Preliminary Analysis of LOCA without Safety Injection for APR1400 using CSPACE Computer Code

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1. Introduction

As an integrated severe accident computer code development in Korea, CINEMA (Code for INtegrated severe accidEnt Management Analysis) has been developed for a stand-alone severe accident analysis [1]. The basic goal of this code development is to design a severe accident analysis code package by exploiting the existing domestic DBA (Design Basis Analysis) code system for the severe accident analysis. The CINEMA computer code are composed of CSPACE [2], SACAP (Severe Accident Containment Analysis Package) [3], and SIRIUS (SImulation of Radioactive nuclide Interaction Under Severe accident) [4], which are capable of core melt progression with thermal hydraulic analysis of the RCS (Reactor Coolant System), severe accident analysis of the containment, and fission product analysis, respectively, as shown in Fig. 1.

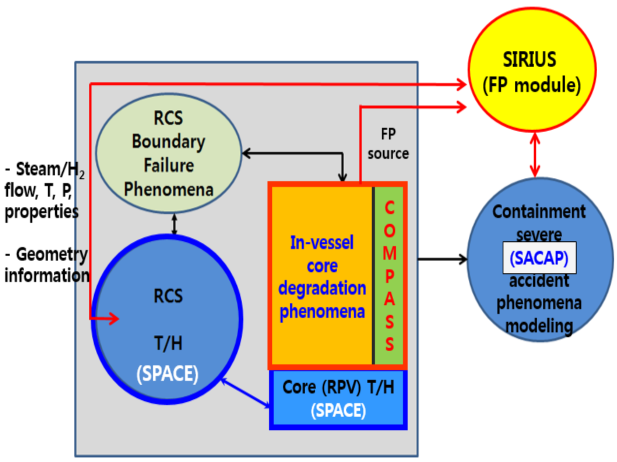

Fig. 1. CINEMA code structure.

The CSPACE is the result of merging the COMPASS (COre Meltdown Progression Accident Simulation Software) [5] and SPACE (Safety and Performance Analysis CodE for nuclear power plants) models [6, 7], which is designed to calculate the severe accident situations of an overall RCS thermal-hydraulic response in SPACE modules and a core damage progression in COMPASS modules. For the purpose of CSPACE verification for a real power plant, LOCA (Loss Of Coolant Accident) without SI (Safety Injection) of severe accidents for the APR1400 has been analyzed in this study. This preliminary analysis has been performed to estimate the efficiency of the CSPACE computer code and the predictive qualities of its models from an initiating event to a core damage progression. Best estimate calculations from the initiating events of the SBLOCA (Small Break LOCA) of 2inch equivalent diameter and the LBLOCA (Large Break LOCA) of 9.6inch equivalent diameter without SI (Safety Injection) have been performed by using the CSPACE computer code.

2. CSPACE Input Model for APR1400

The input model for the CSPACE calculation of the APR1400 [8] was a combination of the SPACE and COMPASS input models. Heat structures for the fuel rods and the lower part of the reactor vessel in the SPACE input model were replaced by the COMPASS input models. In the SPACE model, the reactor core was simulated as 3 channels to evaluate the thermal-hydraulic behavior in detail, and each channel was composed of 5 axial volumes, as shown in Fig. 2. A surge line and a pressurizer were attached to one of the hot legs in the primary coolant loop. In the COMPASS input model of this analysis, the component numbers for the fuel and control rods were 3 and 5.

A steady state calculation was performed in order to verify the input nodalization of CSPACE for the APR1400. The steady state results for a selected set of parameters were in very good agreement with the operating conditions of the APR1400. The maximum error of the steady state results using the CSPACE computer code with operating values of the APR1400 is approximately 5% in the coolant mass flow rate at the core inlet. The steady state conditions obtained from the simulation were used as initial conditions for the transient calculation.

