Study on the Steady State Layer Inversion of Melt Pool during Severe Accidents

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1. Introduction

In general, a two-layer melt pool with a light metallic layer of Fe-Zr on top of oxidic pool was assumed to be a bounding melt configuration in the analyses for the severe accidents. The experimental results of the OECD MASCA, however, have shown that when a sufficient amount of non-oxidized zirconium (Zr) is available, then metallic uranium (U) migrates to the metallic layer [1]. The transfer of species between the U, O, Zr melt and the steel can result in a significant density increase of the metallic phase. The density increase of the metallic phase can lead to inverse stratification with an additional heavy metal layer below the oxidic pool. In this study, thermodynamic analyses were performed to examine the final melt pool configuration during severe accidents in the APR1400. The thermodynamic analyses were performed using the GEMINI code. Combined with the GEMINI code calculation result and the peer review on the RASPLAV/MASCA experimental result, the final melt pool configurations were determined for the major accident scenarios of the APR1400. In this study, for the evaluation on the layer inversion of molten core, a small-scale the test facility that can handle prototypic materials was constructed. As for the material compositions of the TLFW (Total Loss of Feedwater), preliminary test was successfully performed using the prototypic melt. Thermo-material inspection is in progress to validate the layer inversion of melt pool.

2. Evaluation of Layer Inversion of Melt Pool

For the quantitative evaluation on the layer inversion phenomena, the density variation of oxidic and metallic phases under the thermodynamic equilibrium should be determined. In addition, the systematic effects of the U/Zr ratio, the Zr oxidation fraction, the mass of UO_2 and steel should be considered.

In this study, density evaluation graph for oxidic and metallic phases in thermodynamic equilibrium was developed by making use of the NUCLEAR07 data base and the methodology for density calculations applied in the MASCA program. As for the individual accident sequences, the U/Zr ratio, the Zr oxidation fraction, and the mass of UO_2 were determined by the SCDAP/RELAP5 code analyses. For various iron mass from 5 to 60 ton, GEMINI2 code calculations were performed to determine the compositions and the mass of specie in the oxidic layer and the metallic layer, respectively. And finally, the density of mixture of the oxidic and the metallic layer was calculated.

In determining the density of mixture, the density of each pure liquid species should be precisely defined at given temperature of accident sequences. Using the density evaluation graph, the mass of metallic layer which is heavier than the oxidic phase can be calculated. In addition to this iron mass relocated below the oxidic pool, the whole metallic U and the part of metallic Zr calculated from the GEMINI code analysis can stratify below the oxidic pool. Metallic Zr can be distributed between the heavy metallic layer and the light metallic layer. The estimation of the metallic Zr partitioning between the heavy and the light metallic layer is a very hard task. In this study, the mass of metallic Zr which stratify below the oxidic pool was calculated by assuming that the mass fraction of uranium is fixed at 0.4 among the total mass of heavy metallic phase below the oxidic pool [2]. Therefore, the total mass of heavy metallic layer below the oxidic pool can be obtained by summing the iron, the U, and the Zr in each accident sequence of the APR1400. Fig. 1 shows the melt pool configuration of the representative accident scenarios of the APR1400.

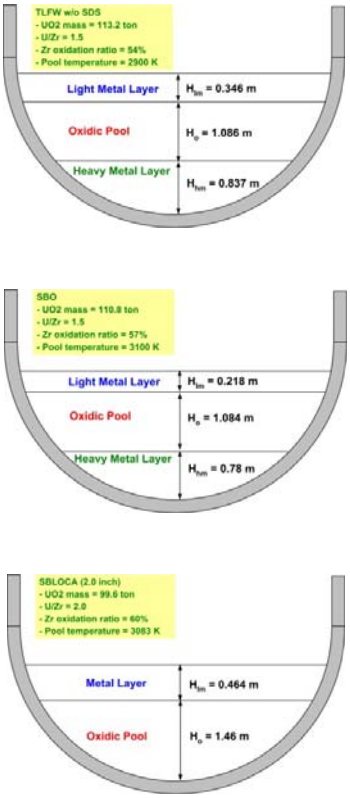

Fig. 1. Melt pool configurations for the major accident sequences of the APR1400.

