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Modeling of annular gap thickness formed by interaction between corium and water in lower head of reactor vessel

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ABSTRACT

The existing gap cooling studies have shown the coolability of debris retained in the lower head of a vessel and effective mitigation of the rupture of a reactor vessel, but no plausible mechanism of the gap formation has been clearly identified. Several experiments of the gap formation, pretests of FARO-19, LAVA, ALPHA, and EC-FOREVER- 5 and 6, were reviewed to find out the mechanism of the gap formation. We confirmed that a pre-flooded condition, in which a simulant of a reactor vessel is filled with water before pouring a melt to the vessel, makes it possible to form the gap. We performed simple tests to pour a melt onto a plate under both pre-flooded and dry conditions discovering the gap formation under the pre-flooded condition. We proposed a model for the initial gap thickness considering the Inverse Leidenfrost effect. The initial gap thickness is estimated solving the balance equations for mass, momentum, and energy. For the estimation of the transient gap thickness, we considered the thermal fracture as well as the thermal contraction of the crust. For the estimation of the thermal fracture of a melt, we adopted Yeo and No's study (Yeo and No, 2019) considering the crust cracks of a melt being cooled down under the flooded condition. The proposed model was validated against experimental data of the KAIST test, ALPHA tests performed at JAERI, and LAVA-6, LAVA-10, LMP200-1, and LMP200-2 tests performed at KAERI. The current model predicts the gap thicknesses much better than the existing approach with the linear thermal contraction model and the assumed initial gap size but no consideration of the crust crack formation. Also, it well agreed against the experimental data.

1. Introduction

One of the definitions of the nuclear severe accident is that there is significant damage to nuclear fuels and meltdown accidents (IAEA, 2006). A large amount of nuclear core was molten on the Three-Mile-Island-2 (TMI-2) accident and the Fukushima accident (Wolf et al., 1994; Thomsen Kund Ladekarl, 1998; Pellegrini et al., 2019). The molten core material, called corium, was relocated into the lower head of a reactor vessel. It may cause a thermal attack on a reactor vessel. The reactor vessel of the TMI-2 accident, in which around 19 tons of corium was retained, did not fail. Different from the TMI-2 accident, the reactor vessel failed in the Fukushima Daiichi Unit 1, 2 and 3 accidents in which the whole core was molten (OECD/NEA, 2015).

In detail of the TMI-2 accident, the 19 tons of corium, whose temperature was around 2800 K was retained in 2.4 m radius reactor vessel made from carbon steel whose melting temperature was around 1700 K. From the existing thermal analysis for these conditions, substantial thermal attack of the reactor vessel may occur (Stickler et al., 1994; Müller, 2006). However, the reactor vessel did not fail due to a gap between the melt and the reactor vessel. It is commonly believed that water penetration through the gap not only prevented direct contact between the melt and the reactor vessel but also continuously removed heat from the melt to the reactor vessel (Herbst et al., 1999; Park et al., 2002; Kim and Suh, 2003; Uchibori et al., 2003; Seiler, 2006; Rempe et al., 2008).

Hence, several experimental studies and modeling for the gap

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