer, 2001) [1-4].

In this paper, to simulate MCCI behavior of SURC-2 experiment with basaltic concrete used CINEMA code.

2. Physical Model of CINEMA code[5]

As shown Fig. 1, the molten corium pool consists of several corium layers such as TCL (Top Crust Layer), UML (Upper Metal Layer), MPL (Mixed Pool Layer), and LML (Lower Metal Layer). TCL is defined as the solidified oxide layer which located at the uppermost region of corium pool. UML is defined as the metal layer region present on the oxide layer. MPL is defined as the oxide layer which may contains a small amount of metal components. LML is defined as the metal layer below the oxide layer. Surroundings above the corium is described by specified time dependent pressure and temperature are defined as WTL (Water Layer) or ATM (Atmosphere).

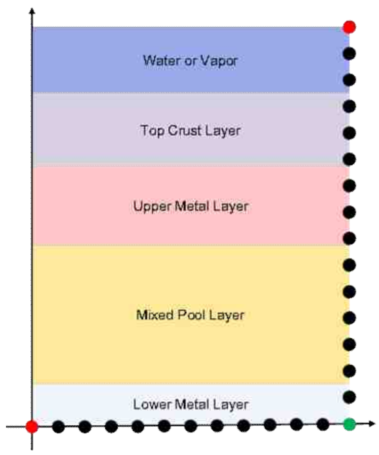

Fig. 1. Stratified layer model

2.1 Heat and Mass Transfer between layers

The mass and heat transfers by diverse mechanisms take place between layers. They are represented in Fig. 2 and 3. The following mass and heat transfer mechanisms are considered:

- Heat transfer with various interfaces
- Heat generation by the decay of fission products and the chemical reactions
- Mass transfer between TCL and MPL due to melting and freezing
- Mass transfer between UML and LML by the layer flip
- Mass transfer among Metal Layers and Oxide Layers by chemical reaction
- Mass sources due to the ablation of concrete

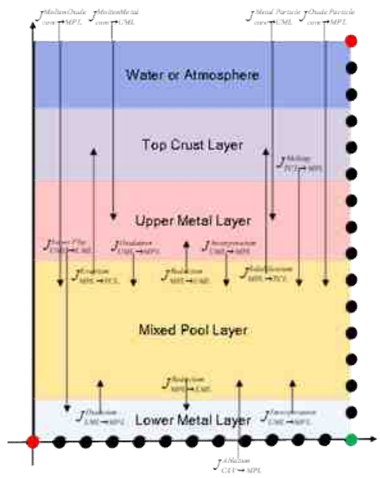

Fig. 2. Mass transfer among layers

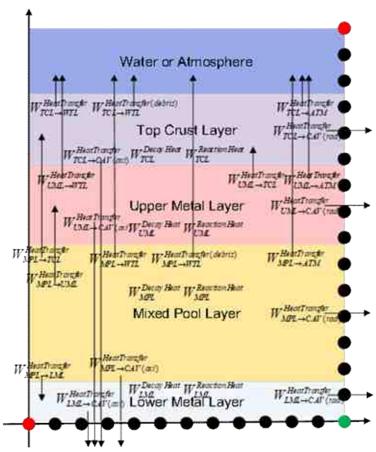

Fig. 3. Heat transfer among layers

2.2 Mass Conservation Equation

The mass conservation equation of the individual corium layer can be expressed in the following basic ways.

$$\frac{dm_{Layer}}{dt} = \dot{m}_{Layer}\Big|_{in} - \dot{m}_{Layer}\Big|_{out}$$

The molten metal components were supposed to blowdown into the UML and the molten oxide components were supposed to blowdown into the MPL. At the initial stage of blowdown, the average density of the metal layer is lighter than the average density of the oxide layer, for this reason, the UML is present on the MPL. Over time, the density of the oxide layer becomes lighter than that of the metal layer due to the influx of concrete components caused by the reactor cavity ablation. At this time, actually the components of UML are moved through the MPL sequentially to the LML, however, in the code, when the average density of the UML becomes greater than the average density of the MPL, it is assumed that the metallic components of UML is moved to LML without considering the time delay.

