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TEXAS-V Code Analysis for Ex-vessel Fuel Coolant Interaction in IVR-ERVC Strategy

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1. Introduction

Steam explosion phenomenon has been studied and reviewed in various perspectives due to its high importance connecting to the possibility of threatening the containment integrity in ex-vessel scenarios.

In the severe accident management strategy of advanced pressurized water reactors such as APR1400 (Advanced Power Reactor 1400 MWe) or SMART (System-integrated Modular Advanced ReacTor), cavity flooding is preceded for retaining the corium in vessel by external reactor vessel cooling (ERVC). According to the purpose of the strategy, the water level in the cavity must be maintained at the level of the cold leg bottom; however, when a reactor vessel is failed and a corium is discharged, water level is dependent on various factors in accident sequences and conditions.

In the analysis of the steam explosion, the water level in the cavity is one of the most important parameters as it changes the degree of jet fragmentation in gas space, jet velocity and diameter during fuel coolant interaction (FCI) [1].

Experiments focusing on FCI were simulated using TEXAS-V code [2]. The experiments were set for the various water level conditions for the IVR (In-Vessel Retention)-ERVC strategy.

This paper has a purpose to analyze the effect of water level on FCI in the IVR-ERVC condition.

2. Simulation Code

The TEXAS-V code developed in University of Wisconsin-Madison was used for simulating steam explosion. The results of experiments were compared with those of the simulation calculations.

TEXAS-V uses a transient, three fluid, and one-dimensional models capable of simulating fuel-coolant mixing interactions [3]. Three hydraulic fragmentation models are included in the code. They are Rayleigh-Taylor instabilities (RTI), Kelvin-Helmholtz instabilities (KHI) and boundary layer stripping (BLS).

3. Code Validation with TROI

Validation for TEXAS-V has been carried out by utilizing experimental programs including FARO in Italy ISPRA, KROTOS in France IRSN, and TROI in Korea KAERI. In addition, it has been used in many reactor application programs for estimating the pressures and impulses caused by the steam explosion.

In this paper, the experimental cases in TROI (Test for Real cOrium Interaction with water) were used for analyzing the effect of water level and free-fall distance. The TROI-13 case in which a spontaneous steam explosion occurred was firstly simulated for the direct validation of the code. The free-fall distance of the corium was 3.8 m in TROI-13. The pressure variations, which were detected in the experiment and calculated in the code, were compared in Fig. 1. The corium was ejected through the hole with 5.6 cm diameter which was measured after the experiment. It was considered that the actual diameter of the falling corium was varied to be lower than the size of the hole.

As shown in Fig. 1, the average diameter of the melt jet in the experiment was estimated to be about 3 to 4 cm. When the diameters of the melt jet were 3 and 4 cm, the maximum pressures were 5.9 and 10.6 MPa each. They are compared with 6.8 MPa detected in the experiment. While the melt fell in the air, the surface tension of the corium and the dispersion of the melt jet decreased the actual diameter of the melt. It resulted in the lower contribution on the impulse of the steam explosion.

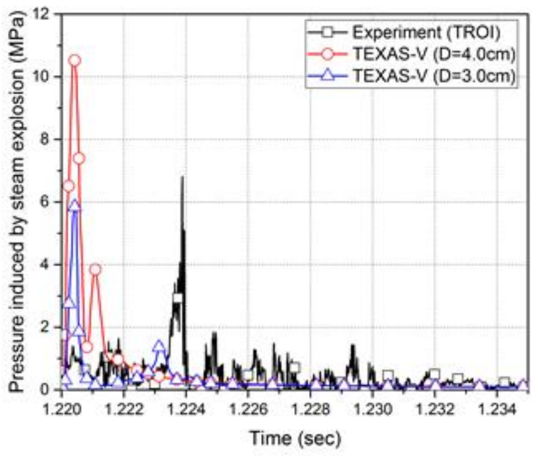

Fig. 1. Pressure variations in the experiment and simulations

4. FCIs Varying with Free-Fall Distances

Two experimental cases were simulated by TEXAS-V for comparing the results of experiments and codes when the water level changed. The case of TROI-68 represents the partially flooded cavity condition. It has a 1.0 m free-fall distance between a release nozzle and a water surface. In this paper, this condition is assumed that the level of the water surface is lower than that of the reactor vessel. It means the failure of supplying the water due to a certain reason after the initiation of the strategy.

The case of TROI-79 represents the fully flooded cavity condition. As there is no free-fall of corium, the corium is directly released to the water in test section. The second was set for analyzing the effect of no free-fall distance on FCI in the IVR-ERVC condition by comparing with the first.

In the two experiments, each specific condition remained the same excluding the free-fall distance of corium. The corium consisted of 80 % UO_2 and 20 % ZrO_2. The temperature of the corium was about 3,000 K. A 360 kg of water in 341 K was filled in the test section below the release nozzle as a coolant in a cavity. The test section was a water tank whose height and area were 1.0 m and 0.36 m^2. The detailed conditions and results of the experiments were cited from the previous papers [4, 5].

In the simulations, the empirical variables including melt properties, cavity geometry and coolant properties were inputted as described above. Main phenomenological variables were set as described in Table 1.