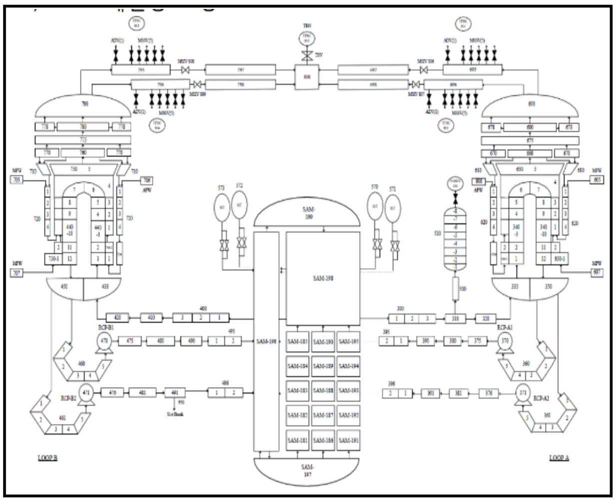

Fig. 2. CSPACE input model for APR1400.

3. Results and Discussion

The accident was initiated by producing 2inch of the SBLOCA and 9.6 inch of the LBLOCA equivalent diameter breaks in the cold leg. The reactor and the RCP (Reactor Coolant Pump) s were assumed to be tripped at an accident initiation time. The RCS water inventory rapidly decreased and a boiling started in the core because the safety injection pumps were not actuated. The fuel began to heat up when the core was uncovered. Oxidation of the fuel cladding began when the cladding surface temperature reached 1,000K and produced an oxidation heat. The fuel cladding was failed by a sausage-type ballooning. When the cladding surface temperature reached 1,700K, oxidation of the zircaloy was accelerated as the steam was supplied from the bottom of the reactor vessel. This resulted in a rapid increase of the cladding surface temperature.

At about 2,129K of the cladding surface temperature, the zircaloy inside the oxide shell began to liquefy and the outer portion of the fuel pellets was dissolved. The relatively thin ZrO_2 shell ruptured at about 2,390K because the shell strength decreased with the temperature increase. The bottom of the core dried out because a hot mixture of liquefied fuel and cladding had relocated downward. The debris formed at the bottom of the fuel rods, where the liquefied mixture had resolidified. The melting temperature of the zirconium dioxide is 2,390K, and that of the uranium dioxide is 2,400K in these calculations. The flow blockage in the lower part of the core region occurred because of a fuel melting and a cohesive debris formation. The melted core material had relocated to the lower plenum of the reactor vessel. Finally, the reactor vessel was failed by a creep through a melt thermal attack.

Fig. 3 shows the pressurizer pressure during the LOCAs without the SI. After the LOCAs occur at 0sec, the pressurizer pressure rapidly decreases to the saturation pressure corresponding to the hot leg temperature at the beginning of the transient. As the coolant began to boil, the expansion of the coolant caused by a boiling was able to compensate for the break flow, and the pressure maintained a saturation pressure. In the LOCAs without the SI, the volumetric flow out through the break is greater than the coolant expansion caused by a boiling, and the pressure began to decrease again. The steady decrease in the pressurizer pressure stopped after the SITs began a coolant injection to the RCS. When the injected liquid entered the core, it boiled, then raising the pressurizer pressure. The increased pressure terminated the coolant injection by the SITs actuation, and the pressure decreased again. When the pressure was low enough again, more coolant was injected. This cycling of the SITs actuation slowed down the depressurization. When the molten core material relocated to the lower plenum, the pressurizer pressure increased because of a coolant boiling in the lower plenum. In the SBLOCA transient, frequent cycling showed because the break size is small.

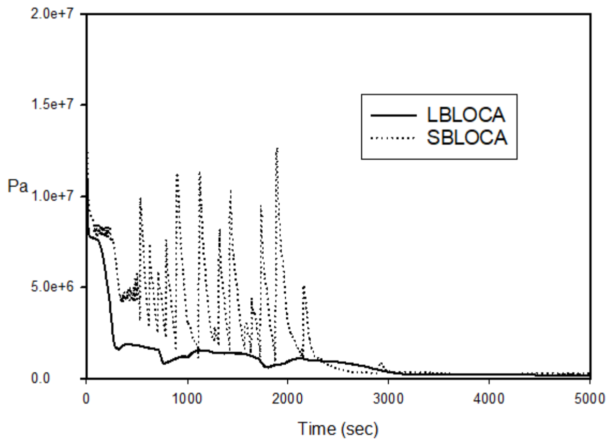

Fig. 3. CSPACE results on the pressurizer pressure in the LOCA without SI of APR1400.

