Validation of Layer Inversion Model in MAAP5

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1. Introduction

According to the results of OECD MASCA project, it was found that heavy metal layer can be formed from oxide pool in the lower plenum by thermochemical interaction between Uranium Dioxide (UO2) and Zirconium (Zr). This reaction leads to three-layer-configuration, light metal layer above and heavy metal layer under oxide pool [1]. As a result, this configuration in the lower plenum plays a significant role to determine failure modes of Reactor Pressure Vessel (RPV) with respect to heat flux to the RPV wall. The formation of heavy metal layer causes decrement of thickness of light metal layer. In other words, the heat flux, a so-called 'focusing effect', considerably increases from the light metal layer to the RPV wall.

In this paper, we calculate the layer inversion model using MATLAB by validating MASCA experiment. Additional validation are performed for a high power reactor case.

2. Description of Layer Inversion Model

The layer inversion model is based on separation model [1]. Figure 1 shows simplified U-Zr-O-Fe phase diagram. From the initial mole fractions of uranium, zirconium, oxygen and steel at the point C_0, the mole fraction at the point C_1 and C_2 on the tie line are respectively calculated on the U/Zr-O-Fe plane. The point C_1 represents the mole fractions of oxidic metal pool. On the other hand, the point C_2 represents the mole fractions of heavy metal pool. The condition of heavy metal layer formation is that the temperature of corium pool is higher than miscibility gap temperature which is 2673K as a default value. The formula (1) and (2) represent the mole fractions in the oxidic melt, N_{OXI}, and heavy metal layer, N_{HM} respectively. X_O, X_1 and X_2 are mole fractions calculated at the point C_0, C_1 and C_2 from the phase diagram [2].

$$N_{OXI} = \frac{\frac{m_{U1}}{238} + \frac{m_{Zr1}}{91.22} + \frac{m_{S1}}{55.85} + \frac{m_{O1}}{16.0}}{\frac{m_{U0}}{238} + \frac{m_{Zr0}}{91.22} + \frac{m_{S0}}{55.85} + \frac{m_{O0}}{16.0}} = \frac{X_0 - X_2}{X_1 - X_2} \quad (1)$$

$$N_{HM} = \frac{\frac{m_{U2}}{238} + \frac{m_{Zr2}}{91.22} + \frac{m_{S2}}{55.85} + \frac{m_{O2}}{16.0}}{\frac{m_{U0}}{238} + \frac{m_{Zr0}}{91.22} + \frac{m_{s0}}{55.85} + \frac{m_{O0}}{16.0}} = \frac{X_1 - X_0}{X_1 - X_2} \quad (2)$$

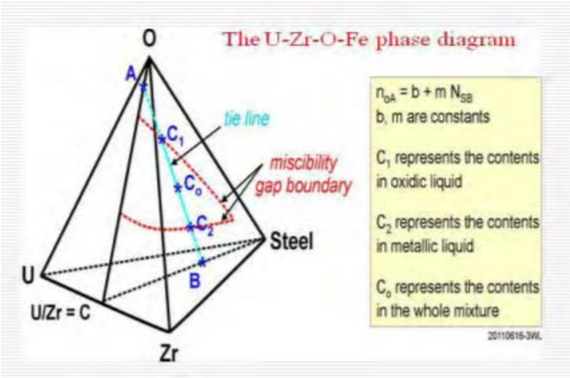

Fig 1. U-Zr-O-Fe phase diagram [2]

3. Validation with MASCA experiment

The layer inversion model is validated using MATLAB. Calculation result is compared with 15 cases in MASCA experiment and the model suggested by Salay and Fichot [1]. Figure 2 shows the mass fractions of uranium and zirconium in the heavy metal layer. Figure 3 shows the mass fractions of heavy metal layer. Figure 4 and 5 show the mole fractions of uranium and zirconium in the heavy metal layer respectively. EXP, MATLAB and S&F represent result of experiment, MATLAB and Salay and Fichot model, respectively. U and Zr represent uranium and zirconium. The calculation are well agreed with the results of MASCA experiment and Salay and Fichot model. Especially, the results were in accordance with the validation results of MAAP5 described in the MAAP5 manual.

