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An Evaluation of Severe Accident Progression during SBLOCA in the SMART Using the CSPACE code

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1. Introduction

KAERI (Korea Atomic Energy Research Institute) is developing SMART (System-Integrated Modular Advanced Reactor) 365 MW_{th} and performing a severe accident sequence analysis using the CSPACE code (COMPASS and SPACE) to develop the AMP (Accident Management Program) of the SMART [1]. The AMP will be used to prevent and mitigate a core damage, maintain a containment integrity, and to minimize a radioactive material release from the containment [2]. In this study, we analyzed a severe accident progression initiated by a SBLOCA (Small Break Loss of Coolant Accident) with assumption of the failure of all safety system in the SMART. The purpose of this analysis is to evaluate whether the CSPACE can reasonably predict the severe accident progression from a core heat-up to a vessel failure.

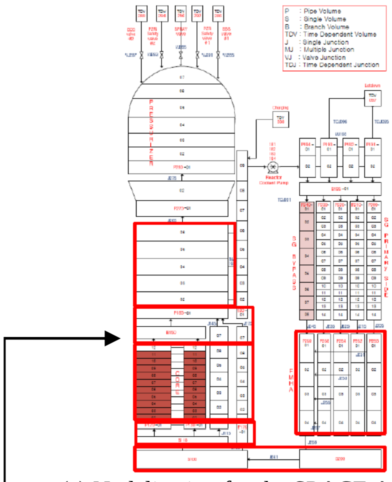
2. Overview of the CSPACE Code [3]

The CSPACE code to analyze a severe accident in the reactor coolant system was developed in close link with COMPASS (COre Meltdown Progression Accident Simulation Software) to simulate the progression of a severe accident in the core and SPACE (Safety and Performance Analysis CodE for nuclear power plants) to simulate the thermal-hydraulic power in the primary and the secondary system. The COMPASS includes the basic core configuration model to simulate the steady-state condition which is the initial state of the core, the model for fuel rod heating which can occur when the core is exposed due to a loss of cooling water, the rearrangement behavior model which describes the melting of a fuel rod being moved from the original position and rearranged in the bottom space as the supply of coolant water if the core fails, the model describing the formation of the corium pool due to the formation of the fragment layer and loss of the geometrical thermal-hydraulic structure during the rearrangement process, and the model to evaluate the behavior of corium transferred to the lower plenum and the integrity of the lower plenum. The SPACE code is the transient phenomena analysis code for the design of a nuclear power plant and includes the multidimensional non-equilibrium two-phase flow model based on the 2-phase (liquid and vapor phases governing equation) 3-flow field (continuous liquid, vapor, and droplet) governing equation.

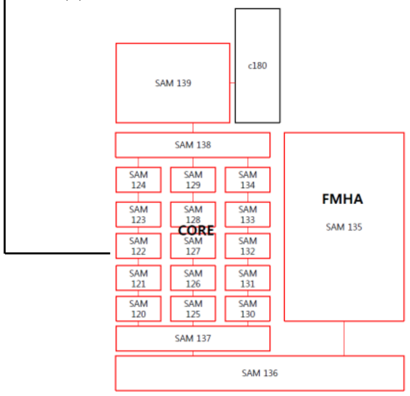
3. CSPACE Analysis

3.1 Input Model and Calculation Method

A nodalization used for the CSPACE analysis is shown in Fig. 1. In Fig. 1(a), the regions of the upper plenum, core, lower plenum, and FMHA (Flow Mixing Head Assembly) in the nodalization for the SPACE calculation are replaced by the COMPASS nodes (Fig. 1(b)). A steady state calculation was first performed to make initial conditions for a transient analysis. The calculated steady state results by the CSPACE show a good agreement for the major design parameters of the SMART. The transient calculation initiated by the 2 inch pipe break which occurred at the PSIS (Passive Safety Injection System) pipe connected to the RCP (Reactor Coolant Pipe) pipe.



(a) Nodalization for the SPACE Analysis



(b) Nodalization for the COMPASS Analysis

Fig. 1 Nodalization for the CSPACE analysis.

