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Effect of Thermal-hydraulic Coupling on the Fission Products Behavior by Using SIRIUS Modules in CINEMA Code

Yongjun Lee[a*], Chang Hyun Song [a], Joonyoung Bae [a], JinHo Song [a], Sung Joong Kim [a,b*]
[a]Department of Nuclear Engineering, Hanyang University, 222 Wangsimni-ro, Seongdong-gu, Seoul 04763, Republic of Korea
[b]Institute of Nano Science and Technology, Hanyang University, 222 Wangsimni-ro, Seongdong-gu, Seoul 04763, Republic of Korea
**Corresponding author:* sungjkim@hanyang.ac.kr

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1. Introduction

A domestic comprehensive analysis code for severe accidents code, CINEMA (Code for Integrated severe accident Evaluation and Management) was developed and has been under improvement to simulate the hypothesized accident progression of light water reactor systems. The CINEMA code is structured with four key modules to simulate various accident progressions such as CSPACE (Core meltdown progress simulation coupling with Safety and Performance Analysis CodE) for in-vessel phenomena, SACAP (Severe Accident Containment Analysis Package) for ex-vessel phenomena, SIRIUS (SImulation of Radioactive nuclide Interaction Under Severe accident) for analyzing fission product behavior, and MASTER, a linkage analysis module facilitating coordination between individual modules.

Among these modules, the SIRIUS simulates the behavior of fission products (FPs), specifically modeling the processes of FP gases released from the reactor core entering the Reactor Coolant System (RCS). It includes the transportation of FPs and its transformation process into aerosols, as well as the deposition FPs to the RCS pipes, steam generators, or release into containment structures. The SIRIUS does not directly simulate the core degradation, and FP gas movement, and instead it receives thermal-hydraulic information from other modules to conduct calculations **[1-2]**.

Current study compares and verifies the SIRIUS in the CINEMA code with the MELCOR code through uncertainty analysis conducted on conventional NPPs. Uncertainty analysis should be conducted through the data from a substantial number of inputs, potentially reaching up to 1,000 runs **[3]**. Therefore, an efficient code execution under the available computational resources is crucial. The SIRIUS is standalone module that can run independently without other modules in CINEMA. In other words, it can perform standalone calculations using pre-generated thermal-hydraulic data files.

Standalone calculations by SIRIUS can be performed with remarkably short time compared to the entire CINEMA code run. Nonetheless, an effective standalone code execution requires appropriate settings for the recording frequency when generating thermal-hydraulic data files. Setting a short recording period could yield the results like the overall CINEMA code calculations. However, it can increase the file size excessively and diminishes the time difference compared to full CINEMA code calculations. In contrast, an excessively large recording frequency can reduce code execution time; however, it may lead to significantly divergent results compared to the result of the entire CINEMA code run. Therefore, validation work is essential to determine the most efficient options for generating thermal-hydraulic data files. This study focuses on comparing various thermal-hydraulic data files and their results to derive the most effective thermal-hydraulic file setting.

2. Methodology

The code utilized in this study consists of four sub-modules, all belonging to CINEMA 2.0.2 version. The detailed version information for each sub-module is as follows:

- MASTER: 2.0.2.118
- SACAP: 2.0.2.118
- SPACE-SAM_O2p: 2.0.2.327
- COMPASS.DLL: 2.0.2.327
- SIRIUS: 2.0.2.327

The actual code employed for simulating fission product behavior is SIRIUS 327 version. The remaining codes were utilized for generating thermal-hydraulic data files necessary for simulating fission product behavior by the SIRIUS. The interaction between each module in CINEMA is illustrated in Fig. 1.

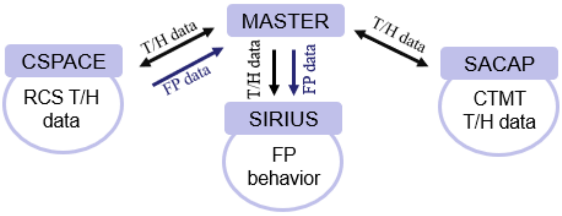

Fig. 1 Structure of CINEMA code

In this study, the hypothesized accident scenario to acquire thermal-hydraulic data file generation is Large

Break Loss of Coolant Accident (LBLOCA) in Optimized Pressurized Reactor 1000 (OPR1000), without any mitigation strategies. The nodalization of the code used in the simulation is presented in Figs. 2 and 3 [4].