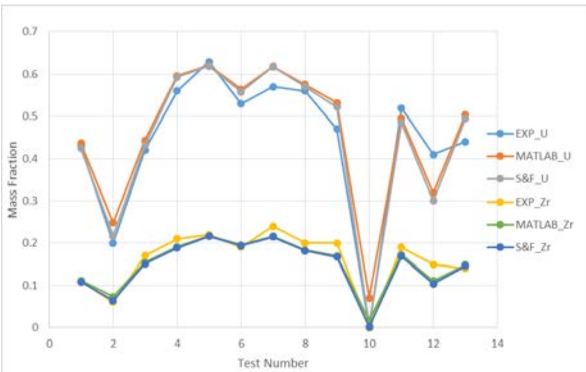

Fig 2. The mass fractions of Uranium and Zirconium in heavy metal layer

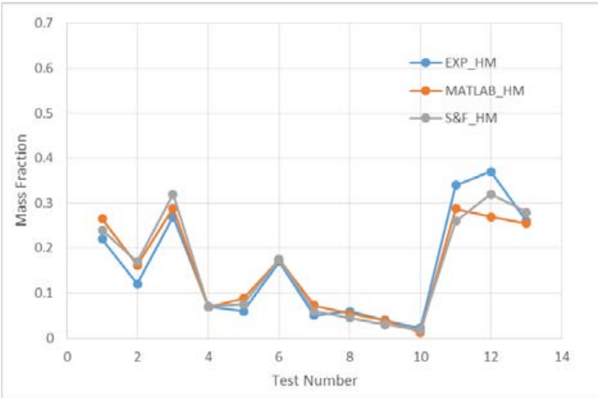

Fig 3. The mass fractions of heavy metal layer

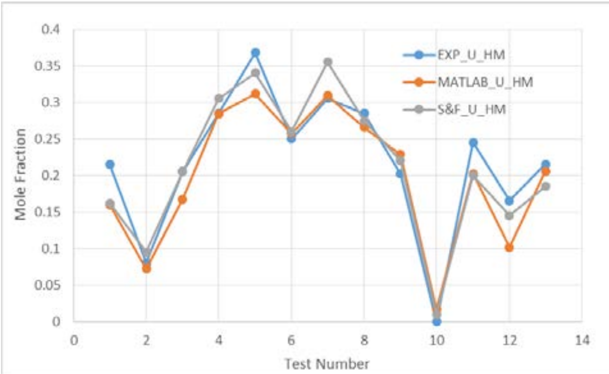

Fig 4. The mole fractions of Uranium in the heavy metal layer

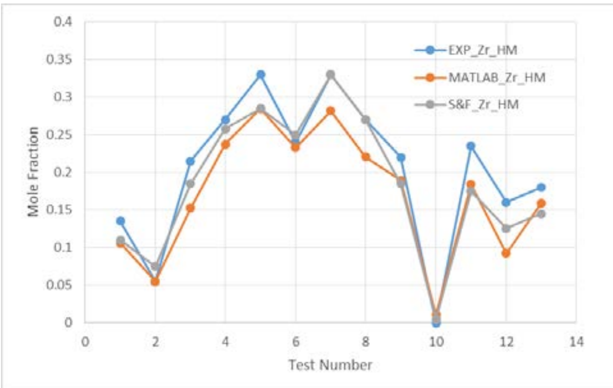

Fig 5. The mole fractions of Zirconium in the heavy metal layer

4. Validation with the Reactor Case

K.Lim et al. performed the study for the purpose of comparison between MELCOR and MAAP5 in terms of severe accident progress of a high power reactor [3]. The MAAP5 results using layer inversion model showed the formation of heavy metal and enhanced focusing effect in the lower plenum. To figure out whether the constitution mass of heavy metal was appropriately calculated according to its model, validation was carried out. The mass of UO_2, Zr, ZrO_2 and Steel at the previous step, immediate time before formation of heavy metal layer, were utilized as an input parameter for the MATLAB code. The time difference was 30 seconds between the formation step for heavy metal and immediately previous step. Table 1 shows the mass fractions of heavy metal layer and oxidic metal layer in the corium pool and uranium, zirconium, oxygen and steel in heavy metal layer. HM represents heavy metal layer and OX represents oxidic metal layer respectively. The calculation showed good agreement with the MAAP calculation results. The errors for the ratio of heavy metal and oxidic metal are about 0.8% and 0.16%, respectively. The mass fractions of respective constitution in the heavy metal layer have errors within 1.7% except for the steel. The error of mass fraction of steel is about 3.58%. It is considered that steel mass increased due to ablation of lower plenum wall.

Table 1. The mass fractions compared with the results of MAAP5 and MATLAB

	HM	OX	U_HM	Zr_HM	O_HM	S_HM
MAAP5	0.1642	0.8358	0.5637	0.1606	0.0073	0.2683
MATLAB	0.1629	0.8371	0.5707	0.1632	0.0074	0.2587
Error (%)	0.7917	0.1555	1.2418	1.6189	1.3698	3.5781

5. Conclusions

It was found that heavy metal can be separated from the oxidic pool because of thermochemical reaction between uranium dioxide and zirconium from the MASCA experiment. This phenomenon is considered as a layer inversion model in MAAP5. The layer inversion model is validated using MATLAB, and it is concluded that MAAP5 appropriately calculates the mass of formed heavy metal.

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REFERENCES

[1] Salay, M., Fichot, F., Modelling of Corium Stratification in the Lower Plenum of a Reactor Vessel, OECD/NEA

MASCA Seminar 2004, Aix-en-Provence, France, June 10th to 11th, 2004.

[2] FAI, MAAP5 User Manual, 2008

[3] K.Lim., et al., Code-to-code comparison between severe accident integral codes for the analysis of the severe accident progress of a high power reactor, KINS/RR-1598, Korea Institute of Nuclear Safety, 2016.