3.2 Discussion on the Calculation Results

The transient analysis was started by opening the time dependent valve at 0 s which simulating the break flow. When the pressurizer pressure decreased to the low-pressurizer pressure set point of 12.13 MPa from 15.0 MPa (Fig. 2) at 1030.0 s, the reactor trip occurred at 1031.1 s. As soon as the reactor was tripped, the RCP operation mode was changed to the coast-down and the main feedwater pump was terminated. As shown in Fig. 3, the core uncover started at 5049.0 s caused the cladding temperature increase. As a result of this process, the severe accident entry condition, the core exit temperature of 923.15 K, reached 7,320.0 s (Fig. 4).

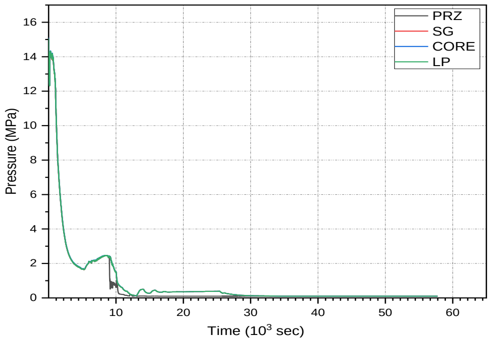


Fig. 2. Pressure behaviors in the RCS.

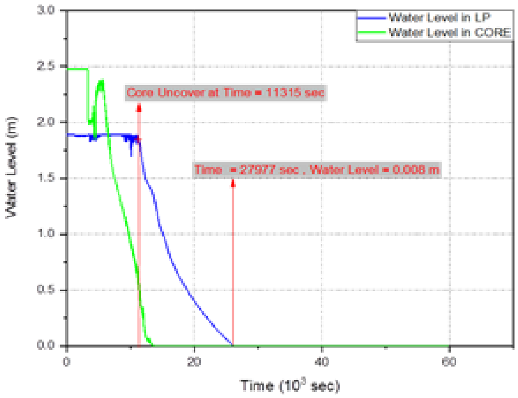


Fig. 3. Water level in the lower plenum and core.

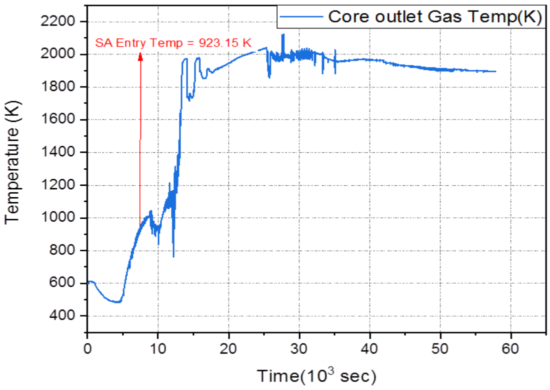


Fig. 4. Vaper temperature at the core exit.

When the fuel cladding temperature reached approximately 1000K (Fig. 5), the rapid increase of the cladding temperature occurred by the start of the cladding oxidation, which is resulted from the exothermic reaction between the steam and zirconium. In addition, the hydrogen was generated during the cladding oxidation (Fig. 6). The fuel rod was melted and relocated to the core lower part when the fuel rode temperature reached 2300 K (Fig. 7). The corium composed of the cladding oxide material and the dissolved fuel material flowed down to the core lower part. The molten pool surrounded by the crust was formed in the core lower part because the heat loss from the molten pool surface to the environment took place. However, the crust formed at the outer surface of the molten pool was broken when the integrity of the crust was weakened due to the decay heat genration from the dissolved fuel rod in the molten pool and the change of the pressure distribution around the crust [4]. As the crust broken, the corium started to relocate to the lower plenum. This relocation finally caused the RV (Reactor Vessel) failure at 48,826.0 s because the RV temperature was increased by the corium (Fig. 8). The above explained severe accident progression is summarized at Table 1. When compared to the MELCOR 1.8.6 results [5], the CSPACE predicted approximately 5000 s faster progression from the severe accident entry condition to the RV failure.

