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Melting test of penetrating tube through BWR-RPV bottom wall

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ABSTRACT

Melt behavior of a BWR in-core monitor (ICM) guide tube, which penetrates a RPV bottom wall, under a severe accident condition was tested using a corium with a mixture of UO_2, ZrO_2 and Zr. There are several BWR-ICMs; two of them are a short range monitor (SRM) and an intermediate range monitor (IRM), which are made of stainless steel, have the same tube dimensions and the bottom ends of the tubes open to the drywell (or, the pedestal region). In the test, the full scale SRM/IRM guide tube with the same dimension as one of Fukushima Daiichi Unit-1 but short length, was installed in the lower crucible which simulated the lower plenum and which bottom simulated the RPV bottom wall with about 200 mm thickness. The melt corium was generated in the upper crucible and it was discharged into the lower crucible. The test result showed that:

(1) The corium discharged into the lower plenum attacked the guide tube first resulting in the tube melt from the top and then accumulated in the lower plenum.
(2) Small amount of corium had fallen out from the bottom opening of the tube into the pedestal as particles, and such outflow stopped soon because a stainless steel melt had solidified in the tube and blocked the flow path.
(3) The depth of the melt ingression into the tube was 60–65 mm from the inner surface of the RPV bottom wall, where the tube was completely blocked by the solidification of steel melt and no oxide melts had ingressed there.

1. Introduction

The Fukushima Daiichi Nuclear Power Plant Unit-1, -2, and -3 were severely damaged after the huge Tsunami followed by the earth quake occurred at March 11, 2011. Core meltdowns occurred at all the units. The radioscopic images of the Unit-1 reactor core were taken by the cosmic muon radiography with the attenuation method Takasaki et al. (2015)[1]. The images showed that the Unit-1 reactor core was almost empty, which suggested that almost all of the fuel debris had fallen down from the reactor pressure vessel (RPV) onto the pedestal floor.[1] Recent investigation inside the primary containment vessel (PCV) of Unit-1 also suggested the existence of fuel debris inside the pedestal.[2] Similar investigations inside the PCVs of Unit-2 and Unit-3 showed piles of fuel debris on the pedestal floors.[3,4] The question arose: how a large amount of corium had fallen down. The question still remains. That is, from which a large amount of corium had fallen down; from the break location due to melt, or creep of the RPV bottom wall itself, or, due to melt of the in-core monitor guide tubes which penetrate the RPV bottom wall.

There are many tubes which penetrate the BWR lower head as shown in Fig. 1; control rod guide tubes (CRGTs) and in-core monitor guide tubes (ICM-GTs). Two of the ICMs are a short range monitor (SRM) and an intermediate range monitor (IRM): the configurations of their guide tubes are the same and the bottom ends of the tubes open to the pedestal region. The other ICM-GTs than SRM/IRM guide tubes are bottom closed. When high temperature corium accumulates in the lower plenum under a severe accident condition,

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[1] Open information obtained from the web site; http://photo.tepco.co.jp/en/date/2015/201503-e/150319-01j.html, updated at March 19,2015.

[2] Open information obtained from the web site; http://www.tepco.co.jp/en/nu/fukushima-np/handouts/2017/images/handouts_170327_01-e.pdf, updated at March 27, 2017.

[3] Open information obtained from the web site; http://www.tepco.co.jp/en/nu/fukushima-np/handouts/2018/images/handouts_180119_01-e.pdf, updated at January 19, 2018.

[4] Open information obtained from the web site; http://www.tepco.co.jp/en/nu/fukushima-np/handouts/2017/images/handouts_171130_03-e.pdf, updated at November 30. 2017.

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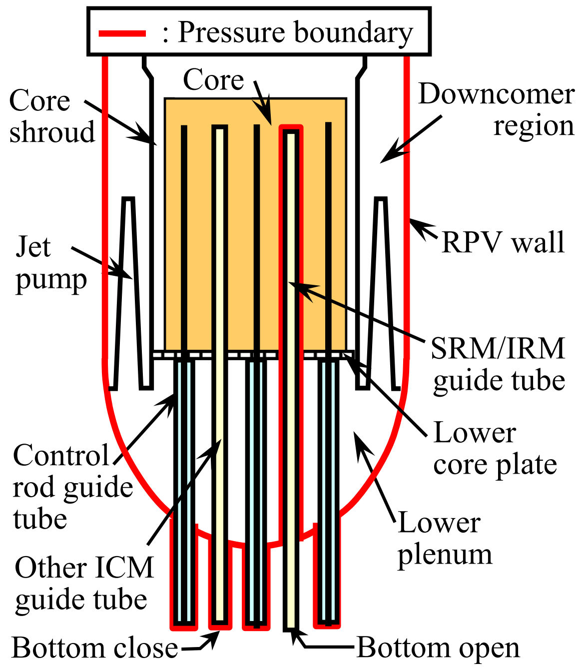

Fig. 1. Pressure boundary.

it may melt the SRM/IRM guide tubes made of stainless steel, resulting in corium release into the pedestal, before the melting of the RPV bottom wall.

