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Effects of Kelvin-Helmholtz Instability on the Triggered Steam Explosion under High Water Level Condition in Reactor Cavity

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1. Introduction

Nuclear power plants are designed for the safety in operation and accidents. In spite of that, after an occurrence of an initiating event, the assumptions for the failures of safety systems can cause the failure of the decay heat removal. Therefore, the analysis for various severe accidents are carried out to prove the safety of a nuclear power plant even though the probability of a severe accident is very low. Even though the reliability of the in-vessel corium retention through external reactor vessel cooling (IVR-ERVC) is high, the analyses for ex-vessel phenomena are needed to be performed to show that the containment integrity is maintained in the severe accident condition with the failure of a reactor vessel.

An ex-vessel steam explosion is one of the phenomena to prove the safety in a severe accident condition. Various papers were published to identify the behavior of fuel-coolant interaction and improve the capability to simulate the steam explosion phenomenon. A paper was focused on modeling corium jet breakup in water pool and application to ex-vessel fuel-coolant interaction analyses using the TRACER-II code [1].

The purpose of this paper is to analyze the steam explosion of molten fuel discharged directly into water without free-fall in air. An experimental test in the TROI (Test for Real cOrium Interaction with water) facility introduced and explained in the previous paper is reviewed and used for the simulations [2]. The test was analyzed by TEXAS-V code developed by the University of Wisconsin-Madison for the simulation of the fuel-coolant interaction [3]. In this paper, the submerged reactor vessel condition or high water level condition mean that the water level is not high enough to cover the entire lower head of a reactor vessel. Even though the water level does not reach the target level for some reason to accomplish the IVR-ERVC strategy, it is high for a reactor vessel to be partially submerged and there is no free-fall in air when the molten fuel is discharged from a reactor vessel.

2. TROI Test and Simulations for the Submerged Reactor Vessel Condition

The premixing test (TROI-79) for the submerged reactor vessel condition was firstly performed without the triggering material on the bottom [4]. In the test, the behavior of the core melt in the water was analyzed by the detectors and test section for the visualization. The simulation for the TROI-79 was performed and the characteristics were reviewed in previous analysis paper [5]. Following the simulations for the premixing tests, the TROI-82 test for the steam explosion of molten fuel discharged directly into water without free-fall in air was analyzed [2]. The simulations for the TROI-82 test where the triggered steam explosions occurred were performed in the previous paper [6]. In the previous paper, one of the conclusions implied that simulations of the steam explosion in the submerged reactor vessel condition required more detailed modeling for the fragmentation by the Kelvin-Helmholtz instability (KHI) and mixing area between the core melt and water [6]. That is because fragmentation by the KHI model was somewhat overestimated in the simulations for both partially and fully flooded cavity conditions.

3. Sensitivity Analysis on Fragmentation by KHI

In this paper, the TROI-82 test was simulated based on the reference input variables used for the previous paper [6]. Accordingly, the detailed information and input data explained in the previous paper were used in this paper. Table I shows the sequence of the TROI-82 test.

Fig. 1 shows the melt front locations in the TROI-82 test (T82-test) and the base case simulation (T82-C2). For the experimental test, the location of the melt jet was marked by the increase of the thermocouple at each height.

In order to reduce the fragmentation intensity by the KHI, the coefficient for the KHI decreased in the sensitivity analysis comparing with the simulation of the T82-C2 case in the previous paper.

The variations of the dynamic pressure at a height of 0.4 m from the bottom were calculated by the TEXAS-V code. The results were compared with the result of the TROI-82 test as shown in Fig. 2. The case of T82-0.004 shows the peak pressure of the steam explosion is similar with that in the T82-test.

Table I: Sequence of the TROI-82 Test

Time (s)	Event
0.0	Open of intermediate catcher for melt delivery to the water
0.1	Melt-water contact
0.56	External triggering

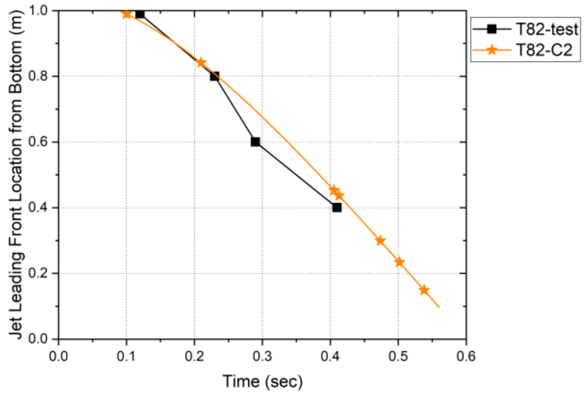

Fig. 1. Melt front location in T82-test and T62-C2

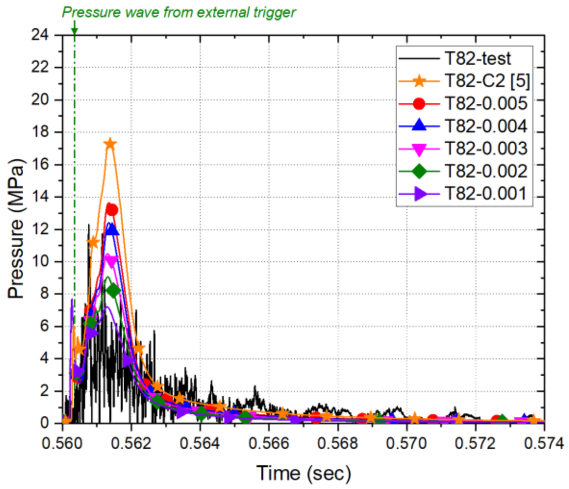

Fig. 2. Dynamic pressure from the steam explosion at a height of 0.4 m in the TROI-82 test and simulations

Fig. 3 shows the impulse from the steam explosion at the bottom of the test section and simulations for the TROI-82 test. First, the force sensor was installed on the bottom of the test section in the test facility for the TROI-82 test. The dynamic load recorded in the detector was integrated by time. The values was shown as the IVDL101 in Fig. 3. Second, the pressure variations at the height of 0.4 m were integrated by time. Then, the calculated values were plotted as IVDP103 in Fig. 3. The simulated case of T82-0.003 shows the impulse similar with those in the IVDL101 and IVDP103 cases. Otherwise, as the fluctuations in the detectors of the experimental test were considered in the integration, the final impulses calculated from the two detectors would be slightly underestimated.

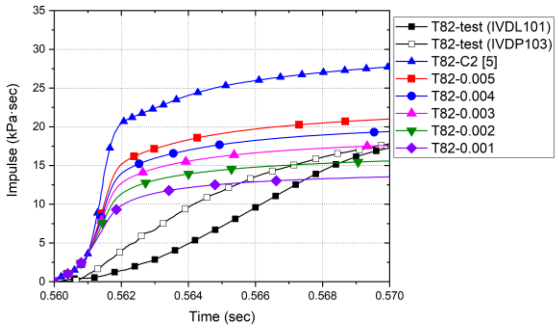

Fig. 3. Impulse from the steam explosion at the bottom of the test section in TROI-82 and simulations

5. Conclusions

The melt jet under the high water level condition shows the gradual increase on the velocity in water. It affects the melt jet breakup length and premixing with water. Therefore, in that condition, the importance of the simulation for the fragmentation by the KHI relatively has increased. Comparing with the peak pressure and impulse from the experimental tests and simulations, it was concluded that the intensity of the KHI would be needed to be finely tuned for the simulations of the condition that the damaged part of a reactor vessel was fully submerged. A study on the size effects of the particles fragmented by the KHI is proposed as a further work.

Acknowledgement

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