3. Experiment on the Layer Inversion of Corium

In this study, for the evaluation on the layer inversion of molten core, a small-scale the test facility that can handle prototypic materials was constructed. Induction heating method using a cold crucible was implemented for melting of the UO_2-ZrO_2-Zr-Fe mixture. The maximum electric power and frequency of the generator were 100 kW and 120 kHz, respectively. Fig. 2 shows the photographs of the test facility. The inner diameter and the height of the crucible were 10 cm and 24 cm, respectively. In the test facility, steam supply line and by-pass line were installed in order to perform the transient test of corium behaviour. After the completion of the layer inversion test under the steady-state condition, in order to investigate the melt pool behaviour transient test will be performed under the steam environment and the additional supply of Fe during the reaction.

Fig. 2. Photograph of the layer inversion test facility.

For the precise evaluation on the melt pool layer inversion, a series of test will be performed for the initial melt pool conditions of the major severe accident sequences of the APR1400. In the test, temperature of the melt pool surface will be measured using the Pyrometer. Several material inspection methods such as EPMA, XRD, and SEM will be implemented in order to precisely examine the distribution and composition of the melt layer as a post-inspection of the test. In this study, as for the material compositions of the TLFW, preliminary layer inversion test was successfully performed using the prototypic melt. In the preliminary test, UO_2-ZrO_2-Zr-Fe mixture was melted. The mass ratio of UO_2-ZrO_2-Zr-Fe was 72.8-11.8-7.5-7.9. Total mass of mixture was 6.29 kg and 84% of charged mixture was melted. Fig. 3 shows the photograph of the solidified melt in the preliminary test. Cutting of the solidified melt and material inspection are in progress to investigate the melt composition distribution. And GEMINI code analysis will be performed in order to check the applicability of the present thermodynamic methodology for predicting the melt layer inversion phenomena.

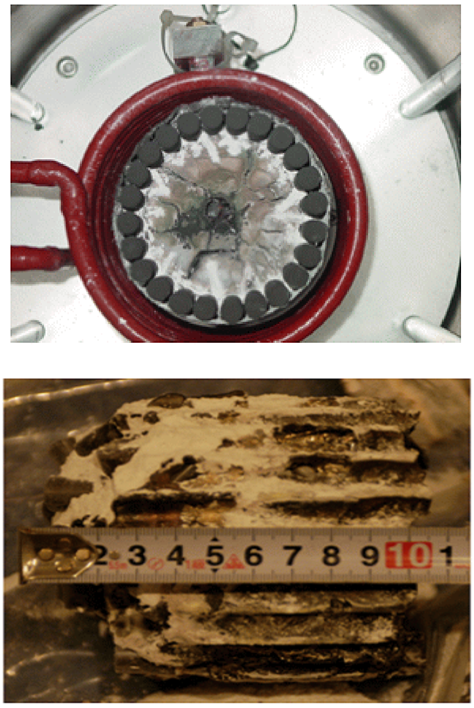

Fig. 3. Photographs of the solidified melt.

4. Conclusions

Combined with the GEMINI code calculations and a peer review of the RASPLAV/MASCA experimental results, the final melt pool configurations were determined for the major accident scenarios of the APR1400. The thermodynamic analyses results address the possibility of a melt pool layer inversion in the APR1400 accident sequences. Melt pool configurations were different in the representative accident sequences of the APR1400. In case of SBLOCA where U/Zr ratio and initial melt pool temperature were relatively higher, layer inversion phenomena can be precluded. In other cases, however, possibility of layer inversion should be considered in evaluating melt pool configuration and consequent thermal load from the melt pool.

For the precise evaluation on the layer inversion of molten core, a small-scale the test facility that can handle prototypic materials was constructed. As for the material compositions of the TLFW, preliminary test was successfully performed using the prototypic melt. In this study, GEMINI code analysis will be performed in order to check the applicability of the present thermodynamic methodology for predicting the melt layer inversion phenomena.

REFERENCES

[1] M. Barrachin and F. Defoort, “Thermophysical Properties of In-Vessel Corium: MASCA Programme Related Results,” Proceedings of MASCA Seminar 2004, Aix-en-Provence, France, June 10 ~ 11, 2004.

[2] H. Esmaili and M. Khatib-Rahbar, “Analysis of In-Vessel Retention and Ex-Vessel Fuel Coolant Interaction for AP1000,” NUREC/CR-6849, 2004.