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Effect of two-way coupling in aerosol behavior analysis using CINEMA code

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1. Introduction

Under the severe accident condition, fuel and cladding can be failed due to the lack of residual heat removal. During this period, fission products in fuel and gap can be released to reactor coolant system and containment in gaseous form. Because the released fission products can be transformed into aerosol form, they can be deposited in the system. The decay heat from these aerosols will be a heat source of the system. To simulate this phenomenon in CINEMA code, the decay heat from the released fission products calculated by SIRIUS module should transfer to system thermal hydraulic analysis module (CSPACE and/or SACAP) as a heat source. This is called two-way coupling in CINEMA code, the effect of this option in aerosol behavior analysis will be confirmed in this research.

2. Method

CINEMA code is the integral code that can perform linked analysis by integrating individual modules capable of interpreting individual phenomena that occur during a severe accident independently. CINEMA code divides various severe accident phenomena into in-core phenomena and ex-core phenomena. There are three analysis modules in CINEMA code as shown in Fig. 1, ranges of each module are like below [1]:

- CSPACE (SPACE + COMPASS): System thermal hydraulics and in-core phenomena
- SACAP: System thermal hydraulics and ex-core phenomena
- SIRIUS: fission product behavior
  (Classification of fission products is presented in Table I [2])

SIRIUS module calculates fission product behavior such as airborne mass, deposited mass, and decay heat over time based on system thermal hydraulic analysis result for each time step. In CINEMA code, one-way coupling is considered as a default option for conservative analysis in terms of core cooling. But for the realistic analysis, the decay heat from released fission products which is calculated by SIRIUS module should be considered in CSPACE and/or SACAP module as a heat source for each system thermal hydraulic nodes. It is assumed that all of the decay heat from fission products (gas, airborne aerosol, deposited aerosol) in each node was considered as a heat source only for gas as a simplistic approach.

To confirm the effect of two-way coupling in aerosol behavior analysis, PHEBUS FPT3 was analyzed using CINEMA code. The PHEBUS tests were conducted between 1988 and 2010. Its purpose was to improve the understanding of the phenomena occurring during a core meltdown accident in a light water reactor and to validate the computational software used to represent these phenomena in reactor safety evaluations. The fifth test (FPT3, in 2004) determined the influence of a boron carbide (B4C) control rod on fuel degradation and behavior of the FPs [3]. The FPT3 test is divided into four phases: degradation phase (1), aerosol phase (2), washing phase (3), and chemistry phase (4). Degradation phase includes start of the test until 22,500 seconds, the main process is core damage and the release of nuclear fission products through the primary system to the containment building. After this phase, the behavior of fission products within the containment building was tested following the closure of the isolation valves of the primary system and containment building [4]. The schematic diagram of test facility is shown in Fig. 2.

The test was simulated until 20,000 s using CSPACE and SIRIUS modules. SACAP was not used in this research. In-core nodalization for CSPACE is shown in Fig. 3 [5]. The PHEBUS containment was considered as a single volume with about 10 m^3. Total decay heat from fission products was assumed as a constant, 120 W.

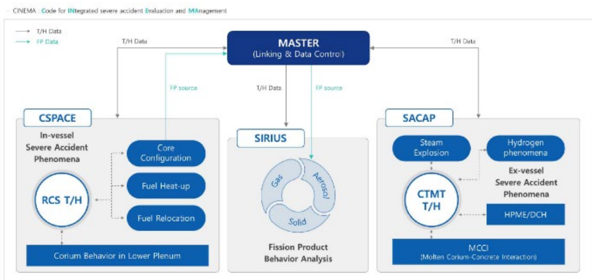

Fig. 1. Structure of CINEMA code

Table I. Classification of fission products in SIRIUS

No	Group	Representative
1	Noble gases	Xe
2	Alkali metal iodides	CsI
3	Alkali metal hydroxides	CsOH
4	Chalcogens	Te
5	Alkaline earths	Ba
6	Platinoids	Ru
7	Rare earths	La
8	Structural materials	Zr