Fig. 4 & 5 show the fuel temperatures in the SBLOCAs and LBLOCA without the SI, respectively. Positions of nodes 0, 1, 2, 3, 4 are 0.38m, 1.14m, 1.90m, 2.66m, and 3.42m from the bottom of the fuel rod, respectively. The fuel temperature is a little higher than the surrounding coolant temperature until the coolant in the core volume corresponding to each fuel rod is vaporized. Fuel temperature at the top of the fuel rods rises when a core uncovery occurs at the top of the core. When the fuel cladding temperature rises up to 1,000K, a fuel cladding oxidation begins. Following this time, the fuel cladding temperature rises abruptly due to a core oxidation heat generation. The fuel cladding temperature rises abruptly due to a vigorous core oxidation heat generation when the fuel cladding temperature reaches 1,700K. This temperature rise stops when the fuel cladding temperature reaches 2,390K because the ZrO_2 is ruptured by a melting and relocated to the lower core at this temperature. When the fuel cladding temperature reaches 2,400K, the UO_2 is melted and the molten pool slumps to the lower head vessel due to a crust failure. In the small and the large break LOCAs without the SI, the fuel cladding temperature is rapidly increased. The maximum fuel cladding temperature is very similar in all the LOCAs without the SI. These fuel melting and relocation affected the fuel mass, as shown in Figs 6&7.

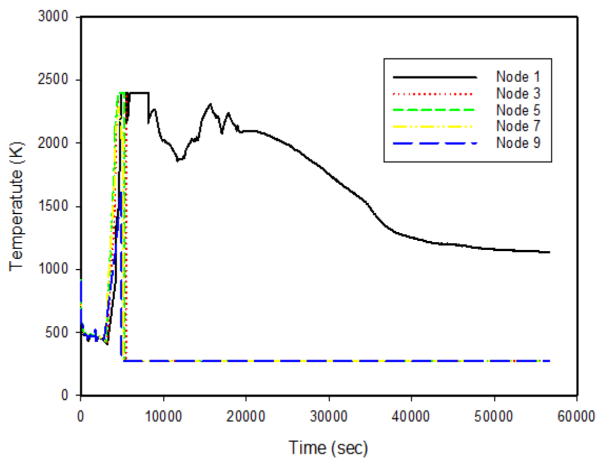

Fig. 4. CSPACE results on fuel temperature in the LBLOCA without the SI of APR1400.

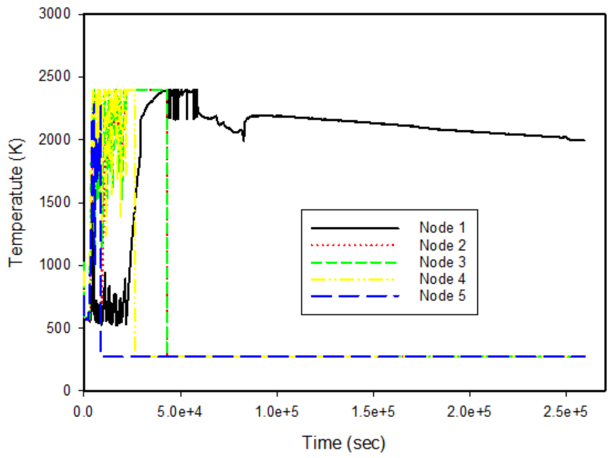

Fig. 5. CSPACE results on fuel temperature in the SBLOCA without SI of APR1400.

The SIT actuation depends on the RCS pressure. The coolant injection into the reactor vessel by the actuation of the SITs leads to a postponement of the reactor vessel failure. For this reason, the actuation of the SITs is possible for the operator to have time for an action of the severe accident mitigation strategies to prevent a reactor vessel failure in the small break LOCA without the SI. In the SBLOCA without the SI, the reactor vessel may be failed at an early time, because much coolant was lost by the break.