The test has been implemented in order to examine melt behavior of the SRM/IRM guide tube and behavior of melt ingression into the tube. In the test, a full sized SRM/IRM guide tube with the same dimension as one of Fukushima Daiichi Unit-1 but short length was used and a melt with a mixture of UO_2, ZrO_2 and Zr was used as a corium. This paper describes the test results.

2. Possible accident progression at the Fukushima Daiichi Nuclear Power Plant

The decay heat was removed by the cooling systems at early phase after the reactor scrams at Units 1, 2, and 3. The reactor pressures rose to about 7 MPa and were kept almost constant by steam release through the safety relief valves after the stop of the decay heat removal systems, resulting in water level decrease in the reactor cores. After the core uncovery, fuel temperatures rose due to decay heat generation and core meltdowns occurred. Some of melt materials, corium, might flow down continuously into the lower plenums of the RPVs from the core regions, but many of them was considered to be retained on the lower core plate for a while. Then, it was supposed that the corium on the lower core plate slumped down into the lower plenum.

There were a lot of penetration tubes in the lower plenum as typically shown in Fig. 1. The top ends of them were closed. The bottom ends of them were also closed except the SRM/IRM guide tubes of which bottom ends were open to the pedestal. Supposing formation of corium pool with the temperature of around 2700 K in the lower plenum, the SRM/IRM guide tubes made of stainless steel with the melting temperature of around 1750 K were considered to be damaged earlier than the other tubes, since their tube wall thickness was the most thinnest. There were ten-odd SRM/IRM guide tubes Installed distributedly at every Unit 1, 2, and 3. The SRM/IRM guide tubes might be damaged successively, or when once one tube was first damaged, all the corium in the lower plenum might fall down through the damaged portion, depending on amount of corium pool in the lower plenum.

This paper focuses on the behavior of the single SRM/IRM guide tube melt and ingression of melt materials into the tube, supposing the corium formation in the lower plenum. Some of the SRM/IRM guide tubes penetrated the inclined RPV bottom heads, but only a single tube through the flat plate was used as the test specimen.

3. Test facility

3.1. Test specimen and test vessel

Fig. 2 shows the test specimen of the SRM/IRM guide tube. The dimensions of the cross-section of the test specimen is the same as ones of Fukushima Daiichi Unit-1, but its length was short. The SRM/IRM guide tube was inserted in the core region in the actual plant, but the length of the test specimen was limited to 336 mm. Similarly, the length of the actual tube below the RPV bottom

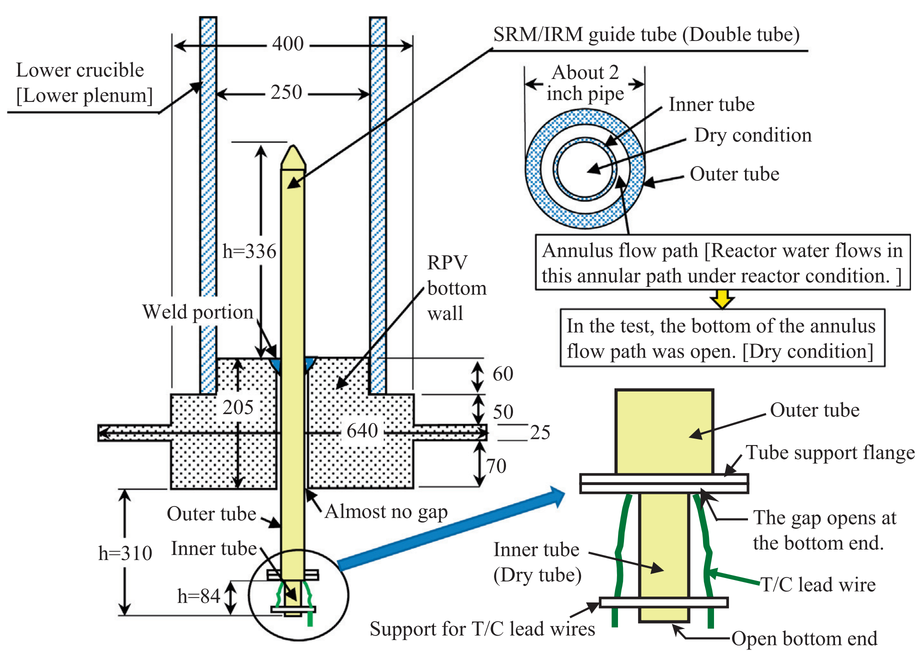

Fig. 2. Test specimen of SRM/IRM guide tube.