2.3 Energy Conservation Equations

The energy conservation equation of the individual corium layer can be expressed in the following basic ways, which consist of inlet, outlet, and internal terms.

$$W_{Layer} = W_{Layer}\Big|_{in} - W_{Layer}\Big|_{out} + W_{Layer}\Big|_{internal}$$

Heat transfers among layers are shown in Fig. 3. When calculating the heat transfer between each layer, if the height of each corium layer is less than 1/10 of corium layer radius, it is assumed that the corium is not spread well.

2.4 Reaction Boundary Transition Model

Fig. 4 shows the reaction boundary transition model. The basic law assumes that the progression of each node is carried out in the middle angle of each node forming the boundary side. The progress of the ablation on the individual nodes is calculated by obtaining the fraction according to the position of node and the geometry of the boundary surface on the downward heat transfer rate from the corium pool. The position of the individual nodes and the boundary heat transfer area are determined based on the cylindrical coordinate system.

3. Benchmark of the SURC-2 experiment

3.1 Description of the experiment facility and condition

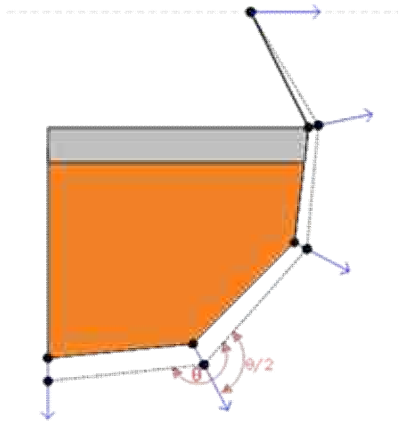

Fig. 4. Reaction boundary transition model

The purpose of the SURC-2 is to analyze when the MCCI occurs at the cavity floor of basaltic concrete.

As shown Fig. 5[2], the cavity used in experiment is a diameter of 40 cm and a height of 60 cm. Composition of basaltic concrete at the floor of cavity is shown in Table I[6]. Total mass of corium that interacts to floor concrete is 203.9 kg, and composition of corium is shown in Table II[6]. Air is kept in a dry condition. The input power to simulate decay heat is shown in Fig. 6[2].

Table I: SURC-2 basaltic concrete composition

Constituent	Wt% for Test
CO_2	1.5
H_2O	5.0
K_2O	3.8
Na_2O	1.4
TiO_2	0.8
SiO_2	57.9
CaO	13.8
MgO	4.0
Al_2O_3	7.2
Fe_2O_3	4.4

Table II:: SURC-2 Corium Composition

Constituent	Mass (kg) for Test
Zr	16.9
ZrO_2	46.1
UO_2	140.9
Total	203.9

3.2 CINEMA Input Modeling

CINEMA input was modeled by using single node required for SURC-2 simulation. Initial and boundary conditions are as same as the test.