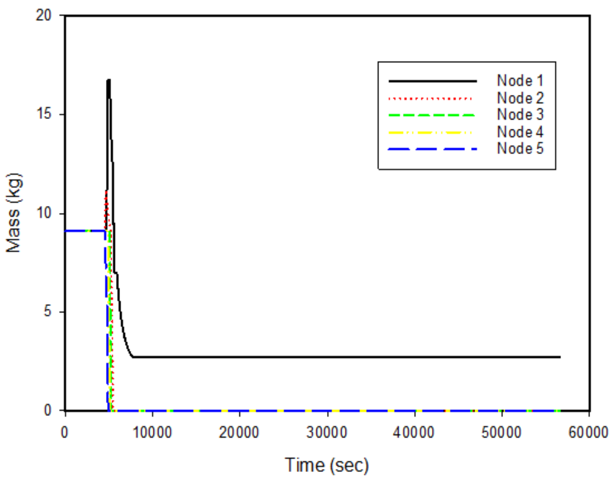

Fig. 6. CSPACE results on fuel mass in the LBLOCA without the SI of APR1400.

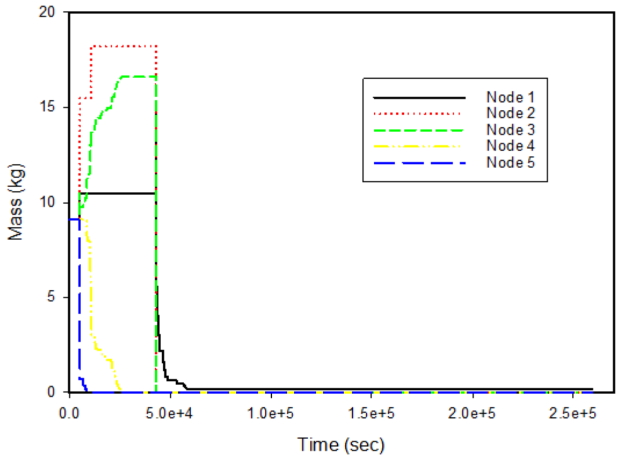

Fig. 7. CSPACE results on fuel mass in the SBLOCA without the SI of APR1400.

Fig. 8 shows the CINEMA results on the integrated hydrogen generation mass in the LOCA without the SI of the APR1400. T he total hydrogen generation masses in the SBLOCA and LBLOCA without SI are approximately 280kg and 500kg, respectively. The total hydrogen generation mass of the LBLOCA case is larger than that of the SBLOCA case, because of the core damage time and coolant inventory difference by a coolant loss inventory through the break, which are reasonable value.

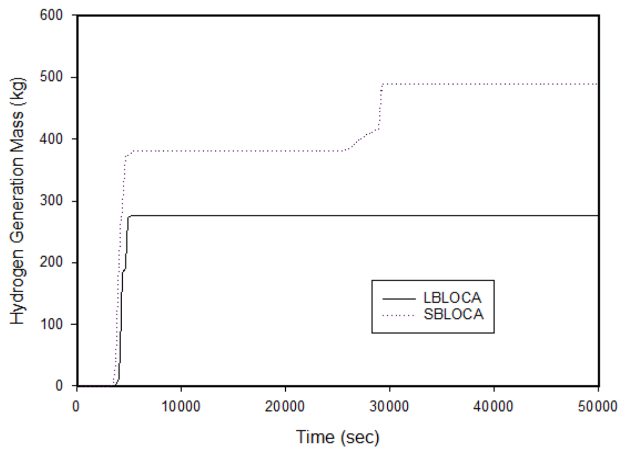

Fig. 8. CSPACE results on the integrated hydrogen generation mass in the LOCA without SI of APR1400.

4. Conclusion

For the purpose of CSPACE verification for a real power plant, a preliminary analysis of the LOCAs without SI for the APR1400 has been performed using the CSPACE computer code. The pressure behavior, fuel temperature, fuel mass change by melting and relocation, and hydrogen generation mass showed the reasonable values. More preliminary analysis of corium behavior in the lower plenum and reactor vessel failure wil.be performed for the APR1400. In addition, preliminary analysis of SACAP and SIRIUS models will be performed.

ACKNOWLEDGMENTS

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