Updates of in-vessel severe accident analysis model of CINEMA

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1. Introduction

CINEMA (Code for INtergrated severe accident Evaluation and MAnagement) is an integrated severe accident analysis code developed by KHNP, KAERI, FNC, and KEPCO-E&C [1, 2]. The CINEMA is composed of three functional modules: 1) in-core phenomenon and RCS analysis module, 2) fission product behavior analysis module, 3) ex-core phenomenon analysis module. In 2019, 3rd phase of CINEMA development project was started: the target of project is to update and validate CINEMA. In the present study, we summarized recent updates of in-vessel severe accident analysis model of CINEMA.

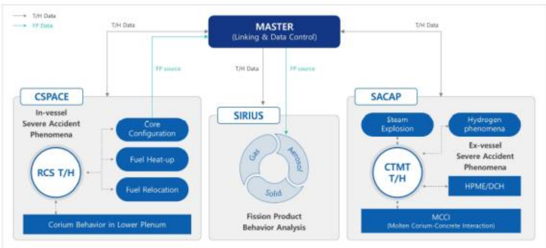

Fig. 1. Structure of CINEMA [1]

2. Model updates

2.1 Penetration failure model

Korean Pressurized Water Reactors (PWRs) have several in-core instrumentation (ICI) penetration tubes at the lower head of the reactor vessel. During a melt relocation to the lower plenum of the reactor vessel during a severe accident, the presence of the molten corium at the lower head penetrations of the reactor vessel may allow the melt to enter a penetration tube and heat up the penetration tube, which may cause penetration rupture [3]. In CINEMA, we modeled penetration failure model based on KAERI developed "PENetration Tube Analysis Program (PENTAP)" [4, 5]. The CINEMA can simulate penetration tube ejection out of lower head vessel (including weld failure at the vessel wall) and the tube rupture outside of the vessel (figure 2).

Figure 3 shows binding shear force of penetration tube at different locations. Based on the temperature, gap between penetration tube and RPV wall changes and the binding shear force decreases.

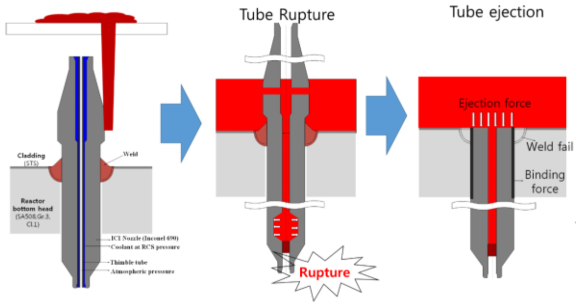

Fig. 2. Penetration tube failure mechanism of CINEMA [3]

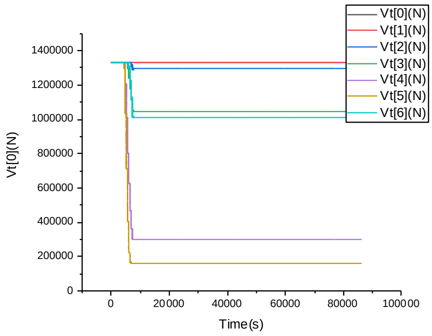

Fig. 3. Binding shear force of penetration tube at different location

2.2 Corium discharge with wall ablation model

When the lower head of RPV is failed, high temperature corium can be discharged to the cavity. In such situations, corium attacks RPV wall directly, resulting in the wall ablation during corium discharge. Therefore, most of severe accident analysis codes (such as MELCOR, MAAP, etc) modeled corium discharge with wall ablation including RPV failure area widening. We adopt existing model used in the MELCOR and MAAP, now CINEMA can simulate corium discharge with wall ablation.

Figure 4 shows mass flow rate of corium discharge with RPV failure. After failure, corium flows downward to the lower plenum based on the pressure difference between internal-external reactor pressure vessel. Figure 5 shows corresponding RPV break area. Starting from user defined value, RPV break area increases in time.

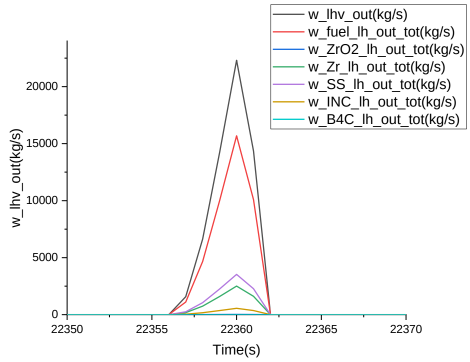

Fig. 4. Mass flow rate of corium discharge with RPV failure.

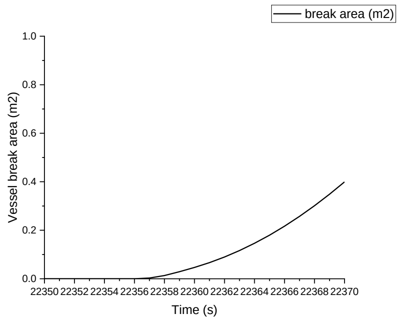

Fig. 5. RPV wall break area in time after RPV failure.

2.3 Multiple heat structure model

To simulate active core region, CINEMA divide the core with axial and radial nodes. In the case of severe accident, the fuel rod can be heated to its own melting temperature, and it can be relocated downward. In such cases, axial temperature difference along the fuel rod increases. Figure 3 shows schematic of multiple heat structure model for CINEMA. In the same thermo-hydraulic node, user-defined number of heat structure nodes are defined. At each heat structure node has its own mass and temperature, but share the thermo-hydraulic condition. This model can analyze stiff temperature gradient along the axial direction of fuel rod.

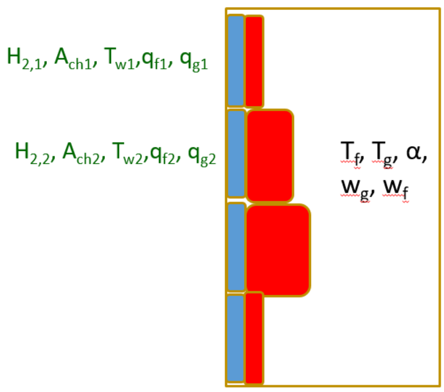

Fig. 3. Multiple heat structure model of CINEMA [1]

2.4 Other updates

So far, critical flow model (Henry-Fauske model), lower plenum corium pool analysis model, lower plenum wall heat transfer and melting model, material property calculation model is updated for CINEMA. A few verification and validation problems (QUENCH, PHEBUS, etc.) will be presented.

3. Summary

In this paper, we summarized recent updates of in-vessel severe accident analysis model of CINEMA. Models are newly updated to simulate severe accident scenarios, and validation work is now on going.

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