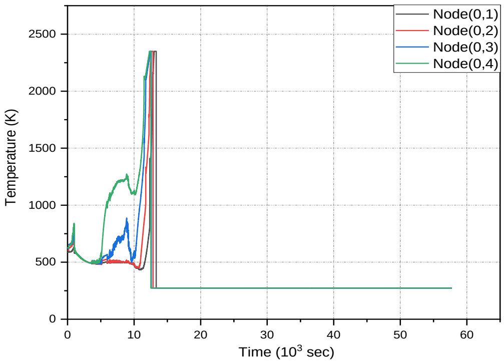


Fig. 5. Cladding surface temperatures.

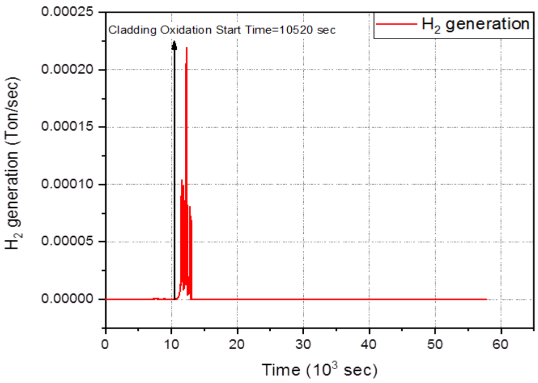


Fig. 6. Hydrogen generation rate.

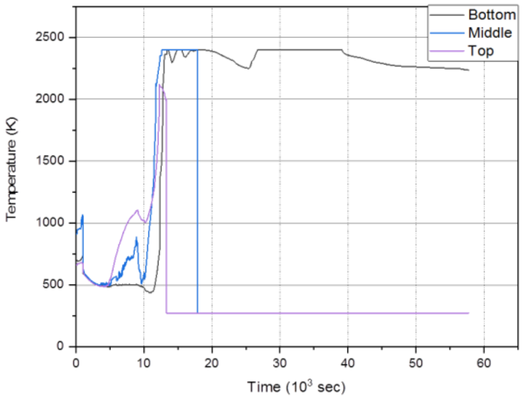


Fig. 7. Fuel rod temperatures.

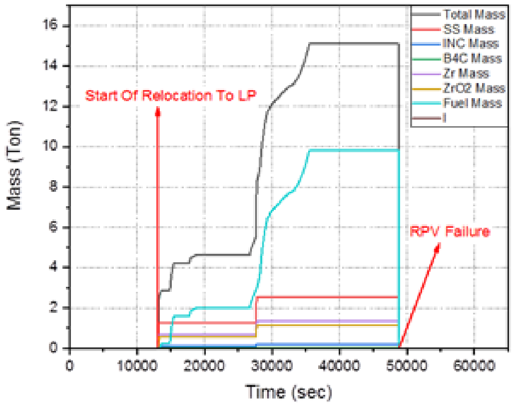


Fig. 8. Fuel and cladding masses variation

Table 1. Predicted Severe Accident Sequence by CSPACE

Main Events	**Time (sec)**
SBLOCA start	0.0
Actuation LPP signal	1030.0
Reactor trip	1031.1
RCP trip & MFW trip	1031.1
Start of core uncover	5049.0
SA entry	7320.0
ADS open	9120.0
Oxidation start	10520.0
Total core uncover	11315.0
Relocation to lower head	13996.0
LP uncover with water	27977.0
RPV rapture	48826.0

4. Conclusions and Further Work

We analyzed the severe accident progression initiated by the SBLOCA using the CSPACE code to evaluate whether the CSPACE code can be used as a proper tool in developing the AMP of the SMART. Through the comparison of the CSPACE results and the MELCOR 1.8.6 results, we found that the CSPACE can reasonably simulate the severe accident progression. However, the computational time consumed in the CSPACE calculation to complete the severe accident sequence was much larger than that of the MELCOR 1.8.6. Therefore, it is necessary to establish an efficient analysis methodology to reduce the total computational time needed in the severe accident analysis by the CSPACE code.

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