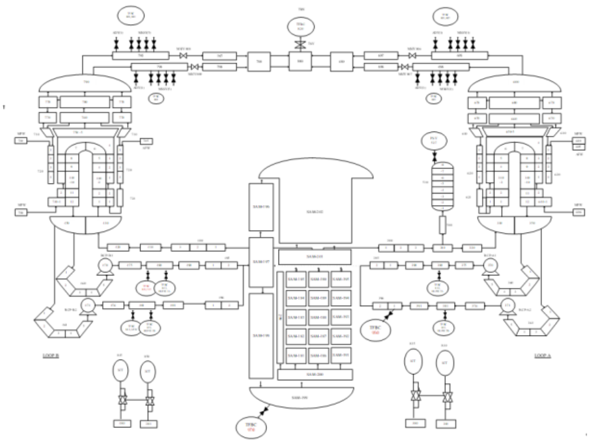

Fig. 2 OPR1000 NSSS model for CSPACE

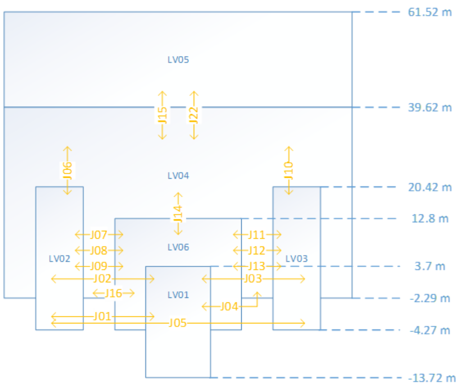

Fig. 3 OPR1000 containment model for SACAP

The calculations for thermal-hydraulic data file generation were conducted over approximately 1,000 s of steady-state calculation, followed by 72 h simulation. Due to the nature of the LBLOCA scenario, the primary system pressure dropped to atmospheric levels at 200 s since the accident occurrence, and rapid progression, including RPV failure at 6,710 s was observed. The rapid progression of the accident scenario has led us to select the LBLOCA scenario for this study, as it is believed to effectively enable the analysis of differences in SIRIUS results based on variations in thermal-hydraulic data files.

This study mainly focused on adjusting options and settings to create thermal-hydraulic data files necessary for running the SIRIUS code. The six different files were generated by changing the recording frequency. The TIME criteria were determined by the average time recorded when generating thermal-hydraulic files for each STEP criteria. The specific detailed in Table I:

Table I. Applied STEP and TIME criteria

STEP	10	100	1000
TIME (sec)	2	5	30

The MASTER module of CINEMA allows for setting the recording frequency of thermal-hydraulic data files based on either STEP or TIME. STEP records the thermal-hydraulic information based on the number of iterations during the calculation, while TIME records information based on the elapsed time during the calculation.

The thermal-hydraulic data were then used to calculate SIRIUS results, focusing on aerosol suspension and deposition as Figures of Merit (FOM). The aerosol group considered was Alkali metal iodides, with a specific emphasis on aerosols suspended on RCS and containment buildings. These parameters were selected as indirect indicators for other sensitive and uncertainty analysis results, such as the release quantity of fission products [5].

3. Results

3.1 Result of FOM – suspended aerosol

Firstly, when generating thermal-hydraulic data files based on the STEP criterion, the difference in the quantity of suspended aerosols is illustrated in Fig. 4 below.

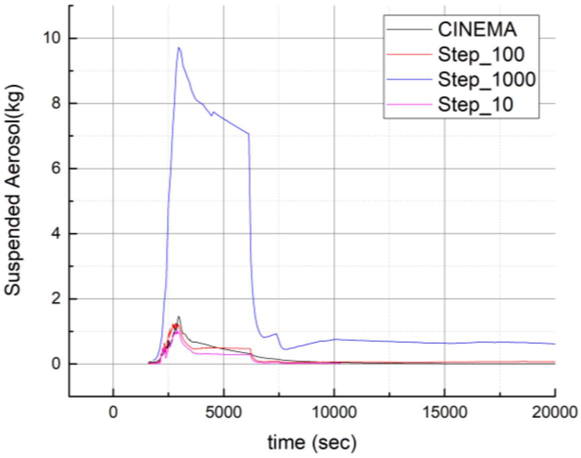

Fig. 4 Amount of suspended aerosol according to STEP

As presented in Fig. 4 and Table II, setting the STEP to 1,000 resulted in a significant difference in the quantity of suspended aerosols compared to the baseline from the entire CINEMA code execution. However, for STEP 100 and STEP 10, the results showed minimal deviation from the outcomes of the complete CINEMA code execution. Specifically, examining the maximum number of suspended aerosols revealed a difference of 8.26 times, as shown below.

Table II. Amount of maximum suspended aerosol according to STEP

STEP	10	100	1000	CINEMA
Airborne aerosol(kg)	1.05	1.25	9.73	1.47

The differences in the quantity of suspended aerosols when generating thermal-hydraulic data files based on the TIME criterion are presented in Fig. 5 and Table III.

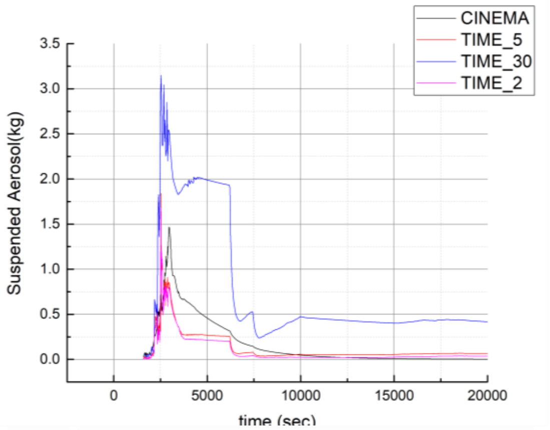

Fig. 5 Amount of suspended aerosol according to TIME

Table. III. Amount of maximum suspended aerosol according to TIME

TIME	2	5	30	CINEMA
Airborne aerosol(kg)	1.68	1.84	3.14	1.47

As shown in Fig. 5, setting the TIME to 30 resulted in an approximately twofold difference in the maximum quantity of suspended aerosols compared to the baseline from the entire CINEMA code execution. However, for TIME 5 and TIME 2, the difference appeared relatively small.