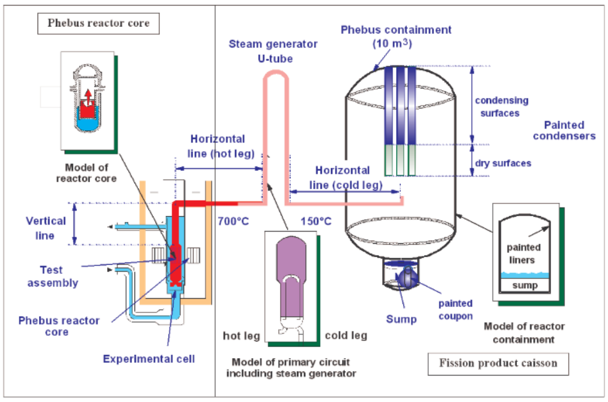

Fig. 2. Schematic diagram of PHEBUS FPT3

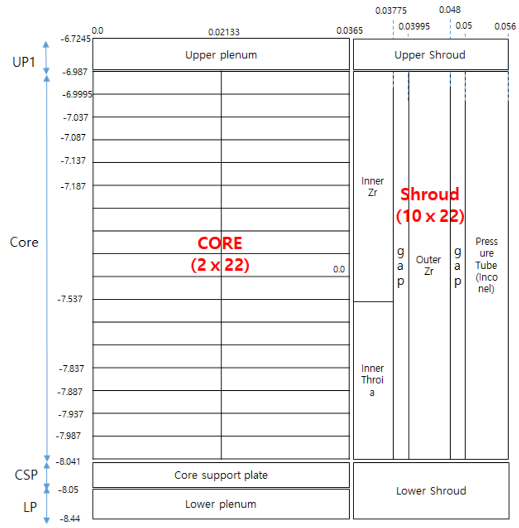

Fig. 3. In-core nodalization for CSPACE

3. Result

Main analysis results of PHEBUS FPT3 using CINEMA code are shown in Fig. 3 to 5. After the onset of gap release, in-fuel decay heat decreases following the release of fission products. Vapor temperature is higher as expected when two-way coupling is considered. But results of release fraction of CsI in containment are almost similar regardless of two-way coupling.

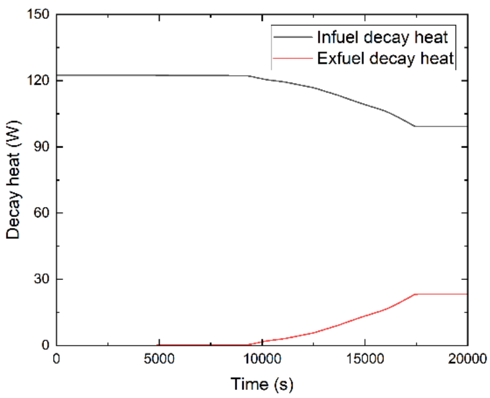

Fig. 3. In-fuel and ex-fuel decay heat
(when two-way coupling option is ON)

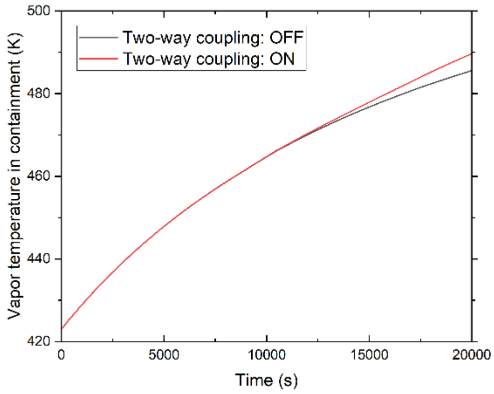

Fig. 4. Comparison of vapor temperature in containment

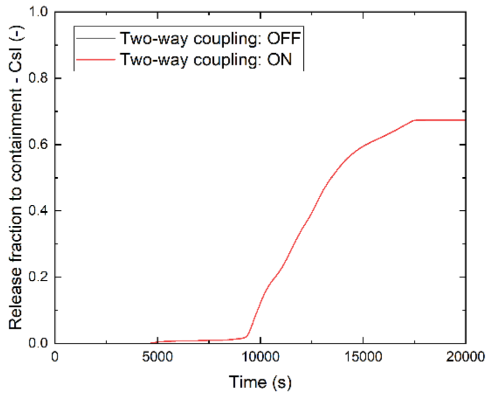

Fig. 5. Comparison of release fraction of CsI in containment

4. Conclusion

In this research, the effect of two-way coupling in aerosol behavior analysis using CINEMA code was confirmed. In the analysis, the effect was not clearly identified because the ratio of ex-fuel decay heat is relatively too low compared to full bundle power which is the sum of fission power and total decay heat. Therefore, sensitivity analysis will be performed by increasing total decay power. Also, the effect will be checked in the plant analysis.

Acknowledgement

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