Table I: Simulation Variables in TEXAS-V

Variables	**Value**
No. of leading particles	1
Fragmentation models	RTI, KHI, BLS
Coefficient for KHI	0.01
Void fraction for KHI	0.2

4.1 Case 1: Partially Flooded Cavity Condition

The position changes of jet fronts in TROI-68 and TEXAS-V were shown in Fig. 2. The move of the corium was visually observed and recorded in the experiment. In the simulation, the velocity of the corium at the height of the water surface was about 4.3 m/s. The corium reached the water after 0.44 sec from the release. It took about 0.68 sec to pass through water. The average velocity of the corium jet in water was about 1.47 m/s.

In the both methods, the velocity of the melt jet decreased and increased again in the water; however, the degree of the change in the simulation was larger than that in the experiment. It means the fragmentation is somewhat excessive at the top of the water in the simulation.

4.2 Case 2: Fully Flooded Cavity Condition

The position changes of jet fronts in TROI-79 and TEXAS-V were shown in Fig. 3. The initial velocity of the corium at the height of the water surface was set to be 0.1 m/s in the simulation. It took about 0.6 sec to pass through 1.0 m of water. The velocity continuously increased to 2.3 m/s when the corium reached the bottom of the test section. The average velocity of the corium jet was about 1.67 m/s.

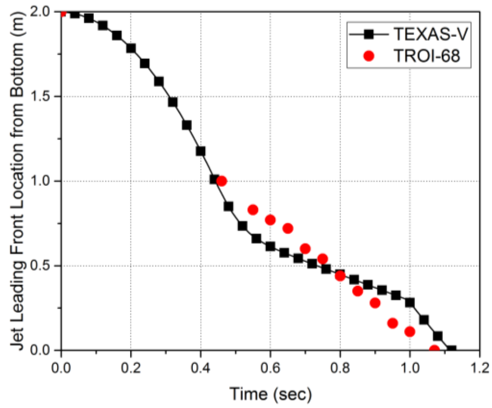

Fig. 2. Jet front position in partially flooded condition

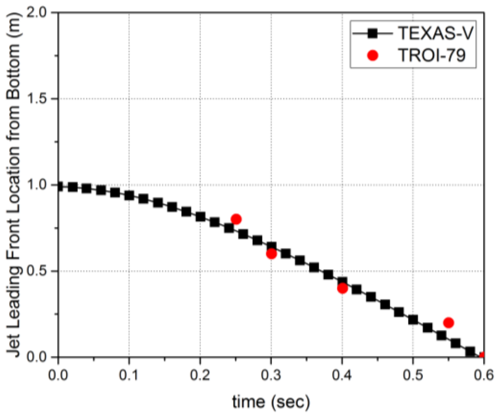

Fig. 3. Jet front position in fully flooded condition

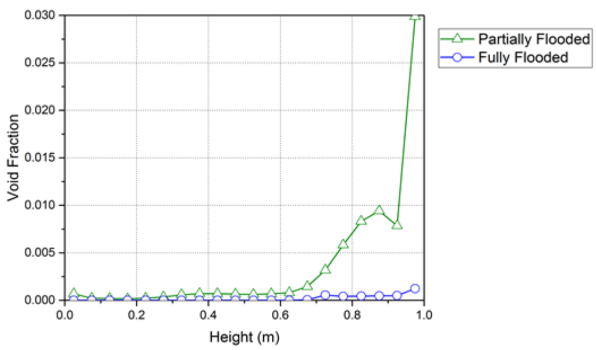

Fig. 4. Void fraction at each height in the conditions

5. Discussion

In the both experiments and simulations, the average velocities of the cases without free-fall distance were larger than those of the cases with the 1.0 m free-fall distance. The initial large velocity of the case with a free-fall distance caused a lot of fragmentation of the melt jet front in the water. Fig. 4 shows void fractions at each height when melt jet reaches the bottom in the simulations. The large increase of void fraction in the case with a free-fall distance means the occurrence of more fragmentation. It results in the increase of heat transfer area between the corium and water.

The difference between the experiment and the simulation for the fully flooded cavity condition was found that much less amount of corium was fragmented in the simulation.

6. Conclusion

The experiments varying with the water level in the same conditions were simulated by the TEXAS-V code. The simulations showed the relatively similar tendency with the experiments; however; some specific values about the fragmentation had difference in the two cases. More sensitivity analyses are needed for the cases.

If the small initial velocity induces less fragmentation in the IVR-ERVC condition that there is no free-fall of the corium, it would imply a low occurrence probability of steam explosion in the triggering step. In addition, the low degree of fragmentation sets a limitation of the propagation from the triggering. Therefore, less amount of corium can contribute to the smaller impulse of steam explosion when it occurs.

The effect of the free-fall distance deeply connects to that of the water level in the cavity. Accordingly, the conclusions of this paper are wholly dependent on the cavity design of nuclear power plants. This approach will be useful when it is applied to SMART (System Integrated Modular Advanced ReacTor) which has the short height of a cavity under a reactor vessel after more validation.

Acknowledgement

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