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Development of a semi-empirical model-based COrium COolability analysis tool (COCOA) validated against a large scale corium experiment, FARO

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ABSTRACT

As molten corium is released from the reactor pressure vessel (RPV) under severe accidents, the molten corium is going to experience various complicated phenomena. If there is no steam explosion, the corium is going to be ejected through the reactor vessel, fragmented, and cooled through the interaction between the corium and water existing in the cavity during its falling stage.

Our research group has recently developed a COrium COolability Analysis tool named COCOA. COCOA is the transient calculation tool for the evaluation of the phenomena from the molten corium release to debris formation through the corium falling stage of FCI. COCOA was corporately developed to calculate the transient results of the pressure, the released energy, the average water temperature, fragmented particle size distribution, particulate debris fraction etc., during the corium falling stage of the FCI phase.

COCOA is validated against FARO, which is a large-scale corium experiment. Comparing to COMETA, which is a 2D severe accident analysis code, COCOA showed better accuracies on the prediction of the pressure, the released energy, and the particulate debris fraction during the corium falling stage of the FCI phase. COCOA gives 16.9% and 26.5% of NRMSD for the pressure and the released energy, while COMETA does 42.2% and 36.0% of NRMSD. Also, COCOA and COMETA predict the particulate debris fraction with 27.22% and 39.25% of RMSE, respectively. Since COCOA is a semi-empirical model-based simple 1-D tool, only small computational effort is required for the calculation.

1. Introduction

As the primary system of a nuclear power plant loses the core cooling ability under a severe accident condition, the meltdown accident could happen. In the case that we cannot maintain the integrity of the reactor pressure vessel (RPV), the molten core would be released to the outside of the vessel. The discharge of molten corium from the RPV could lead the radioactive material released to the environment. Various safety systems such as the core catcher and pre-flooded cavity are introduced to avoid the disaster.

When the core melts and molten corium falls into water in a pre-flooded cavity under a severe accident, a hot corium jet eventually contacts with the subcooled water. The jet fragmentation is mainly caused by Kelvin-Helmholtz instability (KHI) and Rayleigh-Taylor instability (RTI) (Abe et al., 2006). The corium jet is fragmented while it penetrates the pre-flooded cavity. The fragmented particles continuously transfer the heat to the surrounding water until it reaches the bottom of the cavity. The hydrodynamic process is called an ex-vessel fuel–coolant interaction (FCI).

FCI is the most crucial phase in an accident progression since the coolability in FCI eventually determines initial conditions of molten corium-concrete interaction (MCCI), such as an initial temperature and a structure of a deposition (cake or particulate debris). During FCI, after the corium jet breaks up, the heat is mainly transferred from fragmented corium particles to water in a regime of a forced convection film boiling. Usually, we predicted this heat using the model of the forced convection film boiling on a fragmented particle. Thus, for an overall prediction of a severe accident, the high accuracy of physical models is required to calculate the heat transfer for a subcooled film boiling with a particle.

There are several computer codes for physical analysis dealing with the FCI. The Joint Research Centre (JRC) developed a Core MElt Thermal-hydraulic Analysis (COMETA) code to simulate the thermal-hydraulics and the fuel fragmentation phenomena of corium (Pla et al., 2001). The COMETA was planned to analyze the FARO facility, which is a facility for large-scale corium experiment conducted by the Institute

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