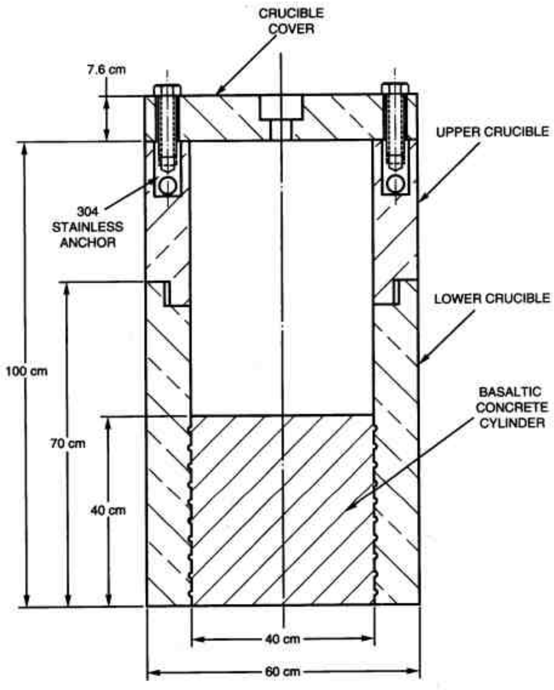

Fig. 5. Test section of the SURC-2 facility

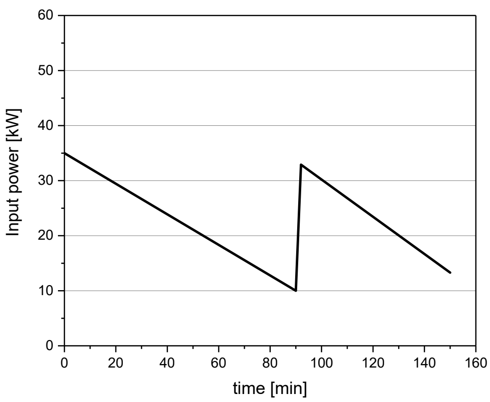

Fig. 6. Input Power relative to onset of ablation for SURC-2

4. Comparison of Code-Experimental Results

As a result of calculation, concrete bottom ablation occurs up to 25.53 cm for 150 minutes. SURC-2 experiment result, bottom ablation occurs from 119 minutes to 25.69 cm. This information is shown in Fig. 7. The melt temperature is interpreted to be 1698.20 K to 150 minutes as shown in Fig. 8.

Table III shows the minimum and maximum melt temperature, ablation rate per hour. The relative error of maximum temperature is 0.32% and 14.73% for minimum temperature. The relative error of ablation for axial direction is 0.62%.

Table III: Result of prediction for SURC-2

	CINEMA	Experiment
Melt Temperature (Maximum, K)	2600.00	2608.33
Melt Temperature (Minimum, K)	1698.20	1991.67
Ablation Depth (Axial, cm)	25.53	25.69

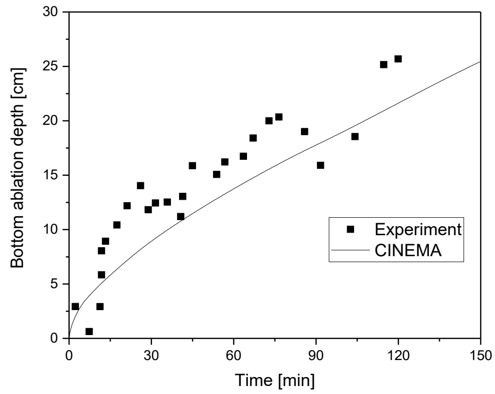

Fig. 7. Axial Ablation depth prediction vs experiment for SURC-2

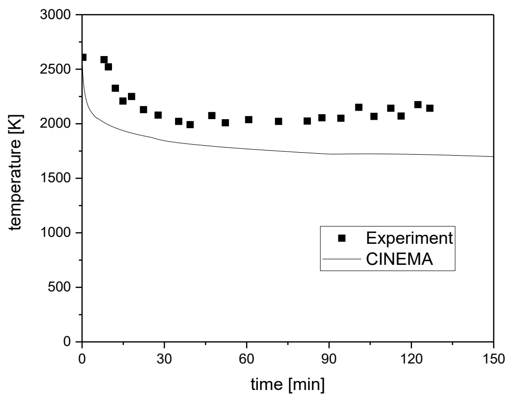

Fig. 8. Melt temperature prediction vs experiment for SURC-2

5. Conclusions

In this paper, the MCCI behavior of SURC-2 experiment with basaltic concrete was predicted using CINEMA code.

As a result of comparison with the experiment result, it was confirmed that the MCCI behavior tendency calculated by the CINEMA code was similar to the experiment result.

In the future, it plans to test the predictive ability of CINEMA code through various MCCI experiment and sensitivity analysis.

ACKNOWLEDGMENTS

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