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Introduction to the modified TROI test facility for fuel coolant interaction under a submerged reactor vessel

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1. Introduction

In-Vessel Retention (IVR) as a Severe Accident Management (SAM) strategy is an attractive method to prevent the failure of the reactor vessel by the high-temperature corium melt, where the reactor vessel is submerged by water as a coolant. If the coolability of the reactor vessel under the IVR strategy fails, the corium melt releases directly into water from the failure of the reactor vessel without a free fall of the corium melt in a gas phase before contacting with a coolant. The molten Fuel-Coolant Interaction (FCI) can threaten the integrity of the reactor cavity under a severe accident. A steam explosion can be occurred by the rapid energy transfer in the high-temperature corium melt jet penetrating into water, which makes the dynamic load applying to the surrounding structure. Before a steam explosion, the corium melt jet breaks into small-sized particles, and the steam is generated continuously by the film boiling on the hot surface of the melt contacting with water. The premixing phase consisting of the corium melt, water, and steam can determine the intensity of the steam explosion. Unfortunately, the previous experimental studies on the FCI phenomena have carried out under a free fall of the corium melt jet in a gas phase before interacting with water [1-3]. Therefore, the experiment on the FCI under a submerged reactor vessel is necessary to consider the failure in the IVR strategy. The previous TROI (Test for Real cOrium Interaction with water) test facility [4], that is a well-known test facility for the FCI phenomena in the world, has observed a steam explosion under a free fall of a corium melt jet in a gas phase before contacting a coolant since 2000, which is changing to simulate the FCI phenomena under a submerged reactor vessel. This study introduces the modified TROI test facility as shown in Fig. 1 and the considerations for the experiment with success.

2. Modified TROI test facility

The previous TROI test facility [3] consists of the three systems as described below:

(1) Melting system makes the prototypic corium melt with superheat using the cold crucible melting method [5] that is an effective method to melt several-tens material with high-melting temperature over 2500 K. This system measures the temperature of the top surface of the corium melt, and discharges aerosol and gases generated in the melting process. A upper vessel in the TROI test facility includes the melting system for the experimental safety from the thermal radiation at high melting temperature.

(2) Delivery system moves the corium melt from the melting system to water as a coolant. The corium melt falls down by the gravity from the bottom of a cold crucible, where a plug and a puncher connecting with moving parts exist below the crucible bottom. A cylindrical plug closing the bottom of a cold crucible makes a thin sintered shell that can be broken by a conical puncher [5]. The corium melt falls down on a valve as an intermediate melt catcher that can be open in 0.02 seconds to make an uniform melt jet before contacting water.

(3) Interaction system is a cylindrical stainless-steel vessel filled with water, where the behavior of the corium melt and the dynamic loading induced by a steam explosion are estimated quantitatively. In addition, to trigger experimentally a steam explosion, explosive PETN with weight of 1 g is installed on the bottom of the interaction vessel. A lower vessel in the TROI test facility includes the interaction system to protect from a possible steam explosion.

The delivery and interaction systems in the previous TROI test facility were modified except the melting system, because the same prototypic corium melt used in the previous studies [3] will be used in the FCI test under IVR condition.

2.1. Modified delivery system

The delivery system in the previous TROI test was modified to simulate the submerged reactor vessel, i.e., the corium melt should stay at the location just above the water level in a short time to neglect a free fall of a melt jet in a gas phase before reacting with a coolant. A releasing valve that can be open in 0.05 seconds was newly installed just above the water level in the interaction vessel.

The opening time of the releasing valve after the operation of a puncher, i.e., the falling and staying time of the corium melt from a cold crucible to the releasing valve, should be determined by heat loss induced by radiation and conduction. The super-heated corium melt will be cooled during free-falling from a cold crucible and staying on a releasing valve. In addition, the thickness of the sintered shell will develop continuously when the high-temperature corium melt contacts with the relatively low-temperature structure such as a nozzle and a valve in the delivery system. If the temperatures of the corium melt decreases by the melting temperature, the liquid-phase corium melt can be solidified before opening of the releasing valve, which can block the corium melt to be released into water. To reduce the heat loss in a delivering progress, a free-falling distance of the corium melt was decreased by 1985 mm, and the staying time of the fallen melt on the releasing valve was set in less than 0.2 seconds. Where, thermocouples were installed in the direction of the free-falling melt to estimate a falling time.

2.2 Modified interaction system

When a releasing valve is open, the corium melt penetrates into water in the interaction vessel that is a stainless-steel cylindrical vessel. Although the center of a releasing valve is the same with that of the interaction vessel, the direction of a penetrating corium melt jet can be changed randomly by the hydrodynamic instabilities in water. Therefore, twenty-six thermocouple junctions were installed in the expected penetrating region with 100 mm in diameter and 1000 mm in height to observe the behavior of the corium melt jet in water.

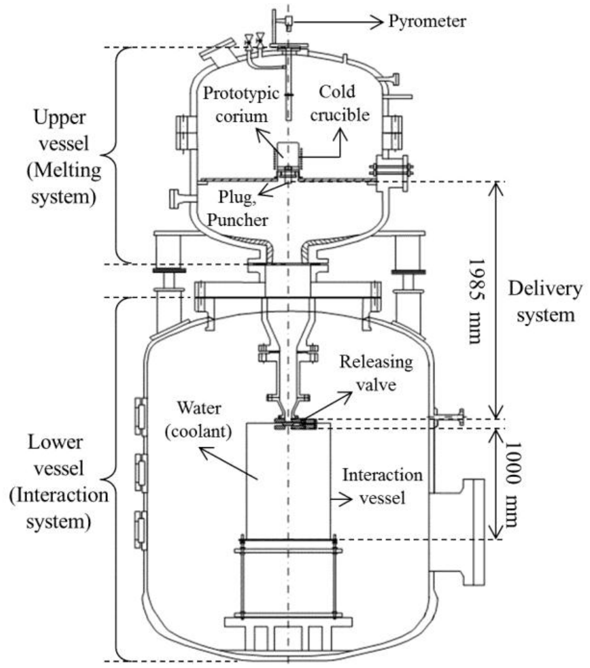

Fig. 1. Modified TROI test facility for molten fuel-coolant interaction under a submerged reactor vessel.

3. Conclusion

The previous TROI test facility, that has observed the molten Fuel-Coolant Interaction (FCI) with a free fall of the prototypic corium melt in a gas phase before contacting a coolant, was modified to simulate the FCI phenomena under a submerged reactor vessel for the assessment of the In-Vessel Retention (IVR) concept, i.e., without a free-fall distance of the corium melt before contacting water. The superheated prototypic corium melt created by the cold crucible melting method moves on a releasing valve newly installed just above the water level in the interaction vessel. The corium melt will stay on a releasing valve in less than 0.2 seconds to reduce heat loss for preventing the solidification, and then the melt jet will penetrate into water. Finally, the behavior of the corium melt jet will be observed by thermocouples in various positions in water. The experiment in the modified TROI test facility will be compared with the previous studies on the free-fall corium melt in a gas phase before the FCI, which can support the useful information to validate the computer code for a severe accident.

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