3.2 Result of FOM – deposited aerosol

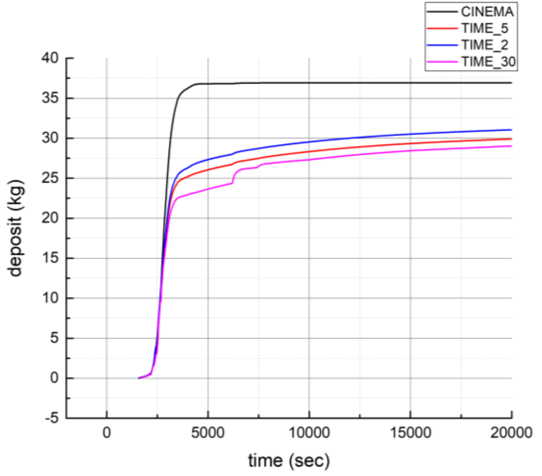

Fig. 6 Amount of deposited aerosol according to STEP

For STEP 10, due to premature termination issues in code calculations, the results could not be fully reported. When comparing aerosol deposition based on the STEP criterion, all results showed a significantly smaller trend compared to the outcomes of the entire CINEMA code execution. The figure shows that the smaller STEP shows more accurate results.

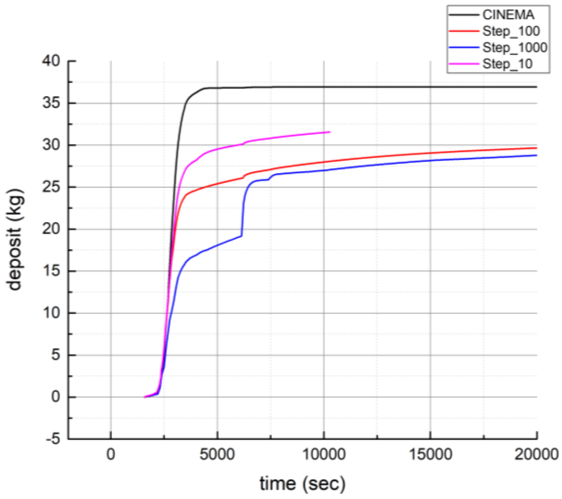

Fig. 7 Amount of deposited aerosol according to TIME

The results based on the TIME criterion for generating thermal-hydraulic data files exhibited a similar pattern to those of the STEP results. This contrasts with the notable differences observed in suspended aerosols, indicating a contrasting trend.

4. Conclusion and future study

In this study, the focus was to identify appropriate options for generating thermal-hydraulic information files essential for the future uncertainty analysis of the SIRIUS system using the standalone SIRIUS. The thermal-hydraulic information files offer effective multi-code calculations, and the study compared two recording options: STEP, which records thermal-hydraulic information based on the iteration count in the system, and TIME, which records information based on the calculation time. The analysis concentrated on two target FOMs: suspended aerosols and deposited aerosols. A comparison was made between the results of the overall CINEMA code calculation and the standalone module calculation for both FOMs.

1) The results indicated that, for suspended aerosols, an increase in the STEP size led to an increase in the graph's shape and maximum values of FOM. An unusually significant outcome was identified within the STEP 1000 option, which is thought to be due to the excessively large time step documented in the thermal-hydraulic data file. Specifically, the thermal-hydraulic data was

recorded at excessively wide time intervals, failing to accurately simulate complex phenomena such as RPV failure, consequently yielding results divergent from the actual phenomenon. While STEP showed similar values at 10 and 100, setting STEP to 10 resulted in a large thermal-hydraulic information file size, nearly 40 gigabytes. Therefore, for practical standalone calculations, setting STEP to 100 is preferable. When generating thermal-hydraulic information files based on TIME, the differences were less pronounced compared to those based on STEP. However, at TIME 30, a significant difference from the results of the overall CINEMA execution was observed. Considering the large file size of TIME 2, choosing TIME 5 as an option is recommended for proper computational analysis.

2) For deposited aerosols, differences were observed in both STEP and TIME criteria when compared to the overall CINEMA execution results. In both cases, as the values increased, inaccuracies became more apparent. Unlike suspended aerosols, deposited aerosols exhibited significant differences from the overall CINEMA results, except for STEP 100 and TIME 30 cases.

This study aimed to identify conditions for effectively generating thermal-hydraulic information files for standalone SIRIUS calculations. However, variations in resulting differences depending on the FOM suggest the need for further research.

ACKNOWLEDGEMENT

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